SEA CHANGE: IMPACTS OF CLIMATE CHANGE ON OUR OCEANS AND COASTS

HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

FEBRUARY 27, 2019

Serial No. 116–3

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE

35–233PDF WASHINGTON : 2019

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C O N T E N T S

February 27, 2019

SEA CHANGE: IMPACTS OF CLIMATE CHANGE ON OUR OCEANS AND COASTS

WEDNESDAY, FEBRUARY 27, 2019

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENVIRONMENT,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 10:03 a.m., in room 2318 of the Rayburn House Office Building, Hon. Lizzie Fletcher [Chairwoman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENVIRONMENT
U.S. HOUSE OF REPRESENTATIVES
HEARING CHARTER

Sea Change: Impacts of Climate Change on Our Oceans and Coasts

Wednesday, February 27, 2019
10:00 a.m.
2318 Rayburn House Office Building

PURPOSE

The purpose of this hearing is to explore the impacts of anthropogenic carbon dioxide emissions on our oceans and coasts. The Subcommittee will receive expert testimony on the state of the science on ocean warming, acidification, deoxygenation, and sea level rise with special attention to findings in recently published significant climate reports and discuss the impacts of climate change to a coastal industry.

WITNESSES

- **Dr. Sarah Cooley (COO-lee),** *Director, Ocean Acidification Program, Ocean Conservancy* – Dr. Cooley is an ocean acidification expert and was the Review Editor for the Oceans and Marine Resources Chapter in the Fourth National Climate Assessment published in 2018. She is currently a Lead Author on Working Group II of the IPCC's 6th Assessment Report.[1]

- **Dr. Radley Horton (HOR-ton),** *Lamont Associate Research Professor, Lamont-Doherty Earth Observatory, Columbia University Earth Institute* – Dr. Horton is a sea level rise expert and co-authored the NOAA technical report on global and regional sea level rise scenarios for the United States published in 2017 that went into the Fourth National Climate Assessment. He was the lead author on the Northeast Climate Change Impacts in the United States Chapter in the Third National Climate Assessment, published in 2014.[2]

- **Dr. Thomas K. Frazer (FRAY-zher),** *Professor and Director, School of Natural Resources and Environment, University of Florida* – Dr. Frazer is an expert in aquatic ecology and broadly studies the effects of anthropogenic activities on the ecology of both freshwater and marine ecosystems, especially in Florida. His recent studies have involved corals, algae, and lionfish.[3]

- **Ms. Margaret A. Pilaro (Peh-LAR-oh),** *Executive Director, Pacific Coast Shellfish Growers Association (PCSGA)* – Ms. Pilaro has been the executive director of PCSGA since

[1] https://oceanconservancy.org/people/sarah-cooley/
[2] https://www.radleyhorton.com/
[3] http://sfrc.ufl.edu/people/faculty/frazer/

2010. PCSGA growers have experienced early negative effects of ocean acidification and deoxygenation on their shellfish hatcheries, and have worked collaboratively with academia and government to develop potential solutions to these impacts on their industry.[4]

BACKGROUND

Overview

The oceans play a central role in regulating the global climate system by absorbing and redistributing heat and carbon dioxide.[5] Since the Industrial Revolution, the oceans have absorbed significant amounts of heat and carbon dioxide from anthropogenic (human-caused) emissions, resulting in three main changes to the physical and chemical state of the oceans: warming, acidification, and deoxygenation. Without the oceans acting as a climate change buffer, the surface of the earth would be heating up much faster than it is. Ocean warming, acidification, and deoxygenation are already occurring and have been observed across the global oceans. These processes interact with, and potentially aggravate, one another and interact with other human-influenced stressors in the marine environment, such as pollution, nutrient runoff, habitat degradation, overfishing, and illegal fishing.

Forty-two percent of the U.S. population lives along the coasts, spanning three oceans as well as the Gulf of Mexico, the Great Lakes, and the Pacific and Caribbean islands.[6] Climate change is already affecting the social, economic, and environmental systems along the coasts. The oceans and coasts provide important ecosystem services in the way of carbon storage, oxygen generation, flood and storm surge protection, food security, and jobs. Primary production in the oceans (primarily from phytoplankton) produces approximately half of the oxygen in the atmosphere.[7] Coastal ecosystems such as mangroves, salt marshes, and seagrasses are much faster and more efficient at storing carbon than terrestrial forests.[8] Climate change threatens to alter these services from the oceans and coasts on which humans depend.

While our understanding of the physical, chemical, and biological changes in the oceans and resulting impacts has increased significantly in the last several decades, more research is needed. The Fourth National Climate Assessment (NCA4) identifies major research gaps in our understanding of climate change. Some of the major research gaps specific to the oceans and coasts identified in the NCA4 include the need to: continue efforts to improve the understanding, modeling, and projections of sea level change, and ocean processes and chemistry, especially at the regional scale; improve characterization of important sources of uncertainty, including feedbacks and possible thresholds in the climate system associated with changes in ocean

[4] https://pcsga.org/our-staff/
[5] Pershing, A.J., R.B. Griffis, E.B. Jewett, C.T. Armstrong, J.F. Bruno, D.S. Busch, A.C. Haynie, S.A. Siedlecki, and D. Tommasi, 2018: Oceans and Marine Resources. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 353–390. doi: 10.7930/NCA4.2018.CH9
[6] NCA4; Volume II; Ch. 8
[7] NOAA.gov. May 21, 2018. "Marine organisms produce over half of the oxygen that land animals need to breathe." https://oceanexplorer.noaa.gov/facts/oceanproduction.html
[8] IUCN.org. November 2017. "Blue Carbon." https://www.iucn.org/resources/issues-briefs/blue-carbon

dynamics; and maintain and enhance research and development of data collection and analyses to monitor and attribute ongoing and emerging climate impacts across the United States, including changes in ecosystems and oceans. The IPCC is set to finalize a Special Report on the Ocean and Cryosphere in a Changing Climate[9] in September 2019 that will include potential solutions, policy options and governance, as well as resilience pathways, and adaptation options.

Major Ocean and Coastal Changes

Warming

Warming of sea surface temperatures is the most well-documented and obvious impact of climate change on the oceans.[10] The oceans have absorbed more than 93 percent of the extra heat in the atmosphere due to carbon emissions since the mid-20th century.[11] Consequently, sea surface temperatures have warmed on average 1.3° ± 0.1°F (0.7° ± 0.08°C) per century globally between 1900 and 2016.[12] Globally, ocean warming is occurring fastest near the surface, with the upper 75 meters having warmed 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010;[13] however, warming is now being observed at depths of over 1,000 meters.[14] If global carbon emissions continue unabated, the oceans are expected to warm as much as 4.9° ± 1.3°F (2.7° ± 0.7°C) by the end of 2100, with even higher levels of warming in some U.S. coastal regions.[15]

There are many consequences of ocean warming: sea levels are rising, sea ice is melting, ice shelves and glaciers are destabilizing, ocean circulation is changing, and waters are becoming more stratified (density contrast between the surface and deeper waters).[16] In addition, warmer oceans make waves stronger,[17] fuel stronger storms and increase damage from hurricanes and tropical storms.[18] Warmer water also changes biological productivity, for example, potentially enhancing the productivity of fish stocks at the cold end of their range (such as Atlantic croaker), while causing reductions in others (such as the Pacific cod).[19] Harmful algal blooms have also been linked to warm events and increasing temperatures in both the Atlantic and Pacific Oceans.[20] The Atlantic meridional overturning circulation (AMOC), the major surface and deep currents in the Atlantic that include the Gulf Stream,[21] is potentially slowing due in part to

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[9] https://www.ipcc.ch/report/srocc/
[10] NCA4; Volume II; Ch. 9
[11] NCA4; Volume 1; Ch. 13
[12] NCA4; Volume II; Ch. 9
[13] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp
[14] Levitus, S., et al. (2012), "World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010," Geophys. Res. Lett., 39, L10603, doi:10.1029/2012GL051106.
[15] NCA4; Volume 1; Ch. 13
[16] NCA4; Volume II; Ch. 9
[17] Reguero, B.J., Losada, I.J., Mendez, F.J. (2019), "A recent increase in global wave power as a consequence of oceanic warming." Nature Communications. https://doi.org/10.1038/s41467-018-08066-0
[18] NCA4; Volume II; Ch.8
[19] NCA4; Volume II; Ch. 9
[20] NCA4; Volume II; Ch. 9
[21] NCA4; Volume II; Ch. 18

increasing ocean heat content – this could dramatically slow the ability of the oceans to act as a sponge for atmospheric heat and carbon dioxide and have climate feedback effects.[22]

Global sea level rise is due primarily to thermal expansion of seawater from warming, as well as sea ice melt. Sea levels have already risen 6.3–8.3 inches since 1900.[23] Since the IPCC Assessment Report 4 was released, sea level rise simulations have improved due to an increased understanding of changes in glaciers and ice sheets.[24] The Fourth National Climate Assessment (NCA4) predicts global mean sea level to rise an additional 1.0-4.3 feet by 2100.[25] Studies published since the NCA4 was released show the contribution of ice melt from the Greenland[26] and Antarctic[27] ice sheets is much larger than previously known.

Ocean Acidification

Since the Industrial Revolution, the oceans have absorbed approximately one-third of the carbon dioxide emissions from the atmosphere.[28] This has caused ocean surface pH to decrease by 0.1, corresponding to a 26 percent increase in acidity.[29] When carbon dioxide gas reacts with seawater, it lowers the pH, which raises the acidity. This process of the gradual reduction in the ocean's pH (and corresponding increase in acidity levels) is known as ocean acidification. The oceans continue to absorb over a quarter of global carbon emissions every year, roughly the equivalent of China's total annual carbon emissions.[30]

Acidification is occurring faster in some U.S. coastal regions as a result of upwelling of naturally low pH water (Pacific Northwest), changes in freshwater inputs (Gulf of Maine), and high nutrient inputs (for example, in agricultural watersheds).[31] Under a higher emissions scenario, global mean surface acidity is expected to increase by 100-150 percent by the end of the century.[32]

Deoxygenation

Ocean warming is causing a decline in the average oxygen concentrations of seawater due to the relationship between temperature and oxygen solubility because warm water holds less oxygen.[33] Stratification of the water column (density contrast between the surface and deeper waters) due to surface warming further reduces the transfer of oxygen to the deep waters and reduces

[22] NCA4; Volume I; Ch. 13
[23] NCA4; Volume I; Ch. 12
[24] IPCC AR5
[25] NCA4; Volume I; Ch. 12
[26] Trusel, L.D., et al. (2018). "Nonlinear rise in Greenland runoff in response to post-industrial Arctic warming." Nature, 564: 104-108.

[27] Rignot, E., et al. (2019). "Four decades of Antarctic Ice Sheet mass balance from 1979-2017." Proc. of the Nat. Acad. of Sciences, 116 (4): 1095-1103. https://doi.org/10.1073/pnas.1812883116
[28] IPCC AR5
[29] IPCC AR5
[30] Eddebbar, Y.A., Gallo, N.D., and Linsmayer, L.B. 2015. The Oceans and the UN Framework Convention on Climate Change. American Association for the Sciences of Limnology and Oceanography. Pp. 69-72.
[31] NCA4; Volume I; Ch. 13
[32] NCA4; Volume I; Ch. 13
[33] NCA4; Volume II; Ch. 9

biological productivity at the surface.[34] Since the 1960s, oxygen concentrations have decreased in coastal waters and the open ocean surface.[35] In addition, oxygen minimum zones that naturally occur at mid-depths in some regions of the oceans are likely expanding, particularly in the tropics.[36] Human-influenced coastal "dead zones", or low-oxygen zones due to excessive nutrient pollution from human activities, are predicted to expand as well.[37]

Due to continued ocean surface warming, it is predicted that oxygen content of the oceans will decrease by up to 3.5 percent by the end of this century, primarily in the subsurface mid-latitude regions.[38] However, the extent of low oxygen waters in the open ocean is uncertain because of uncertainties in biogeochemical feedbacks and ocean dynamics.[39]

<u>*Resulting Impacts of Ocean and Coastal Changes*</u>

Impacts to Coastal Economies and Property

The most obvious impacts of anthropogenic carbon emissions on the oceans are felt by coastal communities that depend on the oceans and coasts for food and jobs in defense, fishing, transportation, tourism, and commerce. The coasts are economically important to the United States with coastal zone counties (which includes coastal and coastal-adjacent counties) employing 134 million Americans and contributing $16.7 trillion to our national gross domestic product (GDP).[40] The fishing industry alone contributes over $200 billion in economic activity annually and supports 1.6 million jobs.[41]

Climate change threatens the coasts through increasing frequency and extent of high tide flooding due to sea level rise, higher storm surges, and more heavy precipitation events. The resulting impacts of flooding, erosion, waves, saltwater intrusion into aquifers and elevated groundwater tables, changing patterns of local rainfall and river runoff, and increasing water and surface air temperatures, as well as the challenges of ocean acidification harm the coasts and cascading impacts metastasize throughout the U.S. economy. Warmer sea surface temperatures also fuel more intense tropical cyclones, including hurricanes, which lead to more damage upon landfall.[42] The severity of costly compound events is on the rise, in which trends like rising sea levels, increased river discharge, more frequent and intense storms and cyclones, and flooding co-occur.[43]

Sea level rise, higher storm surges, and more intense precipitation events will threaten crucial coastal infrastructure such as roads, bridges, tunnels, pipelines, power plants, military bases, airports, and seaports, with cascading impacts across the national economy, and is already being

[34] NCA4; Volume II; Ch. 9
[35] IPCC AR5
[36] IPCC AR5
[37] IPCC AR5
[38] NCA4; Volume I; Ch. 13
[39] IPCC AR5
[40] NCA4; Volume II; Ch. 8
[41] NCA4; Volume II; Ch. 8
[42] NCA4; Volume II, Ch. 8
[43] NCA4; Volume II; Ch. 8

felt in low-lying cities across the United States, such as Miami, New York City, New Orleans, San Francisco, and Norfolk, Virginia.[44] In addition to storms, floods, and erosion, sea level rise threatens the approximately $1 trillion in national wealth held in coastal real estate.[45] The low to moderate emissions outcomes in the NCA4 found that up to half of this real estate is expected to be below sea level by 2100, which could lead to 13.1 million Americans needing to migrate by 2100 due to rising seas.[46] High tide flooding due to sea level rise is already forcing some East coast cities such as Miami Beach to install costly pump stations to frequently clear floodwaters from the streets.[47] Under a high emissions scenario, daily high tide level will be greater than the current 100-year water level event on most U.S. coastlines, exposing dozens of power plants,[48] and 60,000 miles of U.S. roads and bridges lie in coastal floodplains.[49]

Ocean acidification and deoxygenation have been linked to mortality of shellfish larvae in the Pacific Northwest, causing local commercial hatchery failures and associated major economic losses in the mid-2000s.[50] The hatcheries have been able to improve shellfish growth by treating the water to raise the pH and oxygen levels for the larvae.

Climate change impacts on the coasts are also exacerbating social inequalities. As coastal flooding and erosion become more frequent and widespread, already vulnerable populations are most likely to suffer impacts, such as the elderly, homeless, children, and those economically disadvantaged and with preexisting mental illness; the poor will become increasingly tied to the most at-risk housing.[51]

Impacts to Marine Species and Ecosystems

Ocean warming, acidification, and deoxygenation pose many and varied threats to marine life and ecosystems. These processes work together with localized human-influenced stressors like pollution and nutrient-rich agricultural runoff to create interactive, complex, and sometimes amplified impacts to ecosystems.[52]

Many recent studies show changes in abundance, distribution, and type of marine species across all ocean basins.[53] Ocean warming is causing marine fishes, invertebrates, and phytoplankton to shift distributions poleward and/or to deeper, cooler waters.[54] Further, ocean acidification impairs the ability of shelled organisms, such as corals and shellfish, to build their shells, reduces growth and survival rates in some species, is linked to behavior changes in some fishes, and may exacerbate other physiological stresses.[55] In addition to these changes, phytoplankton production

[44] NCA4; Volume II; Ch. 8
[45] NCA4; Volume II; Ch. 8
[46] NCA4; Volume II; Ch. 8
[47] NCA4; Volume II; Ch. 8
[48] NCA4; Volume II; Ch. 4
[49] NCA4; Volume II; Ch. 8
[50] Phys.org. December 16, 2014. "Ocean acidification a culprit in commercial shellfish hatcheries' failures." https://phys.org/news/2014-12-ocean-acidification-culprit-commercial-shellfish.html
[51] NCA4; Volume II; Ch. 8
[52] IPCC AR5
[53] IPCC AR5
[54] IPCC AR5
[55] IPCC AR5

may be enhanced in some regions due to access to more carbon dioxide, further disrupting ecosystems.[56] Coastal ecosystems like coral and oyster reefs, kelp forests, mangroves, and salt marshes that provide habitat, carbon sequestration, and shoreline protection from storms are also vulnerable to climate impacts.[57]

Oxygen availability plays a key role in structuring marine ecosystems, since nearly all life depends on oxygen. Therefore, deoxygenation will have significant impacts to marine species and ecosystems, especially those that cannot migrate away from low oxygen zones.[58] Some marine organisms are more tolerant to low oxygen than others, such as jellyfish and squid, while others require high levels of oxygen, like fish and crustaceans.[59] Expansion of oxygen minimum zones in the tropical Pacific, Atlantic and Indian Oceans are constraining fish habitat.[60]

While climate change-driven ecosystem impacts are pervasive across the oceans, tropical coral reefs and polar sea ice ecosystems are experiencing the fastest changes from warming.[61] Warm-water coral reefs host approximately 25 percent of the ocean's biodiversity and are in decline globally due to warm water-induced coral bleaching and diseases, impacting iconic habitats and important fisheries.[62] Sea ice loss is occurring at fast rates, causing the loss of habitat for polar bears and ringed seals and disrupting the yearly phytoplankton blooms at ice edge that drive the entire ecosystem.[63] Polar oceans experience the fastest acidification because cold water holds more dissolved gas (carbon dioxide).[64] As a result, an important polar food source, the pteropod, has already demonstrated thinner shells due to ocean acidification.[65]

Across the oceans, many plant and animal species face a high extinction risk due to climate change because they will be unable to migrate fast enough or adapt to the rapid rates of change this century under mid- and high range scenarios.[66] The IPCC's 5th Assessment Report (AR5) found that even natural global climate changes over the past millions of years, which occurred at much lower rates than current anthropogenic climate change, caused significant ecosystem changes and species extinctions.

Impacts to the Great Lakes

The Great Lakes contain 84 percent of North America's surface fresh water,[67] providing drinking water to more than 35 million people and supporting important economic and cultural services

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[56] IPCC AR5
[57] NCA4; Volume II; Ch. 9
[58] Breitburg, D., et al. (2018). "Declining oxygen in the global ocean and coastal waters." Science, Vol. 359, Issue 6371. DOI: 10.1126/science.aam7240
[59] Vaquer-Sunyer, R., Duarte, C.M. (2010). "Temperature effects on oxygen thresholds for hypoxia in marine benthic organisms." Global Change Biology. https://doi.org/10.1111/j.1365-2486.2010.02343.x
[60] IPCC AR5
[61] NCA4; Volume II; Ch. 8
[62] NCA4; Volume II; Ch. 8
[63] NCA4; Volume II; Ch. 8
[64] NCA4; Volume I; Ch. 13
[65] IPCC AR5
[66] IPCC AR5
[67] EPA.gov. January 31, 2019. "Facts and figures about the Great Lakes." https://www.epa.gov/greatlakes/facts-and-figures-about-great-lakes

such as shipping, fishing and recreation.[68] In recent decades, the Great Lakes region has experienced notable changes linked to anthropogenic carbon emissions. Air temperatures have risen 2°F in the region this century,[69] with water temperatures rising even faster, increased summer evaporation rates, declining water levels,[70] and decreasing lake ice cover.[71]

Warmer waters also promote freshwater harmful algal blooms (HABs), which are already becoming problematic in Lake Erie[72] in concert with agricultural runoff. HABs threaten fish, wildlife, and human health.[73] Warming due to climate change is also increasing the duration of stratification of the water, which may fully stop this mixing leading to aquatic species declines. Climate change is tending to make dry regions of the Great Lakes drier and wet parts wetter and increase extreme precipitation events.[74] The Great Lakes are most at risk when these climate stressors interact with land use change, habitat loss, pollution, excess nutrients, and invasive species.

Additional Reading

Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Sites Worldwide
https://www.serdp-estcp.org/Program-Areas/Resource-Conservation-and-Resiliency/Infrastructure-Resiliency/Regional-Sea-Level-Scenarios-for-Coastal-Risk-Management

Coasts, water levels, and climate change: A Great Lakes perspective
https://www.glerl.noaa.gov/pubs/fulltext/2013/20130021.pdf

Climate Impacts on US Living Marine Resources
https://spo.nmfs.noaa.gov/sites/default/files/tm89.pdf

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[68] NCA4; Volume II; Ch.21
[69] Walsh, J., et al. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. J. M. Melillo, T. C. Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program.
[70] Seagrant.umn.edu. February 23, 2015. "Climate change and Lake Superior." http://www.seagrant.umn.edu/climate/superior
[71] NCA4; Volume II; Ch.21
[72] NOAA.gov. "Harmful algal blooms (HABs) in the Great Lakes." https://www.glerl.noaa.gov/pubs/brochures/NOAA_HABs_in_Great_Lakes.pdf
[73] NCA4; Volume II; Ch.21
[74] UMich.edu. "Extreme precipitation." http://glisa.umich.edu/climate/extreme-precipitation

Chairwoman FLETCHER. The hearing will come to order.

Without objection, the Chair is authorized to declare a recess at any time.

Good morning. Welcome to the Environment Subcommittee's first hearing of the 116th Congress. This hearing is entitled, "Sea Change: Impacts of Climate Change on Our Oceans and Coasts." Building on the momentum of our first full Committee hearing on the State of Climate Science, today we'll be discussing how climate change is impacting our oceans and coasts. This is an important topic, and I want to convey a few things as we begin. First, every American should care about changes to the oceans, even those who do not live along the coasts. Second, we are already seeing visible changes and paying a very real price. Climate change impacts are here, happening now, not far-off events for future generations to address. And those impacts can be seen in our oceans and coasts.

According to NOAA (National Oceanic and Atmospheric Administration), nearly half of Americans live along our 95,471 miles of coastline, which span three oceans, the Gulf of Mexico, the Great Lakes, and the Pacific and Caribbean islands. And more people are moving to the coasts each year. The Fourth National Climate Assessment (NCA) found that coastal zones employ 134 million people and contribute a staggering $16.7 trillion to our national gross domestic product. And for the other half of Americans who don't live on the coast, the oceans and coasts impact them directly and indirectly, too, providing economic, recreational, and cultural opportunities. There's a lot to lose—not only for the environment, but for our thriving economy and communities—by failing to address climate change impacts on our oceans and coasts.

As science has established, climate change is real, it's happening, and it's caused primarily by human activity. NOAA just reported last month that 2018 was the fourth-hottest year on record. Many people don't realize that global warming would be significantly worse without the buffering effects of the oceans. Oceans act like a big sponge, soaking up much of the excess carbon dioxide and heat in the atmosphere. In fact, the International Union for Conservation of Nature found that if the excess heat trapped by the oceans between 1955 and 2010 were released back into the lower atmosphere, the temperature would warm up nearly 97 °Fahrenheit. The oceans are protecting us from climate change's impacts by buffering against this increase in temperature, but this buffering is causing major changes to the oceans.

Increased carbon emissions alter the oceans in three main ways: Making them warmer, more acidic, and less oxygenated. These changes are occurring at unprecedented rates. For example, according to research published in the journal Science, the chemistry of the oceans is changing faster now than in the last 300 million years.

Climate change has now claimed its first mammal in a way directly related to today's hearing. Just last week, the Australian Government reported that the Bramble Cay mosaic-tailed rat, a small rodent, was driven to extinction. Their island home became inundated with saltwater from rising sea levels, causing their food and shelter to disappear. The threats of sea-level rise, ocean warming, acidification, and deoxygenation are far-reaching, and many marine species face risk of extinction as these changes occur faster than most species can adapt.

In Texas' 7th Congressional District, which I have the privilege to represent, we're seeing some of the earliest effects of coastal climate change, and we stand to face great risks as the fourth-largest city and biggest energy exporter in the United States. At just 50 feet above sea level and as one of the flattest cities in America, Houston already experiences heavy rainfall, and our region faces the threat of storm surge, increasing the risk and the reality of flooding. Hurricane Harvey set the record for total rainfall from a tropical cyclone in the continental United States. Climate change is intensifying storms—making so called 1,000-year storms like Harvey more frequent—and causing sea levels to rise in Galveston Bay. According to the Fourth National Climate Assessment published in November, sea-level rise along the Texas Gulf Coast is twice as large as the global average. Experts are warning cities that cities like ours don't have that much time to adapt.

That's why I am glad we're here today to hear from our distinguished panel. I would like to welcome our witnesses this morning. Some of our scientific witnesses have been involved in writing and reviewing major climate change reports—the National Climate Assessment and the IPCC (Intergovernmental Panel on Climate Change) Assessment Report—and are here to summarize some of the major findings on ocean and coastal changes. We will also hear from a representative of a coastal industry whose experience of these issues is instructive for us all.

I was encouraged in our first Committee hearing to hear interest from Members on both sides of the aisle toward developing solutions and technologies to address climate change. Adaptation and mitigation are very important. They're important parts of this conversation, and with today's hearing, we're laying the foundation for future discussions that will lead us to legislative solutions.

[The prepared statement of Chairwoman Fletcher follows:]

U.S. HOUSE OF REPRESENTATIVES COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Opening Statement

Chair Lizzie Fletcher (D-TX)
of the Subcommittee on Environment

Subcommittee on Environment Hearing:
"Sea Change: Impacts of Climate Change on Our Oceans and Coasts"
February 27, 2019

Good morning, and welcome to the Environment Subcommittee's first hearing of the 116th Congress. Building on the momentum of our first full Committee hearing on the State of Climate Science, today we'll be discussing how climate change is impacting our oceans and coasts. This is an important topic, and I want to convey a few things as we begin: First, every American should care about changes to the oceans, even those who do not live along the coast. Second, we are already seeing visible changes and paying a very real price. Climate change impacts are here—happening now—not far-off events for future generations to address. And those impacts can be seen in our oceans and our coasts.

According to NOAA, nearly half of Americans live along our 95,471 miles of coastline, which span three oceans, the Gulf of Mexico, the Great Lakes, and the Pacific and Caribbean islands. And more people are moving to the coasts each year. The Fourth National Climate Assessment found that coastal zones employ 134 million Americans and contribute a staggering $16.7 trillion to our national gross domestic product. And for the other half of Americans who don't live on the coast, the oceans and coasts impact them directly and indirectly, too, providing economic, recreational, and cultural opportunities. There's a lot to lose – not only for the environment, but also for our thriving economy and communities – by failing to address climate change impacts on our oceans and coasts.

As science has established, climate change is real, it's happening, and it's caused primarily by human activity. NOAA just reported last month that 2018 was the fourth hottest year on record. Many people don't realize that global warming would be significantly worse without the buffering effects of the oceans. Oceans act like a big sponge, soaking up much of the excess carbon dioxide and heat in the atmosphere. In fact, the International Union for Conservation of Nature found that if the excess heat trapped by the oceans between 1955 and 2010 were released back into the lower atmosphere, the temperature would warm up nearly 97 degrees Fahrenheit. The oceans are protecting us from climate change's impacts by buffering against the increase in temperature, but this buffering is causing major changes to the oceans.

Increased carbon emissions alter the oceans in three main ways, making them warmer, more acidic, and less oxygenated. These changes are occurring at unprecedented rates. For example, according to research published in the journal *Science*, the chemistry of the oceans is changing faster now than in the last 300 million years.

Climate change has now claimed its first mammal in a way directly related to today's hearing. Just last week, the Australian government reported that the Bramble Cay mosaic-tailed rat, a small rodent, was driven to extinction. Their island home became inundated with saltwater from rising sea levels, causing their food and shelter to disappear. The threats of sea level rise, ocean warming, acidification, and deoxygenation are far-reaching, and many marine species face risk of extinction as these changes occur faster than most species can adapt.

