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

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[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]

Resulting Impacts of Ocean and Coastal Changes

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

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[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

[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