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**Testimony of Dr. Eldredge Bermingham**
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***Introduction***

Thank you, Chairman Lipinksi and distinguished members of the Subcommittee for the opportunity to provide testimony today. My name is Eldredge Bermingham. I am the Director of the Smithsonian Tropical Research Institute, or STRI, located on the banks of the Panama Canal in the Republic of Panama, the only bureau of the Smithsonian Institution located outside the United States. I hold a PhD degree in Genetics. I have spent 20 years guiding molecular genetics research programs at STRI and have published more than 140 scientific articles. For the past 7 years I have served as Deputy Director and now Director of STRI, where I oversee about 40 PhD scientists and 350 technical staff. I participate on the Smithsonian's steering committee for its Marine Science Network, and on Secretary Clough's strategic planning teams responsible for the 2010-2015 Strategic Vision for the Smithsonian. I have played the lead role over the past 5 years transforming the Center for Tropical Forest Science that began in Panama more than thirty years ago into the pan institutional Smithsonian Institution Global Earth Observatories (SIGEO). SIGEO is a global network of 40 large-scale forest dynamics plots in 21 countries. The network is a U.S.-led resource that investigates forest dynamics and the response of forests and the ecosystem services they provide – carbon storage, water provision and biodiversity conservation -- to climate change. National and international science education, training and capacity building are core missions of STRI and SIGEO.

My purpose today is to use my experience at STRI to summarize the main themes and importance of post-secondary STEM education at the Smithsonian. At STRI we host more than 1000 visiting undergraduate, graduate and postdoctoral researchers. Our approach is to partner outstanding scientists with outstanding young scholars. At STRI, we apply state-of-the-science technologies to understand the nature and origins of biodiversity, the causes and consequences of climate change, the interconnectedness of global ecosystems, and the cultural heritage of Native American peoples. We mix the necessary, more traditional long-term measurement and observations about the natural world with innovative, new analytic techniques and approaches. At each of the science research units at the Smithsonian the contribution to training the next generation of scientists is impressive and the Institution is recognized at the national and international level for producing scientific leaders. Outstanding examples include education in tropical biology (STRI), astronomy and astrophysics (Smithsonian Astrophysical Observatory), species survival biology (National Zoological Park), biodiversity (National Museum of Natural History) and invasive species biology and coastal zone processes (Smithsonian Environmental Research Center). And the Smithsonian partners with the National Academy of Sciences to develop award-winning science curricula through the National Science Resources Center. We are a remarkable U.S. resource responsible for training the next generation of scientists.

Background:

What has made STRI such an important resource for educating the next generation of scientists? The answer is long-term federal investment in world-class resident scientists supported by superb research facilities located adjacent to tropical forests and coral reefs. This year, 2010, the Smithsonian marks a century of research in Panama, tracing back to the 1910-1912 Smithsonian Expeditions to Panama authorized by President William H. Taft. From the humble beginning of a single research station on Barro Colorado Island (BCI) located in the middle of the Panama Canal, STRI has developed dramatically. STRI is an international focal point for scientists and students interested in the ecological and evolutionary processes that underlie the extraordinary biological diversity of rain forest and coral reef ecosystems. These processes are palpable on an isthmus that formed three million years ago and transformed our planet by joining the continents of South and North America, and separating the Caribbean Sea from the Eastern Pacific Ocean. Long-term environmental research is a STRI trademark, more than eighty years in the case of the forests on Barro Colorado Nature Monument (BCNM), protected under the terms of the Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere, ratified by the U.S. Senate in 1941. The BCNM is the only mainland tropical forest reserve in the world under U.S. stewardship.