In Texas's Seventh Congressional District, which I have the privilege to represent, we are seeing some of the earliest effects of coastal climate change, and we stand to face great risks as the fourth largest city and biggest energy exporter in the United States. At just 50 feet above sea level and as one of the flattest cities in America, Houston already experiences heavy rainfall, and our region the threat of storm surge – increasing the risk and reality of flooding. Hurricane Harvey set the record for total rainfall from a tropical cyclone continental U.S. Climate change is intensifying storms – making so called 1,000 year storms like Harvey more frequent - and causing the sea levels to rise in Galveston Bay. According to the Fourth National Climate Assessment published in November, sea level rise along the Texas Gulf Coast is twice as large as the global average. Experts are warning cities like ours don't have that much time to adapt.

That is why I am glad we are here today to hear from our distinguished panel. I would like to welcome our witnesses this morning. Some of our scientific witnesses have been involved in writing and reviewing major climate science reports – the National Climate Assessment and the IPCC Assessment Report – and are here to summarize some of the major findings on ocean and coastal changes. We will also hear from a representative of a coastal industry whose experience of these issues is instructive for us all.

I was encouraged in our first Committee hearing to hear interest from Members on both sides of the aisle toward developing solutions and technologies to address climate change. Adaptation and mitigation are very important parts of this conversation, with today's hearing laying the foundation for future discussions that will lead us to legislative solutions.

Chairwoman FLETCHER. The Chair now recognizes Mr. Marshall for an opening statement.

Mr. MARSHALL. Thank you so much, Chairwoman Fletcher, for holding this hearing today to discuss a nuanced and significant issue. First off, I want to congratulate you on your appointment to Chair the Environment Subcommittee. I look forward to working with you.

In this Committee, we may not always agree on everything, but I hope that we can agree on objectives and goals. Our objectives should be thoroughly—be to thoughtfully listen to the science and theories surrounding these topics. And our goal, at least in my opinion, should be to leave this environment of this country and the world better than we found it for our children, our grandchildren, and future generations so that we can all flourish.

I was just reminded this past week. I was—I got to help my grandson catch his first fish in the ocean. One of my loves is fishing and tasting the outdoors, so it was great to be able to do that. But I have to be honest; the closest thing we have to oceans in the State of Kansas are amber waves of grain. So this is a unique opportunity for me to learn about the relationship between climate and the ocean. I'm looking forward to hearing from our witnesses today and hope we can find a way to talk constructively about these issues and, more importantly, about potential solutions.

Oceans cover more than 70 percent of the Earth and contain more than 90 percent of life on our planet. Oceans, more specifically phytoplankton, produce most of the oxygen that we breathe and absorb most of the carbon dioxide from the Earth's atmosphere, creating a constant cycle of oxygen and CO_2.

I have to tell you I was giddy when I got to read some of your reports and go back to some of my biochemistry days. And it just brought me back to my college days in so many ways and just really, really enjoyed the papers. I know Congressmen aren't supposed to be excited about science, but I really am.

Like plant and animal life on land, marine life and oceans themselves evolve. The chemistry and ecology change and life adapts. It's been happening for millions of years, but unfortunately, scientific evidence suggests that the pace of change, like the Chairwoman said, has increased over the last century, adding more stress to our complex marine ecosystems.

Some of this stress is the result of increased levels of carbon dioxide and other greenhouse gases in the atmosphere that are absorbed by the ocean. The result is a change in the chemistry of the oceans in which researchers have noted increased water temperature, lower pH levels, and decreased oxygen levels in certain areas.

It's essential that we gain a better understanding of ocean chemistry, effectiveness of potential solutions, and mitigation of negative impacts. For instance, some species are proving more resilient and adaptable to changing conditions. One of our goals should be to better understand this resiliency and find ways to translate this knowledge to broader ecosystem sustainability.

One of our witnesses, Dr. Tom Frazer, is the Director of the University of Florida's School of Natural Resources and Environment. He will go into detail on his research to help us all better understand the impacts and changes in aquatic ecosystems, as well as discuss some of the potential solutions to maximize environmental and economic value of our oceans.

I believe advancing technology is the best path forward. As we speak, industry and governments around the world are examining carbon removal and carbon storage technology. There are some big ideas out there from direct air capture to genetically modified phytoplankton and giant kelp farms, which I'm especially interested to hear about, in the ocean that can absorb carbon dioxide. We learned during our hearing 2 weeks ago that moving entirely to renewables is not realistic or sustainable, so we must consider solutions like these that can help reduce or remove emissions generated around the globe.

Researching, developing, and deploying these technologies will take a little time, but the payoff will be significant. Innovating our way to solutions has been a trademark of the American spirit since our country's inception. For example, in my practice as an obstetrician I have seen how private innovation and response to market demand have done more to improve and drive down the cost of healthcare than any law or regulation written here in D.C.

Just look at the evolution of medical imaging. Forty years ago, MRI machines and CAT scanners were just hitting the market. But now we have high-resolution, microscopic cameras that reduce the need for invasive surgeries and provide us a window into human health in ways that we never thought or I dreamed possible.

Basic research, industry innovation, and thriving marketplace are what brought these technologies and others like it into our lives, not government regulation. We need to prioritize instruments that target the most impactful areas of research and provide specific steps for resiliency planning. America must lead the way and partner with industry to develop innovative technologies and solutions to the problems discussed here today.

I thank our witnesses for being here today, and I yield the balance of my time. Thank you.

[The prepared statement of Mr. Marshall follows:]

Opening Statement of Ranking Member Roger Marshall at Environment Subcommittee Hearing on Ocean Health

Feb 27, 2019

Opening Statement

Thank you, Chairwoman Fletcher, for holding this hearing today to discuss a nuanced and significant issue. First off, I want to congratulate you on your appointment to chair the Environment Subcommittee. I look forward to working with you this Congress.

On this committee, we may not always agree on everything, but I hope we can agree on objectives and goals. Our objectives should be to thoughtfully listen to the science and theories surrounding these topics. And our goal, at least in my opinion, should be to leave the environment of this country and the world better than we found it for our children, grandchildren, and future generations so that they can flourish!

I have to be honest—the closest thing we have to oceans in my home state of Kansas are "amber waves of grain." So this is a unique opportunity for me to learn about the relationship between climate and the oceans. I'm looking forward to hearing from our witnesses today and I hope we can find a way to talk constructively about these issues and—more importantly—about potential solutions.

Oceans cover more than seventy percent of the earth and contain more than ninety percent of life on our planet. Oceans, more specifically phytoplankton, produce most of the oxygen that we breathe, and absorb most of the carbon dioxide from the earth's atmosphere, creating a constant cycle of oxygen and CO_2. Accordingly, it is impossible to overstate the importance of ocean health.

Like plant and animal life on land, marine life and oceans themselves evolve. The chemistry and ecology change and life adapts. It has been happening for millions of years. Unfortunately, scientific evidence suggests that the pace of change has increased over the last century, adding more stress to our complex marine ecosystems.

Some of this stress is the result of increased levels of carbon dioxide and other greenhouse gasses in the atmosphere that are absorbed by the ocean. The result is a change in the chemistry of the oceans in which researchers have noted increased water temperature, lower pH levels, and decreased oxygen levels in certain areas.

It is essential that we gain a better understanding of ocean chemistry, effectiveness of potential solutions, and mitigation of negative impacts. For instance, some species are proving more resilient and adaptable to changing conditions. One of our goals should be to better understand this resiliency and find ways to translate this knowledge to broader ecosystem sustainability.

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Researching, developing, and deploying these technologies will take a little time, but the payoff will be significant. Innovating our way to solutions has been a trademark of the American spirit since our country's inception. For example, in my practice as an obstetrician I have seen how private innovation and response to market demand have done more to improve and drive down the cost of healthcare than any law or regulation written here in D.C.

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Basic research, industry innovation, and a thriving marketplace are what brought these technologies and others like them into our lives, not government regulation. We need to prioritize investments that target the most impactful areas of research and provide specific steps for resiliency planning.

America must lead the way and partner with industry to develop innovative technologies and solutions to the problems discussed here today. I thank our witnesses for being here today and I yield the balance of my time.

Chairwoman FLETCHER. Thank you, Mr. Marshall.

The Chair now recognizes the Chairwoman of the full Committee, Ms. Johnson, for an opening statement.

Chairwoman JOHNSON. Thank you very much, Ms. Fletcher, and congratulations on your first Subcommittee meeting. And let me say, too, let me welcome the witnesses but also welcome to our former Subcommittee Ranking Member Ms. Bonamici, who has prepared legislation in this area. I'm pleased to join you this morning.

Two weeks ago we had our first climate change-related hearing on the "State of Climate Science and Why It Matters." That fruitful hearing was a broad overview of the myriad of ways climate change is affecting multiple aspects of the environment and our society. Today, we continue in that same vein and look specifically at the science and how the anthropogenic carbon emissions are affecting our oceans and coasts.

NOAA has found that almost 40 percent of the U.S. population lives in coastal counties. I'm not one of those. We have manmade lakes for drinking water where I live in north Texas. But we do have a very large coastal area at the other end of the State. From the white sand beaches of Florida to the rocky shorelines of the Pacific Northwest, our coasts are not only iconic, popular tourist destinations, but also economic powerhouses of the Nation. Coastal counties contribute $6.6 trillion to our economy. Given the clear societal and economic importance of our oceans and coastal communities, it is imperative that we work to protect these resources.

But our coastal communities are already seeing impacts of climate change. Ocean warming due to the anthropogenic carbon dioxide emissions is responsible for rising sea levels, melting sea ice, and lower oxygen concentrations in our seawater. Warmer ocean temperatures also fuel stronger storms, which can lead to additional coastal damage from hurricanes. The findings from the Fourth National Climate Assessment were very clear: Cutting our emissions of greenhouse gases will significantly and quickly help stave off the most severe potential impacts of climate change. Laying the foundation of the current state of science on our oceans and coasts in this hearing will help us better understand what we can expect to see if we do not act to mitigate our carbon emissions now.

During the first hearing, many of my colleagues on both sides of the aisle were excited to discuss potential solutions to the climate challenges that many of us are starting to face in our districts. However, in order to come up with robust solutions to the rapid changes we are seeing in our oceans and coastal communities, it is critical that we understand what is driving these changes. Successful mitigation and adaptation solutions will be based on robust science.

I'm looking forward to having another productive hearing on climate change today, and I'm especially interested in receiving testimony from our expert scientific witnesses on how climate change is affecting sea-level rise, the physical and chemical processes within our oceans, and marine ecosystems. I am also glad to have a representative from the Pacific Coast Shellfish Growers Association to speak about concrete evidence of climate change impacts on their livelihood, and how they utilized science to develop solutions to this pressing issue.

The diverse perspectives provided by our witnesses will help guide the Members of this Committee as we work to develop bipartisan policy solutions to address climate change and ocean acidification based on sound science and ensure there is significant Federal funding for climate research.

I thank you, Madam Chair, and yield back.

[The prepared statement of Chairwoman Johnson follows:]

Opening Statement
Chairwoman Eddie Bernice Johnson
House Committee on Science, Space, and Technology
Environment Subcommittee Hearing

Sea Change: Impacts of Climate Change on Our Oceans and Coasts
February 27, 2019

Thank you Madam Chair, and I would also like to join you in welcoming our witnesses this morning.

Two weeks ago we had our first climate change related hearing on the "*State of Climate Science and Why It Matters.*" That fruitful hearing was a broad overview of the myriad ways climate change is affecting multiple aspects of the environment and our society. Today, we continue in that same vein and look specifically at the science of how anthropogenic carbon emissions are affecting our oceans and coasts.

NOAA has found that almost 40 percent of the U.S. population lives in coastal counties. From the white sand beaches of Florida to the rocky shorelines of the Pacific Northwest, our coasts are not only iconic, popular tourist destinations, but also economic powerhouses of the nation. Coastal counties contribute $6.6 trillion to our economy. Given the clear societal and economic importance of our oceans and coastal communities, it is imperative we work to protect these resources.

But, our coastal communities are already seeing impacts of climate change. Ocean warming due to anthropogenic carbon dioxide emissions is responsible for rising sea levels, melting sea ice, and lower oxygen concentrations in our seawater. Warmer ocean temperatures also fuel stronger storms, which can lead to additional coastal damage from hurricanes. The findings from the Fourth National Climate Assessment were very clear; cutting our emissions of greenhouse gasses will significantly and quickly help stave off the most severe potential impacts of climate change. Laying the foundation of the current state of science on our oceans and coasts in this hearing will help us better understand what we can expect to see if we do not act to mitigate our carbon emissions now.

During that first hearing, many of my colleagues on both sides of the aisle were excited to discuss potential solutions to the climate challenges that many of us are starting to face in our districts. However, in order to come up with robust solutions to the rapid changes we are seeing in our oceans and coastal communities, it is crucial that we understand what is driving these changes. Successful mitigation and adaptation solutions will be based on robust science.

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The diverse perspectives provided by our witnesses will help guide the Members of this Committee as we work to develop bipartisan policy solutions to address climate change and ocean acidification based on sound science and ensure there is sufficient federal funding for climate research.

Thank you, and I yield back.

Chairwoman FLETCHER. Thank you, Chairwoman Johnson.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

At this time, I'd like to introduce our witnesses. Our first witness is Dr. Sarah Cooley, the Director of the Ocean Acidification Program at the Ocean Conservancy. Dr. Cooley is an expert on the impacts of ocean climate change on human communities and her research spans ocean climate—and her research spans ocean carbon cycling, science communication, and science-based policy development. Dr. Cooley was a lead author on the Second State of the Carbon Cycle Report and review editor on volume 2 of the Fourth National Climate Assessment, both released last November. She's also a lead author on the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, or IPCC, which will be complete in 2021. Dr. Cooley received her Ph.D. in marine science from the University of Georgia.

Our second witness is Dr. Radley Horton, who is Lamont Associate Professor—Research Professor at Columbia University's Lamont-Doherty Earth Observatory. His research focuses on climate extremes, sea-level rise, tail risks, climate impacts, sea-level rise, and adaptation. Dr. Horton was a convening lead author for the Third National Climate Assessment. He currently co-chairs Columbia University's Climate Adaptation Initiative and is Principal Investigator for the NOAA Regional Integrated Sciences and Assessments-funded Consortium for Climate Risk in the Urban Northeast. He received his Ph.D. in earth and environmental sciences from Columbia University.

Our third witness is Dr. Thomas K. Frazer, who is Professor and Director of the School of Natural Resources and Environment at the University of Florida. His research examines water quantity and quality, nutrient dynamics, biogeochemical processes, fish population dynamics, food web interactions, and ecological restoration of degraded ecosystems. He's conducted field research in both freshwater and marine systems around the globe and is intimately familiar with environmental and resource challenges, including coral bleaching, ocean acidification, and sea-level rise. He received his Ph.D. in biological sciences from the University of California Santa Barbara.

Our final witness is Ms. Margaret Pilaro, who has served as the Executive Director of the Pacific Coast Shellfish Growers Association, or PCSGA, since 2010. PCSGA represents over 100 shellfish companies who sustainably produce mussels, oysters, clams, and geoduck in the States of Alaska, Washington, Oregon, California, and Hawaii. Prior to her current role, she worked for the Washington State Department of Natural Resources for 12 years and as a municipal planner in Rhode Island where she dealt with storm and wastewater issues, restoring the fishery, and harbor management. Ms. Pilaro received an M.A. in marine affairs from the University of Rhode Island. Welcome to all of you.

As our witnesses should know, you will each have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When you all have completed your spoken testimony, we will begin with questions. Each Member will have 5 minutes to question the panel. Thank you so much for being here. We'll begin this morning with Dr. Cooley.

TESTIMONY OF DR. SARAH COOLEY, DIRECTOR, OCEAN ACIDIFICATION PROGRAM, OCEAN CONSERVANCY

Dr. COOLEY. Thank you, Chairwoman. Good morning. My name is Dr. Sarah Cooley, and I'm a chemical oceanographer and Director of the Ocean Acidification Program at Ocean Conservancy. I have studied the ocean carbon cycle for 18 years. I'm an expert on the impacts of ocean climate change on ecosystem services, a lead author on the Second State of the Carbon Cycle Report, and the upcoming Sixth Assessment Report of the IPCC, and I'm a review editor on the Fourth National Climate Assessment.

That report, mandated by Congress, offers three key ocean messages, which I'll explain in my testimony. First, the Nation's ocean ecosystems are being disrupted by rising temperatures, acidification, deoxygenation, and other aspects of climate change, and this will worsen. Second, the Nation's fisheries are at high risk from climate-driven changes. Third, extreme events due to climate are already harming important fisheries.

Our ocean is experiencing unprecedented changes. Rising temperatures and absorption of greenhouse gases is impacting the ocean's ability to sustain human communities and modulate the Earth's climate. The ocean has absorbed 93 percent of the heat energy trapped by greenhouse gases in the atmosphere. Despite this, our planet has still warmed by 1.8 degrees Fahrenheit since the turn of the last century. The ocean has also absorbed 22 percent of the atmospheric carbon dioxide released by human activity this decade.

While this has slightly reduced the planetary warming that would have otherwise occurred, it's also changing the chemistry of the ocean. When carbon dioxide dissolves, it lowers seawater pH and alters chemical balances important for marine life. This is called ocean acidification. In the mid–2000s, widespread death of larval shellfish at hatcheries in Washington State and Oregon was definitively attributed to ocean acidification.

We now know that ocean acidification causes many animals with hard shells and skeletons like corals and shellfish to grow more slowly and recover from damage less successfully. Some fishes and sharks become less able to find prey or avoid predators. Harmful algal blooms could become more frequent or toxic. Complex and hard-to-predict interactions occur among ocean acidification and other stressors, especially in the coastal zone. All of this can and already does impact human communities by disrupting fisheries, tourism, and more.

Ocean heat absorption is also warming seawater and melting sea ice. This causes sea-level rise, and is changing ocean ecosystems and their benefits to people. Warmer ocean water holds less oxygen and allows less of the deep vertical mixing that normally moves oxygen into the ocean. Without enough oxygen in the ocean, ocean species will die. Warming oceans are driving our marine life north at about 5 miles a decade, but American lobsters have shifted north at 43 miles per decade. Rapidly shifting fisheries are very hard to manage, and these strain fishing-dependent communities. Sea ice is melting, causing ice-dependent species to lose key habitats and Arctic waters to warm even more. Subsistence hunting will become dangerous and difficult, which threatens indigenous communities' food security and ways of life. Decreasing sea ice also allows more Arctic vessel traffic, bringing opportunities and risks.

This Committee can make a difference immediately by supporting science that focuses on solutions on how best to apply them, as well as continuing to support research that uncovers how the ocean–human system works. The common theme in the research recommendations detailed in my written testimony is that we need to understand how to apply individual findings to ecosystem scales and how to use that knowledge in an equitable, well-planned approach that will reduce the stress from ocean climate change on marine ecosystems and the human communities they support.

The fundamental solution to ocean climate change is to decrease emissions, particularly of carbon dioxide. That is a formidable global challenge. But the United States is the home of modern oceanography. After the World Wars, we unraveled the secrets of the deep oceans to gain a global military edge. In doing so, we have learned how our planet works. With this rich history, I have no doubt that the United States is up to the task of understanding and addressing climate change, the ocean challenge of today.

Thank you for the opportunity to provide this testimony.

[The prepared statement of Dr. Cooley follows:]

WRITTEN TESTIMONY OF

SARAH COOLEY, OCEAN CONSERVANCY

OCEAN ACIDIFICATION DIRECTOR

HEARING ON:

SEA CHANGE: IMPACTS OF CLIMATE CHANGE ON OUR OCEANS AND COASTS

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY, SUBCOMMITTEE ON ENVIRONMENT

February 27, 2019

Thank you for the opportunity to testify here today. My name is Dr. Sarah Cooley, and I am the Director of the Ocean Acidification Program at Ocean Conservancy. Previously, I was a Research Associate III at Woods Hole Oceanographic Institution, a private, independent ocean research institution. I am an expert on the impacts of ocean climate change on human communities, and served as a lead author on the 2nd State of the Carbon Cycle Report and a review editor on Volume II of the 4th National Climate Assessment. Additionally, I am a lead author on the 6th Assessment Report of the Intergovernmental Panel on Climate Change, which will be complete in 2021.

Ocean Conservancy is a 501(c)(3)nonprofit organization that creates science-based solutions for a healthy ocean and the wildlife and communities that depend on it. For over 40 years, Ocean Conservancy has been deeply engaged in supporting action at the local, national, and global level to the greatest challenges facing our ocean.

Unfortunately, our ocean and the people who depend on it are facing unprecedented challenges. The ocean is a system at risk, struggling to keep pace with rising temperatures, pollution, and the absorption of greenhouse gases. With this testimony, I will describe the state of the science on ocean change as it relates to acidification, warming, and deoxygenation. I will also summarize the main findings of the "Oceans and Marine Resources" Chapter of the 4th National Climate Assessment ("Fourth National Climate Assessment" 2018), a report which is designed to serve as an authoritative assessment on the science and impacts of climate change, with a focus on the United States, and provides important context for understanding the impact of climate change on the ocean and its resources. I will conclude by identifying research gaps in measuring and understanding ocean change that, if addressed, will create a stronger base of scientific evidence from which we can develop responses to better manage the impacts of ocean change.

1. State of the Science

The ocean has absorbed many of the most immediate consequences of carbon pollution, buffering us from some of its most damaging impacts. The ocean has absorbed 93% of the total excess heat energy taken up by greenhouse gas in the atmosphere ("Climate Science Special Report: Fourth National Climate Assessment, Volume I." 2017, chap. 13).[1] Despite this, solar radiation has still heated the

[1] Henceforth, references to the Climate Science Special Report will be abbreviated "CSSR," and the Fourth National Climate Assessment will be abbreviated "NCA4".

atmosphere, land, and ocean surfaces of our planet by about 1.8°F from 1901-2016 (NCA4, chap. 2). At the same time, the ocean has absorbed 22% of the atmospheric carbon dioxide released as waste from fossil fuel burning and land use change from 2008-2017 (Quéré et al. 2018). While this has kept those fossil fuel emissions from warming the atmosphere, it is also fundamentally changing the chemistry of the ocean via ocean acidification.

1.1 Ocean Acidification

Ocean acidification is an invisible but growing threat to the world's oceans. Time-series measurements show clearly that the dissolved carbon dioxide concentration of surface ocean water is rising at the same pace as atmospheric carbon dioxide concentrations (Figure 1). When carbon dioxide dissolves in water, carbonic acid is created, which is gradually lowering the pH of seawater and altering other chemical balances important for marine life.

We are already seeing the effects of ocean acidification. In the mid-2000s, widespread death of larval shellfish at hatcheries in the Pacific Northwest region of the United States alerted the aquaculture industry to a major region-wide problem. In partnership with federal and university researchers, the industry identified the problem as ocean acidification caused by fossil fuel emissions dissolved in Pacific Ocean water that upwelled to the surface decades earlier than previously anticipated (Feely et al. 2008). This finding, plus growing evidence of the ocean's role in taking up a large portion of the annual emissions from fossil fuel burning (e.g., Quéré et al. 2018), helped kick off a nationwide effort to understand ocean acidification's full impacts on marine ecosystems. In 2009, Congress took action to better understand the issue by passing the *Federal Ocean Acidification Research and Monitoring Act* (or FOARAM), which provided for a coordinated response by U.S. federal scientific agencies to understand, track, and address ocean acidification.

Since then, laboratory studies, many of them supported by the federal funding authorized by FOARAM, have shown that ocean acidification has an array of effects on marine species, and the effects are difficult to generalize. Global studies have determined with high confidence that increasing atmospheric carbon dioxide causes ocean acidification (Figure 2), and that acidification decreases the calcification rate of many organisms with hard shells and skeletons. Corals grow more slowly under acidification and are less able to recover from breakage or loss from heat-driven bleaching or disease. Many animals that sustain lucrative fisheries, such as oysters and crabs like Dungeness, red King, and Tanner crabs, are more sensitive at earlier life stages, and acidification causes them to grow more slowly and allows fewer to survive to adulthood. Ocean acidification changes the behavior of some fishes and sharks, impairing their ability to find prey or avoid predators. Some models suggest acidification will generally reduce fish biomass and catch.

We have high confidence that ocean acidification can stimulate growth and primary production in seagrasses and some phytoplankton. Although increased plankton growth can provide benefits to marine ecosystems, some fast growing species can out-compete others and cause harmful algal blooms. Emerging evidence suggests that harmful algal blooms could become more frequent or toxic in response to acidification.

While it is unclear exactly how ocean acidification's impacts will propagate through ocean ecosystems and food webs, there is no question that complex interactions will occur among ocean acidification and other stressors. That's especially true in the coastal zone where warming, deoxygenation, pollution, river discharge and precipitation, seasons, weather, climate, and tides intersect with human activities like fishing, dredging, development, and restoration. The end result is an especially complex system of environmental drivers that affect coastal systems and the humans that depend on them in ways that are difficult to predict. In addition, the variety of factors at play in the coastal zone often makes it difficult to attribute trends in coastal acidification directly to atmospheric carbon dioxide (Figure 3).

Overall, ocean acidification may disrupt important benefits that ocean systems and resources provide to human communities. Coral reef-associated fisheries and tourism are at risk, as well as coastal communities protected from storm waves by corals. Some studies suggest ocean acidification will alter the market qualities of fishery harvests. One study reported changes in flavor of pink shrimp raised under ocean acidification conditions (Dupont et al. 2014), and integrated assessment models show that fishery revenues will decrease if ocean acidification decreases the recruitment or slows the growth of lucrative species like sea scallops and red king or Tanner crab (Cooley et al. 2015; Punt et al. 2014). Studies of the socioeconomic impacts of ocean acidification are fewer in number than studies of its geochemical or biological impacts.

Despite the complexity of predicting ocean and coastal acidification's impacts on marine ecosystems and human communities, an active community has developed to identify, test, and share opportunities to act. In the Pacific Northwest U.S., shellfish hatchery owners have focused on protecting the multi-million dollar-a-year industry that employs thousands of people. Teaming up with researchers, hatcheries have invested in "future proofing" steps such as monitoring seawater chemistry at intake pipes, modifying the chemistry of intake water, and experimenting with selective shellfish breeding. Activities supported by the National Oceanic and Atmospheric Administration (NOAA), and authorized by FOARAM, have developed a rich observing network in the Pacific Northwest and across the nation.[2] This effort allows people who depend on ocean resources to track and respond to acidification and has been likened to "putting headlights on a car."

Engagement of multiple sectors, including university and federal researchers, the shellfish aquaculture community, resource managers and more has been a hallmark of the particularly successful work of adapting to ocean acidification in the U.S. to date. It continues even now: Ocean Conservancy helped convene shellfish industry leaders from across the country last week on the Gulf Coast to share best practices to help the sector plan ahead for ocean acidification.

In the United States, scientists, regional industry and resource management experts, educators, and science communicators are joining largely self-organized groups such as the Global OA Observing Network (GOA-ON) and the regional Coastal Acidification Networks (CANs) that are supported by the NOAA Ocean Acidification program and the U.S. Integrated Ocean Observing System. Lessons learned in one region are being transferred to other regions, accelerating the application of adaptive solutions and technology to monitor ocean acidification. Regional collaboration by the governors' offices of California, Oregon, Washington, and the premier's office of British Columbia recently helped create the International Alliance to Combat Ocean Acidification[3], a voluntary partnership of over 70 governments and nongovernmental organizations dedicated to advancing scientific understanding of acidification, reducing its causes, building adaptation and resiliency, expanding public awareness, and building sustained international support for research, monitoring, and education. At the same time, programs like the International Ocean Acidification Coordination Centre (OA-ICC), supported by the International

[2] http://www.ipacoa.org/Explorer

[3] https://www.oaalliance.org/

Atomic Energy Agency, are increasing international scientific coordination, collaboration, and capacity building.

1.2 Warming:

The increasing heat energy content of the ocean is leading to seawater warming and expansion, along with sea ice melt. A study released this January showed, using multiple different lines of evidence, that ocean heat content is rising more quickly than previous assessments indicated (Cheng et al. 2019). Ocean model projections included in the last IPCC assessment (AR5) had predicted continued steady ocean heat uptake, but the evidence available at the time of AR5's publication, around 2013, showed surface ocean warming had slowed. This was due to redistribution of ocean heat and not reduced ocean heating. The increasing heat content of the ocean is changing ocean circulation, raising sea levels around the world ("Climate Science Special Report: Fourth National Climate Assessment, Volume I." 2017)(hereinafter referred to as CSSR), and affecting biological responses in the ocean from top to bottom.

