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EPA'S ROLE IN PROTECTING OCEAN HEALTH

JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON OVERSIGHT

AND THE

SUBCOMMITTEE ON WATER AND WILDLIFE

OF THE

COMMITTEE ON
ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

ONE HUNDRED ELEVENTH CONGRESS

SECOND SESSION

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C O N T E N T S

EPA'S ROLE IN PROTECTING OCEAN HEALTH

TUESDAY, MAY 11, 2010

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
SUBCOMMITTEE ON OVERSIGHT,
SUBCOMMITTEE ON WATER AND WILDLIFE,
Washington, DC.

The Subcommittees met, pursuant to notice, at 10 a.m. in room 406, Dirksen Senate Office Building, Hon. Sheldon Whitehouse (Chairman of the Subcommittee on Oversight) presiding.

Present: Senators Whitehouse, Cardin, Barrasso, and Udall.

OPENING STATEMENT OF HON. SHELDON WHITEHOUSE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator WHITEHOUSE. The hearing will come to order.

I am delighted to be here with Senator Cardin, who is the Co-Chair of this hearing from his Subcommittee, and Senator Barrasso who is the Ranking Member on my Subcommittee. We are all here today to discuss an issue that is too frequently overlooked, considering its importance to our collective well being, and that is the health of our oceans.

The oceans cover more than three-quarters of our globe and contain at least 70 percent of the Earth's biomass with potentially millions of species still to be discovered. The oceans sustain us with food, support human livelihoods, and for those of us who have had the opportunity to spend time around and on the oceans, they spark inspiration and wonder.

Largely out of our sight, they play a critical role in balancing our Earth's ecosystems, but the oceans are under great stress from a variety of sources. Today, we will look at just two of the many changes affecting our oceans: the level of toxic chemicals we have released into our marine environment and the growing threat of ocean acidification.

I would be remiss if I did not mention the massive oil spill taking place now in the Gulf of Mexico and extend condolences to the families of the crew members who died in the initial explosion. I applaud the Obama administration's rapid and comprehensive emergency response to what could become the largest ecological disaster this country has ever seen.

However, a consideration of the damage that we are steadily wreaking on our oceans, even outside this present disaster, is long overdue.

Today, I am pleased to have witnesses from the Environmental Protection Agency with us to discuss their agency's role in addressing the threat to our oceans posed by acidification and chemical poisoning. Mr. Jim Jones is here from the EPA's Office of Chemical Safety and Pollution Prevention, and Ms. Nancy Stoner is representing the Office of Water.

Thank you both for being here today.

Our second panel I will properly introduce later, is a very distinguished panel of scientists and advocates who have devoted themselves to understanding and protecting our oceans worldwide.

Our oceans are the Earth's largest carbon sink. Over 30 percent of mankind's total carbon dioxide emissions between 1800 and 1995 have been absorbed by the ocean. But as our oceans absorb increasing quantities of carbon dioxide, it is basic chemistry that forces the changes in systems that allow our marine fauna and flora to be functional and productive.

As the ecosystem changes, as the chemistry changes, the pH level of the ocean drops, and the water becomes more and more acidic. Even slight changes in ocean acidity can cause major disruptions to sea life to the point where marine mollusk larvae cannot form their shells; coral reefs bleach and die; and critical plankton cannot multiply. Since plankton formed the base of the oceanic food chain and coral reefs are critical nursery habitat for much marine life, ocean acidification could cause an unprecedented and unpredictable collapse of our ocean ecosystems.

The National Academy of Sciences recently reported that the rate of change in ocean pH is faster now than at any point in the last 800,000 years. We do not yet know if species will be able to adapt quickly enough to survive this type of shift in their environment. Certainly, it is hard for species to survive in an environment that dissolves them.

The second health threat we will be discussing today is the ever growing level of toxic chemicals in the marine environment. Even the remotest parts of the ocean now feel the touch of our industrialized society. Polar bears and seals in the Arctic and birds in the Galapagos, animals that would naturally come in contact with humans, all now contain traces of manmade flame retardants, PCBs and pesticides. We will hear today about an incredible voyage that documented contaminant levels in whales, including poisons referred to as persistent, bioaccumulative toxins, or PBTs.

Since much of humankind sustains itself on the ocean's protein, we need to pay close attention to these accumulating toxics and the sentinel species that show the harm.

While these chemicals can serve important purposes in our society, we must be alert to and protect ourselves against unintended harms as grave as these portend. For too long, we have taken our oceans for granted. We dump trash in the ocean, permit sewage to overflow across our coastal beaches into coastal waters, and allow toxic runoff to flow into our seas.

Our unchecked carbon pollution absorbed by the ocean compounds the harm with changes to the very chemistry of the ocean ecosystem. I am pleased that the Environmental Protection Agency has recognized these threats and is working cooperatively with other Federal agencies to address them. The Obama administration has helped with the establishment of its Ocean Policy Task Force, which for the first time in our Nation's history is looking comprehensively at the myriad uses and threats to our oceans.

I look forward to working with the Administration and with my colleagues on these efforts.

Senator Barrasso.

OPENING STATEMENT OF HON. JOHN BARRASSO, U.S. SENATOR FROM THE STATE OF WYOMING

Senator BARRASSO. Thank you very much, Mr. Chairman. I am pleased to be with you today for this first hearing this year of the Subcommittee on Oversight, along with the Subcommittee on Water.

I want to thank the witnesses for being here today because, of course, ocean health is vitally important, and we need to develop effective responses and tailored solutions to meet the challenges that all of us face.

With regard to ocean health and ocean acidification, I have concerns, Mr. Chairman; we must guard against using current laws as they were never intended to be used. A recent article on March 12 in the New York Times was entitled, Some See Clean Water Act Settlement Opening New Path To Greenhouse Gas Curbs.

I ask unanimous consent, Mr. Chairman, to put that article from the New York Times in the record.

Senator WHITEHOUSE. Without objection.

Senator BARRASSO. Thank you, Mr. Chairman.

[The referenced article was not received at time of print.]

Senator BARRASSO. The article goes on to state that the EPA reached a deal with the Center for Biological Diversity to "begin a rulemaking aimed at helping States identify and address acidic coastal waters." The Times states that the effort could lead to the first Clean Water Act effort to protect acidifying marine waters, a move the Center for Biological Diversity sees leading to restrictions on carbon dioxide emissions. A spokesman for the Center for Biologic Diversity was quoted as saying "if we can use every tool in the box, the Clean Water Act, the Clean Air Act, new climate legislation and State efforts to address it," meaning climate change, he says, "all those things are important."

I think, Mr. Chairman, that statement highlights the goal of these groups to regulate everything Americans do from heating their homes to driving their kids to school. And to me this presents considerable risk to millions of good paying jobs in the energy and manufacturing sectors of our Nation. I worry that this is another attempt to enact a climate change regime without one single vote of this Congress.

So we should not use the Clean Water Act to regulate climate change, just as I believe we should not use the Clean Air Act, NEPA, the Endangered Species Act or any secretarial order from the Secretary of Interior to regulate climate change.

Mr. Chairman, I think we ought to enact true preemption, as Senator Voinovich has proposed to do. Take all these proposals to regulate climate change through regulation off of the table, and then let us decide our clean energy future with a vote of this Congress, a future where we make energy as clean as we can, as fast as we can, without raising prices for American families, while providing for a strong economy and more jobs.

Mr. Chairman, we have a number of issues that remain on the table with regarding to holding oversight hearings in the future. There are multiple topics that need to be explored by this Committee. So I look forward to future oversight hearings to address these topics.

As you and I have discussed, Mr. Chairman, as a result of the tragedy of the oil spill in the Gulf, our full Committee will be meeting here this afternoon with a hearing. I am also on the Energy Committee, and we have a full committee meeting this morning to also ask questions and look into that.

So with that, Mr. Chairman, thank you and look forward to the testimony.

Senator WHITEHOUSE. Senator Cardin.

OPENING STATEMENT OF HON. BENJAMIN L. CARDIN, U.S. SENATOR FROM THE STATE OF MARYLAND

Senator CARDIN. Chairman Whitehouse, thank you very much. When you represent the State of Rhode Island or the State of Maryland, you understand how important our oceans are. I thank you very much for holding this hearing.

You have been planning this hearing for some time, so I first want to acknowledge your patience and perseverance in bringing us to this, and bringing together I think just an excellent two panels of experts in this area that I think can help us try to understand what we need to do in the oceans.

It was Joseph Conrad who wrote in The Heart of Darkness, “There is nothing mysterious to a seaman unless it be the sea itself.” And I think that speaks to it. We don’t see the pollution. We don’t see the damage that we are causing to our oceans. It is a vast area that is mysterious to all of us.

But the two issues that you raised in your opening statement, ocean acidification and toxic chemicals, are having a major impact on the quality of our oceans and I would say our way of life. I think it is important that we establish a hearing record, as we will today, as to the impact of both of these areas.

On ocean acidification, I just really want to mention the Chesapeake Bay for one moment, if I might. The Chesapeake Bay today, we all know that the issues concerning global climate change and the impact it is having on our sea grasses, our sea level increases, the warming of the ocean itself, all that having an impact on the health of the Chesapeake Bay and on the importance of that to our economy and to our way of life.

Let me just talk about the oyster for one moment. The oyster is critically important to cleansing the bay. As you know, it serves in the ecosystem as an extremely valuable commodity. It is not only its economic impact as a crop, but it is also its impact as a cleansing agent in the bay.

Well, we are 1 percent of our historical level of oysters in the bay. And we believe one of the reasons is the increase acidification, because it affects the development of the oyster itself, its shell. So this is an issue that we need to deal with.

I would give you just one example. In regards to the toxic elements, you have listed several that are critically important. I would just like to add one more because I think it is relevant to your introduction, that we have to note what is happening in the Gulf of Mexico today. It is clearly going to have an incredible impact on the Gulf and on the Atlantic Ocean.

And one of the toxins that are being now put into the bay, because we have no choice, is the dispersing agents. We have no choice because we have to prevent the oil from coming to the surface and perhaps getting into the currents or getting onto the beaches and destroying wetlands and destroying wildlife that is critically important to our environment. But instead we are putting a different toxic in, a dispersing agent that we don't exactly know what it is going to cause. But we do know that it has an impact.

We also know that the oil will then end up on the ocean bottom. It doesn't disappear. It just disperses to the bottom. What impact will that have on our environment?

So today America's energy policy continues to rely on fuels that endanger our air, our seas and enrich our enemies. Mother Nature will continue on no matter decisions we make or what energy policy we adopt. But I think the challenge to us is will we still have vibrant fisheries and beautiful beaches? And that is an issue that I think should be of concern to all of us. Will we still have healthy wetlands and bird populations? Will our economy as well as our environment suffer irreparable harm? We are talking about jobs. We are talking about the economic impact that a clean ocean has on our ability to drive our economies.

And will the world that we pass on to our children and grandchildren have all the wonders that we experienced in our childhood? These are the challenges we have.

Mr. Chairman, the Environmental Protection Agency has a critical role to play in helping fill the gaps in our knowledge and in protecting the oceans from harm. I look forward to hearing from today's witnesses as we develop I hope a strategy to deal with these issues.

Mr. Chairman, I would ask that my entire statement be made part of the record, and I look forward to hearing from our witnesses.

Senator WHITEHOUSE. Without objection, it will be.

[The prepared statement of Senator Cardin was not received at time of print.]

Senator WHITEHOUSE. We will turn to Ms. Stoner.

Welcome. Thank you for being here.

STATEMENT OF NANCY STONER, DEPUTY ASSISTANT ADMINISTRATOR, OFFICE OF WATER, U.S. ENVIRONMENTAL PROTECTION AGENCY

Ms. STONER. Good morning, Chairman Whitehouse and Chairman Cardin. I am Nancy Stoner, Deputy Assistant Administrator of the Office of Water at the U.S. EPA. With me today is Jim Jones, Deputy Assistant Administrator of the Office of Chemical Safety and Pollution Prevention. We thank you for the opportunity to speak with you today about EPA's role in protecting ocean health, especially as it relates to ocean acidification and persistent bioaccumulative toxic chemicals, or PBTs.

The National Research Council of the National Academies recently reported that ocean chemistry is changing at an unprecedented rate and magnitude due to human made carbon dioxide emissions, but we don't yet fully understand the specifics of how changes occur, the scope of what is affected, what the effects mean, and what actions might help to prevent, abate or control them.

Similarly, we know that toxics adversely affect the water, sediment and living organisms of the marine environment, but we don't yet fully understand how most chemicals, individually or collectively, affect organisms or ecosystems or how the degraded or metabolized products of those pollutants affect the same.

Ocean acidification refers to the decrease in pH of the Earth's oceans caused by the absorption of carbon dioxide from the atmosphere. The National Research Council has concluded that "Unless anthropogenic CO_2 emissions are substantially curbed or atmospheric CO_2 is controlled by some other means, the average pH of the ocean will continue to fall."

EPA already is taking action to regulate and control the root cause of ocean acidification, fossil fuel CO_2 emissions that are also the main driver of climate change. As you are aware, EPA recently concluded under the Clean Air Act that these greenhouse gases endanger the public health and welfare of current and future generations.

Research over the last 10 years indicates that the implications of CO_2 absorption for oceans and coastal marine ecosystems are potentially very serious. Marine calcifiers, including corals and shellfish, depend on calcium carbonate to produce and maintain their shells, skeletons and other protective structures. Ocean acidification reduces calcification to create such structures and increases dissolution of them. These organisms then have less energy available for feeding, escaping predators and reproduction, leading to decreased survival.

Many of these creatures form the basis of ocean food webs and provide us with extensive resources and vital ecosystem services. For example, a NOAA-supported study in 2003 estimated that Florida reefs have a capitalized value of more than $7.6 billion per year. EPA and other Federal agencies are engaged in a variety of research and monitoring efforts that contribute to our understanding of the effects of ocean acidification.

For example, EPA is working to value reef services, focusing on recreation, tourism, fisheries, shoreline protection, marine natural products and ecological integrity. EPA recently published a Federal Register notice seeking comments on how to address ocean acidification under the Clean Water Act Impaired Waters Program. This notice included a request for recommendations on developing total maximum daily loads or pollution budgets for waters impaired by ocean acidification. EPA will complete a memorandum by November of this year that describes how the agency will approach ocean acidification under this program.

Also, after reviewing a wide range of information, EPA recently decided against revising the marine pH criterion for aquatic life under the Clean Water Act. This decision was based on the fact that in most coastal regions, the data that are available to characterize daily and seasonal variability are so limited that short-term trends in carbon system parameters and pH cannot be determined.

I will now turn it over to my colleague, Jim Jones, who will address toxic chemicals in the marine environment.

[The prepared statement of Ms. Stoner follows:]

Testimony of
Nancy Stoner, Deputy Assistant Administrator
Office of Water
and
James J. Jones, Deputy Assistant Administrator
Office of Chemical Safety and Pollution Prevention
U.S. Environmental Protection Agency
before the
Subcommittees on Oversight, and on Water and Wildlife,
Committee on Environment and Public Works
U.S. Senate

May 11, 2010

Good morning Chairmen Whitehouse and Cardin, Ranking Members Barrasso and Crapo, and other members of the Subcommittees. I am Nancy Stoner, Deputy Assistant Administrator of the Office of Water, U.S. Environmental Protection Agency (EPA). With me today is Jim Jones, Deputy Assistant Administrator of the Office of Chemical Safety and Pollution Prevention. We thank you for the opportunity to speak with you today about EPA's role in protecting ocean health.

I would like to address both of the Subcommittee's areas of focus - ocean acidification and persistent bioaccumulative toxic (PBT) chemicals in the oceans- and then both of us are available to answer your questions.

We know that both of today's subjects of ocean acidification and persistent bioaccumulative toxics in the oceans adversely affect the marine environment. In its new report on *Ocean Acidification: A National Strategy to Meet the Challenges of a*

Changing Ocean[1], the National Research Council of the National Academies reported that ocean chemistry is changing at an unprecedented rate and magnitude due to human-made carbon dioxide (CO_2) emissions, and that there will be "ecological winners and losers." The Interacademy Panel on International Issues, in a statement endorsed by the U.S. National Academy of Sciences, notes that ocean acidification is a "direct and real consequence of increasing atmospheric CO_2 concentrations, is already having an effect at current concentrations, and is likely to cause grave harm to important marine ecosystems." But, as outlined in the National Research Council's report, we don't yet fully understand the specifics of all the possible impacts of ocean acidification to marine organisms and seawater composition, the scope of which organisms are affected, what the effects mean, and what actions might help to prevent, abate, or control them.

Similarly, we know that toxics adversely affect the water, sediments, and living organisms of the marine environment. But we don't yet fully understand how many chemicals--individually or collectively--affect organisms or ecosystems, or how the degraded or metabolized products of those pollutants affect the same. We recently realized that even trace amounts of certain emerging contaminants of concern can have harmful effects.[2] We know that toxics reach the marine environment both directly

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[1] Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean. Committee on the Development of an Integrated Science Strategy for Ocean Acidification Monitoring, Research, and Impacts Assessment; National Research Council. National Academies Press. ISBN: 978-0-309-15359-1. 2010.

[2] "Persistent Organic Pollutants and Stable Isotopes in Biopsy Samples (2004/2006) from Southern Resident Killer Whales", Margaret M. Krahn *et.al.*, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle; Cascadia Research; Fisheries and Oceans Canada (Pacific Biological Station); and Institute of Ocean Sciences, *Marine Pollution Bulletin*, 54(12), pp.1903-1911.
http://www.sciencedirect.com/science/article/B6V6N-4PVY331-1/2/37040056754545c70d03b06c62f47e28

through point sources, such as spills or urban stormwater discharges, or indirectly, through nonpoint sources including legacy pollutants, such as Polychlorinated Biphenyls (PCBs) that survive in sediments or atmospheric volatilization or deposition.

We have many questions left to answer in both of the subject areas of today's hearing. I would like to share with you examples of EPA activities that help us understand and address these challenges.

Ocean Acidification

Ocean acidification refers to the decrease in pH of the Earth's oceans caused by the absorption of carbon dioxide (CO_2) from the atmosphere. This is sometimes referred to as "the other CO_2 problem" with reference to climate change. However, ocean acidification is not a climate process, Ocean chemistry is directly affected as seawater absorbs CO_2 from the atmosphere. Other human activities also affect seawater chemistry, but not nearly to the extent of atmospheric CO_2-driven acidification.[3] We are only beginning to understand specifically how acidification is affecting our oceans and the life of our ecosystems, and to lay the scientific groundwork for possible actions to prevent, abate, or control such effects.

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[3] Caldeira, K.; Wickett, M.E. (2003). "Anthropogenic carbon and ocean pH". *Nature* **425** (6956): 365–365. doi:10.1038/425365a. http://pangea.stanford.edu/research/Oceans/GES205/Caldeira_Science_Anthropogenic%20Carbon%20and%20ocean%20pH.pdf

EPA already is taking action to regulate and control the root cause of ocean acidification: fossil fuel CO_2 emissions that also are the main driver of climate change.[4] As you are aware, EPA recently concluded under §202(a) of the Clean Air Act that these greenhouse gases endanger the public health and welfare of current and future generations. EPA and the Department of Transportation are embarking on a national program to substantially reduce greenhouse gas emissions from mobile sources by requiring better fuel economy for new cars and trucks sold in the United States.

Serious implications for ocean and coastal marine ecosystems. Research over the last 10 years indicates that the implications of CO_2 for ocean and coastal marine ecosystems are potentially very serious.[5] The ocean has a large capacity to absorb carbon dioxide from the atmosphere. However, we have only recently recognized that the resulting lowered pH levels in ocean waters can have serious cascading effects.[6] Ocean acidification reduces the availability of calcium carbonate in the oceans. Marine calcifiers, including corals and shellfish, depend on calcium carbonate to produce their shells, skeletons, and other protective structures, and on saturating concentrations of carbonate ions to maintain their structures. Ocean acidification can reduce the ability of organisms to create such structures and increase dissolution of them. By diverting

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[4] Doney, S.; Fabry, V.; Feely, R. & Kleypas, J.Ocean acidification: the other CO2 problem *Annual Review of Marine Science*, 2009, *1*, 169-192
http://ic.ucsc.edu/~acr/eart254/Doneyetal2009.pdf

[5] Guinotte, J. & Fabry, V. Ocean acidification and its potential effects on marine ecosystems *Annals of the New York Academy of Sciences*, 2008, *1134*, 320-342
http://www.gg.mq.edu.au/rep/websites/docs/paper.pdf

[6] Orr, J.; Fabry, V.; Aumont, O.; Bopp, L.; Doney, S.; Feely, R.; nanadesikan, A.; Gruber, N.; Ishida, A.; Joos, F. & others Anthropogenic ocean aacidification over the twenty-first century and its impact on calcifying organisms *Nature*, 2005, *437*, 681-686
http://www.up.ethz.ch/education/biogeochem_cycles/reading_list/orr_nat_05.pdf

energy from production to maintenance of the skeleton, organisms may have less energy available for feeding, escaping predators, and reproduction, leading to decreased survival.[7] Many of these creatures form the basis of ocean food webs and provide us with extensive resources and vital ecosystem services, including filtering ocean and coastal waters.

Marine calcifiers have an important role in the food chains of nearly all oceanic ecosystems, help regulate ocean chemistry, and are an important source of biodiversity and productivity. Either directly or indirectly, they provide benefits in terms of fisheries, tourism, recreation, and shoreline protection or stabilization, thereby protecting coastal property value. Studies by the World Resources Institute have estimated that coral reefs in the Caribbean region provide ecosystem goods and services with an annual net economic value between $3.1 billion and $4.6 billion in 2000.[8] Another study supported by the National Oceanic and Atmospheric Administration in 2001 estimated that Florida reefs have a capitalized value of over $7.6 billion.[9] Evidence to date shows that ocean acidification could adversely affect these benefits. In addition, changes in ocean chemistry due to ocean acidification are likely to make marine ecosystems less resilient

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[7] Cohen, A.L., and M. Holcomb. 2009. Why corals care about ocean acidification: Uncovering the mechanism. *Oceanography* 22(4):118–127.
http://darchive.mblwhoilibrary.org:8080/bitstream/handle/1912/3179/22-4_cohen.pdf?sequence=1

[8] Burke, L. & Maidens, J. Reefs at Risk in the Caribbean *World Resources Institute*, 2004
http://pdf.wri.org/reefs_caribbean_full.pdf

[9] Johns, G.; Leeworthy, V.; Bell, F. & Bonn, M. Socioeconomic study of reefs in southeast Florida *Final Report. Hazen and Sawyer and Florida State University. October*, 2001, *19*, 2001

to further change in ocean chemistry and more vulnerable to other environmental impacts, including climate change.[10]

EPA's ocean acidification research. The Interagency Working Group on Ocean Acidification, in which EPA participates, is drafting a strategic research plan for ocean acidification, to be completed in 2011. An initial report on the plan's progress, including a summary of existing federally funded ocean acidification research and monitoring activities and their budgets, will be completed shortly. This work results from the Federal Ocean Acidification Research and Monitoring Act of 2009.

Additionally, EPA is engaged in a variety of research and monitoring efforts that contribute to our understanding of the effects of ocean acidification. We estimate our ocean acidification-related research and monitoring activities in 2009 at $2 million. This includes laboratory and field efforts to understand the effects on corals of ocean acidification and other stressors, such as sediment and rising seawater temperatures, which often are related to climate change. Laboratory studies are conducted in specialized coral culture facilities that hold both Pacific and Caribbean corals, in order to study tissue survival and obtain accurate growth measurements. Changes in coral survival and growth are measured under highly controlled laboratory conditions to measure consequences of single and multiple stressors. Laboratory studies are used because small changes in growth rate can be measured over short exposure periods

[10] Hoegh-Guldberg, O.; Mumby, P.; Hooten, A.; Steneck, R.; Greenfield, P.; Gomez, E.; Harvell, C.; Sale, P.; Edwards, A.; Caldeira, K. & others Coral reefs under rapid climate change and ocean acidification *science, AAAS*, 2007, *318*, 1737 http://media.eurekalert.org/aaasnewsroom/2008/FIL_000000000120/HoeghGuldberg%20et%20al.%202007%20complete.pdf

using methods that are not readily adaptable to the. Field studies have focused on the Caribbean Sea and Western Atlantic Ocean, where reef declines appear to be greater than in any other area of the world.[11] In a collaborative effort with resource managers and scientists from Puerto Rico, the U.S. Virgin Islands and Florida, we have surveyed coral condition and identified coral reef measurements, or indicators, that are sensitive to human-generated stresses. These indicators are different than traditional coral reef measurements because they are able to distinguish effects of human activity from natural change. Using these indicators and probabilistic sampling designs specifically developed for large regional assessments, we are able to provide a monitoring approach that addresses CWA reporting and regulatory needs as well as future development of biological criteria. EPA recently completed a regional assessment of coral reefs in the U.S. Virgin Islands, which can serve as the basis for interpreting future gains or losses in coral condition relative to ocean acidification and other environmental stresses.

In addition, we are working to improve our understanding of reef services. We want to ensure that all relevant coral reef services, including recreation, tourism, fisheries, shoreline protection, marine natural products and ecological integrity, are being valued with the best available methods. EPA is preparing a "state of the science" summary of peer-reviewed literature to characterize which reef services have already been measured and how the services were quantified and valued. Filling any gaps will lead to improved measurements in reef assessments--measurements that will better describe

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[11] Mora, C., 2008. A clear human footprint in the coral reefs of the Caribbean. Proceedings of the Royal Society B 275, 767–773.; Gardner, T.A., I..M . Cote, J.G. Gill, A. Grant, and A.R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. Science 301 (5635):958-960.

gains and losses in benefits we receive from coral reef ecosystems. A related effort EPA is undertaking will include consideration of the impacts of ocean acidification in our studies of the impacts of CO_2 emissions. Thus far, estimates of the benefits from reducing CO2 emissions have focused on climate-related impacts. EPA researchers are engaged in a modeling exercise that will also account for ocean acidification impacts when evaluating those benefits.

A Coral Mortality and Bleaching Output (COMBO) Model[12] is one product of our research. This computer program models the effects of climate change and ocean acidification on coral reefs at local-to-regional scales. COMBO projects impacts to coral reefs from CO2 concentrations and from periodic high temperature bleaching events. Coral bleaching, which is a sign of corals responding to stress, can be caused by a number of factors, including ocean acidification and other changes in water chemistry. Coral reefs located in Hawaii and the US Virgin Islands were tested to determine the relative importance of stressors and enabled the identification of priority areas for reef conservation.

Ocean acidification and the Clean Water Act. EPA has used Section 304(a)(2) of the Clean Water Act to develop new information relating to ocean acidification. Using data collected on EPA's Ocean Survey Vessel, the *Bold*, EPA published a reef assessment method ("Stony Coral Rapid Bioassessment Protocol," July 2007) for assessing the

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12 Buddemeier, R.; Jokiel, P.; Zimmerman, K.; Lane, D.; Carey, J.; Bohling, G. & Martinich, J. A modeling tool to evaluate regional coral reef responses to changes in climate and ocean chemistry *Limnol. Oceanogr.: Methods*, 2008, *6*, 395-411

health and condition of stony corals.[13] In addition, EPA is developing a Technical Support Document "Coral Reef Biological Criteria: Using the Clean Water Act to Protect a National Treasure". The latter document will inform coral reef managers of a framework for developing coral reef biocriteria as water quality standards under the Clean Water Act in order to strengthen protection of coral reefs.

EPA recently published a Federal Register notice seeking comments on how to address ocean acidification under the Clean Water Act Section 303(d) impaired waters program, including whether EPA should issue guidance regarding the listing of waters as threatened or impaired for ocean acidification, and what that potential guidance might entail.[14] In addition, EPA requested information regarding recommendations for Total Maximum Daily Load development for waters impaired by ocean acidification. EPA will complete a memorandum by November 15, 2010, that describes how the Agency will approach ocean acidification under the 303(d) program.

After reviewing a wide range of information received in response to a "Notice of Data Availability",[15] EPA recently decided against revising the marine pH criterion for aquatic life under section 304(a) of the Clean Water Act at this time.[16] In most coastal regions, the data that are available to characterize diurnal and seasonal variability are so limited that short term trends in carbon system parameters and pH cannot be determined.

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[13] Link to "Stony Coral Rapid Bioassessment Protocol"
http://www.epa.gov/bioiweb1/pdf/EPA-600-R-06-167StonyCoralRBP.pdf

[14] http://edocket.access.gpo.gov/2010/pdf/2010-6239.pdf

[15] http://www.epa.gov/fedrgstr/EPA-WATER/2009/April/Day-15/w8638.htm

[16] This decision was transmitted in a letter from EPA to the Center for Biological Diversity.

Consequently, without additional monitoring, it would be difficult at this time to establish a national water quality criterion that accurately reflects the impacts of ocean acidification on coastal waters within the 3-mile statutory limit where water quality standards for states, tribes and territories are implemented.

Persistent Bioaccumulative Toxic Chemicals in the Marine Environment

In conjunction with natural toxins, human-made chemicals have become an accepted and significant part of the modern world. They're in what we eat, what we drink, what we touch, and what we breathe. In fact, traces of many such man-made chemicals can be found in the umbilical cords of almost every baby born today. As is true of ocean acidification, our understanding of toxics and their effects on the marine environment is growing, however huge data gaps remain.

Persistent Bioaccumulative Toxic Chemicals (PBTs) are long-lasting substances that build up in the food chain and, at certain exposure levels, may be harmful to human health and the environment. They do not break down, so when they are released to the environment they remain, essentially unaltered, for months or years. With continued use and release, they build up in sediments and soil. Their concentrations increase as they go up the food chain from sediment, to aquatic insects, to fish, for example. It is this concentration in the food chain which, under certain circumstances, can cause adverse effects in humans, including reproductive defects, or in wildlife. Some PBTs are also susceptible to long range transport such that adverse effects can be found far removed from their site of production or use. Combined, these properties are what make EPA concerned not only with historical PBT chemicals, such as DDT and PCBs, but also with chemicals with similar properties entering commerce today or in the future.

As part of Administrator Jackson's comprehensive effort to strengthen EPA's chemical management program and assure the safety of chemicals, EPA has released five action plans -- on phthalates, short-chain chlorinated paraffins, perflourinated chemicals (PFCs), Polybrominated diphenyl ethers (PBDEs), and Bisphenol-A (BPA), -- which outline a range of actions the agency is considering, including utilizing for the first time ever TSCA's section 5(b)(4) authority to list chemicals of concern.

Addressing Persistent Bioaccumulative and Toxic Chemicals (PBTs) Generally. Among efforts to address PBTs, EPA has adapted its standard risk assessment methodologies for pesticides to specifically address the particular needs of compounds that exhibit persistent, bioaccumulative, and toxic characteristics. These refined methods are designed to account for the unique attributes of PBT chemicals and are applied on the basis of internationally-recognized screening criteria.[17] The Agency has begun using these methods to address the potential long-term build up of these chemicals in the environment, their potential biomagnification in aquatic food webs, and their potential transport to remote regions such as the Arctic.

[17] http://epa.gov/oscpmont/sap/meetings/2008/102808_mtg.htm

A number of other activities in our TSCA chemicals program address PBTs. EPA has developed a policy statement for new chemicals that provides guidance criteria for determining persistence, bioaccumulation, and toxicity, and advises the industry about our regulatory approach, including the evaluation criteria, review process, exposure/release controls, and testing strategy for potential new PBT chemicals.[18] This policy statement made clear to submitters of new chemical notifications under TSCA that substances meeting these criteria may need to undergo testing on persistence and bioaccumulation endpoints which, if confirmed, would be followed by appropriate toxicity testing to identify "PBT chemical substances." In addition, the policy statement made clear that control action under TSCA may be needed in varying degrees, based upon the level of risk concern. EPA has also developed a computerized tool, the PBT Profiler, to help evaluate whether chemicals have characteristics of persistence, bioaccumulation, and toxicity and has made this PBT Profiler available on an EPA website at www.pbtprofiler.net. Our regional office in Chicago also has a significant PBT program and our TRI program takes into account the importance or significance of PBT characteristics through lower thresholds for reporting requirements. In addition, PBTs are a major regulatory focus in the Agency's Great Lakes Water Quality Initiative, finalized in 1995.[19] All in all, the breadth of PBT actions throughout the Agency is indicative of the importance we place on protecting human health and the environment from exposure to such harmful substances.

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[18] http://www.epa.gov/oppt/newchems/pubs/pbtpolcy.htm

[19] http://www.epa.gov/waterscience/standards/gli/mixingzones/

Moreover, the Agency recently completed and released five chemical action plans which outline potential steps to address chemical risks, with chemicals selected on the basis of multiple factors, including persistence, bioaccumulative, and toxic characteristics.[20] Three of the first five chemical action plans, covering polybrominated diphenyl ethers (PBDEs), longchained perfluorinated chemicals, and short-chained chlorinated paraffins, include chemicals that are known internationally for their PBT characteristics. We are moving forward to implement the actions in those plans. EPA recently made public a list of chemicals for upcoming Action Plan development and is currently considering its approach for stakeholder engagement.

International Agreements on PBTs. The global nature of many of these substances is why the Obama Administration identified the Stockholm Convention on Persistent Organic Pollutants (POPs) and the Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International Trade as priority treaties for U.S. ratification. The United States was instrumental in negotiating both the Stockholm Convention and the Rotterdam Convention, each of which contributes in its own way to a healthier global environment and to a healthier America. The Stockholm Convention prohibits or restricts the production, use, and release of chemicals that are toxic, persist in the environment for long periods of time, bioaccumulate as they move up through the food chain, and are transported long distances in the environment, often landing far from the sources where they are released. The reduction or elimination of these POPs sources will have

[20] http://www.epa.gov/oppt/existingchemicals/pubs/ecactionpln.html

significant benefit to the United States and other countries around the world by reducing exposures that adversely affect human health and the environment.

The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (PIC) was developed to promote information exchange and informed risk-based decision-making in the global movement of hazardous chemicals and pesticides. The Convention empowers governments to make their own domestic science- and risk-based decisions in an informed manner and, with regard to listed substances, obligates Parties to ensure that such substances are not exported to Parties that have not provided their consent. Additionally, for certain substances considered banned or severely restricted in the exporting country, the agreement requires the exporting government to provide export notification to the importing government. This prior informed consent regime is particularly helpful and important to developing countries that lack the capacity to enforce their own regulatory decisions.

The POPs Protocol to the Convention on Long Range Transboundary Air Pollution (the LRTAP POPs Protocol), which is similar to the Stockholm Convention, also addresses substances that are toxic, persistent, bioaccumulative, and susceptible to long range transport. However, this Protocol is regional in nature, covering the Member States of the United Nations Economic Commission for Europe, which includes, among others, the United States, Canada, the EU, Russia, parts of the former Soviet Union, and Eastern Europe.

Although the United States is a signatory to the Stockholm and Rotterdam Conventions as well as the LRTAP POPs Protocol, it has yet to ratify them. This being the case, and although the United States has already taken some steps to address the risks posed by PBT substances generally, and specifically the risks posed by the PBT substances covered by the Conventions and Protocol, it is of utmost importance for the United States to ratify them and take the final step to establish the legislation necessary to implement these agreements. Full participation in these Conventions and this Protocol by the United States is of special importance, for example, for the people and environment of Alaska, which is impacted more than any other state by POPs transported by air and water from outside the United States. This is particularly true for Alaskan Natives, who, like many around the United States, rely heavily on traditional diets comprised of fish and wildlife. By joining with the rest of the world to phase out or reduce the use and release of these PBTs, we protect both human health and the environment, not only for ourselves, but for the rest of the world. At EPA, we take the risks posed by these substances to our environment and public health very seriously. We are internationally recognized for our sound scientific risk assessments and regulatory decision making, and other countries look to the United States to provide strong leadership in the area of chemical safety. Our actions to protect the environment are respected and often replicated in other countries across the globe. But we are hampered by our lack of implementing legislation.

As your committee considers the issue of PBTs, I would stress the importance of implementing legislation that would allow the United States to join the Stockholm Convention, the Rotterdam Convention, and the LRTAP POPs Protocol. Over the past few decades, the United States has negotiated and signed international agreements that have the goal of protecting human health and the environment from toxic chemicals, but has been unable to join these agreements due to our lack of domestic legislation. The Obama Administration believes that it is time to pursue U.S. ratification and full implementation of these agreements.

Reforming TSCA. The Toxic Substances Control Act (TSCA) was signed into law in 1976 and was intended to provide protection of health and the environment against risks posed by chemicals in commerce. However, when TSCA was enacted, it authorized manufacture and use, without evaluation, of all chemicals that were produced for commercial purposes at that time. As a result of the legal hurdles and procedural requirements that TSCA places on EPA prior to collecting data, there are large, troubling gaps in the available data and state of knowledge about many widely used chemicals in commerce. Although there is a review process for new chemicals being introduced into commerce, chemical producers are not required to provide, without further action from EPA, the data necessary to fully assess a chemical's potential risks.

In the cases where EPA has adequate data on a chemical, and wants to protect the public against well-known risks to human health and the environment, there are legal hurdles that prevent quick and effective regulatory action. Meanwhile, the public may be exposed to chemicals for which we have little understanding of the consequences.

Accordingly, the Administration believes it is important to work together with Congress and all interested stakeholders to quickly modernize and strengthen the tools available in TSCA to increase confidence that chemicals used in commerce, which are vital to our Nation's economy, are safe and do not endanger the public health and welfare of consumers, workers, and especially sensitive sub-populations such as children, or the environment. The Agency released "Essential Principles for Reform of Chemicals Management Legislation" in December to help inform efforts underway in this Congress to reauthorize and significantly strengthen the effectiveness of TSCA. These Principles present Administration goals for updated legislation that will give EPA the mechanisms and authorities to expeditiously target chemicals of concern and promptly assess and regulate new and existing chemicals. We look forward to working with Congress on updating TSCA as it moves forward.

Additional Areas of EPA Focus regarding Toxic Chemicals in the Marine Environment

Impact of Toxic Chemicals on Marine Mammals. Exposure to PBTs has been linked to a wide range of toxic effects in marine mammals. PBTs stored in dolphin blubber can be redistributed to other tissue during stress and consequent weight loss. Two endangered species of orcas in Puget Sound are among the most highly contaminated marine mammals in the world. Their contamination levels reflect the continued presence of high levels of pollutants including PCBs, polybrominated diphenyl ethers (PBDE), and DDT in the greater Puget Sound area and the region's other marine ecosystems.[21]

Pollutants within an estuary can cascade through the food web and have indirect implications for crucial ecosystem processes. The endangered "apex predator" orcas are exposed exclusively to toxic contamination through their diet. Scientists believe that the orcas, for whom salmon are forage fish, are declining in health and reproductive capacity due to dwindling salmon populations which themselves are heavily contaminated by high levels of pollutants.

Examples of the contaminants' impacts on orcas are: impairment of reproduction by reducing hormone production; impairment of liver and thyroid function; skeletal deformities; suppression of the immune system, causing greater susceptibility to infectious disease; and promotion of tumor growth.

To support and restore intact ecosystem processes within the Puget Sound, the Puget Sound Partnership, one of the 28 National Estuary Programs, plans to support new

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[21] "Persistent Organic Pollutants and Stable Isotopes in Biopsy Samples (2004/2006) from Southern Resident Killer Whales", Margaret M. Krahn *et.al.*, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle; Cascadia Research; Fisheries and Oceans Canada (Pacific Biological Station); and Institute of Ocean Sciences, *Marine Pollution Bulletin*, 54(12), pp.1903-1911.
http://www.sciencedirect.com/science/article/B6V6N-4PVY331-1/2/37040056754545c70d03b06c62f47e28

research to fill critical knowledge gaps, inform development of models on food web structure, and identify stressors affecting salmon and other forage fish.[22]

Toxic Chemicals and Marine Debris. Marine debris serves as a vehicle for toxic chemicals to be introduced into coastal and ocean waters. A significant amount of the marine debris collected each year from the marine environment is plastic, such as convenience containers, plastic bottles, plastic bags, and plastic pellets.[23] Plastic can accumulate and concentrate toxic chemicals in the marine environment, serving as a source and a transport medium for toxic chemicals in the food chain. EPA's Marine Debris Prevention Program[24] is working to prevent debris from entering the marine environment and is beginning to explore the relationship between marine debris and toxic chemicals.

National Coastal Assessment Program. The National Coastal Assessment Program collects estuarine and coastal data from hundreds of stations along the coasts of the continental United States to assess coastal conditions. The assessment focuses on five indices of condition: water quality, sediment quality, benthic community condition, coastal habitat loss, and fish tissue contaminants. Toxic chemicals are included in the sediment quality and fish tissue contaminants indices, and are indirectly associated with the benthic community condition index. Results of these monitoring efforts are

[22] *Final Results from the 2007-2009 Puget Sound Conservation and Recovery Plan, July 1, 2007 - June 30, 2009*; http://www.psp.wa.gov/downloads/SOS09/PSPlanResults.pdf , and *Ecosystem Status & Trends; A 2009 Supplement to State of the Sound Reporting, November 2009* http://www.psp.wa.gov/downloads/2009_tech_memos/Ecosystem_status_and_trends_tech_memo_2009_06_11_FINAL.pdf

[23] http://www.epa.gov/owow/oceans/debris/prevention/plastics.html

[24] http://www.epa.gov/owow/oceans/debris/prevention/index.html

presented in the National Coastal Condition Report series, which rates the ecological condition of the coasts as good, fair, and poor based on the five indices.[25]

The National Coastal Condition Report III, released in December, 2008, rates the overall condition of the nation's sediment toxicity as good, with 4% of the U.S. coastal area rated as poor.[26] The sediment contaminants component indicator, which includes PBTs, was rated overall as good. Poor sediment contaminant condition was observed in 3% of the coastal area, and fair condition was observed in an additional 5% of the area. PBT concentrations in fish tissue were also assessed, with 18% percent of all stations where fish were caught showing contaminant concentrations above EPA Advisory Guidance values. These areas were dominated by fish that had elevated concentrations of total PCBs, total DDT, and mercury. Significant regional variation was also observed.