The long-term research conducted by STRI scientists, collaborators and students is a critical contribution to the Smithsonian Institution's 2010-2015 strategic plan "A Smithsonian for the Twenty-First Century" set forth in 2009, particularly through its contributions to the Grand Challenge, *Understanding and Sustaining a Biodiverse Planet*, but STRI also contributes through its Paleontology program to *Unlocking the Mysteries of the Universe*, and through its Anthropology and Archeology programs to *Valuing World Cultures*. As noted in the Smithsonian's strategic vision, the importance of long-term assessment and analysis of forests and ecosystem function in a world marked by significant biodiversity loss and climate change led to the establishment of the BCI 50 hectare forest plot in 1980, a model that has now been replicated at 40 sites around the world including six in the United States providing an innovation platform for new observation technologies.

With laboratories on both coasts of Panama, STRI is the only institute in the Americas providing direct research access to both the Pacific and Atlantic oceans. The two-ocean stage provided by STRI marine facilities permits scientists and their students to move between experiments in the eastern Pacific and Caribbean in a few hours, and represents a principal component of the Smithsonian Marine Science Network extending from the Chesapeake to Florida, Belize and Panama. The recurring two-ocean theme in marine science at STRI has resulted in landmark studies of the evolution and ecology of tropical marine species and communities, as well as research funded by the National Science Foundation (NSF) and the National Institutes of Health (NIH) for ecologically guided discovery of novel pharmaceutical compounds, and research funded by the U.S. Department of Agriculture (USDA) for discovery of novel agrochemicals from nature. Marine facilities with easy access to two oceans take on increased importance as an experimental platform for studying the impact of climate change and ocean acidification on near shore coral reefs, sea grasses, and mangroves.

In addition, BCI and STRI represent important facility resources for other federal agencies, and serve as the base for tsunami monitoring equipment installed by the U.S. Geological Survey; and as sites to monitor mosquitoes and their role as disease vectors by the Environmental Protection Agency, or survey wildlife that could be carriers of avian influenza and other animal-borne diseases in projects funded by NIH.

Thus extraordinary science facilities, the unique geography of Panama and the country's long-term and strongly positive association with the United States, and a world-class group of 40 resident scientists has led STRI to play a key role in the education of tropical biologists. It is fair to say that nearly all tropical biologists pass through STRI at some point in their careers -- many in the formative stages of their development.

**Science/Technology/Engineering/Math Education at STRI – General:**

STRI's research excellence is a function of our ability to attract and nurture the best and brightest young researchers. Indeed, supporting and training promising young scholars is a cornerstone of STRI science and builds our capacity to understand a biologically diverse planet and solve Earth's most challenging environmental problems. STRI actively participates in science, technology, engineering and math (STEM) training: directly by supporting interns, PhD students and postdoctoral scholars, and indirectly by partnering with universities concerned with tropical research and education. Both education avenues foster transformational science by connecting researchers and students with diverse backgrounds, experiences and skills. STRI also partners with institutions in Panama to develop STEM training for Panamanian students at our facilities.

Education at STRI is strongly assisted by mentors of exceptional ability. The relevance, quality, and performance of STRI scientists as mentors of the next generation of tropical biologists is top tier, as evaluated by a Visiting Committee of outside experts. In a recent review, the Visiting Committee used National Research Council criteria to measure the productivity and impact of STRI science compared to 142 of the best university research departments in the United States; STRI scientists ranked first in all measures of scientific relevance (e.g., publication citations), quality (e.g., scientific honors), and productivity (e.g., publication numbers). Furthermore, the number of young scientists who choose STRI as the base for their graduate and postgraduate research training provides an annual measure of the relevance and quality of STRI science to the future of tropical biology and policy. 2009 marked the fifth year in a row that the number of visiting scientists and students choosing to base their research at STRI has increased, from the previous year, to the point that STRI now participates in the training of more than 1000 scientists annually.

The extraordinary hallmark of STEM education at STRI is the mentor-directed research training provided at the undergraduate level to research interns, and at the graduate level to Master's and PhD candidates, and to postdoctoral researchers carrying out independent or collaborative research. Over the past 5 years NSF grants have directly supported 81 undergraduate students, 97 graduate students and a remarkable 71 postdoctoral scholars at STRI facilities. For the same period 57 university faculty spent time at STRI on NSF-supported research.