1.2.1 Impacts of Sea Level Rise on Human Communities

One of the most immediately apparent effects of ocean warming affects coastlines, where sea level is rising. Sea level rise is primarily driven by expansion of warming seawater and melting of land-bound glaciers. Coastal communities in the United States now experience regular flooding, euphemistically called "sunny day flooding" or "king tides." 50 million housing units are within 1/8 of a mile of the coast, and projections suggest that between $66 and $106 billion of real estate value may be underwater by 2050 (NCA4, chap. 8). Moreover, 60,000 miles of roads and bridges are located along the coast (NCA4, chap. 12), many if not most of which will need to be repaired or relocated. These costs will become an increasing economic liability for municipalities and programs like the National Flood Insurance Program, which may become insolvent when properties become unsellable (NCA4, chap. 8). Ocean-dependent businesses like fishing will also be hurt when sea level rise damages or destroys coastal infrastructure like ports, marinas, and docks. And, we are already seeing these costs to our cities and military bases.

The Department of Defense has been studying the potential impacts of climate change on military readiness and installations for decades, having produced at least 64 public reports and assessments on that topic since 1990.[4] Not only is climate change likely to worsen international conflict or complicate military responses, but it will damage key assets like roads, runways, and waterfronts (NCA4, chap. 16). In Hampton Roads Virginia, the nation's largest naval base, Naval Station Norfolk, is at major risk from sea level rise (Office of the Under Secretary of Defense for Acquisition and Sustainment 2019). According to news reports, this is spurring a good deal of innovation and redevelopment in the area,[5] but questions remain about how to help the entire community adapt in a socially and economically equitable way.

Of course, these issues are not confined to military infrastructure. Coastal communities and states throughout the country are already adapting to sea level rise in hope of averting greater costs

[4] https://climateandsecurity.org/resources/u-s-government/defense/

[5] https://insideclimatenews.org/news/15052018/norfolk-virginia-navy-sea-level-rise-flooding-urban-planning-poverty-coastal-resilience; https://insideclimatenews.org/news/10252017/military-norfolk-naval-base-flooding-climate-change-sea-level-global-warming-virginia

associated with flood recovery. In Florida, there are 120,000 properties at risk from frequent tidal flooding (NCA4, chap. 19). Current projections in Florida estimate that between $15 and $23 billion of existing property will likely be underwater by 2050 (Bloomberg et al. 2014, 24). This January, Florida's governor issued an Executive Order to create the Office of Resilience and Coastal Protection, to help prepare Florida's coastal communities and habitats for impacts from sea level rise. In Texas, natural coastal habitats protect about $2.4 billion worth of property and thousands of lives (NCA4, chap. 23) as well as 25 percent of the Nation's refining capacity, four crucial ports, much of the strategic petroleum reserves, and strategic military deployment and distribution installations. The state is planning over $12 billion in sea level rise solutions, which include storm surge protection, drainage and erosion control, and flood mitigation projects.[6]

Migration away from coastal cities is expected to place heavy growth pressure on inland urban centers. A recent modeling study suggests that 1.8 m of sea level rise [slightly more than the 0.3-1.3 m considered very likely to occur by 2100 in NCA4 chap. 2, but much less than the 2.5 m considered physically plausible but whose probability is difficult to determine in the same assessment] could cause Florida to lose more than 2.5 million residents, and Texas to gain nearly 1.5 million additional residents (Hauer 2017). Other sea level rise-impacted communities are already taking steps to leave the coastal zone altogether. In Louisiana, the Biloxi-Choctaw tribe has a $48 million grant from the federal government to develop a plan to relocate residents of Isle de Jean Charles. The island has lost 98% of its landmass since 1955 and has only approximately 320 acres (approximately 1/2 square mile) remaining. The population living on the Island has fallen from 400 to 85 people. Ad hoc migration has resulted in family separation, spreading individuals across southern Louisiana. In addition, the Tribe continues to lose parts of its livelihood and culture, including sacred places, cultural sites and practices, healing plants, traditional foods, and lifeways. (NCA4 chap. 19) In Alaska, the villages of Kivalina, Newtok, Shishmaref, Shaktoolik and others face grave risks from sea level rise and coastal erosion.

1.2.2 Moving marine resources

All along our coastlines, marine life is moving in response to warming oceans. There is a clear northward trend across 360 marine species at a speed of about 5 miles per decade on average (Pinsky et al. 2013). The National Climate Assessment noted that many commercially and recreationally valuable fish and invertebrates are moving poleward or into deeper water, from the net effect of temperature on productivity, recruitment, survivorship, and, in some cases, active movement to follow species' preferred temperature conditions (NCA4 chap. 4). Lobster harvests, for example, have shifted north substantially in the last fifty years, at a speed of 43 miles a decade (Pinsky et al. 2013) and [7]. Shifts in distributions of fisheries stocks can complicate fisheries management and place strain on fishing-dependent communities. Fishermen may try to follow their target species but fishing costs, port locations, regulations, management boundaries, and other factors make it hard for fishers to track species movement (NCA4, chap. 4).

1.2.3 Ocean heat waves

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[6] https://www.estormwater.com/construction-begins-houston-flood-mitigation-projects; http://www.austintexas.gov/department/creek-flooding; http://www.gccprd.com/pdfs/GCCPRD%20Phase%203%20Report%20-%20Recommended%20Actions.pdf

[7] https://www.eurekalert.org/pub_releases/2013-09/pu-mom091113.php

The NCA4 provides details on how America's fisheries are also suffering from extreme heat events. A marine heat wave in the northwestern Atlantic Ocean in 2012, and a heat wave in the northeastern Pacific Ocean during the years 2014-2016, raised temperatures more than 3.6°F [2°C] above the normal range and lasted for several months (NCA4, chap. 19). In the 2012 event, warm temperatures in the Gulf of Maine caused lobster catches to peak 3–4 weeks earlier than usual. The supply chain was not prepared for this early peak, leading to glut of lobster and a severe drop in price. (NCA4, chap. 19) The Northeastern Pacific event included an extensive bloom of a toxic algae species (*Pseudo-nitzschia)* that caused mass mortalities of sea lions and whales and closed the Dungeness crab fishery. When the crab fishery reopened in the spring of 2016, out of step with typical Dungeness fishery open times, increased fishing activity during the spring migration of humpback and gray whales led to more whales becoming entangled in crab fishing gear. Continued warm temperatures in the Gulf of Alaska during 2016 reduced the catch of Pacific cod (NCA4 chap. 19). Overall, marine heat waves are remaking marine ecosystems: for example, warmer water has made sea stars all over the West Coast susceptible to wasting disease, killing the sea stars and allowing their typical prey, sea urchins, to go unchecked and consume vast amounts of kelp (Harvell et al. 2019).

1.2.4. Loss of sea ice

Warming polar oceans are melting sea ice, affecting ecosystems, the planetary heat budget, and human access to the Arctic. In the Arctic Ocean, annual average Arctic sea ice extent has decreased precipitously since the 1980s, and it is likely that there will be an Arctic summer within this century that is sea ice-free (NCA4 chap. 26). Ice-dependent species like Arctic cod, polar bears, and walruses are losing important habitat, which is expected to affect the entire Arctic marine food chain, including Indigenous populations that depend on marine mammals (NCA4 chap. 26). Subsistence hunting will become more dangerous and difficult, which threatens the food security and continuity of ways of life that have existed in communities for millennia. In addition, reductions in sea ice extent increase the Arctic Ocean's ability to absorb solar heat, creating a positive feedback that warms the ocean further (NCA4, chap. 2).

Decreasing sea ice is also facilitating the growth of vessel traffic in the Arctic, including destinational and transarctic shipping. While increasing vessel traffic in the Arctic will bring opportunities and benefits, it also creates risks in this remote region. The National Climate Assessment notes that increased vessel traffic "would bring environmental risks to fisheries and subsistence resources" (NCA4 chap. 26). Transarctic shipping will also create a new avenue for the spread of invasive marine species. From a life and safety perspective, the U.S. Arctic currently lacks deep water ports and has insufficient search and rescue and environmental response capabilities for such a vast and remote region. The U.S. also lacks icebreaking capacity (NCA4 chap. 26)—although Congress has taken the first steps toward remedying that problem by appropriating funds in Fiscal Year 2019 for an Arctic icebreaker.

1.3. Deoxygenation

Ocean oxygen levels are declining because of ocean warming. First, warmer water holds less oxygen because gas solubility decreases as temperature rises. Second, ocean warming helps discourage deep vertical mixing by stratifying, or increasing the top-to-bottom density difference, of the ocean water column. Vertical mixing is the main way oxygen moves into the ocean. Warming and stratification also cause ecosystem changes that alter photosynthesis and respiration, further changing oxygen dynamics (NCA4, chap. 4). Researchers recently noted that ocean deoxygenation may cause short-term increases in fishery catch, as fish stocks are easier to target when squeezed into shrinking areas where oxygen levels are adequate, but ultimately ocean deoxygenation will lead to unsustainable changes as the suitable habitat shrinks (Breitburg et al. 2018).

Oxygen loss from the ocean can also affect the global nitrogen cycle. As ocean oxygen declines, nitrous oxide production may increase. Nitrous oxide is even better than carbon dioxide at trapping solar energy, so an increase in nitrous oxide production would exert an intensifying feedback on planetary warming (CSSR).

2. NCA4 key messages on Ocean and Marine Resources

The 4th National Climate Assessment (NCA4) was published in November 2018. The NCA is a periodic assessment by the U.S. Global Change Research Program, requested by Congress, that evaluates the impacts of climate change on the United States, now and in the future. It is designed to be an authoritative analysis of the science of climate change, with a focus on the United States, to serve as the foundation for efforts to assess climate-related risks and inform decision making about responses. It is the product of more than 300 individuals from governments, indigenous groups, national laboratories, universities and the private sector, and which has been exhaustively reviewed by external experts, the general public, federal agencies, and an ad hoc committee of the National Academy of Sciences, Engineering, and Medicine.[8] My work as a Review Editor on Chapter 9 of NCA4, which examines ocean and marine resources, meant that I was responsible for ensuring that the author team fully considered and responded to the reviews provided by the NAS committee and the general public. The final text of Chapter 9 was organized around three key messages, quoted below.

2.1 Key Message 1: Ocean Ecosystems

> *"The Nation's ocean ecosystems are being disrupted by increasing global temperatures, resulting in the loss of iconic and highly valued habitats and changes in species composition and food web structure. Ecosystem disruption will intensify as ocean warming, acidification, deoxygenation, and other aspects of climate change increase. In the absence of significant reductions in carbon emissions, transformative impacts on ocean ecosystems cannot be avoided."*

This message is supported by the existing evidence of climate impacts on marine resources to date, and the complex connections within marine ecosystems that are likely to be disrupted by future climate impacts. Opportunities for reducing this risk include conservation measures to reduce the effect of human-caused stressors besides climate, but there is growing evidence that many ecosystem changes can be avoided only by substantial and rapid reductions in atmospheric carbon dioxide concentration (NCA4, chap. 9).

2.2 Key Message 2: Marine Fisheries

> *"Marine fisheries and fishing communities are at high risk from climate-driven changes in the distribution, timing, and productivity of fishery-related species. Ocean warming, acidification, and deoxygenation are projected to increase these changes in fishery-related species, reduce catches in some areas, and challenge effective management of marine fisheries and protected species. Fisheries management that incorporates climate knowledge can help reduce impacts, promote resilience, and increase the value of marine resources in the face of changing ocean conditions."*

[8] https://nca2018.globalchange.gov/chapter/front-matter-about/

This message is supported by the existing impacts to marine fisheries that have been observed, and projected changes in fish location and effort that will follow from continued climate impacts. To effectively reduce risks to marine fisheries, we must take steps to quickly and significantly reduce greenhouse gas emissions. Other opportunities for reducing risk to fisheries include instituting climate-ready, ecosystem-based fisheries management that anticipates changing ecosystem conditions and resulting changes in species diversity and relationships, detailing human community vulnerability to climate change and ocean acidification, seeking to diversify fisheries, and using precautionary and dynamic fisheries management (NCA4, chap. 9).

2.3. Key message 3: Extreme events

> *"Marine ecosystems and the coastal communities that depend on them are at risk from significant impacts from extreme environmental events where very high temperatures, very low oxygen levels, or very acidified conditions interact. These events are projected to become more common and more severe in the future, and they expose vulnerabilities that can motivate change, including technological innovations to detect, forecast, and mitigate adverse conditions."*

This message is supported by impacts from extreme ecosystem events to date, such as heat waves, regionally intense ocean acidification, and deoxygenation (Figure 4). In addition to quickly and significantly reducing greenhouse gas emissions, opportunities for reducing this risk include embracing technological adaptation designed to offset the most immediate impacts of extreme events (such as adaptations implemented by shellfish hatcheries), developing operational forecasts for ocean environmental conditions (temperature, acidity, oxygen level) and biological events like harmful algal blooms and fishery opening times (NCA4, chap. 9).

3. Research gaps

Our understanding of climate change in the ocean has grown vastly in the last half-century, but key knowledge gaps remain, and can be addressed with coordinated, transdisciplinary activities founded upon comprehensive monitoring, observations, and research. Detailed examinations of existing uncertainties and the evidence base exist in a number of recent national and international scientific assessments, including the U.S. National Climate Assessment's Volumes I and II (here, CSSR and NCA4), the 2nd State of the Carbon Cycle Report, the Intergovernmental Panel on Climate Change's 5th Assessment Report, its Special Report on Global Warming of 1.5°C, its forthcoming Special Report on Oceans and the Cryosphere, and its 6th Assessment Report. Some of the needs identified in these and other studies include the following:

- *Detecting and attributing the role of overlapping drivers, like acidification, warming, oxygen loss, fishing, pollution, and more, on influencing ocean species at the individual, population, and ecosystem levels.* Tools like numerical ecosystem models, meta-analyses, mesocosms, and in situ studies are useful for this work, but they also require large teams and long studies, which can be difficult to fund.

- *Measuring the ability of species to acclimatize or adapt to ocean change* (recommended in NCA4 chap. 19). Long-term evolutionary studies and "-omics" (genomics, proteomics, metabolomics, etc.) techniques are some of the tools being refined to study this.

- *Identifying the most useful biological indicators of change to use as part of long-term ocean ecosystem monitoring.* Currently, long-term ocean observing skews heavily toward measuring chemical and physical variables, and a full suite of appropriate biological metrics to assess the impacts of stressors like acidification and deoxygenation are still being developed.[9]

- *Determining how best to incorporate ecosystem-scale information in precautionary fisheries management, while maintaining equitable and transparent decision making about fisheries resources.* Fishery management councils in the U.S. are beginning to tackle this challenge, but need support and new tools to adapt their management practices.

- *Evaluating the multitude of non-economic ways in which human communities depend on marine resources.* While food, energy, or natural materials resources are frequently evaluated using economic methods, ocean systems provide a host of additional services (e.g., carbon storage, temperature regulation, support of tourism, cultural meaning) that cannot be well measured with conventional/traditional economic techniques and require different multidisciplinary assessments.

- *Incorporating traditional and indigenous knowledge into ocean resource management and decision making.* Traditional knowledge often spans a longer timescale and a broader range of environmental conditions than contemporary scientific data, but can be captured in ways (e.g., language, the arts) that are not directly compatible with other data used in decision making.

- *Connecting ocean governance across geographic and jurisdictional scales to support robust, coordinated decision making about ocean resources.* Tools such as regional ocean data portals and processes such as collaborative decision making are supporting inclusive, multi-sectoral decision making, and need to be employed in more situations.

4. Future Opportunities

I would like to leave the Committee with one final thought. When looking at an unsolved problem, scientists sometimes fall into the trap of focusing on the unanswered questions and the knowledge gaps where more data and research are needed in order to make informed decisions. However, as an expert on the ocean impacts of climate change, I am here to tell you that we already know a lot about carbon pollution, climate change, and the impacts they have on the ocean and on human communities. What I see is alarming, and it is very clear that the fundamental solution to ocean warming, acidification, and oxygen loss is to decrease greenhouse gas emissions, particularly of carbon dioxide.

Even if we stopped emitting greenhouse gases today, there are still years of "momentum" in the system, as the existing measure of greenhouse gases in the atmosphere will continue to warm and acidify the ocean. As nations around the world work collectively toward reducing greenhouse gas emissions, there are also steps we can take to reduce the stress on marine ecosystems and the human communities they support.

[9] http://goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114

First, we must take steps to decrease other ocean stressors. Studies show that multiple layered stressors on ocean ecosystems have a greater chance of acting synergistically than of counteracting each other (Harley et al. 2006). As a result, reducing overall stress on ocean life requires reducing ocean stressors. This should include combatting oxygen loss, nitrogen pollution, sedimentation, disease, and other types of chemical pollution (Kelly & Caldwell, 2013). Marine resource management has sought to reduce these problems as part of general water quality improvement for decades, with progressive success in doing so (Côté et al. 2017), but the need is even more pressing in the face of climate change. Preventing the expansion of offshore oil and gas activities, especially in sensitive or remote places where the risks of these activities far outweigh any potential benefits, is also an important way to decrease additional ocean stressors. Decreasing marine pollution and other stressors to ecosystems is a "no-regrets" policy approach because of the multiple benefits that accrue—both the immediate value of reducing single stressors, and decreasing the likely value of reducing synergistic effects of multiple stressors acting together (Côté et al. 2017).

Second, we need to support community adaptation planning. To date, ocean climate change has driven piecemeal adaptation. As more adaptation efforts begin, there is an increasing risk that overlapping, uncoordinated efforts could be at best inefficient and at worst counterproductive. Around the world, nations are currently planning both mitigation and adaptation actions to address climate change, but little guidance exists to ensure coordination and inclusion of the ocean in these activities. A similar situation exists within the U.S., where state and local governments nationwide are at widely different stages and levels of coordination in adopting ocean-smart climate policies.

Resources and support for long-term resilience and adaptation planning are desperately needed. At a minimum, this should include support for regional ocean planning through tools that support coordinated data and management like regional ocean data portals. Comprehensive planning approaches underpin community and ecosystem resilience and ecosystem-based management. States and regional ocean partnerships across the country have found value in comprehensive planning, and resources should support the priorities outlined by states. Regional ocean planning should also include support for policies and programs, particularly those within NOAA, that support ocean and coastal resilience. This includes priorities such as ocean acidification monitoring and funding, ocean and coastal habitat and coral reef restoration, and fisheries management adaptation. In addition, there is a particular need to increase resilience and adaptation planning in the Arctic. Funding and support is needed for communities that must relocate, and there are opportunities to plan for coming changes and ensure that Alaskan communities, ecosystems, and economies will be resilient in a changing future.

5. Conclusion

Our ocean and its resources are facing unprecedented challenges. The state of ocean change science indicates that ocean acidification, warming, and deoxygenation are having large effects on marine ecosystems. As detailed by the 4th National Climate Assessment, these changes are rippling through the human-ocean connection, and there are knowledge and research gaps that can be addressed to better help our nation respond to large-scale ocean changes.

I believe there is an opportunity to continue American leadership on ocean science and technology, combining that history of excellence with a forward-looking vision to steward the main resource that makes life on Earth possible: our ocean. Thank you for the opportunity to provide this testimony.

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Figures

Figure 1: The dissolved carbon dioxide concentration of surface ocean water (blue) is rising at the same pace as the atmospheric carbon dioxide concentration (red). This is decreasing the pH (black) and the carbonate ion concentration (green) of surface seawater. These data are from the Hawai'I Ocean Time Series Program in the North Pacific Ocean from 1988-2015. (Figure 13.4, CCSR)

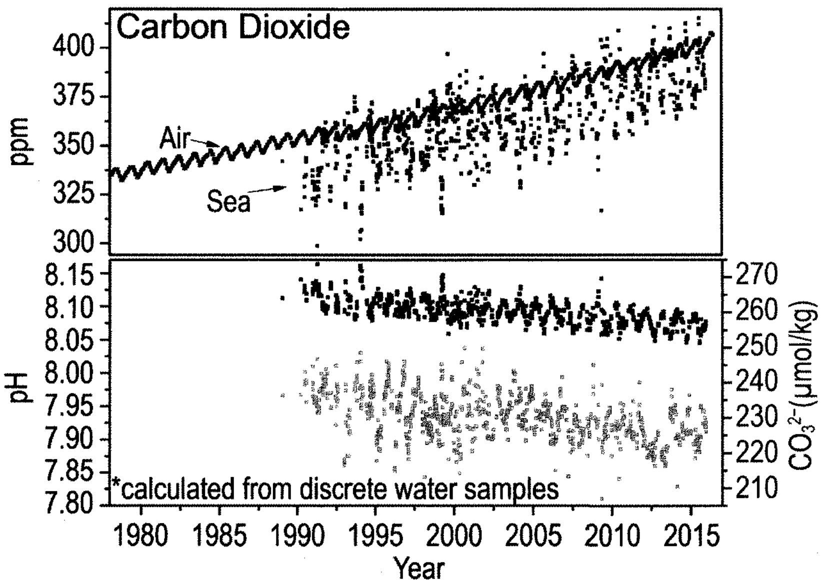

Figure 2: We have high certainty that atmospheric carbon dioxide levels drive ocean acidification, moderate certainty about how it will change organisms and ecosystems, and the lowest certainty about the best policy options for action. (Excerpted from Figure OA-1, IPCC AR5 WG II)

(a)

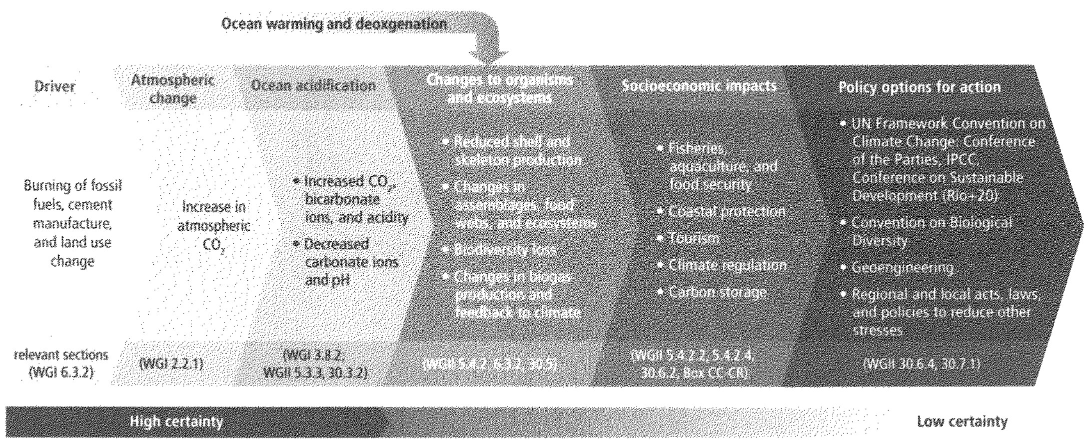

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Figure 3: Coastal waters become acidified through a combination of atmospheric CO2, point and nonpoint sources of pollution and runoff, as well as river input and upwelling (Figure from(Kelly et al. 2011).

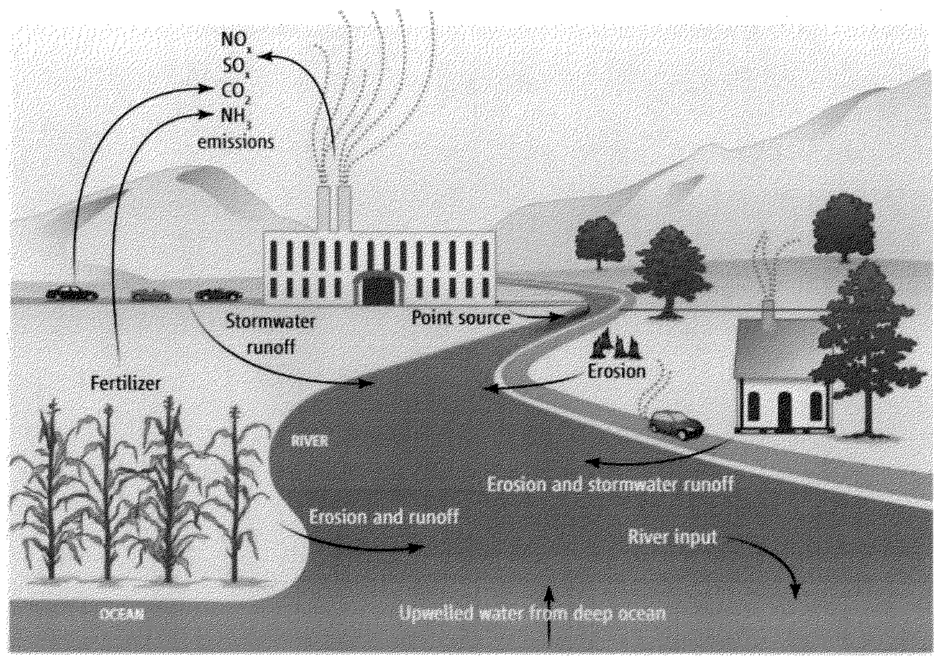
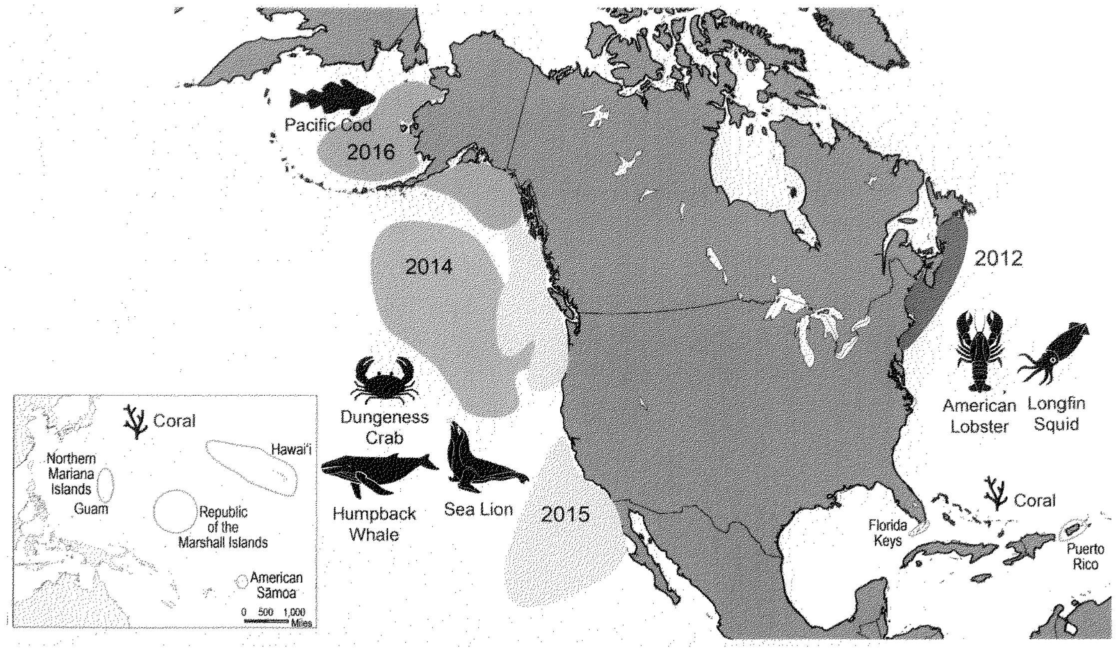


Figure 4: Recent marine heat waves. In 2012 a North Atlantic heat wave was concentrated in the Gulf of Maine; however, shorter periods with very warm temperatures extended from Cape Hatteras to Iceland during the summer of 2012. American lobster and longfin squid and their associated fisheries were impacted by the event. The North Pacific event began in 2014 and extended into shore in 2015 and into the Gulf of Alaska in 2016,leading to a large bloom of toxic algae that impacted the Dungeness crab fishery and contributed directly and indirectly to deaths of sea lions and humpback whales. U.S. coral reefs that experienced moderate to severe bleaching during the 2015–2016 global mass bleaching event are indicated by coral icons (NCA4 chap. 9)



Cooley Bio 2019

Sarah R. Cooley is the Director of the Ocean Acidification Program at Ocean Conservancy, in Washington DC. This program seeks to show that ocean acidification is an issue that is relevant to elected officials and their constituents, and can be acted upon by leaders, to advance this issue in a constructive, bipartisan frame that ultimately leads to longer-term support for action on acidification and a host of other ocean-related issues. Dr. Cooley has been working to incorporate science into decision making at Ocean Conservancy since 2014. She is currently a Lead Author on Working Group II of the IPCC's 6th Assessment Report, and has recently served as Review Editor on the 4th National Climate Assessment, and Lead Author on the 2nd State of the Carbon Cycle Report, as well as the author of dozens of peer-reviewed scientific journal articles in high-impact journals including *Science* and *Nature Climate Change*.