Toxic Chemicals in Vessel Discharges. Pollution from vessels can also have serious impacts on ocean health. Pollution from recreational, commercial, and military vessels emanates from a variety of discharges, including gray water, bilgewater, sewage, ballast water, and anti-fouling paints. These discharges can include metals such as copper, zinc and lead, aromatic organic compounds such as benzene and phthalate, and other toxic chemicals. EPA is implementing existing requirements and developing new

[25] http://www.epa.gov/owow/oceans/nccr

[26] http://www.epa.gov/owow/oceans/nccr3/downloads.html

requirements under the Clean Water Act to address the discharge of harmful substances from vessels.

Toxic Chemicals and Ocean Dumping. EPA prevents toxic chemicals from entering ocean and coastal waters through implementation of the Marine Protection, Research and Sanctuaries Act (MPRSA). MPRSA prohibits the ocean dumping of harmful materials that would unreasonably degrade or endanger human health and the environment. Sediments dredged from our ports and harbors to maintain navigation are one of the more significant materials disposed into the ocean under the authority of MPRSA. Sediments can contain a wide range of organic and inorganic contaminants, such as heavy metals, polyaromatic hydrocarbons and PCBs. Working closely with the Army Corps of Engineers, EPA requires testing of all dredged materials proposed for ocean dumping to determine whether they meet EPA's environmental criteria. This testing process is designed to protect against toxicity and bioaccumulation that may adversely impact the marine environment. In addition, EPA designates and monitors ocean dumpsites using the Ocean Survey Vessel *Bold* to ensure proper placement and disposal of dredged materials, further preventing adverse impact to the marine environment.

Thank you for the opportunity to describe EPA's role in protecting ocean health. We would be happy to answer any questions you may have at this time.

EPA Responses to Questions for the Record (QFRs) From the Hearing Before the Senate Committee on Environment and Public Works, Subcommittee on Oversight and Subcommittee on Water and Wildlife, Held on May 11, 2010, Entitled "EPA's Role in Protecting Ocean Health."

Questions From Senator Sheldon Whitehouse:

1. ***Dr. Payne has established a critical baseline data set for marine mammal health. EPA has helped to create a powerful methodological tool in its coral assessments. This type of information is invaluable for other scientists and research institutions studying stressors in the marine environment. Are these data and methodological tools widely available to the scientific community to draw from and build upon? In what ways are you planning to share this type of information?***

EPA shares our data and methodological tools in a number of ways. Currently, our primary venues are via an EPA website and scientific articles that we make available to the scientific community. EPA has posted methodological tools we developed for coral reef assessments on an EPA web site for Biological Indicators of Watershed Health (http://www.epa.gov/bioindicators/coral/coral_biocriteria.html). In addition, we have shared this information in peer-reviewed reports and journal articles, as discussed below.

We find these information sharing approaches effective. Some of the methods developed by EPA are being used by The Nature Conservancy in their Florida Reef Resilience Program (http://frrp.org/) to survey coral reefs in Florida; and some of the approaches have been recommended for compensatory mitigation of coral reef removal in Guam to accommodate aircraft carriers re-deploying from Okinawa. Resource managers in Florida and the U.S. Virgin Islands have been trained in the use of the methods and several presentations have been made, including a workshop for the Interagency Coral Reef Task Force.

Peer-reviewed articles widely available to the scientific community that incorporate data and methodological tools developed by EPA include:

Fisher, W. S., W. P. Davis, R. L. Quarles, J. Patrick, J. G. Campbell, P. S. Harris, B. L. Hemmer and M. Parsons 2007. Characterizing coral condition using estimates of three-dimensional colony surface area. Environmental Monitoring and Assessment 125:347-360.

Courtney, L. A., W. S. Fisher, S. Raimondo, L. M. Oliver and W. P. Davis 2007. Estimating three-dimensional colony surface area of field corals, Journal of Experimental Biology and Ecology 351:234–242.

Fore, L. S., W. S. Fisher and W.S. Davis 2006. Bioassessment Tools for Stony Corals: Statistical Evaluation of Candidate Metrics in the Florida Keys. U.S. EPA, Office of Environmental Information, EPA-260-R-06-002, 33 pp.

Fore, L. S., W. S. Fisher and W.S. Davis 2006. Bioassessment Tools for Stony Corals: Monitoring Approaches and Proposed Sampling Plan for the U.S. Virgin Islands. U.S. EPA, Office of Environmental Information EPA-260-R-06-003, 24 pp.

Fore, L.S. W.S. Fisher and W.S. Davis 2006. Bioassessment Tools for Stony Corals: Field Testing of Monitoring Protocols in the US Virgin Islands (St. Croix). U.S. EPA, Office of Environmental Information EPA-260-R-06-004, 46 pp.

Fisher, W. S. 2007. Stony Coral Rapid Bioassessment Protocol. U.S. Environmental Protection Agency, Office of Research and Development, EPA/600/R-06/167, Washington, D.C. 60 pp.

Fisher, W.S., L.S. Fore, A. Hutchins, R.L. Quarles, J.G. Campbell, C. LoBue and W.S. Davis 2008. Evaluation of stony coral indicators for coral reef management. Marine Pollution Bulletin 56:1737-1745.

Peer-reviewed articles widely available to the scientific community that elaborate the use of EPA methods, tools and data to protect coral reefs include:

Bradley, P., W. Fisher, H. Bell, W. Davis, V. Chan, C. LoBue and W. Wiltse 2008. Development and implementation of coral reef biocriteria in U.S. jurisdictions. Environmental Monitoring and Assessment 150(1-4):43-51

Fore, L. S., J. R. Karr, W. S. Fisher and W. S. Davis 2008. Making waves with the Clean Water Act. Science (Letter to the Editor) 322:1788.

Fisher, W.S., A.L. Hutchins, L.S. Fore, W.S. Davis C. LoBue and H. Bell 2009. Water quality standards for coral reef protection. 11th International Coral Reef Symposium. Session 23, pp. 1103-1107.

Bradley, P., W. Davis, W. Fisher, H. Bell, V. Chan, C. LoBue and W. Wiltse 2009. Development and implementation of coral reef biocriteria in U.S. jurisdictions. 11th International Coral Reef Symposium. Session 23, pp. 1078-1082.

Fore, L.S., J.R. Karr, W.S. Fisher, P. Bradley and W.S. Davis 2009. Heeding a call to action for U.S. coral reefs: the untapped potential of the Clean Water Act. Marine Pollution Bulletin 58:1421-1423.

Q.1 cont'd: Is there a single public institution that is acting as a clearinghouse for ocean-related science that could collect and disseminate this type of information? If not, do you agree there is a need for an agency or institution to act as an ocean information clearinghouse, and how would you like to see this clearinghouse function?

No, to our knowledge there is no single public institution currently acting as a clearinghouse for the collection and dissemination of information related to ocean sciences. However, a consortium of university and federal researchers have formed the Ocean Carbon and Biogeochemistry (OCB) program (http://www.us-ocb.org/) which is supported by NSF, NASA and NOAA. The OCB Program goals are to promote, plan, and coordinate collaborative, multidisciplinary research opportunities within the U.S. research community and with international partners. Also, the Joint Subcommittee on Ocean Science and Technology has recently formed an Interagency Working Group to develop a national strategy for research on ocean acidification. One of the goals of this group is to facilitate outreach and data and information exchange with stakeholder communities. As part of this work the Interagency Working Group on Ocean Acidification (IWG-OA) is exploring the most effective approach to information sharing and will make a recommendation accordingly.

2. ***You discussed during the hearing that EPA is working on a federal research plan for ocean acidification, in its role as participant in the Interagency Working Group on Ocean Acidification. What is the basic structure of the Working Group?***

The Charter of the IWG-OA convened by the Joint Subcommittee on Ocean Science and Technology (JSOST) describes the purpose of the IWG-OA as including development of a strategic research plan for federal research and monitoring on ocean acidification, including overseeing assessment of the potential impacts of ocean acidification (OA) on marine organisms and ecosystems and adaptation and mitigation strategies to conserve marine organisms and ecosystems, and promoting interagency and international information exchange and coordination of OA activities.

The IWG-OA is co-chaired by NOAA and the National Science Foundation, and its members include representatives from the National Science Foundation, National Aeronautics and Space Administration, the U.S. Geological Survey, U.S. Fish and Wildlife Service, and EPA.

Q.2, cont'd: What is the timing for the completion of this plan?

The Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act) directs the Joint Subcommittee on Science and Technology (JSOST) to develop a strategic research and monitoring plan to guide federal research on OA by March 2012. FOARAM also requires JSOST to report to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science and Technology and the Committee on Natural Resources of the House of Representatives no later than March 2010 on its progress in developing the plan. The Report to Congress on federal OA activities was delivered to the JSOST by the IWG-OA in March 2010. The report contains an inventory of federal ocean acidification activities, the budget for each of these activities, and an update on the development of the Strategic Research Plan. We understand that the report has been reviewed and cleared by the JSOST, but has not yet been submitted to Congress by Office of Science and Technology Policy.

Q.2, cont'd: What has EPA's role been in the creation of the plan?

EPA participates in the IWG-OA and has contributed to its work. EPA does not have a lead role in development of the plan but has participated in advancement of the plan and contributed information on EPA's research efforts related to ocean acidification.

Q.2, cont'd: Does the plan contemplate ocean acidification research being done by EPA?

The initial report submitted to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science and Technology and the Committee on Natural Resources of the House of Representatives included EPA's recent contributions to ocean acidification research. The strategy under development will also identify EPA research opportunities.

Q.2, cont'd: Can you share the plan with us upon its completion?

Certainly.

3. ***Would EPA be willing to come back to the EPW Committee to discuss the plan, and the authorizations and funding EPA would need, if any, to proceed with research outlined by the plan?***

EPA will be happy to join NOAA, the lead agency, in discussing the plan with the Committee and appropriate follow up.

EPA Responses to Questions for the Record (QFRs) From the Hearing Before the Senate Committee on Environment and Public Works, Subcommittee on Oversight and Subcommittee on Water and Wildlife, Held on May 11, 2010, Entitled "EPA's Role in Protecting Ocean Health."

Questions From Senator James M. Inhofe:

1. ***In your testimony, you cite the work of several scientists whose research supports the idea that oceans are becoming more acidic largely due to absorption of CO_2 from the atmosphere. EPA also appears to share this view. However, there is a credible body of science that questions the relationship between an increase in ocean acidity and increases in CO_2 in the atmosphere. Can you discuss why EPA, and your testimony, has ignored this body of scientific work?***

The relationship of atmospheric CO_2 with oceanic inorganic carbon (carbonate-bicarbonate stores) has been well-documented (e.g., Broecker 1974, Chemical Oceanography Harcourt Brace Jovanovich, Inc. New York). The rate of absorption of atmospheric CO_2 into ocean surface waters was first estimated in 1957 (Revelle and Suess, 1957 *Tellus* 9, 18-27). The conversion of dissolved CO_2 to carbonic acid, bicarbonate and carbonate are well accepted tenets of chemistry (e.g., Houghton, R. A. 2005. "The contemporary carbon cycle". in Schlesinger WH(editor). *Biogeochemistry*. Amsterdam: Elsevier Science. pp. 473–513). Empirical observations of declining ocean pH do not contradict the existing construct (Caldeira K, Wickett ME 2003 Anthropogenic carbon and ocean pH. Nature 425, 365). These concepts have been widely vetted within the scientific community (Orr et al. 2005 Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Science 437:681-686).

There are a limited number of studies that question the relationship between acidification and elevated CO_2. The studies we have decided to rely on are those also relied on by such organizations as The Intergovernmental Panel on Climate Change, the U.S. Global Change Research Program, and the National Research Council of the U.S. National Academies. EPA and these organizations have found compelling evidence that elevated CO_2 concentrations in the atmosphere have resulted in increased ocean acidity.

2. ***Before our committee Administrator Jackson admitted that unilateral action by the United States would not impact CO_2 concentrations in the atmosphere. Assuming that ocean acidification is happening and is a direct result of an increase in CO_2 emissions, could we expect action by the US to slow or eliminate ocean acidification without concomitant emission reductions by major emitters such as China and India?***

The Administrator has stated on a number of occasions that there is a direct correlation between atmospheric concentrations of CO_2 and ocean acidification. Because the U.S. is the world's second largest CO_2 emitter (roughly 20% of global CO_2 emissions), EPA also believes that any action taken by the U.S. to reduce our emissions will reduce total atmospheric CO_2 emissions and, by extension, the rate of ocean acidification.

3. To the best of your knowledge, did any of the research or lab studies relied upon by EPA use hydrochloric acid to change pH instead of CO_2?

An EPA-supported study used hydrochloric acid (HCl) instead of CO_2. Results from this study include the following:

Andersson AJ, Kuffner IB, Mackenzie FT, Jokiel PL, Rodgers KS and Tan A. 2009. Net Loss of $CaCO_3$ from a subtropical calcifying community due to seawater acidification: mesocosm-scale experimental evidence. Biogeosciences, 6, 1811–1823

Jokiel PL, Rodgers KS, Kuffner IB, Andersson AJ, Cox EF and Mackenzie FT 2008. Ocean acidification and calcifying reef organisms: a mesocosm. Coral Reefs 27:473–483

Kuffner IB, Andersson AJ, Jokiel PL, Rodgers KS, Mackenzie FT (2008) Decreased abundance of crustose coralline algae due to ocean acidification. Nature Geoscience 1:114–117

4. Would using HCl provide a proper representative result for ocean acidification from CO_2?

Bubbling CO_2 gas into experimental tanks is the preferred methodology for creating conditions to investigate the effects of ocean acidification on marine biota. However, addition of HCl produces a similar distribution of dissolved inorganic carbon species (increased bicarbonate and decreased carbonate concentrations) and similar alkalinity as CO_2 bubbling (Peltzer and Brewer 2008 Nature Geoscience 1:114-117). The HCl approach is acceptable for measuring effects on calcification rates of shell formation but would not necessarily be appropriate for estimating effects of increased atmospheric CO_2 on other biological processes. The use of HCl rather than CO_2 permits research on shell formation in large mesocosm-like studies where establishing an equilibrium with CO_2 bubbling is technically challenging and introduces additional experimental variability. A recent best practices guide (Riebesell, Fabry, Hansson and Gattuso 2010, Guide to Best Practices for Ocean Acidification Research and Data Reporting, European Commission, http://www.epoca-project.eu/) accepts HCl addition as a legitimate and defensible substitute for CO_2 bubbling and addresses the strengths and weaknesses of different approaches.

Some research has demonstrated more deleterious impacts from seawater acidified by CO_2 compared to seawater acidified by HCl. Copepod survival, for example, was lower in CO_2-acidified seawater than HCl-acidified seawater (Watanabe et al. 2001 Bulletin of the Japanese Society of Science and Fisheries 67: 764-765). Sea urchin fertilization rate also was more severely affected by CO_2-induced pH reductions (Kurihara and Shirayama 2004. Marine Ecology Progress Series 274: 161-169). One reason for this may be the greater diffusion of CO_2 across cell membranes, resulting in more rapid physiological disruption (Kurihara 2008 Effects of CO_2-driven ocean acidification on the early developmental stages of invertebrates, Marine Ecology Progress Series 373:275-284). These studies indicate that effects of ocean acidification on aquatic life from CO_2 might be underestimated when HCl or other mineral acids are used to decrease pH in toxicity testing.

5. Is there coordination between OW and OPPTS on toxics in the oceans?

Yes. The Office of Chemical Safety and Pollution Prevention (OCSPP -- formerly OPPTS) coordinates routinely with the Office of Water on issues associated with toxic chemicals and pesticides in aquatic environments. For instance, OCSPP and OW collaborate to ensure consistent regulatory outcomes when both organizations are reviewing the same pesticides. OCSPP and OW are also collaborating with EPA's Office of Research and Development to develop a harmonized process for evaluating the effects of pesticides on aquatic organisms, including marine species. In regulating disposal of PCBs, OCSPP has worked closely with OW on permitting issues associated with sinking ships for artificial reefs, although this aspect of the Agency's PCB efforts is now managed by the Office of Solid Waste and Emergency Response.

In addition, OW coordinates with OCSPP on issues related to marine debris as a part of EPA's Marine Debris Prevention Workgroup. OCSPP and OW work together to examine the potential toxicity of marine debris to the aquatic environment and work to reduce or eliminate waste at the source by reducing the amount and the toxicity of marine debris entering the oceans.

6. What is the role of OPPTS in ocean regulation?

Historically, the Office of Chemical Safety and Pollution Prevention (OCSPP -- formerly OPPTS) has not had a major statutory role in ocean regulation. Nonetheless, the regulation of pesticides and industrial chemicals contributes to overall environmental protection, including the protection of marine environments by regulating pesticides and chemicals that can enter marine environments. For example, in the regulation of pesticide use, risk assessments conducted in support of pesticide registration and reregistration decisions take into account potential risks to aquatic organisms in both freshwater and estuarine/marine environments. These assessments always consider pesticide residue levels in the environments where pesticides are used. Therefore, when OCSPP makes decisions that ensure the safety in various aquatic environments, OCSPP is also being protective for any residues that may be translocated to more distant estuarine/marine environments.

7. What role does EPA have in mitigating debris?

EPA is one of the lead federal agencies working on the marine debris issue and has been for more than 20 years. Marine debris is an environmental problem that stretches beyond the set responsibilities of any individual EPA office. As an agency, however, EPA is well equipped to address the stressors that lead to marine debris (e.g., solid waste, wastewater, stormwater, vessels, watersheds, plastics) using a comprehensive watershed approach. Using this comprehensive approach, statutory authorities such as the Marine Plastic Pollution Research and Control Act, Clean Water Act, and Resource Conservation and Recovery Act target the different types, sources, and conveyances of marine debris throughout the watershed and not just where it accumulates along the coastline.

EPA's Marine Debris Prevention Program is involved in a number of outreach programs that address marine debris through public awareness. The National Marine Debris Monitoring Program (NMDMP) was a five-year study that used volunteer groups to monitor and remove marine debris from selected U.S. beaches once every four weeks over the duration of the study. Site selection was based factors such as beach size, grading, soil texture, and accessibility. EPA is using the results from NMDMP to better address marine debris issues and develop new research activities. EPA has also been sponsoring and participating in the International Coastal Cleanup (ICC) for over 20 years. The ICC is an international event, held annually on the 3rd Saturday in September, where volunteers from all around the world collect trash and debris from rivers, beaches, and underwater sites.

EPA coordinates its marine debris prevention efforts through the EPA Marine Debris Prevention Program Workgroup which consists of members from the Offices of Resource Conservation and Recovery; Wastewater Management; Pollution Prevention and Toxics; Wetlands, Oceans, and Watersheds; International Affairs; and relevant Regional Program Offices. Using a number of the Workgroup offices' statutory authorities and individual programs, EPA is involved in the implementation of prevention and control programs that address marine debris, including improper disposal of waste at sea and on shore; addressing trash entering waterways through storm water drains and combined sewer overflows; promoting proper trash disposal and recycling; promoting sustainable packaging and product design; and monitoring marine debris trends in the environment.

EPA also works closely with other federal agencies to address the marine debris issue. EPA is the co-chair (with NOAA) of the Interagency Marine Debris Coordinating Committee (IMDCC). The IMDCC is an interagency group responsible for developing and recommending comprehensive and multi-disciplinary approaches to reducing the sources and impacts of marine debris to the nation's marine environment, natural resources, public safety, and economy. The IMDCC consists of representatives from the following federal agencies: NOAA, EPA, USN, USCG, USFWS, MMS, DOS, MMC, DOJ, and other federal agencies that have an interest in ocean issues and water pollution prevention and control.

8. What about regulating marine dumping?

EPA prevents toxic chemicals from entering ocean and coastal waters through implementation of the Marine Protection, Research and Sanctuaries Act (MPRSA), also known as the Ocean Dumping Act. MPRSA prohibits the ocean dumping of harmful materials that would unreasonably degrade or endanger human health and the environment. Before MPRSA, many potentially harmful materials were ocean dumped, including industrial waste, sewage sludge, radioactive waste, demolition waste, and contaminated dredged material. Virtually all material ocean dumped today is uncontaminated dredged material (sediment) removed from the bottom of waterbodies to maintain navigation channels and docks.

Ocean dumping cannot occur unless a permit is issued under the MPRSA. In the case of dredged material, the decision to issue a permit is made by the U.S. Army Corps of Engineers, using EPA's environmental criteria and subject to EPA's concurrence. EPA is the permitting agency for all other materials (e.g., vessels, fish wastes, human remains, ice piers in Antarctica).

Dredged materials, as well as other materials proposed for ocean disposal, must undergo a series of tests and evaluations to determine whether they meet EPA's environmental criteria for ocean dumping. EPA's ocean dumping criteria consider the environmental impact of the dumping; the need for the dumping; the effect of the dumping on aesthetic, recreational, or economic values; and the adverse effects of the dumping on other uses of the ocean. The testing and evaluation procedures are designed to protect against toxicity and bioaccumulation that may adversely impact the marine environment or human health, and to produce information about the potential for these effects efficiently and reliably.

EPA is responsible for designating ocean disposal sites for all types of materials. EPA designates and monitors ocean dredged material disposal sites using the Ocean Survey Vessel Bold to ensure proper placement and disposal of dredged materials, further preventing adverse impact to the marine environment or human health.

9. Please update us on the status of EPA regulation of marine and vessel discharges.

Significant environmental impacts to coastal and ocean ecosystems can occur from vessel discharges, and vessels can serve as a vector for non-indigenous species. Regulations, best management practices, guidance, recommendations, and research are all key components of the Vessel Discharge Programs within EPA. EPA is currently addressing vessel discharges in several areas, including cruise ships, ballast water, and marine sanitation devices (MSDs) on recreational and commercial boats.

EPA is developing and implementing regulations under the Clean Water Act (CWA), as well as technical guidance, to control pollutants from vessels. Under Section 312(b) and (f) of the Clean Water Act (CWA), EPA sets standards for sewage discharges and establishes No Discharge Zones, respectively. Currently, EPA is assessing whether revised or additional discharge standards for sewage and graywater from large cruise ships in Alaska are warranted under HR 4577 which contained Title XIV "Certain Alaskan Cruise Ship Operations" (33 U.S.C. 1901 Note). In 2009, EPA also began the development of proposed regulations to establish best management practices for discharges incidental to the normal operation of recreational vessels under the Clean Boating Act (CBA; CWA Section 312(o)). The CBA will impact approximately 17 million recreational vessels and cover discharges such as bilge water, graywater, bottom fouling (invasive species), and cleaning and maintenance discharges. Under CWA Section 402, EPA has developed a first-ever Vessel General Permit under the National Pollutant Discharge Elimination System program, which addresses 26 types of discharges (including ballast water) incidental to the normal operation of a vessel. The permit covers non-recreational vessels that are 79 feet in length or longer and any commercial fishing vessel which discharges ballast water. The Vessel General Permit is national in scope and currently covers approximately 70,000 non-recreational vessels.

EPA is working closely with the US Coast Guard (USGC) to support their development of standards and practices to help prevent the introduction of invasive species by ballast water discharges. EPA also supports international marine protection programs under MARPOL and the IMO Ballast Water Management Convention adopted in 2004.

10. ***Could you please clarify the safety of dispersants and the importance of their uses?***

EPA publicizes all dispersants that have been authorized for use on the National Contingency Plan (NCP) Product Schedule, which is a list of authorized dispersants and other chemicals that may be used to respond to oil discharges. As the Federal On-Scene Coordinator for this spill response, the Coast Guard is responsible for approving the use of the specific dispersant used from the NCP Product Schedule. Coast Guard issues approval for the use of specific dispersant in consultation with the Regional Response Team, which consists of federal agencies, including EPA, and the states within the region.

Dispersants contain a mixture of chemicals, that, when applied directly to the spilled oil, can break down the oil into smaller drops that can sink below the water's surface. Dispersed oil forms a "plume" or "cloud" of oil droplets below the water surface, and mixes vertically and horizontally into the water column, and is ideally rapidly diluted. Bacteria and other microscopic organisms are then able to act more quickly than they otherwise would to degrade the oil within the droplets.

The application of dispersant is part of a broader environmental triage approach to minimize the known threat to the environment to the greatest extent possible. The spill management strategies, practices, and technologies currently being implemented include mechanical removal techniques (use of sorbents, booming and skimming operations), *in-situ* burning, and lastly dispersants. There are environmental tradeoffs and uncertainties associated with the widespread use of large quantities of dispersants. We know dispersants are generally less toxic than the oils they break down. We know that surface use of dispersants decreases the environmental risks to shorelines and organisms at the surface and when used this way, dispersants break down over several days to weeks. In addition, the use of dispersants at the source of the leak represents a novel approach to addressing the significant environmental threat posed by the spill. Results to date indicate that subsea use of the dispersant is effective at reducing the amount of oil reaching the surface, and can do so by using less dispersant than is needed to disperse oil after it reaches the surface, and has resulted in significant reductions in the overall quantity of dispersants being used to minimize impacts in the deepsea.

The EPA and the U.S. Coast Guard authorized BP to use dispersants underwater, at the source of the Deepwater Horizon leak. Subsea dispersant application had been in use since May 15, 2010. After determining the effectiveness of the subsea dispersant use, on May 26, 2010, EPA and USCG directed BP to significantly decrease the overall volume of dispersant used and to cease use of dispersant on the surface of the water without appropriate justification. In the following month, the total volume of dispersants used decreased by 75% from their peak levels. No dispersant has been applied since July 19. The Federal Government reviews the effectiveness and impact on the environment of subsea application of dispersants; EPA specifically monitors the water and air for dispersant and its potential impacts through a rigorous monitoring program. EPA also continues to post all monitoring data on its Web site, www.epa.gov/bpspill. The toxicity data generated from this monitoring to date does not indicate significant effects on aquatic life. We are closely watching the dissolved oxygen levels, which so far remain in the normal range. Moreover, decreased size of the oil droplets is a good indication that, so far, the dispersant is effective.

EPA began its own scientific testing of eight dispersant products on the National Contingency Plan Product Schedule. EPA required toxicity tests to standard test species, including a sensitive species of Gulf of Mexico invertebrate (mysid shrimp) and fish (silverside) which are common species in Gulf of Mexico estuarine habitats. The invertebrate and fish species tested are considered to be representative of the sensitivity of many species in the Gulf of Mexico, based on years of toxicity testing with other substances. Initial peer reviewed results from the first round of EPA's toxicity testing indicated that none of the eight dispersants tested, including the product currently in use in the Gulf, COREXIT 9500 A, displayed biologically significant endocrine disrupting activity.

EPA conducted a second phase of its independent toxicity testing on mixtures of eight oil dispersants with Louisiana Sweet Crude Oil. EPA conducted the tests as part of an effort to ensure that EPA decisions remain grounded in the best available science and data. EPA's results indicate that the eight dispersants tested have similar toxicities to one another when mixed with Louisiana Sweet Crude Oil. These results confirm that the dispersant used in response to the oil spill in the gulf, Corexit 9500A, when mixed with oil, is generally no more or less toxic than mixtures with the other available alternatives. The results also indicate that dispersant-oil mixtures are generally no more toxic to the aquatic test species than oil alone. The results are posted on our website at http://www.epa.gov/bpspill/dispersants-testing.html Regarding the safety of seafood from the Gulf, to date, every seafood sample from reopened waters has passed sensory testing for contamination with oil and dispersant. Modeling data on the individual components of the dispersant indicate that the dispersants used to combat the oil spill break down rapidly and become highly dispersed in Gulf waters. Science, to date, also indicates that dispersants do not accumulate in seafood. Thus, all our evidence shows that seafood from the reopened Gulf waters is safe to eat.

STATEMENT OF JIM JONES, DEPUTY ASSISTANT ADMINISTRATOR, OFFICE OF CHEMICAL SAFETY AND POLLUTION PREVENTION, U.S. ENVIRONMENTAL PROTECTION AGENCY

Mr. JONES. Thank you, Nancy.

And thank you, Chairman Whitehouse and Chairman Cardin.

I am Jim Jones, Deputy Assistant Administrator for the Office of Chemical Safety and Pollution Prevention at EPA. Our office is responsible for implementing the Toxic Substances Control Act, or TSCA, as well as the pesticide laws FIFRA and the FFDCA. We also implement the Pollution Prevention Act.

As you know, persistent bioaccumulative toxic chemicals, or PBTs, are long lasting substances that build up in the food chain, and at certain exposure levels may be harmful to human health and the environment. They do not readily break down, so when they are released to the environment they remain essentially unaltered for months or years.

With continued use and release, PBTs buildup in sediments and soil. Their concentrations increase as they go up the food chain from sediment to aquatic insects to fish, for example. It is this concentration in the food chain which under certain circumstances can cause adverse effects in humans or wildlife.

As part of Administrator Jackson's comprehensive effort to strengthen EPA's chemical management program and assure the safety of chemicals, EPA has released five action plans which outline a range of actions under TSCA that the agency intends to take to address concerns with these chemicals. Three of these action plans for PBT chemicals: short-chain chlorinated paraffins, or SCCPs; perfluorinated chemicals; and polybrominated diphenyl ethers, or PPDEs as they are commonly known. SCCPs and PPDEs are known to be found in marine mammals.

Taking action under TSCA has proven to be very difficult. The agency has the burden of demonstrating risk. Requiring manufacturers to generate data is time consuming and inefficient. The statute creates legal and procedural hurdles that have stymied the agency from taking quick and effective regulatory action. For these reasons, the Administration believes it is important to work together with Congress and all interested stakeholders to quickly modernize and strengthen the tools available in TSCA to increase the American public's confidence that chemicals used in commerce are safe.

Last September the agency released a set of essential principles for reform of chemicals management legislation to help inform these discussions, and we look forward to working with Congress on updating TSCA.

Thank you for the opportunity to describe EPA's role in protecting ocean health. We ask that our full written statement be made a part of the record of this hearing, and we would be happy to answer any questions that you may have.

Senator WHITEHOUSE. Without objection, the statement will be made part of the record.

I appreciate it. I thank you very much for being here.

Ms. Stoner, where do you think would be the most helpful places that EPA could do or support research to begin to better identify the acidification trends and the likely effects of those trends on the marine ecosystem?

Ms. STONER. Senator, the EPA is engaged in research now with the Interagency Working Group on Ocean Acidification. So we are coordinating our research with a variety of Federal agencies. We are currently working on a research plan for the Federal Government as a whole that will enable us to ensure that we target those efforts to where we can achieve the most. We are looking both at what is happening in the water in terms of ocean acidification and changes in chemistry.

We are also looking at how that change in chemistry affects a variety of different kinds of organisms, including coral and looking at coral reefs and shellfish. As you noted in your opening remarks, there are significant concerns about shell formation associated with the ocean chemistry changes associated with ocean acidification.

Senator WHITEHOUSE. Let me show a photograph that we have of a shell over 45 days of exposure to the surface sea water at pH levels that are expected in 2100, perhaps my children's lifetimes if not mine. And obviously that shell is degrading and dissolving pretty rapidly, and it makes it very challenging for that species to live, again, in an environment in which it is soluble.

And to the extent that some of these species are basic bottom of the food chain core species for the rest of the marine ecosystem, it portends potentially very significant adverse results. Are you fully comfortable and confident that responding to that is something that is within EPA's jurisdiction, even though there may not be an immediate human health effect?

Ms. STONER. Senator, as I mentioned, we are looking closely at those issues. The two related points, the saturation rate of calcium carbonate minerals and then the dissolution of the shell, both weaken the shell, and we are looking at both of those now.

We have not yet developed a plan for how to address this. We are actually looking at how individual species as well as populations are affected, and as the National Academy referred to it, who the winners and losers might be; how it might affect the ecosystem as a whole.

So we are in the process of developing our approach and our plan based on acquiring the best science.

Senator WHITEHOUSE. But you are comfortable that the EPA's current statutory authority allows it to consider these kinds of harms in its analysis of what parts of the environment need to be protected. You don't feel a jurisdictional gap when you are dealing with this?

Ms. STONER. The jurisdiction of the Clean Water Act goes out to 3 miles. So we actually don't have jurisdiction out in the middle of the ocean to address this. And the tools that we have under the Clean Water Act don't necessarily reach all of the sources.

Senator WHITEHOUSE. How about the Clean Air Act?

Ms. STONER. Yes, sir. I am talking about the Clean Water Act.

Senator WHITEHOUSE. I know.

Ms. STONER. Right.

Senator WHITEHOUSE. Let me ask you, that takes you out 3 miles. Where does the Clean Air Act take you, if it turns out that there is damage being done as a result of emissions that you regulate?

Ms. STONER. Right, yes, sir. And so the main source is carbon dioxide emissions which we are working to regulate under the Clean Air Act. The Clean Water Act does not directly enable us to do that, although it would enable us to identify that as the source of the problem, for example in a pollution budget or total maximum daily load.

Some of our experience with mercury pollution is instructive here. That, again, is a water related problem, a fish tissue problem, but it comes mostly from air emissions.

Senator WHITEHOUSE. And Mr. Jones, let me ask you a similar question. Very often when we have hearings about TSCA, the targeted species is humankind, and that is our constant and primary target. But when you do see the kind of information that Dr. Payne will be providing later, and I think you have seen it in his pre-filed testimony about the extent to which marine mammals have been poisoned by regulated chemicals that have gotten out into the oceans and concentrated in them at the top of the food chain.

Do you have any restrictions in EPA's ability to take action off of that evidence in terms of putting regulatory restrictions on various chemicals? Can you make regulatory decisions based on that information?

Mr. JONES. That information can be considered in our regulatory determinations. As we have stated before to this Committee, TSCA is a difficult statute to operate within. However, while we are working with Congress to reform TSCA, we are pursuing assessment and regulation of several persistent bioaccumulative toxins, in particular the ones that I mentioned here earlier that have direct impact that we know as it relates to the marine environment, the short chain chlorinated paraffins and the PBDEs.

So we are considering their impact on the marine environment. One of the other action plans that we are looking at, bisphenol-A is related to its aquatic impacts, particular in estuarine environments.

So, it is an area that we do focus on, and we are going to try to use the tools that we have to protect not only the terrestrial environment and human health, but also the marine environment.

Senator WHITEHOUSE. Very good.

Senator Cardin.

And I would like to welcome Senator Udall who has joined us.

Senator CARDIN. Thank you.

And let me thank our witnesses for their testimony.

I guess I want to start with I strongly support EPA using the authorities it has under both the Clean Water Act and Clean Air Act to deal with the pollutants entering our ocean and the impact it has on not only the environment, but I think public safety and public health. So I strongly support that.

My question is, and Ms. Stoner, in your original statement you say you don't fully understand, which I understand that you don't fully understand the impact here.

How do we improve the research that is being done? What tools do we need so that you have the scientific information necessary to support the regulatory efforts that you are making? You are going to be challenged every step of the way. What do we need to do in order to get the best science to make the right judgments?

I want to make sure that the regulatory framework is the most effective framework, not just because we know there is a problem and want to do something about it, but we have the scientific information to support that and the remedies and regulations that you are seeking are aimed at reducing the problem.

Ms. STONER. Thank you, Senator. Of course, we are doing the best we can with the resources we have, in coordination with the other Federal agencies. There are additional research needs. This is a worldwide problem, of course, and there are coral reefs in various places in the U.S. and Puerto Rico, Florida, Hawaii and so forth that studying those reefs in particular could be helpful in how they are being affected.

There are lots of different kinds of species and populations that are affected, crustaceans and mollusks, for example. And there is lots of additional science that could be done that could help inform these decisions.

Senator CARDIN. I just urge you to let us know if you need additional tools from Congress in order to be able to deal with the scientific information necessary. We understand this is international, but the United States has to be in the leadership here. Other countries are doing a much more aggressive job than we are doing, so I think we could learn from each other. But if there additional tools you need from Congress, I think we need to know that in order to support your decisions.

Mr. Jones, let me go to the issue I raised in my opening statement, the use of these dispersants to deal with the tragic accident in the Gulf of Mexico. Dispersants have been used in the past. EPA has been asked for its judgment on that and has given, I believe, an OK, recognizing the relative risk. There is a risk involved in whatever we do, and you try to minimize that.

Can you, though, tell us the process EPA went through to allow the dispersants to be used? And what risk factors are present in the use of the dispersants?

Mr. JONES. Yes, Senator, thank you. Let me first say that the agency's response to this and basically any other emergency along these lines is directly managed by the Office of Solid Waste and Emergency Response. My colleague Nancy and I are in offices that provide support to that office and we have been communicating with them. So we are generally aware of the agency's response to the BP oil spill, but we may lack some of the specificity.

So with that preface, let me say that the first thing is that before any dispersants can be used in this context, it has to be on an approved list in our national contingency plan, which is a statutorily created plan that governs the use of remediation approach such as the use of dispersants. So the chemical being used in this context had already been approved for that purpose.

To get on to that list, the agency needs two kinds of information: information with respect to its efficacy—will it do what it is supposed to do, in this case disperse the oil? Second, marine related hazard data is required. So the chemical that is being used right now had both demonstrated effectiveness as well as the appropriate toxicity data for use on the surface of the ocean.

There has been an interest in pursuing whether or not this chemical may be effective below surface, and in that context the agency has authorized the manufacturer to test it for that purpose. So we have authorized just three tests to see whether or not it meets these two criteria: Is it effective at dispersing the oil? And what is the toxicity in that context? We have made it clear that we will not authorize the use in a sub-surface context until successful tests have been completed.

Senator CARDIN. But it is toxic? It is a toxic?

Mr. JONES. The chemicals that are being used have toxicity associated with them. And I think as the agency has tried to be very clear, this is about an environmental tradeoff that we are making.

Senator CARDIN. And I support that. I am not challenging that. But we need to know the damage that is being caused as a result of the choice that has been made. It may be less damage than otherwise would have been caused, but it is creating a different set of factors. And I think it is important that we understand that, and that the public understands that.

One of the concerns I have is that by dispersing, it won't be seen as much, and therefore the public might think damage hasn't been done. But in reality damage has been done. It has been done to the water quality as a result of the toxins being placed in the ocean. And second, the oil still is there. It is not being eliminated. It goes to the ocean bottom, as I understand, which has its own set of problems.

Mr. JONES. That is correct, Senator. I think the agency is trying to do its best to make sure people understand this is about an environmental trade off that is being made. Damage has been done. That is absolutely correct.

Senator WHITEHOUSE. Senator Udall.

Senator UDALL. Thank you very much.

I first of all want to thank Chairman Whitehouse and Chairman Cardin for their effort. They, as I have observed here, have been real champions on this issue. I know Senator Whitehouse has additional spurring effort from the home front. His wife is a Ph.D. scientist in this area. I have been on trips with him where I have learned a lot from her. I hope that she is watching today and seeing that you are doing a good job here, Sheldon, on this front.

Let me first of all follow up a little bit on what Senator Cardin asked about. When you talk about research, I think the first issue is do you have any idea how much we are doing in this area in dollar amount across the Federal Government to look specifically at the acid buildup in the ocean?

Ms. STONER. Senator, I know that EPA's budget for 2009 for research on ocean acidification was about $2 million.

Senator UDALL. Which isn't much, right?

Ms. STONER. It is a relatively small amount. This is a new area of research area for us, but that is what we are doing in 2010. I don't have handy the budget for the entire Federal Government. We can get back to you.

Senator UDALL. OK. That would be great. That would be great.

Do you have any numbers on the worldwide effort? Is there any cooperative effort in terms of sharing research, pooling money, trying to do that? One of the reasons I ask that is I think it is so important when we get into these scientific issues that we share he science and that we build the consensus through sharing the science. And I am wondering, either one of you, what is happening there on that front?

Ms. STONER. Senator, first of all, I got the number on the Federal budget for direct monitoring, which is $1.426 million in 2008 and $1.289 million in 2009.

Senator UDALL. And that is specifically targeted to the buildup of CO_2 and acidification of the ocean?

Ms. STONER. Yes, sir. It is direct monitoring of ocean chemistry and biological impacts associated with ocean acidification. And that is EPA, the Marine Minerals Service, NASA, NOAA, NSF, and USGS. And we are all working together through the Ocean Acidification Task Force. We are also coordinating with other research entities across the world through that effort.

So it is a coordinated effort. It is a new effort under the new law. So we are developing a research plan now.

Senator UDALL. On these countries that are cooperating around the world, is there participation by most of them? Or is this just the countries that are on the ocean? What can you say about that?

Ms. STONER. My guess is that coastal and ocean countries are more involved, but I don't know the full extent.

Senator UDALL. Yes. Now, you also mention in your testimony the global nature of the toxic chemicals that are released into the oceans and the need for ratification of global treaties such as the Persistent Organic Pollutants Treaty, the POPs Treaty as it is known. Can you describe some of the specific chemicals that these global treaties look to curb on a global basis?

Mr. JONES. Yes, sir. I will answer that. Many of the original chemicals that were listed on the treaty are chemicals, for example, the organochlorine pesticides which have largely been regulated in the United States. Well, they have been totally regulated in the United States.

Some of the more recent additions to the list include chemicals that are on our list of action plans, such as the short chain chlorinated paraffins and the PBDEs. So we are beginning to see chemicals being listed without the U.S. participation in those treaties, which have yet to be fully evaluated and regulated in this country.

Senator UDALL. So what you all are urging is that we ratify these treaties and move forward with the countries around the world, and that we are slow to do that at this point.

Mr. JONES. That is correct. There are problems with not being at the table, one, because there may be very important uses that we would like to see maintained because they are very important to the country, and so our voice is not being heard there. Also it is not allowing us to be global leaders on the issues of those chemicals for which we think quick action is necessary.

Senator UDALL. Thank you both for your testimony. Very good panel, and once again, I appreciate the hard work of the two Chairmen on this.

Senator WHITEHOUSE. Thank you, Senator Udall.

I thank the members of this panel for coming forward. I think you have heard from all of us a cheering and enthusiastic response to your work. As Senator Cardin suggested, if you feel you need additional resources or authorities, we would be only too delighted to hear from you about how to supplement both of those. Thank you very much.

We will excuse this panel and take a 2-minute recess while we call up the next panel and get people squared away.

[Recess.]

Senator WHITEHOUSE. All right, I think what we will do, first of all, we will come back to order.

