TESTIMONY
OF
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IMPACTS OF CLIMATE CHANGE ON THE CHESAPEAKE BAY
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Introduction

Thank you Chairwoman Bordallo and Chairman Grijalva and distinguished members of the Subcommittees for the opportunity to provide testimony today. My name is Anson Hines. I am the Director at the Smithsonian Environmental Research Center located here in Edgewater, Maryland. I hold an advanced degree in Zoology. I have led Smithsonian's environmental research programs on Chesapeake Bay for more than 22 years and have served on the Smithsonian's steering committee for its Marine Science Network of coastal research facilities that extend from Chesapeake Bay to Florida, Belize and Panama for 15 years. I have conducted intensive long-term research on the ecosystems, species composition and population dynamics of estuarine organisms in Chesapeake Bay for 30 years. I am very pleased that the Smithsonian Environmental Research Center is hosting the joint subcommittees' field hearing on impacts of climate change on Chesapeake Bay.

The greatest challenges to our environment today are in the coastal zone where 70 percent of the world's population lives, works, and plays. The ecosystems at the land-sea interface are also among the most biologically productive, and their health and sustainability is critical for the survival of both ocean and terrestrial environments, and the wide range of services they provide. These are the ecosystems that will be the most affected by climate change in the United States. There can be no better focus for impacts of climate change in the coastal zone than the Chesapeake Bay, the nation's largest and historically most productive estuary.

The Smithsonian Environmental Research Center (SERC) is one of the world's leading research centers for environmental studies of the coastal zone. The Smithsonian Institution established SERC in 1965 to track and understand effects of human interactions in coastal ecosystems, using Chesapeake Bay as its primary study system and a model for the nation. SERC science and education focus on key environmental issues facing this nation and the world. SERC works with government agencies, academic institutions, and the public to incorporate rigorous science into resource management and stewardship decisions.

My purpose today is to summarize the main themes and results of SERC's world-class research on climate change. From its inception, SERC was established to track and understand the effects of climate change on coastal ecosystems of Chesapeake Bay. SERC's primary study system now encompasses 2,650 acres of land and 16 miles of shoreline surrounding a subestuary of the Bay, providing a unique opportunity for intensive monitoring and controlled experiments on linked ecosystems of watershed and estuary. From its beginning, this research has focused on analyses and long-term measures of the ecosystem responses to what ecologists call “forcing factors” of weather – the seasonal and annual fluctuations in temperature, rainfall, and storm events. For more than four decades, SERC scientists have been developing unique long-term data sets, models, and experiments on ecosystem responses to climate change that extend out to the large Chesapeake region. I cannot emphasize enough the importance of the Smithsonian’s commitment to long-term research. Without this sustained effort and these unique data sets, we would not be able to identify and assess changes occurring in the environment. Moreover, SERC’s commitment to understanding the mechanisms of complex – often interactive - ecosystem responses allows us to provide sound advice to resource management and policy.

Atmospheric Change, Climate Change and Environmental Change

Since SERC began its long-term studies on Chesapeake Bay, our scientists have measured many environmental changes associated with climate change in studies conducted over time periods of 20 to 40 years. These variables are the “forcing factors” of the environment that drive the ecological responses in the Bay’s ecosystems.

Much of the rise in atmospheric CO_2 has occurred in the past half century, which is the time period since SERC was established. SERC monitoring at Chesapeake Bay show that the concentration of atmospheric CO_2 has risen by 40 parts per million (ppm) or 14% since 1987, when it was measured at 340 ppm and it is now about 387 ppm.

Due to changes in composition of gases in the upper atmosphere, characteristics of solar radiation – particularly the ultraviolet (UVB) portion – reaching the surface of the Earth have changed. As part of a national and international monitoring network, SERC scientists have developed the longest running data set in the world for this portion of the sun’s energy, and these data show that the UVB level (as average midday sunburn radiation) at Chesapeake Bay has increased by 15% in the past 36 years.

During SERC’s 45-year history of research on Chesapeake Bay, we have witnessed much warmer temperatures, with a record number of hot summers and also milder winters. Water temperature of the Bay has increased by about 2.5^{o}F (1.3^{o}C). Most of these temperature changes have occurred in the past two decades.

Patterns of rainfall are much more varied and lack clear trends, but climate models generally predict greater rainfall overall for the Chesapeake Bay watershed, with precipitation likely to be more episodic and dispersed among drought periods. These changes could have large impacts on watershed discharges into the Bay. SERC scientists have documented the frequency and intensity of storm events and of droughts at its long-term study site on the Rhode River subestuary and watershed in relation to the broader regional variations in precipitation and consequences of the Bay’s water balance and water quality. These records include a full spectrum of storm intensity from Hurricane Agnes in 1972 and Isabel in 2003 to localized thunderstorms.