Dr. Cooley's scholarly focus spans ocean carbon cycling, science communication, and science-based policy development. In her position at Ocean Conservancy, she works to educate and engage decision-makers and stakeholders from every political perspective at regional to international levels on ocean acidification, identifying ways that different groups can take concrete, stepwise action on the issue. In her work, Dr. Cooley combines science synthesis, strategic communications, political strategy and advocacy, and public advocacy.

Prior to joining Ocean Conservancy, Dr. Cooley was a researcher and postdoctoral investigator at Woods Hole Oceanographic Institution (WHOI), as well as the ocean acidification scientist in the Ocean Carbon and Biogeochemistry Program Project Office. She received a Ph.D. in Marine Science from University of Georgia and a B.S in Chemistry from Haverford College.

Chairwoman FLETCHER. Thank you, Dr. Cooley. We'll now hear from Dr. Horton.

TESTIMONY OF DR. RADLEY HORTON, LAMONT ASSOCIATE RESEARCH PROFESSOR, LAMONT-DOHERTY EARTH OBSERVATORY, COLUMBIA UNIVERSITY EARTH INSTITUTE

Dr. HORTON. Madam Chair, Members of the Subcommittee, my name is Radley Horton. I'm a Lamont Associate Research Professor at Columbia University's Lamont-Doherty Earth Observatory. Thank you very much for the opportunity to participate in this important hearing. I'm going to focus my remarks today on how the anthropogenic activities that we've heard about that have warmed the upper oceans are causing sea levels to rise.

So there are two primary ways that global sea level rises as a result of that ocean warming. First and foremost, the upper oceans have warmed the surface of the ocean a degree Fahrenheit since 1900. That warming has made its way down to about 3,000 feet. That literally causes the ocean to stand taller. It's called thermal expansion.

The second centrally important process globally is what's happening to land-based ice sitting in Greenland, Antarctica, and in high mountain glaciers. As the ocean warms, it's literally wearing away at the dams or buttresses if you will that are preventing that ice from sliding in part into the ocean. As more and more of that ice on land melts and makes its way into the water, we add mass to the ocean, causing further sea-level rise.

So we've seen about 7 or 8 inches of sea-level rise globally since 1900. And there—importantly, there's been some acceleration over the past 2 decades or so. As we look to the future, projections of sea-level rise for, say, 2100, we see a big range. We hear about a most-likely range in the last National Climate Assessment of 1 to 4.3 feet. In my remarks I'm going to take an optimistic approach and just focus on what 1 foot of sea-level rise would mean, as I say, a very optimistic take on it.

And really, you know, fundamentally what I want to highlight is that even a little bit of sea-level rise means much more frequent coastal flooding and much more intense and higher-magnitude coastal flooding whenever you're having a storm.

[Slide.]

And as we can see from figure 1 here, we're already seeing that nuisance or sunny-day flooding is happening far more often than it used to across the U.S. coastline. For many locations, a five- or tenfold increase just over the last two generations in how often we are seeing these high water levels from Miami to Norfolk, for example. These are events that flood people's basements, make it impossible for businesses to open for normal operations, prevent people from being able to drive home along their normal coastal routes. When these events are rare, we can call them nuisances, but at what point if they're happening more and more often do they become something more than that, something that impacts real estate values, the ability to fund key infrastructure?

Now, let's go to slide 2 and focus as we look out to the future at what just 1 foot of sea-level rise by 2100 could mean.

[Slide.]

What could it mean for the really extreme high water levels that currently happen once every 100 years along various parts of the U.S. coast? These are the high water levels that determine insurance rates and zoning plans. And what we can see is across the whole United States, events—high water levels that used to happen once per 100 years become things that you expect during the lifetime of the typical home mortgage. And in many places every year or two you could be seeing those high water levels occurring that used to happen once every 100 years. Again, this is with just 1 foot of sea-level rise and no assumption about stronger storms. In reality, we expect—the balance of evidence suggests that the strongest hurricanes probably get stronger precisely because of ocean warming. That would make these effects worse than what you see here.

It's not just more frequent coastal flooding, though. It's also higher magnitudes of flooding whenever a storm happens. One recent study found that if the New York region had been precisely the same when Hurricane Sandy struck except somehow the oceans had been a foot lower, as they were 100 years ago, 80,000 fewer people would have experienced flooding in their homes. That's the impact of just a little bit of sea-level rise.

So this is also obviously a public health and safety issue. It means less time for people to evacuate around low-lying coastal areas, and for those unable to evacuate, it means greater risk of death, more damage to buildings as those water levels are higher, waves are able to penetrate further inland.

Along our coasts are assets worth trillions of dollars: businesses, homes, hospitals, I–95, Amtrak, our airports. But the economic impacts are going to make their way further inland as well. U.S. taxpayers bear the brunt of the bill for these coastal flood damages, and our coasts are economic hubs for all activities. There are also national security implications that I hope we may have a chance to discuss.

Far inland from our coasts, extreme weather events are impacted by that warming of the ocean as well. We're loading the dice toward more heavy rain events and combinations of high heat and humidity that harm our most vulnerable populations and affect the economic productivity of our outdoor laborers as well.

I've had the good fortune to learn a great deal from decisionmakers, as well as young people eager to tackle these problems and learn more. For example, investors are demanding now that companies disclose their exposure to sea-level rise. These experiences have convinced me that although we are fast running out of time, a window still remains open for the ultimate tipping point or surprise, specifically rapid societal action to reduce our greenhouse gas emissions and prepare all of us for these climate changes that are underway.

Thank you for inviting me to testify, and I look forward to our discussion.

[The prepared statement of Dr. Horton follows:]

Written Testimony of Radley Horton
Lamont Associate Research Professor, Columbia University

before the
Committee on Science, Space, and Technology
Subcommittee on Environment
Sea Change: Impacts of Climate Change on Our Oceans and Coasts
February 27, 2019

Madam Chair and Members of the Subcommittee, my name is Radley Horton. I am a Lamont Associate Research Professor at Columbia University's Lamont-Doherty Earth Observatory. Thank you very much for the opportunity to participate in this important hearing on the impact of climate change on our oceans and coasts. I have served as an author on the 3rd and 4th U.S. National Climate Assessments, and as a Lead Principal Investigator within NOAA's RISA Program. I speak to you today though in my personal capacity as a private citizen.

Primarily as a result of human activities including the burning of fossil fuels and land use change, carbon dioxide concentrations in the atmosphere have increased by more than 40 percent since the Industrial Revolution (Wuebbles et al. 2017). For most people, warming of the *atmosphere* is probably the first thing that comes to mind when they think about the climate changes that have resulted from these human activities. Indeed, based on records going back to the 19th century, surface air temperatures the last five years have been the five warmest on record, and the 20 warmest years have all occurred within the last 22 years (Climate Central, 2019).

It may come as a surprise therefore that since the middle of the 20th century, 93 percent of the excess heating associated with human activities has actually gone towards warming the *oceans* (Wuebbles et al. 2017). As a result, the surface of the ocean has warmed by well over 1°F on average since 1900. The enormous energy imbalance required to heat the upper oceans so rapidly can only be plausibly explained by human activities (Wuebbles et al. 2017).

This warming, in conjunction with related ocean acidification and deoxygenation, has directly affected all living organisms in the upper ocean, as other speakers today will describe. It is also affecting sea level, which will be the subject of the majority of my brief remarks today.

We have seen about 7-8 inches of sea level rise since 1900 (Wuebbles et al. 2017). Although there is a delay between carbon dioxide emissions and sea level change, acceleration of the rate of sea level rise has been observed during the past generation (Wuebbles et al. 2017). I'd now like to briefly discuss the causes, impacts observed to date, and where we could be headed later this century.

Globally, there are two predominant ways that climate change is causing sea levels to rise. First, as the ocean warms, it expands. Second, the ice sheets and glaciers that that sit on land are disgorging ice and water into the oceans, thereby adding mass. Although the first process had a bigger impact on sea level during the 20th century, it is thought that the second now rivals the first, and is set to surpass it this century. (Other drivers of sea level, of less importance globally, include 1) global storage of freshwater on land, 2) changes in local land height, and 3) regional variations in the change in ocean height due to factors ranging from ocean currents to the gravitational attraction of ice sheets (Sweet et al. 2017.)

But what about the future of sea level rise? It is often said that there is a lot of uncertainty about sea level rise, and in one sense, it is true. But it is asymmetric or 'high tail' uncertainty. According to Volume 1 of the Fourth National Climate Assessment (Wuebbles et al. 2017): "[Global mean sea level) is *very likely* to rise by…1.0–4.3 feet by 2100." There has been a lot of focus on whether the plausible worst-case scenario for 2100 is 4.3 feet, six feet, or even 8 feet of sea level rise. But I would like to highlight a less appreciated point. Even the most optimistic scenario imaginable--of one foot of sea level rise by 2100--would have direct and profound impacts. I am going to focus on the most obvious impacts, but there will be less direct ones as well.

Sea level rise means more frequent coastal flooding and more intense/higher magnitude coastal flooding (Wuebbles et al. 2017). Already we are seeing nuisance (also known as 'sunny-day') flooding happen far more often than it used to across the U.S. coastline, as shown in Figure 1. For some locations, the past two generations have seen a 5 to 10-fold increase in the number of days with nuisance flooding. (It should be noted that some of these places, including the Mid-Atlantic states, have had more sea level rise than the global average, but even for those states that have not, the trend towards more nuisance flooding is clear.) From Miami to Norfolk, this means for exmple: 1) more stores unable to open for normal business, with associated ripple effects on the economy; 2) people not able to drive home along their normal routes, leading to delays, and 3) more water in people's basements. These events perhaps deserve to be called a mere 'nuisance' when they only happen a few times per year—but at what point does it become something more than a nuisance?

Now lets look to the future of coastal flooding. And instead of looking at nuisance flooding, lets look at the big coastal floods—what are colloquially known as the '1 in 100 year' events—heights that flood insurance, and zoning decisions are made based upon (Figure 2). With just one foot of sea level rise, and even if coastal storms do not change at all, the 1 in 100 year high water levels of the past become events that for most of the U.S. coast will be experienced within the 30-year lifetime of the typical home mortgage. In some areas, these high water levels could happen every couple of years in the future. Rather than focusing on the exact numbers in any one location, I would encourage you to note how the statistics shift strongly across the entire U.S. And once again, this is a lower end sea level rise scenario of one foot, and one that includes no assumptions about coastal storms changing in the future. For hurricanes, this assumption is probably somewhat optimistic, since the balance of evidence suggests that major hurricanes will become more frequent and intense, in large part due to the warming of the upper oceans (Weubbles et al. 2017).

But sea level rise does more the just cause more frequent flooding. It means that when a coastal storm makes landfall, additional areas are flooded that would not have flooded before. And deeper floodwaters, which allow for greater wave penetration, cause more economic damage and loss of life. If the foot of sea level rise in the Greater New York/New Jersey Metropolitan Region since 1900 had somehow not occurred, 2012's Superstorm Sandy would have flooded the residences of 80,000 fewer people (Climate Central 2013; Miller et al. 2013). One recent study found that three feet of sea level rise would inundate 2 million American's homes (Hauer et al., 2016). Globally the number would be approximately two orders of magnitude larger.

The more frequent and intense coastal flooding brought on by sea level rise will impact all Americans. Along our coasts are assets worth trillions of dollars. From our homes, to critical service providers, to critical infrastructure including interstates like I-95, rail lines including Amtrak, airports including the 'big three' in the New York Metropolitan Region, and municipal water treatment plants.

And sea level rise is also a public health and safety issue. It means less time to evacuate from low lying areas in advance of a coastal storm, and greater risk of injury and death for those vulnerable members of our communities who are unable to evacuate. Sea level rise also mobilizes hazardous pollutants from our soils.

And just as all Americans suffer when the health and safety of any American is imperiled, so too will all Americans suffer the economic costs of sea level rise. It is after all U.S. taxpayers who bear much of the bill for coastal flood damages. And coasts are economic hubs for the entire nation. Our ports, which almost by definition are vulnerable to sea level rise, serve inland interstates and rail systems, as well as regional distribution centers. If ports are damaged or operating at reduced capacity, we therefore see supply chain implications, and economic disruption.

And then there are the national security implications. From NASA's Kennedy Space Center on Florida's Space Coast and Johnson Space Center outside Houston, to Norfolk's Naval Base and shipyards, what happens along U.S. coasts can have global implications. Recent coastal storm damages made worse by climate change have led to billions in damages at an Air Force base and a Marine Corps camp.

In my remarks, I have focused on a linear story—describing how *small* amounts of sea level rise profoundly increase the frequency of coastal flooding, and pointing primarily to relatively direct impacts of coastal flooding, like local damage. However, I feel an obligation to mention that the more greenhouse gases we emit into the atmosphere, the greater the potential for tipping points or 'surprises', such as sea level rise far in excess of the 4.3 feet described above. There is growing evidence from the ice sheets that further warming of the atmosphere and ocean could unleash positive feedbacks that lock us into more rapid ice sheet losses, and resultant high end sea level rise. Because extreme sea level rise of say 6 to 8 feet this century would be so difficult to adapt to, it follows that the further we increase greenhouse gas concentrations, the greater the odds of other impact/societal 'surprises' like conflict, which would presumably make it that much more difficult to reduce greenhouse gas emissions at the scale needed given the magnitude of the problem.

While I have focused my brief remarks here on how human activities lead to sea level rise and its impacts, it is important to remember that earth systems are connected. On land, the impacts of warming oceans extend far inland. Warming oceans are loading the dice towards 1) heavier rain events; 2) combinations of high heat and humidity that put the health of our vulnerable populations, as well as outdoor labor productivity, at risk; and 3) all other things being equal, stronger hurricanes. And of course, these changes interact. For example, for a low lying coastal city, even a small increase in rainfall intensity, combined with a small increase in a hurricane's storm surge could lead to a large increase in flooding if accompanied by even modest sea level rise.

While my training is in climate science, during the past decade I have had the good fortune to learn a great deal from decision-makers (including large municipalities, federal agencies, small communities, the private sector, and NGOs) as they devise solutions to climate change. These experiences have convinced met that, although we are running out of time, a window still remains open for the ultimate tipping point/surprise—specifically, rapid societal action to reduce greenhouse gas emissions and make society more resilient in the face of growing climate risks.

Thank you for inviting me to testify, and I look forward to our discussion.

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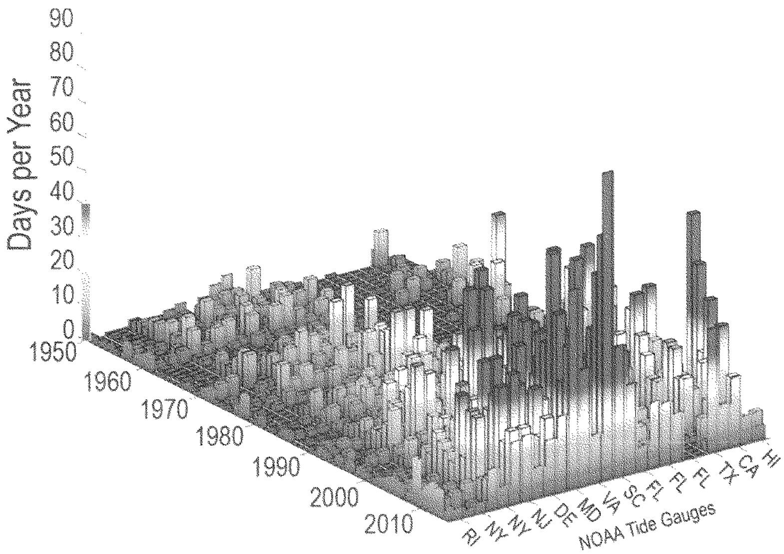

Figure 1. Tidal floods (days per year) exceeding NOAA thresholds for minor impacts at 28 NOAA tide gauges through 2015. Source: Sweet et al., 2017.

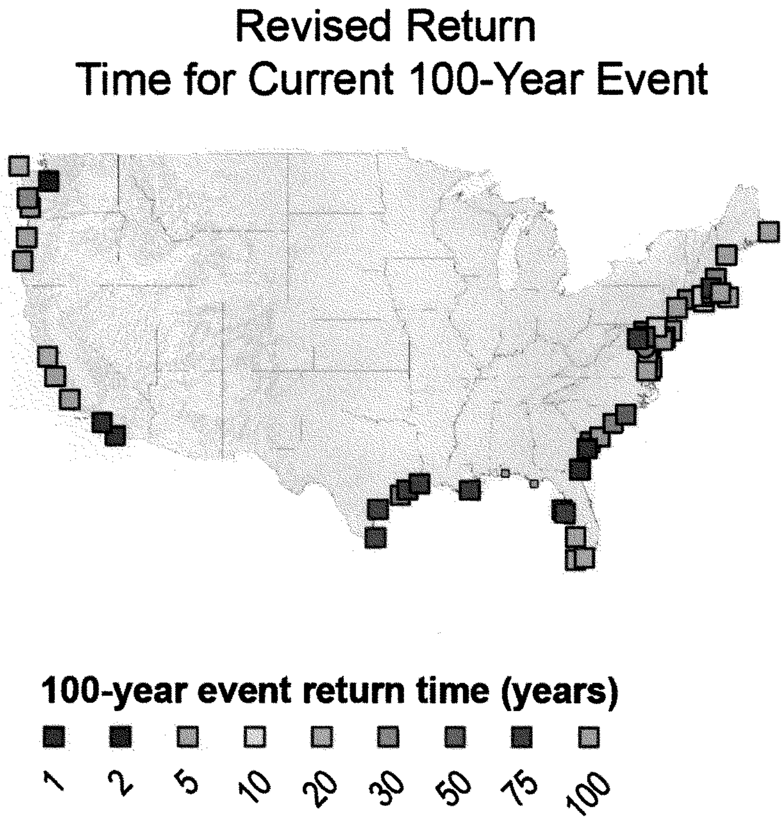

Figure 2. The amount of sea level rise (SLR) by 2050 will vary along different stretches of the U.S. coastline and under different SLR scenarios, mostly due to land subsidence or uplift. This figure shows how a 1.05-foot SLR by 2050 could cause the level of flooding that occurs during today's 100-year storm to occur more frequently by mid-century, in some regions as often as once a decade or even annually. All estimates include the effect of land subsidence. Source: Moser et al., 2014.

Radley Horton
Lamont Associate Research Professor, Lamont-Doherty Earth Observatory

Radley Horton is a Lamont Associate Research Professor at Columbia University's Lamont-Doherty Earth Observatory. His research focuses on climate extremes, sea level rise, tail risks, climate impacts, and adaptation. Radley was a Convening Lead Author for the Third National Climate Assessment. He currently Co-Chairs Columbia University's Climate Adaptation Initiative, and is Principal Investigator for the NOAA-Regional Integrated Sciences and Assessments-funded Consortium for Climate Risk in the Urban Northeast. Radley is also the Columbia University lead for the Department of Interior-funded Northeast Climate Adaptation Science Center. He has served on numerous national and international task forces and committees, including the Climate Scenarios Task Force in support of the 2018 National Climate Assessment. Radley teaches in Columbia University's Sustainable Development department.

Chairwoman FLETCHER. Thank you, Dr. Horton. We'll now hear from Dr. Frazer.

TESTIMONY OF DR. THOMAS K. FRAZER, PROFESSOR AND DIRECTOR, SCHOOL OF NATURAL RESOURCES AND ENVIRONMENT, UNIVERSITY OF FLORIDA

Dr. FRAZER. OK. Good morning, Madam Chair and Members of the Committee. So my testimony is a little longer than 5 minutes, so I think I'll cut right to the meat of it.

My background is in marine ecology and fisheries science, and I draw on my academic training and other professional experiences to provide here some examples of how and where investments in science would yield substantial value.

Wild-caught fisheries yield approximately 90 million metric tons of fish and shellfish per year. However, this bountiful natural resource is already threatened with about 1/3 of global fish stocks classified as overfished. And changing climate introduces new challenges. Among those challenges are changes in the ranges of exploited species, both expansions and contractions, and changes associated with alterations to habitats. As sea surface temperatures increase, some warm water species can expand their ranges northward, but some colder water species will be forced to contract their ranges.

As global climate changes, we will also see changes in habitats. These changes range from shifts in major ocean currents that will alter patterns in movement and recruitment to potential loss of inshore structural habitats such as seagrass meadows that provide food and shelter for a large number of exploited fishery species.

In response to such challenges, managers will have to adapt their strategies with the key thrust being a commitment to ecosystem-based fishery management, as proposed by NOAA Fisheries. For example, managers will need to be able to differentiate between range expansions driven by increased stock abundances that result from effective management actions and range shifts driven by changes simply due to water temperatures and ocean currents. Fisheries managers will also need to factor habitat and other environmental variables into stock assessments and stock projections because altered habitats appear to be an inevitable consequence of climate change.

Overall, managers will need to move from harvest quotas established primarily on the basis of historical landings to quotas that account for a changing or nonstationary environment. In addition, managers will need to consider ways to help, potentially even fund, adaptation by the recreational and commercial fishing industry such as moving access points in wholesale and retail outlets. Without such adaptations, we in the United States stands to lose a substantial portion of more than 1.7 million jobs, more than $212 billion in sales, and $100 billion in gross domestic product generated by these industries.

Science comes into play because it is the best base for designing and implementing the necessary adaptations to existing management of our Nation's fisheries. One way that science can help us by providing timely and accurate information on the status and trends of stocks and habitats. A second way that science can help us is to transform the tools and techniques needed to mitigate undesirable changes in fish stocks or the habitats that support them.

Given the time constraints imposed on this hearing, I will focus on one example in mitigating loss of habitat: Rehabilitating coral reefs. Coral reefs occupy a relatively small proportion of the ocean realm, but harbor more than 25 percent of marine biodiversity. Coral reefs also support important recreational, commercial, and subsistence fisheries around the globe. In fact, coral reefs yield approximately 25 percent of the total fish catch in developing nations and contribute substantially to the economies of more than 100 countries that promote reef-related tourism, including our own. They are, however, one of the most imperiled habitats on the planet due to nutrient pollution, physical damage, overfishing, and other local stresses.

Global climate change only exacerbates this problem. Managers must continue to address local stresses and, as already indicated, we need to reduce emissions of greenhouse gases to address global stresses. Regardless of our efforts, nearly all coral reefs will be threatened by conditions generated from existing levels of climate change by the year 2050. In fact, managers should prepare to mitigate both existing damage and the damage that will occur from the inevitable changes in global climate that have already been initiated.

Rehabilitating and restoring damaged and degraded reefs will require transformational innovations and advancements based on sound science. Key questions to be addressed are included in my written testimony. Answering those questions and transferring the new knowledge into effective and efficient innovations and investments will take time and a consistent stream of resources. In fact, it is an investment that we should begin now.

In conclusion, I reiterate my agreement with much of what you have heard from others. Climate change poses significant threats, and now is the time to begin addressing the human activities that drive it. My goal today was to introduce a potentially new topic, the need for consistent investment in science that will support incremental adaptation to the effects of climate change and build the basis for transformational change in mitigating existing and future effects. My hope is that this initial contribution might persuade you and the Committee Members to include discussion of the risk and rewards associated with long-term investments in science in your future deliberations.

I will close by saying that I am happy to participate in those discussions.

[The prepared statement of Dr. Frazer follows:]

Statement of

Thomas K. Frazer
Professor and Director, School of Natural Resources and Environment
Institute of Food and Agricultural Sciences
University of Florida

before the

Committee on Science, Space, and Technology
U.S. House of Representatives
February 27, 2019

Good morning, Madam Chair and members of the committee. Thank you for affording me this opportunity to speak with you today. My name is Tom Frazer. I am a Professor and Director of the School of Natural Resources and Environment in the Institute of Food and Agricultural Sciences at the University of Florida.

I understand, based on the background information provided by staff, that the committee has received substantial testimony focused on the causes of climate change, as well as its consequences, both realized and potential. You have heard from internationally renowned scholars and experts that climate change is real and that humans are responsible for it. I agree. You have heard also that marked reductions in global greenhouse gas emissions are essential and urgently needed to stabilize the earth's climate and avoid significant detrimental effects. Again, I agree. In fact, I would argue that the substantial, long-lasting opportunity costs associated with delaying reductions in greenhouse emissions outweigh any short-term benefits. The climate-related challenges that we face today are certainly not going away in the near future, and they will only be exacerbated by further increases in greenhouse gas emissions [1,2]. For example, if current conditions were stabilized, we will still see a 1.1°F (0.6°C) increase in global temperatures over the next century [2], and a scenario with continuing increases in emissions and no mitigation yields a 5.0° – 10.2°F (2.8° – 5.7°C) increase during the same time frame [2]. Given these projections, reducing greenhouse gas emissions and staying on that course for the foreseeable future should be major investments.

With that said, we also should be compelled, as a society, to invest aggressively in the science needed to inform effective adaptation and mitigation. Reducing emissions is key. It is essentially the equivalent of feeding, clothing and housing your children today. Investing in science, on the other hand, is equivalent to saving for their college education. In fact, consistent, long-term investment in science makes the most sense because many valuable insights can only be gained by observations and experiments conducted over time. In other words, good science can take a while to come to fruition.

The science I am talking about is needed to incrementally adapt existing management to the new norm so that we are able to conserve and safeguard natural resources that sustain livelihoods and economies of communities in the United States and around the globe. In addition, science drives technological innovation and advancement or transformational change, and given the challenges that we will experience due to past actions and potential challenges that depend on current and future actions, I suggest to the committee that the call for transformational change has never been as strong as it is today.

My background is in the arenas of marine ecology and fisheries science, and I draw on my academic training and other professional experiences to provide here some examples of how and where investments in science would yield substantial value.

Wild caught fisheries yield approximately 90 million metric tons of fish and shellfish per year, with the bulk of this production being consumed by people, including those who have little access to other sources of protein [3]. However, this bountiful natural resource is already threatened, with about one-third of stocks classified as overfished [3], and changing climate introduces new challenges.

Among those challenges are changes in the ranges of exploited species, both expansions and contractions, and changes associated with alterations to habitats. As sea surface temperatures increase, some warm-water species can expand their ranges northward, but some cold-water species will be forced to contract their ranges. As global climate changes, we will also see changes in habitats. These changes range from shifts in major ocean currents that will alter patterns in movement and recruitment to potential loss of inshore, structural habitats, such as seagrass meadows, that provide food and shelter for a large number of exploited fishery species. As a less drastic, but still significant example, a "flashier" environment caused by more frequent, and larger storm events can alter the salinity regime in estuaries, which could make them less hospitable for juveniles of many fished species. Furthermore, warmer temperatures have added stress to the world's coral reefs, which were already challenged by coastal development and associated human activities (I'll talk about this in more detail in just a minute).

In response to such challenges, managers will have to adapt their strategies, with the key thrust being a commitment to ecosystem-based fishery management as proposed by NOAA Fisheries [4]. For example, managers will need to be able to differentiate between range expansions driven by increased stock abundances that result from effective management actions and range shifts driven by changes in water temperatures and ocean currents. Fisheries managers will also need to factor habitat and other environmental variables into stock assessments and stock projections because altered habitats appear to be an inevitable consequence of climate change. Overall, managers will need to move from harvest quotas established primarily on the basis of historical landings to quotas that account for a changing or non-stationary environment. This flexibility is not explicitly articulated in the current version of the Magnuson-Stevens Fisheries Conservation and Management Act. In addition, fisheries managers will need to consider ways to help, and potentially even fund, adaptation by the recreational and commercial fishing industries, such as moving access points and wholesale and retail outlets. Without such incremental adaptations, we, in the U.S., stand to lose a substantial portion of the 1.7 million jobs, $212 billion in sales and $100 billion in gross domestic product generated by these industries [5].