I think what I will do is I will introduce each witness and ask them to give their opening statements, and the hold questions until all four statements have been given, and then we can have more open season, more robust discussion.

So I will begin just going across the panel here with Dr. Roger Payne. He is the Founder and the President of Ocean Alliance, a nonprofit organization dedicated to the preservation of whales and all marine life. Many of us remember his discovery that humpback whales sing to one another, and the LP, if that doesn't date me too badly, that resulted from that discovery.

Dr. Payne has led over 100 expeditions to all oceans and studied every species of large whale in the wild. He pioneered many of the benign research techniques now used throughout the world to study free swimming whales, and has trained many of the current leaders in whale research. He publishes technical articles and writes for general audiences. In one of this three articles in National Geographic magazine contained a record of whale sounds for which 10.5 million copies were printed, still the largest single print order in the history of the recording industry.

His publications include the book Among Whales and three recordings, Songs of the Humpback Whale, the best selling natural history recording ever released; Deep Voices; and with musician Paul Winter, Whales Alive. He is a writer and presented for television documentaries and co-writer and co-director of the IMAX film Whales.

Payne's honors and awards include a knighthood in the Netherlands, a MacArthur Fellowship, the similar Lyndhurst Prize Fellowship, and the Joseph Wood Krutch Medal of the Humane Society of the U.S.

We are delighted to have him here, and thank you for your testimony. It is also a banner day because today he is announcing and releasing the report of his latest study. So thank you, Roger Payne.

STATEMENT OF ROGER PAYNE, FOUNDER AND PRESIDENT, OCEAN ALLIANCE

Mr. PAYNE. Thank you very much.

The oceans are downhill from everything on land, and that means that everything that can be moved by wind or water eventually ends up in the sea where ocean currents then spread it around the world. Some of the most insidious things that reach the sea are the chemicals humans synthesize, and through use release into the environment.

Such compounds have such unmemorable names as polychlorinated biphenyls, polybrominated diphenyl ethers, dioxins, furans, phthalates, bisphenol-A and so on. Collectively, these chemicals threaten our future. Other contaminants have more familiar names like chromium, mercury and lead.

Eighteen years ago I wanted to know how extensive oceanic contamination had become, and I decided that my institute should establish a global baseline for many pollutants by measuring their worldwide concentrations in sperm whales. We chose sperm whales because they occur worldwide and live about as high on food pyramids as humans do. Seeing how badly sperm whales are poisoned tells you how badly you are likely to be poisoned.

To this end, we conducted the voyage of the Odyssey, a 5-year circumnavigation of the globe during which we collected 955 samples from sperm whales, giving us the first worldwide sample set from a single species, the first trip to measure how badly polluted all oceans are with synthetic chemicals and toxic metals.

Our samples contained some of the highest levels of pollutants ever found in any free ranging animal. The very highest readings were from whales that we sampled in some of the remotest regions of the world. In short, the oceans are polluted to a far worse degree than anyone had imagined.

For the moment, consider just one of the many pollutants we studied, chromium. The film Erin Brockovich was about chromium poisoning. Chromium is a known human carcinogen with the ability to break and destroy DNA. With our partner, Dr. John Wise at the University of Southern Maine, we found levels of chromium in sperm whale skin tissue that are on a par with chromium levels found in the lungs of industrial workers who died of chromium induced cancer, workers with decades of exposure to chromium from working in factories that made chromium compounds. Our results show that whales are experiencing similar, even higher levels of exposure.

We also tested the effects of chromium on sperm whale cells grown in laboratory, and found that chromium damages whale DNA just as it does human DNA, suggesting that chromium poses problems to whales that are growing and developing. The most polluted whales lived in waters around Kiribati in the Central Pacific, about as far as you can get from industrialization and big agriculture on this planet.

This whale contained a concentration of chromium 183 times higher than is needed to break chromosomes. In short, we have a major pollution problem. We are poisoning the entire ocean ecosystem. We cannot afford any longer to expect the ocean to be able to take what we are putting into it. We are poisoning and chemically sterilizing the marine world.

Seafood is the principal source of animal protein for over 1 billion people. If we keep polluting, humanity will eventually lose access to a key food resource. The prospect of over 1 billion people losing their principal source of meat because it has become too contaminated with pollutants for safe consumption will be one of the most serious public health crises humanity has ever faced.

In spite of the obvious seriousness of this problem, it is not on any government's radar. Before Ocean Alliance circled the globe sampling sperm whales, no one had measured how polluted ocean life had become globally. However, if we address this problem vigorously, it is not too late.

We offer the following policy recommendations. One, we need global legislation to stop industries from discarding harmful substances into the sea or the air, which simply carries them into the sea.

Two, we need to thoroughly test chemicals for safety. According to a major report released last Thursday by the President's Cancer Panel, a top policy voice on cancer, "Only a few hundred of the more than 80,000 chemicals in use in the United States have been tested for safety. Many known or suspected carcinogens are completely unregulated."

Three, when we have evidence that chemicals damage wildlife, we need to apply the precautionary principle and get them out of circulation for the sake both of the wildlife and of humans that are most at risk, children and fetuses.

Four, we need to allocate funds specifically aimed at studying and reducing ocean pollution. There are next to no Federal funds available to measure ocean pollutant levels. The usual Federal agencies don't fund such studies, and most of the EPA funds are expended internally on its own projects, which is very important, but so are the projects folks like us would do if we could find funding for them.

What is needed is a specific setaside, specific allocations. It is crucial to stop the flow of toxic contaminants into the sea. It is easier to stop than global warming, but no less important.

Thank you.

[The prepared statement of Mr. Payne follows:]

Written Testimony of Dr. Roger Payne
Founder/President, Ocean Alliance
191 Weston Road, Lincoln, MA, 01773

I am Roger Payne, Founder and President of Ocean Alliance a non-profit research organization that has been working to conserve ocean life for the past 40 years.

The oceans are downhill from everything on land. That means that everything that can be moved by wind or water eventually ends up in the sea where ocean currents then spread it around the world. Some of the most insidious things that reach the sea are the chemicals humans synthesize and, through use, release into the environment.

Such compounds have unmemorable names such as Polychlorinated biphenyls, Polybrominated diphenyl ethers, dioxins, furans, pthalates, Bisphenol-a. Collectively, these chemicals threaten our future. Other contaminants have more familiar names like chromium, mercury and lead.

18 years ago I wanted to know how extensive oceanic contamination had become. I decided that my institute could establish a global baseline for many pollutants by measuring their worldwide concentrations in sperm whales. I chose sperm whales because they occur worldwide and live about as high on food pyramids as humans do. Seeing how badly sperm whales are poisoned tells you how badly you are likely to be poisoned.

To this end, we conducted the Voyage of the *Odyssey*, a 5-year circumnavigation of the globe during which we collected 955 samples from sperm whales, giving us the first worldwide sample-set from a single species. It made our trip the first to measure how badly polluted all oceans are with synthetic chemicals and toxic metals.

We discovered that our samples contain some of the highest levels of pollutants ever found in any free-ranging animal—the very highest readings were from whales we sampled in some of the remotest regions we visited. In short, the oceans are polluted to a far worse degree than anyone had imagined.

For the moment, consider just one of the many pollutants we studied - chromium. (The film *Erin Brockovich* was about chromium poisoning). It is a known human carcinogen with the ability to break and destroy DNA.

With our partner, Dr. John Wise, at the University of Southern Maine, we found levels of chromium in sperm whale skin tissue that are on a par with chromium levels found in the lungs of industrial workers who died of chromium-induced lung cancer. These workers had decades of exposure to chromium because they worked in factories using and making chromium compounds. Our results show that whales are experiencing similar, even higher, levels of exposure.

We also worked with sperm whale cells grown in the laboratory to see how these cells are affected by chromium. We found that chromium damages whale DNA just as it does human DNA, suggesting that chromium poses problems to whales as they grow and develop.

The most polluted whale lived in waters around Kiribati (in the central Pacific) about as far as it is possible to get from industrialization and big agriculture. This whale contained a concentration of chromium 183 times higher than is needed to break chromosomes.

In short, we have a major pollution problem—we are poisoning our entire ocean ecosystem. We cannot afford any longer to look at the ocean as a giant sink capable of diluting to "safe levels" whatever we put into it. We are slowly and surely poisoning and chemically sterilizing the marine world.

Seafood is the principal source of animal protein for over a billion people. If we keep polluting, humanity will eventually lose access to this key food source. The prospect of over a billion people losing their principle source of meat - because it has become too contaminated with pollutants for safe consumption - will be one of the most serious public health crises humanity has ever faced.

In spite of the obvious seriousness of this problem, it is not on any government's radar. Before Ocean Alliance circled the globe sampling sperm whales, no one had measured how polluted ocean life had become.

However, if we address this problem vigorously it is not too late. We offer the following Policy Recommendations:

1) We need global legislation to stop industries from discarding harmful substances into the sea or the air (which simply carries them to the sea).

2) We need to thoroughly test chemicals for safety. According to a major report released last Thursday by the President's Cancer Panel, (a top policy voice on cancer) [Quote] "Only a few hundred of the more than 80,000 chemicals in use in the United States have been tested for safety, many known or suspected carcinogens are completely unregulated." [End quote]

3) When we have evidence that chemicals damage wildlife we need to apply the precautionary principle and get them out of circulation—for the sake both of wildlife and the humans most at risk—children and fetuses.

3) We need to allocate funds specifically aimed at studying and reducing ocean pollution.

There are next to no federal funds available even to measure ocean pollutant levels. The usual Federal Agencies don't fund such studies, and most EPA funds are expended internally on its own projects... very important, but so are the projects folks like us would do if we could find funding for them. What's needed is a specific set-aside—specific allocations.

It is crucial to stop the flow of toxic contaminants into the seas—it's easier to stop than global warming, but no less important.

Thank you for this opportunity to address you; I would be glad to try to answer your questions.

Questions for Payne
Questions from:
Senator Sheldon Whitehouse

1. Dr. Payne has established a critical baseline data set for marine mammal health. EPA has helped to create a powerful methodological tool in its coral assessments. This type of information is invaluable for other scientists and research institutions studying stressors in the marine environment.
Are these data and methodological tools widely available to the scientific community to draw from and build upon? In what ways are you planning to share this type of information?

Yes the methodological tools are standard tools that are widely available for use by others. Some of the data have already appeared in peer reviewed journals; other data are presented in our Voyage report, and we are currently striving to get all the remaining data published in peer reviewed journals where it will be fully available to the scientific community. Our future plans also include building a website where the data will be available to the general public.

Is there a single public institution that is acting as a clearinghouse for ocean-related science that could collect and disseminate this type of information?

We are unaware of such a public institution or clearinghouse.

If not, do you agree there is a need for an agency or institution to act as an ocean information clearinghouse, and how would you like to see this clearinghouse function?

There is a clear need for such an information clearinghouse to expedite, strengthen and enhance ocean research. The chief function of such a clearinghouse would be to collect and make available all possible data to all possible users. A stakeholder who collected a given data set would be given a reasonable time period within which to mine the data in it for his or her professional purposes, but when that period was up the data would automatically be made available to all. It seems only reasonable that having supported such research, taxpayers should reap the maximum benefits of the data they paid for by making sure that the data become as broadly available as possible—thereby increasing their influence.

2. At the time of the hearing, you did not yet have data on PBDE's in your sample.

PBDEs are known to both bioaccumulate and biomagnify. The full spectrum of PBDE toxicity is currently unknown but is actively under investigation. The most recent data strongly indicate an impact on the developing nervous system.

Would you like to provide further comments on their bio-accumulative effects, and in particular the risk they pose to lactating mammals?

PBDEs are known to both bioaccumulate and biomagnify. The full spectrum of PBDE toxicity is currently unknown but is actively under investigation. The most recent data strongly indicate an impact on the developing nervous system. As regards lactating mammals, PBDEs are turning up at very high levels in human breast milk and tissue indicating that nursing children are at particular risk of exposure. This risk, coupled with animal data showing developmental neurotoxicity raises strong concerns for children's health in particular.

3. What do you believe is the most pressing research question related to either of the threats to ocean health that we discussed; ocean acidification, or toxics in the marine environment?

Both issues are of significant concern, however, of the two, ocean pollution is without doubt the most pressing of the two because it is already occurring, has been in place for many years and is impacting wildlife health. One need only look to our Southern coast which is bathed in oil and chemical dispersants constituting what is the greatest marine pollution disaster in US history.

Questions for Payne
Questions from:
Senator James M. Inhofe
1. Given that many types of chromium appear to occur naturally, which type or types of chromium did you find in whales?

In nature chromium occurs in two biologically relevant states: trivalent chromium and hexavalent chromium. The hexavalent form is extremely rare and typically occurs in the mineral/gem crocoite. Thus, it is extremely unlikely that whales were exposed to hexavalent chromium. Hexavalent chromium is a very important product commercially and the chemical industry manufactures it from trivalent sources. Trivalent chromium is more common in nature but typically one has to mine it to access it. In biological systems the hexavalent chromium is rapidly absorbed by cells but immediately converted in the cell to trivalent chromium. By contrast trivalent chromium is very poorly absorbed by biological systems. Because of these factors, virtually all chromium in a biological tissue shows up as trivalent chromium which provides no indication as to whether the original source was trivalent or hexavalent. Consequently, all of the chromium we measured in our samples was trivalent chromium. The Senator's question seeks to determine whether the exposure was to naturally occurring or man–made chemicals. One cannot clearly distinguish the source of the exposure from a biopsy measurement. However, in the case of chromium one can make reasonable inferences from the data. The sperm whale skin chromium levels were very high. Because the trivalent form is so poorly absorbed biologically, in order to achieve the levels we found the original form was most likely hexavalent. And because hexavalent chromium is exceedingly rare in nature it would seem very unlikely that the cause of the levels we measured were natural sources of chromium.

2. Do you think these high concentrations of chromium were a result of bioaccumulation perhaps from a young exposure or from a more severe limited exposure in an isolated area of high concentration?

One cannot determine the specific exposure duration from analysis of a biopsy. Both scenarios described in the question are possible. Chromium bioaccumulates but does not biomagnify. Therefore, the exposure that occurred is specific to the individual animal. We have seen in a whale less than a year old a high level of chromium, indicating that these levels could be achieved with less than a year of exposure. We are unaware of any dramatic release of chromium into the marine environment that would have been likely to cause a sudden severe increase in exposure. Thus, the more probably scenario is one of more chronic exposure over time, though perhaps less than a year.

3. Do you believe these levels of chromium you found in whales are harmful?

Yes, we believe that chromium is reaching levels that are harmful to whales. We have done studies showing that chromium levels in this range overtly kill sperm whale cells grown in culture, and in those cells that do survive the chromium damages their DNA. The chromium levels we found in sperm whales also cause cancer and damage DNA in humans.

4. If so, why have we not seen more damaging effects on much smaller sea mammals?
We respectfully disagree that we have not seen more damaging effects in smaller sea mammals. For example, over the past 30 years the western population of Stellar sealions has declined by 80%. It is clear that environmental factors are involved and that chromium is a candidate for such involvement. We have shown that chromium will kill and damage the DNA of Stellar Sealion cells grown in culture.

5. How does the size of a sperm whale compare to the size of the workers you described in your example with similar chromium levels?

Adult sperm whales cover a large spectrum of size but the smallest weighs as much as several adult humans. Thus, one wonders if the differential size comes into play. In the case of chromium the answer is no. The answer is no because the data are expressed as weight of chromium per gram of tissue. Thus the size of the tissue has no influence on these measurements of chromium concentrations. A measurement of 100 micrograms per gram of tissue would represent the same amount of accumulated chromium in both a human worker and a whale.

6. How does the level of elevated chromium in lung tissue of humans compare to similar levels in skin tissue of whales?

They are known to be the same (please see the previous question for a further explanation).

7. In your policy recommendations you advocate for use of the "precautionary principle" when evidence shows that chemicals damage wildlife. The precautionary principle, according to an EU Commission's communication on the subject, "presupposes that potentially dangerous effects deriving from a phenomenon, product or process have been identified, and that scientific evaluation does not allow the risk to be determined with sufficient certainty." What level of scientific information would you recommend we as policy makers require before using this principle?

In my statement when I referred to wildlife I was implying vertebrate animals. The fundamental point is that if we have determined a 'safe level' for humans the same protection should be extended to wildlife. We should not argue that wildlife may have some special protective mechanism that protects them in ways that humans are not protected. Instead we should assume that they are similarly sensitive and apply the precautionary principle until there is evidence to the contrary. For example: we know that mercury is toxic. We limit the amount of mercury that people can be exposed to in the fish they eat. When mercury levels are higher in fish we ban fishing at that location. However, we pay no heed, nor do we worry as to what that same mercury concentration will do to fish. We are comfortable allowing other fish to eat mercury-poisoned fish even though we know it will be toxic to them. Ultimately this approach is going to come back to haunt us because the population of fish will decrease due to chemical toxicity.
As a second example: we know that chromium is a human carcinogen and we know that it breaks DNA. Our current policy assumes that chromium might have a different effect on wildlife and people (on which we can't experiment) and it requires us to prove for each species that chromium is toxic to

it. This approach is impractical, prohibitively expensive and logically flawed. What I was suggesting is that instead, the policy should do the same thing for other vertebrate species that it does for humans and that therefore we should extend the same protection to other vertebrates that we extend to ourselves.

The burden of proof is straightforward for those chemicals that have been evaluated for human safety we simply use the same data that we used to establish human protection and extend it to wildlife. It requires no expense and no additional work to determine those levels. It's the same level as in the humans. For those chemicals that have not been evaluated for human safety the burden of proof would simply parallel the burden of proof for humans.

a. How can we shift the burden of proof to require findings are not dangerous or harmful?

I am unsure of just what this question is asking, but if it seeks to understand how the burden of proof of the safety of some compound can be placed on those who make and benefit from producing it, I think that the only way to achieved this is through legislation. One possible example is the REACH program implemented by the European Union which does just that.

8. Would you consider your whale study alone to be enough evidence to use the "precautionary principle," and in your words, get chemicals such as chromium "out of circulation"?

The challenge behind hexavalent chromium is that it is considered an essential component for national security. Therefore, saying we should get a chemical out of circulation is, for some chemicals too extreme. The major point is to reduce levels to a point that is considered safe for humans. Where possible, it would be better to remove a chemical from circulation such as occurred for DDT. But where there is a compelling reason why a chemical cannot be removed from circulation then efforts should be taken simply to reduce exposure levels.

We do believe that our whale data indicate that chromium levels are simply too high in the environment and that they show there is a need to reduce emissions into the environment.

9. When describing your whale study you mention that "the very highest readings were from whales we sampled in some of the remotest regions" and that the most polluted whale lived "about as far as it is possible to get from industrialization and big agriculture." How would you explain these findings of pollution being so much worse in such isolated areas.

The explanation is uncertain; however, one possibility is that since sperm whales are known to make lengthy migrations that they were perhaps exposed to pollutants and carried them to where we encountered and biopsied the whales.

Senator WHITEHOUSE. Thank you, Dr. Payne.

Senator Cardin will introduce our next witness.

Senator CARDIN. Let me introduce Dr. Mitchelmore. She joins us today from the University of Maryland Center for Environmental Science at the Chesapeake Biological Lab. Dr. Mitchelmore is an internationally recognized expert in aquatic technology, and her research experience includes investigating a broad array of toxics and their effects. Much of her research is directed at understanding the fate and effects of oil, dispersed oil, and oil dispersants.

I am happy to be here to shed light on the impacts toxics are having on our coastal and marine ecosystems and to have her insight as we begin to investigate the impacts of the BP oil spill and clean up.

I welcome Dr. Mitchelmore to our Committee.

STATEMENT OF CARYS MITCHELMORE, ASSOCIATE PROFESSOR, UNIVERSITY OF MARYLAND CENTER FOR ENVIRONMENTAL SCIENCE, CHESAPEAKE BIOLOGICAL LABORATORY

Ms. MITCHELMORE. Thank you.

Good morning, Chairman Cardin, Chairman Whitehouse and members of the Subcommittees. I am Carys Mitchelmore. I was asked today to provide insight into a few examples of the critical issues we face concerning pollution in our coastal and marine environments.

I have been researching the impacts of pollutants on aquatic organisms for 15 years. There is irrefutable scientific evidence that our coastlines and oceans are being inundated with pollutants. Related to this, I would like to stress three major points, using two case studies, to illustrate these issues.

First, limited toxicity data exists for many chemicals.

Second, there are multiple sublethal ways in which contaminants can negatively affect organisms.

Third, chemicals impact and alter delicate food webs.

Since the industrial revolution tens of thousands of chemical pollutants have been released into the environment, ultimately making their way into the oceans. Through bioaccumulation and biomagnification, high levels of these chemicals are found in the bodies of coastal and oceanic organisms, even those remote from direct pollution sources. If these organisms are being polluted, so are we. They are sentinels of our own health.

New chemicals are entering the marketplace daily, many with unknown or unpredicted environmental risks. Often very few toxicological evaluations are carried out before their use. Many formulations are proprietary, so predicting their potential effects is difficult. Chemicals that do end up showing environmental harm are removed from the market, yet the damage has already been done. Furthermore, they can persist in sediments, contaminating organisms for years to come.

For example, the persistent bioaccumulative and toxic flame retardants, PBDEs, have recently been phased out. However, their effects will be felt for years to come. Fire retardants are important. They save lives, and so alternatives are being developed and used. But are these PBDE replacements any less toxic? We simply can't tell. Limited toxicological information for these proprietary products is available. In testing some of these alternative formulations, my laboratory has found that they bioaccumulate in fish, cause DNA damage, and are transformed into unknown chemicals.

Perhaps it is time that we become more proactive and precautionary before releasing new products. We are constantly unraveling even for historic chemicals new and more subtle sublethal ways that they can influence a species' survival. For example, contaminants can depress an organism's immune system, making them vulnerable to infections. Organisms expend energy trying to remove contaminants from their bodies. This directs energy away from normal process. Repercussions of this include reduced growth, low quantities of offspring, or ultimately even death.

Aquatic organisms have highly developed nervous, sensory and behavioral systems that are important for timing of migration, mating, finding food and predator avoidance. Chemical contaminants have been shown to affect these processes. Chemicals affect food webs. They biomagnify up the food chain. If contaminants kill species at the base of the food chain, then higher trophic level organisms, including ourselves, will struggle to find food.

Unfortunate recent events in the Gulf have once again brought to the forefront issues pertaining to the impacts of dispersants and dispersed oil. What will the environmental consequences be of dispersant application? Currently, this is impossible to predict for many reasons.

First, the sheer volume applied and continued use of dispersants is unprecedented. Additionally, dispersants are usually only applied to surface slicks.

Second, dispersants contain mixtures, including proprietary chemical components and limited toxicological data is available. Specifically, there is a lack of studies addressing the potential long-term effects of dispersants and dispersed oil in organisms. What are the sublethal effects? Will there be delayed effects? How are organisms even exposed? Do dispersants make the oil more bio-available?

My research exposing corals to low levels of Corexit 9500 and dispersed oil demonstrated sublethal behavioral effects. There was a narcotic response resulting in the cessation of coral pulsing. Corals bleached. Ulcers were formed. And the tissues simply started to break down. Low dose, short-term exposures led to delayed effects and significant reductions in growth rates.

If we had more information, we may be better prepared to deal with such disasters. Increased knowledge translates to better solutions. The more data and oil spill responder has regarding these effects, particularly on sensitive species of interest, allows them to better decide upon the appropriate trade off decisions to make.

In summary, Chairman Cardin, Chairman Whitehouse and fellow Senators, new chemicals and formulations are released daily for which we have very little or no environmental toxicity data for. Multiple mixtures exist and chemicals interact in unpredictable ways. We are constantly unraveling even for historic chemicals new and more subtle sublethal ways in which detrimental effects occur.

Chemicals directly or indirectly can alter the fine balance of food webs, alter ecosystem services, and the overall health of the ocean. Pollutant impacts our global economies, food sources, recreational activities, and even the sensitivity of our coastlines to erosion. Pollution cannot simply be treated as out of sight, out of mind, or that the solution to pollution is dilution.

We are beginning to lose the memory of what an unimpacted coastline and ocean looks like, and that needs to change.

Thank you.

[The prepared statement of Ms. Mitchelmore follows:]

Written Testimony of Carys L. Mitchelmore, Ph.D.

Before the Senate Committee on Environment and Public Works

Hearing entitled " EPA's Role in Protecting Ocean Health"

May 11th, 2010
(Testimony submitted May 9th, 2010)

Carys L. Mitchelmore, Ph.D.,
Associate Professor,
University of Maryland Center for Environmental Science,
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Good morning Chairman Whitehouse and members of the subcommittees. I am Carys Mitchelmore and I would like to take this opportunity to thank you for inviting me today to highlight a few examples of the many issues we face today concerning pollutants in our coastal and marine environments.

By way of background: I am faculty at the UMCES Chesapeake Biological laboratory with expertise in studying the fate and effects of pollutants on aquatic organisms. I have been conducting research and publishing books and articles for 15 years concerning the impacts of metals, organic chemicals, biological pollutants, oil and oil spill dispersants on many species, including corals, reptiles, fish and oysters. Today I am representing my views as a researcher in the field of environmental health and as a local resident concerned with the deteriorating Health of the Chesapeake Bay watershed and our global aquatic ecosystems. I feel very strongly about pollution issues, indeed my career path as an aquatic toxicologist was set in place at the young age of 6, after stepping on a tar ball at a local beach. That left a lasting impression on me and I grew up fascinated with the rock pools and, unfortunately the all too often, oil sheens within. A challenge for me today was my choice of specific topics to discuss; we are indeed faced with multiple issues pertaining to pollution of our aquatic ecosystems. My testimony today will focus on four main issues; using case examples from my own research, including those relating to oil and oil spill dispersant toxicity.

Currently, the greatest threats to our coastal and marine environments can broadly be described as;

1. Land-use changes and increasing impervious surface coverage. Urban stormwater run-off has been described as a major source of pollutants, such as sediments, nutrients, metals and organic contaminants including oil, polycyclic aromatic hydrocarbons (PAHs), bacteria and garbage.

2. The expansion of human populations inhabiting coastal locations. The rate of expansion often outstrips the outdated and/or inappropriate infrastructures. Waste water treatment plants (WWTP), rivers and coastlines are often overloaded with nutrients and bacterial contaminants and are inundated with a diverse array of chemicals, from industrial compounds, PAHs, metals, radionucleotides, pharmaceuticals and personal care products.

3. The increased use of our oceans. Increased shipping traffic has led to pollution including, garbage and trash, sewage (bacteria), metals and organic pollutants. It has also enhanced the global movement of species to non-native habitats (invasive species).

4. New products and technological expansions. Huge numbers and diversity of manufactured chemicals have been produced since the industrial revolution and there appears to be little slowing of this trend. Numerous new chemicals are entering the market place, many with unknown (or un-predicted) environmental risks. For example, the environmental risks associated with nanoparticles have not been fully addressed, although these are currently the focus of many new initiatives and programs (such as the National Nanotechnology Initiative).

The four key points I would like to raise during my testimony are the following:

1. The issue of contaminant mixtures and multiple sources.

- Unknown and unpredicted interactions occur between contaminants (and additional interactions can also occur with environmental variables).

2. Emerging contaminants of concern.

- New products (Case study 1; flame retardants).
- Are we replacing the 'bad' with the 'ugly' or the 'good'?

3. Sub-lethal toxicity issues.

- Increased knowledge of the subtle, yet deadly, effects of contaminants.
- Multiple ways in which contaminants act on biological systems; there are common themes (mechanisms) exhibited by many chemicals.
- Examples; bioenergetic and behavioral toxicants.
- Case study 2; oil and oil spill dispersants.
    - sublethal and delayed effects in sensitive species.
    - altered routes of exposure.

4. Ecosystem-based approaches.

- The effects of chemicals on food webs (indirect toxicity mechanisms).
- Sensitive species.

Overview and Introduction:

Our coastlines contain highly diverse complex ecosystems, teeming with multiple and interacting species that carry out many important ecosystem services. Coastlines (and connected estuaries and rivers) are often important nursery grounds for numerous organisms, including oceanic species. The pollution of our aquatic ecosystems, including our coastlines and oceans is increasing. Water, sediment and the tissues of resident organisms contain a multitude of industrial chemicals. Even species far from pollution sources have been shown to contain chemical contaminants in their tissues. For example, flame retardants (e.g. polybrominated diphenyl ethers or PBDEs) have been detected in Arctic seals and polar bears (REF 1).

Chemical contaminants affect the health and functioning of these impacted ecosystems in numerous ways, by altering the water itself and/or impacting the resident flora and fauna (in potentially positive and negative ways). Ecosystems and food webs are changing, ecosystem services are lost, species are lost, resources (water and food) are being contaminated. Not only are we loosing sources of food, we are also loosing species that protect our coastlines from erosion (storm damage). These effects have consequences to our economy, recreation and even lead to potential health issues. Many historic local cultures and ways of life that have been traditional for generations of families have been eroded by declining fisheries. Fish consumption advisories are commonplace for many species of fish, even those residing mainly in the open Oceans. In addition, rivers, lakes and beaches are being closed for recreational use, impacting tourism. We are beginning to loose the memory of what an un-impacted coastline looks like.

Many examples of ecosystem health declines appear to correlate well with the onset of the Industrial revolution and the increased expansion of industrial and residential chemicals (e.g. increases in coral bleaching spatially and temporally (REF 2,3)). Our oceans and coastal systems are receiving a barrage of pollutants, that are numerous, increasing in concentration and are of diverse origins and types. Pollutants are defined as anything that impacts the normal functioning of an ecosystem. These include trash and garbage, nutrients, metals, organic contaminants, sediments, radionucleotides, biological entities including toxins (e.g. for example from harmful algal blooms), bacteria, viruses even invasive species. Pollutants also include alterations in temperature, pH and salinity. Although my testimony is limited to using examples of manufactured chemical contaminants and oil, I highlight these other pollutants as they often work in concert, enhancing the toxicity of chemical contaminants.

Two broad types of chemical contaminants exist; those chemicals that are designed for a specific purpose that inadvertently affect aquatic systems. Second those specifically produced and used for their toxicological properties, e.g. pesticides, antifoulant paints and oil spill dispersants.

1. **The issue of contaminant mixtures and multiple sources.**

Recent years have shown dramatic increases not just in the sheer volume of chemical contaminants but also in the numbers of different types of chemicals used today. Thousands of different chemicals are present in our aquatic environments. This creates the potential for a toxic 'soup' of unknown effects, which cannot be predicted even if the individual chemical constituents are known. Interactions of chemicals with other physical, chemical or biological entities can change the exposure routes of chemicals, make them more available to organisms (bioaccumulative) and in some cases even make them more toxic. We are only just beginning to unravel some of the complex interactions that occur when these chemical contaminants make their way ultimately into coastal and oceanic ecosystems.

Chemicals interact with each other often in unknown ways. We know this in the medical field. For example, when we get sick our Doctors and pharmacists carefully check for interactions between prescription medications if we are taking more than one item. In some cases taking drug A with drug B can result in negative consequences, the combination may even be fatal. Yet if you took drug A and B singly at different times using the same doses no adverse effects would be seen. This phenomenon is called synergism. This analogy also holds true for organisms exposed to the barrage of multiple contaminants they are often now faced with. There are numerous examples of these types of synergistic effects in the aquatic environment; where the toxicity of a chemical mixture far exceeds that which could have been predicted based on the individual contaminant toxicities alone. For example, synergism was observed using combinations of organophosphates in toxicity tests examining the response of salmon to these exposures (REF 4).

Furthermore other environmental variables and stressors, including issues related to global climate change (i.e. increased temperatures, acidification) can influence the toxicity of a chemical, either due to inherent chemical properties of the contaminant or the organisms biological response to the contaminant and environmental variables. For example, an organism's exposure to a chemical contaminant can also increase its susceptibility to disease. Many contaminants have been shown to depress an organism's immune system making them vulnerable to infections (REF 5).

These contaminant mixtures lead to difficulties in determining cause and effect and from a regulatory perspective assigning 'blame' as a large amount of our pollutants are derived from non-point sources. In some cases we are purposely moving pollutants from one area to another. For example in cleaning up our wastewater treatment plant (WWTP) effluents many chemical contaminants become concentrated in sewage sludge (biosolids). A recent survery found a minimum of 38 different pharmaceuticals and personal care products in every composite U.S. biosolid sample analysed. High levels of triclosan (the active ingredient in antibacterial soap) were found with mean concentrations of 12 mg kg^{-1}; REF 6). Biosolids are minimally regulated (primarily for pathogens and metals) and commonly applied onto land as fertilizers. They have the potential to run off the land and contaminate local aquatic ecosystems. A recent research paper published by colleagues at the Virginia Institute of Marine Science (VIMS) jointly with my laboratory demonstrated the presence of multiple organic contaminants in biosolids, often at high levels. Fish exposed to these biosolids exhibited sublethal toxicological effects, such as, increased DNA damage (REF 7). Are we simply transferring pollutants that ultimately may make their way back into aquatic systems? In some cases, for example oil spill dispersants, moving pollutants is indeed one of the main reasons behind their intended use. Dispersants are used to prevent the oil from impacting sensitive shorelines by moving the surface-slick into the water column and potentially also to the benthos (e.g. sea-floor).

Sediment, trash/garbage and potentially nanoparticles have been shown to enhance the toxicity of some chemical contaminants by making them more bioavailable to organisms i.e. changing their route of exposure. For example, dissolved pollutants can stick to sediment particles and be ingested by fish or suspension feeding organisms.

2. **Emerging contaminants of concern.**

Recent surveys of rivers, groundwater, lakes and coastal waters have highlighted the diversity of pollutants reaching these aquatic environments. Not surprising considering the multitude of chemicals released to the environment on a daily basis. Many new chemicals, so called emerging contaminants of concern have been highlighted, based either on their environmental concentrations and/or their specific chemical/biological properties. Many of these new chemical contaminants are persistent and bioaccumulative, others are known to influence sensitive biological processes. However, in many cases we have very limited knowledge regarding the impact(s) that these chemicals pose to the health of aquatic organisms and ultimately (through drinking water and aquatic food sources) to ourselves. Many pharmaceuticals and personal care products have been detected in water, including caffeine, ibuprofen, antibiotics, hormones and steroids (REF 8). The release of nanoparticles in the environment is also an unknown risk. They may or may not inherently be toxic but as already discussed above their physical/chemical properties may enhance the uptake of other chemicals contaminants. We have come a long way, for example, in understanding the basic toxicity of heavy metals; that toxicity is not based on the total amount of metal but rather it's specific chemical form (species). The question now is size also a critical factor? Last year a summer undergraduate research project (NSF, REU student) in my laboratory in collaboration with others at the Chesapeake Biological Laboratory demonstrated that nanoparticulate forms of copper were more toxic to larval frogs compared with there dissolved counterparts, however, larval salamanders were not impacted. These results reflect the differing routes of exposure for copper uptake by herbivorous species (results from this study can be provided if requested).

Coastal sediments have also been shown to contain an array of pollutants, that through benthic organisms and food web interactions may influence a variety of organisms, including us. I will use the polybrominated diphenyl ether flame-retardants (PBDEs) as a case study example for this topic of emerging contaminants of concern. Also included are issues relating to some of the new flame-retardant formulations.

Case Study (1) – Flame retardants.

Undoubtedly the use of flame-retardants has saved hundreds of lives across the U.S., but at what environmental cost? Since PBDEs were first detected in environmental matrices and in human breast milk an exponential increase in research papers has demonstrated that these chemicals are persistent, bioaccumulative and toxic products. Although we really shouldn't be too surprised by this. PBDEs, especially some specific congeners (e.g. BDE-47) show a striking resemblance to natural thyroid hormones (which are part of the endocrine system; see figures within REF 9). These PBDEs have been shown to mimic or disrupt the normal functioning of these natural hormones in many species. The normal functioning of these hormones is critical in maintaining basic metabolic processes, growth, and development. Additionally, the endocrine system is also tightly coupled with the neurological and immune systems.

In collaboration with Dr Heather Stapleton (Duke University) we have demonstrated the bioaccumulation and metabolism of these compounds in fish and suggested a novel metabolic pathway by which these compounds are converted into potentially more toxic products (REFS 9-11). This metabolism involves the enzymes responsible for the maintenance of normal thyroid levels.

In response to the overwhelming evidence describing the environmental persistence and toxicity of PBDEs, many of these flame retardant formulations have been phased out with the final, and most highly used formulation (deca-BDE) due to be phased out in the U.S. by 2013. Despite this encouraging news, unfortunately PBDEs, just like the historic polychlorinated biphenyl (PCBs), will be around polluting our waters, sediment, aquatic organisms and ultimately ourselves for years to come.

Fire retardants are required to be used in consumer products. So if not PBDEs what are the chemicals being used? PBDEs are not the only flame-retardants; in fact many alternate products have been in use for a number of years. Two of these formulations are currently being studied in my research laboratory (again in conjunction with Dr Stapleton's laboratory). Firemaster® 550 and Firemaster® BZ-54 are two brominated formulations containing mixtures of chemicals (e.g. TBB and TBPH; see REF 11 for complete chemical names and structures). Both of these chemicals have been measured in environmental matrices including house dust, biosolids and sediments, however, scant toxicological information for these chemicals exist. The only existing toxicological data for TBB and TBPH are the standard acute aqueous toxicity tests (i.e. 96 hour LC50s) summarized on the Material Safety Data Sheets (MSDS) for these formulations.

Are these chemicals bioavailable to aquatic organisms? Do they bioaccumulate, do they have sublethal effects? We have recently shown that these formulations when fed to fish, are bioavailable and bioaccumulate in fish tissues. Furthermore, they are metabolized to various alternate compounds and causes DNA damage in exposed fish. (REF 12). The question remains are we trading off one toxic product for another? How often are these trade offs going to continue? We need to compare new chemicals before their release, not just with other known toxic chemicals but also with natural substrates. There are numerous examples of current chemical contaminants that are structurally very similar to natural thyroid hormones. Thyroid hormone disruption seems to be a common thread for many emerging contaminants.

Often the original, or parent chemical contaminants, are not highly toxic themselves but it is their breakdown products or metabolites (that are not looked for and often unknown) that can be highly toxic. There is a need to fully understand how pollutants are metabolized in aquatic species to fully assess their fate and effects in aquatic ecosystems. Determining the specific metabolic pathway in multiple species together with understanding sublethal toxicological effects (see below examples) is an ongoing (although unfunded) research project in my laboratory.

3. **Sub-lethal toxicity issues.**

The focus regarding a chemicals toxicity is often how acutely toxic it is, i.e. at what concentration does it cause death to individuals. But is death really the worse endpoint? Obviously, yes for that individual but not necessarily if we are looking at the bigger picture i.e. at the species, population and ecosystem levels?

Traditional toxicity tests use simple measures, e.g. LC50s (the concentration of a chemical that causes death to 50% of the organisms). These standard tests allow us to compare the toxicities of different chemicals and also the different sensitivities of particular species to the same chemical. These tests (called acute toxicity tests) are of short-term duration (i.e. 24-96 hours) and are of limited value in assessing the effects of pollutants that remain in aquatic systems for long-periods of time (persistent contaminants) or for those that are continually being released at low-levels. Additionally, these tests are usually carried out with single chemicals.

In recent years there have been great advances in further developing standard toxicity tests that assess sublethal effects (i.e. endpoints other than death). Longer-term exposures (weeks to months) of lower (and often more environmentally relevant) concentrations of chemicals (again usually in isolation) are used and sublethal impacts assessed using endpoints such as growth and reproduction. Derivations of these tests, whole effluent toxicity (WET) tests are applied to assess the overall toxicity of effluents and other point source discharges (i.e. assessing the combined toxicities of unknown chemicals and other stressor mixtures). My laboratory together with other colleagues at the Chesapeake Biological Laboratory have run many of these tests to assess questions such as the toxicity of ballast water treatment options (REF 13). These tests are very useful in providing an overall look at potential toxicity to aquatic organisms although they cannot be used to pinpoint the causative agent(s).

Reductions in growth and reproduction are used in these chronic tests as these endpoints may translate to a species reduction in numbers at the population level. Indeed these are endpoints that can be used in population models to predict the potential effects of a chemical contaminant. These endpoints integrate the complex interactions that chemical contaminants may have at the molecular/biochemical and physiological levels.

Studies of chronic toxicity are still in their infancy and are highlighting the numerous subtle ways or mechanisms of action in which pollutants can negatively affect organisms. Our understanding of the complexities of contaminant interactions with organisms has evolved given our increasingly sophisticated forensic toolboxes. However, many more studies are needed to fully investigate these issues, allowing us to group classes of chemicals together that display similar physiological, biochemical mechanisms of action.

For example, chemicals that impact the normal functioning of the endocrine system are called EDCs or endocrine disrupting chemicals. This classification represents an integration of many numerous molecular/biochemical insults to the endocrine system.

Case Study (2) – Sub-lethal effect examples;

(a) Bioenergetic impacts: There are numerous subtle sublethal events that can result ultimately in population level declines. For example, an organism may cope with the toxicological insult by protecting itself through the up-regulation of one or more metabolic systems. However, organisms have a finite source of energy, if they use more of this energy to try to stay alive and cope with the toxicological insult then energy is directed away from growth and reproductive processes. These bioenergetic effects of chemical contaminants are a focus of research at the Chesapeake Biological Laboratory. For example, bioenergetic assessments in shrimp exposed to Baltimore harbor (MD, U.S.) sediments demonstrated elevated metabolic rates that translated into lower lipid contents (food reserves) and significant reductions in growth and reproduction (REF 14). In addition, this study, like many others, has raised issues concerning the importance of the maternal transfer of pollutants to developing and sensitive offspring. This transfer and novel exposure route of chemicals in the aquatic environment may be a significant way in which the young of a species are dying. This is particularly important in longer lived organisms and species higher up the trophic level that bioaccumulate much higher levels of contaminants compared with lower life span or lower food chain organisms. Increased body burdens (bioaccumulation) of chemicals are, in part, a reflection of the time and concentration of the chemical that an organism is exposed to. Maternal transfer occurs in mammals (including ourselves) by placental transfer and breast milk although egg-laying animals are particularly at risk. Persistent organic chemicals (e.g. PCB's, PBDE's) bind to lipids and are stored, often away from harm for the adult, but are then passed during reproduction into the yolk reserves in eggs for developing embryos. High levels of chemical contaminants have indeed been found in eggs (see reptile example REF 15).

