Discover Life in America, Inc., and The All Taxa Biodiversity Inventory in Great Smoky Mountains National Park

A statement for the Subcommittee on National Parks of the Senate Committee on Energy and Natural Resources

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"This . . .Smokies . . . . all species project, called ATBI (for All Taxa Biodiversity Inventory), has enlisted experts on different kinds of organisms from all over . . . . Assisted by volunteers, and with only a shoestring budget, they have built it into a major enterprise of biological research, as well as teaching center for students at every level from grammar school to PhD and postdoctoral programs."

-- Harvard biologist E.O. Wilson writing in his recent book, The Creation

Discover Life in America (DLIA), Inc., is the non-profit organization coordinating the All Taxa Biodiversity Inventory in Great Smoky Mountains National Park. As a member of the Board of Directors of DLIA, I am happy to have the opportunity to share with you one of the most valuable and exciting projects that I have been involved with. We began planning the All Taxa Biodiversity Inventory (ATBI) in Great Smoky Mountains National Park in December, 1997, and, after time spent on organization and pilot projects, we now have logged eight full field seasons. We were pioneers when we started and have learned much. I am delighted to present our experience and success with you and to answer your questions. At the end of this statement I have addressed the five questions you have posed for this hearing.

The concept of National Parks owned by the people is a uniquely American and democratic contribution to world conservation, initiated in 1872 with the creation of Yellowstone National Park. In 2016, the National Park Service itself reaches is 100th Anniversary. The National Park Service Centennial Challenge includes the beginnings of the extension of the ATBI to additional national parks. We are very excited by this effort and the role of the National Park Service as America's premier federal agency for the stewardship of the Nation's biological diversity.

I thank DLIA Chair Ernest Bernard, DLIA Executive Director Todd Witcher, past DLIA Director Jeanie Hilten, NPS biologists Keith Langdon and Becky Nichols, and many

fellow DLIA Board Members and fellow scientists for providing information for this statement which nonetheless remains my own statement to you.

The Largest Sustained Natural History Inventory in the United States

The All Taxa Biodiversity Inventory in Great Smoky Mountains National Park, North Carolina and Tennessee, is the largest sustained natural history inventory in the United States and one of the largest in the world. We make this claim based on the number of individuals who have been involved (over **1,000 scientists** and university students from **20 countries** and **more than half of the states** of the U.S. and hundreds of educators). Dozens of universities and museums have taken part in the efforts. The effort has generated seven large National Science Foundation grants (totaling $1,876,347) as well as many smaller grants and a large in-kind contribution of time and effort. We have trained over **800 volunteers** (scientists, students, teachers, and citizens) in our Citizen Science project and have logged nearly **50,000 volunteer hours**. In-kind support has averaged **$120,000** per year, and leveraged support has averaged **$400,000** per year.

The Results have been Remarkable: 877 species new to science, 5,251 species previously unknown from the Park, and 250,000 data records

The world around us is rich in undiscovered and unexplored biological diversity. Great Smoky Mountains National Park's rugged landscape, old growth forest, climate, unglaciated history, and diverse habitats produce a park that is teeming with biological diversity. Even though there is a time lag between field work and confirmation of species identities and relationships, we have found **877 species** new to science and **5,251 species** previously unknown from Great Smoky Mountains National Park. The species new to science have included **74 butterflies and moths, 41 spiders, 70 algae, 314 bacteria, 34 beetles, 27 crayfish and crustaceans, 37 fungi, 19 bees and their relatives,** and **14 tardigrades.**

Speaking of bacteria, let us remember that an inventory in hot springs of Yellowstone National Park produce the heat-tolerant bacteria that are the basis of all of the modern applications of DNA technology from forensics to genetic identity and disease treatment. One of our researchers, Sean O'Connell of Western Carolina University, is finding a wide array of bacteria in our samples, some with links to the Yellowstone species. Before we leave the subject of DNA technology, I want to note that we one of our researchers, Dave Wagner of the University of Connecticut, has been collaborating with the DNA Barcode project to create a DNA data base for the lepidopterans of the Park (this group is very diverse in the Smokies, with 1,367 species). I will describe the DNA Barcode project below. DNA technology is also used routinely in the survey of bacteria and other cryptic groups of organisms.