Science comes into play because it is the best base for designing and implementing the necessary adaptations to existing management of our nation's fisheries. One way that science can help is by providing timely and accurate information on the status and trends of stocks and habitats. Our existing monitoring of recreational and commercial catches and our tracking of critical habitats are insufficient, and we will only fall further behind given the pace of change we will experience in the coming decades. In addition, our understanding of the interactions between fished species and their habitats and our ability to employ models to provide early warnings of detrimental consequences are inadequate. A second way that science can help is to transform the tools and techniques needed to mitigate undesirable changes in fished stocks or the habitats that support them. Given the time constraints imposed as part of this hearing, I will focus on one example of mitigating loss of habitat, rehabilitating coral reefs.

Coral reefs occupy a relatively small proportion of the ocean realm, but harbor more than 25% of marine biodiversity. Coral reefs also support important recreational, commercial and subsistence fisheries around the globe. In fact, coral reefs yield approximately 25% of the total fish catch in developing nations and contribute substantially to the economies of more than 100 countries that promote reef-related tourism [6]. They are, however, one of the most imperiled habitats on the planet due to nutrient pollution, physical damage, overfishing and other local stresses. Recent reports suggest that greater than 60% of the world's reefs are threatened due to these stresses and climate change only heightens this percentage [6,7].

Managers must continue to address local stresses, and, as already indicated, we need to reduce emissions of greenhouse gases to address global stresses. Regardless of our efforts, nearly all coral reefs will be threatened by conditions generated from existing levels of climate change by the year 2050 [6]. In fact, managers should prepare to mitigate both existing damage and the damage that will occur from the inevitable changes in global climate that already have been initiated.

Rehabilitating or restoring damaged and degraded reefs will require transformational innovations and advancements based on sound science. Key questions to be addressed include the following:

- How do we create a supply chain for coral reef rehabilitation that does not consist solely of transplanting survivors?
- Can we identify and culture genotypes that exhibit increased resistance and resilience to local or global stressors?
- Can we identify genes that encode increased resistance and resilience in the symbiotic algae that sustain reef-building corals and what are the risks and rewards associated with manipulating those genes?
- How might we increase survivorship of transplanted corals?
- What characteristics do rehabilitated reefs need to possess to ensure they provide most if not all of the ecosystem services derived from natural coral reefs?

Answering these questions and transferring the new knowledge into effective and efficient innovations and advancements will take time and a consistent stream of resources. In fact, it is an investment that we should begin now.

In conclusion, I reiterate my agreement with much of what you have heard from others. Climate change poses significant threats, and now is the time to begin addressing the human activities that drive it. My goal today was to introduce a potentially new topic: the need for consistent investment in science that will support incremental adaptation to the effects of climate change and build the basis for transformational change in mitigating existing and future effects. My hope is that this initial contribution might persuade you to include discussions of the risks and rewards associated with long-term investments in science in your future deliberations regarding the essential and urgently needed efforts to reduce greenhouse gas emissions. I will close by saying that I am happy to participate in those discussions.

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Thomas K. Frazer is a Professor and the Director of the School of Natural Resources and Environment at the University of Florida. Dr. Frazer holds a Bachelor's Degree in Fisheries Biology from Humboldt State University and a Master's Degree in Fisheries and Aquatic Sciences from the University of Florida. He earned his Ph.D. in Biological Sciences from the University of California, Santa Barbara. His research addresses contemporary and emerging environmental issues, and it is, by nature, interdisciplinary. His work involves collaborators from disparate disciplines, and it includes sampling and experiments conducted across a wide range of spatial and temporal scales. During his tenure at the University of Florida, Dr. Frazer has garnered substantial research funding to address topics pertaining to water quantity and quality, nutrient dynamics, biogeochemical processes, fish population dynamics, food web interactions, and ecological restoration of degraded ecosystems. He has conducted field research in both freshwater and marine systems around the globe, and he is intimately familiar with a broad suite of environmental and natural resource issues (e.g., eutrophication of fresh, estuarine, and coastal waters; invasive species; and the ecological impacts of contemporary environmental change, including coral bleaching, ocean acidification, and sea level rise). Dr. Frazer has authored and/or co-authored more than 175 peer-reviewed publications, technical reports, and book chapters. He serves as Chief Specialty Editor for the Coral Reef Research section of Frontiers in Marine Science, currently holds an at-large seat on the Gulf of Mexico Fishery Management Council, and is a member of APLU's Board on Oceans, Atmosphere and Climate.

Chairwoman FLETCHER. Thank you, Dr. Frazer. We'll now hear from Ms. Pilaro.

TESTIMONY OF MARGARET A. PILARO, EXECUTIVE DIRECTOR, PACIFIC COAST SHELLFISH GROWERS ASSOCIATION

Ms. PILARO. Thank you very much, Madam Chair, for having me here today.

I am—as the Director of the Pacific Coast Shellfish Growers Association, I am extremely proud to represent some of the hardest-working women and men on the West Coast. Shellfish farming, which employs thousands of people in rural economies on the West Coast, depends on the tides, with the most rigorous work occurring at low tide, which half the year falls during the winter months. And as a bit of a cruel joke from Mother Nature, those tides occur during the middle of the night.

There is both significant amount of pride and responsibility among shellfish growers because most of the members of my organization are second-, third-, and fourth-generation farmers, all of which depend upon a healthy environment to farm, and therefore are avid protectors of coastal and marine ecosystems.

Shellfish farming began commercially in the mid-to-late 1800s, and we know that oysters fueled the California gold rush. In the 1920s the native oyster populations along the West Coast became depleted from overharvesting but also due to poor water quality, and this was one of the first periods of adaptation that growers faced.

The shellfish industry turned west to Japan and brought over the Pacific oyster, which naturalized well. However, in part because of natural reproduction of that oyster was not robust enough to support the growing demand, the industry in the 1970s moved to hatchery production for larvae and seed, or baby oysters. The largest of these hatcheries at the time was Whiskey Creek Shellfish Hatchery in Oregon. It's a family run business to this day, which at that time supplied over 70 percent of the West Coast farms with seed. The predictability of hatchery seed allowed the industry to flourish well beyond Oregon and Washington and now to California, Alaska, and Hawaii, and beyond oysters to now clams, mussels, and a large West Coast burrowing clam called the geoduck.

In 2007, Whiskey Creek stumbled upon the next chapter in shellfish farming's path of adapting when the hatchery witnessed a 70 to 80 percent mortality of oyster larvae. They immediately tried to determine the cause, looking to natural bacteria and disease, but in consultation with researchers at the University of Washington understood that the issues related to acidic water, or low pH, and carbonate concentration.

Buffering the water, Whiskey Creek Hatchery and a second hatchery experiencing the same fate had begun to do, had been a solid fix, although somewhat temporarily. A longer-term adaptation needs to be considered and is necessary, especially since oceanographers tell us that this change in pH is due to older water, which has been absorbing the Earth's carbon emissions for a century and that even stopping the carbon emission inputs today would mean

30 to 50 years of acidic waters in the future. It also means issues not just for oysters but for all marine organisms.

During the past 10 years, we are beginning to learn that other climate-related changes impact the growth and health of shellfish beyond the hatchery and onto the beaches of farms. We are experiencing hypoxic periods, increasing temperatures, a decrease in available food in the water column, an increase of disease and harmful algal blooms, changes in growth patterns for the shellfish such as yield, size, and the way in which they grow generally. One specific example is that we are seeing impacts to the abyssal threads of mussels. These threads are what allows mussels to attach to structure for them to grow. Without healthy abyssal threads, mussels cannot grow. We are also seeing a decrease in resistance to shellfish predators, such as oyster drills, and an increase in intensity and frequency of storm events. These are all things to which the industry must adapt.

Real-time oceanography data collected by the Integrated Oceanographic Observing System, or IOOS, plus the guidance of NOAA's Ocean Acidification Program have been essential to the industry. Shellfish farmers who had just been used to consulting tide books are now looking at real-time temperature, salinity, and carbonate data on their phones while they are on the beach working. In addition, the industry on both coasts. The industry on both coasts takes advantage of discussions at local universities, nonprofits, and governments in finding ways to help.

We need more. We need to better understand the interactions of shellfish and other organisms such as kelp and grasses. We need to look into genetics to see if there are families much better suited to survive these changes, much like we've done in the wheat and grain industry. We need to understand how rising sea levels will impact where and how shellfish will grow. We're in exciting times of technology, and shellfish farmers are not easily discouraged because if they were, they wouldn't get out of bed each morning. But we need help in policies and leadership to allow the tradition of shellfish and the families that have been farming shellfish for generations to continue long into the future.

Thank you very much for inviting me here today.

[The prepared statement of Ms. Pilaro follows:]

Margaret A. Pilaro
Executive Director, Pacific Coast Shellfish Growers Association
Written Testimony
Congressional Committee of Science, Space and Technology
"Sea Change: Impacts of Climate Change on our Oceans and Coasts"
February 27, 2019

Oysters have been grown commercially on the West Coast since the mid-to-late 1800s, thriving in the brackish water found in the shallow, cool estuaries along the Pacific Coast. By the 1890s, oystermen were pulling 200,000 bushels a year out of the Puget Sound. But the boom was followed by bust, as over-harvesting and declining water quality decimated the native population of *Ostrea lurida*, or Olympia oysters. In the 1920s, as a way of saving their industry, the West Coast oyster growers began importing *Crassostrea gigas*, or Pacific oysters, from Japan. The Pacific oysters thrived, and oyster farmers began growing the species in large numbers. The shellfish industry continued to grow – beyond Washington, into Oregon, California, Alaska and Hawaii and in coastal areas around the US. It also grew beyond oysters to include clams, mussels, scallops, and geoduck.

Shellfish aquaculture provides economic opportunities for rural and coastal communities through harvests of healthy seafood products. Farming mussels, clams, oysters, and geoduck provides invaluable ecosystem services in coastal waters by improving water quality, removing excess nutrients, providing critical habitat for juvenile fish and invertebrates, and sequestering nitrogen. The most recent Census of Agriculture identified over 1700 shellfish farms - 240 along the West Coast and 1500 on the East Coast - producing nearly $300 million in annual sales and employing 1000's of people in mainly rural economically depressed counties.

But unlike the native Olympia oyster, the Pacific oyster was never able to reproduce quite as successfully in the wild—so in the 1970s, the shellfish industry began installing hatcheries along the Pacific Coast, in order to supply oyster farmers with the seed needed to sustain their businesses. In 1978, the Whiskey Creek Shellfish Hatchery set up shop next to Netarts Bay, five miles southwest of Tillamook, Oregon. A family-run business, it eventually grew to supply Pacific oyster larvae to 70 percent of the West Coast's oyster farms stretching from Canada to South America.

In 2007 two of the three largest shellfish hatcheries along the west coast, including Whiskey Creek Shellfish Hatchery, witnessed 70-85% mortality of oyster larvae. Hatchery employees immediately sought to determine the reason for these unimaginable results. They turned to bacteria or disease then learned of a research out of the University of Washington which linked changes in climate on coastal marine organisms. It became clear the carbonate concentration, compound essential for shell growth, was severely out of balance. High levels of $C0_2$ in water are correlated with developmental abnormalities, reduced fertilization success, slowed growth, and the precipitation of weaker thinner shells.

Shellfish farmers witness, first hand, the changing environmental conditions and weather patterns. They also encounter the related impacts to shellfish farming. All of these threats to the industry create hardship for shellfish farmers; added expense in equipment, additional testing, uncertainty of harvest, and consumer confidence. The increase in frequency and duration of storms impacts the amount of time farmers can safely work on the water and increases challenges with maintaining gear. The increase of shellfish-related disease is also linked to changing climate, specifically rising temperatures. As the temperatures of coastal waters rise, harmful algal blooms (HABs) are more likely to occur. These blooms produce marine biotoxins that are poisons. Shellfish ingest the biotoxins, which remain in their systems, causing illness in humans who consume the infected shellfish. As shellfish adjusts to different conditions, it becomes stressed and more susceptible to naturally occurring bacteria, such as Vibrio, and shellfish-related disease such as MSX, Dermo, and Pacific Oyster Mortality Syndrome (POMS).

Shellfish growers are also starting to examine how increases of shellfish predation and increasing populations of organisms that prey on shellfish are to climate; and how shellfish may respond to growing at different depths and substrates if sea-level rise estimates are realized.

Today's shellfish farmer has incorporated review of real-time oceanographic data collected by NOAA's Integrated Ocean Observing System (IOOS) at its dozens of monitoring buoys and stations along the coast of the US. In addition to tides, farmers now base activities and farm management on salinity, temperature, and carbonate chemistry of the water.

The industry is also hoping to address climate-related impacts through genetics. Shellfish farming is a relatively new enterprise and it is based on stocks that have not been subject to intensive, long-term genetic improvements, like we have for wheat and cattle. With the assistance of genetics research programs at Virginia Institute of Marine Sciences, University of Rhode Island, University of Washington, and Oregon State University, the industry is hopeful to that genetics can play a critical, long-term, solution to developing disease-resistant lines.

Published in *Read the Dirt*
January 2012
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Oysters and Ocean Acidification

by: **Pacific Coast Shellfish Growers Association: Margaret Barrette** Posted on: January 06, 2012

By Margaret Pilaro Barrette, Executive Director for the Pacific Coast Shellfish Growers Association

Editor's Note: The Executive Director for the Pacific Coast Shellfish Growers Association takes us through her realization of the harm Ocean Acidification is doing to the oceans, shellfish populations, and a way of life for shellfish growers. Yet another reason to check our unfettered consumption of fossil fuels.

Submitted as part of written testimony for Margaret Pilaro, February 27, 2019

I am not a physical scientist. It's not that I don't "get" science, or that my palms get clammy when I hear about the scientific processes. I'm one of those people who when faced with something very scientific, is more interested in the "So what's that mean?" or "How's that going to impact people?" rather than the "Hey, how'd that happen?" I guess that makes me more of a social scientist.

About 18 months ago, I left my position at the WA Department of Natural Resources and began working as the Executive Director for the Pacific Coast Shellfish Growers Association (PCSGA). This organization has been around for over 80 years and is made up of shellfish farmers who produce oysters, mussels, clams and geoduck in Washington, Oregon, Alaska, California and Hawaii.

Within my first few weeks on the job, I attended the Association's annual conference –the first day of which was entirely dedicated to the topic of "Ocean Acidification". I was struck by all the long faces. I needed to learn more.

The learning process took me knee-deep into science. When water absorbs CO2 from the atmosphere, the CO2 is converted to carbonic acid. I learned that the water along the Pacific Coast is layered. The top layer is made up of "newer water", which comes from fresh water inputs like rivers and runoff. "Older water" is deeper in the water column and because of its age has absorbed more CO2 and carbonic acid making it acidic or corrosive, with a lower pH. During certain weather events, such as a north west wind, the older water "up-wells" or rises towards the surface, bringing with it higher concentrations of CO2 and acidic water.

At one time the oceans were thought to be essential in helping us deal with the rise of carbon dioxide in the atmosphere – capable of storing large amounts of CO2. Now we realize that the ocean's ability to store CO2 is impacting those that live within it. In the case of oysters, corrosive water makes the shells of oyster larvae dissolve faster than they can form. Oyster larvae need that early shell development in order to grow into a baby oyster "seed" and live a healthy life.

The folks at Whiskey Creek Shellfish Hatchery in Netarts Bay, Oregon first drew attention to this issue in 2007. At first they thought it was due to bacteria. Finding nothing, they turned to the pH levels of the water.

We now know that acidic water, with a low pH, is responsible for a significant decline in oyster larvae production at west coast shellfish hatcheries. It's also likely responsible for the lack of natural oyster recruitment in the Willapa Bay region, as spawning events have not naturally occurred there in the past six years. This change in the water is clearly responsible for all the long faces and defeated spirits I witnessed at my first shellfish growers conference.

The oyster industry contributes over $270 million to Washington's economy and supports 3,200 jobs. When places such as Willapa Bay don't experience naturally occurring oyster spawning events for six years, those working in the industry as well as all who enjoy eating shellfish, lose. Shellfish is a high-quality protein that is sustainably produced under the most comprehensive environmental laws in the world, such as the Clean Water Act, the Endangered Species Act. The demand for Washington-produced shellfish far exceeds the supply and as we've seen with other American-produced products, foreign competition from China and New Zealand are standing by ready to fill the need. Importing foreign shellfish ignores the issue of Ocean Acidification, reduces jobs in rural communities, and introduces seafood into our markets that is produced without high standards for environmental sustainability or human health.

Acidic water (with low pH) kills Phytoplankton, a staple in the marine food chain and a major component of juvenile salmons' diet. Other marine organisms such as crabs, corals, and shellfish depend upon carbonate to build skeletons and protective shells. As the amount of available carbonate in marine waters declines with acidity, the health of these species is compromised. We're also learning that certain types of harmful algae blooms thrive in acidic waters. During such a bloom, the algae release toxins that can kill fish, mammals, and birds and can cause human illness. Impacts to marine species also translate to impacts to the overall health of the marine environment. Bottom line – Ocean Acidification is bad news for everyone.

Researchers and shellfish hatchery operators on both the east and west coast are trying to understand and adapt to the changing conditions. Thanks to funding obtained by the Pacific Coast Shellfish Growers Association, monitoring stations exist at the Whiskey Creek Hatchery as well as in Bellingham, Dabob Bay, Gray's Harbor and Willapa Bay. Among other things, these sites monitor for pH, temperature, salinity, and bacteria levels. By knowing the composition of the chemistry of the water, hatchery operators and shellfish farmers can adjust their schedules to work around times of low pH.

Unfortunately, Ocean Acidification can't be addressed through a single piece of legislation. In fact if we were to stop emitting carbon into the atmosphere today, we'd still experience acidic ocean water for decades. But we can bring attention to the issue and demonstrate the related impacts. Last spring, PCSGA hosted a Congressional Briefing on the issue of Ocean Acidification. We were joined by our colleagues from Maine to express need for continued research funding and support of federal programs that conduct marine monitoring.

Turns out you don't need to be a lab coat scientist to understand the basics of Ocean Acidification. You also don't need to be a social scientist nor a shellfish consumer to appreciate why it's bad. Chances are if you appreciate sustainably produced food, species diversity, and the many other values the marine environment provides, you probably want to pay attention to Ocean Acidification.

For more information visit NOAA's webpage and search "ocean acidification" or visit the following links:

http://www.oar.noaa.gov/oceans/ocean-acidification/index.html

http://www.pmel.noaa.gov/co2/story/Ocean+Acidification

Also, to learn more about how University of Washington is playing a role go to:

http://depts.washington.edu/coenv/news-blog/2011/11/23/featured-video-oyster-standoff-with-ocean-acidification-uw-360/

P.S. from the Editor:

For more on Ocean Acidification and its impact on the Great NW see the Sightline Institute's report on Northwest Ocean Acidification.

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2 Responses to "Oysters and Ocean Acidification"

- G'day Margaret Simplified the story of Ocean Acidification very nicely. I take issue to your implied comments on New Zealand's shellfish produced without high standards for environmental sustainability or human health. I'm an Aussie so its unusual I'd be sticking up for the Kiwis, but their environmental systems of production, and human health are world class, and having just finished visiting the US, Canada and Europe looking at shellfish production, I'd make the comment that this issue of Ocean Acidification and environmental influences on shellfish production is one that "we" as a global industry should be standing shoulder to shoulder on. The PCSGA does a great job uniting your growers together, and informing the public about the issues. Keep up the good work. Regards Ian Duthie
  by: **Ian Duthie**on: *Tuesday 6th of November 2012*
- ScienceDaily (May 12, 2008) — For members of the multimillion-dollar West Coast shellfish industry, their world is the oyster. Unfortunately, the oyster industry's ability to meet rising demands is hampered by two species of burrowing shrimp. So Agricultural Research Service (ARS) scientists are collaborating with colleagues from Washington State University and Oregon State University to develop sustainable shrimp-control strategies. Ghost shrimp and mud shrimp inhabit the tideflats in estuaries where West Coast oysters are raised. The shrimp burrow into the estuaries, making the intertidal mud soft and unstable. As a result, oysters and other shellfish can sink beneath the silty surface and suffocate. Brett Dumbauld, an ARS ecologist stationed in Newport, Ore., and his colleagues are uncovering information about the shrimps' habitats, life history and natural predators—information that can be used to help develop new methods to protect oysters from pests. ... http://www.sciencedaily.com/releases/2008/05/080509112525.htm
  by: **Dan**on: *Wednesday 28th of November 2012*

Impacts of Ocean Acidification on United States West Coast Shellfish Aquaculture and Adaptation Responses

Bill Dewey, April 2017

Oyster growers from Alaska to California on the west coast of the U.S.A. have struggled in recent years to find seed and oysters to keep their businesses viable. Scientists from the National Oceanographic and Atmospheric Administration (NOAA) and various Universities have linked the oyster seed losses to ocean acidification. Shellfish growers' understanding of what has caused these oyster seed shortages and their response to the issue have evolved in recent years through sea water monitoring and collaborative research.

From 2007 to 2009 U.S.A. West Coast shellfish growers experienced a severe oyster seed shortage. Oyster larvae production at two of the four major seed producing hatcheries declined by approximately 75% during this period. In addition to the drop in hatchery production there was no significant natural recruitment of larval oysters in Willapa Bay from 2006 through 2012. Willapa Bay is one of the largest oyster producing estuaries in the country and many oyster growers there rely on natural recruitment of Pacific oysters to seed their beds. These seed production failures had a real and profound effect on shellfish production.

In 2012, Washington State's Governor appointed an Ocean Acidification Blue Ribbon Panel to develop a response for the state. This diverse group of shellfish growers, business representatives, politicians, scientists and environmental nongovernmental organizations arrived at 42 recommendations for the state, which the Governor memorialized in an Executive Order for implementation. This response garnered international recognition as one of the first to address ocean acidification. In December 2015, through an effort of the Pacific Coast Collaborative the International Alliance to Combat Ocean Acidification (OA Alliance) was launched. The OA Alliance is providing collaboration and tools for countries and affiliates to combat changing ocean conditions.

Due to these initiatives, the West Coast oyster seed situation has improved. The outstanding response from policy makers and an unprecedented collaboration between University, agency and industry scientists has advanced knowledge of the problem dramatically in a very short period of time. Created by the Washington State Legislature in 2013, the Marine Resources Advisory Council is overseeing implementation of the Blue Ribbon Panel's recommendations. Also created by the Legislature in 2013, the Washington Ocean Acidification Center at the University of Washington is studying the effects of ocean acidification on the state's marine resources. Today, U.S.A. West Coast shellfish hatcheries have sophisticated monitoring equipment deciphering seawater chemistry as it is drawn from the ocean and automated systems treat the water to make it more conducive to oyster larvae survival.

In addition to the monitoring systems in the hatcheries equipment has been added to several buoys that are part of NOAA's Integrated Ocean Observation System (IOOS). This allows shellfish growers and scientists to understand changes in the ocean's carbonate chemistry around the hatcheries and farms. Five of the IOOS regions in the Pacific Ocean have linked to provide one data portal (IOOS Pacific Region OA data Portal - www.ipacoa.org) that serves data from all five regions. This data portal streams live real-time data from various government, academic and Native American facilities and buoys including five major West Coast shellfish hatcheries. Beyond the outstanding monitoring collaboration in the United States the Global Ocean Acidification Observing Network (GOA-ON, http://www.goa-on.org/) is working to gather and exchange ocean acidification data internationally.

Submitted as part of written testimony for Margaret Pilaro, February 27, 2019

As a result of these responses the production has improved, at least temporarily for shellfish growers. Hatchery production has largely recovered and ocean conditions have resulted in some limited natural oyster seed recruitment in Willapa Bay since 2012. While oyster seed supplies have improved, they are still not adequate to meet all growers' needs.

What do West Coast shellfish growers know about ocean acidification that they didn't a few years ago?

Initial efforts to determine the causes of oyster larvae losses focused on the naturally occurring bacteria *Vibrio coralliilyticus* (initially misidentified at *V. tubiashi*). As it turns out these bacteria thrive in the water conditions created by upwelling off the West Coast. Filtration systems were designed and installed to eliminate the bacteria only to find the oyster larvae were still dying. In 2008 NOAA ocean acidification experts informed shellfish growers that the likely cause of the oyster larvae deaths was changing seawater chemistry resulting from the ocean absorbing anthropogenic carbon dioxide.

The ocean absorbs approximately 30% of all anthropogenic carbon dioxide emitted into the atmosphere. This results in the formation of carbonic acid which reduces the ocean pH making it more acidic. Since the industry became aware that ocean acidification may be the cause of the hatchery issues operators with the help of university scientists have identified the availability of carbonate ions as most critical. They are the building blocks for the oyster shells and carbon ion availability diminishes as the ocean acidifies.

The carbon dioxide from 250 years of burning fossil fuels has made the ocean surface waters 30% more acidic and reduced the availability of carbonate ions by 16%. By the end of this century scientists predict the acidity of the ocean surface waters will have increased by 100-150% and reduced carbonate ion availability by 50%. A more troubling message for shellfish growers from the experts studying ocean acidification is that the water currently upwelling off the U.S.A. West Coast is 30-50 years old. So even if carbon dioxide emissions were curtailed today the waters along Washington State's coast will continue to get more acidic for decades to come because of the residual effects of carbon dioxide already absorbed by the Pacific Ocean.

Shellfish growers have now come to understand through monitoring and research that natural factors associated with summer upwelling off the U.S.A. West Coast can result in ocean chemistry conditions detrimental to the development and growth of oyster larvae. Research suggests these conditions occurred about 11% of the time prior to the industrial revolution. Corrosive events for oyster larvae are now happening an estimated 33% of the time and are more severe when they occur.

Taylor Shellfish Farms has a second hatchery in the State of Hawaii where they haven't experienced the same ocean acidification related problems. As an additional adaption response to larval failures in their Washington State hatchery the company has expanded production capacity at the hatchery in Hawaii. In 2012 another Washington State shellfish farming business, Goose Point Oyster Company started up a hatchery in Hawaii in also in response to the West Coast oyster seed shortage.

Currently West Coast shellfish growers seem to have found a temporary solution to the impacts of ocean acidification by treating hatchery water to restore larval production. Juvenile and adult oysters on farms in the estuaries have not yet been visibly impacted. Growers expect under worsening ocean conditions that shellfish in the nurseries and on beds will eventually be impacted as well. Unlike in the hatcheries there is no way to control the seawater chemistry over thousands of acres of beds in the ocean. To address this vulnerability the University of Washington and Oregon State University are working with shellfish growers to determine if selective breeding may yield oysters that can tolerate reduced levels of carbonate ions. Research is also underway to see if culturing seaweed together with shellfish or culturing shellfish in or around seagrass beds be may provide refuge for the shellfish in an increasingly acidic ocean by naturally reducing carbon dioxide concentrations and increasing carbonate ion availability.

All these actions demonstrate ways in which the shellfish industry is adapting to changing seawater chemistry.

What can be done to improve the environment for the shellfish industry?

As mentioned above, the response from policy makers and scientists to date has been proactive and effective. Washington State's Governor and Legislature continue to fund the Marine Resources Advisory Council and the University of Washington's Ocean Acidification Center.

The science on ocean acidification is rapidly evolving and having a coordinated review and response by the Marine Resources Advisory Committee is critical. Efforts to expand this coordination throughout the West Coast are underway and similar efforts are being undertaken on the east coast of the United States. Continued monitoring and the development of predictive models is also key for managing the adaptation response.

It is important to remember the impacts of ocean acidification extend well beyond shellfish. They are just one of many calcifying organisms in the ocean likely being effected by changing ocean chemistry. In addition, scientists are finding other detrimental impacts beyond calcification. The governance, coordination and adaptation responses for the west coast shellfish industry[1] can be applied to other aquaculture ventures and fisheries that face similar climate change impacts.

Bill Dewey is Director of Public Affairs for Taylor Shellfish Farms. Based in Shelton, Washington USA, Taylor is the largest producer of farmed shellfish in the United States. Mr Dewey also owns and operates his own clam farm in Washington. He served on governor Gregoire's Ocean Acidification Blue Ribbon Panel and serves today on Governor Inslee's Marine Resources Advisory Council which advises Washington State's ocean acidification response.