(b) Behavioral toxicants: Aquatic organisms often have highly developed nervous, sensory and behavioral systems that are important for their timing of migration, reproduction, mating, in finding food and in predator avoidance. For thousands of years humans have been aware of chemicals that impact the brain and, for example, alter behavior. Aquatic organisms are also sensitive to certain pollutants in a similar way. Declining salmon populations off the West coast of the U.S. led to research investigating why this was occurring; was it pollution, if so, by what and how? Although this is still under debate one interesting article recently published demonstrated a potential link between salmon survival and urban stormwater runoff affecting their sensory systems (REF 16). Our development of coastal locations has led to increased pollution entering our coastal waterways and estuaries. Pollutants accumulate on impervious surfaces (e.g. roads) and are transported to aquatic habitats via stormwater runoff. Noteworthy is that during the first rains of a wet season these first stormwaters can carry huge loads of pollutants into local waterways that often contain reproducing organisms and their sensitive young offspring. This study demonstrated that the levels of copper often seen in estuarine systems, impacts the olfactory system of juvenile salmon. They concluded that sensory physiology and predator avoidance behaviors of the salmon were significantly impaired. These fish populations may be decreasing simply because they are unable to avoid their predators. Recently pesticides were also implicated to negatively alter fish olfactory processes (REF 17), potentially influencing their ability to migrate to spawning grounds.

Case Study (3) – Oil and Oil Spill dispersants

Unfortunate recent events in the Gulf have once again brought to the forefront issues pertaining to the impacts and effects of oil, oil spill dispersants and dispersed oil in our coastal and marine ecosystems. I have focused much of my research (albeit recently limited due to funding constraints) trying to understand the effects of oil; it's components and oil spill dispersants on aquatic organisms (REFS 19-27). We are all fully aware that organisms can die if they are coated with, inhale or ingest large amounts of oil. Often these are the enigmatic species that are highlighted in the news; the oil coated birds washed onshore, the dead marine mammals exposed to the oil slick because they come up to the surface to breath. Oil coated shorelines not only decimate intertidal food reserves for ourselves (e.g. oysters, crabs, fish) and other organisms but cripple recreational activities and local economies. Sensitive coastal habitats, such as wetlands, often serve as nursery grounds to numerous species, including species that migrate long distances to these breeding areas.

When oil is spilled response decisions must be quickly made and are based on numerous and continually changing variables; what specific type of oil is spilled, how much?, what are the weather conditions (including oil trajectory), what response options are available and what and where are the sensitive habitats and species. Ultimately the question is often, what do I need to protect the most and what do I have available to do it? Using the recent Gulf oil spill as an example, decisions were made to protect the very sensitive coastal wetlands, that currently contain many species that are in their breeding season. To achieve this 100,000's of gallons of the dispersant, Corexit has been sprayed onto the open ocean slick to prevent it from coming ashore in huge quantities. This is an example of a known pollutant, albeit one classified as having low to moderate toxicity to environmental organisms, purposely added to the marine environment. It is used because its overall benefit to the environment offsets its risk. However, it actually represents an environmental trade-off, the protection of one habitat is at the cost of another. In this case the protection of shoreline species at the expense of organisms residing in the water column and potentially also those at the seabed given that some dispersants have been used to disperse oil at the source of the oil leak.

As many have asked in the past weeks, potentially what will the environmental consequences be of the applied dispersants, what will be affected, to what extent and how? This is impossible to predict for many reasons.

First, the sheer volume of dispersants applied is unprecedented; no spill in U.S. waters has used the amount of chemical dispersants that have currently been used. Additionally, dispersants are usually only applied to surface slicks, which is one of the main reasons why they are pre-approved for use in the open ocean. The movement of dispersed oil (and dispersants) in all dimensions in such a huge volume of water (as in the open ocean) results in a plume of dispersed oil (and dispersants) that is quickly reduced to low levels i.e. at depths >10m water it is estimated that the concentration of dispersed oil is <12.5ppm (REF 18). In addition, this dispersal effectively increases the surface area to volume ratio of oil so that micro-organisms (bacteria) that naturally degrade oil can be more effective at doing so. However, organisms that live in the surface waters under the dispersed slick will now be exposed to dispersed oil (in addition to dispersants). Without dispersant application the oil slick would have floated over the top of these water column organisms and these organisms would not have been exposed. Although it should be noted that a small portion of the oil does dissolve in the water column and some droplets are also formed as a result of natural physical processes (i.e. from wind and wave action).

The second reason is that limited prior toxicological information exists to fully assess risks to exposed organisms. The majority of toxicity data regarding the dispersant Corexit 9500 and dispersed oil are those detailing acute and short-term effects (see summary tables in Chapter 5 of the 2005 NRC report, REF 27). Oil is a mixture of 100's of different chemicals all with their own specific physical, chemical and biological properties. Different oils contain different amounts of these individual components. In addition, dispersants contain mixtures, including proprietary chemical components so that we do not know exactly what the exact chemical make-up of the dispersed oil plume is. As summarized in recent NRC publications (see REFS 27, 28) oil and oil spill dispersants can cause a variety of effects, including death and a variety of sublethal impacts including reduced growth, reproduction, cardiac dysfunction, immune system suppression, carcinogenic, mutagenic and teratogenic effects and alterations in behavior. Some aquatic species are more sensitive than others to dispersants and /or dispersed oil (again see tables within Ref 27). However, often it is the early life stages, e.g. eggs and larvae that are at particular risk. These early life stages are at risk because of numerous reasons relating to their physiological and biochemical make-up but also how they are exposed to the oil (i.e. differing exposure routes) also plays a role.

There are still many unanswered questions that we need to know to fully assess the risks involved with dispersants and dispersed oil. These were highlighted in the 2005 NRC report (REF 27). Although this report was specifically tasked to address the potential risks of dispersant use in near-shore environments many of the conclusions of the report are valid in open-ocean spills (note in the Gulf example, these dispersants were applied in the open ocean in waters of greater depth). This report highlighted that there were many areas that lacked adequate research and in addition there were other areas of study in which conflicting data existed.

These include questions and issues, such as;

1. What are the potential-long term effects of dispersant and dispersed oil, even after a brief exposure, to aquatic organisms? What are the sublethal effects? Will there be delayed effects?
2. Limited studies on sensitive at risk organisms (see example on corals below).
3. Does dispersed oil reduce or enhance uptake/bioavailability of oil to organisms?
4. Does dispersed oil enhance microbial degradation?

5. Is dispersed oil less 'sticky' to biological surfaces and sediment?
6. What is the route of exposure to organisms to dispersed oil? Is it dissolved PAHs or the oil droplets, or both.

In the last few years my research group has in part investigated topics relating to questions 2, 3 and 6 (RFES 20-23). Knowing that there was a lack of information on the toxicity of dispersants and dispersed oil on sensitive species such as corals a series of laboratory experiments were conducted to investigate the effects of Corexit 9500 and dispersed oil (Corexit 9500 and weathered Arabian light crude oil, 1:25 ratio) on symbiotic cnidarians (anemones and corals). In summary, soft corals died in low ppm concentrations of Corexit 9500 (LC50 8 hours ~30ppm; LC50 96 hours <16.5ppm). Sublethal behavioral effects (narcotic response resulting in the cessation of coral pulsing) were observed within hours at low (10ppm) dispersant exposures. In attempting to mimic a dispersed oil plume moving through a coral reef the soft corals were exposed for 8 hours to dispersant alone (at 20ppm i.e. a 1:25 dispersant:oil ratio), dispersed oil (dissolved PAHs and oil/dispersant droplets and dispersant) and undispersed oil (i.e. dissolved PAHs under an oil slick) using an oil loading of 0.5g l^{-1} oil:water. After 8 hours of exposure these corals were placed in clean seawater to follow potential delayed effects and sub-lethal repercussions of exposure. After 32 days growth was significantly reduced in dispersed oil and dispersant exposures and delayed effects (further death in the dispersed oil treatments) were observed (see EXHIBIT 1). Our research also demonstrated that cnidarians accumulated PAHs from both the dissolved oil components and the oil droplets.

These results have been submitted to the funding agency in the form of a final report and peer-reviewed publications are pending. I will be happy to provide any further information on these subjects.

4. Ecosystem based approaches; Sensitive species and food web effects (indirect toxicity).

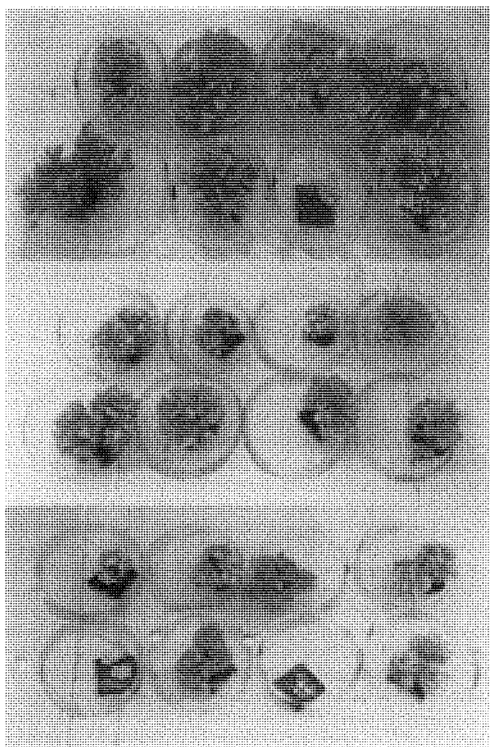
A species of interest does not need to be exposed and take up a chemical contaminant directly for that chemical to have a detrimental effect upon it. Contaminants alter food webs, for example, it may kill a lower trophic level species (e.g. phytoplankton or zooplankton). This has knock on effects for the more enigmatic higher trophic level species (e.g. fish). The fish is faced with a reduction in it's food source so that it may die from starvation. More subtly it may not grow or reproduce well as it has to expend energy travelling further distances to locate it's prey or it may be feeding off alternate food sources that are of lesser quality. Not only does this increased foraging for food have bioenergetic consequences but it may inadvertently make the organism more susceptible to predation given that it has to move out of it's usual habitat. Even subtle changes in food webs can have drastic effects on other organisms. Some organisms are much more sensitive than others, these species may not be the most enigmatic, but are none-the-less hugely important to ecosystem functioning.

We need to be protecting species at the foundation of the food chain and those that serve important ecosystem services. Coral reefs are a perfect example of this. Corals are the primary producers, in which the entire reef system depend upon. In addition, corals are extremely important for biodiversity, fisheries, coastline protection and local economies. The loss of corals will have huge impacts to our Oceans on a global scale. Corals are extremely sensitive to environmental disturbances (increased warming, ocean acidification, UV and pollutants) and have been a focus of research in my laboratory for the past 10 years. Again we still do not fully understand exactly how these species work, there are many biochemical and molecular pathways we do not know the significance of let alone how pollutant stressors impact them. For example, corals when stressed release large amounts of a biochemical compound called dimethylsulfide (DMS). This compound in open ocean algae has been stated to be responsible for over 30% of the global sulfur cycle, the significance of corals in this cycle is unknown but it may alter local climate. Dimethylsulphoniopropionate (DMSP) is the precursor of DMS that is found at high concentrations in coral symbionts. We are only just beginning to investigate it's role and function(s) in corals. It potentially may be extremely important in determining a corals sensitivity to pollutant stressors. Indeed, we have recently shown alterations in levels in copper exposed corals, which may reflect an antioxidant protective role for this natural chemical (REF 30).

In summary

I would like to thank you again for allowing me to testify today on a topic I care deeply about. We face huge challenges to protect our coastal and oceanic ecosystems from the barrage of insults we, as a single species, have created. Pollution cannot simply be treated as 'out of sight out of mind' or that 'the solution to pollution is dilution'. The mind boggling huge numbers and types of diverse chemical contaminants, coupled with other interacting pollutant stressors has led to a 'toxic' soup for which we often do not fully understand the impacts of. New chemicals are released onto the market daily for which we have very little or no environmental toxicity data for. We are constantly unraveling, even for historic chemicals, new and more subtle sublethal toxicological pathways that ultimately have dire consequences to a species survival consequences of which, alter the fine balance of food-webs, alter ecosystem services, and the overall health of the environment. These events will impact our global economies, food sources, recreational activities and make our coastlines increasing sensitive to erosion. Human exploitation of species, habitat destruction and global climate change are impacting species, but let's not forget the often severe effects of our continued reliance and release of the thousands of industrial chemicals and other pollutants into these sensitive systems. We cannot even begin to understand some of their detrimental impacts and unless we act now the tipping point for the health of our coastlines and oceans may soon be reached.

Exhibit 1: Photo depicting corals held in clean seawater 32 days after an exposure to Corexit 9500 and dispersed oil (using Corexit 9500 and weathered Arabian light crude oil). Significant reductions in growth were observed compared with controls.



CONTROL SOFT CORALS

SOFT CORALS EXPOSED TO COREXIT 9500 (20ppm, 8 hours).

SOFT CORALS EXPOSED TO DISPERSED OIL (using 20ppm Corexit (1:25 ratio dispersant:oil) and 0.5g l^{-1} weathered Arabian light crude oil with 8 hour exposure).

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Question from Senator Sheldon Whitehouse.

1. What do you believe is the most pressing research question related to either of the threats to ocean health that we discussed; ocean acidification, or toxics in the marine environment?

Response.

Thank you Senator Whitehouse for an excellent question. I believe that ocean acidification is an important issue that should be addressed and indeed is now being studied given the new research opportunities that have become available. However, I believe that toxics in the marine and furthermore in our coastal, estuarine and river systems is a greater threat. We are releasing 10,000's of chemical contaminants that end up in our coastal and marine environments. Many of these chemicals have not been tested for toxicity and may have even further effects when combined with other stressors. We do not fully understand where these chemicals will end up, who will be exposed to them and their ultimate effect.

The demonstration by Dr R. Payne during this Committee hearing highlighted the accumulation to high levels of chemical contaminants in Arctic marine species, despite these animals being far removed from direct sources of pollutants. Long- range transport of pollutants that contaminate marine organisms and our food chain do not bode well for our own health. Contamination of our air, drinking water and food (including seafood) exposes ourselves to toxic chemicals. We already are faced with seafood safety limits, although these are only based on a handful of chemical contaminants. There are many others we do not have guidelines for or are even aware of their presence and potential effects in our seafood. Aquatic organisms are sentinels of our own health, the outlook of which is not looking good.

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Questions from Senator James M. Inhofe.

1. Over the past few decades, water quality has been improving throughout the U.S. while the prevalence of industrial chemicals has been increasing. There have been great strides in technological advancements to deal with polluted waters. However, you conclude that the "tipping point for the health of our coastlines and oceans may soon be reached". Given the improvements in water quality and safety and, as you mentioned in your testimony, the uncertainty in chemical testing and chemical fates, what is the basis for your conclusion?

Response.

Thank you Senator Inhofe for an excellent question. I agree water quality has indeed improved based upon specific targeted compounds, for example, nutrients. However, water quality is based on just a handful of chemical contaminants. There are 10,000's of chemicals that are not measured in these water quality tests, furthermore we do not have a complete knowledge of the interactions with the mixtures of chemicals that are in our waters. Only recently have we been looking at the new emerging chemicals of concern and we are finding them throughout our water systems. These are things like pharmaceuticals, personal care products and caffeine etc. As many chemicals can have similar modes of action (e.g. impacting the endocrine system), then small amounts of multiple chemicals can add up to cause effects. We are seeing numerous issues in our aquatic organisms that are demonstrating sub-lethal effects to contaminants. Fish with reproductive abnormalities, tumors and increased disease prevalence.

I agree with your comment on the limitations of chemical testing and I highlight the need for both chemical AND biological monitoring. Often the organisms themselves can show impacts at levels lower than can be detected chemically and they also integrate and process the mixtures of chemicals that they are exposed to.

2. You mention ocean acidification a few times in your testimony and its role in influencing the toxicity of chemicals. While the claim of ocean acidification due to increases in CO_2 is unproven and at best may cause a slight shift to neutralization, do you think it is appropriate to include ocean acidification in chemical risk assessments?

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Response.

Thank you Senator Inhofe. I mention in passing the role of acidification on influencing chemical toxicity. It is well known that environmental variables can influence the toxicity of a chemical, for example, the toxicity of metals varies greatly depending upon the pH of the water. In addition, when organisms face multiple stressors they can become more susceptible to other stressors because of this. For example, organisms coping with metal pollution can become more disease susceptible.

I also believe there are many research papers that have indeed documented a reduction in Ocean pH. For example, the paper by Byrne et al., 2010. It should be noted that even 'slight' shifts (i.e. 0.1 pH unit) are very significant as pH is reported on a logarithmic scale so that a 0.1 shift translates to a 30% increase in surface-ocean acidity (Kerr, 2010). Shifts to 'neutrality' do not infer a non-issue, the issue is that acidification is occurring i.e. shifting away from the normal slightly basic pH of the Oceans.

3. Are there any flame retardants that you are aware of that don't have detrimental impacts on the environment?

Response.

Thank you Senator Inhofe for your question. Of course we need to maintain flammability standards, however, the use of additive flame retardant chemicals has been shown to be problematic for the health of the environment. This has been demonstrated for the persistent brominated flame retardants, that have been found contaminating to high levels Arctic organisms (specifically the polybrominated diphenyl ethers; PBDEs). These chemicals have also been found in human samples. With these chemicals banned or phased out new alternatives are being used. As we have shown these also demonstrate toxicity.

The problem lies in that minimal (if any) toxicological testing is carried out before these products are used. Often these are proprietary mixtures and we do not even know what is being used. Until all products used are known and they are tested, even in a minimal way for toxicity, we will not know if they are detrimental to the environment.

The other issue is that it depends on the application and where the materials are being used. There are many flame retardants in building materials that pose little environmental risk (e.g. Calcium silicate), except for human inhalation issues.

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Thank you again for the invitation to testify. We certainly face huge challenges to protect our Oceans and coastal systems. With concerned Senators, such as yourselves, I hope this subject will continue to be looked at in depth and progress will be made to understand and stop the barrage of insults that our aquatic environments are facing. If there are any further questions I can help with please feel free to contact me.

Sincerely,

Dr. Carys L. Mitchelmore,
Associate Professor.

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Senator WHITEHOUSE. Thank you very much, Dr. Mitchelmore.

Our next witness is Mr. Sam Waterston, who is widely known for his long running role as lawyer Jack McCoy in the television series Law and Order and his Academy Award-nominated portrayal of Sydney Schanberg in The Killing Fields.

He is here, however, as a member of the Board of Directors for Oceana, an international non-profit organization focused on ocean conservation. It is an organization based here in Washington, DC, that works to protect and restore the world's oceans, with staff located in Alaska, California, New York, Oregon and Massachusetts, as well as international offices in Brussels, Madrid, Belize City and Santiago. The organization has more than 300,000 members and supporters from all 50 States and from countries all around the globe.

Explaining his work with Oceana, Mr. Waterston has written, "I have loved the ocean all my life. As a New Englander, I have seen the nasty effects of fisheries collapses on the life of seaside towns. Scientists now warn us that unless we do something, the world is on a path to global fishery collapses by mid-century, a calamity of mind boggling proportions we can still avert. The time to act is now, which is why I am very happy to be working with an organization as effective as Oceana."

And as a Rhode Islander, I am proud to note that he learned his love of the sea in his boyhood and summers at Matunuck.

So we are delighted to have you with us, Mr. Waterston; please proceed.

STATEMENT OF SAM WATERSTON, BOARD OF DIRECTORS, OCEANA

Mr. WATERSTON. Thank you. Thank you, Mr. Chairman.

Thank you, Chairman Cardin.

Thank you for the opportunity to provide testimony on ocean acidification. I am honored to be here before your Subcommittees to talk about an issue that frightens me. Acidification of our oceans is an impending environmental crisis that we must stop before it catalyzes the crash of ocean food webs and the end of ocean ecosystems as we know them.

Before I talk about ocean acidification, I would be remiss not to mention the deepwater drilling disaster in the Gulf of Mexico. Our thoughts and prayers are all with the families of the 11 missing workers, and I hope for a speedy recovery of all those that were injured.

As of today, at least 4 million gallons have spilled into the Gulf of Mexico. The leaks have not been stopped, and oil continues to gush into our oceans and flood our coastlines. Until this leak is stopped, oil will continue to harm life both in the ocean and on the shore. We need to end all new offshore drilling, including for exploration.

The Gulf tragedy was created by an exploratory well, and we can now see that even exploration poses serious risks to the marine environment and coastal economies.

Now, on to the reason you invited me, ocean acidification. Oceana, an international ocean conservation organization that works to protect and restore the oceans, is an organization that I believe in enough that I serve on its Board of Directors. Through my work with Oceana, I have been privileged to learn of the most recent science and data on our oceans, a lot of which you have been hearing about today.

I have learned that an impending crisis is barreling toward us, acidification of our oceans. The burning of fossil fuels is increasing the amount of carbon dioxide in our atmosphere, and this is leading to global climate change. The carbon dioxide level in the atmosphere is currently nearly 40 percent greater than pre-industrial levels. At 387 parts per million now, it is up more than one-third of the levels that existed before the industrial revolution.

Atmospheric carbon dioxide levels have not reached this amount in at least 800,000 years, and the 800,000 year figure only refers to the amount of time that we are able to measure with ice cores, and it may have been a much, much longer time.

The oceans for the last 250 years have been a great sink, absorbing much of the carbon dioxide we put into the atmosphere through the burning of fossil fuels and deforestation, moderating and masking its global impact and returning bounty until now.

While the oceans have been providing us this great service, they have been part of the solution to the climate change problem, but that important task is making them sick. Ocean acidification is a concrete and immediate reason to cap and reduce carbon dioxide emissions into our atmosphere. There is no other way to stop it, and the only way to reduce CO_2 is to shift from fossil fuels to a clean energy economy.

If we continue on current trends, levels are likely to double pre-industrial levels by the middle of this century. If this occurs, scientists predict that we will see major changes to coral and other shell forming species and that if we continue business as usual, we will likely cause a mass extinction of corals by the middle to end of this century due to the combined threats of rising acidity and increasing temperatures.

I am not talking about far into the future. It is a reality, and it is happening as we speak. Some corals on the Great Barrier Reef already have reduced growth rates by 14 percent, and similar reductions in growth rates are being seen on reefs in Thailand and the Caribbean, and shellfish hatcheries in the Pacific Northwest have seen massive die-offs of juvenile oysters called spats. This is just an early warning sign in a story that we don't want to see through to the end.

The carbon dioxide that is absorbed by the seas combines with seawater to create an acid which changes the acidity of the oceans, and that causes serious mischief for all the kinds of sea life, beginning with corals and including swimming snails, my favorite little animal, the pteropod, and continuing on through shellfish. A chain reaction begins.

Why does this matter? Because animals like pteropods form the base of the food web. Whales and salmon need pteropods for dinner. Fish need coral for habitat. As with any unwanted chain reaction, the thing to avoid reaching is critical mass, where the problem outruns any effort to control it.

This particular chain reaction isn't getting the right kind of attention. And with 1 billion people relying on the oceans for their primary source of animal protein, a collapse of the ocean food web would have major and dire consequences for humans.

What can we do? We must cap and reduce carbon dioxide emissions, period. It is simple chemistry. The more carbon dioxide absorbed by the oceans, the more acidic our oceans will become. Congress already recognized the importance of this issue and passed the Federal Oceans Acidification Research and Monitoring Act as a first step to focus Federal agencies on how acidification will impact our oceans and coastal communities. This program needs to be fully funded and implemented.

Congress also needs to preserve the Environmental Protection Agency's authority to address and regulate carbon dioxide. And we need to end our reliance on fossil fuels and shift to clean renewable energy.

To start, we need to end all new offshore drilling now. The risk to coastal communities and our oceans is too great, and accidents clearly do happen. But at the end of the day, the only way we have any hope to address ocean acidification is to reduce carbon dioxide emissions. Regardless of whether you think the climate is changing or whether or when or at what speed it will impact the United States, carbon dioxide is impacting our oceans now. It is occurring. It is simple chemistry, and Congress needs to step in and do something about it.

Thank you very much.

[The prepared statement of Mr. Waterston follows:]

Written Testimony of Sam Waterston
Subcommittee on Oversight and Subcommittee on Water and Wildlife of the Environment and Public Works Committee
Hearing on EPA's Role in Protecting Ocean Health

May 11, 2010

I. Introduction

Thank you for the opportunity to provide testimony on an issue that I care deeply about. I serve as a member of the Board of Directors of Oceana, a global ocean conservation organization based here in Washington, D.C. that works to protect and restore the world's oceans. Besides our headquarters in Washington DC, Oceana also has staff located in Alaska, California, New York, Oregon, and Massachusetts, as well as international offices in Brussels, Belgium; Madrid, Spain; Belize City, Belize; and Santiago, Chile. We have more than 300,000 members and supporters from all 50 states and from countries around the globe. Our mission is to protect our oceans and the fish and wildlife that depend on them.

Today, I will present testimony regarding the threat of ocean acidification to our oceans. Since the industrial revolution, humans have been burning fossil fuels and producing carbon dioxide at an alarming rate. While atmospheric carbon dioxide fluctuates in the short term, the most dramatic increase in the past 1000 years has occurred since the beginning of the Industrial Revolution, more than 250 years ago. The concentration of carbon dioxide in the atmosphere is currently 387 part per million (ppm), which is already almost 40% greater than the pre-industrial level of 280 ppm. The current level of carbon dioxide in the atmosphere is higher than any other time in the last 800,000 years.

Where does all of this carbon dioxide go? About 30% is absorbed by the oceans. [1] The oceans are the largest repository for anthropogenic carbon dioxide on Earth, having absorbed over 460 billion metric tons of carbon dioxide since the Industrial Revolution.[2] Currently, the world's oceans absorb about 30 million metric tons of carbon dioxide daily[3], nearly twice the amount of carbon dioxide that is emitted in the United States each day.[4]

There is no debate that carbon dioxide is changing our oceans. Ocean acidification is a result of a simple chemical reaction that occurs when carbon dioxide combines with seawater. When seawater reacts with carbon dioxide, it forms carbonic acid, making the water more acidic. The acidity of the oceans has increased by 30% since the Industrial Revolution[5], and if current emissions trends continue, it could rise by another 100% by the end of the century[6], making it higher than any other time in the past 20 million years.[7]

A tool used to measure the relative acidity of a liquid is the pH scale. The pH scale runs from 0 (a highly acidic solution) to 14 (a highly basic solution). For example, vinegar has a pH of 2, pure water has a pH of 7, and bleach has a pH of 13. The pH of the ocean surface has already fallen 0.1 units, representing a 30% increase in acidity.[8] The pH scale can be misleading because it is logarithmic, so while 0.1 units may sound insignificant, it actually represents a major change in acidity. If we continue to emit carbon dioxide at current levels, it could fall by another 0.3 units.[9] In the last 300 million years, the pH of the oceans has never fallen to more than 0.6 units below the level it was at the start of the Industrial Revolution.[10]

These chemical changes to seawater impact marine life. Large additions of carbon dioxide can reduce the availability of ions that are essential to animals that form calcified shells, such as corals, mollusks, crabs and lobsters, as well as organisms at the bottom of the food chain, like swimming sea snails, pteropods. Increased acidity reduces the availability of carbonate which is vital to sea life. In the future, the oceans could experience a reduction of carbonate so significant that calcium carbonate shells and skeletons could start to dissolve.

Ocean acidification is already having a negative impact on marine organisms, including decreased growth rates of some corals on the Great Barrier Reef [11] and massive die-offs of oyster larvae in commercial hatcheries on the West Coast. If current emissions trends continue, reefs will continue to degrade and could be pushed past a tipping point, which is likely to occur at an atmospheric carbon dioxide concentration of 450 ppm. Beyond this tipping point, reefs as we know them would be threatened with extinction.[12] Tropical coral reefs could be gone by the middle to end of this century.[13] Since coral reefs take decades or even centuries to form, once the damage is done, the impacts will be irreversible for generations.

The loss of coral reefs would mean a loss of habitat for many millions of species. Reefs provide homes, nurseries, feeding grounds and spawning sites to a diversity of life that is virtually unparalleled anywhere else in the world. Without reefs, severe consequences would result for as many as nine million different species (including four thousand species of fish) that rely on reefs for shelter and nourishment.[14] Coral reefs are often called the rain forests of the sea, I actually like to call rain forests the reefs of land because reefs are more diverse and hold more life than rain forests do.

Cold water, deep sea corals are especially at risk, particularly since acidification is occurring more rapidly in colder waters. Carbon dioxide is more soluble in cold water, accelerating the rate of ocean acidification in these areas. Not only are cold water deep sea corals at risk, but acidification also threatens the many marine species that rely on deep sea corals for their habitat. Since a large portion of the U.S. fishing industry relies on cold, deep waters ocean acidification would impact the industry and the people who rely on it for food and jobs.

Coral reef ecosystems provide food for millions, they protect coastal communities from storms and erosion, they provide habitat and feeding, nursery and spawning grounds for many commercially important fish species, and they provide jobs and income to local economies. An estimated half billion people worldwide rely on coral reefs for food, income, and protection, and provide a net global economic benefit of approximately $30 billion per year.[15]

Coastal economies rely on healthy oceans. Coastal tourism and recreation produce $70 billion in annual revenue in the United States.[16] In 2008, commercial fisheries contributed almost $70 billion in economic activity to the United States gross domestic product (GDP) and recreational fisheries contributed more than $31 billion to the GDP in 2006.[17,18] Coastal and marine waters support over 28 million jobs, and provide a tourism destination for 180 million Americans each year.[19]

The impact to commercial and recreational fisheries has the potential to be devastating. On the West Coast, an upwelling of acidified water occurred to an extent not expected to occur until 2050. At the same time, major die-offs occurred in oyster beds in the area. The oyster industry in the Pacific Northwest contributes more than 100 million to the economy each year, but in 2007 and 2008, one of the region's largest oyster hatcheries, the Whiskey Creek[20] Shellfish Hatchery at Netarts Bay, saw a 70-80% decrease in production.[21] Initially attributed to a bacterium, scientists eventually determined that the die-offs were in fact due to the acidity of the seawater. Similar experiences have been reported with clams in East Coast bays, and acidified water has been observed in the rich fishing grounds off Alaska, such as the Bering Sea.

Not only will marine calcifiers be impacted, but so will the animals that rely on them as a food source. In the cold waters of the polar and sub-polar regions, many species, including whales and salmon, rely on tiny marine organisms called pteropods, or swimming sea snails, as their major food source. Pteropods account for up to 45 percent of the diet of the Alaskan pink salmon.[22] Preliminary studies indicate that a 10 percent reduction in pteropod production could result in a 20 percent reduction in pink salmon body weight.[23] Because pteropods exist in cold water regions, they are particularly vulnerable to ocean acidification, and a disruption in pteropod production means a disruption at the base of marine food webs. Rising acidity could ultimately affect even the largest of top predators in the oceans, as well as many fisheries.

Action is needed and it is needed now. While research and monitoring are necessary to mitigate the damage due to ocean acidification, the only way to actually stop acidification is to reduce carbon dioxide emissions. Burning fossil fuels such as oil and coal makes ocean acidification worse and contributes to climate change. We must cap and reduce carbon emissions to stop the acidification of our oceans and promote U.S. innovation and investment in renewable carbon-free fuels.

II. A Clean Energy Future Without Offshore Drilling

Rather than perpetuating our addiction to fossil fuels, Congress should create an energy policy that increases investments in responsible renewable energy development consistent with the protection of wildlife and habitat, and that promotes energy efficiency and conservation, while creating jobs in new clean energy sectors, without putting our oceans and coasts and the economies they support at risk.

In the face of ocean acidification and climate change, the continued extraction and burning of offshore oil and gas reserves makes even less sense. Alternative offshore resources, such as wind, have the potential to contribute greatly to our energy needs, while drastically reducing carbon dioxide emissions. Offshore wind farms do not pollute the air, water, or coastal communities.

The recent tragic events in the Gulf of Mexico provide incentive and urgency to end new offshore drilling, including any exploratory wells. All new leasing should be permanently off the table. As of May 5th, about 4 million gallons have spilled into the Gulf of Mexico, and an estimated 200,000 gallons still freely flows into the surrounding waters each day. It is still unclear what the long term impact to the Gulf coast, fisheries, wildlife and economy from this tragedy will be. What is clear is that we can't let this happen again.

The oceans can and should be part of the solution. The United States has a great resource offshore that could power our economy cleanly, and create hundreds of thousands of jobs for generations to come. The U.S. offshore wind resource is arguably the best in the world. The Department of the Interior estimates offshore wind could provide more electricity than the current U.S. demand.[24] If we follow Europe's example and significantly develop this resource, it could create well over 300,000 jobs by 2030.

Europe is already realizing the potential of their offshore wind resource. More than two gigawatts of offshore wind farms are installed off European coasts[25] – or about as much as two nuclear power plants. The United Kingdom has the most offshore wind farms currently installed and by 2020, the UK plans to install enough offshore wind farms to power every household in the country.[26]

Europe's ambitious offshore wind plans will not only supply substantial amounts of clean energy, but will also support nearly 300,000 direct and indirect jobs annually by 2030.[27] These "Green Collar" jobs will slash carbon dioxide emissions by 200 million metric tons annually[28]- helping prevent the worst effects of climate change and ocean acidification. Even China recognizes the significance of offshore wind energy – that country just last month finished the installation of its first offshore wind farm near Shanghai.[29]

The United States has been a laggard when it comes to offshore wind. But, just two weeks ago, Secretary of the Interior, Ken Salazar approved the country's first ever offshore wind farm – the Cape Wind project off Massachusetts's coast. Cape Wind and other United States projects will benefit from the nearly 20 years of offshore wind experience gathered from operational European offshore wind farms. Offshore wind power is a reality, and we need to play catch-up with the rest of the world to develop this amazing resource.[30] The Senate should prioritize innovation and incentives for clean, renewable energy that will not put our oceans and coastal economies at risk. This is the future and as country that prides itself and benefits from being a leader technologically, the United States should be a leader here.

III. Cap and Reduce Carbon Dioxide Emissions

The only way to stop ocean acidification is to cap and reduce carbon dioxide emissions. Any climate legislation moving forward must reduce carbon dioxide to levels low enough to still allow for healthy, robust and productive oceans.

The International Panel on Climate Change (IPCC) concluded that in order to stabilize carbon dioxide in the atmosphere at 350 ppm, global carbon dioxide emissions would need to be cut 85 percent below 2000 levels by 2050.[31] There are several pieces of climate legislation under consideration by Congress this session, and it is vital that we remain focused on passing the strongest possible bill if we hope to halt ocean acidification as well. Obviously ocean acidification being simple chemistry lends force for immediate action on climate change and its effects.

Furthermore, the Environmental Protection Agency's authority to regulate greenhouse gases must be preserved. Any actions to the contrary undermines the finding announced on April 24, 2009 by the administrator of the EPA that greenhouse gas emissions are a threat to public health. This finding is consistent with the 2007 Supreme Court decision in *Massachusetts vs EPA* which ruled that under the Clean Air Act, the EPA is responsible for regulating greenhouse gas pollution as it endangers public health.

The Senate must be diligent in passing the strongest possible climate legislation. This means remaining focused on increasing investments in clean energy technology such as solar and wind; reducing harmful giveaways to fossil fuel industries such as coal and oil; and stopping any new offshore drilling, including any exploration, off our coasts. Ocean acidification is simple chemistry that is observable and preventable if we take action now to reduce the amount of carbon dioxide in the atmosphere. From the decreased growth rates of corals on the Great Barrier Reef to the massive die-offs of oyster larvae at the Whiskey Creek Oyster Hatchery in Oregon, acidification is already beginning to damage ecosystems and fisheries alike.

IV. Support Implementation of the FOARAM Act

Last year, Congress passed the Federal Ocean Acidification Research and Monitoring (FOARAM) Act, which represents a great first step in addressing ocean acidification. The FOARAM Act recognized the lack of funding and coordination of research, and called for the development of an interagency plan for ocean acidification research and monitoring. The bill authorized $55 million over four years for the National Oceanic and Atmospheric Administration (NOAA) and $41 million over four years for the National Science Foundation (NSF).

The FOARAM Act is a great starting point, and now that the funds have been authorized, it is time to appropriate those funds at their full levels. Acidification is a serious threat to our oceans, and the federal agencies need to seriously addressing it. Implementing and fully funding the FOARAM Act will allow for monitoring and research into the impacts of acidification and the development of strategies to assist marine organisms and ecosystems in adapting to the harsh new environment.

V. Conclusion

Ocean acidification poses a grave threat to marine wildlife, fisheries, and coastal economies. While the chemistry driving acidification is simple and broadly accepted, less is understood about the exact impacts that it will have on marine ecosystems. One thing we do know is that the impacts will be far-reaching and potentially catastrophic.

In order to stop further ocean acidification, we must cap and reduce carbon dioxide emissions now to turn the tide on ocean acidification. Carbon dioxide emissions are wreaking havoc on our air and our oceans, and we must act now to restore the health of our planet.

Our oceans are already under extreme stress from acidification, overfishing, warming and pollution. As illustrated by the recent disaster with the Deepwater Horizon rig in the Gulf of Mexico, offshore oil and gas drilling is a dangerous endeavor, and one where the risk far outweighs the reward. Ending all new offshore drilling, including exploratory wells, in U.S. waters including the Arctic will protect coastal communities, economies and marine life from further impacts of drilling.

Even with the strongest possible climate legislation, it will take time to reduce atmospheric carbon dioxide, and acidification will continue to impact our oceans. Funding for research and monitoring programs such as that authorized in the FOARAM Act must be appropriated so that work can begin to restore the health of our oceans. The programs outlined in the law must be implemented immediately in order to prevent further losses to our fisheries such as those suffered by the West Coast oystermen.

The House of Representatives introduced H. Res. 989 on ocean acidification in December. This resolution supports adopting national and international policies to prevent acidification and to research and address the impacts of ocean acidification on marine ecosystems and coastal communities. The Senate should introduce and pass a companion resolution.

For the health of marine wildlife, coastal tourism and recreation economies, and the vitality of our nation's fisheries, it is time to take action to stop destroying oceans.

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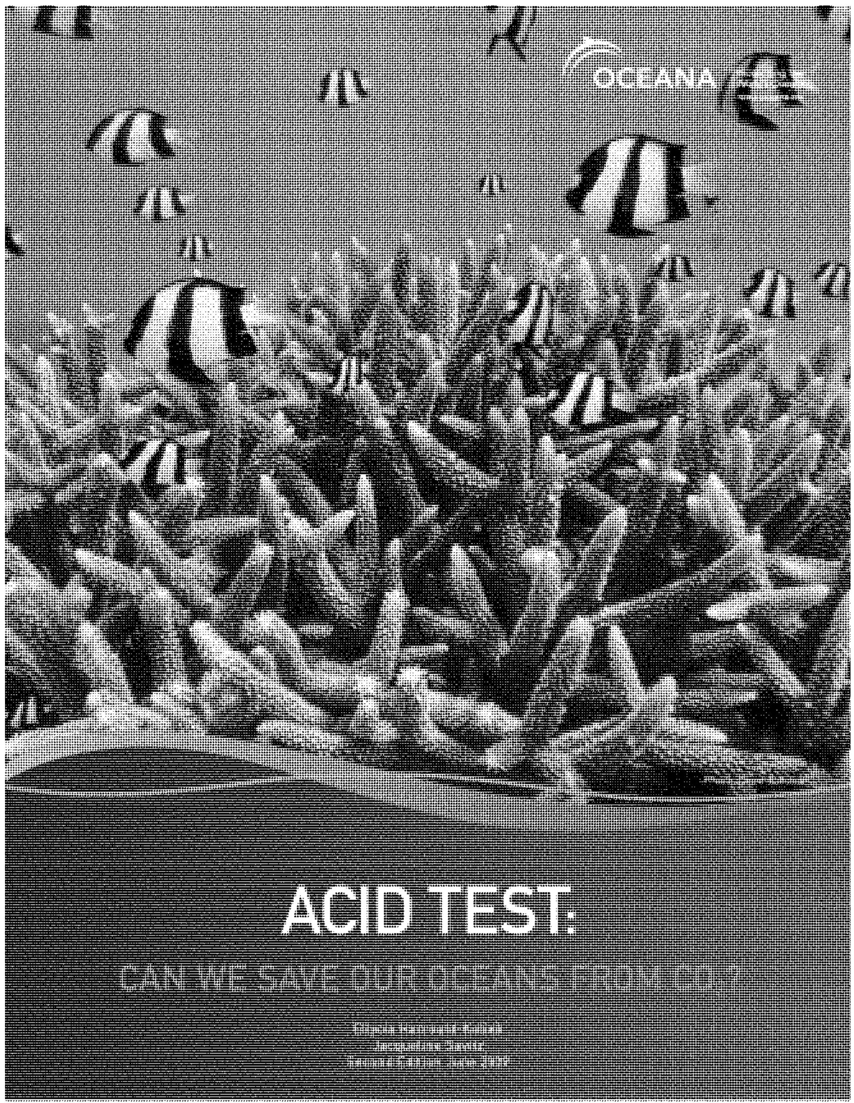
OCEANA
ACID TEST:
CAN WE SAVE OUR OCEANS FROM CO_2?

