The Great Smoky Mountains National Park All Taxa Biodiversity Inventory: A Search for Species in Our Own Backyard
2007 *Southeastern Naturalist* Special Issue 1:1–26

Forward

In 1997, 120 scientists, resource managers, and educators met in Gatlinburg, Tennessee, on the edge of Great Smoky Mountains National Park (GSMNP) to discuss launching an All Taxa Biodiversity Inventory (ATBI) in the Park. Keith Langdon, an excellent all-round naturalist and head of the Park's Inventory and Monitoring program, had called us together. The slopes of Mt. LeConte and the Great Smoky Mountains, with their old-growth forest, great habitat diversity, and tremendous biological diversity, loomed above us as we sought to map out what such a project would be. These were days of vision and excitement. The Park had always been a key field site for biologists and had attracted much research over the years, but we imagined a great step forward. As I write these words, we are entering our 11th year as a project and our 8th full season of field discovery.

Soon after the 1997 meeting, we organized a non-profit organization, Discover Life in America, to oversee and coordinate the project. Great thanks must be given to our partners for making this possible: Great Smoky Mountains National Park, the Great Smoky Mountain Association, the Friends of Great Smoky Mountains National Park, the National Park Service (NPS), the US Geological Survey, National Biological Information Infrastructure (NBII), and many universities and other institutions. Substantial in-kind contributions have driven the project forward. One measure of success is that our seed grants and coordination have supported six of our teams in acquiring prestigious multi-year NSF grants to expand their work. Another is that our project caught the imagination of the public, with articles in such diverse places as Newsweek, the Smithsonian, Southern Living, Scientific American, and Science. A third measure (and one that never fails to amaze) are the numbers of species discovered that are new to science (over 600) or never before recorded in the park (over 5000) (see Nichols and Langdon in this volume).

In 2006, Patricia Cox organized a full-day symposium entitled "All Taxa Biodiversity Inventory: A Search for Species in Our Own Backyard" for the Annual Meeting of the Association of Southeastern Biologists (ASB) on the ATBI in GSMNP. The symposium presented 23 papers (the abstracts are presented in Appendix 1) and truly showed the wide involvement and scope of the project that had begun in 1997. By my count, the symposium and this volume present the work of 51 individuals from 30 institutions and 15 states. More broadly, the project involves some 200 scientists and over 100 volunteers. Eleven countries are represented on the list of participating scientists. Clearly, the ATBI had generated a great deal of interest in exploring, discovering, teaching, and enjoying the biodiversity of GSMNP. I am delighted to write the forward to the special issue that presents papers from the 2006 symposium.

What emerged over these years is a unique project that is the largest biological inventory in the country, one that has been a model and inspiration to other projects. What characterizes this project and has become solidified as its contribution to the world of ideas? I have three answers, all of which were part of our very earliest discussions.

First, the project focused on *all* taxa. Not just indicator taxa, not just well-known groups, not just taxa already known to be important ecologically, but the proclamation that all groups would be considered. We borrowed the title from Dan Janzen's efforts in Costa Rica (Dan was an advisor at the first meeting, helped us present the project in Washington, DC, and served as our keynote speaker in 2005). In this age of global change, ongoing threats, and the permeating effect of people, biodiversity has become a major focus of study and conservation. As one of the few projects ever to study all of a region's biodiversity, we found ourselves investigating everywhere: not only under rocks, but also climbing the tallest trees, examining grains of soil, and descending into the deepest caves. ATBI investigators examined the species that live in the feathers of birds and in the guts of other species. At the ASB Symposium, I found myself, for the first time since my early undergraduate courses, dealing with all of biology (not just my specialty, higher plants). The project has brought biologists from separate societies, disciplines, and departments together.

Second, the project was not solely a scientific effort, but rather a deliberate weaving together of science, stewardship, and education. Involving the public, helping it to understand biodiversity and the role of conservation areas in its protection, and providing education at many levels, was also a key part of the project. One area, however, that I did not anticipate at the beginning, was art! Photographers, artists, and even musicians, inspired by the excitement of exploration and the beauty and intricacy of the life forms we discovered, soon joined our project. Artists collaborated with the science teams as essential members responsible for illustration and documentation, and scientists realized that they could produce high resolution scans and photographs that were fine pieces of art as well.

Along with the variety of interests and talents, our project has attracted a diverse array of people. Scientists, educators, students at all levels, artists, volunteers, and citizen scientists have all helped to define who we are. At each of our December annual meetings, I am impressed that the 100-150 attendees cover a wider array of ages and backgrounds than any other science-based meeting I regularly attend.