[1] To learn more about Washington State's response to ocean acidification go to: http://www.ecy.wa.gov/water/marine/oceanacidification.html. To learn more about what individuals can do in response to ocean acidification go to: http://wsg.washington.edu/our-northwest/ocean-acidification/

Submitted as part of written testimony for Margaret Pilaro, February 27, 2019

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Margaret Pilaro joined the Pacific Coast Shellfish Growers Association (PCSGA) as the Executive Director in 2010. She brings to the position experiences in both local and state government - working primarily on aquatic resources issues, community planning and public involvement. PCSGA represents over 100 shellfish companies who sustainably produce mussels, oysters, clams and geoduck in the states of Alaska, Washington, Oregon, California and Hawaii. Pilaro received both a Bachelor of Arts and Master of Arts in Marine Affairs from the University of Rhode Island. She is also an alumni of the National Fisheries Institute's Future Leaders, class of 2012.

While in Rhode Island, Pilaro worked as a municipal planner and dealt with storm and waste water issues as they related to a city-wide effort to restore the local Quahog (*mercanaria mercanaria*) fishery. She also led the city's harbor management planning process. Prior to joining PCSGA, Pilaro was with the Washington State Department of Natural Resources, where she served five years as the Constituent Relations Manager for the Commissioner of Public Lands and 7 years as a planner in the Aquatic Resources Division. Some of her projects included: Columbia River Estuary Management Plan, the development of both the Aquatic Reserves and Conservation Leasing Programs for state-owned aquatic lands, Sustainable Recreation, Forest Land Planning, and managing the agency's public involvement and constituent relations activities.

Chairwoman FLETCHER. Thank you, Ms. Pilaro.

At this point we will begin our first round of questions. And the Chair recognizes herself for 5 minutes.

So I want to ask a general question to everyone on the panel. It seems that—to us that the scientific consensus that we've heard in this hearing this morning and in our full Committee hearing is pretty solid, but on the state of the oceans it seems that there are major challenges to being able to understand because of the breadth and the scope of the research left to do.

There have been some major advances in our understanding of how carbon emissions impact the oceans and coasts through ocean warming, acidification, deoxygenation. But I think there's still a lot that we understand is unexplored, inaccessible, and expensive to study.

So my question, if each of you could share with us your thoughts on what the biggest challenges to studying these changes are and what are the ways that the Federal Government can help in exploring these and addressing the challenges that you experience in your research?

Dr. COOLEY. I would say that one of the biggest challenges is the ocean is vast. And as you note, it's very difficult to be everywhere and understand all the processes. There have been substantial advances in the last decades on remote observing systems where autonomous devices can go out through the ocean and measure different variables and then send back the data to researchers on land. That's only one piece of it, though. We have satellites that can help as well with that same type of work. However, bringing that information together and making sure that there's no drift in the instruments still requires some individuals to be out there sampling.

So I think an integrated viewpoint of how to inquire what is happening in the ocean is important to keep in mind. You know, no one is more excited than oceanographers about cool devices that go through the ocean, but we realize that there is—there needs to be sort of a network to bring that information together and put it to work.

Dr. HORTON. Another piece I might highlight is the modeling component, greater resources, and supercomputing that leverages some of those observations and helps us understand processes at various scales in the ocean, but also as we think about some of the tail risks that I didn't have a chance to talk about, why we might get more than a foot of sea-level rise, for example, to really understand those risks, we have to understand the interaction of things like changes in ocean currents with loss of Arctic sea ice, what might that indirectly mean for the Greenland ice sheet, for example, and how could changes in that ice sheet feed back on ocean circulation? Those are where we start to see the uncertainties, and the further we push greenhouse gas concentrations, the bigger the risk of unpleasant surprises, so we need models to help us understand those risks more fully.

Chairwoman FLETCHER. Thanks.

Dr. FRAZER. I would agree with what I just heard. Data are key, and there are certainly observing systems that are becoming better and better all the time. I think we need to continue to improve on those and develop the technologies that will allow them to advance further. Again, I come from a fisheries background, right, and data in that regard, real-time data collection or near real-time data collection is super, super important. Right now, we assess stocks based on data that might have been collected 5 years ago, but things are changing much faster than that, and so we need to probably incorporate a more regular sampling of fishes, to get the data that we need to make good assessments to inform the industry as to what they can do.

And I would agree also that modeling is key. Modeling integrates all of that information and helps us to make predictions so that we can adapt in a timely manner. Thank you.

Ms. PILARO. Well, I will agree with everything else that the panel has said. I will emphasize the relationship between species is important, how does shellfish interrelate to other organisms in the ocean?

Funding is harsh. There's a lot of competition for small amount of funds. And getting the data, the information, the output from models, all of what was mentioned into the hands of someone who really can use it like the shellfish growers is beneficial because: A) they're using it to solve real-world problems, and B) it brings attention to the applicability of the data and research, which then hopefully will reinforce the need and the acceptance of funding these important activities.

Chairwoman FLETCHER. Thank you all. I yield back the remainder of my time, and I now recognize Mr. Marshall for 5 minutes.

Mr. MARSHALL. All right. Thank you, Chairwoman.

I'm going to ask you all about innovation. I want you to think about what's out there, the greatest, latest, don't be afraid if it's a crazy idea. Think outside the box. What's going on in the world that's innovative? I'm particularly interested in phytoplankton farming or kelp farming, and I think about, you know, the shellfish industry. Maybe we should be trying to grow more kelp than worried about the genetic editing of oysters or something like that. So maybe, Ms. Pilaro, we'll start with you and go backward. Maybe take 30 seconds. What's out there that's great and late in innovation?

Ms. PILARO. Well, I agree with you that there is some really great innovation in kelp farming, and the relationship between kelp and shellfish is fabulous.

Mr. MARSHALL. Right.

Ms. PILARO. Multi-trophic farms, where shellfish and kelp are growing together, have been difficult to permit. So when we talk about policies, this is something that we'll need to talk a little bit more about.

Also, to make a connection with your amber waves of grain, I think there's a lot of fabulous genetics work for wheat and grain that can also be applied to shellfish, which is a fairly new approach, compared to other agriculture crops. We're not looking to alter the organisms genetically, rather finding families that are more resistant to some of these challenges.

Mr. MARSHALL. Great. If you can get to us your—what you need. You mentioned some type of—some processes or—that would help you to do more of the kelp farming. Let us know. And, by the way, I think the Department of Agriculture would do a great job overseeing the gene editing compared to the FDA (U.S. Food and Drug Administration), just an aside. Dr. Frazer, you're up.

Dr. FRAZER. Great, thank you. So I would agree as well. I think that there are certainly molecular advances that we can employ to help identify more resilient strains of particular organisms and to focus on perhaps using those in mitigation efforts.

I'm interested in your phytoplankton and kelp question. I agree with you there that phytoplankton and kelp take up and assimilate a large amount of CO_2, and so do other things such as seagrass beds. And I think what we should try to do is safeguard those habitats so that they can continue to perform like they're supposed to. The issue of actually trying to increase their abundance or grow them, I think we do face some challenges right now with regard to scalability, and it's something that——

Mr. MARSHALL. Are people doing it? Are people researching it? Is University of Florida leading the charge? Who's leading the charge on it?

Dr. FRAZER. I think there's—universities are—certainly the University of Florida is doing some of that, and other universities around the Nation are trying to invest to figure out how to increase the capabilities of autotrophs, including phytoplankton, and other organisms to grow, and sequester that carbon.

Mr. MARSHALL. Thanks. Yes, Dr. Horton.

Dr. HORTON. Yes, I like how your question about innovation references both the potential for greenhouse gas mitigation, measures that could take carbon out of the atmosphere but also adaptation and resilience. I think we really do need both. By reducing emissions, we can buy ourselves time for some of these technologies to come into play with the right kind of investments, as you say.

I guess one other quick thing to highlight within the adaptation space is, again, from a modeling perspective, can we test out some of these solutions, things like storm surge barriers, dredging, so we can better understand costs and benefits associated with those activities? There might be an obvious benefit of preventing a storm surge, but what could be some of the potential downsides? And some of that gets into the social science, that sort of moral hazard, what if a barrier fails? I think those are a whole bunch of social science questions involved in those living at the coast, how they perceive some of these emerging hazards, potential changes in real estate value that are maybe sort of outside the realm of the science component but deep social science questions that we are engaging with communities and as they sort of lead the charge in thinking about these resilience issues.

Mr. MARSHALL. Thanks. Yes, Dr. Cooley?

Dr. COOLEY. I think it's a great question. Innovation is so important, but technology and devices is just one piece. So the other piece is innovation and decisionmaking and how we put that information to work. You mentioned that you work in healthcare. You've gotten a great front seat to what innovation has done. What we see there is that new devices have given more information for better patient care and better collective decisionmaking. We're learning a lot more about how to do that in the ocean environment.

The example that Ms. Pilaro outlined in the West Coast has been a great example of how better technology for shellfish growers has led to a better regional outcome. And I think we need to take the best lessons from that and learn how to apply it to the ocean common resources that we want and care about.

Mr. MARSHALL. All right. I'm going to go over my time here, so I better yield back since this is a new Chairwoman in charge here. I'll yield back. Thank you.

Chairwoman FLETCHER. Thank you, Mr. Marshall.

I'll now recognize Ms. Bonamici for 5 minutes.

Ms. BONAMICI. Thank you, Chair Fletcher and Ranking Member Marshall. And thank you to our witnesses. I've been looking forward to this hearing, and I'm really glad, Mr. Marshall, to hear you're excited about science. And this is an important issue even for our colleagues and constituents who do not represent coastal areas because, as we've heard this morning and we know, the health of our oceans reflects the health of our planet.

Oregon's economic vitality is dependent on the health of the Pacific Ocean and the lower Columbia River estuary. We're very vulnerable to the effects of climate change, especially ocean and coastal acidification. As Co-Chair of the House Oceans Caucus, I know that the health of our natural resources and marine resources is critical, and I'm advocating for investments in research to predict and adapt these challenges.

I recently reintroduced the bipartisan *Coastal and Ocean Acidification Stressors and Threats, or COAST, Research Act*, with Representative Young, also the other Co-Chair of the Oceans Caucus, Representative Pingree, and Representative Posey to expand the scientific research and monitoring to improve our understanding of ocean and coastal acidification. The bill would improve research on ocean and coastal acidification in the context of environmental stressors, assess adaptation and mitigation strategies, and designate NOAA as the lead Federal agency responsible for implementing the Federal response.

Additionally, the bill would increase our understanding of the socioeconomic effects of ocean acidification and coastal acidification in estuaries. It would engage stakeholders, including the commercial fishing industry, researchers, and community leaders through an advisory board, and provide for the long-term stewardship and standardization of data on ocean acidification from different sources, including the National Centers for Environmental Information and the Integrated Ocean Observing System. These efforts will help identify risks and inform vulnerable communities, industries, and coastal and ocean managers on how they can best prepare and, when possible, adapt to changing conditions.

Dr. Cooley, I appreciate in your written testimony you discuss some of the research gaps. Thank you for that. You also discuss how the fundamental solution to ocean warming, acidification, and oxygen loss is to decrease greenhouse gas emissions, emphasizing the connection between ocean acidification and greenhouse gas emissions. And I think we heard that from everybody on the panel today.

How do you—Dr. Cooley, how do human-caused greenhouse gas emissions change seasonal upwelling, when the winds cause nutrient-rich deeper water to rise from below, especially on the Pacific coast?

Dr. COOLEY. Thank you for that question, Congresswoman, and thank you for your leadership on introducing the *COAST Research Act*.

The action of atmospheric warming tends to change or enhance upwelling favorable winds. Winds that come from a certain direction along the coastline will drive upwelling naturally, and that can be enhanced when those winds become stronger. And that allows deeper waters to move up along the coast and reach coastal resources and fisheries decades sooner than they would be expected to.

So in the Pacific Northwest, as Ms. Pilaro highlighted, shellfish growers were experiencing waters that upwelled 50 to 100 years earlier than expected, and they were carrying water that had an extra enhanced amount of carbon dioxide in it from being exposed to the atmosphere this century.

Ms. BONAMICI. Thank you. I want to get two more questions in. Dr. Cooley and Dr. Horton, how can Congress best support adaptation and mitigation strategies to address the socioeconomic effects? And if you could answer briefly because I really want to get in a question for Ms. Pilaro.

Dr. COOLEY. I think probably the most important piece is to support structures that involve multiple stakeholders and set a collective vision.

Ms. BONAMICI. Great. Dr. Horton?

Dr. HORTON. I would agree with that. Vulnerable communities, just to give one example. When we think about the combination of high temperature and high humidity, that's going to affect the elderly, those with pre-existing health conditions. It's not one-size-fits-all. We need science to help us understand how different communities differ in their vulnerability and in the adaptation strategies that make the most sense for them because ultimately these are about long-term decisions that are good for all of society.

Ms. BONAMICI. Thank you. And, Ms. Pilaro, at Oregon State University Dr. Burke Hales developed the Burke-o-Lator, a device the size of a piece of carry-on luggage that can analyze when the shellfish growers across the Pacific Northwest should grow larva based on the acidity and effects of calcium carbonates needed for the shell formation. As you discuss in your testimony, the shellfish hatcheries, especially Whiskey Creek Shellfish in my home State of Oregon, have been on the frontlines of responding. Why are Federal investments in tools like the Burke-o-Lator and the data from the Integrated Ocean Observing System necessary for our fishers and the shellfish industry?

Ms. PILARO. It's critically necessary because some of these impacts are happening regardless of where the shellfish farming happens and where hatcheries are, so it's not bound by a State, it's not bound by a region. And so having that Federal commitment and input is vitally important. We don't want to be in a situation where a private entity builds something and then keeps it to themselves. It would be helpful to have something that all of the folks who are interested in harvesting from the sea, whether it's kelp or shellfish or anything else could use. Any other fisheries resource can gain access to that information and that technology.

Ms. BONAMICI. Thank you. And, Chair Fletcher, I apologize for going over time, but as I yield back, I request unanimous consent to add several letters from ocean stakeholder groups to the record in support of the *COAST Research Act*.

Chairwoman FLETCHER. Without objection.

Ms. BONAMICI. Thank you, Madam Chair. I yield back.

Chairwoman FLETCHER. I will now recognize my colleague from Texas, Mr. Babin, for 5 minutes.

Mr. BABIN. Thank you, Madam Chair. I appreciate it. And thank you, witnesses, for being here as well.

Dr. Horton, many of the Green New Deal proponents are suggesting that greenhouse gas emissions are at a catastrophic level, some of which are claiming that we have 12 years left. Do we have 12 years in your opinion?

Dr. HORTON. So——

Mr. BABIN. Just keep it as brief as you can if you don't mind. I've got some other questions, too. You need to turn on your microphone.

Dr. HORTON. The further we turn up the dial on greenhouse gas emissions, the greater the risk of potential surprises that are very hard to predict.

Mr. BABIN. So it's—we're getting close to that point then in other words? And also, do you think it's responsible for some of our Nation's leaders and the media to suggest that certain doom will arrive unless we adopt the Green New Deal policies?

Dr. HORTON. I can't speak to the specifics of Green New Deal policies. What I can say is that to the extent that it represents an appreciation of the urgent need to reduce greenhouse gas emissions, I agree that's something that we really do need to do, given the hazards I described in my testimony.

Mr. BABIN. OK. Thank you. Because some of these policies may cost some jobs, and some of the costs that we've heard have been stunning.

And, Dr. Cooley, do you think that the Green New Deal should be passed into law?

Dr. COOLEY. Well, I'm not here to talk about the Green New Deal, but what is——

Mr. BABIN. Do you think it's a good idea that we—that it's been put forward——

Dr. COOLEY. The Green New Deal has started a conversation about details, which we haven't had before. We're having discussions across the aisle about the future we want and the specific ways we can get there, and that is incredibly inspiring as a scientist who's interested in details and solutions. How do we get from here to there?

Mr. BABIN. OK.

Dr. COOLEY. That's a really tough question.

Mr. BABIN. Yes, thank you very much.

Dr. COOLEY. Thank you.

Mr. BABIN. And, Dr. Frazer, what are some of the solutions that you think will aggressively target climate change that might not hurt American families or the economy? Because some of the proponents of the Green New Deal have put forward these provisions that would absolutely hurt my District 36 in Texas and much of the economy. Give me some ideas that you have of what might be some of these solutions that wouldn't be so hurtful because of my constituents—concerns for my constituents?

Dr. FRAZER. Well, as I said in my testimony, I think that there are lots of vulnerable habitats out there, for example, that are affected by a large number of stressors. And if we could make sure that we manage and maintain those habitats, they would continue to play a role in ameliorating some of the risk associated with climate change but not entirely. So I would pay attention on proper management of the habitats so they don't continue to degrade. Seagrass, this would be one of those, kelp habitats, and others.

Mr. BABIN. Absolutely. Thank you.

And, let's see, Dr. Frazer, one more. If the United States does implement the Green New Deal, how would we keep American jobs here? In your opinion would costs rise as much as some of these—we've looked at $93 trillion of costs to the American taxpayer. In your opinion, would that—is that true? We've seen time and again that green companies take their production overseas for cheaper cost and production, so how do we address this, you know, when the American taxpayer is expected to foot the bill for some of the biggest polluters in the world, and China being one of them? It doesn't seem fair. What is your opinion there? What are your thoughts?

Dr. FRAZER. So, again, I—what I would say is that what we've heard today is that there's an investment that needs to happen with regard to data collection, and it's all kind of data collection from innovation and technologies, modeling, and real-time data collection.

With regard to the area that I'm mostly involved in, fisheries, that increased data collection actually increases the certainty by which we can estimate the stocks that we can access, and by increasing that certainty, we can actually exploit more fishes. And that actually ends up being an economic benefit. So sometimes in order to make money, you have to pay money, right——

Mr. BABIN. Sure, yes.

Dr. FRAZER [continuing]. And so I think what we should be thinking about is making wise investments and getting good return on those investments.

Mr. BABIN. Do you think the Green New Deal is a good thing and should be passed into law?

Dr. FRAZER. I'm not going to speak specifically to the Green New Deal because I don't—I haven't read it. I apologize.

Mr. BABIN. OK. All right. Well, Madam Chair, I think that finishes me up. Thank you very much.

Chairwoman FLETCHER. Thank you, Mr. Babin.

I'll now recognize Mr. Crist for 5 minutes.

Mr. CRIST. Thank you, Madam Chair and Ranking Member Marshall, and thank you to our witnesses for being here today.

The Intergovernmental Panel on Climate Change's special report that came out last year states that coral reefs are projected to decline by an additional 70 to 90 percent with an increase in global temperatures of 1.5 °C. A 99 percent loss would be experienced with an increase of 2 °C. Florida, where I live, which is home to the fourth-largest barrier reef in the world, the Florida Keys reef system, is already experiencing an unprecedented coral disease outbreak.

Dr. Cooley, can you discuss in more detail how global temperatures increases to impact our coral reefs and what this means for places like Florida that rely on these oceans and coastal resources?

Dr. COOLEY. Thank you for that question. Coral reefs are extremely sensitive to temperature, and when they receive too much of a heatwave effect or too much intense heating in a short period of time, they will lose the cells that live inside the corals that help them produce food. And so the corals are without resources at that point. That's a coral bleaching event. That can quickly lead to coral death. And at the same time acidification is sort of decreasing the ability of those corals to recover because it's decreasing the net growth rate of corals. So when corals experience bleaching or breakage, they're less able to recover. And that really is a one-two punch. It's very, very serious for corals.

Mr. CRIST. Thank you. My next question is addressed to all of the panelists. What can we do to preserve our coral reef systems overall? Whoever wants to go first.

Dr. FRAZER. I'm happy to field that one for sure. I mean, there's a tremendous amount of local pressure on coral reefs. There's eutrophication that's a consequence of increased nutrient delivery. There's physical damage, again, due to anchoring and other activities. There's sedimentation due to coastal development. All of those types of things contribute to the degradation of coral reefs, and they make them more vulnerable obviously to the stresses that are associated with increasing warming temperatures. So I think you need to pay attention to both the local stressors and certainly continue to increase the greenhouse gas emissions problem.

Mr. CRIST. Anyone else?

Ms. PILARO. I would just add I'm not a scientist but one of the things that's important in a situation like this be it coral reef reduction or shellfish larvae mortality, is education is education and communication and sharing that information with a wide variety of people. To a certain extent, it affects everybody, and you need to find the right message, the right way to tell that story to as broad a population as possible.

Dr. HORTON. So maybe this is a window to talk a little bit about correlation across different types of extreme events and sort of compounding factors. So for those reefs if we're seeing even just a little bit of an increase in rainfall and more runoff as a result and if we're seeing just a little bit stronger storms as those oceans warm, once we couple that with sea-level rise, we see nonlinear combinations now where suddenly there's a lot more standing water, a lot more runoff, and maybe some unpredictable effects on coral reefs related to that sort of linking of the global and more local scales. So those are the kind of hazards we need to understand better, and we need science to do so.

Mr. CRIST. Great. Thank you. Dr. Frazer, as a fellow Floridian, I know that you're extremely familiar with the red tide outbreak that Florida suffered this past year. One thing that struck me about the outbreak was the lack of information as to why the—it was so severe this past year. Do you have any suggestions as to that?

Dr. FRAZER. Again, I—I'm super familiar with that as well, and I—and one of the things that we don't understand about red tides is why they actually establish themselves. And it gets to this issue that we talked about earlier about data acquisition, right? And we need to make sure that we have the data collection systems in place so that we're not behind the eight ball in this particular case. So that's my answer.

Mr. CRIST. OK. Thank you, sir.

Thank you, Madam Chair. I yield back.

Chairwoman FLETCHER. Thank you, Mr. Crist.

I now recognize Mr. Gonzalez for 5 minutes.

Mr. GONZALEZ. Thank you, Madam Chair and Ranking Member Marshall, for holding the hearing today. I also want to thank the witnesses for being here. I know it takes a lot of prep and can be stressful, so I appreciate your participation.

So I do believe climate change is real and global industrial development has been a contributing factor, but I also believe that the proposals that we've seen in the Green New Deal quite frankly would devastate my community. I'm from northeast Ohio, think steel country, a lot of manufacturing, a lot of agriculture, these kind of energy-intensive businesses if you will, and the proposals being presented would raise our energy cost to such a level that I can't help but think that our citizens, my constituents, would be making tradeoffs between things like fueling up their car or putting food on the table. And I think that is just fundamentally unsustainable. That makes no sense.

But, again, the problem is real, and I'm committed to finding a broad basket of market solutions to tackle the challenges of the present and future. What I believe is that we need to focus on technologies that are going to make consumers and industry essentially neutral when it comes to the energy source. And the only way we can do that is by making our energy sources affordable and reliable. We ignore the reliability part but—too often, but the Green New Deal and all those proposals kind of ignore it, and I think that's wrong. So I believe we need to focus on technology solutions that we can export abroad that are going to make energy cheap and reliable, bottom line.

And so I represent, as I mentioned, a non-coastal district located in northeast Ohio. We don't have an ocean reef or coastal beaches. So my first question will go to Dr. Frazer or anyone on the panel. But, you know, when I'm educating my constituents on why this challenge, specifically the one we're here to address today, affects them, what—you know, what would you say for somebody from my district?

Dr. FRAZER. Well, I'm again going to speak about fisheries, right——

Mr. GONZALEZ. Yes.

Dr. FRAZER [continuing]. And there's—people tend to think of fisheries as being a coastal resource, but those fisheries products are—serve the Nation in its entirety, right? There is a supply chain there. There are businesses, retailers, wholesalers, restaurants, and I'm pretty sure that in Ohio people eat lots of seafood. And so, again, it's something that—it's not just a natural resource issue——

Mr. GONZALEZ. Yes, right.

Dr. FRAZER [continuing]. It's a food security issue as well, right? So that's why you should care.

Mr. GONZALEZ. We have the best walleye in the world by the way.

Dr. FRAZER. Excellent.

Mr. GONZALEZ. So, again, Dr. Frazer, you discuss the importance of long-term investment in science and state good science can take a while to come to fruition. And again, that's kind of where I think we need to be headed is technological innovation that's going to bring cost down and reliability up. In this instance how do you suggest we as Congress differentiate between good science and bad science, and how do we make sure the science is robust enough?

Dr. FRAZER. I think that Congress—well, let me step back a minute and say that we have organizations in the United States, the National Science Foundation, for example, and NOAA that are in the business of evaluating science in a peer-reviewed process. I think you would—should depend on that. The priorities can be established elsewhere, and they certainly involve tradeoffs. And I think that's something that's best in the hands of the policymakers.

Mr. GONZALEZ. OK. And then where—and this is for anybody if anybody wants to jump in. Where are we seeing the most promise from a technological standpoint? Where is the research saying, hey, you know, if we could double down on this set of activities, I think we could really make some headway? Anybody, feel free.

Ms. PILARO. One way in which I think—and I spoke to it earlier in Mr. Marshall's question is, in looking at how animals respond to these climate-related changes and what genetic traits they carry that make them more resistant to some of the stressors that they are experiencing. As things are changing, we need to better understand the physiology of the animal and what they have. Growing shellfish with native eelgrass is something that's been happening for a long time and is a symbiotic relationship for both of those species, but, as I mentioned earlier, with cattle and grain they've looked at those families and their genetic make-up which allows them to be more commercially viable under certain conditions. This approach for fisheries is fairly new and for shellfish it is very new; both of which would benefit from additional work. The Animal Research Service under the USDA (U.S. Department of Agriculture) is the most appropriate and would be a fabulous place to invest some——

Mr. GONZALEZ. Great.

Ms. PILARO [continuing]. Funds.

Mr. GONZALEZ. Thank you, and I yield back.

Chairwoman FLETCHER. Thank you. I'll now recognize Mr. Casten for 5 minutes.

Mr. CASTEN. Thank you, Chair—Chairwoman. The—I'd like to ask some questions of Dr. Horton, and I wanted to follow on—you described in your testimony a delay between CO_2 emissions and sea-level rise, and given how rapidly we are—on an unprecedented basis we're increasing CO_2, you can appreciate that that makes me a little nervous. How far back in the geologic record do you have to go to find CO_2—atmospheric CO_2 levels of where they are right now?

Dr. HORTON. Literally millions of years.

Mr. CASTEN. And if you look back in that time, do you have any sense of what the temperature was then relative to what it is now?

Dr. HORTON. Well, our understanding is that, you know, as we look back at sort of the deep paleo climate, especially times when the planet was a little bit warmer, it—a couple things appear clear. One, sensitivity—temperature sensitivity to CO_2 appears to be higher than it might seem if we just looked at the climate models of today. And furthermore, sea-level rise sensitivity over long timescales appears to be very sensitive to even, say, 1 degree of global warming. So I think consistent with your point, when we look at deeper history, we can find times when it was a degree or two warmer maybe, sea levels were tens of feet higher in some cases. And likewise, when it was a little bit cooler, times when sea level was far lower, not a little lower. So that suggests some of these kinds of powerful positive feedbacks.

Mr. CASTEN. So if we were to look at the—you know, the empirical data that we have and recognizing that the climate models get better and better but are still models, the—what is a reasonable assumption to make about where we might equilibrate on an empirical basis at current CO_2 levels with respect to both temperature and sea levels?

Dr. HORTON. So I guess to be clear, equilibration we mean over the long timescale, multi-centuries, maybe even out to 1,000 years potentially. Those numbers I think are disturbingly, disturbingly high. I mean, one key question is what carbon dioxide levels, concentrations would we assume as the equilibration? I mean, even if we could somehow turn off greenhouse gas emissions tomorrow, not reduce emissions but turn them off, we'd still be stuck with greenhouse gas concentrations close to the levels they're at now for decades to centuries. So even without future emissions, you know, as we're starting to get out into multiple centuries out, you see continued large amounts of sea-level rise. But of course we need to not have those greenhouse gas emissions so that we avert the risk of some of these tail responses, rapid change in the ice sheet——

Mr. CASTEN. So——

Dr. HORTON [continuing]. But we don't know exactly where those thresholds are.

Mr. CASTEN. So when you talk about being—having, you know, potential risk of 8 feet of sea-level rise, am I understanding you correctly to say that it actually could be higher than that if we—if we're sitting at current sea levels and saying if we look at the historical record, where were those sea levels in prior periods?

Dr. HORTON. It depends on the timescale. In my personal opinion sort of worst-case scenario for the year 2100 might be about 8 feet. I can't say if it's a low—a little lower or a little higher. That is not the most likely outcome. That's a low probability but extremely high-consequence outcome should it happen for society. So my personal opinion and also the opinion of the last National Climate Assessment is that 8 feet by 2100 is about the worst-case scenario with big uncertainties on both sides. There's much less uncertainty in that sort of lower end, 1-foot level that I highlighted and showed how even that would have such a big impact on coastal flooding.