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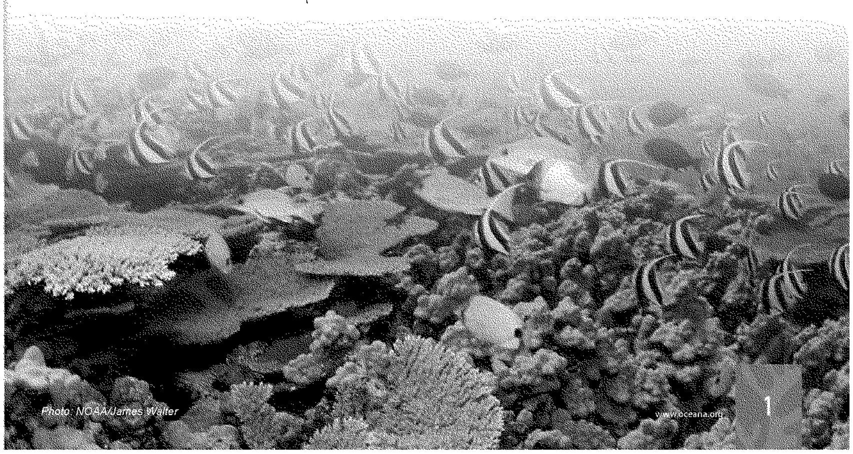
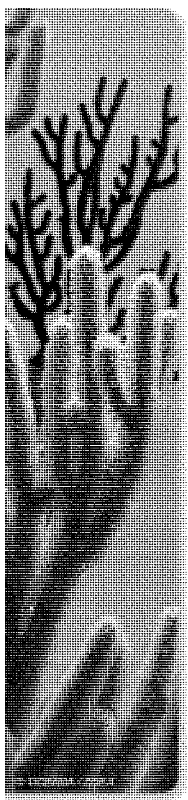


Photo: NOAA/James Walter

"Not only are the oceans warming and rising, but they are also becoming more acidic."

EXECUTIVE SUMMARY



Introduction

Climate change is now widely recognized as the most significant environmental challenge of our time. This does not just mean that the environment or 'nature' is in danger. We too will suffer the consequences. We are inherently inseparable from the environment around us and are reliant upon the services it provides, from the air we breathe and the climates we inhabit, to the fertilized crops we consume. We are exquisitely adapted to the Earth as we know it. Unfortunately, our activities are now altering the balance of gases in the atmosphere—the very gases that help regulate the temperature and climate.

Our ever-growing greenhouse gas emissions, predominantly carbon dioxide, are trapping more heat in the atmosphere, causing the temperature of the Earth's surface to rise. The result? Melting ice caps, sea level rise, hotter average temperatures, shifting wildlife populations, changing disease patterns, and more severe droughts and storms.

The disrupted climate system will dramatically change the way people live on this planet. We can expect to see more heat-related sickness and death, and food supplies and food prices disrupted by more severe droughts. There will likely be widespread hunger in some countries and perhaps even famine. Rising sea levels will flood huge swaths of coastline. Within the coming centuries some of the world's largest and most important cities—including New York City, Bangkok and London—will be at risk of flooding and even total immersion. Entire countries such as Bangladesh and most small island nations will lose significant land area forcing millions of climate refugees to flee the rising seas.

Along with a disrupted climate system, our emissions of carbon dioxide are having a severe, but more insidious, impact on the oceans. The oceans absorb roughly 30 percent of global carbon emissions and 80 percent of the heat generated by increased levels of greenhouse gases, thereby mitigating some of the climate change that would otherwise occur.[1,2] However, this relief comes at a great cost. Not only are the oceans warming and rising, but they are also becoming more acidic.

The increasing amount of carbon dioxide in the oceans results in reactions that are changing the chemistry of the oceans, through a process known as ocean acidification. This threatens marine organisms like hard corals, clams and crabs that create calcium carbonate shells and skeletons. The acid created by excess carbon dioxide in the oceans takes the materials these organisms would otherwise use to create shells and skeletons, and makes it unavailable. This makes it increasingly difficult for corals and other marine animals to strengthen existing structures and build new ones. If ocean acidification continues, the very water that these organisms live in could become so corrosive that it would dissolve their shells and skeletons directly.

While the chemical processes making the oceans more acidic are well understood and accepted, we are just beginning to understand the wide-ranging effects acidification is likely to have on marine wildlife. Increased acidity may not directly kill non-calcifying organisms, but many are likely to be harmed in ways that reduce their overall fitness and ability to survive. These impacts could include decreased growth rate, reduced reproduction, disrupted respiratory and nervous system function and increased susceptibility to predators and disease, all of which could produce ripple effects through food webs and ecosystems. Ultimately, ocean acidification could transform the oceans, leaving them far less diverse and productive and making the lives and livelihoods of those who depend on them far more uncertain.

According to Stanford University oceanographer Ken Caldeira and his colleagues:

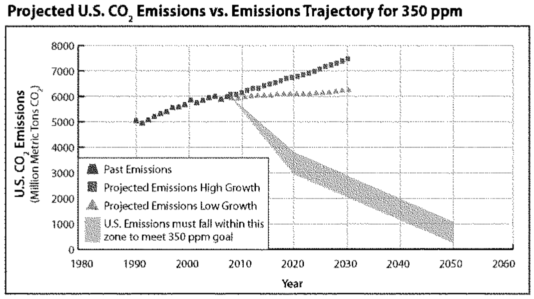
> *"[The] chemical effects of CO_2 on the marine environment may be as great a cause for concern as the radiative effects of CO_2 on Earth's climate."*[3]

"The longer we wait to act the more difficult averting catastrophe becomes"

Reaching the Limits

Current atmospheric carbon dioxide concentrations are already above safe levels. As a result, significant changes are already taking place throughout the oceans, from decreasing growth rates of corals on the Great Barrier Reef to massive coral bleaching events across the tropics. Coral reefs provide important habitat to a quarter of all marine species and are critical to the lives and livelihoods of many humans. Allowing coral reefs to disappear would result in intolerable changes throughout the oceans and to the lives of hundreds of millions of humans. What happens to coral reefs will foreshadow other catastrophic changes that are likely to take place around the world due to ocean acidification and climate change.

Projected U.S. CO_2 Emissions vs. Emissions Trajectory for 350 ppm



Source: Oceana, based on EIA (2008) and IPCC (2007)

To prevent the loss of coral reefs, and ultimately avert a climate crisis, we must reduce atmospheric carbon dioxide levels below 350 parts per million (ppm).[4] Unfortunately, carbon dioxide in the atmosphere has already reached 385 part per million and is still climbing.[5] This current level is also much higher than it has been at any time over the course of human civilization.[6]

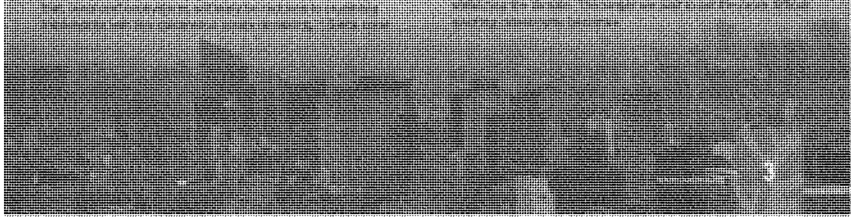
In today's society carbon dioxide emissions are directly tied to our continually growing need for energy. Recent figures released by the U.S. Energy and Information Administration (EIA) suggest that staying on the current business-as-usual (BAU) path, where current laws and policies remain unchanged, will result in world energy consumption in 2030 that is 50 percent above 2005 levels.[7] This would result in an atmospheric carbon dioxide [illegible]

[illegible]

reefs take decades or even centuries to form, once such damage is done, the impacts will be irreversible for generations.

To save coral reefs from ocean acidification, we must stabilize atmospheric carbon dioxide at or below a concentration of 350 ppm. By doing so, we will also prevent other climate-related catastrophes. Current atmospheric carbon dioxide levels already exceed this amount, and with a projected increase over the coming decades it is vital to get on the right trajectory within the next few years and to make sure that carbon emissions peak and begin to decline within a decade.

The Intergovernmental Panel on Climate Change (IPCC) concluded that in order to stabilize carbon dioxide in the atmosphere at 350 ppm, global carbon dioxide emissions would [illegible]



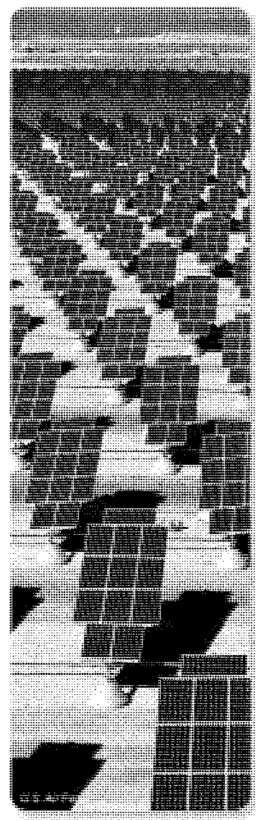
Findings

This report highlights the following recent findings demonstrating that ocean acidification is already occurring and threatening the oceans. It also identifies the likely consequences of continued carbon dioxide emissions for oceans and marine ecosystems.

- Carbon dioxide in the atmosphere is higher than it has been for 800,000 years and probably for much longer.[12]
- The acidity of the ocean surface has increased 30 percent since before the Industrial Revolution.[13] If current trends continue, it could rise by another 100 percent by the end of this century[14], exceeding the levels of the past 20 million years.[15]
- The increased amount of carbon dioxide the oceans are absorbing alters the movement of nutrients and chemicals in the oceans and has wide-ranging effects on ecosystems and marine life.[16]
- The higher acidity will also affect growth, reproduction, disease resistance and other biological and physiological processes in many species.[21]
- Many species will be unable to adapt to the rapid changes in ocean acidity and carbonate concentrations, especially those that build calcium carbonate shells and skeletons. This may lead to population crashes in many species, including oysters, mussels, crabs and lobsters.[17,18,19,20]
- Impacts on carbonate-dependent species like corals and pteropods could cause major ripple effects throughout ecosystems and food webs ultimately affecting even the largest animals in the oceans, as well as many commercial fisheries.[22]
- Nearly 30 percent of the world's tropical corals have vanished since 1980, mainly due to warming events. At the current rate of emission growth, tropical corals could be gone by the middle to the end of this century.[23,24]
- If current emission trends continue, cold-water corals will be severely stressed by 2040, and two-thirds of them could be in a corrosive environment by the century's end.[25]
- The disappearance of coral reefs would cost society billions of dollars annually due to losses in fishing, tourism and coastal protection services.[26]
- Over 100 million people depend on coral reefs economically,[27] and subsistence communities may experience health consequences and lack of food security due to the loss of protein associated with coral reefs.[28]
- Many commercial fisheries depend on reefs which provide food and shelter for fish.[29,30] The loss of reefs may further destabilize already depressed commercial fish populations.
- To protect coral reefs and the ecosystems that depend on them, we must stabilize carbon dioxide in the atmosphere at or below 350 ppm. To achieve this, global emissions must be reduced to 85 percent below 2000 levels by 2050, which will require industrialized nations to reduce their emissions 25 to 40 percent below 1990 levels by 2020 and 80 to 95 percent by 2050.[31,32,33]

Solutions

A variety of solutions will be needed to reduce levels of carbon dioxide in the atmosphere to 350 ppm. These include: (1) a shift away from our carbon-based energy economy, which can been done by building an infrastructure for energy alternatives such as solar, wind and hydrogen, and scaling back the use of coal unless carbon capture is effectively employed; (2) increasing energy efficiency in cars, trucks, trains, planes and ships, as well as in homes, office buildings, power generation and the industrial sector; and (3) reducing deforestation while also planting more forest land to help "draw down" carbon dioxide levels. If we want to save our coral reefs and shellfish fisheries, the ecosystems that depend on them and the values that we derive from them, we need to start now. With a 25-to-40 percent reduction needed by the industrialized countries of the world by 2020, there is no time to waste.



Recommendations

Adopt a Policy of Stabilizing Atmospheric Carbon Dioxide at 350 ppm
Governments must commit to stabilizing the levels of carbon dioxide in the atmosphere at 350 ppm or below. To achieve this, serious strides need to be taken within the next five years to set society on a path to zero net carbon emissions within the coming decades.

Promote Energy Efficiency and Low Carbon Fuels
Energy should be conserved at every opportunity, including through improved fuel efficiency of cars, trucks, airplanes and ships, provision of cleaner fuels, investment in efficient mass transit, and individual, institutional and corporate actions to reduce energy use.

Shift to Alternative Energy Sources
New or expanded coal-fired power plants and other expanded uses of coal should be prohibited until global warming pollution can be trapped and safely stored. In their place, governments and the private sector should implement programs to stimulate the development and use of renewable energy options such as wind and solar, and invest in upgrading the national power transmission grid so that energy produced from alternative sources can be cost-effectively moved to markets. Governments should immediately eliminate any and all subsidies that encourage the use of fossil fuels. Fossil fuels currently in the ground in sensitive ecosystems such as the Arctic and offshore should stay in the ground.

Regulate Carbon Releases
Governments should immediately begin regulating carbon releases using a system that internalizes emissions costs and prevents continued releases that harm the oceans. Under-regulated sources of carbon dioxide emissions, such as those from shipping and aircraft should be included in a post-Kyoto Agreement and regulated by the appropriate international bodies, such as the International Maritime Organization and the International Civil Aviation Organization.

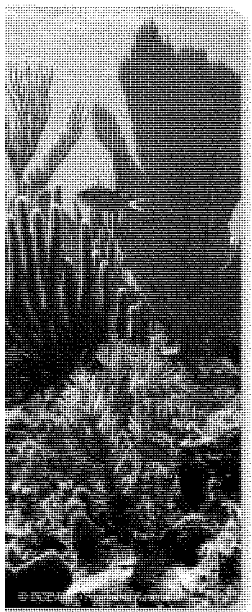
Preserve Natural Resilience
The natural resilience of marine ecosystem should be maintained by curtailing other human caused threats, such as overfishing and pollution. Ocean acidification and climate change are not isolated threats, but act in concert with other impacts on ecosystems and species. Ocean ecosystems will have the best chance of surviving the pressures of ocean acidification if they are not simultaneously struggling to survive in the face of other threats.

INTRODUCTION

Our continued burning of fossil fuels is increasing the levels of carbon dioxide in the atmosphere, and what goes into the atmosphere eventually ends up in the oceans. Consequently, the oceans have been absorbing large amounts of carbon dioxide since the Industrial Revolution (approximately 1750). It is this increasing amount of carbon dioxide in the oceans that is causing ocean acidification.

When carbon dioxide enters the ocean it combines with seawater to produce carbonic acid, which increases the acidity of the water, lowering its pH.[35] Although it is unlikely that the ocean will ever become actual acid (i.e. fall below a pH of 7.0), the term acidification refers to the process of the oceans becoming more acidic.

A major consequence of increasing ocean acidity is a reduction in the amount of carbonate available for use by marine animals. One of the most important uses of carbonate in the ocean is in the formation of calcium carbonate or limestone structures like coral skeletons, shells and pearls, and the tests (shells) of some marine plankton. Ocean acidification will severely impact the ability of these creatures to create their protective calcium carbonate structures, and will likely disrupt some of the most important chemical and biological functions of the oceans.[36]



WHAT IS OCEAN ACIDIFICATION?

The absorption of carbon dioxide by the oceans moderates the impacts of climate change on terrestrial life. Since the Industrial Revolution the oceans have been acting as a "carbon sink" for carbon dioxide emissions, thereby lessening the extent of climate change. Without the oceans playing this role, the concentration of carbon dioxide in the atmosphere would have risen an additional 55 percent more than it has over the last 250 years.[37]

Prior to the Industrial Revolution the oceans were in relative equilibrium with the atmosphere, absorbing about the same amount of carbon dioxide each year as they released (2.15 billion metric tons of CO_2).[38] However, as the concentration of carbon dioxide in the atmosphere has increased, due mainly to the burning of fossil fuels, the amount of carbon dioxide the oceans have been absorbing has also increased. The oceans will continue to absorb carbon dioxide from the atmosphere as long as the concentration of carbon dioxide in the surface waters is less than that in the atmosphere.[39]

The pH of the ocean surface has already fallen 0.1 units, representing a 30 percent increase in acidity.[40] By the end of this century, if current emission trends continue, it could fall by another 0.3 units, an almost 100 percent increase in acidity.[41] The pH scale can be misleading because it is logarithmic, so its units may seem incremental, when in fact, they represent major changes in acidity. For example, a seemingly small drop of 0.4 units in pH actually represents more than a doubling (an almost 150 percent increase) in the acidity of the ocean.[42] In the last 300 million years or more, ocean pH has never fallen to more than 0.6 units below the level of 1750,[43] however if fossil fuel use continues unabated over the next couple of centuries, ocean pH could fall more than 0.7 units below the 1750 level (see Table 1).[44]

The oceans are the largest repository, or carbon sink, for anthropogenic carbon dioxide on earth.[46] Since the Industrial Revolution the oceans have absorbed over 460 billion metric tons of carbon dioxide,[47] which represents almost half of the carbon dioxide emissions from the burning of fossil fuels, or approximately 30 percent of all human-caused carbon dioxide emissions.[48] The oceans are currently taking up some 30 million metric tons of carbon dioxide daily,[49] nearly twice the amount of carbon dioxide emitted by the U.S. each day.[50]

The current concentration of carbon dioxide in the atmosphere is much higher than it has been at any time over the course of human civilization – in fact, as far back as scientists have currently determined (800,000 years), the natural range has not exceeded 300 ppm.[51] If we continue on our current emissions trajectory, by 2050 ocean pH will be lower than at any point in the last 20 million years.[52]

Even more significant is the rate at which ocean chemistry is changing. The current rate of acidification is at least 100 times faster than the maximum rate over hundreds of thousands of years.[53,54] Carbon dioxide is being absorbed so rapidly that it is unlikely the buffering capacity of the surface waters of the oceans will be able to prevent a substantial lowering of ocean pH.[55]

Table 1: Current and expected changes in ocean pH[45]

	CHANGE FROM PRE-INDUSTRIAL pH		pH CONDITIONS HAVE NOT BEEN EXPERIENCED FOR
	pH UNITS	PERCENTAGE	
Today	-0.1	30	800,000 years
Business-as-Usual at 2050	-0.2	60	20 million years
Business-as-Usual at 2250	-0.7	210	300 million years

Table 2: Past and future chemistry of surface sea water under a "Business-as-Usual" emissions scenario[56]

YEAR	ATMOSPHERIC CO_2 CONCENTRATION (ppm)	SURFACE OCEAN pH
1750	280	8.19
2008	385	8.09
2020	440	8.03
2040	510	7.97
2060	600	7.91
2080	700	7.85
2100	850	7.78

Based on geologic history, marine calcifiers and the natural biogeochemical cycles of the ocean could be adversely affected by even small changes in the concentrations of carbon dioxide in the surface waters of the oceans.[57,58] Past mass extinctions and reef gaps (periods of time, on the order of millions of years, that reefs have taken to recover from mass extinctions) can likely be attributed to ocean acidification.[59] An acidification event that occurred fifty-five million years ago at the Paleocene-Eocene Thermal Maximum (PETM) caused the extinction of a significant proportion of benthic calcifiers.[60] We are currently on a path to equal or surpass the PETM acidification event. If the entire fossil fuel reservoir is exploited, similar amounts of carbon dioxide will be absorbed by the oceans as at the PETM, however the rate at which current emissions are occurring is much faster (over the space of decades to hundreds of years, as opposed to thousands), so it is likely that the consequences of current ocean acidification could be even more catastrophic than the PETM event. This means another mass extinction may be looming.[61,62]

"It is likely that a continuation of current trends in carbon dioxide emissions will lead to an extinction of corals and may lead to the extinction of other marine species."[34]

— Dr. Ken Caldeira

How Does the pH Scale Work?

Chemists identify an acid or base by the concentration of hydrogen ions (H+) present, which is expressed using the pH scale. The scale runs from 0 (a highly acidic solution, with high concentration of H+) to 14 (a highly basic solution, with a low concentration of H+). The pH of battery acid, for example is about 0, and drain cleaner, on the other hand, is about 14. A neutral solution has a pH of 7 and pristine sea water has a pH ranging from 8 to 8.3. A change of 1 unit represents a 10 fold increase in the concentration of hydrogen ions and therefore acidity. For example, pH 5 is 10 times more acidic than pH 6 and 100 times more acidic than pH 7.

Concentrations of Hydrogen ions compared to distilled water (pH)		Examples of solutions and their respective pH
10,000,000	0	Battery Acid
1,000,000	1	Hydrochloric Acid
100,000	2	Lemon Juice, Vinegar
10,000	3	Orange Juice, Soda
1,000	4	Tomato Juice
100	5	Black Coffee, Acid Rain
10	6	Urine, Saliva
1	7	"Pure" Water
1/10	8	Sea Water
1/100	9	Baking Soda, Toothpaste
1/1,000	10	Milk of Magnesium
1/10,000	11	Household Ammonia
1/100,000	12	Soapy Water
1/1,000,000	13	Bleach, Oven Cleaner
1/10,000,000	14	Liquid Drain Cleaner

Source: Richmond River County Council www.rrcc.nsw.gov.au

OCEAN CHEMISTRY

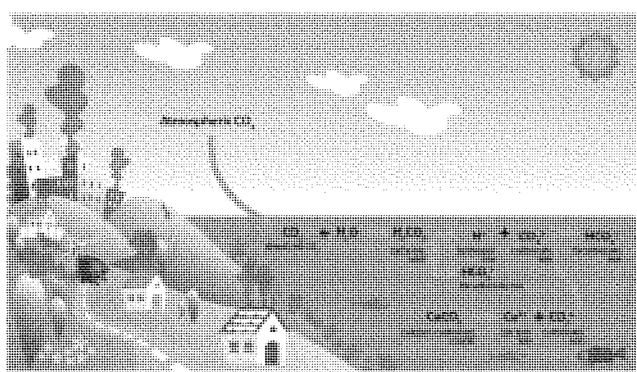
The chemical composition of seawater buffers against large shifts in pH. However, large additions of carbon dioxide can reduce the availability of carbonate, and even make the seawater corrosive to calcium carbonate structures.

High Levels of Carbon Dioxide in Seawater Lowers Carbonate Availability

Water reacts with carbon dioxide absorbed from the atmosphere to form bicarbonate ions and, in the process, depletes carbonate ions. Carbonate and bicarbonate are in equilibrium with one another in the oceans, so an increase in the abundance of one causes a decrease in the abundance of the other. Carbonate is needed by marine animals to make their calcium carbonate shells and skeletons. At typical pH levels, most of the ocean's inorganic carbon is stored in the form of bicarbonate ions but there is still enough carbonate available for the formation of calcium carbonate. When carbon dioxide absorbed by the oceans reacts with water, it forms a bicarbonate ion and a hydrogen ion. This hydrogen ion can then bind with a carbonate molecule that would otherwise be available to make calcium carbonate (see Figure 1). This tips the balance of the system away from carbonate ions, reducing the availability of this important molecule, which is vital to sea life.

Some of the species that will likely be affected by a decrease in the availability of carbonate ions include; corals, starfish, oysters, crabs, shrimp, mussels, lobsters, coccolithophores (a type of phytoplankton), pteropods (sea snails) and foraminifera (plankton related to amoebas).

Figure 1: The Chemistry of Ocean Acidification

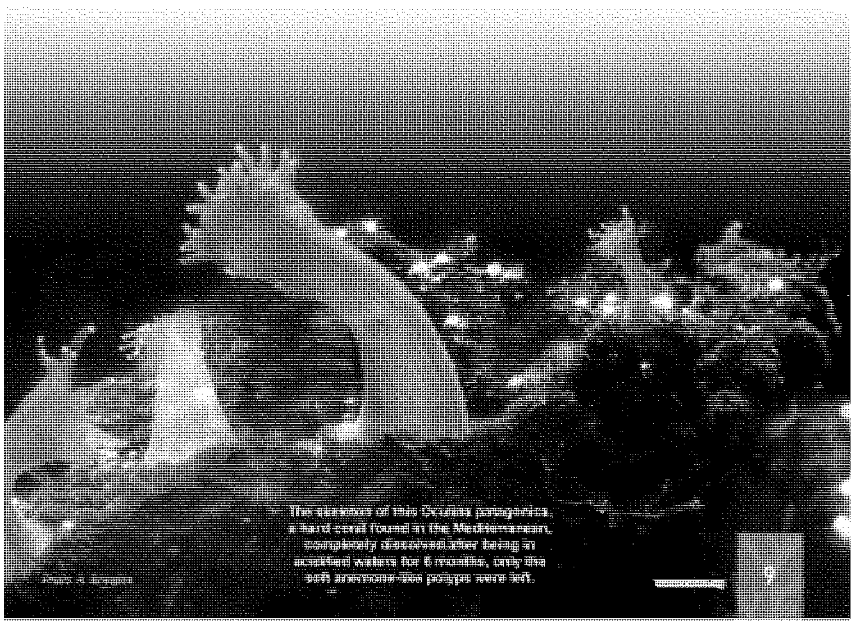


As CO_2 is absorbed by the atmosphere it bonds with sea water forming carbonic acid. This acid then releases a bicarbonate ion and a hydrogen ion. The hydrogen ion bonds with free carbonate ions in the water forming another bicarbonate ion. This free carbonate would otherwise be available to marine animals for making calcium carbonate shells and skeletons.

Seawater Becomes Corrosive

In some acidified waters, the reduction of carbonate is so significant that calcium carbonate structures can start dissolving. Since calcium carbonate structures only exist in waters where sufficient levels of carbonate ions are available, the addition of hydrogen ions to waters that already have low concentrations of carbonate ions further decreases the availability of carbonate and can actually cause existing calcium carbonate structures to begin to dissolve. With the accumulation of enough carbon dioxide, regions of the oceans that already have low enough pH to be corrosive to calcium carbonate structures will expand and more such areas are likely to develop.

Since it is the concentration of hydrogen ions that actually defines the ocean's level of acidity, the binding of hydrogen ions with carbonate ions is a buffering process against the oceans becoming more acidic. However, since such large amounts of carbon dioxide are being absorbed, the dissolution of calcium carbonate structures is the only way to return the ocean to its pre-industrial acidity levels. However, this is a slow process, which will take thousands of years to complete. In the meantime, it is currently being outpaced by the influx of carbon dioxide[63] and many vitally important calcium carbonate structures such as coral reefs and shellfish may begin to dissolve.



OCEAN ACIDIFICATION

The Role of Calcite and Aragonite

While the dissolution of calcium carbonate is primarily driven by the availability of carbonate ions, it is also affected by other factors, such as the chemical structure of calcium carbonate. Calcium carbonate is commonly found in two forms: calcite and aragonite. Organisms will generally create one form or the other, and some also add magnesium to their calcite structures. Aragonite and magnesium calcite are at least 50 percent more soluble than calcite and are therefore more vulnerable to the effects of increasing acidity.[64] As a result of their greater sensitivity to acidic conditions, organisms such as corals and pteropods that build their skeletons and shells out of aragonite, and coralline algae that produce magnesium calcite are particularly threatened by ocean acidification.[65]

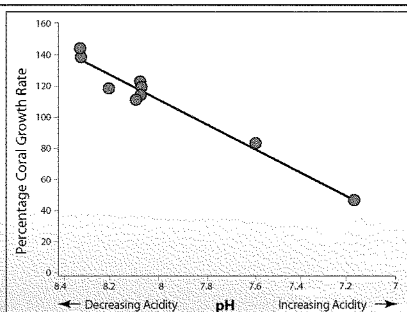
Calcification strongly depends on the "saturation state" of the surrounding water. This depends on a variety of factors including water temperature and pressure.[66] Currently, seawater near the surface is "super-saturated" with respect to all forms of calcium carbonate (i.e., the carbonate ion concentration is so high that calcium carbonate is easily created) so surface waters are therefore the most calcium carbonate 'friendly' areas of the oceans[67]. Cold and deep waters hold higher levels of carbon dioxide and therefore are naturally more acidic and less calcium carbonate friendly than warm surface waters. Calcification rates, which are a measure of the ability of an animal to build a calcium carbonate structure, are higher when the pH is higher and water is "saturated" with respect to carbonate ions. As the saturation level decreases, as it does in deeper water, the growth of these species declines (see Figure 2).[68] Once "under-saturation" is reached, calcium carbonate will begin to dissolve. However, calcification rates can decline long before under-saturation is reached so some calcifiers may not even survive to reach the point of under-saturation.[69]

As more carbon dioxide enters the oceans, the saturation horizons (the boundary between saturated and under-saturated waters) for both aragonite and calcite move closer to the surface, thereby shrinking the area in which calcification can take place.[70] The amount of carbon dioxide already absorbed by the oceans has caused the saturation horizons to rise between 50 and 200 meters closer to the surface than they were before the Industrial Revolution.[71]

The Southern Ocean, due to its cold water, has the lowest concentrations of carbonate of all the world's oceans, and is the least hospitable to calcium carbonate structures, even near the surface.[72] As a result, the calcifiers of the Southern Ocean are most at risk from increasing carbon dioxide levels.

If we continue burning fossil fuels at the current rate, the entire Southern Ocean could become under-saturated with aragonite by the middle to the end of this century.[73] With an atmospheric carbon dioxide concentration of 450 ppm, 7 percent of the Southern Ocean, below 60°S, would be under-saturated with respect to aragonite.[74] With a carbon dioxide concentration of 560 ppm, aragonite, under-saturation will spread through the polar oceans, the sub-polar Southern Ocean and portions of the sub-Arctic North Pacific[75] making it almost impossible for aragonite structures to exist in these areas, which would have devastating consequences for cold-water corals, pteropods and other organisms that create their shells and skeletons out of aragonite or magnesium calcite.

Figure 2: Tropical Coral Calcification (growth rate) Decreases as Acidity Increases



For every 0.1 decrease in pH there is an approximate 8% decrease in calcification.

Source: Fernand, L. and Brewer, P. (Eds) (2007) Report of the Workshop on the Significance of Changing Ocean CO2 and pH in Shelf Sea Ecosystems, defra and ICES CIEM, with changes made with permission from author, F.Marubini

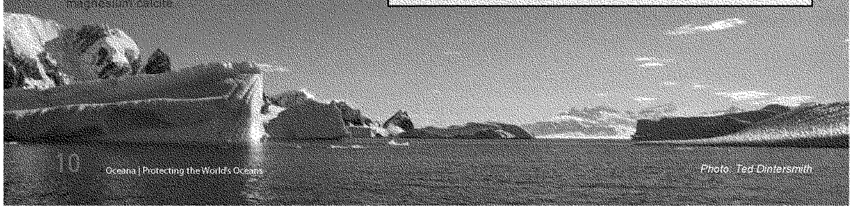
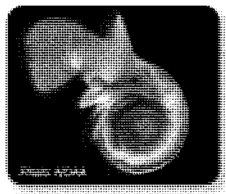


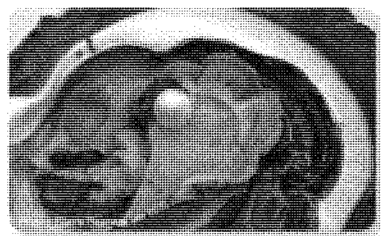
Photo: Ted Dintersmith

EFFECTS OF OCEAN ACIDIFICATION

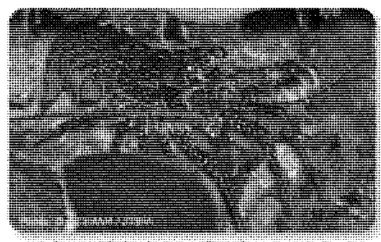
The biological and physiological processes of many organisms will be challenged by increasingly acidic conditions[76] which, in turn, will result in changes to many marine ecosystems. According to The Royal Society's report on ocean acidification, the impacts on ecosystems could be severe and long lasting.



A swimming pteropod (Limacina helicina)



Oyster and Pearl



Spotted Spiny Lobster (Panulirus guttatus)

Smooth-skinned Red Starfish (Hacelia attenuata)

Calcification

Calcifying organisms are found throughout the oceans in shallow, deep and open-water ecosystems. Calcification is the physiological process by which organisms create structures, such as shells and skeletons, out of calcium carbonate. Some calcifiers build large structures, such as coral reefs, while others are minute, like coccolithophore tests that can only be seen with a microscope. Calcifying organisms include some of the most abundant and important species in the oceans including shallow and deep water corals; clams, oysters, pteropods and other mollusks; crustaceans, including lobsters and crabs; echinoderms like starfish; and even some types of phytoplankton.[77,78]

These organisms create calcium carbonate structures by taking calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions from the surrounding water. Calcium ions are generally abundant throughout the oceans, so they are not a limiting factor for growth. Carbonate ion availability, on the other hand, is more variable and scarce and therefore can limit calcification.[79] As mentioned earlier, increasing levels of carbon dioxide cause a decrease in carbonate ions which can slow or stop calcification altogether.[80,81]

Marine organisms produce calcium carbonate structures for various reasons at different stages of their lives. Corals, for example, produce calcium carbonate skeletons not only as an anchor and protective housing, but also to elevate their polyps toward the light and into the flowing currents. This allows them to more easily obtain the light, nutrients and minerals they need for growth.[82] It has also been suggested that some life phases, such as reproductive maturity, are triggered by the ability to calcify. Reproductive maturity in the coral, *Goniastrea aspera*, for example, is reached when the animal grows to a certain size which depends on its ability to calcify.[83] As a result, the inability of many organisms to calcify could affect their fitness and survivorship,[84] which could trigger significant secondary effects throughout marine ecosystems and food webs.[85]

Tropical Corals

A 20 percent increase above current carbon dioxide levels, which could occur within the next two decades, could significantly reduce the ability of corals to build their skeletons and some could become functionally extinct within this same timeframe.[86] According to Dr. Ken Caldeira:

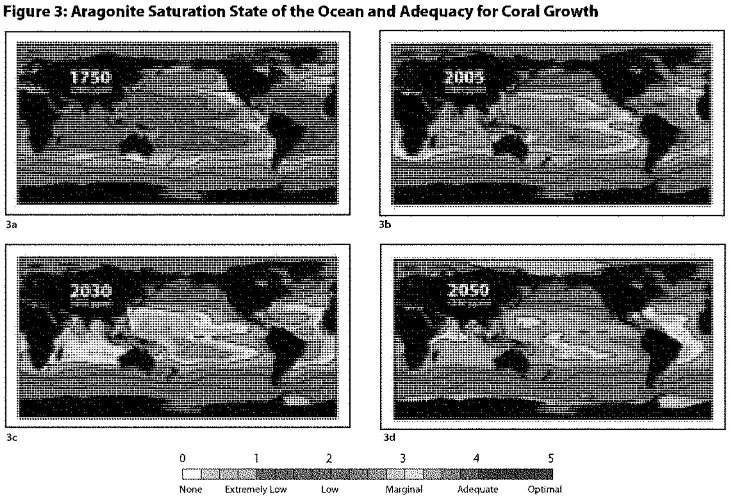
> *"There is at least a reasonable expectation that if current carbon dioxide emission trends continue, corals will not survive this century."*[87]

Experiments on shallow water corals found that concentrations of carbon dioxide of 560 ppm (twice pre-industrial levels) reduced calcification up to 66 percent.[88] On a business-as-usual emissions path, this level of atmospheric carbon dioxide can be expected around the middle of this century.

In real terms this does not just mean corals grow more slowly, but also that they will be less able to overcome typical pressures. Coral reefs are constantly engaging in a battle to grow. Many reef dwellers actually break apart pieces of the corals' skeletons, either to feed upon or to create homes. This process is known as bioerosion. Even the healthiest reefs are constantly trying to grow faster than they are being eroded.[89] In a high carbon dioxide world not only is coral growth slower, it is also less robust, so the skeletons that are produced are weaker.[90] Consequently, coral reefs in more acidic conditions may not be able to overcome the typical amount of destruction and may start to shrink much earlier than otherwise predicted.

Prior to the Industrial Revolution around 98 percent of coral reefs were surrounded by waters with adequate or optimal aragonite saturation states (see Figure 3a), however this has rapidly changed with increasing ocean acidification. At today's carbon dioxide concentrations about 60 percent of coral reefs are surrounded by waters that have less than adequate saturation states (see Figure 3b) and if carbon dioxide concentrations increase to 450 ppm, more than 90 percent of coral reefs will be surrounded by such waters (see Figure 3c). No corals that exist today will be near waters with adequate saturation states if carbon dioxide concentrations are allowed to reach 550 ppm (see Figure 3d).[91]

Figure 3: Aragonite Saturation State of the Ocean and Adequacy for Coral Growth



Source: Adapted from: Cao L., & Caldeira K, (2008) Atmospheric CO2 stabilization and ocean acidification. Geophysical Research Letters, in press, with permission from the authors.

In fact, an atmospheric carbon dioxide concentration of 560 ppm could produce ocean conditions so inhospitable to corals that almost all of the sites where corals grow today will be under-saturated with respect to aragonite causing the corals to dissolve.[92] However, coral calcification could virtually end before we reach 560 ppm because aragonite structures will likely be eroding due to acidification once carbon dioxide concentrations reach 480 ppm (see Table 3).[93] It is likely that under a business-as-usual scenario, only a few tiny areas in the oceans will remain optimal for coral growth by 2040, and by the end of this century no adequate conditions will remain.[94] It is for this reason that scientists have recommended that carbon dioxide concentrations in the atmosphere be stabilized at 350 ppm or below to maintain the coral dominated ecosystems we know today.[95]

Table 3: Coral Reef Devastation has Begun and will Worsen as CO_2 Concentrations Increase[96]

CO_2 CONCENTRATION (ppm)	CONDITION OF CORAL REEFS
380	Reefs will change due to ocean acidification, however they will remain coral dominated.
450	Density and diversity of corals on reefs will decline, including the loss of coral associated fish and invertebrates.
450-500	Reefs will likely become "rapidly eroding rubble banks". This may be seen as the tipping point for corals, beyond which reefs as we know them would be extremely rare, if not non-existent. It would be millions of years before coral reefs returned to their former diversity and density.

The loss of coral reefs would mean a loss of habitat and services for many millions of species. Reefs provide homes, nurseries, feeding grounds and spawning sites to a diversity of life that is virtually unparalleled anywhere else in the world. Unfortunately, due to the threats of ocean acidification and climate change, coral reef communities will become much less common.[97] Without reefs, severe consequences would result for as many as nine million species (including four thousand species of fish) that rely on reefs for shelter and nourishment.[98]

The chemistry of the oceans is changing so quickly it is unlikely that corals will be able to adapt to these new conditions.[99] Already, almost 30 percent of the world's tropical corals have vanished since 1980, predominantly due to ocean warming events.[100] If reefs continue to disappear at this rate, by the middle to end of this century no warm-water corals will remain.[101]

Cold-Water Corals

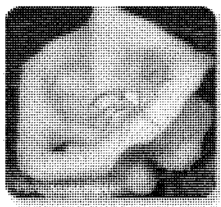
While tropical corals are probably the best known and most widely loved calcifiers in the oceans, they are not the only type of corals that will be hit hard by ocean acidification. Cold-water or deep sea calcifying corals are possibly the most vulnerable marine ecosystems when it comes to anthropogenic carbon dioxide emissions.[102]

Although cold-water corals have been known to exist for more than two hundred years, most of what we know today we have learned only over the last few decades.[103] Cold-water, reef-forming corals have extremely high biodiversity and provide habitat and nursery areas for many deep-sea organisms, including several commercially important fish species.[104] There is still much that we do not know about these organisms and yet with the current rate of ocean acidification we may cause their disappearance before we even fully appreciate their true beauty and importance.[105]

Cold-water corals, sponges and their associated ecosystems have been recognized as important sources of new medical treatments for diseases as varied as cancer, arthritis, Alzheimer's and skin conditions.[106] For example, bamboo corals, a type of sea fan, have been used to synthesize human bone analogs for grafting, and may provide a model for artificial synthesis for collagen.[107]

There are six species of cold-water, reef building, stony corals that create calcium carbonate skeletons out of aragonite.[108] As some of the slowest growing corals on earth, acidification poses a real and immediate threat to these species.[109]

Stony cold-water corals, such as Lophelia, rely on their hard skeletons to support their polyps so that they can capture food and nutrients from the surrounding water.



Deep-sea sponges along **with corals provide important habitat for crabs and many other species.**

Cold-water corals are found in oceans around the world, some at depths of more than five and a half kilometers below the ocean's surface. Cold-water corals live in cold, often deep areas that are generally less favorable to calcification.[110] The maximum depth for the cold-water corals that create aragonite skeletons appears to coincide with the depth of the aragonite saturation horizon.[111] While some species of reef-forming corals are found in the North Pacific, the reefs they create are not, which could be due to the shallow depth of the aragonite saturation horizon in this area.[112] The continued reduction in aragonite saturation state will likely affect cold water corals before shallow water reef builders.[113,114] Cold-water corals probably have such slow growth and calcification rates, at least in part, because of the low aragonite conditions in which they live.[115]

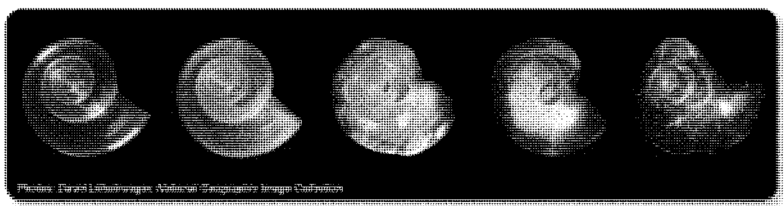
The aragonite saturation state could decrease enough to be too low to support the deepest cold water corals within a decade or less.[116,117] Assuming they react to lowered pH in the same way as shallow-water corals, cold-water corals could be facing significant reduction in growth rates well before 2020.[118] By 2040 all cold-water corals that we currently know to exist could be located in marginal growing conditions or worse,[119] and by the end of the century at least two-thirds of all cold-water corals could be in waters that are corrosive to aragonite.[120] Before the end of this century if we continue emitting carbon dioxide at current levels, it is likely that most of the world's oceans will be "completely uninhabitable" for these corals.[121,122]

Other Critical Calcifiers

It is not only corals that are going to be severely affected, and possibly eliminated, by ocean acidification. For example, mollusks, oysters, crustose coralline algae and huge numbers of planktonic calcifiers create skeletons, shells and tests out of calcium carbonate. Some of these organisms may be tiny, but they play very important roles in the ocean and in marine food webs.[123]

Crustose Coralline Algae

Crustose coralline algae are the primary calcifiers on coral reefs and play an important role in the growth and stabilization of these reefs, make significant contributions to reef sediments and serve as an important food source for sea urchins, parrot fish and several species of mollusks.[124,125] One recent study found an 86 percent reduction in the growth of crustose algae in acidified waters.[126] These algae make their skeletons out of magnesium calcite and are therefore likely to be among the first organisms on coral reefs to be affected by acidification.[127] Decreases in their ability to calcify and grow could severely impact the stability and diversity of coral reefs.