The numbers that I have provided for NSF-associated scholars are exceeded by the numbers in

each category of young investigators supported by Smithsonian funds, non-NSF grants and contracts and donations. For example, we received a $1.5 million dollar donation from a private citizen to fund three 5-year postdoctoral positions in tropical neurobiology. The idea behind the donation is to use the remarkable biological diversity found in the tropics to inform new approaches to nanotechnology by understanding how insects carry out complex behaviors as brains decrease over evolutionary time to very small sizes. In 2007, we received an $8 million dollar grant from the Hong Kong Shanghai Bank (HSBC) to establish a regional training center at SERC in Maryland in collaboration with the environmental organization Earthwatch Institute in order to promote science education and citizen involvement in climate change science. The HSBC grant funds citizen scientists, undergraduate research interns, graduate students and postdoctoral researchers to study how climate change impacts carbon fluxes across SIGEO forest dynamic sites in Maryland and Virginia as well as across companion training centers located in Brazil, United Kingdom, China and India.

To provide a sense of the resonance associated with the educating of scientists at STRI, it is useful to highlight the experience of Dr. Phyllis Coley, a PhD student at STRI in the 1980s. Dr. Coley went on to a career as professor of biology at the University of Utah, and then supported by NSF continued her groundbreaking studies of herbivory and plant defenses in the field in Panama. In the late 1990's Dr. Coley's insights into chemically mediated plant defenses led her to develop a Panama International Cooperative Biodiversity Group (ICBG) grant. The ICBG program is a unique effort that addresses the interdependent issues of biological exploration and discovery, socioeconomic benefits, and biodiversity conservation. Dr. Coley was successful with her application and the Panama ICBG is now in its third round of funding by NIH, NSF, and now includes funding from USDA as well. Twelve years later the program has trained 21 students -- including 10 PhDs and 2 MD's -- representing 19 U.S. universities. The program has also educated 135 Panamanian students and 15 young investigators from other nations in the study of ecology and natural products chemistry. But the true resonance comes from the fact that four recent Panama ICBG PhDs and postdoctoral researchers are continuing with their Panama-based research as beginning faculty in departments of Chemistry or Pharmaceutical Sciences at the University of California, Santa Cruz, University of Connecticut, York College of Pennsylvania and Oregon State University.

STRI also maintains robust partnerships with a number of universities that offer degree-granting, semester-abroad, capstone or collaborative research programs. These partnerships provide students, teachers, and policy makers with an up-close and personal experience with biological diversity at our field stations across Panama, and an increased understanding of global threats to tropical ecosystems. To provide some numbers, in the past 5 years alone STRI has hosted 43 U.S. universities offering 65 different courses in tropical biology and anthropology. These courses have utilized STRI facilities, STRI staff scientists and the knowledge of the tropics gleaned across a century of study to educate 825 undergraduate students. Princeton University has run a semester abroad at STRI every year since 1998. Courses range from forest ecology, marine ecology, tropical evolution, tropical conservation, tropical landscape ecology, tropical paleontology, Mesoamerica anthropology and archeology, conservation genetics and tropical environmental policy. Courses are typically run from STRI facilities at our Gamboa campus and BCI in the midst of tropical lowland forest, and our Bocas del Toro marine laboratory adjacent to mangrove, sea grass and coral reef ecosystems, in addition to a tropical cloud forest field site at

La Fortuna and archeological excavations at Cerro Juan Diaz and El Caño.

***STEM Education at STRI – The SIGEO model:***

A major goal of the 2010-2015 strategic plan for the Smithsonian is headlined "Crossing Boundaries," which refers to the implementation of interdisciplinary consortia aimed at sparking innovative research and education programs, and brokering partnerships. These consortia are being established in recognition of the fact that solving the grand challenge of *Understanding and Sustaining a Biodiverse Planet* requires integrating information across different biological scales (i.e. from cells to individuals to ecosystems) and different fields of scientific inquiry. Key to these challenges is training scientists to: 1) work comfortably across research disciplines and biological scales, 2) interact synergistically, 3) incorporate new and innovative technologies, and 4) participate in larger national and international collaborations.