Sea level has risen approximately four inches (10 cm) over the course of SERC's long-term research. The present rate of rise at 3mm per year appears to be accelerating globally and may be exacerbated in the Chesapeake region by coastal subsidence and by changes in off-shore currents that can push water up into the Bay. Rising sea level may have major impacts on the marshes and other shoreline ecosystems of the Bay.

Chemical changes in the Bay are occurring as a result of, and interacting with, climate change. Clearly, the large problem of nutrient loading (nitrogen and phosphorus) running off the watershed and into the Bay is not only a problem of managing land use, but it is also related to the quantity and timing of precipitation effects on stream discharges. One third of all anthropogenic CO2 emitted into the atmosphere has been absorbed by the oceans, reducing pH by about 0.1 of a unit and significantly altering their carbonate chemistry. There is widespread concern that these changes are altering marine habitats severely, but little or no attention has been given to the biota of brackish and fresh waters, which have less pH buffering capacity than the ocean. The amount of mercury falling from the atmosphere into ecosystems has tripled over the past 200 years as a result of burning of fossil fuels since the Industrial Revolution.

Responses of Chesapeake Ecosystems to Climate Changes

The pervasive and accelerating rates of these climate changes are becoming ever more evident. However, responses of the Bay's and the Earth's biological systems to these forcing factors are a major source of uncertainty in predicting effects of climate change. The complex and interactive aspects of the Bay's responses to climate change require detailed studies of mechanisms of ecosystem controls across the coastal landscape.

Salt Marshes. Salt marshes and other wetlands are important ecosystems providing nursery habitats for fish and shellfish and other animals, sources of carbon into the Bay's food web, modifiers of water quality, and regulators of key chemical compounds including nitrogen, sulphur, carbon dioxide, methane, and mercury in the Bay. Salt marshes are also relevant models for the responses of plant communities to rising atmospheric CO_2, because they are include common species that are representative of the two major biochemical pathways of photosynthesis in plants. Termed C3 and C4, the two types of plants are hypothesized to respond differently to rising CO_2.

For 24 years (1985-2009) SERC scientists have conducted the worlds' longest running experiment on effects of rising CO_2 concentrations on natural plant communities at a salt marsh ecosystem of Chesapeake Bay. Funding from the Department of Energy allowed these scientists to test the effect of doubling of CO_2 levels on two major plant species of the marsh. The experiment showed that growth and biomass production of marsh communities dominated by one species – *Scirpus olyneyi*, a sedge representative of C3 plants - is markedly enhanced by rising CO_2. By contrast, marsh communities dominated by another species – *Spartina patens*, a salt marsh hay representive of C4 species - shows no significant response. These results suggest that rising CO_2 could cause shifts in species composition of salt marshes and probably other plant communities, with decreasing grasses (C4) and increasing sedges (C3) species. SERC's long-term marsh experiment shows changes in species composition in response to the interactions of both more modest rises in CO_2 and variations in other factors.

This long-term experiment yielded unique insights into the effects of environmental variability on CO_2 impacts, especially the importance of rainfall affecting water availability and salt stress in the marsh. Because rising CO_2 enhances water-use efficiency of plants, low rainfall and drought markedly enhances the effects of CO_2 impacts on plants. Importantly, this unique on-going experiment allows SERC scientists to track the long-term ecosystem responses to the complete array of climate change variables with controls for the effects of rising CO_2.

The salt marsh project has been supplemented in recent years by funding from the National Science Foundation and U.S. Geological Survey to SERC scientists to address carbon storage in peat of marsh soils of Chesapeake Bay. This aspect of the project is focused on interactive effects of nutrient (nitrogen) enrichment and rising sea level – two key confounding factors in coastal systems. Initial results indicate that carbon sequestration enhanced by rising CO_2 resulting in peat accumulation in salt marshes is keeping up with sea level rise in Chesapeake Bay. However, increased nitrogen loading – a major problem for the Bay – can inhibit or divert below-ground carbon storage, preventing peat accumulation from keeping up with sea level rise. This confounding effect of nutrient pollution and rising CO_2, coupled with the probability of acceleration in sea level rise, could cause inundation of the Bay's salt marshes and other wetland, with serious losses of ecosystem function for the health of the Bay.