Dissolution of pteropod shell in acidified water

Pteropods

Pteropods, or swimming sea snails, are an integral part of the base of the polar and sub-polar food webs, where they serve as important prey for much of the ecosystem, including whales and top predators.[128] For instance, they account for up to 45 percent of the diet of Alaskan pink salmon.[129] Some preliminary studies suggest that a 10 percent reduction in pteropod production could result in a 20 percent reduction in mature pink salmon body weight.[130] Since their shells are made of aragonite and they are found in the cooler high-latitudes which will be among the first areas to become under-saturated, pteropods may be one of the first calcifiers to be threatened by acidification.[131] In a series of experiments, live pteropods were exposed to the level of aragonite under-saturation expected in the Southern Ocean by 2100. Within 48 hours their shells began to dissolve, despite the animal itself still being alive.[132] Increasing acidity could result in lower calcification rates in pteropods, which could produce a disruption near the base of ocean food webs causing major ecosystem shifts and a decoupling of predator-prey interactions. This could ultimately affect even the largest of top predators in the oceans along with many commercial fisheries.[133]

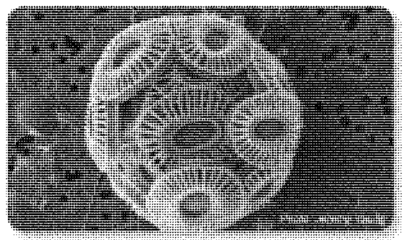
Coccolithophores

Coccolithophores are single-celled algae encased in calcite layers. Studies in some species have found declines in calcification when exposed to acidified waters, while others have not. One species actually increased its rates of calcification in higher carbon dioxide conditions.[134] However, a decrease in the calcification of even some species of coccolithophores could amplify climate change. Coccolithophores create massive algal blooms that have a lighter coloration than the surrounding water due to their chalky tests. This increases the amount of sunlight reflected back to the atmosphere and not absorbed by the oceans. Without these lighter shells to reflect sunlight, the Earth's albedo (reflectivity) could decrease by 0.13 percent.[135] In this way, a reduction in coccolithophore calcification could act to accelerate climate change.

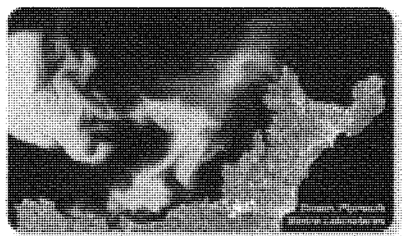
Coccolithophores also produce dimethylsulfide (DMS), which reacts in the atmosphere to stimulate the development of clouds. It is possible that production of DMS by coccolithophores may be disrupted by ocean acidification. This could greatly reduce atmospheric concentrations of DMS, decreasing cloud cover over the oceans that reflects sunlight back to space, and resulting in even further warming of the planet.[136,137] Reductions in DMS could also have wide ranging ecosystem effects, as this compound is an important signal used by many animals such as seabirds,[138] reef fish[139] and seals[140] to navigate toward feeding grounds. Reductions in DMS could cause disruptions in the feeding patterns and ability of these animals to find adequate food.

Planktonic Calcifiers

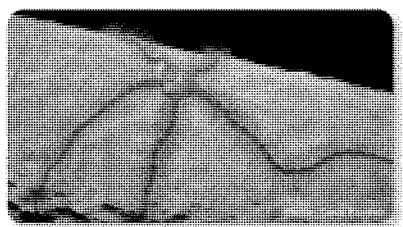
Many species produce calcium carbonate during their larval phases, so increasing ocean acidification may also affect species that are not likely to be affected as adults. The larvae of two sea urchins, for example, showed decreased calcification and decreased developmental rate when exposed to increased carbon dioxide.[141] Other species, such as mussels, oysters, sea stars, brittle stars and crustaceans have shown decreases in larval phase calcification rates in elevated carbon dioxide conditions.[142,143] Disruption of the early development and life history of marine organisms will likely result in reduced fitness and survivorship, with potentially serious consequences for marine ecosystems.



Coccolithophores surround themselves in layers of tiny calcium carbonate plates called tests.



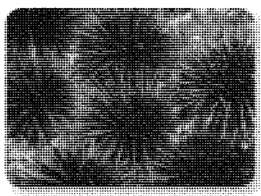
Massive, lightly colored coccolithophore blooms reflect light back to space and have a cooling effect.



Brittle stars have shown decreases in larval phase calcification under high CO_2 conditions.

PHYSIOLOGICAL EFFECTS ON MARINE LIFE

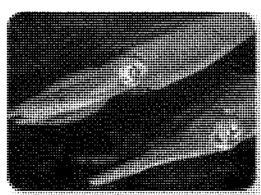
Along with a decrease in the ability to calcify, many other biological and physiological processes will be disrupted by ocean acidification.[144] These impacts could include decreased growth rates,[145] reduced reproduction[146] and increased susceptibility to disease,[147,148] all of which could produce ripple effects through food webs and ecosystems.[149] Fundamental physiological functions, such as respiratory and nervous system functions could also be disrupted by ocean acidification.[150] In addition, ocean acidification may result in behavioral changes in some species.[151]



Purple Sea Urchin
(Heliocidaris erythrogramma)

Effects on Reproduction

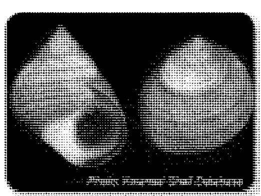
Larvae and juveniles are often most sensitive to increased acidity. For example, the fertilization rate of two species of sea urchin eggs (*Hemicentrotus pulcherrimus* and *Echirometra mathaei*) decreased with increasing ocean acidification. They also had malformed skeletons caused by the increased levels of carbon dioxide.[152] Another species of sea urchin, *Heliocidaris erythrogramma*, had a 25 percent reduction in fertilization success at acidification levels that are expected by the year 2100 on a "business-as-usual" emission path.[153] High levels of carbon dioxide caused a number of other reproductive effects including declines in the sperm motility of Pacific oysters, reduced numbers of hatchlings of a species of sea snail (*Babylonia areolata*), and a lowered number of eggs produced by copepods.[154,155,156] If ocean acidification impacts reproduction, reductions in community size would likely follow.[157]



Squid
(Sepioteuthis sp.)

Effects on Respiration

Ocean acidification in conjunction with climate change may cause oxygen stress in many marine organisms. As the oceans become warmer they will hold less oxygen, and this low oxygen along with the higher levels of carbon dioxide may cause the oxygen transport mechanisms in some species (like hemoglobin in humans) to bind more readily with carbon dioxide than with oxygen, making it difficult for the animals to breathe.[158] Squid are especially sensitive to oxygen stress since they require high levels of oxygen for their energy intensive form of swimming.[159] Inability to swim adequately could have severe consequences for individual fitness and ability to survive. Along with oxygen stress the metabolic functions of many organisms may be altered as they attempt to adapt to new acidity levels around them.[160] While this may not always kill individuals, it could impact growth and reproduction rates, which may result in harmful consequences at the population and species scales.[161]



Common Periwinkle
(Littorina littorea)

Effects on Behavior

With increasing acidity and its consequent changes to the physiological and biological processes in some species, resultant changes in behavior may occur to compensate for depressed functions. For example, a recent study showed that the common periwinkle (*Littorina littorea*) increased its avoidance behavior in response to the presence of crabs in high carbon dioxide conditions.[162] Under normal conditions this species relies on the ability to thicken its calcium carbonate shell when it senses crabs. However, when high acidity levels prevented the periwinkles from thickening their shells, they compensated by increasing their avoidance behavior.[163] While it is difficult to predict the effects such a change in behavior could have, it could plausibly compromise the fitness of the individuals that may now spend more time avoiding predators than feeding or performing other important tasks, and it could also have other unforeseen consequences for predators and ecosystems.

Some organisms will scale back important activities in order to maintain calcification when carbonate is scarce. For example, a type of brittlestar, *Amphiura filiformis*, spent less time ventilating its burrow and feeding in order to focus on regenerating lost arms. The brittlestars in more acidified waters also had smaller arm muscles as they were converting muscle mass into energy.[164] In this case ocean acidification prompted these animals to increase their rates of calcification in order to keep pace with decreasing availability of carbonate ions. But these actions came at a cost, one that may also reduce fitness and survival of the species.

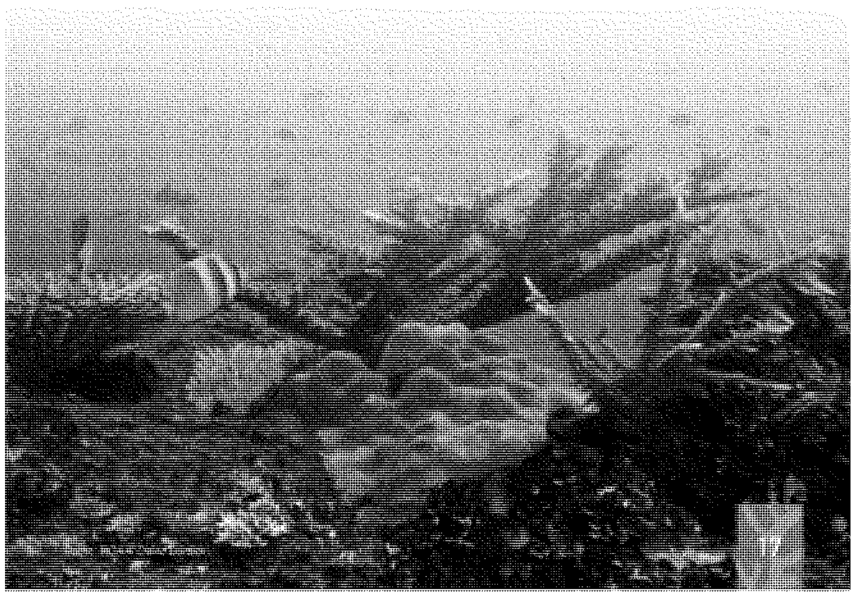
EFFECTS ON ECOSYSTEMS

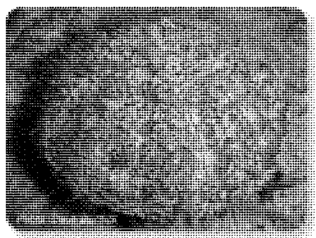
It is currently unclear how acidification will affect community structure and ecosystem functioning; however, as a report of the Royal Society stated:

> *"Without significant action to reduce carbon dioxide emissions into the atmosphere, this may mean that there will be no place in the future oceans for many of the species and ecosystems that we know today."*[165]

The reduction in planktonic calcifiers is likely to result in changes in the species composition within communities, which could have ripple effects throughout food webs.[166] Planktonic calcifiers form an important part of the base of many food webs in the oceans. If these species shift, become less nutritious, or disappear as a result of ocean acidification, the species that rely on them, including whales, turtles, and commercial fish species, could suffer from a lack of adequate prey. This could result in massive changes in the way that organisms interact throughout the oceans.

Even if the adults of some species are more resistant to the effects of ocean acidification, the heightened sensitivity of larvae and young will likely have significant impacts throughout populations and on ecosystem structure.[167] The impacts of ocean acidification will be varied among species, with many being chronically affected by increases in acidity.[168] Even species not directly affected biologically or physiologically are likely to be adversely affected by changes in food webs and ecosystem structure.





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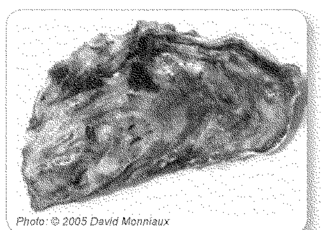
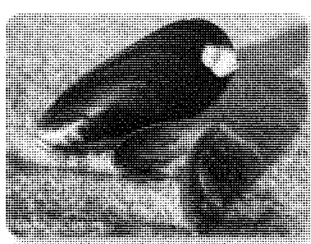


Oyster (Crassostrea gigas)



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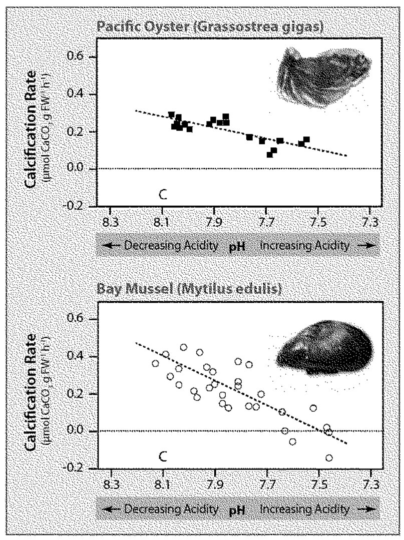
Many calcifiers play important ecosystem roles, such as sea stars that act as keystone predators, balancing community diversity by feeding on species that would otherwise out-compete other species in the community. Other examples include urchins which are important grazers and oysters and mussels which are vital ecosystem engineers since they create or modify the habitats they live in.

With increasing levels of carbon dioxide the calcification rates of Pacific oysters (*Crassostrea gigas*) and bay mussels (*Mytilus edulis*) decreased linearly (see Figure 4).[169] If atmospheric concentrations of carbon dioxide reach 740 ppm, which could happen before 2100, the calcification rates in these species are expected to decline 10 and 25 percent, respectively.[170] The loss of oysters and mussels could be quite severe since they are vitally important to the ecosystems they live in and make up significant proportions of global aquaculture production.[171]

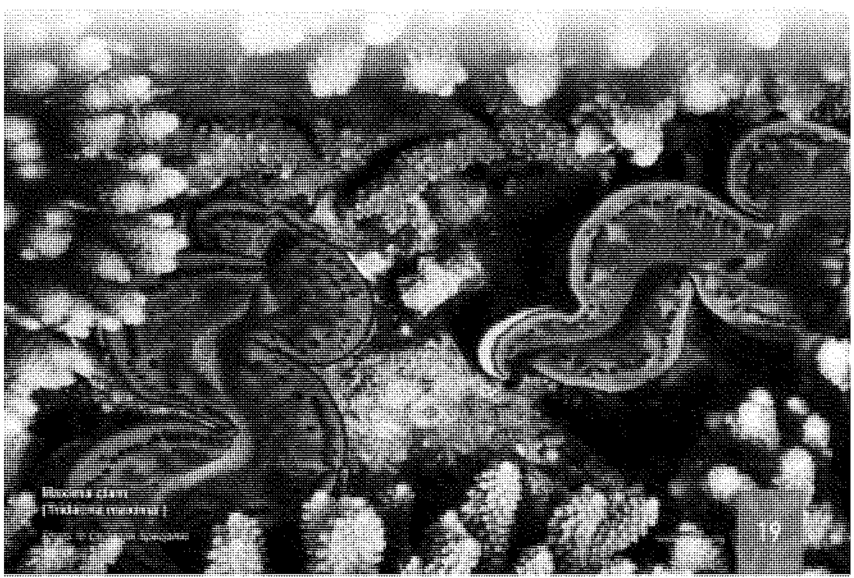
Figure 4: Increasing Acidity Decreases Calcification Rates



Source: Adapted from Gazeau, Frederic et al. (2007) Impact of Elevated CO2 on Shellfish Calcification. Geophysical Research Letters, 34, with changes made by permission from author.

Oysters provide important habitat for other benthic organisms and help to govern the flow of nutrients and energy in coastal ecosystems.[172] They are filter feeders, which means they filter their food out of the water they live in. This provides an added service by filtering out excess phytoplankton, along with chemicals and other pollutants that could otherwise cause harm in the surrounding water. If acidification results in a reduction in these important species, waterways can rapidly become polluted and unsafe and there could be significant changes in coastal biodiversity and ecosystem functioning.

Marine mussels provide habitat for smaller invertebrates, enhance sediment stability and serve as an important food source for many species, including sea birds and humans.[173] Increased acidification is expected to reduce mussel calcification,[174] reduce metabolic activity,[175] and growth rates,[176] and even suppress immune function.[177] If these species and others like them that provide important ecosystem services are severely affected by rising acidity levels, the loss of the benefits these species provide could be catastrophic to the wildlife and humans alike that depend upon them.



IMPACTS OF OCEAN ACIDIFICATION ON HUMANS

Not only do the oceans govern some of the most important geochemical cycles that make the planet inhabitable, they also serve as an important provider of food, livelihood, recreation and rejuvenation for billions of people. Unfortunately, ocean acidification could completely change the oceans as we know them today. Less diverse and vibrant oceans could in various ways negatively impact life as we know it.

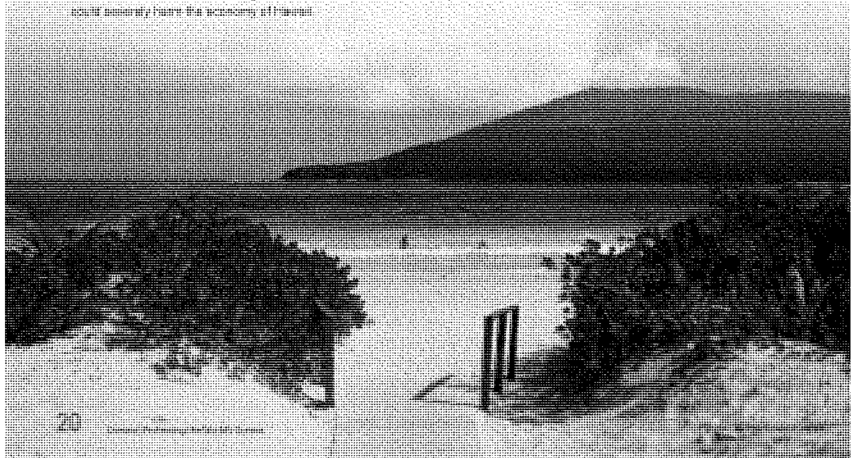
For example, more than 100 million people are economically dependent upon corals reefs, with many more reliant on reefs for protection, resources and pleasure.[178] The disappearance of coral reefs could result in the loss of many billions of dollars every year since the reefs provide some 30 billion dollars annually to the global economy through coastal protection, tourism, fishing and other goods and services.[179] Many subsistence fishing communities rely on the fish found in reef ecosystems for vital proteins,[180] the loss of which could result in serious health consequences and food security concerns for these communities.

Coastal Protection

Coastal communities across the globe depend on the protection of reefs from storm surges, tsunamis and coastal erosion.[181] In the December 2004 tsunami, coastlines that had less robust coral reefs experienced greater loss of life and damage to infrastructure than those with well-developed reefs.[182,183] A scientific model developed by researchers at Princeton University showed that coasts with healthy reefs were at least twice as protected from tsunamis as coasts with dead reefs.[184] The loss of coral reefs due to ocean acidification could result in increased threats to the health, safety and well-being of many coastal communities.

Tourism

Coastal communities will also suffer significant economic losses from the degradation of coral reefs. As reefs decline and their associated ecosystems becoma less diverse, many tourists will find new, less affected areas in which to spend their money. This will likely mean major losses to coastal communities that are dependent upon tourism for their incomes. The coastal reefs in Hawaii alone are estimated to generate 364 million dollars annually in net business revenues.[illegible] The loss of this income could severely harm the economy of Hawaii.



Fisheries

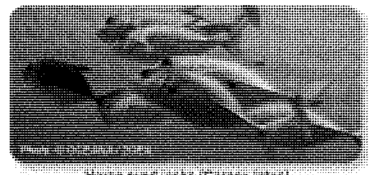
In 2004, about 85.5 million metric tons of marine fish worth 76.4 billion dollars were caught globally.[186] While it is difficult to estimate the impact that increasing acidity will have on fish and shellfish populations, it is likely that many will be adversely affected.

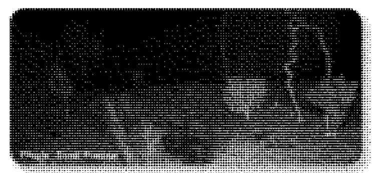
As tropical coral reefs begin to disappear due to acidification, many commercially important fish species that rely upon these reefs for critical habitat could also be in danger since many species depend on coral reefs for shelter and food.[187] There have already been some examples of fish that have disappeared from reefs during bleaching events. In 1998, after a bleaching event on the Okinawan reefs, the orange-spotted filefish (*Oxymonacanthus longirostris*) was unable to survive without the living coral.[188] While this filefish was not particularly important commercially it provides an example of what could happen to important fish species as acidification worsens.

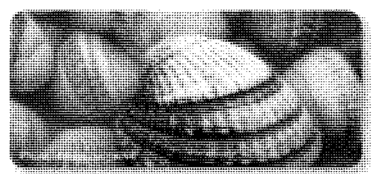
Deep-water reefs, like their shallow-water counterparts, are biodiversity hotspots providing important habitat to many species, including many commercially important species of fish like grouper.[189,190] More than half of the total U.S. fishery landings (an over 4 billion dollar per year industry) is derived from Alaskan waters.[191] Many of the commercially important species in this region rely upon the cold-water corals off the Alaskan Aleutian Islands.[192] These corals are likely to be severely affected and may even begin to dissolve before the end of this century, a situation that would undoubtedly harm their dependant fish populations and fisheries.[193] The cold-water coral reefs of the Atlantic coast of the United States also form a veritable oasis of corals, sponges, crabs, lobsters, sea stars and fish.

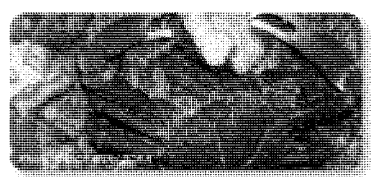
Many of the world's commercial fisheries are likely to be threatened by ocean acidification either directly, by biological and physiological changes due to increased acidity, or indirectly through changes in habitat and prey availability. Many of the areas where acidification is predicted to be most severe within the coming century are highly productive and support some of the world's most important commercial fisheries.[194]

The effects of ocean acidification on mollusks (e.g. clams, oysters and mussels) and crustaceans (e.g. lobsters, crabs, crayfish and shrimp) are likely to present great losses both economically and to ecosystem services. Shellfish farming has increased at around 8 percent per year over the last 30 years and in 2004 the market was worth over 9.8 billion dollars.[195] Crustaceans will be particularly vulnerable to ocean acidification as they require carbonate ions to harden their new shells after molting.[196] The calcification rates of both edible bay mussels (*Mytilus edulis*) and Pacific oysters (*Crassostrea gigas*) have been found to decrease with increasing acidity.[197] In 2005, U.S. fishermen captured over 330 thousand metric tons of crustaceans and over 877 thousand metric tons of mollusks.[198] The 2005 U.S. revenue from shellfish was close to 17 million dollars.[199] Decreases in these populations due to ocean acidification could have massive economic repercussions.


Horse-eyed jacks (Caranx latus)


Cold-Water Coral Garden

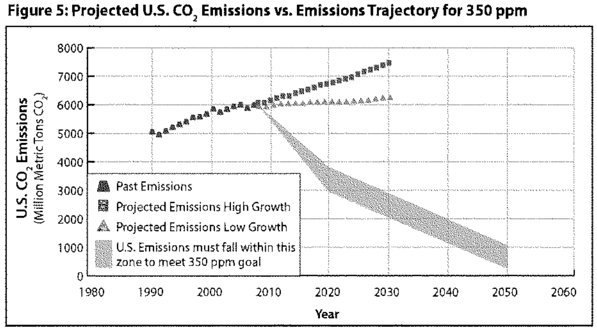

Common Cockle (Cerastoderma edule)


Channel clinging crab (Mithrax spinosissimus)

REACHING THE LIMITS

"If there's no action before 2012, that's too late. What we do in the next two to three years will determine our future. This is the defining moment." Dr. Rajendra Pachauri, scientist, economist and Chair of the IPCC. (2007)

Figure 5: Projected U.S. CO_2 Emissions vs. Emissions Trajectory for 350 ppm



Source: Oceana, based on EIA (2008) and IPCC (2007)

Current atmospheric carbon dioxide concentrations are already above safe levels and as a result we are seeing significant changes taking place throughout the oceans, from decreasing growth rates of corals on the Great Barrier Reef to massive coral bleaching events across the tropics. Coral reefs are acutely vulnerable to ocean acidification and climate change. They provide important habitat to a quarter of all marine species and are significant to the lives and livelihoods of many humans. Allowing coral reefs to disappear would result in intolerable changes throughout the oceans as well as major disruptions in the lives of hundreds of millions of people. What happens to coral reefs will foreshadow other catastrophic changes that are likely to take place around the world due to ocean acidification and climate change.

To prevent the loss of coral reefs, and ultimately avert a climate crisis, we must reduce atmospheric carbon dioxide levels to below 350 ppm.[200] Unfortunately, carbon dioxide in the atmosphere has already exceeded this safe level, having reached 385 ppm and climbing.[201] Besides being too high to protect the planet's coral reefs, this current level is also much higher than it has been at any time over the course of human civilization.[202] In fact, as far back as scientists have currently determined (800,000 years), the natural range has not exceeded 300 ppm.[203]

If we stay on our current emissions trajectory we will far exceed the 350 ppm goal and we will not prevent the extinction of the corals. In today's society, carbon dioxide emissions are directly tied to our need for energy, and that need is growing. Recent figures released by the U.S. Energy and Information Administration (EIA) indicate that staying on the current business-as-usual path, where current laws and policies remain unchanged will result in world energy consumption in 2030 increasing by 50 percent above 2005 levels.[204] This will result in a steady increase in anthropogenic carbon dioxide emissions, with 51 percent more carbon dioxide in the atmosphere by 2030 than there was in 2005, resulting in an atmospheric carbon dioxide concentration of over 570 ppm.[205]

With carbon dioxide levels this high, ocean acidification will be extremely severe within the next few decades. We have already entered the danger zone and reefs are already starting to decline. It is unlikely that reefs will be able to sustain themselves for many decades at the currently high carbon dioxide conditions. However, if we continue along our current emissions path reefs could be pushed passed a tipping point, likely to occur around 450 ppm, at which point reefs as we know them would be extremely rare, if not non-existent. Once we surpass this tipping point coral reefs will shrink rapidly,[206] at least half of coral-associated wildlife will become rare or extinct, and the services reefs provide to millions of people will grind to a halt. Shortly after that, coral reef ecosystems will likely be reduced to crumbling frameworks with few calcareous corals remaining.[207] Since coral reefs take decades and even centuries to form, once such damage is done, the impacts will be irreversible for generations.

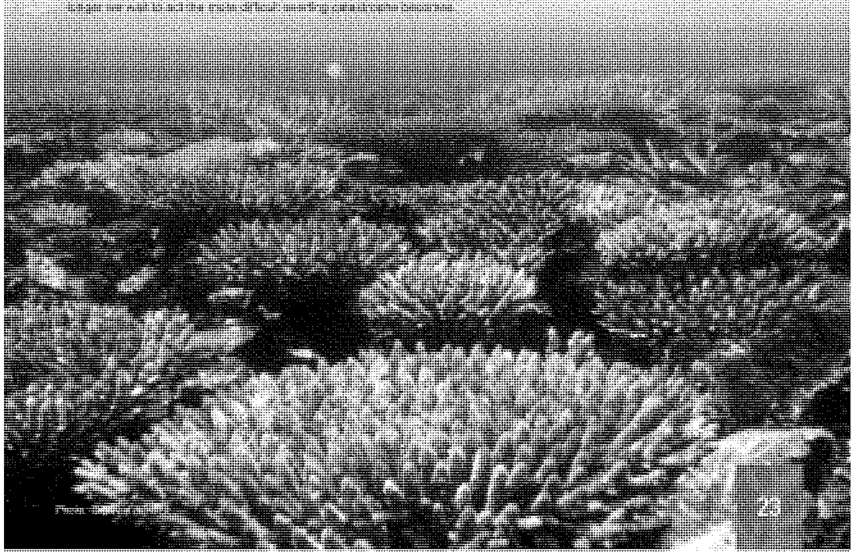
However, this does not have to be the future of the oceans. By making the correct choices we can save coral reefs, and the wildlife and humans that depend upon them, and ultimately the Earth as we currently know it, from ocean acidification and climate change. By choosing a low carbon future, atmospheric carbon dioxide concentrations can be stabilized at safe levels below 350 ppm.[209] At these levels changes will still take place across reef ecosystems; however, they will remain coral dominated and continue to create calcium carbonate.[209]

To save coral reefs from ocean acidification we must stabilize atmospheric carbon dioxide at or below 350 ppm. Scientists looking at other vulnerable ecosystems have identified similar limits beyond which positive feedback loops could prevent full recovery. By preventing ocean acidification and stabilizing the climate at safe levels we will also be preventing other climate-related catastrophes.

Since we can not expect to simply halt all emissions immediately we must expect there will be some overshoot of the ultimate 350 ppm stabilization goal.[210] However, remaining in the current danger zone we are in for longer than a couple of decades will result in intolerable changes taking place. This means that it is vital to get on the right trajectory within the next few years and to make sure that carbon emissions peak and begin to decline in less than a decade.

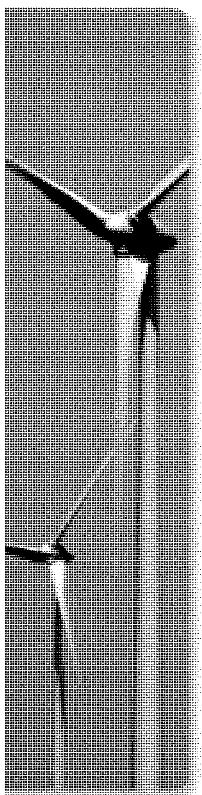
The Intergovernmental Panel on Climate Change (IPCC) concluded that in order to stabilize carbon dioxide in the atmosphere at 350 ppm by 2050 global carbon dioxide emissions would need to be cut by 85 percent below 2000 levels,[211] and in order to achieve this, Annex I countries (industrialized countries and countries with economies in transition, such as the Russian Federation) would need to reduce their carbon emissions by 25 to 40 percent below 1990 levels by 2020 and 80 to 95 percent by 2050. (see Figure 5). These are not easy goals to achieve and consequently, the United States and the international community must make immediate serious commitments to meet them.

Our ability to set and meet short-term goals over the coming years will determine how successful we will be at safely stabilizing the climate. In order to realize the greatly needed cuts of 25 to 40 percent by 2020 countries will need to act immediately. The longer we wait to act the more difficult averting catastrophe becomes.



OCEAN ACIDIFICATION

SOLUTIONS



Many of the foremost scientific thinkers on this issue have demonstrated that it is possible to prevent runaway climate change, though there is certainly no silver bullet and doing so will not be easy. James Hanson of NASA has argued that the critical 350 ppm target needed to protect corals is achievable. It should come as no surprise that this will require a concerted effort by individuals, companies and institutions throughout the world. In their study Pacala and Socolow propose a "wedge-based" approach involving some combination of fifteen viable solutions and concluded:

> *"Humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century."*[212]

While our carbon dioxide reductions need to be significant and timely, there are many, varied options ranging from conservation and increasing energy efficiencies to advanced reduction technologies, the use of alternative energy options and renewable fuels. The diverse array of solutions available require our shifting to a less carbon dependent energy economy which means building an infrastructure for energy alternatives such as solar, wind, and hydrogen, and scaling back or even stopping the use of coal, unless carbon capture is effectively employed. They also include increasing energy efficiency efforts in cars, trucks, trains, planes and ships, as well as in homes, office buildings, power generation and industrial sectors; and cutting down on deforestation while also planting more forest land to help "draw down" carbon dioxide levels.

In the meantime, when the use of carbon fuels is unavoidable, technologies such as end of the pipe scrubbers and carbon capture devices would play an important role in reducing the amount of carbon dioxide released to the atmosphere. Placing a cost on carbon dioxide emissions would allow these alternatives to enter the market and be truly competitive.[213]

To prevent future ocean acidification we need to switch from a trajectory of rapidly increasing carbon dioxide emissions to one in which net emissions have been reduced to zero.[214] However, some alternative measures have been suggested to address ocean acidification, such as adding chemicals to ocean waters to lower their acidity. But these are at best short-term, local stop-gap measures, which will not prevent ocean acidification on a global scale.[215]

Furthermore, such geo-engineering solutions could wreak havoc on already fragile ecosystems causing a whole host of other unintended and unforeseen consequences.

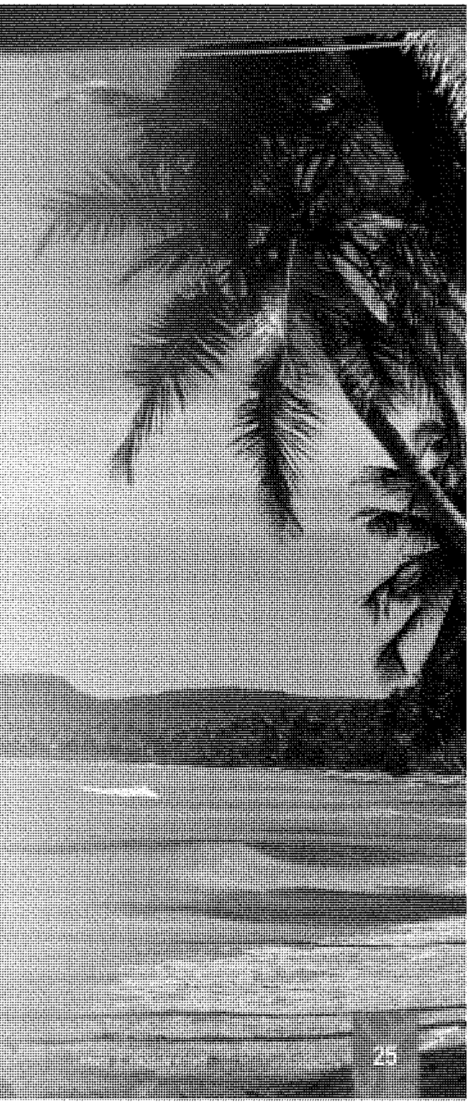
Geo-engineering solutions have also been proposed to address carbon dioxide levels in the atmosphere. These include iron fertilization and deep ocean sequestration, both of which are likely to exacerbate ocean acidification.[216,217,218] These approaches should be viewed with caution and only employed if and when they are proven effective and their impacts on the oceans are understood and known to be negligible.

Unfortunately, the acidity of the oceans has already increased by 30 percent due to anthropogenic carbon dioxide released since the Industrial Revolution. There will be some lag time between the time when humen emissions are reduced to appropriate levels and the point at which level of acidity of the ocean decreases. Therefore, it is vitally important that we cut emissions as soon as possible so that ocean conditions do not become unbearable for many marine animals. We must also do all we can to reduce other pressures on ocean ecosystems to ensure their resilience and give them every possible chance to survive. Threats such as overfishing and destructive fishing techniques, pollution and climate change all act in concert to weaken ocean ecosystems and make survival even more tenuous. By stopping these and other threats we can provide the ocean with a fighting chance to survive the looming dangers of ocean acidification.

Essentially, every decision we make from here on out must be influenced by the need to make these changes. Debate continues about whether and how market approaches will work, and how to place a price on carbon, but one thing is clear: If we want to save our coral reefs and shellfish fisheries, the ecosystems that depend on them and the values that we derive from them as humans, we need to start now. With a 25 to 40 percent reduction needed by the industrialized countries of the world by 2020, there is no time to waste.

At the same time, ocean acidification should not be seen as a reason to throw up our hands and cry that saving the oceans is hopeless; it is not. Rather we should realize the seriousness of this threat and take immediate appropriate actions to move society away from our dependence on carbon-based fossil fuels to a low carbon future in which coral reefs and other marine organisms will not be threatened by acidic waters.

RECOMMENDATIONS



Adopt a Policy of Stabilizing Atmospheric Carbon Dioxide at 350 ppm

Governments must commit to stabilizing the levels of carbon dioxide in the atmosphere at 350 ppm or below. To achieve this, serious actions need to be taken within the next few years to set society on a path to zero net carbon emissions within the coming decades.

Promote Energy Efficiency and Low Carbon Fuels

Energy should be conserved at every opportunity, including through improved fuel efficiency of cars, trucks, airplanes and ships, provision of cleaner fuels, investment in efficient mass transit, and individual, institutional and corporate actions to reduce energy use.

Shift to Alternative Energy Sources

New or expanded coal-fired power plants and other expanded uses of coal should be prohibited until global warming pollution can be trapped and safely stored. In their place, governments and the private sector should implement programs to stimulate the development and use of renewable energy options such as wind and solar, and invest in upgrading the national power transmission grid so that energy produced from alternative sources can be cost-effectively moved to markets. Governments should immediately eliminate any and all subsidies that encourage the use of fossil fuels. Fossil fuels currently in the ground in sensitive ecosystems such as the Arctic and offshore should stay in the ground.

Regulate Carbon Releases

Governments should immediately begin regulating carbon releases using a system that internalizes emissions costs and prevents continued releases that harm the oceans. Under-regulated sources of carbon dioxide emissions, such as those from shipping and aircraft should be included in a post-Kyoto Agreement and regulated by the appropriate international bodies, such as the International Maritime Organization and the International Civil Aviation Organization.

Preserve Natural Resilience

The natural resilience of marine ecosystems should be maintained by curtailing other human caused threats, such as overfishing and pollution. Ocean acidification and climate change are not isolated threats, but act in concert with other impacts on ecosystems and species. Ocean ecosystems will have the best chance of surviving the pressures of ocean acidification if they are not simultaneously struggling to survive in the face of other threats.

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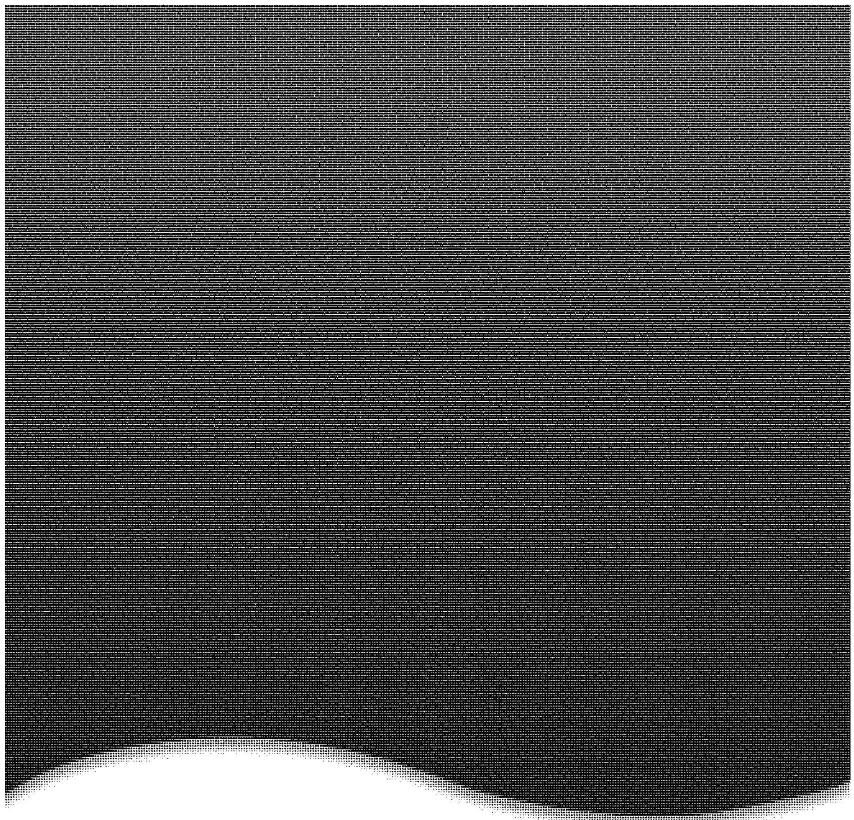

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Environment and Public Works Committee Hearing
May **11,2010**
Follow-Up Questions for Written Submission

Questions for Waterston

Questions from:

Senator Sheldon Whitehouse
1. What do you believe is the most pressing research question related to either of the threats to ocean health that we discussed; ocean acidification, or toxics in the marine environment?

A: Scientists have answered the question of what is occurring, we know that ocean acidification is real and is happening now, we also know that the best and only effective way to stop it is by reducing carbon dioxide emissions. However, scientists are still trying to better understand how organisms and ecosystems will respond to changing ocean chemistry; this is one of the most pressing questions and issues for research.

Senator James M. Inhofe
1. Calcium carbonate shells and corals have been shown to dissolve more readily in strongly alkaline seawater than neutral water with a pH of7.0. Ocean pH is moving slightly towards neutralization, not acidification. Is it your view that calcium carbonate shells and skeletons will readily dissolve or weaken at a pH between 7 and 8?

A: The ocean is acidifying. The pH scale is a continuum and a shift towards the lower end of the scale denotes a solution is becoming more acidic, so as the pH of the ocean falls it is becoming more acidic. The ocean will not turn to acid; however they are already 30 percent more acidic than they were at the beginning of the industrial revolution. For wildlife that are adapted to higher pH levels, this change can be problematic. Experiments on various species, including corals and pteropods, have found shell and skeleton dissolution at pH levels between 7 and 8. Field studies have also observed decreased skeletal growth in some corals across the Great Barrier Reef, Thailand and the Caribbean, most likely resulting from acidification and increased ocean temperatures.

2. In any of the research/lab studies that you cited, did they use hydrochloric acid to change pH instead of C02?

A: The use of hydrochloric acid is a well accepted laboratory technique that simulates the changes in seawater carbonate chemistry induced by carbon dioxide uptake. No systematic difference is found in the responses of calcifying organisms exposed to seawater acidified by hydrochloric acid or through carbon dioxide aeration.

3. C02 is only the 7th most prevalent substance that can impact the oceans acid-base balance. Would it make sense to look at other substances that can alter the oceans acid-base balance?