Presently, SIGEO is the best example of an interdisciplinary center and boundary-crossing training opportunities at SI. Global climate systems and life on the planet are in flux. Policy-makers and scientists need long-term data on the fluctuations in primary productivity of forests around the globe, as well as changes in the abundance and distribution of biological diversity, to distinguish the components of global change that can be ascribed to planetary processes from those that may be caused by human activity. The Smithsonian Institution is building on its unique research and science education infrastructure to provide the required data by expanding its global network of long-term tropical forest dynamic plots into the temperate zone and by collecting additional data on vertebrates, insects and soil microorganisms, in addition to the trees that we have monitored for three decades. It is the students being educated by the Smithsonian that will answer the following questions: Does climate change significantly alter forest biomass, and does the rate of carbon sequestration by forests vary with latitude, hydrological condition and soil fertility? How are the diversity and the relative abundance of forest organisms changing over time and space? What components of observed changes are due to human activities? How can we modify our behavior and economies?

SIGEO promotes large-scale environmental monitoring and maintains enormous banks of data and metadata, which help galvanize advanced data networks and sophisticated analyses, extending from single forest plots to the remote sensing of forests at landscape scales monitored from space-based observatories. The result -- big data sets, global comparisons and research and policy opportunities to investigate the impact of climate change on forest function -- attract top-caliber students and provide extraordinary opportunities in science education. Thus it is little wonder that students attracted to the long-term data of SIGEO go on to big things. Dr. Helene Muller-Landau, for example, went on from her Princeton University PhD dissertation research on seed dispersal and community dynamics of the BCI SIGEO forest plot to a position as an Assistant Professor at the University of Minnesota. In quick turn, Dr. Muller-Landau was honored with an $875K Packard Fellowship for Science and Engineering -- one of 16 new faculty members selected out of 100 national nominees by university presidents across the U.S.. Dr. Muller-Landau is now the lead scientist for the SIGEO Global Forest Carbon Research Initiative.

The Global Forest Carbon Initiative provides *in situ* measures of above- and below-ground carbon and its change over time in response to rising levels of carbon dioxide. Two recent and high profile publications by young scholars associated with the SIGEO network provide direct evidence of the quality of science education based from the network. In the first study a PhD student using 25 years worth of data from two forest plots (BCI, Panama and Pasoh, Malaysia) has shown that, despite increased atmospheric carbon fertilization, the growth rates of trees have decreased in at least some tropical forests, perhaps in response to global warming. On the other hand, research led by a SIGEO postdoctoral investigator using 30 years of data on long-term changes in species survival and growth in mapped plots of tens of thousands of trees at SERC on the Rhode River in Maryland, has demonstrated that that the rate of carbon sequestration is increasing in the Maryland sample of temperate forests. These two studies demonstrate the need for objective long-term data, and the utility of the global network of forest plots to provide opportunities for educating scientists and for the critical empirical data needed for modeling carbon dynamics and directly measuring the response of global forests to environmental change. Young scholars play a direct role in the network's overall aim to forecast the consequences of global climate change on forest function and biodiversity in tropical and temperate forests, and to provide objective and rigorous scientific data quickly via the World Wide Web to scientists, policy makers, and people around the world.