Forests. Forest ecosystems play crucial roles in regulating water run off in the Chesapeake watershed. They also play a major role in carbon sequestration that mitigates the CO_2 inputs into the atmosphere from fossil fuels. For the past 30 years, SERC scientists have been tracking long-term changes in species survival and growth in carefully mapped plots of tens of thousands of trees at the Rhode River site, which has the highest biodiversity of tree species in the region. Tracking 50 species, this research allows SERC forests scientists to measure and model tree growth in response to climate variation. Some species are responding vigorously to CO_2 and temperature, especially tulip poplar and sweet gum, while other species such as oaks appear to be declining in growth rates. This suggests that climate change will promote significant changes in species composition of forests of the watershed, which will in turn affect rates of carbon sequestration, leaf litter decomposition and nutrient cycling. Forests also have major effects on water processing and transfers across the landscape, because evapotranspiration by trees can send as much as 60-70% of rainfall back into the atmosphere, reducing run-off and modifying rising temperatures. Thus, forests play a key role in regulating stream discharges and nutrient pollution into the Bay.

Additionally, SERC and other science research units of the Smithsonian are engaged in partnerships linked to national and global networks for tracking forest responses to climate change. SERC's detailed forest studies are now being integrated into both the emerging National Ecological Observatory Network (NEON) of the National Science Foundation and the Smithsonian Institution Global Ecological Observatory (SIGEO) initiative. SIGEO is a multi-institutional global network of 34 forest research plots. NEON has proposed that the Smithsonian's Conservation and Research Center in Front Royal, Virginia, serve as the permanent monitoring site for the mid-Atlantic "domain" (region) of the nation; and SERC has been proposed as one of the initial "re-locatable sites" for the region. NEON seeks to provide additional research infrastructure and instrumentation to track long-term environmental change within and among regions of the country in response to climate change and other factors.

SIGEO will link these Chesapeake forest studies to a network of mapped forests in the tropics around the world and to several additional mapped forests in the temperate zone of North America. SERC scientists will be using these networks to set up instrumentation that measures the ecosystem fluxes of carbon dioxide, water, and energy through forests in response to climate change and forestry management. Variation in these fluxes, and the factors that control them in forests, account for much of the uncertainty of climate change predictions in the Chesapeake Bay watershed, with important ramifications for Bay waters proper.

Chesapeake Watershed Dynamics: Stream Discharges

As climate change affects the quantity and timing of precipitation, it will affect watershed dynamics and stream discharges that are critical to managing water quality and health of Chesapeake Bay. SERC's watershed studies measure and model stream discharges of water, sediment and nutrients as a function of precipitation, land use, and geological features. SERC's watershed models have significantly improved predictions of nutrient loading into the Bay. One of the important uncertainties of watershed dynamics is understanding the effects of variation in evapotranspiration by forests on stream discharges. SERC's expanding analysis of factors affecting water balance in forests will contribute new insights in this area. Long-term measures of storm events on the Rhode River watershed also provide measures of sediment transfers and fluxes of toxic chemicals such as mercury. SERC data, like data from other regions, clearly show that these large storm events caused major disturbance and influxes of water-borne sediment and chemicals. This means predictions of increased frequency and intensity of storms associated with climate change will have negative impacts on Chesapeake Bay.

Bay Water Quality, Plankton Production, and Oxygen Levels

Watershed discharges of nutrients into the Bay affect water quality and fuel phytoplankton production, which in turn affect oxygen levels. SERC researchers have tracked the sources of nutrient discharges that stimulate plankton dynamics and harmful algal blooms in the Rhode River as a model system for the upper Bay. These studies suggest that the spring plankton bloom may be occurring earlier with advanced seasonal discharges from the Susquehanna River. SERC's long-term research shows that summer-time turbidity is increasing in the Rhode River and upper Bay, much of which appears related to re-suspension of sediments rather than to plankton blooms. This indicates that factors other than watershed discharges also affect water quality, adding further uncertainty about the effects of climate change and watershed discharge into the Bay. The seasonal timing and intensity of plankton production affects light penetration into the Bay's waters, and SERC research and models show how these factors affect light needed for growth and restoration of submerged aquatic vegetation, which forms important habitat that has declined drastically during the past 40 years.

Fishery Production

Climate change can have both positive and negative affects on fishery species of the Bay. SERC scientists have conducted extensive studies of blue crabs, as the major fishery in Chesapeake Bay. As a species of tropical origin, blue crabs are likely to be favored by warming. SERC research on the life history and demography of blue crabs indicate that their reproductive output will increase, growth will speed up, and time to reach maturity will shorten as the warm season lengthens in Chesapeake Bay. SERC research indicates that mortality of small juvenile and adult female crabs during harsh winters may be reduced by climate warming that makes for milder winters. While this will have positive effects on population dynamics, a number of other factors may have negative effects on blue crabs. For example, rising temperatures cause losses of sea grass beds in the lower Bay, which is important habitat for newly settling juvenile crabs. SERC research shows that warming temperatures will also increase predation rates on juvenile crabs, and may increase the abundance and species of crab predators from southern latitudes.