A: There are substances other than carbon dioxide that cause acidification of the oceans, however they are currently at much lower concentrations in the atmosphere and not entering the oceans at the current rate carbon dioxide is. Close to 11 billion metric tons of carbon dioxide enter the oceans each year, while less than 9 million metric tons of nitrogen oxides are released globally each year. Emissions of these other substances, like sulfur and nitrogen oxides, are regulated to some extent and should continue to be regulated as they also contribute to premature deaths and acid rain, carbon dioxide emissions are however, unregulated and should be regulated. It is important to keep these other substances in mind as they can contribute to ocean acidification; however carbon dioxide, the main driver, should be the focus of efforts to curb increasing ocean acidity.

4. During the Cambrian Era, the C02 concentration was around 7500 parts per million. During the Jurassic Era, the C02 concentration was around 6500 parts per million. For most of the past 750 million years, the C02 concentration has been at least 1000 parts per million. But during this time, calcite corals and aragonite corals have thrived and the ocean never became acidic. Does it make sense to assume that the oceans will become acidic when the C02 concentration today is less than 400 parts per million?

A: The average surface ocean pH has remained close to 8.2 for millions of years. Species today are adapted to this level and are unlikely to be able to adapt to the rapid changes taking place in today's oceans. The present rise in atmospheric carbon dioxide is around 100 times great than rates experienced over most of geologic history. The rate of change is important as geological buffering is a very slow process and does not occur quickly enough to maintain ocean pH when huge influxes of carbon dioxide occur very rapidly. There is no evidence in the geologic record of sustained rates of change as great or greater than those of today, other than at times of the great mass extinctions. For example, 65 million years ago, during the Cretaceous extinction (when the dinosaurs perished) coral reefs disappeared, some corals were able to survive, but reefs did not recover for millions of years – in human terms (decades to centuries) these important systems were extinct.

5. Have you looked at the impact that the alkaline rocks that run underneath the oceans have on pH?

A: Dissolution of calcium carbonate minerals underwater and in sediments increases the alkalinity of seawater, offsetting decreasing pH. However, such a large amount of carbon dioxide is entering the oceans so rapidly from human activity that it would take thousands to tens of thousands of years to counteract. The natural process of dissolution is not fast enough to counteract the carbon dioxide currently entering the oceans hence their chemistry is changing.

6. With the numerous errors found in the most recent UN IPCC report, should we look at other resources to inform us on economy changing issues such as capping C02 emissions?

A: The reports produced by the Intergovernmental Panel on Climate Change involve thousands of scientists and quite unsurprisingly have made some mistakes. When these have been found they have been corrected. Despite these errors, the fundamentals of the IPCC reports and its conclusions - that the climate is warming mainly due to human activities, which will result in changes across the planet - are sound and continue to be supported by the scientific community.

Senator WHITEHOUSE. Thank you very much, Mr. Waterston.

Our final witness on the panel is John T. Everett. Dr. Everett is the President of Ocean Associates, a company that provides consulting services on oceans and fisheries policy and sustainability, ecosystem and fisheries relationships, and global climate change and its impacts at the global and local level on fisheries and oceans.

He worked 31 years in 13 positions in NOAA, National Marines Fisheries Service, as a researcher, analyst and manager in fisheries and oceans programs, until recently holding the post of Chief of the NOAA Fisheries Division of Research. He has chaired or co-chaired several scientific analyses by the Intergovernmental Panel on Climate Change and has served on the National Academy of Sciences Panel on Ecosystem Indicators of Climate Change. Since its inception in 1999, Dr. Everett has also been Manager and Chief Editor of the U.N. Atlas of the Oceans.

We are delighted to have him here.

Dr. Everett.

STATEMENT OF JOHN T. EVERETT, PRESIDENT, OCEAN ASSOCIATES, INC.

Mr. EVERETT. Mr. Chairman and members of the Committee, thank you for inviting me. My views are mine alone. My approach is a product of my education and work for NOAA and IPCC that you have already reviewed.

I am also president of Ocean Associates, as you said, which is an oceans and fisheries consulting firm with 70 people in six States. I have a Web site, www.ClimateChangeFacts.info to share information.

The Gulf oil spill and President's Cancer Panel point out the immediate threats to our sea life and ourselves from oil or chemicals. But the oil damage will eventually heal. Better procedures will be employed, and this oil will be recycled and assimilated.

The flow of chemical materials into our waters is another matter. There are too many insidious contaminants causing genetic harm and poisoning our marine birds, turtles and mammals and seafood. EPA's focus should be to stop this flow and clean it up.

I respect the view of Mr. Waterston. He is not alone. However, I have some different views. If CO_2 increases beyond this century, there might be changes in the mix of marine plants and animals, but it will mostly leave humans without impact. In contrast, contaminants create only losers.

My statement on acidification focuses on marine life's ability to make shells and whether there will be less to eat at the base of the food chain. These concerns are from scientists who believe the IPCC scenarios of the early 1990s will dangerously increase acidification. Other scientists believe these scenarios are obsolete since the rising fuel cost is slowing usage, CO_2 shows no acceleration, and the Earth's ability to absorb it has not diminished.

With all the hype, many people are afraid of the acid in the oceans. Oceans are not acidic except in natural cases such as volcanic events, in some parts of estuaries in late summer and in very deep waters. We are talking about an increase in acidity of two times. In contrast, a puddle of rainwater or handful of snow is over 100 times more acidic than the oceans.

Many lakes are 10 or more times acidic, and 70 percent of Maine's are actually acidic, yet they teem with many of the kinds of life that are in the oceans. Lake research shows that acidity is unrelated to productivity. These are important clues.

Americans will not dissolve when they jump in the water, just as when they jump in a lake in Maine. And seafood is safe to eat. It may be hard to believe, but many people are really concerned about the acid.

Four factors shape my views. First, research shows pluses and minuses among shelled plants and animals. Ries found that crabs, shrimp and lobsters build more shell with elevated CO_2. Some other shelled animals and algae increase shell growth at moderate levels, but slower at higher levels, while hard clams and corals slowed shell formation at very high levels. Soft clams and oysters slowed much sooner, while mussels did not change at any level.

None of the shells dissolved until the highest levels, but grew slower at very high CO_2. Miller found shells of other oyster species increased along with CO_2, and shells of other animals did not dissolve. Iglesias-Rodriguez found major growth benefits to an important shelled algae, essentially a plant.

Second, the Earth has been this route before. The oceans have been far warmer, colder and more acidic than is projected. Marine life endured CO_2 many times higher and temperatures that put tropical plants at the poles or covered our land by thick ice. The memory of these events is in the genes of all surviving species.

Virtually all ecological niches have always been filled. If there were no corals, clams, oysters or shelled plankton when CO_2 was double or triple, I would be concerned. The opposite is true. If we examine mass extinctions, we find they were not caused by double or triple CO_2, if it had anything to with extinctions at all.

Third, IPCC found no observational evidence of ocean changes from acidification. And well designed research suggests that organisms' responses will be variable and complex. How individual organisms will respond is not known.

Last, contrary to all the information, natural oceanic changes are greater and faster than those projected. Warming, cooling and pH changes are a fact of life, whether over a few years in an El Niño, over decades as in the Pacific oscillation, or over a few hours in a burst of upwelling or a storm that brings cold acidic rainwater to an estuary or shallow coral reef.

Despite severe and rapid changes, the biology adapts rapidly. The .01 change in pH since 1750 and the 1 degree Fahrenheit rise since 1860 are but noise in this rapidly changing system. Whether changes occur over days or millennia, some species flourish while others diminish.

I see no overall acidification harm to marine fisheries, mammals, turtles or other animals. More research is needed to determine how the response of individual organisms will reverberate throughout food webs and ecosystems. The real and immediate threat lies in the chemicals that flow down our rivers.

Second, we need to improve oil drilling and transport so disaster cannot happen. It may be as simple as increasing redundancy of valves, hulls, navigation traffic controllers or captains. As my daughter said, "Dad, ocean acidification is not a problem for the oysters. They will all be dead from the oil."

Thank you.

[The prepared statement of Mr. Everett follows:]

Statement of

DR. JOHN T. EVERETT

Joint Hearing on
"EPA's Role in Protecting Ocean Health"
before the
Subcommittees on **Oversight** and on **Water and Wildlife** of the
Committee on Environment and Public Works

United States Senate
May 11, 2010

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

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

I have worked with EPA on various climate change issues over the years, particularly sea level rise and ocean dumping, including serving as Co-Chair of the interagency NOAA, EPA and Coast Guard Committee on ocean dumping. My company is on the team holding a 5-year EPA science and technology support contract for ocean and coastal issues.

1 http://www.OceanAssoc.com
2 http://www.ClimateChangeFacts.Info

This statement provides my analysis of the effects of ocean acidification on our living resources and our economy. It lightly touches on the other topics of the Hearing: the oil spill and the EPA role in ocean health. All opinions are mine alone.

The Gulf oil spill and the new President's Cancer Panel report remind me of the importance of dealing with the here and now threats to our sea-life and to ourselves. But even the oil damage will eventually heal, better procedures will be employed, and this oil will be recycled and assimilated. The flow of chemical materials into our waters is another matter. There are too many insidious contaminants entering our estuaries, causing genetic harm and poisoning our birds, turtles, and seafood.

EPA's focus should be on stopping this flow and restoring the ecology.

CO2 is not a pollutant or contaminant. If it increases beyond this century, there may well be changes in the makeup of plants and animals in the sea. But it will mostly leave us humans without impact. In contrast, contaminants create only losers and directly impact us as well. There are no winners.

I. THE CONCERNS

There are several concerns about CO2 entering the oceans and causing its pH to become lower. Their discussion in the press and among policy officials has led to the inclusion of acidification in this hearing. These concerns are:

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

The concerns are based on the work of respected scientists who have shared the above beliefs or authored papers that argue the above points. They believe increased atmospheric CO2 will increase the acidification of the oceans. The basis is largely a set of emission scenarios developed by IPCC in the early 1990s in an attempt to reign in the mass confusion about the future trajectory of CO2 emissions. With this standard set of scenarios, climate modelers could then have a standard set of inputs in terms of what was broadly considered a primary determinant of climate – the proportion of CO2 in the atmosphere. This proportion is based on new contributions after deducting removals by the Earth system and assumes a decreasing removal ability as CO2 increases. For the first time, modelers around the world could compare results while impact assessment scientists and policy makers could look at points on which most models agreed. Standardization of scenarios allowed modelers to identify errors or alternative ways to predict or handle parameters, such as cloud cover. One of the scenarios became heavily used and is identified as IS92 – Business as Usual. Nearly 20 years ago, it was a reasonable approach and in the middle range of alternative scenarios. It underpins much of the research findings I will present today.

There are other respected scientists who believe that the Business as Usual scenario has been overtaken by events. The cost of fossil fuels is rising, reflecting increasing scarcity and contributing to a slower CO2 growth in the atmosphere and a lack of acceleration. New science shows the Earth's ability to absorb the same proportion of new CO2 each year has not been diminished, removing a key assumption that underpins "acceleration". Importantly, oceans are alkaline - not acidic, so use of the term "acidification" unnecessarily promotes fear. If all the CO2 in the air were put into the ocean, the oceans would still be alkaline. With all this talk of acidification, we need to reassure bathers that their feet will not dissolve when they step into the ocean. Ocean water at the surface generally has a pH over 8 and neutral is 7.0 (pure water) while a puddle of rain water (pH 5.6) is 100 times more acidic after having picked up CO2 in its fall through the air. Many of our recreation lakes and drinking water reservoirs (such as most of those in some states; (e. g., 70% in Maine) have pH values so low that they are truly acidic (pH <7). There is nothing wrong with the fish and the water in these lakes. It is often just that the lakes have less limestone and more granite on their bottoms. Technically, we should say the oceans could become less alkaline, rather than more acidic. In any case, unlike rainwater, the oceans will never become acidic.

Whether or not laboratory studies provide the answers we think are reasonable, we need to look more broadly. The Russian academicians (of their Academy of Sciences) I worked with in IPCC taught me to look at how the Earth responded in past ages when conditions were like those projected, and to get up from the computer and look around. They gravely distrusted computer models. So, what can we learn from the past and what do we see around us? The oceans and coastal zones have been far warmer and colder and much more acidic than is projected. Marine life has been in the oceans nearly since when they were formed. During the millennia life endured and responded to CO2 many times higher than present, and to temperatures that put tropical plants at the poles or covered our land by ice a mile thick. The memory of these events is built into the genetic plasticity of the species on this planet. Impacts will be determined by this plasticity from past experiences. If we open our eyes, we see that nearly all of our ponds and lakes are often more acidic than the oceans (pH 8.1), yet they team with most of the kinds of life that are in the oceans. This is important.

We should also consider that CO2 is required for all plant life and it is in short supply, to the point it limits growth rates for most plants. This is yet another clue regarding impacts.

II. THE PHYSICS

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

As a research manager much of my life, I have a healthy skepticism of things that underpin important decisions. Whether it is a column of numbers that will tie up a fishing fleet because of an addition error or a wiring harness on a manned lunar rocket that doesn't quite fit, I have learned to pause and check it out. There are some things at the bottom of the CO2 pyramid that make it seem wobbly and in need of a check.

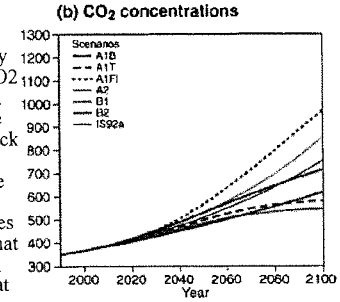
Physics tells us that increasing atmospheric CO2 lowers oceanic pH and carbonate ion concentrations, thereby decreasing calcium carbonate. Surface ocean pH today is believed to be 0.1 unit lower than pre-industrial values. (See footnote on pH[3].) The median value of ocean model runs projects that pH will decrease by another 0.3 to 0.4 units by 2100. This translates into

[3] Because the pH scale is logarithmic, a one-unit decrease in pH is a 10-fold increase in [H+]. A change of 0.3 is half or double.

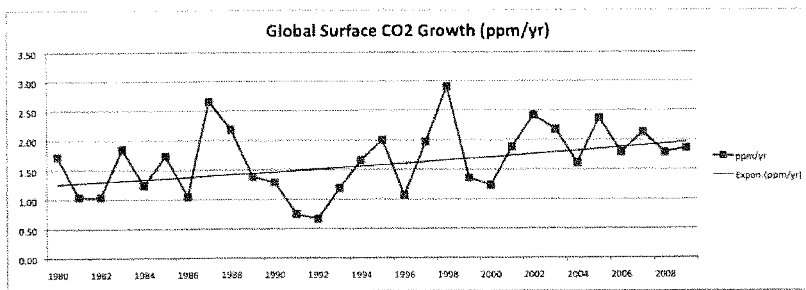
a 100 to 150% increase in the concentration of H+ ions while carbonate ion concentrations will decrease. When water is undersaturated with respect to calcium carbonate, marine organisms can no longer form calcium carbonate shells, **if** the living shell is directly exposed to the water. The model simulations project that undersaturation will be reached in a few decades[i]. The conventional wisdom also says that as CO2 concentration becomes higher, saturation will mean that more of it will remain in the atmosphere each year, accelerating its accumulation.

However there are some major problems with the science. The wisdom at the time of the IPCC 2007 report was that half of CO2 emissions would remain in the atmosphere and that we would have 712 ppm (IS92a) by 2100[ii]. This would require the atmosphere to more than double the present rate of growth of CO2 to 3.05 ppm, yet the growth rate seems to be leveling off, if not declining (see chart below). The meaning of this information (and the future of all climate models 0 became VERY cloudy on 31 December 2009 with the ScienceDaily acknowledgment of a paper published by American Geophysical Union and authored by Wolfgang Knorr that shows "No Rise of Atmospheric Carbon Dioxide Fraction in Past 160 Years", despite the predictions of carbon cycle/climate models[iii]. The implications of this have yet to be assimilated by the modeling community. This does not mean that CO2 proportion is not rising but rather that the proportion not being assimilated has not changed since 1850. Importantly, it means that the rate of CO2 cycling increases as it becomes more concentrated, and does not decrease as assumed in climate models. The rate of projected growth in CO2 appears to be greatly exaggerated.

(b) CO_2 concentrations



The CO2 scenarios are literally falling flat and need revision. The observational trend line shows monotonic growth – pretty much a straight line as in the chart below of global marine CO2 measurements (NOAA data)[iv], while the IPCC scenarios used in most research rely on an accelerating growth. Certainly the predicted rapid acceleration of the IS92a model (see solid black line in middle of the figure on the right) is missing from the NOAA data plotted below. In fact, if the last 8 or 12 years are representative of the future, we might imagine a downward slope in the growth rate. This could be real as rising fuel prices cut usage and lead to economic distress. It could also mean that the ocean is absorbing more CO2, which might not bode well to those concerned over acidification. However, it may be that the ocean is converting and storing the CO2 as calcium carbonate in the form of shells of oyster, clams and planktonic organisms as found by Iglesias-Rodriguez et al. (below). It is a complicated environment and there is much we do not know.



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

Thus, if the projections we are concerned with today are based on the IPCC IS92a model, or one of its cohorts, and the concept of CO2 sink saturation, we should give the information on its impacts a second look.

Further, if a model can't replicate the past by relying on principles of physics and mathematics, without "tuning" its parameters to reflect past variations, we must question whether it properly represents the real world. Some important physics may be missing or misrepresented. This is particularly true of any model that failed to predict the present leveling of temperatures in the face of rising CO2. I know of none that got it right.

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

III. THE BIOLOGY

Much of the concern flows form the latest IPCC report. The text from the Summary for Policy Makers states: "The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units. Increasing atmospheric CO2 concentrations lead to further acidification. Projections based on SRES scenarios give a reduction in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century. While the effects of observed ocean acidification on the marine biosphere are as yet undocumented, the progressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species"[v]

The Concerns

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

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

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

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

5. **Oysters and clams are dying.** In the Pacific Northwest there are charges that an acidic ocean is to blame for extensive mortalities of young oysters and clams. Fears include the possibility that relatively acidic upwelling waters will get less alkaline from the infusion of high CO2 air.

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

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

Biological considerations

There is limited research. I have reviewed the major papers and the critiques of the papers. Below are a few that I think merit bringing before the Committees. It is only a few that show no obvious bias. For example, it is quite common among researchers vying for scarce funding dollars to hype their findings or the importance of the problem. Whether it is the use of hydrochloric (HCl) acid to mimic CO2 but which introduces other issues such as shell decay, or presenting the findings of grave consequences at high acidity while not mentioning the lack of change at lower levels, or not investigating whether low pH was due to degraded water quality from runoff and sewage, the real cause of reduced growth or mortality. In some cases a lower base year is chosen that exaggerates the percentage change, such as "pH levels will drop 30% from pre-industrial levels – when current levels are far less disputed, but the % change is less.

Each study must be scoured for hints of inappropriate procedures and unfounded statements. None can be accepted at face value. The peer review process has warts. A good example is the dispute over whether acidification is good or bad for "shell"-forming plant plankton, a vital part of the ocean's biology with the ability to sequester vast amounts of CO2. The first paper says more CO2 is good, the second that it is bad, and then the first successfully refutes the criticism and gets the last word, sustaining the positive assessment in great detail - all published in *Science*. This is important because much of the alarmist literature is based on work that is refuted in this series. The verdict: shell forming algae do much better in a higher CO2 environment.

> "Ocean acidification in response to rising atmospheric CO2 partial pressures is widely expected to reduce calcification by marine organisms. From the mid-Mesozoic, coccolithophores have been major calcium carbonate producers in the world's oceans, today accounting for about a third of the total marine CaCO3 production. Here, we present laboratory evidence that calcification and net primary production in the coccolithophore species *Emiliania huxleyi* are significantly increased by high CO2 partial pressures. Field evidence from the deep ocean is consistent with these laboratory conclusions, indicating that over the past 220 years there has been a 40% increase in average coccolith mass. Our findings show that coccolithophores are already responding and will probably continue to respond to rising atmospheric CO2 partial pressures, which has important implications for biogeochemical modeling of future oceans and climate."[vi] "However, Riebesell et al. vigorously attacked the paper, claiming that "shortcomings in their experimental protocol compromise the interpretation of their data and the resulting conclusions."[vii] In rebuttal, also in Science, Iglesias-Rodriguez et al. get the last word by successfully demonstrating that the logic and methods of Riebesall et al. are the ones that are flawed and the original findings of increased calcification are valid[viii].

Perhaps the most thorough review of the literature on acidificaton impacts is by Fabry et al.[ix] They found that little research was done on CO2 concentrations that were relevant to answer today's questions. They express much concern that acidification will retard development of shells. They, as do several other authors, note that studies have not been long-term enough to discover adaptations over multiple generations. I believe this is key because these genera have genetic information about past events and this may well take several generations for stabilization. In any scenario, there will be ample time for this to happen. In a laboratory it happens with the throw of a switch. If my family or its descendants needs to hold its head underwater for 4 minutes and they have a few decades or a couple generations to adapt, it can be done. However, I can't do it very well today.

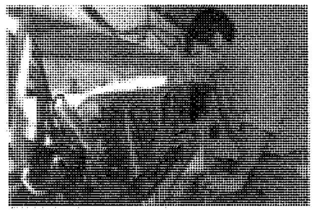
With respect to corals, Atkinson reviewed recent literature on ...."how ocean acidification may influence coral reef organisms and coral reef communities. We argue that it is unclear as to how, and to what extent, ocean acidification will influence calcium carbonate calcification and dissolution, and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

Kurihara et al investigated the "effects of seawater equilibrated with CO2-enriched air (2000 ppm, pH 7.4) on the early development of the mussel" and found that the mussels, as clams studied by them earlier, were significantly impaired when exposed to CO2 over 5X! that of today[xii].

Marubini et al. found that seawater acidification may lead to a decrease of tropical coral growth calcification. This effect is either mediated by a decrease in carbonate, in pH, or by an alteration of the internal buffering system leading to a disruption of carbon supply to calcification rather than by a direct effect of CO2 or a change of HCO3 - concentration. Results showed that the negative effect of acidification may be counteracted by increasing the bicarbonate concentration of seawater, resulting in an increase in the carbonate concentration.[xiii]

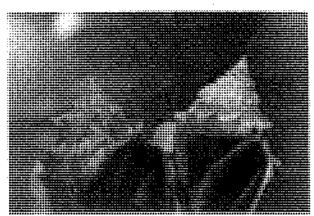
RMore relevant research shows that shell growth is slowed in some animals and enhanced in others. Woods Hole Oceanographic Institution (WHOI) researchers Ries et al. (2009)[xiv] and Ries (2010)[xv] found that 7 of 18 species of animals "such as crabs, shrimp and lobsters—unexpectedly build more shell when exposed to ocean acidification caused by elevated levels of atmospheric carbon dioxide (CO2)". They tested as high as 7 times present levels. They found that hard clams and corals slowed formation of shells but only above 1,000 ppm, while soft clams and oyster slowed formation at lower levels. Note that the shells did not dissolve, but only grew somewhat slower at 7X. Miller et al. tested several calcifying organisms at pre industrial, present and forecast scenarios. Some

Example of shell formation at 7X current CO2. Source: Ries et al.. 2009



Enlarge Image

Lead researcher Justin Ries works on CO2 study in WHOI lab. (Tom Kleindinst, Woods Hole Oceanographic Institution)



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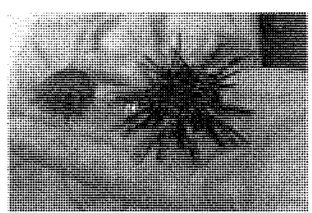
The conch shell at left was exposed to current CO2 levels; the shell at right was exposed to the highest levels in the study. (Tom Kleindinst, Woods Hole Oceanographic Institution)



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The larger of these two pencil urchins was exposed to current CO2 levels; the smaller was exposed to the highest CO2 levels in the study. (Tom Kleindinst, Woods Hole Oceanographic Institution) oyster species such as that tested by Ries et al. declined while others increased as CO2 increased. Animals usually predicted to experience dissolving shells did not. They conclude that "biological responses to acidification, especially calcifying biota, will be species-specific and therefore much more variable and complex than reported previously"[xvi]. Kurihara et al., cited their own research on urchins and copepods and reviewed the work of other researchers; negative impacts began at about 6.8-7.1, a factor of 10 reduction in alkalinity[xvii]. Suffrian et al. tested microzooplankton grazing and algae growth responses to increasing CO2 levels. They found that "Despite a range of up to 3 times the present CO2 levels, there were no clear differences in any measured parameter between the different CO2 treatments."[xviii] A study going the other way, by Chen and Durbin, measured the effect of high pH (8.8 to 9.4), on the growth of phytoplankton. They found that growth was limited at the higher levels[xix]. This confirms that these "plants" do better with the lower pH values associated with higher CO2.

I believe we should study the idea that ocean production would be enhanced by CO2 increases. The research points in this direction rather than the Armageddon we read about in the news. For example, with adequate nutrients, algae generally are more productive as CO2 increases (as are sea grasses). Further, algae-eating krill and copepods and the myriad zooplankton like them at the base of the food chain are more similar than not to the lobsters, shrimp, and blue crabs that show increased shell formation as CO2 increases.

There has been much research on the effect of acid rain in the Americas and Europe. Various articles place the boundary for damage at pH 5-5.5. Thomas Wolosz provides a good summary: in lakes the limiting pH is about 5 for the presence and good health of crustaceans, snails and insects and fish[xx]. This may apply to oceans as well. This is 1000 times more acidic than the oceans of today. At these levels species might be quite different, but each niche would likely be filled. Writings in fisheries management grey-literature indicate that the optimum for salmon streams is a pH of 7-8, and that below pH 6 should be avoided.

Any study showing damage to shelled organisms usually has a myriad of faults that include any of the following: failure to allow time for adaptation; when testing algae eaters, failure to allow commensurate food that would come with higher CO2; use of HCL or H2SO4 to increase acidity (directly destroying shells); not controlling for rainfall or upwelling or pollution; and not considering that rapid growth also causes thinner shells (witness aquacultured clams). In the studies without obvious flaws, no impacts that would change species mixes occur within a doubling of CO2 in the ocean. There is no basis to predict the demise of shelled animals living in the sea or the animals above them in the food chain at any likely level of CO2 that might be put in the air by humans. If freshwater organisms can form shells at pH of 5-5.5, it is hard to imagine damage at pH 7.8 to all species.

With respect to the homing ability of fish, a study at the University of Hawaii found the olfactory-based homing ability of clownfish was disrupted at 1,000 ppm and non-existent at 2,000 ppm. The values of CO2 acidification were high: "These values are consistent with climate change models that predict atmospheric CO2 levels could exceed 1,000 ppm by 2100 and approach 2,000 ppm by the end of next century under a business as usual scenario"[xxi] This has implication for all fish that need to find their way back to natal streams, if we were ever to get to 1,000 ppm. Since European and American eels reproduce in the Sargasso Sea and the young find their way home, their homing ability likely developed or survived periods when the continents were in different places and CO2 several times higher. Further freshwater fish must contend with water hundreds of times more acidic. The clownfish results, if valid, would not appear to be universally applicable.

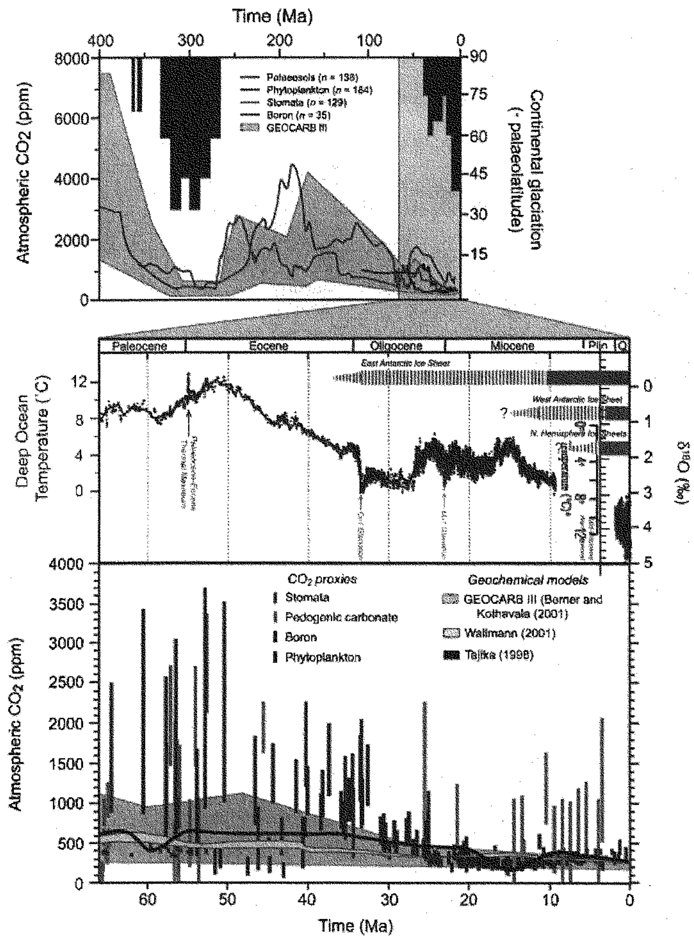
With respect to clam and oyster mortalities being caused by acidified water, it is unlikely that CO2 deposition from the air is the culprit. Upwelling brings water from the depths to the surface. This water has been out of sunlight perhaps for centuries. There has been no photosynthesis for plants to turn the CO_2 into oxygen, and whatever oxygen there was, has been converted into CO_2 by animals. When this cold water reaches the surface, it is saturated with CO_2 and is relatively acidic (but still alkaline), plus it has little oxygen. As this water warms, it will be outgassing CO_2, rather than picking it up as claimed by some. Less alkaline water is also symptomatic of coastal eutrophication, whether caused by runoff or sewage. The Ries et al. work cited above shows that the growth of clams and oysters can be slowed by CO_2-induced acidification. In their studies, the animals did not die even at rates several multiples of today's CO_2 levels and for hard clams, growth slowed only at the highest levels of CO_2. It is not clear if the animals with slowed growth had access to the higher food availability that would also come with increased CO_2.

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

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

IV. HAS THIS HAPPENED BEFORE?

From 50-600 million years ago, atmospheric CO2 levels were usually 2-20 times higher than at present. All the animals of concern evolved during this period. This included the age of the dinosaurs, when life was so prolific that we still use its carbon, limestone and chalk. The animals of concern all should have the innate genetic plasticity to quickly respond to the relatively modest changes of even the most unlikely scenarios, none of which approach the earlier range. The source of most CO2 emissions is from hydrocarbons deposited in epochs when the species of concern flourished. The chart below compiles the work of several authors and methods. It is from the latest IPCC report, showing time in Ma (millions of years) before present. For comparison, the present CO2 level is 388 ppm.



V. IS THIS BAD OR GOOD OR JUST DIFFERENT?

We and all other animals use oxygen and expel CO2. Each of us breathes out about two pounds per day to the atmosphere (of little consequence to the present issue). Plants do the opposite. CO2, combined with light and nutrients is their food. We must not lose sight of the fact that plants have consumed once-abundant CO2 to the point that it is 0.000388 of the atmosphere. Many greenhouse operators pump CO2 into their buildings to enhance growth, indicating plants evolved during higher concentrations of CO2. Plants in the ocean also rely on CO2. There is a high ability to move the excess out of circulation, turning it into oxygen (by plants) or calcium carbonate (by plants and animals). A view of the CO2 growth chart (above) and analyses such as that of Wolfgang Knorr, cited above, show this has not been adequately taken into account by climate modelers or those who provided their inputs.

We know that the Earth has seen these conditions before, and that all the same types of animals and plants of the oceans successfully made it through far more extreme conditions. Virtually all the ecological niches were filled at all times. If someone could demonstrate that there were no corals, clams, oysters, or shelled plankton when the Earth had double or triple the amount of CO2 in the air, we would have reason for concern. Just as IPCC has concluded, there is no observational evidence that things would be better or worse, or even different. Similarly, there is nothing conclusive in the very recent scientific literature to indicate any reason for concern. If anything, the science indicates plants, at least, will be more successful, and since they are the bottom of the food chain, this cannot be totally bad.

During the acid rain issues in the 1980s, a lake basin in Wisconsin was deliberately acidified (with EPA and NSF funding) to a pH of 4.7 then allowed to recover. "Some species were decimated and others thrived, but the sum-total of life in the lake stayed the same." This is a level of acidification 1,000 X the worst-case scenario for the oceans. It provides a clue as to what a 2X change might be[xxiv]. Moyle found that "chlorides, pH, and dissolved carbon dioxide are of little value in comparing waters and judging potential productivity" of lakes[xxv], another indicator that if changes occur, they won't automatically be "bad".

VI. WHAT CAN BE DONE ABOUT IT?

Oceans are actually alkaline with a surface pH of around 8.1. But it can vary from higher levels in shallow areas, where CO2 and hydrogen ions are consumed by plants, to relatively acidic areas in eutrophic estuaries. Upwelling areas are also less alkaline, as cold bottom waters are brought into sunlight near the surface where algae use the deep-water CO2 and nutrients to create a productivity boom that sustains fisheries production in several areas of the world. There are no long-term data, using similar instruments that provide a real clue as to global trends in alkalinity. There are only a few data sets of over a decade, such as that of the Monterey Bay Aquarium. The variability, because of nearby ocean currents and upwelling, shows the difficulty in portraying a global average value.

Some pundits have argued that we could add limestone to the oceans to make them more alkaline, but this has little merit due to costs and the fact that the oceans already contain immense buffering capability. We should bear in mind that this limestone and chalk, for the most part, came from the shells of plankton, as they fed on the CO2-laden ancient seas.

VII. RESEARCH SUGGESTIONS

There are some items that would go a long way toward establishing the likely effects of an increased CO2 world.

1. Develop a CO2/temperature timeline based on extant research on past climates, at least back to about 600 million years before the present. This effort would provide a critical review of candidate papers and unpublished work that goes well beyond a typical peer-reviewed journal publication, or prior summary reports of the IPCC.

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

3. Examine the growth rates, densities, and shell thicknesses of clams, oysters, or other mollusks from Indian middens and sediments to determine if any changes can be detected and if they correlate to any known changes in the oceans or atmosphere, including pH and CO2 levels.

4. Before the next IPCC assessment begins, assemble a USA review team and nominees for the IPCC writing and Chair assignments that make up a cross-section of scientific view-points. There are qualified scientists in agencies, industry, and among the citizenry who can contribute. Just as we shouldn't have too many from the energy industry, the same goes for the agencies, universities, and NGOs. We all have biases, even if we think it is the other person who is the one with an agenda. We cannot afford to have homogenous authoring and review teams.

VIII. CONCLUDING REMARKS

There is no reliable observational evidence of negative trends that can be traced definitively to lowered pH of the water. If there were, it would be suspect because there is insignificant change relative to past climates of the Earth. Scientific studies, and papers reviewing science studies, have similar messages. Papers that herald findings that show negative impacts need to be dismissed if they used acids rather than CO2 to reduce alkalinity, if they simulated CO2 values beyond triple those of today, while not reporting results at concentrations of half, present, double and triple, or as pointed out in several studies, they did not investigate adaptations over many generations. If there are reports of increases in ocean acidification in a region, the likely causes are upwelling, pollution, and rainfall (or runoff) and these all need to be addressed.

The oceans and coastal zones have been far warmer and colder and much more acidic in the past than is projected by climate models. Marine life has been in the oceans nearly since when they were formed. During the millennia life endured and responded to CO2 levels well beyond anything projected, with temperature changes that put tropical plants at the poles or had much of our land covered by ice more than a mile thick. The memory of these events is built into the genetic plasticity of the species on this planet. IPCC forecasts are for changes to occur faster than evolution is considered to occur, so impacts will be determined by this plasticity from past experiences and the resiliency of affected organisms to find suitable habitats. However, in the ocean, I believe natural climatological variation has greater amplitude and speed, making projected changes less significant.

In the oceans, major climate warming and cooling and pH (ocean pH about 8.1) changes are a fact of life, whether it is over a few years as in an El Niño, over decades as in the Pacific Decadal Oscillation or the North Atlantic Oscillation, or over a few hours as a burst of upwelling (pH about 7.59-7.8) appears or a storm brings acidic rainwater (pH about 4-6) into an estuary. Natural, clean rainwater is over 100 times more acidic than ocean surface water and upwelling seawater is about the same as modeled climate scenarios (IPCC: 7.76-7.86).[4] It is noteworthy that these IPCC projections closely match the center of upwelling waters, the most productive areas of the ocean. In these areas, the supply of CO2, mixed with sunlight and nutrients, causes a bloom of algae that raises pH to 8.5 on its edges, an increase in alkalinity of over 200%[xxvi], and creates the most productive fisheries on earth.

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

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

The most important approach in determining the impact of CO2 on the oceans is to examine what happened during past times. The world has been down this path before and all the existing genera, and many species, endured. It has often been a difficult journey, with volcanism, meteoroid collisions, severe ice ages, and great heat, with many of these events causing mass extinctions. The ancestors of these animals were on Earth long before humans. They are the survivors of great disasters. The memory of these difficult times is in their genetic makeup. Adaptation will be swift, if needed.

With no laboratory or observational evidence of biological disruption, I see no economic disruption of commercial and recreational fisheries, nor harm to marine mammals, sea turtles or any other protected species. Whichever response the US takes, our actions should be prudent. Our fishing industry, maritime industry and other users of the ocean environment compete in a world market and are vulnerable in many ways to possible governmental actions to reduce CO2 emissions. We already import most of our seafood and many of the nations we compete with do not need further advantages. Our research should focus on those ecosystem linkages we need to understand in order to wisely manage our fisheries, and conserve our protected species.

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

The real threat lies not in warming or less alkaline water but in the pervasive chemicals that flow down our rivers to the sea. Secondly, we need to improve our oil drilling and transport so disasters cannot happen: it may be as simple as building in more redundancy, whether to valves, hulls, or captains. As my daughter said, "Dad, Ocean acidification is not a problem for the oysters. They will all be dead".

[4] On the pH logarithmic scale (where $1.0\Delta = 10X$)

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Environment and Public Works Committee Hearing
May 11,2010
Follow-Up Questions for Written Submission
Questions for Everett
Questions from:

Senator Sheldon Whitehouse
1. What do you believe is the most pressing research question related to either of the threats to ocean health that we discussed; ocean acidification, or toxics in the marine environment?

I do not believe ocean acidification is a significant issue overall, although there could be winners and losers among individual species. The science that indicates there is a problem is not compelling. On the other hand, toxics that persist for long periods in the environment cause damage genetically and to individual organisms, including humans. The science is sound. Toxics originating from human activities are a far more pervasive problem than increased CO_2 in the marine environment.

Environment and Public Works Committee Hearing
May 11,2010
Follow-Up Questions for Written Submission
Questions for Everett
Questions from:

Senator James M. Inhofe
1. I like your discussion of the "the concerns" about the biology, particularly your notation about alarmist scientific literature. Can you elaborate on that problem and how it has shaped the debate on this subject, as well as climate change?

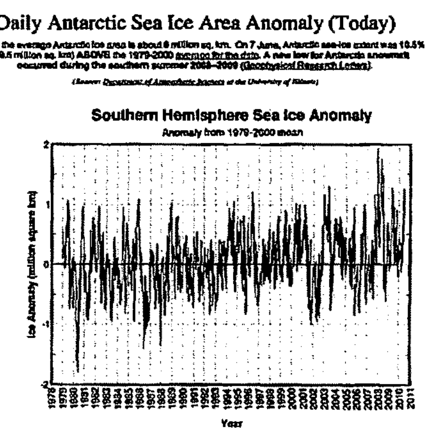
People are attracted to issues of concern, and study disciplines that interest them. For example, fishery biologists care more about the health of fishery resources than the average citizen. Often seen by biologists as "exploiters" ready to catch the last mating pair of fish, fishermen care at least as much about fish welfare as do the biologists. Beyond the stewardship concerns they share with environmentalist, their livelihoods and the future of their families depend on a sustainable fishery. They are generally at least as knowledgeable and as caring as the most ardent environmentalist. If people from either of these groups are asked to study the effects of climate change on fish, they will look for the damages and see right through the benefits. We end up with a skewed analysis due to natural thought processes. It is not a deliberate misrepresentation.

In my IPCC work, I asked people on my groups to list the same number of benefits as damages. It forced people to think more deeply and to develop a more useful analysis. Without trying to find all impacts, we tend to find only that which we seek. This is human nature and it is at the core of the alarmist literature in science. It is easily observable in the introductions of many scientific papers, or in funding proposals, each justifying the importance of the research. Justification for the quality of a piece of research usually lies in the fact that it had to be reviewed by knowledgeable scientists prior to publication. However, peer reviewers come from the same fields of research, are usually of similar mind, and rarely notice the inherent bias. There is a great deal of poor quality research, which is not necessarily the fault of the authors or the reviewers, but rather the responsible publishing organization that failed to bring in, or listen to, dissenting scientists.

On the day in August 2007 when the Washington Post and many other groups trumpeted on their front pages that the Arctic had the least sea ice since satellite-based analysis began, the Antarctic was at its record high. In follow-on text in the body of the Post, their article stated only that the Antarctic sent mixed signals. This is another type of alarmist literature. This may well be an item of agendas, or of newsworthy decisions, or of the same factors at play among journalists as among the example of the fishery biologists and fishermen. I am not a conspiracy theory proponent.

There is a great example of alarmist news and literature from today, even as I write this.

Where has anyone lately read about Antarctic sea ice? On 7 June 2010, Antarctic sea-ice extent was 10.5% (1.0/9.5 million sq. km) ABOVE the 1979-2000 average for the date. The global sea ice extent, the ultimate test of warming, is at the average of the satellite data record (0.1% above average) and yet all we learn from the media is that the Arctic is 9.3% blow average. Are news organizations withholding news of nonsupporting events, deliberately removing the public's ability to make an informed decision about whether or not there is global warming? Perhaps no one is looking? I do not believe there is a vast conspiracy, yet the effect is the same. Click on "See for Yourself" at my site, http://www.climatechangefacts.info/, which mostly provides direct links to University of Illinois sea ice data products (Antarctic shown to right). Views of the overall rising ice level in Antarctica should give serious pause to anyone contemplating costly action due to global warming.