It is worth emphasizing that students and scientists like Dr. Mueller-Landau play a major role for STRI and SIGEO in directly supporting U.S. government goals in the environmental sciences. Such activities send an international message regarding the U.S. commitment to the provision of objective, long-term data needed for understanding the consequences of climate change. As one of the premier U.S.-led international partnerships, SIGEO integrates the SI network of forest dynamics plots with the U.S. Group on Earth Observations (USGEO), and promotes an international Global Earth Observation System of Systems (GEOSS) to further advance the progress of science and science education across borders. In the context of Global Earth Observatories, the Smithsonian collaborates with the Environmental Protection Agency (EPA), United States Geological Survey (USGS), U.S. Department of Agriculture (USDA) Forest Service, the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and NSF's National Ecological Observation Network (NEON). NEON and SIGEO sites are co-located in Virginia/Maryland (Smithsonian Conservation Biology Institute/SERC), the Harvard Forest, MA, and the Wind River Experimental Forest, WA, providing a tremendous opportunity for cross-fertilization and synergy between the two earth observation networks.

Moreover, SIGEO extends globally beyond the Smithsonian and direct partners. As an educational resource, the SIGEO network leverages huge intellectual horsepower, much of that from PhD students and postdoctoral fellows. The network is extremely well used by independent, university-associated faculty, students and network partners. More than 200 scientists have published research from the SIGEO data sets, many of them students, attesting to the broad usability and science education benefits of the network. One measure of this effective leveraging is the large number of NSF-funded research projects based within the network. As one example, Dr. Stephen Hubbell, currently a UCLA professor of biology and originator of the first 50 hectare forest plot on BCI 30 years ago, has directed approximately $7 million dollars in NSF support to his studies of forest dynamics. In the process Dr. Hubbell has chaired the PhD committees of 19 students

currently found on the faculties of Stanford University, University of Minnesota, Ohio State University, Louisiana State University, Taiwan University and others, and as science leaders on the staff of SAS Institute, Wisconsin Department of Natural Resources, National Park Service of Portugal and The Nature Conservancy. Dr. Hubbell has also trained 9 postdoctoral researchers on the faculties of the University of Illinois, University of Pittsburgh, STRI and others, who carry on the tradition of STRI-based science education. The tradition of science education is so profound across the SIGEO network, that Harvard and Yale universities have provided $9 million over five years to support the network and its science education and policy initiatives.

***STEM education at STRI- looking forward:***

The long-term, cross-disciplinary, multicultural and collaborative nature of STRI science provides unique STEM training opportunities for the leaders of tomorrow. As we look to the future, landscape transformation and remediation in the developing world will take on increasing prominence as we consider food and water security and human migration associated with sea level rise and desertification. Science education in this light is critical, a need that the Smithsonian is addressing with the Panama Canal Watershed Experiment, a collaboration between the Panama Canal Authority, Panama National Environmental Authority, the HSBC Climate Partnership and universities around the world. The experiment is large-scale and aims to quantify the diverse set of ecological, social, and economic services provided by tropical forests and alternative land use in the Panama Canal Watershed. The project is a remarkable science education tool that takes advantage of the Panama Canal's central role in world commerce to focus global attention on ecosystem services provided by tropical forests.

The Panama Canal Watershed Experiment is also an extraordinary research and education opportunity. The experiment provides scaling opportunities across the 300,000-hectare Panama Canal watershed using remote sensing technologies. These studies are carried out in conjunction with students and postdoctoral researchers at the Carnegie Global Ecology Institute at Stanford University. It is also important to note that climate variation in the Panama Canal Watershed, particularly El Niño and La Nina events, provide experimental results that can be used to build models permitting the forecasting of ecosystem services under different climate change scenarios. In addition to studying services delivered locally, the experiment takes specific aim on ecosystem services that affect people at some distance. For example, the Panama Canal shortens shipping routes and reduces carbon emissions associated with transportation, thus extending the benefits of water management in the Panama Canal watershed from local to global.

The list of ecosystem services that the Panama Canal watershed provides and different opportunities for science and engineering education is impressive: 1) regulation of water supply to the canal – ensuring sufficient water to run the locks and reduction of the risk of floods; 2) regulation of drinking water quality for more that 50% of the population of Panama; 3) hydropower; 4) regulation of soil erosion and siltation in the Panama Canal; 5) avoided deforestation, reforestation and carbon sequestration, which couple to represent a low-risk opportunity for the United Nations Framework Convention on Climate Change Reduced Emissions from Deforestation and Degradation approaches; 6) timber and food production; 7) provision of ecosystem processes and habitat for endangered species; 8) regulation of disease vectors; and 9) ecotourism.