Mr. CASTEN. And does the 8 feet assume that we actually take meaningful efforts to slow CO_2 now or does that assume a business case as usual?

Dr. HORTON. For the most part, it assumes continued greenhouse gas emissions at a relatively high level. The RCP (representative concentration pathway) 8.5 scenario, if you're familiar with that, high greenhouse gas emissions, but especially as those concentrations get up higher and higher, we run the risk that the ice sheets could give up a lot of ice even if we then were to reduce our emissions. But for the most part those 8-foot type scenarios do assume continued high increases in greenhouse gases.

Mr. CASTEN. OK. My final question, and, Dr. Cooley, you may have some thoughts on this as well. And I'm leaving this hearing to go question Jerome Powell about our—among other things, our housing policy. Talk to me about what housing in the United States looks like over the realm of 30-year mortgages in a world with 3- to 8-foot-level sea-level rise.

Dr. HORTON. So talk about sort of unanswerable questions, but I think the key point I'd say there is, is it really safe to assume that property values don't start to drop before the water arrives? You know, if people are sort of waiting on this assumption that we have enough time until the water actually gets there, given what we've been talking about how we're sort of locked into additional sea-level rise, you know, that's an assumption that could be questioned. And I think, you know, I can't tell you exactly when, but towards your point, I think there are a lot of assets potentially at risk, whether it's homes, whether it's the ability to fund—underwrite certain types of infrastructure. And if people start to move away from some of these communities, who gets left behind? What happens to the tax bases there? We're really opening Pandora's box the further we increase greenhouse gas emissions.

Mr. CASTEN. Thank you.

Chairwoman FLETCHER. Thank you. Thank you. The Chair will now recognize Mr. Weber for 5 minutes.

Mr. WEBER. Thank you, ma'am. Dr. Frazer, south Texas has some of the best fishing in the world. Pardon me. I was listening to your discussion with Dr. Babin, and you talked about getting more data to exploit more fishes. I thought that was an interesting choice of words, exploit. How about enjoy? Would that be better?

Dr. FRAZER. Either one would work.

Mr. WEBER. OK. Well, I'd like to request unanimous consent to change that word in the record. I—no, I just want to make sure that we have a lot of good fishing and that we do enjoy those, and we do protect those fisheries.

Dr. FRAZER. Can I explain that further? Would that be all right?

Mr. WEBER. I'm dying to hear.

Dr. FRAZER. OK. So what happens is when we do a stock assessment, there's some uncertainty surrounding that assessment. And increased data collection allows us to increase the certainty, right? And when we increase the certainty, it's possible that we can adjust the quotas such that you can actually harvest or enjoy more fish. And so it's a case where increased data collection or an investment yield a positive economic benefit.

Mr. WEBER. I get it. That's the most egregious word you could use to encourage that data collection. We're all adults here. And that's fine.

But I have a question for all the witnesses. I'm from the Gulf Coast of Texas. Galveston and Freeport, Texas are both cities in my district with economic ties to shipping industries. The ports located there are important to both our local and national economy. We move 95 percent of the Nation's LNG (liquified natural gas). We produce 65 percent of the Nation's jet fuel, 20 percent of the Nation's gasoline east of the Rockies. And that doesn't include the Port of Houston. So we're a huge energy district.

Now, some of my colleagues like the gentleman to my right, Mr. Posey in Florida, face a different challenge in adapting to this rise when compared to the ports and the tributaries I represent in some of our—in our areas, some of our district. Ports would actually benefit from increased water levels.

So I guess my question to each of the witnesses is, how could a more localized approach to mitigation help protect our economy and better prepare individual communities? Should there be a Federal role in helping communities prepare and address these issues, and if so, what is it? How can we better address local communities should there be a Federal role in doing this? And if so, what is it? And Dr. Cooley, I'll start with you.

Dr. COOLEY. Well, I think we know beyond a shadow of a doubt that effects of climate change are regionally variable. And so there's no one-size-fits-all solution. As you noted, your region is going to have a different set of needs than Congressman Posey's district. There are best practices, however, that emerge from handling a particular issue, adapting to a particular issue, type of issue, for example. For example, we've learned quite a lot from the example of the shellfish growers in the Pacific Northwest. Those growers are now sharing their knowledge with growers in Maine, on the Gulf Coast so that American aquaculture can thrive and grow with the benefit of foresight. So I think that's one thing the Federal Government can absolutely facilitate.

Mr. WEBER. Thank you for the short answer. Dr. Horton, you've got a hard act to follow.

Dr. HORTON. Yes, I think a blend of scales, as we heard. Each community is going to have unique solutions. But similarly, some solutions are going to need to operate at scales far beyond what a local community could afford, so I think we do need consistent policies in that regard. We also just more practically need to make sure that different adaptation strategies across, say, different agencies or different communities aren't operating at cross purposes, right? The sort of superficial example would be if one community, you know, builds a seawall, does that increase the flooding for the nearby community? That's sort of an oversimplified example, but I think it's emblematic of why we need coordination——

Mr. WEBER. Let's jump to Dr. Frazer. He seems to be the fishing expert except for his one faux pas of exploit. And that would be—oystering is huge in my district, so CO_2 levels—and I read some of the testimony on the Japanese oysters that were brought over and how they've suffered some setbacks and stuff. So, Dr. Frazer, for you, for my Gulf Coast district in Texas, what needs to be specifically aimed at the Gulf Coast there?

Dr. FRAZER. So I'm going to say that the Federal Government could invest in the science that's going to allow us to take some of these global-scale models and be able to downscale them so that we can make predictions about specific regional areas like yours. Those predictions would allow us perhaps to develop the infrastructure that we need to deal with increased flooding, for example, or other storm-related events.

Mr. WEBER. Now, is it Pilaro? Is that how you say that? I'm a little over time, but you've got 30 seconds with the indulgence of the Chair, thank you.

Chairwoman FLETCHER. Without objection.

Ms. PILARO. Well, Texas oysters are great. We'd like to have them around for a long time because I think with anything, diversity in the market is wonderful. And the——

Mr. WEBER. You can stop right there, you know.

Ms. PILARO. I think I will. I'll yield the rest of my time. Thank you.

Mr. WEBER. No, go ahead and say the rest of what you were going to say.

Ms. PILARO. I think, and as Dr. Cooley said, some of the lessons learned from how shellfish are responding to these changes in the Northwest is applicable to what you might be seeing in Texas. And as people are seeing something that's different than what they've experienced, they should be encouraged to ask more questions to a broader audience because it might be just the variability of something localized or it might be something grander with some oceanographic element that's happening. So I think it's really important to look carefully and ask lots of questions about what might be happening there.

Mr. WEBER. Thank you, ma'am. Thank you, Madam Chair.

Chairwoman FLETCHER. Thank you, Mr. Weber.

I will now recognize Mr. Posey for 5 minutes.

Mr. POSEY. Thank you, Madam Chair. And I want to thank the Ranking Member and the Chair for inviting me to participate here today.

I live upon the Atlantic shores of the Florida peninsula. My constituents understand in a very deep way the economic and environmental importance of our oceans. We also have an estuary. It's one of those special places, as you all know, where the rivers meet the seas. And ours is named the Indian River Lagoon. And it has been identified as the most diverse estuary in the country. This is one of the important reasons that I co-founded a congressional Estuary Caucus with Chairwoman Bonamici, and we have re-chartered a caucus again for this session.

I also want to thank the panel obviously for showing up and say a special hello to Dr. Frazer from our University of Florida.

In addition, I want to acknowledge the work of the Florida Institute of Technology (FIT) on the ocean and estuary issues, and I have received a statement from Dr. Robert Weaver, Director of Indian River Lagoon research at FIT on matters we're discussing today, and I ask unanimous consent to that entered into the record.

Chairwoman FLETCHER. Without objection.

Mr. POSEY. Thank you. I'm also proud to be a co-sponsor of the *National Estuary Acidification Research (NEAR) Act*. The bill has the objective of focusing acidification research on the impacts of our estuaries as well.

I'm also pleased to be a co-sponsor of the *Coastal and Ocean Acidification Stressors and Threats Research Act*, and you all are familiar with that as well. I won't describe that for the record.

I just make those points leading up to the questions that are very vital to all of us in this Committee and everyone—single one of my constituents, and that is how we solve the problems that we have. And, you know, first and foremost, we talk about our estuary, and I've always said that the answer is very simple as two steps. One, stop putting bad stuff in it; and two, start removing the bad stuff that is already there. And a lot of people are offended by that, but that's the top line.

It only gets confusing when you start delving into the details of how to do that. There are so many different options to do it, and it's one of those cases where it seems everybody in the room knows how to make a baby stop crying except the person holding it. And it's very hard to get a consensus on the order and the way to do it. There are so many variable solutions, and I'm guessing there's over 100. We could probably list 100 different solutions. And I just wonder if there's ever been any research that would quantify all the different potential solutions for cleaning it up and, you know, the cost roughly per the benefit or the amount of clean water in each of those.

If any of you are aware of any research on that or a source, I would really like to have your comments on it generally speaking. Start with Dr. Cooley.

Dr. COOLEY. Thank you. And thank you for your leadership on the *NEAR Act* as well. That is—that solution—or assessment of the solutions that we have is critically needed. I—having been participating in the National Climate Assessment, I'm a big believer in the process of scientific assessment where all of the information is gathered and assessed as one to look at risks and likelihoods. We have much fewer research studies looking at the impacts of solutions partly because they take a long time to apply——

Mr. POSEY. Yes.

Dr. COOLEY [continuing]. And then even longer to measure how well they're doing. But I think that is a key knowledge gap that this Committee can turn to and begin to address.

Dr. HORTON. Very quickly, I'd second that. Evaluating adaptation strategies but all—in the context of a changing climate, but also the nuts and bolts of implementation, right, working with the existing agencies, existing funding cycles, bringing all that together to come up with solutions that work for all.

Mr. POSEY. Dr. Frazer?

Dr. FRAZER. Thank you. I would agree with you. The problem is complex, right, and there are certainly lots of issues that we have to consider simultaneously. With regard to the issue in your own backyard, I would point you to the TMDL process and what that is is the total maximum daily loads, and that incorporates input from all of the stakeholders and people that might be involved in the way to identify what are the sources of pollutants into the estuary and how can they collectively reduce those inputs.

Ms. PILARO. I agree we need to be working toward a solution, and in the process of doing that, we need to really keep this communication and collaboration open and engaged and robust. We've learned quite a bit from our experience in the Northwest. We have valuable information to exchange, and one of the things that is happening that I think is most important, and perhaps most exciting, is that we've got nonscientists thinking about science and we've got nonfarmers thinking about farming. In that, there is a wonderful opportunity for all of us.

Mr. POSEY. Right. Another moment? You know——

Chairwoman FLETCHER. Sure.

Mr. POSEY [continuing]. If somewhere there could just be just, say, given a certain level of pollution, you know, or certain measurements that you've taken, and here is a list of every single thing from oyster beds to oxygenating to on down the list, and then, you know, here's the cost of cleaning up 10 gallons of that water with this method and that method just as a baseline so that, you know, there's just not such a food fight over evaluating the different methods, that somewhere there's a legitimate method of determining an economic return or priority, which of these is most effective.

So anyway, I hope somebody will start that research sometime. I'd be glad to help you pursue it and beat on doors and raise money or whatever it takes. Thank you.

Chairwoman FLETCHER. Thank you, Mr. Posey.

Mr. POSEY. Thank you, Madam Chair.

Chairwoman FLETCHER. I'll now recognize Mr. Beyer for 5 minutes.

Mr. BEYER. Madam Chair, thank you very much. Let me just begin. Since entering Congress, I've been working with Senator Sheldon Whitehouse from Rhode Island on building up our ocean resilience capacity. Following my dear friend, Congresswoman Suzanne Bonamici, who's been leading ocean acidification for years and years, the concern about it. And we've been working both through the Regional Coastal Resilience Grants and with the National Ocean and Coastal Security Fund, which have now been combined into the National Coastal Resilience Fund. It's obvious with climate change we need much more resilient communities with increasing storms, incessant flooding worsened by continued sea-level rise. I think Northrop Grumman has a chart that shows Norfolk and Portsmouth, Virginia will be underwater 50 percent of the year by 2050.

This means ensuring that our fisheries are healthy, that we're adapting as those fisheries adapt to changing ocean conditions, and it certainly means taking advantage of the offshore wind potentials, which Virginia is moving forward on right now.

Dr. Cooley, the Washington Post recently reported that the White House is planning to create its own panel to, quote, "reassess the government's analysis of climate science and counter conclusions that the continued burning of fossil fuels is harming the planet." Apparently, the President had not read the Fourth National Climate Assessment before it came out.

And with Dr. Horton, you are contributing authors of previous National Climate Assessments. How much concern do you have that Dr. Professor William Happer is going to lead this, one of the very few scientists who believes that most of the warming is due to national—natural causes, that he disagrees with the scientific consensus that—he wrote a paper called, "In Defense of Carbon Dioxide," that it's a boon to planet life.

Dr. COOLEY. Well, what's interesting about the National Climate Assessment is that it qualifies as a federally defined highly influential scientific assessment. And so, as such, it is required to go through a thorough review process. And it needs to meet the standards of the *Information Quality Act*. These rules have been in place for nearly 20 years to ensure scientific accuracy, and so really review and assessment—review of this assessment has been baked in all throughout its creation. There were stakeholder engagement conversations, there were expert reviewers at every step, there were Federal agencies reviewing this report. And so really any reassessment of this report with a small panel is bound to be narrower than what it's been through already.

And, you know, I think it's just—it's not going to be as transparent because we know that process is not subject to the same reporting rules that the NCA has already been subject to.

Mr. BEYER. Thank you very much. Dr. Horton. In Dr. Cooley's testimony, she wrote something I had not really focused on before, that the oxygen loss from the ocean will affect the global nitrogen cycle and that since nitrous oxide production is actually a worse greenhouse gas than carbon dioxide, a lot of the predictions we've been making we're underestimating. And this ties in with your comment about tipping points, about something James Hansen has warned us about for years and years at NASA. Can you talk about what some of the surprises are?

And I say this having just come back from the Northern Triangle of Guatemala, Honduras, El Salvador where they say one of the big reasons why they're moving from Guatemala to our southern border is because of the extreme drought, extreme heat, and climate change, one of those surprises.

Dr. HORTON. Absolutely right. I think there are really three types of surprises. There's climate change happening faster than we thought, right, so a greater sensitivity to greenhouse gases than we thought. Then there's society being more vulnerable to a given amount of warming than we thought, which you just alluded to. And then hopefully maybe some potential for surprises where we as a society move quickly to deal with this problem.

In terms of physical hazards, some of the tipping points that are getting so much attention, marine ice cliff instability, this idea that perhaps paradoxically as you move inland in parts of Antarctica the land actually slopes downward due to the incredible weight of all that accumulated ice. If you start that process of water beginning to make its way down due to warming and melting, over long timescales it can be a runaway. That's one tipping point.

Arctic sea ice, we've lost more than 50 percent of the volume of late summer sea ice in the last 35 years or so, another possible tipping point because there's a feedback there, right, where you remove that white surface, dark surface that absorbs more sunlight and causes more warming. Those are just a couple of them that we worry about.

But I like how you highlighted the sort of impact side, too. You know, what if we're underestimating how sensitive our crops might be to real extreme temperatures, our vulnerable populations to combinations of heat and humidity, the potential for conflict around the world as sea levels rise. Could we lose control of this narrative, the ability to even deal with the problem in a collective way? That's another risk the further we push the system I think.

There are also these possibilities for tipping points on the solution side, too. I think, you know, we have to keep hope because we can't rule out the extent to which, for example, young people may really sort of rise up and demand that their institutions address these hazards. And they pick the companies they want to work for ultimately, the businesses they want to invest their money in. They may be looking to see which companies are disclosing their vulnerability to the risks and the extent to which they are contributing to some of these problems, too.

Mr. BEYER. Great. Thank you very much.

Madam Chair, I yield back.

Chairwoman FLETCHER. Thank you, Mr. Beyer.

And before we bring the hearing to a close, I want to thank all of my colleagues for their questions, their thoughtful questions, and especially Ranking Member Marshall for his opening the hearing with our shared value that we all want to leave the world better than we found it. And I think we all agree on that, and we have a lot of work ahead of us.

So I appreciate the witnesses coming today to testify before the Committee and also for submitting their written testimony.

The record will remain open for 2 weeks for additional statements from the Members and for any additional questions the Committee may ask of the witnesses.

So I thank you all for your time here today, for your valuable contributions and look forward to working with the entire Committee and with you as we move forward. The witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 11:41 a.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Sarah Cooley

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March 28, 2019

Dear Congresswoman Fletcher:

Thank you again for the opportunity to testify before the Subcommittee on Environment of the House Committee on Space, Science, and the Environment during the hearing titled "Sea Change: Impacts of Climate Change on Our Oceans and Coasts" on February 27, 2019. It was an honor to review the state of ocean climate change science for the Committee, and a pleasure to answer the questions posed by the Committee and its guests that day. The breadth of knowledge represented by my fellow witnesses was impressive.

I have reviewed the transcript of the hearing and it represents my comments to the best of my recollection. I confirm that the transcript should be entered into the record as it stands.

Below are my responses to the additional questions submitted by Congresswoman Bonamici (in italics). I would be happy to expand on these answers or answer subsequent questions as necessary.

Dr. Cooley, in your testimony you identify current research gaps that persist in federal efforts to address ocean acidification and coastal acidification. How would the COAST Research Act and the NEAR Act address those gaps, particularly related to the effects of ocean acidification and coastal acidification on estuaries?

The Coastal Acidification Stressors and Threats Research Act of 2019 (COAST Research Act) (H.R.1237) provides several routes to close research and knowledge gaps regarding ocean and coastal acidification. It updates and reauthorizes the engagement of federal agencies in ocean acidification research and monitoring originally set up by the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM). Like FOARAM, it recommends funding levels for the next 5 years that will support the entire federal research enterprise regarding ocean acidification. The levels recommended in the COAST Act are modest and still below early recommendations to fully fund this program. A 2012 report from the National Marine Sanctuary Foundation[1] includes an unofficial agency estimate of approximately $95 million needed for all federal OA research and monitoring by FY20. Like FOARAM, the COAST Act charges NOAA with leading the Interagency Working Group on Ocean Acidification, engaging in international research and observation activities, and developing a strategic research plan. All of NOAA OAP's activities are subject to regular reassessment and re-visioning under FOARAM. The COAST Act updates FOARAM in another key way, by providing for the establishment of an advisory body that will help NOAA's OAP continue keeping its activities maximally relevant to communities and industries touched by ocean acidification. The activities laid out in FOARAM have contributed to make the United States the leader on ocean acidification research and coordination, and on the science-to-policy pathway for ocean acidification, and the COAST Act would help continue this leadership role.

The National Estuaries and Acidification Research Act (NEAR Act)(H.R. 988) directs the National Academies of Science, Engineering, and Medicine to commission a study on coastal ocean acidification that will 1) synthesize

[1] Levison, 2012, "Federal Policy and Funding Relating to Ocean Acidification," National Sanctuary Foundation Report. 44 pp.

the state of existing knowledge in a complex ocean region, and 2) outline research gaps that could be closed to improve our understanding of coastal acidification. Coastal regions are immensely complex systems, where influences converge from human and natural processes spanning the land, the coastline, and the shelf seas. It is well established that there are numerous chemical, physical, and biological processes in the coastal zone that affect acidification.[2] Attributing observed conditions in the coastal region to specific processes therefore remains challenging and just a few studies have been able to do this.[3] Simply measuring acidification accurately across the entire inland-to-offshore salinity gradient is technically challenging and not possible by most water quality measurement campaigns. Moreover, the interaction of coastal seawater pH and carbonate chemistry with coastal ecosystems and species is a developing focus of study. There is some suggestion that acidification may enhance harmful algal blooms, which plague coastal areas in many parts of the United States, and understanding the interactions and implications of acidification, HABs, and other coastal concerns is of critical importance for making strong resource management decisions. The sort of study outlined in the NEAR Act will help outline future directions for ocean and coastal acidification research that can be pursued, helping ensure that resource management in the coastal oceans is holistic and ecosystem-focused, and uses the most complete information about acidification and its interaction with other drivers.

Dr. Cooley, in your testimony you discuss how interactions between different environmental stressors will change the ecosystem of our oceans. Why is it important to understand the interactions between ocean acidification, warming, and deoxygenation?

Ocean water is warming, losing oxygen, and acidifying all at once because of rising atmospheric CO_2 and planetary warming. In the laboratory, rigorous experimental design requires individual variables, like ocean acidification, be isolated for study. But in the ocean, local biological, physical, chemical, and geological characteristics ensure that different areas experience a different simultaneous mixture of acidification, oxygen loss, and warming. This means that there is no one-size-fits-all solution to protect ocean systems from acidification (and other ocean changes). It also means that ocean ecosystems experiencing multiple drivers including acidification, warming, and oxygen loss will have many hard-to-predict outcomes, because different species within the ecosystem will have different tolerances to each type of ocean change, and will thrive differently. Ecosystem models[4] are being used now that simulate competitive, predator-prey, and other interactions within a specific ecosystem. Ocean changes like acidification, warming, and oxygen loss can be imposed on the model ecosystem to determine possible outcomes. This is developing a much more nuanced view of how ecosystems will respond to ocean change, and holds great promise for informing resource management in the future.

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[2] RP Kelly et al., 2011. "Mitigating Local Causes of Ocean Acidification with Existing Laws." *Science*. 332(6033): 1036-1037; SC Doney, 2010. "The growing human footprint on coastal and open-ocean biogeochemistry." *Science*. 328(5985):1512-1516; CM Duarte et al., 2013. "Is Ocean Acidification an Open-Ocean Syndrome? Understanding Anthropogenic Impacts on Seawater pH". *Estuaries and Coasts*. 36(20):221-236.

[3] AJ Sutton et al., 2016. "Using present-day observations to detect when anthropogenic change forces surface ocean carbonate chemistry outside preindustrial bounds." *Biogeosciences*. 13(17):5065-5083; RA Feely et al., 2010. "The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary." *Estuarine, Coastal and Shelf Science*. 88:442-449.

[4] DS Busch et a., 2013. "Potential impacts of ocean acidification on the Puget Sound food web." *ICES Journal of Marine Science*. 70(4):823-833; IC Kaplan et al., 2010. "Fishing catch shares in the face of global change: a framework for integrating cumulative impacts and single species management." *Canadian Journal of Fisheries and Aquatic Sciences*. 67(12):1968-1982; G Fay et al., 2017. "Assessing the effects of ocean acidification in the Northeast US using an end-to-end marine ecosystem model." *Ecological Modelling*. 347:1-10. E Olsen et al., 2018. "Ocean Futures under Ocean Acidification, marine Protection, and Changing Fishing Pressures Explored Using a Worldwide Suite of Ecosystem Models." *Frontiers in Marine Science*. https://doi.org/10.3389/fmars.2018.00064

Dr. Cooley, what further steps can Congress take to address the socioeconomic effects of ocean acidification and coastal acidification? How would the advisory board established in the COAST Research Act help increase partnerships with stakeholders affected by lack of sufficient action to address ocean acidification?

Congress' support of socioeconomic studies by NOAA's ocean acidification program (OAP) is an excellent first step to address acidification's effects. As researchers develop a clearer understanding of the ways in which human communities can be affected by losses or changes in marine resources, this information can guide community planning to strengthen coastal communities. Frequently, the roots of human community vulnerability lie in factors well outside of ocean systems: overall economic opportunity, health and wealth of residents, and strength of governance. By better connecting how human vulnerability can be addressed by communities, coastal communities will be stronger overall.

The advisory board established in the COAST Research Act would help extend and formalize the very successful engagement on ocean acidification across many sectors of society that exists already. In my written testimony, I noted "Engagement of multiple sectors, including university and federal researchers, the shellfish aquaculture community, resource managers and more has been a hallmark of the particularly successful work of adapting to ocean acidification in the U.S. to date." The rapid development of adaptations that are assisting the U.S. shellfish industry today has come directly from these partnerships and engagement.[5] Although acidification has not arrived as a clear and present danger for every U.S. shellfish grower yet, the industry is paying close attention to the issue among their other concerns, and the advisory board would help share knowledge of options and successes from areas that have acted to other areas where knowledge, inspiration, and advice are needed. It is well proven that multi-stakeholder processes for decision making lead to more lasting outcomes, and the advisory board model provided for in the COAST Research Act will take advantage of that by ensuring federal scientific activities focused on OA are carried out with a clear focus on the resources and communities affected.

Dr. Cooley, what role do the regional coastal acidification networks play in assessing changes in ocean health regionally? Why is it important to integrate the efforts of the coastal acidification networks and the Integrated Ocean Observing System into the federal response to ocean acidification?

The regional ocean acidification networks, often called the coastal acidification networks, or CANs, supported by NOAA and the IOOS system help integrate ocean acidification observations and monitoring into existing sensor networks and ongoing studies. This places ocean acidification data into local context, where specific circulation, biogeochemical, or human characteristics affect the development or impacts of acidification. Because the IOOS networks have strong community ties and high reputations for disseminating quality science, they are trusted entities to help convene key stakeholders whose points of view are important for planning future studies or managing resources. The CANs provide a wonderful regional foundation to support the development of the stakeholder advisory board in the COAST Act, and a vehicle to disseminate information from NOAA's centralized program. They serve to broaden NOAA's reach, and strengthen its community ties and heighten its regional relevance.

Dr. Cooley, is there a need or opportunity for federally funded research on ocean acidification mitigation strategies? What should Congress be doing to support these efforts?

The fundamental solution to ocean warming, acidification, and oxygen loss is to decrease greenhouse gas emissions, particularly of carbon dioxide. Mitigating ocean acidification equates to decreasing the availability of carbon dioxide in the ocean, either by removing it from the ocean or from the atmosphere. There is a good deal of interest in locally mitigating ocean acidification via technological advances, but methods are still in development or early testing. For example, pilot studies culturing marine plants such as kelp or seagrass are under way because this represents a low-regrets opportunity that has other ecosystem (and likely economic)

[5] AS Barton et al., 2015. "Impacts of coastal acidification on the Pacific Northwest shellfish industry and adaptation strategies implemented in response." *Oceanography*. 28(2) 146-159.

benefits beyond mitigating OA. Some have theorized that ocean acidification could be mitigated by distributing minerals like limestone or olivine in the ocean,[6] but, like other fertilization-type intervention methods proposed for climate, side effects are wholly untested and cost of implementation appears high.[7] Another recent proposal involves strategically timed air bubbling around acidification-sensitive systems like corals.[8] Supporting research into these and other technological intervention methods is essential for two reasons: 1) the safety of different interventions must be understood, and 2) the effectiveness of interventions in terms of acidification reduction, net carbon footprint, and cost must be measured. However, it is foolish to hope that new technological interventions will solve acidification if they are implemented without also reducing carbon dioxide emissions.

Thank you for your questions.

Respectfully,

Sarah Cooley

Sarah R. Cooley, Ph.D.

Ocean Acidification Program Director

[6] Rau, G. H. 2008. "Electrochemical Splitting of Calcium Carbonate to Increase Solution Alkalinity: Implications for Mitigation of Carbon Dioxide and Ocean Acidity." *Environmental Science & Technology* 42, 8935-8940); P Kohler, et al. 2010. "Geoengineering potential of artificially enhanced silicate weathering of olivine." *Proc Natl Acad Sci U S A* 107:20228-20233; LDD Harvey, 2008. "Mitigating the atmospheric CO2 increase and ocean acidification by adding limestone powder to upwelling regions." *Journal of Geophysical Research* **113**: doi:10.1029/2007jc004373.

[7] R Albright, SR Cooley. In revision. "A review of interventions proposed to abate impacts of ocean acidification on coral reefs." *Regional Studies in Marine Science.*

[8] DA Koweek, et al. 2016. "Bubble Stripping as a Tool To Reduce High Dissolved CO2 in Coastal Marine Ecosystems." *Environ Sci Technol* 50:3790-3797.

Responses by Ms. Margaret A. Pilaro

What support does the shellfish industry need to better respond to harmful algal blooms and hypoxic events? - Submitted by Representative Suzanne Bonamici.