We are creating more than a list of species. We seek to discover not only which species are present in each taxonomic group in the Park, but also (1) which of these species are rare enough to be of management concern, (2) where each species is found in terms of natural community affinities (we will use this information to make predictive maps of

species distributions), (3) the seasonal occurrences and changes in abundance of each species, and (4) what the ecological role and interactions of the species are. Some species groups are better known that others and thus we have been able to proceed past the simple listing of species to information on distribution, abundance, and ecology. For instance, bird species were well known in the Park when our work began. Ted Simons of USGS and North Carolina State University, along with his students and collaborators, have assisted us in producing detailed information on our web site about this taxonomic group (www.dlia.org/atbi/species/Animalia/Chordata/Aves/index.shtml). In addition to birds, you will see on the web site that we display ecological and distributional information, as well as high quality photographs, of many taxonomic groups.

We have produced many scientific publications (to date we count **107 peer-reviewed publications**), a volume that synthesizes what we have found through 2006 (special issue, ***the Southeastern Naturalist***), and an information-rich web site (www.dlia.org) which has over **two million hits per year**. The web site houses over **10,000 images** donated by staff, photographers, scientists, and citizens. Our project seeks to make a list of the species known from the Park, but also to capture data on abundance, distribution, seasonal occurrence, and ecological relationships. Our database has now logged over **250,000 records**.

We have conducted both sustained, structured, question-driven research and 24-hour to two-week BioQuests and BioBlitzes that bring together scientist, students, educators, and the public in intensive searches. Among those are Algal Forays, Millipede March, Diptera Blitz, Protista Pursuit, Ant Quest, Fern Forays, Lepidoptera Blitz, Snail Search, Team Odonate, Bat Blitz, Beetle Blitz, High Country Quest, Myxo Blitz, Fungi Foray, Springtail Bioquest, Fly Bioquest, Aquatic Insect Bioquest, Scorpion Fly Bioquest, Litter Blitz, and Sedge Search.

Who is involved in Discover Life in America and the ATBI?

We are scientists and this is a science-based project, but the project is also a deliberate weaving together of educators and conservation managers and involves students of all ages and volunteers who act as Citizen Scientists. Our project has even inspired artists to join: photographers, painters, writers and even musicians have created works of art that illustrate and celebrate the diversity of life in the Smokies!

In addition to the universities and museums that have been involved, we have many partners. Among the major partners are Great Smoky Mountains National Park, Friends of the Smokies, the Great Smoky Mountains Association, the US Geological Survey (biologist Charles R. Parker has been a major organizer and participant in the ATBI), the Great Smoky Mountains Institute at Tremont, the Appalachian Highlands Learning Center, the Southern Appalachian Information Node of the National Biological Information Infrastructure of USGS, and the Alcoa Foundation.

One example of our partnerships, representative of our work with colleges and universities, is with **Warren Wilson College** very near Asheville, North Carolina.

Professor Paul Bartels became involved in the inventory of Tardigrades at the earliest stages of our project. Tardigrades are minute invertebrates that live on mosses and other moist surfaces and are a poorly understood aspect of the biodiversity and ecology of the Smokies. Bartels worked with his students to develop one of the three most important centers for the study of these organisms globally (the others are in Italy and Poland). Bartels has also incorporated units for public school students. His research collaborations with international experts have expanded the knowledge of Tardigrades in the Park from three to 73 known species, of which 14 species are new to science. Are these animals important beyond their immediate habitat? Recently, a variety of international laboratories have proposed using this group as a new "model" organisms for the study of development and genetics.

Catching the Public's Imagination

Our project has taken root and intrigued the public. We have attracted attention both nationally and internationally. Stories have appeared in outlets as diverse as ***Newsweek, Southern Living, Scientific American, the Smithsonian,*** and ***Science***.

What is the ATBI like?

We are inventorying all the Park's habitats. Teams have searched the limestone caverns of the western part of the Park deep below ground. Tree-climbing teams, primarily under the leadership of Harold Keller from **Central Missouri University**, have reached the tops of the tallest old growth trees that harbor unique lichens, insects, and other species. We are inventorying the soil, dry habitats, swamps, and rock faces that stay wet in our rain forest climate.

We study all Park organisms, large and small, and extend our research to the finest scale to the species that are, though tiny, important in ecological functions like the flow of energy and the cycling of organic matter and nutrients. In many ways, these species are the power plants and lungs of the ecosystems. In one gram of soil, for example, there are habitats that range from desert to swamp—and as a result hundreds of species of bacteria that can be identified through DNA analysis.