We also continue to build on our record of research and training excellence through increased partnerships with U.S. universities. Recently, the Smithsonian has established research and training partnerships with the University of Maryland, George Mason University and Arizona State University (ASU). The ASU partnership, in particular, seeks to connect undergraduate and graduate students interested in global environmental change to the tropical ecosystems where environmental transformation is the most pronounced. Student researchers are also using information about past tropical environments to inform our interpretation of earth's response to climate change. The University of Florida and STRI, led by paleontologist Carlos Jaramillo, have recently been awarded $3.8 million dollar NSF International Partnership in Research and Education (PIRE) grant to study new fossils and geology exposed by the excavations of the multi-billion dollar expansion of the Panama Canal. This massive excavation provides PIRE undergraduate and graduate students with an unparalleled opportunity to strengthen our understanding of the role the Isthmus of Panama has played with regard to climate and biodiversity change through time, and a unique perspective on how increasing $CO_2$ levels may shape the forests of the future.

Lastly, STRI is in the process of developing new relationships aimed at utilizing STRI's scientific legacy and position in the tropics to increase STEM education for an increasingly diverse student community. As a concrete step in this direction, STRI established the new position of Academic Dean in late 2009 -- a first for the Institution. The role of the Dean is to further align STRI science with education and training opportunities, and immediate results are new relationships with: 1) NSF Tree of Life, Encyclopedia of Life and taxonomy workshops focused on the marine biology of Bocas del Toro; 2) Louisiana State University to create a NSF/Louis Stokes Alliance for Minority Participation Center for International Research (funding pending); 3) University of Texas at Austin to establish a NSF Research Experiences for Undergraduates collaboration (application in development); and 4) University of Illinois Urbana-Champaign to develop a NSF Integrative Graduate Education and Research Traineeship (IGERT) program (application for full proposal to NSF approved June 2010). Reviewers of the IGERT pre-proposal favorably recognized the strengths that STRI brings to the collaboration, and to a science education model that aligns emerging genomic technologies with intimate knowledge of the organisms themselves.

***Conclusions:***

***(1)*** The unique combination of top-notch resident research scientists, excellent laboratories and field stations, and geographical position adjacent to tropical lowland rainforests and coral reefs has led to an extraordinary long-term knowledge base at the Smithsonian Tropical Research Institute, and has established an exceptional resource for 21$^{st}$ century innovation and education.

***(2)*** The STRI knowledge base and resident scientific staff has served as a magnet for educating scientists at the undergraduate, graduate and postdoctoral levels, financed in order of amount by U.S. federal funds awarded through Smithsonian fellowships and grants, NSF PI-led grants, NIH-NSF ICBG grants, NSF PIRE grant, NSF predoctoral fellowships, NSF Dissertation Improvement grants, NSF International Fellowships, NSF workshop grants, and

NSF Research Experiences for Undergraduates grants. The U.S. federal investment in science education at STRI is nearly matched by non-government grants and contracts, EU fellowships and private fellowship donations.

**(3)** STRI serves as one example of post-secondary STEM education at the Smithsonian, but the Smithsonian formula of long-term investment in top-flight resident scientists and science facilities has led to similar excellence and educational success at all the science units at the Smithsonian.

I cannot emphasize enough the importance of the Smithsonian's commitment to long-term research and education. With our research perspective, sustained effort and long-term data sets, we are uniquely positioned to assess, identify, understand and predict environmental threats to biodiversity and incorporate rigorous science into resource management and stewardship decisions. We will continue to work with academic institutions, government agencies, and the public to educate and cultivate the science leaders of tomorrow.

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