Response provided by Ms. Margaret Pilaro, Pacific Coast Shellfish Growers Association

An early-warning system for hypoxic events and the conditions that stimulate harmful algal blooms (HAB's) would allow shellfish growers to plan farming activities, and gain important insight on when harvest should occur in advance of a closure. Shellfish growers would also benefit tremendously by having adequate funding to support consistent monitoring of marine waters for the conditions conducive to HABs. Often these programs are cut from state programs where competition for limited funds is strong. In some states, shellfish growers currently have to pay for testing out of their pocket. Further research in both HABs and Hypoxia in our marine waters is imperative. There's much we don't know about why these events occur and even less on how marine organisms respond over the long-term. As we learn more, we need to ensure forward-thinking policies are in place to allow shellfish growers, and others dependent on a healthy marine ecosystem, to explore options to increase survival. For example, if it takes years to obtain a permit to grow shellfish on a parcel of tidelands, could that permit offer enough flexibility to explore growing shellfish in different areas within that parcel, or with different methods, to determine if impacts to shellfish may be lessened? Currently, and depending on the jurisdiction, flexibility within one's permit requires significant additional review.

Appendix II

Additional Material for the Record

LETTERS SUBMITTED BY REPRESENTATIVE SUZANNE BONAMICI

CONSORTIUM FOR
Ocean Leadership

March 1, 2019

The Honorable Suzanne Bonamici
2231 Rayburn House Office Building
Washington, D.C. 20510

Dear Congresswoman Bonamici:

On behalf of the Consortium for Ocean Leadership (COL), which represents our nation's leading ocean science, research, and technology organizations from academia, industry, and aquariums, I am writing to express support for the *Coastal and Ocean Acidification Stressors and Threats (COAST) Research Act* (H.R. 6267). America relies on our ocean and coastal communities for our basic individual needs as well as our overall security and prosperity. Keeping these environments, and therefore their communities, safe from the myriad threats associated with ocean acidification is paramount to our ocean security. COL applauds the *COAST Research Act* in its mission to strengthen existing ocean acidification initiatives and introduce new strategies to better understand and manage this environmental stressor.

Ocean acidification, which occurs as the ocean absorbs higher concentrations of atmospheric carbon dioxide, threatens the health of the entire ocean. As corals, shellfish, and many types of plankton struggle to create and maintain their shells or exoskeletons in more acidic waters, ocean food webs are disrupted. This, in turn, threatens the crucial balance in many ecosystems, as well as our own food security, and jeopardizes the stability of those whose livelihoods depend on a healthy ocean. Combatting the causes and mitigating the effects of ocean acidification requires sustained congressional support and interagency collaboration, as well as engagement from stakeholders in the private sector and academia. I strongly commend the *COAST Research Act*'s commitment to advancing ocean acidification research and monitoring efforts, as well as promoting cooperation among stakeholder groups.

I offer my sincere thanks to you, Congresswoman Bonamici, along with Congresswoman Chellie Pingree and Congressmen Don Young and Bill Posey, for your bipartisan efforts to help us better understand ocean acidification and improve overall ocean health by strengthening federal investments in the research and increasing monitoring of changing ocean conditions. Our lives and our future may well depend on it.

Respectfully,

Jonathan W. White, RADM (Ret.), USN
President and CEO
Consortium for Ocean Leadership

DISCOVERY • UNDERSTANDING • ACTION

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IOOS
ASSOCIATION

March 5, 2019

The Honorable Suzanne Bonamici
2231 Rayburn House Office Building
U.S. House of Representatives
Washington DC 20515

Dear Congresswoman Bonamici,
On behalf of the Integrated Ocean Observing System (IOOS) Association and its national network of eleven coastal observing systems, I write to support the Coastal and Ocean Acidification Stressors and Threats (COAST) Research Act.

NOAA's Integrated Ocean Observing System (IOOS) links together Federal agencies and eleven Regional Associations (RAs) to design and to operate regional observing systems to provide timely and reliable data and information on our oceans, coasts, and Great Lakes. Coastal acidification is becoming an even more pressing concern for many of our stakeholders and users, such as shellfish growers, shellfish harvesters, fishermen, resource managers, and coastal communities.

The impacts of coastal acidification vary, and each system must be tailored to the unique situation of the region. The IOOS RAs work closely with NOAA's Ocean Acidification Program to understand the regional context, to deploy and operate sensors, support the data that can detect and monitor acidification to support and improve warnings and alerts and to provide for the sharing and integration of data.

The COAST Research Act will enhance these and other efforts to understand, monitoring and manage the nation's ability to respond and adapt to ocean acidification. The Act does this be expanding the Advisory Board to include representatives of the variety of industries and stakeholder impacted by ocean acidification, expanding the strategic plan for research and monitoring, and expanding the role of the Federal agencies for addressing ocean acidification.

Sincerely,
Ella S Quintrell

Ella (Josie) Quintrell
Director

Northwest Association of Networked Ocean Observing Systems

7 March 2019

The Honorable Suzanne Bonamci
2231 Rayburn House Office Building
U.S. House of Representatives
Washington DC 20515

Dear Congresswomen Bonamici,

As the Director of the Northwest Association of Ocean Observing Systems (NANOOS), I write in support of the Coastal and Ocean Acidification Stressors and Threats (COAST) Research Act.

NANOOS provides access to near-real time observations, forecasts, and other tools that can be used to observe water properties in the Salish Sea and the coastal waters off Washington and Oregon. NANOOS can only serve our stakeholders via NOAA's Integrated Ocean Observing System (IOOS), which links together Federal agencies with our collective of local universities, government agencies, tribes, non-profits, and industry organizations who collect quality oceanographic and meteorological data from moorings, buoys, and satellites from across the Pacific Northwest region. But our resources are limited and this COAST Research Act would help to highlight the payoff investments can make.

In the Pacific Northwest, we know that ocean acidification is an issue already, as witnessed by the difference that monitoring water chemistry has made to shellfish growers. We know that impacts from ocean acidification may affect shellfish harvesters, fishermen, resource managers, and tribal and other coastal communities. NANOOS' work with IOOS and NOAA's Ocean Acidification Program have been instrumental in aiding adaptation.

The COAST Research Act will enhance these and other efforts to understand, monitor, and manage the nation's ability to respond and adapt to ocean acidification. NANOOS will be better able to meet the needs of our stakeholders if this Act is passed.

My thanks for your leadership and insights.

Sincerely,

Jan Newton
NANOOS Executive Director

March 10, 2019

The Honorable Suzanne Bonamici
U.S. House of Representatives
2231 Rayburn House Office Building
Washington, DC 20515

Dear Representative Bonamici,

From coast to coast, ocean acidification is having a broad range of impacts on the health of our ocean and coastal communities. Coastal industries are continuing to face the reality of an increasingly acidic ocean. In 2017, researchers at Oregon State University recorded some of the highest levels of ocean acidification in the world off the coast of the Pacific Northwest. Additionally, 63% of test sites on the west coast experienced levels of acidification known to cause commercial oyster production failures.

Our Pacific Northwest economies, our recreational and commercial fishing, and shellfish industry as well as our great northwest tourism economy - all depend on a healthy ocean. And because we are already seeing the effects of ocean acidification, we support your efforts and we support H.R. 1237, the Coastal and Ocean Acidification Stressors and Threats (COAST) Research Act of 2019.

Much of our knowledge and understanding of ocean acidification that has emerged in the last decade can be credited to the federal funding authorized by Federal Ocean Acidification Research and Monitoring (FOARAM) Act of 2009. FOARAM established the federal government's work on ocean acidification by creating the NOAA Ocean Acidification Program and an interagency working group on ocean acidification. FOARAM's authorization expired in 2012. The COAST Research Act amends FOARAM to further improve our ability to understand acidification in the open ocean as well as in the coastal zone.

We support the COAST Research Act and believe it will help our coastal communities better prepare for the effects from ocean and coastal acidification. Thank you for your leadership to strengthen the nation's focus and investment in oceans and coastal acidification.

Sincerely,

Lyf Gildersleeve, Owner, Flying Fish Company – Sustainable Seafood
Grant Putnam, President, Northwest Guides and Anglers Association
Liz Hamilton, Executive Director, Northwest Sportfishing Industry Association
Joseph Bogaard, Executive Director, Save Our Wild Salmon Coalition
Greg Block, Executive Director, Sustainable Northwest
David Moskowitz, Executive Director, The Conservation Angler
Kurt Beardslee, Executive Director, Wild Fish Conservancy
Guido Rahr, Executive Director, Wild Salmon Center

1300 19th Street NW
8th Floor
Washington DC 20036

Ocean Conservancy

202.429.5609 Telephone
202.872.0619 Facsimilie
www.oceanconservancy.org

February 27, 2019

The Honorable Suzanne Bonamici
U.S. House of Representatives
2231 Rayburn House Office Building
Washington, DC 20515

Dear Representative Bonamici,

On behalf of Ocean Conservancy, please accept this letter of support for H.R. 1237, the *Coastal and Ocean Acidification Stressors and Threats (COAST) Research Act of 2019*. Americans depend on a healthy ocean, and ocean acidification threatens millions of jobs and livelihoods, cultures, and ways of life, from the Pacific Northwest's shellfish industry to Florida's coral reef tourism. We believe the COAST Research Act strengthens our nation's investments in ocean and coastal acidification, and we are proud to offer our support for this legislation.

From coast to coast, ocean acidification is having a broad range of impacts on the health of our ocean and coastal communities. Coastal industries are continuing to face the reality of an increasingly acidic ocean. In 2017, researchers at Oregon State University recorded some of the highest levels of ocean acidification in the world off the coast of the Pacific Northwest. Additionally, 63% of test sites on the west coast experienced levels of acidification known to cause commercial oyster production failures.[1] From the Atlantic to the Pacific, ocean and coastal acidification has had extensive biological and socioeconomic impacts.

In 2009, Congress recognized the urgent need for federal investments in ocean acidification research and monitoring, and subsequently passed the *Federal Ocean Acidification Research and Monitoring* (FOARAM) *Act of 2009*. FOARAM established the federal government's work on ocean acidification by creating the NOAA Ocean Acidification Program and an interagency working group on ocean acidification. Much of our knowledge and understanding of ocean acidification that has emerged in the last decade can be credited to the federal funding authorized by FOARAM. The law's authorization, however, expired in 2012, and there are changes that can be made to further improve our ability to understand acidification in the open ocean as well as in the coastal zone.

We believe the COAST Research Act will help our nation and coastal communities better prepare for the effects from ocean and coastal acidification. Thank you for your leadership on this issue, and we look forward to working with you to craft solutions for our changing ocean environment.

Sincerely,

Sarah Cooley

Sarah Cooley, Ph.D.
Director, Ocean Acidification Program
Ocean Conservancy

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[1] https://today.oregonstate.edu/archives/2017/may/acidified-ocean-water-widespread-along-north-american-west-coast

The Oregon Coordinating Council on
Ocean Acidification and Hypoxia

Date: March 8th, 2019

The Honorable Suzanne Bonamici
2231 Rayburn House Office Building
Washington, DC 20515

Re: Coastal and Ocean Acidification Stressors and Threats (COAST) Research Act

As the Co-Chairs of the State legislatively mandated, Oregon Coordinating Council on Ocean Acidification and Hypoxia (or "Oregon OAH Council"), we appreciate the opportunity to provide you with a letter of strong support for the Coastal and Ocean Acidification Stressors and Threats (COAST) Research Act. Addressing intensifying ocean acidification (OA) conditions here in Oregon, as well as across the United States, is critical to our Nations understanding of larger impacts from CO_2 emissions.

Oregon is among the first places in the world to observe direct impacts of ocean acidification and hypoxia (OAH), due to our unique geographic and oceanographic context, putting our fragile marine ecosystem at risk. Our coastal economies rely on our vibrant marine ecosystem. Our nearshore waters are home to sport and commercial fisheries, all of the State's mariculture operations, and contain critical nursery grounds for economically important species including rockfish, oysters, salmon, pink shrimp, and Dungeness crab. Oregon is not alone in experiencing the impacts from OA or hypoxia. Through actions such as those in the COAST Research Act we must act together as Americans to develop solutions for our coastal communities, economies, and ecosystems to prepare for future conditions.

In the coming years, the Oregon OAH Council will continue to take a thoughtful, collaborative, science-based approach to developing recommendations to address OAH in our state and beyond. Through further investments and initiatives, Oregon and the United States will benefit from adaptation and mitigation measures and will model to the world how to develop actionable solutions for OA adaptation and mitigation.

The Oregon OAH Council has identified three urgently needed strategic actions[1], which directly align with objectives within the COAST Research Act.

(1) *Monitoring of key oceanographic and biological indicators of impacts from OAH.*

At the same time that OA has been impacting our coasts, oxygen-depletion is on the rise; Oregon and much of the West coast has seen several seasons in a row with extended periods of hypoxia in our coastal waters. The Oregon OAH Council is encouraged that the COAST Research Act identifies the need

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[1] The Oregon Coordinating Council on Ocean Acidification and Hypoxia. First Biennial Report. September 2018. https://www.oregonocean.info/index.php/ocean-documents/oah-hypox/oah-council-1st-biennial-report/1766-oah-council-1st-biennial-report-sept-15th-2018-1/file

to strengthen investments in OA research and monitoring in the context of other environmental stressors. Ocean acidification and hypoxia are compounding stressors for a wide range of marine animals, and as such must continue to be studied together. Through the COAST Research Acts reauthorization of funding of NOAA, NSF, and NASA, much needed resources will be made available to researchers across the United States to continue to expand our knowledge of OAH. The Oregon OAH Council also supports the initiative of the COAST Research Act to create data processing, storage, and archive facilities to provide for the long-term stewardship and standardization of data. By creating a central repository for OAH data it provides governments, scientists, and industry better access to the information need to inform their mitigation and adaption planning. Only by maximizing our current data and filling our knowledge gaps of OAH, can we as a Nation begin to be able to piece together for solutions for our coastal communities.

(2) *Projects or programs that promote coastal economic and ecosystem resilience to OAH.*

Fisheries and aquaculture are central to our history, are enjoyed by Americans across the nation year-round, and remain key to many of Oregon's coastal economies today. Yet, the future sustainability of these marine resources and communities' ability to rely on them, are uncertain in the face of significant ocean changes, including OAH, and uncertain in the face of our current state of preparation to adapt to those changes over time. This is why the Oregon OAH Council supports activities and initiatives that promote resilience to increased OAH conditions, for both human communities and ecosystems. The COAST Research Act also stresses the importance of increasing our understanding of the socioeconomic effects of OA by expanding federal research to assess adaptation and mitigation strategies. There will be costs of inaction relative to CO_2 mitigation and the United States has an obligation to relieve these costs wherever possible for our citizens.

(3) *Tools and strategies to increase awareness of OAH science, impacts and solutions.*

As the impacts of OA intensify, it is going to be vitally important for our Nation to identify and advance opportunities to raise awareness of and communicate OAH science, impacts, and mitigation solutions. This is why the Oregon OAH Council is encouraged by the fact that the COAST Research Act recognizes the need to address the effects of OA on estuaries and integrate research, monitoring, and adaptation strategies. By integrating OA causes and effects, it better demonstrates the complexity of this climate issue, and provides a clearer message to communities. The Oregon OAH Council also supports the COAST Research Act establishment of an Advisory Board to increase coordination among stakeholders, including members of industry, to work with State and Federal governments to improve coordination. Recognizing the importance of a broad membership, our Oregon OAH Council includes members from industry, academia and state government agencies. For the benefit of our marine ecosystem and the human communities that rely on a healthy marine ecosystem, the Nation's adaptation and mitigation approaches to OA should include successful communication of new science, monitoring, and adaptation strategies.

As Co-Chairs of the Oregon OAH Council, we appreciate the opportunity to provide you with a letter of strong support for the COAST Research Act. The strategic investment and coordination opportunities outlined in this act are meaningful and will make a difference in our understanding of OAH science, impacts, and solutions. Through passage of this Act and the subsequent investment in science, adaptation and communications, the United States will demonstrate meaningful action in fighting OA and the global challenges of climate change, and preparing our citizens and economies for the changes ahead.

Thank you for your consideration of these comments.

Sincerely,

John Barth, PhD

Co-Chair, Oregon OAH Council
Executive Director
Marine Studies Initiative
Oregon State University

Oregon State University

Caren Braby, PhD

Co-Chair, Oregon OAH Council
Marine Resources Program Manager
Oregon Department of Fish and Wildlife

OREGON Fish & Wildlife

Oregon State University

Office of the Provost and Executive Vice President
624 Kerr Administration Building
Oregon State University
Corvallis, Oregon 97331
oregonstate.edu

8 March 2019

The Honorable Suzanne Bonamici
U.S. House of Representatives
2231 Rayburn House Office Building
Washington, DC 20515

Re: H.R. 1237 - The COAST Research Act of 2019

Dear Representative Bonamici:

We write to offer Oregon State University's strong support for H.R. 1237, the COAST Research Act of 2019.

As marine habitats face new and daunting pressures threatening their sustainability, the COAST Research Act identifies the growing need for strategic and robust investments in ocean acidification (OA) research, monitoring and stakeholder collaboration.

Oregon State University is committed to interdisciplinary approaches to address the national and global challenges facing our oceans and coast communities. OSU has a deep history of global leadership in oceanography and engages in nationally ranked oceanographic monitoring programs and world-leading OA research. Further, the university recognizes that Oregon's estuaries and coastal regions are home to some of the world's most productive ecosystems and economically vital shellfish farms.

The university is encouraged that the COAST Research Act expands the definition of OA to include coastal and estuarine systems, and identifies OA as being affected by a combination of factors, including hypoxia. The university believes that by expanding federal definitions of OA and by increasing funding opportunities, researchers and managers will be able to best utilize resources to find solutions to address OA.

The university also is encouraged that this legislation recognizes the need for federal engagement to continue important investments. Doing so will enhance the integration of OA research, monitoring and adaptation strategies across principal federal research agencies, including the National Science Foundation, National Oceanographic and Atmospheric Administration, and the National Aeronautics and Space Administration.

Oregon State University understands that effective and collaborative partnerships and communication are essential for our state and nation to find adaptive and mitigation solutions to address OA. For example, the proposal to establish an Ocean Acidification Advisory Board will be essential for facilitating the important work still to be done.

The world's ocean belongs to everyone, and ocean health is critical to our future. In the coming decades, it will be essential for the nation and its universities to work collaboratively to improve and sustain the health of our oceans. Doing so, we will assure human wellness, environmental health and economic prosperity for future generations.

In closing, Oregon State University believes that the COAST Research Act proposes new strategic tools to expand understanding and address the problems facing our oceans and coastal communities.

Sincerely,

Edward Feser
Provost and Executive Vice President

Irem Tumer
Interim Vice President for Research

PCSGA

PACIFIC COAST SHELLFISH GROWERS ASSOCIATION

March 9, 2019

The Honorable Suzanne Bonamici
US House of Representatives
2231 Rayburn House Office Building
Washington DC 20515

Dear Representative Bonamici,

On behalf of the members of Pacific Coast Shellfish Growers Association (PCSGA), I am submitting this letter of support for H.B. 1237, the *Coastal and Ocean Acidification Stressors and Threats* (COAST) *Research Act of 2019.* Shellfish growers were the first community to call attention to the problems associated with ocean acidification when, in 2007, they experienced sever oyster larvae mortality in two out of three major west coast shellfish hatcheries. Since then, PCSGA has engaged in several local, state, and federal efforts and initiatives to ensure a future for this historic industry.

Shellfish farming on the west coast began in the late 1800's, fueled the California Gold Rush and was the reason for the development of many coastal towns. Today, PCSGA proudly represents 120 shellfish farms in Alaska, Washington, Oregon, California and Hawaii which farm mussels, clams, oysters and geoduck. Our members not only produce sustainable, healthy, food, but also provide significant ecosystem services such aquatic habitat and water filtration, and support thousands of family-wage jobs within rural coastal communities.

For nearly a decade, the shellfish industry has benefited from NOAA's Ocean Acidification Program and the Integrated Ocean Observing System (IOOS), both of which relate to the Federal Ocean Acidification Research and Monitoring (FOARAM) Act of 2009. These programs and the directives within FOARAM have influenced the way shellfish growers operate their farms among the uncertainty of changing ocean conditions. Historically, growers only consulting their tide charts. Now, growers rely upon a variety of real-time data and tools to understand the ocean changes and adapt methods and practices which allow them to continue farming in a productive and profitable manner. There much work ahead of us and much yet to learn. COAST Research Act provides an essential pathway forward.

We are excited by the intent of COAST Research Act and the opportunities it provides. Not only is it a reasonable follow up to FOARAM but it also allows us to continue asking questions and seek innovative approaches to mitigate the impacts related to ocean acidification.

Thank you very much for your leadership on this and for your commitment to ensuring the long-term health of our coastal and marine areas upon which shellfish growers depend.

Respectfully,

Margaret A. Pilaro
Executive Director

PACIFIC STATES MARINE FISHERIES COMMISSION
205 SE Spokane Street, Suite 100 - Portland, Oregon 97202
PHONE (503) 595-3100 FAX (503) 595-3232
website: www.psmfc.org

March 4, 2019

The Honorable Suzanne Bonamici
U.S. House of Representatives
Washington, D.C. 20515

Dear Representative Bonamici:

The Pacific States Marine Fisheries Commission has a standing resolution adopted by the Commissioners to support and encourage new funding should be identified to augment coast-wide research and monitor changing ocean conditions, harmful algal blooms, and ocean acidification.

We have had an opportunity to review the Coastal and Ocean Acidification Stressors and Threats (COAST) Research Act. The bill would reauthorize the Federal Ocean Acidification Research and Monitoring Act to continue funding research through the National Oceanic and Atmospheric Administration and the National Science Foundation. The bill would designate NOAA as the lead federal agency in the coordination of the federal response to ocean acidification. The bill also broadens the program to include marine estuaries.

The bill, as introduced, strengthens the federal research programs that focus on ocean acidification. West Coast and Alaska ocean stakeholders are already feeling the socioeconomic impacts of ocean acidification. We view ocean acidification research as an important ongoing federal responsibility in seeking to address the negative impacts to these stakeholders. Pacific States therefore supports the your efforts and that of other Members of the Ocean Caucus in seeking to expeditiously move the Coast Research Act through the House of Representatives.

Regards,

Randy Fisher
Executive Director

"To promote the conservation, development and management of Pacific Coast fishery resources through coordinated regional research, monitoring and utilization"

SURFRIDER FOUNDATION

March 7, 2019

Honorable Congresswoman Suzanne Bonamici
439 Cannon House Office Building
Washington, DC 20515

RE: Support for Coastal and Ocean Acidification Stressors and Threats (COAST) Research Act

Dear Honorable Congresswoman Bonamici:

On behalf of Surfrider Foundation's 160 Chapters and student clubs and our 250,000 supporters, activists and members worldwide, **we write to express our enthusiastic supports for Coastal and Ocean Acidification Stressors and Threats (COAST) Research Act.** The Surfrider Foundation (Surfrider) is a non-profit grassroots organization dedicated to the protection and enjoyment of our world's oceans, waves and beaches.

As climate change continues to impact our ocean and coast, local communities need to plan ahead to better understand and plan for a changing climate. Ocean acidification (OA) is particularly concerning for Surfrider. The current understanding of ocean acidification impacts on ocean and estuarine ecosystems is inadequate and must be improved to fully prepare for and adapt to changing environmental conditions and manage our natural resources in nearshore locations. In addition, more integration and coordination is needed between local, state, and national entities to ensure adequate scientific research and investments in related topics such as nutrient loading, hypoxia, ocean acidification, and harmful algae bloom research and other observational systems are targeted to meet coastal communities' needs.

Surfrider is particularly pleased to see the legislation focuses on adaptation strategies for ocean acidification and expands the definition of ocean acidification to include estuaries. In addition, we are pleased to see that the bill would expand the Interagency Working Group's strategic research plan to also address socioeconomic effects of ocean and coastal acidification and assess adaptation and mitigation strategies.

Furthermore, establishing an Advisory Board to increase coordination among stakeholders, and requiring NOAA to facilitate an Interagency Working Group's strategic research plan, that coordinates monitoring and research efforts among federal and local agencies and stakeholders is critical to ensure success of this important piece of legislation.

Thank you for introducing such important legislation.

Sincerely,

Stefanie Sekich-Quinn
Surfrider Foundation
Coastal Preservation Manager
San Clemente, CA

Charlie Plybon
Surfrider Foundation
Oregon Policy Manager
Newport, OR

LETTER SUBMITTED BY REPRESENTATIVE BILL POSEY

Florida Institute of Technology

College of Engineering and Science
Department of Ocean Engineering and Marine Sciences

February 25, 2019

The Honorable Eddie Bernice Johnson
Chairwoman
House Committee on Science, Space, and Technology
2306 Rayburn Office Building
Washington, DC 20515

The Honorable Frank Lucas
Ranking Member
House Committee on Science, Space, and Technology
2405 Rayburn HOB
Washington, DC 20515

The Honorable Lizzie Fletcher
Chairwoman
Subcommittee on Environment
1429 Longworth HOB
Washington, DC 20515

The Honorable Roger Marshall
Ranking Member
Subcommittee on Environment
312 Cannon House Office Building
Washington, DC 20515

Dear Chairwoman Johnson, Ranking Member Lucas, Chairwoman Fletcher, and Ranking Member Marshall,

On behalf of the Florida Institute of Technology (Florida Tech), a national research university in Melbourne, Florida, please accept our appreciation of the House Science, Space, and Technology Committee and the Subcommittee on Environment for investigating solutions to the impacts of climate change on our oceans and estuaries. As the Director of the Indian River Lagoon (IRL) Research Institute at Florida Tech, I write to express my support for public policy advancing research into coastal and ocean acidification.

Environmental impacts related to abrupt climate change pose some of the greatest threats and challenges to our society. Increasing temperatures and $CO2$ in the oceans and atmosphere results in rising sea levels, increasing storminess, changes in weather patterns, and changes in ocean chemistry. With much of our nation's population and critical infrastructure near the coast, realized risk of flooding from sea-level rise and extreme storm events may ultimately result in significant dollar damages and displacement of residents. Increased temperatures and $CO2$ along with the excess nutrients entering the coastal waters are changing the chemistry of our estuaries and oceans on which habitats and economies depend. The effects of changing chemistry on estuarine habitat is still not well understood.

My primary role in supporting my colleagues at the Florida Tech IRL Research Institute is to investigate causes and develop engineering solutions for our impaired coastal waters. All of my educational, training and research activities continues to re-emphasize the following principle: sound science must be the framework on which our engineering solutions are built. By basing our solutions on scientific research, we reduce the likelihood of unintended consequences from the solutions proposed by experts.

150 West University Boulevard, Melbourne, FL 32901-6975 • (321) 674-8034 • Fax: (321) 674-7212

It is our duty as citizens, scientists and engineers to address the issues of climate change head on. We have identified several paths to move forward:

First, we must strengthen our investment in researching technologies and methods for mitigating the effects of climate change. This includes funding fundamental research into the causes and effects of climate change (e.g. sea level rise, acidification, eutrophication, habitat loss, etc.). There is opportunity for the United States to lead a worldwide economic market in high-tech carbon reduction and sequestration, clean renewable energy, coastal hardening methodologies and low impact technologies.

Second, we must work to reduce our impact on the coastal ocean. There are promising mitigation projects focusing on utilities and infrastructure: septic-to-sewer conversions, wastewater retrofits and upgrades, storm water management, and water control structures.

Third, we must work to restore the natural filtration systems of our estuaries which provide habitat for marine life and the economic livelihood for millions of Americans. Restoration includes removal of the legacy loading of nutrients and fine sediments that was the result of decades of inadequately managed land development. Restoration also includes the reintroduction of critical habitat in the regions where that habitat has disappeared.

We thank the House Science, Space, and Technology Committee and the Subcommittee on Environment for investigating solutions to the impacts of climate change on our oceans and estuaries. Florida Tech will continue to participate in the development of solutions to global climate change issues and improve the quality of life for our citizens.

Sincerely,

Robert J. Weaver, Ph.D.
Director Indian River Lagoon Research Institute
Associate Professor of Ocean Engineering
Department Ocean Engineering & Marine Sciences
Florida Institute of Technology
RJWeaver@FIT.edu
321.674.7273

cc: The Honorable Bill Posey
2150 Rayburn House Office Building
Washington, DC 20515