Our project is more than a list. Where do the species live? How abundant are they? How do they take part in the web of life? Are they increasing, decreasing, or stable? Are they threatened by acid rain, ozone exposure, or new diseases? How will they respond to anticipated climate change? As a result, we are recording data on location, distribution, seasonal changes, abundance, and ecological relationships. Early on we drafted a **Science Plan** that called for both traditional taxonomic inventory and structured observation at biodiversity reference points. The Plan discussed the questions that drive the work and outlined the breadth that would include science, management, and education.

DNA Barcoding for Lepidopterans in the Park

The Smokies ATBI has collaborated with Paul Hebert of the "DNA Barcodes of Life" project. Let me a give a short introduction to the use of DNA segments in biodiversity inventory. Some segments of DNA are so invariant that humans and chimpanzees are identical, while other DNA segments in the same organisms are so variable that we can tell not only humans from chimpanzees, but also one individual human from another. In between these extremes are DNA segments that correlate with the species level of identification.

Professor David Wagner of the University of Connecticut is a leading researcher on the moths and butterflies of the Park. Work on this group has increased the Park list by 476 species (the total is currently 1,367 species of lepidopterans in the Park), of which 74 species are new to science. Wagner has worked with Paul Hebert to sample each species for DNA analysis to document the segments of DNA that correlate with species identifications. The DNA data then form a data base that will be extremely valuable to future discovery and to researchers studying lepidopterans in any park or other study area. The DNA data base has many applications. This information can be used to link caterpillars to the adult forms without the necessity of raising each caterpillar to its adult stage. This technology will eventually develop to the point that small samples (including the traces and fragments that plants and animals leave behind) can be used to rapidly identify species and to estimate the probability that a new collection represents a species new to science, thus allowing taxonomists to prioritize their work.

DNA analysis is also being used in our project to identify cryptic but important microorganisms, such as non-sporulating soil fungi and bacteria that are hard to study from a classical morphological perspective.

The association of caterpillars and adults is an important application, but consider also that some aphids have seven morphologically distinct life stages that can be linked with this technology. DNA evidence can unmask lookalike species and show when different forms belong to the same species. DNA can also be harvested from museum specimens, thus allowing comparison of field collections and documented species. This technology can also be used to detect diseases carried by organisms. Some scientists even speak of a day perhaps only decades in the future when the public will be able to carry hand-held species identifiers that are based on DNA analysis from small samples and fragments.

Education: Giving children the opportunity to be biodiversity explorers and inquiry based learning for the public

Glenn Bogart will present a fuller statement on the educational value of this project. I simply want to state that this is a project that is putting children back in the woods to be first-hand explorers and discoverers. Children are innately curious about the living world and are closer to the ground that we are—and more ready to turn over rocks and logs. From the beginning we have envisioned that our project would support public education and would help recruit new generations of scientists, experts, and citizens informed about

and interested in the national parks and other conservation areas. At all ages, there is an appetite for natural history information—and a basic interest and sympathy with other species with which we share our environment.

Why do an ATBI? Why discover life in America?

We are doing the ATBI for four basic reasons.

First, we conduct the ATBI for basic science and the curiosity that drives that science. E.O. Wilson has argued that the human brain has evolved in a diverse biological world and that humans have a basic desire to understand and name the species around us. He calls this "biophilia", an intrinsic interest and curiosity in the living world. Basic curiosity is a strong motivator of the ATBI and leads to the joy of discovery of previously unknown species and the appreciation for the abundance of life in our back yards, under rocks, in drops of water, and in the soil and rocks below ground.

Second, the ATBI supports the mission of Great Smoky Mountains National Park and the National Park Service, which is charged with the conservation of the natural objects and wild life (NPS legislation uses two words, not "wildlife" as a single word that often refers to larger animal species). It follows that we have to understand the biodiversity of parks better than we do. In so doing, we also understand better the presence of undesirable invasive pest species, which species are rare enough to be of management concern, and which species are sensitive to environmental change. We will also understand better the web of life and how biodiversity underlies ecosystem function and resilience. We will gain information important to ecological restoration. The information will be essential to understanding the potential for global climate change to affect biodiversity on a national scale.