2. What about subjects like toxics or any other you would like to point out?

Toxics that are of human origin are generally bad news. There are others, such as open-ocean mercury that naturally occur and are often the victim of hysteria by EPA and others. To the extent these natural "toxins" exist in the environment, life has evolved to deal with them. In the case of mercury, life has adapted by binding it with selenium. We can't evaluate the impact of mercury on mice without giving them access to selenium. This was not done until recently. If mercury in large ocean fish were a grave problem, we would have no sperm whales and killer whales. A bay that has been contaminated by mercury from a factory is a different matter and that mercury is bad for nearly all life forms.

3. You also discussed the fact that the ocean is constantly changing and evolving. Could you elaborate on that concept?

The oceans change in response to many natural interacting forces such as the gravitational pull of solar system planets and our moon and sun, the output of the sun, shifts in wind patterns, and other factors known and unknown. There are some cycles at the longer tem level such as the Pacific Decadal Oscillation and the North Atlantic Oscillation, and shorter term changes such as El Niño. These changes influence ocean life and the atmosphere on a global basis. None have a regular schedule and sometimes a whole cycle may not occur. The sea level changes by many inches along the coasts, the temperatures by several degrees, and upwelling may appear or disappear. The marine life changes accordingly. Whatever nutrients exist will become utilized, perhaps by a whole new set of animals. This is not good or bad (unless you are one of the species affected) but it certainly is different.

4. Is there anything else you would like to state for the record?

Yes, I would like to replace the written statement in order to correct some of the technical discussion about the chemical processes associated with ocean acidification. There is no substantive change to any content.

Senator WHITEHOUSE. Thank you very much, Dr. Everett.

I wanted to begin with two photographs from Rhode Island. This first photograph was taken in South Kingstown this weekend, a whale washed ashore along the shoreline. And this whale washed ashore in Narragansett in 2008.

Dr. Payne, based on your research, what can you guess, and I know you don't know specifically about these exact whales themselves, based on the extent of the contamination that you are finding, what is your guess as to what the status is of these whale bodies in terms of their toxicity?

Mr. PAYNE. I am not sure of the species. I am sorry. I can't see the pictures very well, but my guess would be that when you find a single animal——

Senator WHITEHOUSE. A minke whale on your right and a humpback on your left.

Mr. PAYNE. Oh, that is a humpback. I couldn't see. OK. My guess would be that when you find a single whale stranded like that, it is less likely to be some event that would be caused, for example, by red tide or something of that nature. But I would imagine that if you looked at any of these whales, the minke whale on the right, of course, feeds on a lot of fish. Most people think it is only on smaller species. If you get up to a species which is feeding very high on a food chain, you end up with higher concentrations.

I just want to give a quick example. If you had a pound of swordfish sitting in your plate, and you were about to eat it, the question is how many pounds did it take of diatoms at the bottom to make that pound of swordfish? Well, swordfish, or at least many of them, live at as much as the sixth level of a food chain, so that means you get a multiplication times 10 six times over. So 10 times 10 times 10 times 10 times 10 times 10 times 10. That is a million.

So the question is answered by, it is a million pounds of diatoms to make that one pound of swordfish on your plate. A million pounds is 500 tons. Five hundred tons is 50 10-ton truckloads. So now you park 50 10-ton trucks in a row and you tie your liver to one end of it, and you detoxify all of the 50 10-ton loads of these diatoms with your liver. And what's what you do when you eat a pound of swordfish, like it or not.

And what happens to these substances, they remain in your body. And if you have a pound tomorrow, you end up with higher concentrations. These are long lived animals, both of them, so the result is that they undoubtedly have high concentrations of a series of chemicals in their body. Whether that is what put them on the beach, I don't know. It could have been, but I don't know.

Senator WHITEHOUSE. I am not suggesting that is the reason, but I think your evidence shows that no matter where you go, whales that feed at the top of the food chain carry enormous loads of toxins in their bodies, even in the farthest corners of the globe.

Mr. PAYNE. Absolutely right.

Senator WHITEHOUSE. How does that fact that whales are mammals, since they lactate, bear on this problem?

Mr. PAYNE. Thank you. Yes, that tenderest of all mammalian acts, a mother nursing her babe, actually what she is doing is dumping her lifetime's accumulation of fat soluble PBTs or POPs into her babe. And the result is that the infant is no longer a sort of pure creature. It starts with its mother's toxic load. It adds a lifetime of its own toxic load and dumps the double dose into its baby, which receives a lifetime of its own toxic dose and dumps a triple load into its baby.

Humans can avoid that bullet by in fact feeding formula to their infants. That is not an option for a whale. The result is that if you go long enough with these substances which last for longer than the lifetimes of whales, you can expect actually extinction of species that eat high on food chains.

Senator WHITEHOUSE. So it bioaccumulates not only in the body of an individual whale as it continues to swim and eat and age, it will also bioaccumulate in the species because lactation passes it on to the next generation in an upward ratchet of poisoning.

Mr. PAYNE. Right. That is true. Any animal that you eat high on a food chain is going to give you these extraordinarily high concentrations of contaminants.

Senator WHITEHOUSE. And how do flame retardants get there?

Mr. PAYNE. I wish we had our data on flame retardants from the trip around the world. We expect it this week sometime. It just hasn't come in, the analyses. But they are also climbing food chains, and one would expect them to be therefore contributing problems to humanity. I think it is over 90 percent of human females have flame retardants in their bodies.

And of course, part of the problem is when you lie on a bed. Flame retardants, as you know, as used in all sorts of fabrics for preventing fires, and a good thing to prevent fires. But when you lie with your head on a pillow which is soaked in it, or the foam of the pillow is, you are actually breathing all night in these substances. And therefore, you are loading your system with them.

Senator WHITEHOUSE. Senator Cardin.

Senator CARDIN. Wow. This has been a fascinating panel, but this has me now wondering in talking to my wife about finding out the seafood we eat, what part of the food chain they consumed, which is not on our labels. It is something that just has us all thinking about it.

The more you realize the depth of information we have and we don't have about the risk factors in the oceans, it really does point out two facts. First, what Mr. Waterston said, and that is prevention would be the best course here. Global climate change and greenhouse gas emissions, that needs to be dealt with so that acidification is at least slowed down. That is issue No. 1.

No. 2, stopping further exploration of oil offshore would be No. 2.

And Dr. Everett, I appreciate the comment you said about redundancy, but let me just remind you that the oil rig in the Gulf of Mexico had redundancies in it as far as the shut-off valves, several redundancies in it. And the risk factor was considered to be minimal that it didn't require extra scrutiny on the regulators.

So stopping further exploration is clearly in our best interest. It is in our best interest for an energy policy, as well as for an environmental policy.

And if you want to speculate on this, fine, but I think about what would have happened if we would have had the comparable amount of oil spill 50 miles off the coast of Rhode Island or 50 miles off the coast of Maryland. For those of you who say that cannot happen, let me remind you that site 220 is 50 miles off the coast of Maryland. And there were plans to start that as early as 2011 or 2012.

Now, that is not going to happen as a result of what happened in the Gulf of Mexico, but it could have happened. And if would have had redundancies, I am sure, in its process, but there could have been a spill of comparable number. What I find surprising is that the Gulf of Mexico spill if it lasts for another month, it will surpass *Exxon Valdez*. And *Exxon Valdez* was number 34 on the all-time list of spills. So there have been horrific spills that are having generational impacts on the quality of our oceans.

I don't even want to think about the impact it would have on the Chesapeake Bay. I still worry about if the Gulf of Mexico spill gets into the currents it could very well come up the East Coast of the United States. We don't know. We don't have that.

So I guess my first question, if any of you would care to respond, is I am not satisfied we have enough information. I really worry about these dispersants that are being used, not that we have any choice, because I am not sure we have any choice, but to try it.

We never tried using a dispersant at such a depth, to try to disperse the oil before it hits the surface, and that is what they are trying to do, and EPA is very frank with us saying we don't know whether it can work. And second, we don't know the impact it has on our environment.

Am I right to be concerned that we might be hiding the true damage done to our environment from this spill in an effort to mitigate it, but then not to let the public know exactly what damage has been caused as a result of the use of these oil dispersants?

Any of you care to speculate on that?

Ms. MITCHELMORE. Sure. I can chime in and add to what I said earlier. It is going to be a while before we know the potential environmental effects of the dispersants. As I mentioned earlier, there are unprecedented volumes of this dispersant that are being applied in the Gulf right now. And in addition, the way that the dispersant is being used potentially under consideration. Dispersants are usually applied on the surface oil slicks, and they are approved for open ocean use because of the huge volume, for example, that they dilute into. They are pre-approved for use in open oceans, in waters greater than 10 meters depth, more than 3 nautical miles from the shore, for example, because of the dilution effect.

So by putting this right on the seabed, it is unknown, for example, what the consequences of that be. First of all, with any dispersant application, effectiveness has to be determined. Not all oil can be dispersed. It depends on temperature, weather parameters. But ultimately, we are taking a normal top-down approach to potentially looking from the bottom up now. That seabed, as it is so deep, wouldn't have been potentially exposed to a dispersed oil reaching those depths. It would have gone sideways and diluted out, but of course there is this continued oil and this continued dispersant use to consider as well.

Senator WHITEHOUSE. I know that Mr. Waterston has to leave, and before he does I just wanted to ask him for a closing comment by him. We are a terrestrial species. We focus a great deal of our attention on the land, the earth around us. We call our planet Earth, even though it is far more water than it is earth. We talk about climate change and global warming, but the worst effect for humankind of the carbon pollution of our planet may very well prove to be ocean acidification.

What can we do? And from our perspective, let me add one final point, we see reports coming back from far away oceans where most of us never have the chance to go. Dr. Payne brings them back from the remote corners of the globe. Scientists go out and sample and bring them back from the remote corners of the globe. And they are our news source. They are our reporters, our scouts, our sentries as to what is happening to this great resource of ours.

Then we come to Washington and big industries go right to work, as they are in the climate change debate, saying don't worry; that is just science; there is some doubt, attacking the process, attacking the people, doing everything they can to maintain their economic status as exploiters of the resource; in the case of climate change, free polluters at all of our expense.

What is your advice to us on how we can best try to get more attention paid by our terrestrial bi-ped species to these oceans so that we are better attuned to hear their warnings before it is too late?

Mr. WATERSTON. It is a huge question, and I don't have a ready answer except to say that we need to change our minds to recognize the obvious fact that life emerged from the sea, and it depends on the sea. And that there is no escaping the fact that what we do to the oceans comes back to bite us.

Oceana's contention all along—its reason for being, really—is to argue that we are taking too much good stuff out and putting too much bad stuff into the oceans and that it is having an immediate effect on life as we know it, the life that we enjoy, on jobs, and on food that a billion of us depend on.

By the way, the United States is one of the countries that will be most impacted by a drop in the availability of seafood because we eat so much of it. So this is an immediate issue for us. And making the connection is all our job, but it sounds to me as if you are way ahead of me in expertise. So I am glad to be here to be able to point at this, and I think it is high time we all paid more attention.

Senator WHITEHOUSE. Thank you for being here. I understand you have scheduling requirements, and it is 11:30.

Mr. WATERSTON. I do.

Senator WHITEHOUSE. Senator Cardin.

Senator CARDIN. Let me thank the entire panel. I found this very, very helpful.

Dr. Everett, I had a question for you, but you might have answered it in your last sentence. In preparation for today's hearing, I was very intrigued with your daughter's quote that you ended the testimony with, the quote that said, "Ocean acidification is not a problem for the oysters. They will all be dead."

But then in your verbal presentation, you said from oil. I don't know whether that was in her quote or not, and I will give you a chance to clarify.

Mr. EVERETT. I wanted to be clear why they would be dead, and she was talking about them being oil covered, and they would die from the oil.

Senator CARDIN. Because my point and the question I would at least put for the record is that the oyster issue is a very sensitive issue for all of us because we are doing everything we can to get the oyster back. And by the way, we are making progress in Maryland. I heard in Rhode Island you are also making progress.

We are seeing some very positive signs of the programs that we have in place and the work that we are doing that we are seeing a larger oyster crop. It is very tentative and we are working very hard. It is not the Asian oyster. This is going to be native in the Chesapeake Bay.

But there are multiple problems here. Acidification is a problem. The sediments that are going into the bay are problems. But if we say that one isn't causing the reductions, we will never get to an answer. We have to deal with all these issues, including acidification. We know it is not good.

So I guess my point is that I think your testimonies here point out, first, we need more science. We need better information. And I know it is difficult because the oceans are so vast. We need better information.

I think, Dr. Payne, your examples that you brought back is very, very valuable to us, and we thank you for that. The principal responsibility rests with governments. Unfortunately, the oceans are multi-jurisdictional so there is not one country. It is an international responsibility to deal with the science, and we need to have a level of understanding so that we have a coordinated strategy.

We are starting to get there today on global climate change, and that is good. And the United States, I think, will take on leadership which was lacking during the last 8 years. I think we will be in the forefront under President Obama and this Administration, but we need to do the same thing with the oceans.

What I take out of this hearing is that we need to have a stronger international leadership to deal with the complexities of what is happening in our oceans. And the sooner the better because this multiplies quickly. And if you don't get a handle on it, it is going to be more challenging for the future.

Mr. Chairman, this hearing was Senator Whitehouse's recommendation that we start to develop a record here in this Committee and this Senate and this Congress on this issue because it is going to be with us, and we need to develop a strategy. I just want to compliment our Chairman for bringing you all together.

Senator WHITEHOUSE. Well, thank you, Chairman Cardin. It has been such a pleasure to work with you and your office in preparing this hearing. It has been a true team collaborative effort. And as I mentioned earlier to the witnesses, there is a bit of a rivalry between the two of us as to who has the more oceanic ocean State, but that did not prevent us from working well on this, and he has been a great friend.

I have just a few additional questions before the hearing concludes. I would like to ask Drs. Mitchelmore and Everett to comment a little bit on the chemical pollution that is flowing into the oceans.

You had a rather stunning phrase in your testimony, Dr. Mitchelmore, where you said that the potential for a “toxic soup of unknown effects which cannot be predicted even if the individual chemical constituents are known,” as a result of the multiplicity of chemicals that flow into the sea.

And Dr. Everett, you said the “flow of chemicals materials into our waters is another matter. There are too many insidious contaminants entering our estuaries causing genetic harm and poisoning our birds, turtles and seafood. These contaminants,” you continue, “create only losers and directly impact us as well.”

I would be interested in hearing first from Dr. Everett and then from Dr. Mitchelmore a little bit on the extent to which the interaction between multiple chemicals creates an independent condition or an independent risk aside from the one single chemical. We usually tests things chemical by chemical. If you could comment on that, if that is an area you have looked at, I would appreciate it. And then to have Dr. Mitchelmore fill in a little bit more on her testimony.

Mr. EVERETT. I am particularly sensitive to the chemicals. I grew up as a commercial fisherman, and even after having my master’s degree I continued fishing. I was in the Fairhaven, Massachusetts, side of the New Bedford Harbor, which is a Superfund site. So we knew well what was in all the products out there and that they didn’t stay where they were. They didn’t die of old age. And we knew that there was something really bad about this stuff.

It is all, I think, throughout the different chemicals, they interact. If there is something that attacks the liver, there might be something attacking some genetics. And it all goes together. There is no one cause in any of this. And it is important to get them stopped. I think that this is the real harm, and there are a lot of people who are very concerned about it, and legitimately so, as we heard.

That is one part of everyone’s testimony that I will agree with.

Senator WHITEHOUSE. So the toxic soup notion of either chemical interactions working against the environment or its effects on a particular creature accumulating from one chemical harming them here to one chemical harming them there, it is a very real problem.

Mr. EVERETT. Yes. I worked in the National Marine Fisheries Service, and one of the last things I did was getting together the status of the marine habitats. The report is called Our Living Oceans. I worked on that as a contractor after I left the Fisheries Service. It is a very important document, and I am concerned about the contaminants through all aspects of the life passing on genetic defects and everything. It is not good stuff.

Senator WHITEHOUSE. And you agree with Dr. Payne that some of these contaminants will not only bioaccumulate in the individual creature, but for mammals through lactation they will poison the next generation in an increasing cycle of chemical loading?

Mr. EVERETT. We know that when the infant is growing that it is not good to be giving them contaminants. Not only will they accumulate, but they will cause damage from the first moment.

Senator WHITEHOUSE. Dr. Mitchelmore.

Ms. MITCHELMORE. Thank you, Senator. Those are excellent questions.

We know very well that chemicals can interact with each other, and sometimes that is in unknown ways. We have learned this from the medical field, for example, when we go to the doctors and the pharmacist. They carefully check interactions between different prescriptions, especially if you are taking more than one item.

In some cases, for example, taking drug A with drug B can result in negative consequences. The combination may even be fatal. And yet if you took those drug A and drug B singly and at different times, using exactly the same dose, you would have no adverse effect.

Well, this phenomenon is called synergism, and this analogy holds true for the organisms that are now being exposed to a barrage of multiple contaminants in the coastal and ocean systems.

And chemicals not only interact with other chemicals, they also interact with environmental parameters. For example, temperature can potentiate the effect of a chemical either by direct chemical means or by the temperature impact on that organism and how that organism can now deal with that chemical.

And another point is that many chemicals actually look similar to a lot of natural chemicals that are within us. And this is one of the highlights for a lot of these emerging contaminants of concern right now. Many of them look just like our natural thyroid hormones. And so unsurprisingly, they are affecting the thyroid hormone system, and that is critical for development, and especially in the young.

You brought up about the maternal transfer issue. And it is really critical for these young organisms. They haven't got the fully developed systems that can break down these chemicals that we have in our bodies. And so these young are very sensitive often to these chemicals.

The maternal transfer is not just through breast milk. It is also through placental transfer, and it is particularly critical for other higher trophic level organisms like reptiles that put all of their fat reserves which contain these persistent chemicals into the yolk which their developing embryo are exposed to.

Senator WHITEHOUSE. So it works for eggs as well as for lactation in the same way.

Ms. MITCHELMORE. Yes, very high levels of PCBs, PBDEs have been found in reptile eggs.

Senator WHITEHOUSE. Thank you.

Dr. Payne, looking at the variety of whale species that you have studied for many, many years, what is the general prognosis for our big marine mammals? Does it differ species by species? Are there some that are you think quite safe in this environment compared to others that at very grave risk? And what do we need to be prepared for if we don't change our ways?

Mr. PAYNE. If you are looking at the various species, any toothed whale is likely to be eating higher on the food chain than at least some of the baleen whales. But everybody seems to think that baleen whales feed just on krill or on plankton, that which would be lower on food chains, but no. Minke whales, for instance, feed on huge quantities of fish, and Japan has exhausted itself trying to demonstrate that to the rest of the world in its false argument that these minke whales are actually out-fishing humans for fish. The examples they have come up with are completely unconvincing.

But the other species, for instance, fin whales are in Norway called by a name which translates out to herring whale, because in fact they eat so much fish. So those animals that eat fish are high on food chains.

And what is the future for all of them? I think it is extinction. When I first made this suggestion about 8 or 10 years ago, I received a great deal of criticism, particularly from a fellow I have worked with over the years who later came to me and apologized and said I'm sorry; no, it is right; there is no other way out.

And I don't think there is unless we do something about it. And if we don't do something about it, we will ultimately put ourselves out of business in terms of being able to sell fish from the sea. They will be too polluted to sell.

So I think it is an incredibly important issue, and as I say, you could make a fairly tight suggestion that it was the biggest public health issue humanity has ever faced. A billion people will be affected directly by it since they get their principal source of animal protein from fish or from seafood. And that is a number about five times greater than the entire number of people whose lives were shortened by plague. So you think—it is probably a big problem.

Senator WHITEHOUSE. Thank you.

A vote has begun, so I will conclude this hearing. I want to thank all of the witnesses. It has been extremely helpful. I want to just briefly thank Brad and Kata and Anna Marie of my staff who went to a lot of work to put this hearing together.

I think it is particularly important for EPA to be alert to the damage that both carbon pollution and chemical pollution are likely causing or are causing in our oceans. And I think it is equally important that the Environment and Public Works Committee be alert to that and attuned to it, and that it be an important part of this Committee's focus.

So today was for me an important hearing because it brought this issue before our Committee through the two Subcommittees, through Senator Cardin's Subcommittee and mine, in a way that I hope will be lasting for the reasons that Dr. Payne has said, and in fact Dr. Everett an Dr. Mitchelmore as well. We are at grave risk of the chemical contamination to our oceans and the seafood and species contained therein.

So I will keep the hearing open for an additional week for any materials that anybody wishes to submit for the record of this hearing. I will take the opportunity to ask a few questions for the record of the witnesses, and hope that you can get back with us. My staff will send them directly to you.

I am the only one here so I don't have to sign off with anyone. I will just call the hearing to an end, but I am very, very grateful to all of the witnesses for how helpful they are and look forward to working with you further.

We are adjourned.

[Whereupon, at 11:48 a.m. the Subcommittees were adjourned.]

[An additional statement submitted for the record follows:]

STATEMENT OF HON. JAMES M. INHOFE, U.S. SENATOR FROM THE STATE OF OKLAHOMA

Good morning. We are here today to examine EPA's work to monitor and reduce environmental risks to our marine and coastal ecosystems. This subject is particularly timely given the challenges we currently face in responding to the oil spill in the Gulf of Mexico, though I will save most of my comments on that terrible event for the hearing this Committee is conducting this afternoon. I look forward to hearing more about EPA's work to protect ocean health as well as the private-public partnerships that exist to understand and reduce risks to this important ecosystem.

Our oceans are a precious resource, and we should take appropriate steps to ensure they are protected. Though I hail from Oklahoma, I have a particular personal interest in the ocean and coasts.

We know that many things affect the health of oceans and coastlines—in some cases, human activities, and in some cases, natural processes. So, one of the most important things I hope to learn today is the state of the science on oceans. I hope the witnesses will discuss what we really do, and perhaps most important do not know about oceans. Fully understanding all the circumstances that impact ocean health will help us make informed decisions about how to better protect these important natural resources as well as the communities and economies that depend on them.

We will hear today about how certain toxins affect oceans. Much has been done already to minimize and mitigate the most potent of these toxins, so I hope that the witnesses will acknowledge and make recommendations building on this progress.

We will also discuss the concept of ocean acidification. Without question, the pH of oceans impacts the creatures that live there. But there is scientific uncertainty as to whether, in general, oceans are actually becoming more acidic, and if so, what that means and what is the cause. We must be certain that we have a full picture of all the outside sources and natural cycles that affect the balance of the ocean.

To help us understand the full picture, we will hear from Dr. John Everett, a former scientist with the National Oceanic and Atmospheric Administration, who's now a consultant on ocean issues, about his studies that suggest the oceans will remain alkaline even as they absorb more carbon dioxide. I look forward to his testimony and his broader points that open minded research is needed to keep this issue in perspective.

[Additional material submitted for the record follows:]

April 17, 2010

The Honorable Maria Cantwell, Chair
The Honorable Olympia Snowe, Ranking Member
Committee on Commerce, Science, and Transportation
Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard
United States Senate
Washington, DC 20510

Dear Madam Chairwoman and Ranking Member Snowe:

As shellfish growers, commercial fishing and seafood industry representatives from all over the United States, we are very concerned about ocean acidification. Together with scientists whose research has been instrumental in bringing to light the urgent threat that ocean acidification poses to fisheries and marine ecosystems, we respectfully request help from policy makers to mitigate the causes and reduce the economic harm resulting from ocean acidification.

It has been proven that ocean acidification results from an excess of CO_2 dissolving into the ocean from the atmosphere. This CO_2 is primarily from the burning of fossil fuels followed by deforestation, cement manufacture, and other human activities.

Acidification from fossil fuel emissions is compounded by the effects of local acidifying factors, such as river runoff containing high loads of nitrogen and carbon, greatly accelerating impacts that scientists predicted from ocean acidification. This confluence of global and local acidification poses grave risk (and in some cases outright harm) to the marine food web and commercially important species. Changes exhibited in parts of Alaska, the East Coast and the West Coast raise serious concerns for fisheries in other regions, such as the Gulf of Mexico, where CO_2-driven acidification may compound the already serious impacts attributed to hypoxia.

A few examples:

1. Clams are dissolving before they can grow beyond their larval stage in parts of many East Coast bays, where impacts of river-borne effluents and eutrophication are aggravated by effects of global CO_2 emissions. This dissolution of young clams now represents a leading cause of mortality for these shellfish in many bays (Green et al). Scientists who documented this mortality say that it offers a preview of conditions that are expected to prevail throughout much of the ocean if CO_2 emissions are not sharply reduced.
2. On the West coast, upwelling of acidified water to a degree not anticipated until 2050 was documented in 2007 in a North American Carbon Program (NCAP) West Coast Cruise that surveyed the length of the west coast from Canada to Baja California (Feely et al 2008). Concurrently, natural oyster beds in the Pacific Northwest have experienced a multi-year recruitment failure, producing no commercially significant oyster sets. Acidification poses a severe threat to hatcheries that supply most of the region's $100 million+ oyster industry. Because this corrosive seawater kills oyster larvae, one of the region's largest hatcheries (Whiskey Creek Shellfish Hatchery at Netarts Bay) suffered a 70- 80% decline in oyster larval production in 2007 and 2008.
3. Laboratory studies subjecting sea urchins and other shellfish to CO_2–enriched seawater situations also have demonstrated larval shell deformation, reduced recruitment and settlement (Hofmann et al 2008); the tipping point for purple sea urchins is 540 ppm. In

the 2007 NOAA cruise, Feely et al found surface pCO_2 at about 850 µatm near the shelf break and higher inshore on some transects in northern California. Coincidentally, a 20-year data set of sea urchin larval recruitment in California indicates diminished recruitment in northern California during high upwelling events.

4. Seasonally acute acidification has now been observed in key fishing areas off Alaska, including the Bering Sea and the Gulf of Alaska (Fabry et al 2009), raising concerns for fisheries in a state that produces more than half the U.S. seafood catch. As in severely acidified waters along the West Coast and East Coast, these corrosive conditions are linked to compounding local acidifying influences from upwelling and river borne effluents. Scientists note that rising CO_2 emissions can be expected to make these corrosive conditions more persistent and widespread in the future.

Globally, ocean acidification has been identified as a serious threat to marine life and fisheries, and scientists have issued a series of unusually clear and urgent warnings about this problem. In the Monaco Declaration (2008), 155 scientists from around the world wrote: "Ocean acidification is accelerating and severe damages are imminent." Representatives from more than 70 national academies of science (including the United States, China, India, the U.K., Germany, France, and many others) signed a joint statement that read in part: "Marine food supplies are likely to be reduced with significant implications for food production and security in regions dependent on fish protein, and human health and wellbeing" (Inter-Academy Panel 2009).

While some organisms are likely to be more adaptive than others in a high-CO_2 ocean, seafood producers and consumers cannot afford to "whistle in the dark" about these changes. The U.S. seafood industry generates approximately $70 billion annually, fueling jobs and businesses that sustain many thousands of families along the Gulf, Atlantic, the Pacific and Alaskan coasts. Even for fisheries where no direct harm from acidification has yet been documented, the disturbing signs of trouble on the "front lines" reveal a compelling case to prevent the impacts from spreading and growing more severe.

POLICY RESPONSES

If seafood production is to be sustained and the oceans protected for future generations, federal political action is required now:

• **Adequate funding is urgently needed** to develop monitoring and research systems to track biological and ocean-chemistry changes in key areas, including estuaries. By utilizing and building on currently available studies we can create baseline data. From this we will have an accurate characterization of current water conditions thus enabling us to recognize "early warning" signs that may appear in the future. Data, current and future, should be coordinated with existing monitoring effort, such as NOAA's Integrated Ocean Observing System [IOOS] and the regional partners. Only by knowing what's coming at us can we hope to protect the resources that provide our food and livelihood.

• **Develop shellfish hatchery techniques and other methods of protecting important finfish and shellfish resources** from acute impacts of acidification. Small-scale experiments have shown that shellfish hatcheries, for example, can dodge some harm by halting production during periods when corrosive water is present and by maximizing production during "good water" periods. Within shellfish hatchery systems, certain water treatments show promise to reduce mortality of larval oysters. Brood stock programs have identified strains of shellfish that appear better able to survive in acidified seawater. Research and development is also needed to create methods of protecting other fish stocks during vulnerable early life stages. If hatchery techniques can shelter juvenile animals (including finfish if in a hatchery situation) when they are most vulnerable, it may be possible to sustain seafood production while solutions to the global carbon problem are developed.

• **Finance energy efficiency and other measures where needed to reduce carbon emissions within the seafood industry, and encourage private investment that improves carbon efficiency in the sector.** The seafood industry is a small source of carbon emissions, but seafood enterprises recognize the need do their part. Many of the necessary investments to curtail emissions will be initially costly but ultimately cost-effective. For example, to repower with more efficient engines and equipment, or to switch to lower-carbon fuels will require capital that vessel operators, producers, and seafood vendors may not be able to obtain on their own. Programs will need to be in place to encourage these upgrades. The seafood industry also should be encouraged to consider and permitted to improve its carbon and energy efficiency through reforms in fishery management. For example, in many cases rebuilding fish stocks can result in more energy-efficient harvesting. In some cases significant emissions reductions may be obtained by enabling vessel replacement, fleet renewal, downsizing overbuilt fleets, or implementing other management reforms. These changes are not "a one size fits all solution" and can have complex socio-economic effects. Not all communities and segments of the industry will choose them nor should the changes be implemented without regional industry involvement.

Critically important, the United States must lead in the search for global solutions, including:

• **Research in and support of alternative energy initiatives**

• **Cut emissions of carbon dioxide** in order to minimize future harm to fishery resources from ocean acidification. Research on "tipping points" for marine ecosystems and organisms shows that preventing irreversible harm will require limiting maximum atmospheric concentration of CO_2 at no higher than 450 ppm, and then reducing this concentration significantly in the decades ahead. This will require bold steps to place the United States in a position to lead (not lag) in solving this problem globally. To protect fishery resources, as well as future life on this planet, it will be necessary to:

1) cap emissions throughout the U.S. economy,
2) improve energy efficiency,
3) enhance low-carbon energy sources, and
4) negotiate a commensurate international agreement to control emissions throughout the global economy.

In closing, the undersigned shellfish growers and commercial fishing representatives and scientists respectfully request your help to address the urgent threat of ocean acidification.

Sincerely,

(Names are for identification only, do not represent or imply official endorsement from our employers.)

Dale Kelley
Executive Director
Alaska Trollers Association
Juneau, AK

Dorothy Childers
Program Director
Alaska Marine Conservation Council
Anchorage, AK

Dale Beasley
President
Columbia River Crab Fisherman's Association
Ilwaco, WA

Diane Pleschner-Steele
Executive Director
California Wetfish Producers Association
Buellton, CA

Linda Behnken
Executive Director
Alaska Longline Fishermen's Association
Sitka, AK

Bob Rheault
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East Coast Shellfish Growers Association
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Darius Kasprzak
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F/V Malka
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Mike Friccero
Commercial Fisherman
F/V Miss Gina
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Pete Wedin
Owner
Captain Pete's Alaskan Experience
Homer, AK

Craig Pendleton
Owner / President
F/V Ocean Spray/PENDLE Inc.
Saco, ME

Johnny Greene
Owner/Operator
Intimidator Charters
Orange Beach, AL

Joel Kawahara
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Bruce Wallace
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Ian Pitzman
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Fortune Sea, F/V Kona Kai, F/V Cape Caution
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Margaret Curole
Former Shrimper/Fisheries Activist
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Mark Green, PhD
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F/V Kelsey
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F/V Cape Cleare
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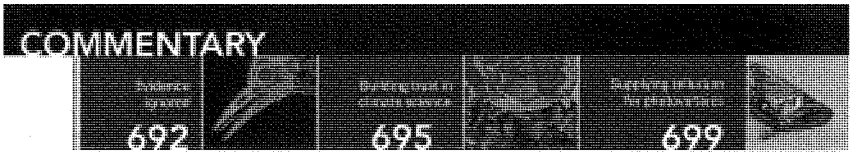


LETTERS I BOOKS I POLICY FORUM I EDUCATION FORUM I PERSPECTIVES

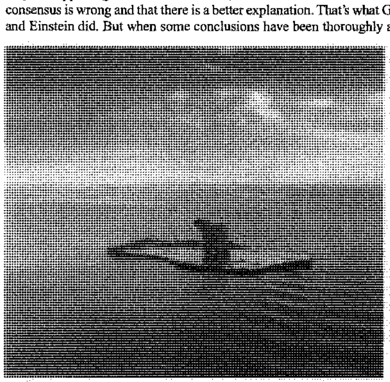
LETTERS

edited by Jennifer Sills

Climate Change and the Integrity of Science

WE ARE DEEPLY DISTURBED BY THE RECENT ESCALATION OF POLITICAL ASSAULTS ON SCIENTISTS in general and on climate scientists in particular. All citizens should understand some basic scientific facts. There is always some uncertainty associated with scientific conclusions; science never absolutely proves anything. When someone says that society should wait until scientists are absolutely certain before taking any action, it is the same as saying society should never take action. For a problem as potentially catastrophic as climate change, taking no action poses a dangerous risk for our planet.

Scientific conclusions derive from an understanding of basic laws supported by laboratory experiments, observations of nature, and mathematical and computer modeling. Like all human beings, scientists make mistakes, but the scientific process is designed to find and correct them. This process is inherently adversarial—scientists build reputations and gain recognition not only for supporting conventional wisdom, but even more so for demonstrating that the scientific consensus is wrong and that there is a better explanation. That's what Galileo, Pasteur, Darwin, and Einstein did. But when some conclusions have been thoroughly and deeply tested, questioned, and examined, they gain the status of "well-established theories" and are often spoken of as "facts."



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For instance, there is compelling scientific evidence that our planet is about 4.5 billion years old (the theory of the origin of Earth), that our universe was born from a single event about 14 billion years ago (the Big Bang theory), and that today's organisms evolved from ones living in the past (the theory of evolution). Even as these are overwhelmingly accepted by the scientific community, fame still awaits anyone who could show these theories to be wrong. Climate change now falls into this category: There is compelling, comprehensive, and consistent objective evidence that humans are changing the climate in ways that threaten our societies and the ecosystems on which we depend.

Many recent assaults on climate science and, more disturbingly, on climate scientists by climate change deniers are typically driven by special interests or dogma, not by an honest effort to provide an alternative theory that credibly satisfies the evidence. The Intergovernmental Panel on Climate Change (IPCC) and other scientific assessments of climate change, which involve thousands of scientists producing massive and comprehensive reports, have, quite expectedly and normally, made some mistakes. When errors are pointed out, they are corrected. But there is nothing remotely identified in the recent events that changes the fundamental conclusions about climate change:

(i) The planet is warming due to increased concentrations of heat-trapping gases in our atmosphere. A snowy winter in Washington does not alter this fact.

(ii) Most of the increase in the concentration of these gases over the last century is due to human activities, especially the burning of fossil fuels and deforestation.

(iii) Natural causes always play a role in changing Earth's climate, but are now being overwhelmed by human-induced changes.

(iv) Warming the planet will cause many other climatic patterns to change at speeds unprecedented in modern times, including increasing rates of sea-level rise and alterations in the hydrologic cycle. Rising concentrations of carbon dioxide are making the oceans more acidic.

(v) The combination of these complex climate changes threatens coastal communities and cities, our food and water supplies, marine and freshwater ecosystems, forests, high mountain environments, and far more.

Much more can be, and has been, said by the world's scientific societies, national academies, and individuals, but these conclusions should be enough to indicate why scientists are concerned about what future generations will face from business-as-usual practices. We urge our policy-makers and the public to move forward immediately to address the causes of climate change, including the unrestrained burning of fossil fuels.

We also call for an end to McCarthy-like threats of criminal prosecution against our colleagues based on innuendo and guilt by association, the harassment of scientists by politicians seeking distractions to avoid taking action, and the outright lies being spread about them. Society has two choices: We can ignore the science and hide our heads in the sand and hope we are lucky, or we can act in the public interest to reduce the threat of global climate change quickly and substantively. The good news is that smart and effective actions are possible. But delay must not be an option.

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Notes

1. The signatories are all members of the U.S. National Academy of Sciences but are not speaking on its behalf.
2. Signatory affiliations are available as supporting material at www.sciencemag.org/cgi/content/full/328/5979/689/DC1.

Shifting the Debate on Geoengineering

AS DISCUSSED IN THE RECENT POLICY FORUM "The politics of geoengineering" (J. J. Blackstock and J. C. S. Long, 29 January, p. 527), there is growing recognition that avoiding dangerous climate change during the 21st century may require society to adopt geoengineering technologies to supplement CO_2 emission reduction efforts. Unfortunately, despite the essential role that CO_2 removal (CDR) and solar radiation management (SRM) technologies may play in reducing the risks of dangerous climate change, discussions of the necessary research and development [including the Policy Forum and others (*1*, *2*)] frequently turn into debates about the environmental costs and benefits of SRM. A more productive approach would shift the debate to comparing the relative costs and benefits of CDR and SRM.

CDR approaches are frequently discounted because, as Blackstock and Long explain, "technical challenges and large uncertainties [surround] large-scale CDR deployment." Although this may be true for human-built systems that capture CO_2 from air at ambient concentrations, there are other technologies based on biological carbon fixation that could be fast-tracked for rapid deployment during the next few decades (*3*). Most major international energy corporations are investing in algal-based biofuel technologies because of the tremendous production potential of algae relative to terrestrial energy crops (*4*). Commercial-scale production of algal biofuels will begin during the next 5 years, and rapid scaling up can be expected afterward if the economic incentives are favorable. However, becoming carbon negative will require society to develop plans for retrofitting existing coal-fired power plants and building future ones so that they can burn algal biomass and capture the emitted CO_2 for subsequent sequestration. The basic technologies described here are not novel; rather, I am proposing a conceptual rearrangement that may enable society to transition more gracefully

CORRECTIONS AND CLARIFICATIONS

Research Articles: "Doc2b is a high-affinity Ca^{2+} sensor for spontaneous neurotransmitter release" by A. J. Groffen *et al.* (26 March, p. 1614). Several author affiliations were not footnoted properly; three corrected affiliations follow. Y. Takai, Department of Biochemistry and Molecular Biology, Kobe University Graduate School of Medicine, Kobe 650-0017, Japan. J. G. Borst, Department of Neuroscience, Erasmus MC, University Medical Center, Rotterdam, 3000 CA, Netherlands. N. Brose, Max-Planck-Institut für Experimentelle Medizin, Abteilung Molekulare Neurobiologie, 37075 Göttingen, Germany.

Letters: "Oil and water do mix" by J. L. Kavanau (19 February, p. 958). Due to an editorial error, the title was incorrect. It should have been "Opposites attract."

Reports: "100-million-year dynasty of giant planktivorous bony fishes in the Mesozoic seas" by M. Friedman *et al.* (19 February, p. 990). The author Matt Friedman's affiliation should have been "Committee on Evolutionary Biology, University of Chicago, 1025 East 57th Street, Chicago, IL 60637, USA." The affiliation that was listed is his present address.

News of the Week: "*DSM-V* at a glance" by G. Miller and C. Holden (12 February, p. 770). In the sidebar, it was reported that the term "gender identity disorder" has been retained. In fact, a different term—"gender incongruence"—has been proposed.

Research Articles: "PRDM9 is a major determinant of meiotic recombination hotspots in humans and mice" by F. Baudat *et al.* (12 February, p. 836). M. Lichten was incorrectly listed as an author in references 18 and 19. The correct authors for reference 18 are C. Grey, F. Baudat, and B. de Massy; for reference 19, the correct authors are E. D. Parvanov, S. H. Ng, P. M. Petkov, and K. Paigen.

Reports: "Epigenetic transgenerational actions of endocrine disruptors and male fertility" by M. D. Anway *et al.* (3 June 2005, p. 1466). As clarification of the abstract to Anway *et al.*, the F_1 to F_4 generations were examined after vinclozolin treatment, and F_1 and F_2 generations were examined after methoxychlor treatment. To clarify data referred to in the last paragraph of the Report, serum testosterone measurements after vinclozolin treatment were shown in reference 21 (Uzumcu *et al.*) for the F_1 generation. Data for the F_2 to F_4 generations were subsequently published in Anway *et al.*, *J. Androl.* **27**, 868 (2006). Serum testosterone measurements after methoxychlor treatment were shown in reference 20 (Cupp *et al.*) for the F_1 generation, but measurements of the F_2 generation have not been published. The *Science* Anway *et al.* manuscript showed DNA methylation analysis after vinclozolin treatment, but the DNA methylation data after methoxychlor treatment have not been published.

from fossil to modern carbon fuel sources while simultaneously reducing CO_2 levels in the atmosphere and ocean.

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Response

GREENE SUGGESTS THAT CO_2 REMOVAL methods deserve expanded evaluation and research. We agree. In the long run, these methods may be the only way to reduce atmospheric concentrations of CO_2 to values closer to those of the preindustrial era. Greene suggests a scheme for using biomass to generate electricity combined with carbon capture and storage. This idea has merit. Even schemes that capture CO_2 directly from the air deserve expanded research.

However, Greene's statement that "discussions of the necessary research and development…frequently turn into debates about the environmental costs and benefits of SRM [solar radiation management]" misses a key point motivating all three of the articles he cites [our Policy Forum and (*1*, *2*)]. The two approaches differ in both strategic impact and risks. Most CO_2 removal schemes, including those suggested by Greene, would be slow acting and expensive, and would pose no transboundary risks. In contrast, SRM techniques appear inexpensive and could have rapid climatic impact, but present a host of global climatic and political risks.

The low cost and technical feasibility of some SRM technologies (particularly stratospheric aerosol injection) mean that SRM might be our only response if a "climate emergency" develops. However, these traits also mean that SRM could be globally tested unilaterally by a single country, to the possible detriment of others (*3*). Beyond the climatic risks this presents, such actions could also severely disrupt progress on international climate policy.

The discussion of urgent governance challenges in the articles Greene cites is not a distraction; it is central to figuring out how to safely and prudently conduct research into SRM technologies. No such acute research governance challenges exist for most CO_2 removal techniques.

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Letters to the Editor

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Additional material submitted by Ocean Alliance and Transocean Holdings, LLC, is available in the Committee files.

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