Oysters require calcium carbonate for shell growth, and restoration of this ecologically and economically valuable species may be affected by acidification of Bay waters due to rising CO_2, just as ocean acidification may have adverse impacts on coral reefs. Current research by SERC scientists show that acidification of estuarine water has negative impacts on shell growth of larval oysters as higher levels of CO_2 cause shifts in the chemical balance of carbonate deposition calcium in their shells. Larvae of native oysters (*Crassostrea virginica*) experienced a 16% decrease in shell area and a 42% reduction in calcium content when comparing treatments of CO_2 levels projected from pre-industrial time periods and the end of 21st century.

Invasive Species

SERC is a national center for study of marine invasive species and the home of the National Ballast Information Clearinghouse, which tracks ballast water discharges by all commercial ships arriving to all U.S. ports – the major source of introduced species in coastal waters. SERC researchers are analyzing the patterns of invasions in Chesapeake Bay in comparison to other parts of the U.S. coastal system. SERC's national data base documents more than 160 invasive species in Chesapeake Bay. Increasing temperatures can facilitate invasive species spreading from the south into the mid-Atlantic region. SERC research shows that such range expansions often result from warmer winter temperatures and earlier springs, rather than from hotter summers. Other invasive species such as the southern marsh reed *Phragmites australis* are spreading very rapidly across Chesapeake salt marshes, appear to respond very positively to rising CO_2, and are likely to out-compete the native plants that are already under stress from rising sea level and nitrogen pollution. Terrestrial invasive species also affect the Bay's responses to climate change. For example, SERC research on earthworms – most are invasive species introduced long ago from Europe – have major effects on carbon processing and sequestration of leaf litter in forest soils. These effects facilitate shifts in species composition of trees in the forests, again with important consequences for water movement through the watershed. SERC's research show that still other species, such as mitten crabs and snakehead fish from Asia, may become established and spread in the region through complex factors interacting with climate and a range of other disturbance factors.

Complex Interactions: Mercury in Seafood as an Example

The environmental forcing factors of climate change interact with many effects of other human activities that are impacting Chesapeake ecosystems (such as land-use change, fishery management, shipping and ballast water, pollution controls). These interactions are likely to have complex and indirect consequences for Chesapeake Bay that may be just as important as the direct effects of climate change. This complexity contributes much of the uncertainty in predictions about ecosystem responses to climate change. These complex interactions are a major focus of SERC's research on the mechanisms of ecosystem responses to climate change.

For example, new SERC research and elsewhere indicates that mercury is a major toxic contaminant that can accumulate in seafood. Mercury is an atmospheric pollutant that often results from burning of coal in power plants, and is transferred into the food chain by a series of steps. As mercury falls from the atmosphere into coastal ecosystems, it is converted into methylmercury by bacteria that reside in wet, low-oxygen soils and sediments. This bacteria-processed methylmercury is what is picked up by organisms and concentrated up the food chain into seafood. Recent and on-going SERC research shows that once mercury falls into salt marshes and other wetlands, it is transformed and released into the Bay's food web. New SERC research and elsewhere indicates that methylmercury is also forming in coastal groundwater, which is released into the Bay in wet spring periods, which are predicted by the Science and Technology Advisory Committee of the Chesapeake Bay Program to be enhanced by climate change in the mid-Atlantic region. Thus, SERC research on mercury contamination illustrates how climate change may indirectly affect the environment and human health.

Conclusions

(1) While climate change is already upon the Chesapeake Bay, and the rate of change is accelerating globally, the responses of ecosystems to the changing environmental forcing factors are highly uncertain. Much of this uncertainty is due to the complex ecological interactions with many other factors that are changing simultaneously across the coastal landscape with population increase. To reduce this uncertainty, much more environmental research is urgently needed to determine the mechanisms of ecosystem response to climate change. The Smithsonian Institution will utilize its substantial scientific capabilities towards monitoring, understanding and predicting effects of climate change in Chesapeake Bay.

(2) Environmental research should utilize the key long-term data and analyses that are already in place and are critical to interpreting future change. The Smithsonian's commitment to environmental research on Chesapeake Bay clearly shows the value of these data, and the importance of the scientific efforts needed to sustain them.

(3) The immense scale and complexity of the climate change problems require teamwork and partnerships at many levels of scientific and management organization. The Smithsonian Environmental Research Center intends to continue to play a major role in collaboration with academic institutions, State and Federal governmental partners, and non-governmental organizations to address these critical needs.

Thank you for the opportunity to testify today and I look forward to answering any questions you may have.