The ATBI helps develop the idea that Parks are oases, storehouses, and protectors of biological diversity, not just recreational areas or vacation destinations. The ATBI creates basic information for management—as many have said about protected areas, you cannot manage what you do not know. Information from the ATBI will be important for counteracting existing threats to the Park and for detecting and resisting new threats.

Third, ATBIs are important for society at large. Some species are important to human well-being and the economy beyond Park boundaries. While the DNA technology based on Yellowstone species of bacteria is an extreme example, and it is impossible to predict whether any similar cases will develop from our project, the potential is there. For instance, the Southern Appalachians were heavily damaged by soil erosion after the highly exploitive and non-sustainable logging of the early 1900s. While forest soils outside the Park have been affected by this erosion, the old growth forest soils of the Smokies may harbor organisms that are important to forest restoration on damaged sites. I cannot state this for a fact—but I think it is a question that deserves to be answered. But we don't have to speculate on other values, such as the understanding of new diseases such as the West Nile Virus and its distribution or connection between biodiversity and ecotourism.

Biological diversity benefits people (for example, pharmaceuticals and microbes that support forest productivity), but we must also inventory nature to understand potential threats to human well being (e.g., parasites and diseases). Knowledge about biological diversity is essential to society. Ecosystems and species provide for an early warning system for the health of the biosphere and the human habitat. Living things in Great Smoky Mountains National Park depend on clean air and water, just as people do. Understanding biological diversity supports our understanding of environmental change. Species in the Park have different sensitivities to environmental change—for example, soil fungi, which play a critical ecological role, may be essential to understanding pollutant effects on forest productivity. In studying the unknown, we are carrying out an activity in which serendipitous discovery is possible.

Fourth, biodiversity inventory is a cornerstone of environmental education and for connecting students of all ages, but particularly children, to the natural world. Some of those exposed to the inventory will go on to become the experts of tomorrow and all will be more informed participants in our democratic institutions.

Human beings have an innate love of distinguishing, identifying, and naming. This is especially true in terms of naming other living things. From wildlife watchers to birders to wildflower hunters to fall color enthusiasts, people repeatedly demonstrate enthusiasm for a diverse environment and for recognizing species. The act of identification leads to an interest in habitats, the physical environment, species interactions, and the history of life. The project draws people from the human scale to see the hidden, unknown, and obscure, but often beautiful, intricate, and ecologically important species of natural ecosystems. The ATBI seeks participation from people of all ages, educational backgrounds, and abilities and seeks to enthuse the public with biological science. The project has been very successful in welcoming non-scientists and making everyone feel that they are part of the exploration and discovery. The project has helped erase the gap between academic and public education.

Why an ATBI in Great Smoky Mountains National Park?

In the temperate zone, the Smokies are a hot spot of biological diversity because the Park has a great range in environmental conditions and because the land has been above sea level and unglaciated for millions of years. The Southern Appalachians harbor **global high points**, at least for the temperate zone, of diversity and endemics in several groups, including **plants, amphibians, fish, land snails,** and **aquatic insects**. The Park comprises 5% of the high peak region of the Southern Appalachians, a substantial portion of this biotic province. The Park supports diverse ecosystems that represent the major ecological gradients of the eastern United States, from warm and dry oak-pine forests to cold and wet spruce-fir forests. Mountain landscapes offer gradients over relatively small distances, allowing for assessment of climate change effects.

The Park contains the best old growth watersheds in the eastern United States. These old forests harbor species missing from more human affected lands and are essential for

comparisons with human dominated landscapes and for understanding human impacts generally. These forests may hold the key to understanding forest productivity and the effects of soil erosion during the early 1900s on lands outside the Park.

The Park has substantial past taxonomic research and continuing interest and enthusiasm of the academic community.

The Park was set aside partly for its wildlife and rich array of species and continues to enjoy that image—people love the wildlife, fall color, and spring wildflowers of the Park.

The Park has and will continue to change. We study the Park now to understand future change.

Responses to the Five Questions Posed by the Committee for this Hearing

1. How much has been learned and at what cost?

We were pioneers and have proved that an All Taxa Biodiversity Inventories can be designed and organized and that it will gain support and attention. We have validated the concept and created a successful and widely emulated model. We have embedded biodiversity inventory in a ecological, conservation, and educational context. We have established an inspirational and influential reference point for other parks interested in biodiversity studies.

We measure our accomplishments by 877 species new to science, 5,251 species previously unknown from the Park, 250,000 data records, 10,000 images of species, a web site with over 2 million hits, and 100s of participants that include scientists, conservation managers, educators, students of all ages, and artists. We have inspired the public with our enthusiasm for the living world and underscored the important of Great Smoky Mountains National Park and the National Park Service for caretaking the nation's biological diversity. We have learned that basic support through Great Smoky Mountains National Park (at first primarily from the Friends of the Smokies and the Great Smoky Mountains Association, and later through the NPS budget) has been multiplied at least four-fold by leveraged, in-kind, and external grant support.

We have shown that there is much to discover and much that is unknown about biological diversity. The five groups of vertebrates and higher plants were thought to be well known before we started, but we have made discoveries even in these groups and we have created a template for increasing the understanding and usefulness of information about even the groups that are better known from a taxonomic point of view. We have greatly expanded our knowledge of other, less known, groups of organisms.

2. What is left to be done and what is the estimated time and cost to complete the inventory

In the next few years we must capitalize on the development and evolution of our project over the last eight field seasons. Although the intensive inventory of the ATBI will wind down, our work will transform to modeling, monitoring, management, and education. In that sense, the importance of biodiversity inventory to Great Smoky Mountains National Park and the National Park Service will continue as central missions of these agencies in perpetuity, as in fact expressed in the legislation that established them. In addition, there will always be new generations to educate and to train and new citizens to affirm the importance of the national parks.

It is always hard to answer the question: when will the inventory be complete? As Phil Francis, then Assistant Superintendent of the Park and now Superintendent of the Blue Ridge Parkway, once remarked: How many species are there in the Smokies? It reminds me of the question we used to get at Mammoth Cave National Park: How many miles of unexplored cave are there? This is further complicated by the fact that cave mileage presumably remains constant, but the number of species will shift through time with environmental change and the invasion of new pest organisms from abroad.

Science and sampling design help us address this issue through what is called the "collector's curve". The collector's curve describes the phenomenon that it is relatively easy to find and list the common species, but as we hunt for the last and rarest species we have to invest more and more time. Thus, a biodiversity inventory proceeds up the collector's curve as far as time and budget allow. Ultimately, we use statistical tools to estimate the total numbers of species. To be able to use those statistical tools, though, we need to have explored all habitats in a series of seasons and years with standardized methods of observation. One of the shifts we have made over the last several years is to focus on the structured sampling aspect of our inventory in which we are sampling standardized plots and processing backlogs of specimens from previous collections on those plots. In addition, there are a few understudied groups that we must find a way to add to our inventory. We must also document all of our methods and produce products that will be useful as the ATBI Alliance moves forward on a national scale.

3. How has the data been used and are there other ways to use it?

Information developed by the ATBI has been used and has the potential for additional use by Park managers, environmental educators, society at large, and the scientific community, including contributions made to national and international data bases of DNA sequences.

The value to Park managers resides first in the principle that good decisions are based on scientific evidence. The project is helping us understand which species are rare and potentially threatened and which are not. The project is helping us detect new species invasions and the response of natural ecosystems to the damage caused by new pests and diseases. During the inventory, for example, the Chinese jumping worm was discovered

in the Park. This is a worm that causes severe damage to soils by consumption of the upper organic layers of the soil that help recycle nutrients and retain moisture. The worm was likely released inadvertently by fishermen who had purchased the worms from bait shops. This species was detected before becoming widespread in the Park; further, this case shows how the National Park Service should work with local businesses to reduce threats to Park biodiversity. In all of its decisions, including land acquisition, fire management, species reintroductions, habitat restoration, and invasive species reductions, the Park needs the best possible information and the ATBI is helping to supply that information.

As we are able to transition from inventory to monitoring we note that the inventories undertaken are comprehensive, done in the same geographical study area, and contemporaneous. No current or future threats/changes will occur in a vacuum, so doing these inventories within a few years makes them more valuable than the same inventories done sporadically over a longer time period.

I believe that Glenn Bogart will speak more about the educational use of the project. Let me just comment that this project is helping to inspire children with natural history discovery and teaching about the living world that surrounds us. The project is also supporting and stimulating higher education in taxonomy and biodiversity studies, thus maintaining skills in society that are needed for the future.

Society at large will benefit through the conservation of biological diversity and education about the mission of the National Park Service, but there can be other benefits, as well. We are studying the diseases and parasites carried by species in the Park. This knowledge may one day be helpful in understanding the occurrence of new human diseases or the appearance of pests and diseases that can affect timber resources, crops, fish, wildlife, and livestock beyond Park borders.

The scientific community will benefit because taxonomic studies are cumulative—that is, the specimens collected in the Smokies, data bases, and the DNA sequence data bases will form a library of information that will be used by biodiversity inventories elsewhere as research seek to build a better understanding of the tree of life. The scientific community also benefits because the work is done in the same locations—thus building understanding across taxonomic groups and helping to put the work in an ecological context. We also seek to better understand the co-occurrences, interactions, and dependencies among species, thereby building an understanding of the web of interactions among species, and thus be better able to predict how biodiversity and ecosystem function are connected and how the populations of larger animals and plants are influenced by more obscure but functionally important species like bacteria, soil fungi, and insects. We have shown the importance and excitement of scientific discovery and the importance of natural history museums, universities, and national parks in the development of scientific understanding.

4. What changes if any should be made in the program?

We are the pioneers of large scale, all taxa inventory and had to organize, write plans, develop structures, identify project needs, and coordinate the research of many individuals. We have therefore learned lessons to share with future projects. We have learned the importance of standardized data bases and the need to work with researchers to make sure data is efficiently captured. We have learned the interest of the scientific community and that facilitating work through small start-up grants and assistance with logistics, and especially assisting with housing and the processing and sort of collections and data in lab space, will result in a great return in leveraged and in-kind support so that dollars invested will be multiplied many times.

We have learned the importance of documenting methods, so that these can be repeated. We have learned the importance of trade-offs between intensive sampling at particular locations and less intensive but more extensive surveys across a full range of conditions that control the distribution of species. We have learned the need for both traditional and structured methods of observation and collecting. We are now in a phase of the project when we are making a transition to an emphasis, at least with our internal funding, on the structured sampling aspects of the work. We have learned the public appeal of intensive short-duration bioblitzes, while at the same time learning that these are ideally integrated with a long-term sustained effort. The structured sampling, capture of data, and archived methods will also allow the transition from intensive inventory to monitoring. As the work proceeds to additional sites, it will be important to develop economies of scale so that different projects aren't competing for, but coordinating the work of taxonomic experts, museums, and universities. Central coordination will facilitate a project that will be more than the sum of its parts. An important aspect of taxonomic information is, in fact, that its value lies in its accumulation across sites and time.

5. Should the program be expanded to more National Parks?

We believe that the most important next step in ATBIs is to expand to a series of National Parks and other conservation areas, in order to better cover the biological diversity of the United States and to create more centers of learning and environmental education. We feel this is so central to the National Park Service mission, that the popularity and success of our project will be duplicated elsewhere. In fact, as I write these words we are pleased that the National Park Service Centennial Challenge has established ATBIs in additional parks. Nine new parks were included as Centennial Challenge projects this year. Some 70-80 parks have expressed interest in participating and engaging in taxonomic inventories at some level. Representatives from a variety of parks and other conservation areas have joined our annual meetings in the Smokies and contributed to discussions of the organization of a national ATBI Alliance. We are thrilled that our idea has generated interest and "caught fire" so widely. The expansion and creation of the ATBI Alliance will require us to coordinate data bases, funding sources, and the work of taxonomic experts at natural history museums and universities across the country.

We feel the National Park Service is positioned to lead and catalyze this expansion. The National Park Service is a premier guardian of America's biodiversity and natural ecosystems. National discussions and coordination are, in fact, essential to creating a project that has value that is more than the sum of the work in individual parks.

Discover Life in America has helped facilitate discussions of organization for the ATBI Alliance. Our name "Discover Life in America" was chosen to reflect our interest in biological discovery beyond the Smokies. We share with you the draft mission statement from discussions of the ATBI Alliance: *To inventory and document the biodiversity of the United States, for all the branches of the tree of life by intensive, scientific sampling at selected reserves, parks, and other protected areas while infusing our citizenry with a strong awareness of biodiversity and an appreciation of the fragile complexity of our nation's resources.*

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