The third unique defining characteristic of this project is that team members are united by a common focus on a conservation tract: the Great Smoky Mountains National Park. The combination of an intensive biological inventory in a protected conservation area served to bring together and integrate the diverse areas of interest—a way to marry the fields of ecology and systematics and to meld both in a way that would serve conservation stewardship and education. Whereas taxonomists often focus on a particular group of organisms regardless of location in order to fully circumscribe the species, the park itself provided the common denominator to make us all focus on goals, and also brought us together in ways that will support ecological understanding, monitoring, and conservation objectives. There is a larger spin-off, too: the museum specimens and data collected from this very diverse field site will support better understanding of taxa across the country.

The ATBI has involved many different kinds of efforts in the field, ranging from the sustained work of individual researchers to teams of scientists and the public in bioquests (also known as bioblitzes) in which an intensive collection effort is conducted over a period of a few days to a few weeks. One of our early accomplishments was the drafting of a Science Plan (Appendix 2) to provide a general template or umbrella for the work. In that plan, we describe both traditional collecting and observing and structured sampling. In traditional collecting and observing, investigators search areas they believe to be keys to understanding Park diversity or which are likely to hold new species for Park checklists. In structured sampling, researchers select biodiversity reference areas for multiple taxa to insure that all of the factors (environmental, historical, and spatial) that structure the distribution of organisms are systematically covered.

The Science Plan uses five themes: coordination across taxonomic groups, a taxonomic working group (TWiG) structure, taxonomic inventory in an ecological and conservation context, GIS as an organizational and analysis tool, and involvement of the public and students of all ages. The goals of this work are to improve the checklists of all organisms within the Park and thus create a growing archive of information, and also to create maps and databases that will describe the location (season, spatial coordinates, environmental factors), abundance, and interactions of the organisms (with each other and habitat). Some of the work is driven by pure curiosity and celebration of the teeming life forms of the Park; other projects are driven by explicit scientific questions (What controls diversity patterns? How can we create a benchmark for understanding threats and future change?). Time-honored methods are used, but the project also employs new technologies such as GPS, GIS, and the rapid communication of the internet. Thus, for examples, a new genus of beetles was diagnosed within days; we have used GIS to assess the environments of the Park; working with Dean Urban and myself, graduate student Todd Jobe has created high-resolution ecological zip-code maps for the Park, a way of insuring that observations cover the environmental, spatial, and historical (e.g., disturbance history) variables of the Park; and statistical methods are being used to design the best set of observations and to estimate how complete our lists are. We can go as far as our energy and our funding allows.

One of the most exciting new tools in biology uses the sequence of DNA bases along chromosomes. DNA technology has been used in a variety of ways and holds the promise for quantifying bacterial diversity in the soil, resolving evolutionary patterns, and helping us associate juvenile with adult life stages and sort out pathogens and diet patterns. DNA barcoding is being carried out for the lepidopterans by David Wagner and Paul Hebert. Some parts of the DNA along chromosomes are so variable that even between individuals within the same species there is great variation; other parts of the DNA chains are so constant, that they unite genera or even family. But in between these two extremes, DNA barcoding is used to search DNA variation that correlates well with the species level. Such sequences offer the promise of rapid sorting of unknown taxa (along with an estimation of their probability of being new to science), the detection of species from fragmentary evidence and specimens, and the ability to associate juvenile and adult forms.

The work is ongoing, but products are already emerging. In addition to this volume, NPS biologist Becky Nichols edited a series of papers in the George Wright Forum in 2006 (Volume 23, number 3). A recent compilation showed that at least 65 papers has been published on this work. We hope also that you will visit our web site (www.dlia.org) to keep up with the news of this project.

In conclusion, in support of the National Park Service mission of conservation of biodiversity, we have created a project to further pursue scientific and public understanding, and to place management in the context of fuller knowledge and benchmarks for detecting and understanding change. We are producing lists, but we are also anticipating the evolution toward better understanding of ecosystem function and its dependence on biodiversity. We have discovered how truly diverse the Park is, and in this discovery, we have realized that we greatly expanded the available knowledge. Even if some checklists are not completed within the next few years (for want of funding, interested experts and partners, or simply because of the nature of the task), we have also seen that it is not just about that ending point of completion, but also about the journey to get there. It has been a thrilling project to be involved with, full of the sense of being on the edge of the unknown. The idea is indeed spreading. Other conservation areas are starting ATBIs, and a national ATBI Alliance is being organized.

Peter White
University of North Carolina at Chapel Hill

Appendix 1. Title, authors and affiliations, and abstracts of papers presented at the symposium, "**All Taxa Biodiversity Inventory: A Search for Species in Our Own Backyard**" held at the 67th meeting of the Association of Southeastern Biologist in Gatlinburg, TN, March 29–April 1, 2006.

History and Introduction of ATBI

Keith Langdon and Becky Nichols
Great Smoky Mountains National Park

The All Taxa Biodiversity Inventory (ATBI), a project of Discover Life in America (DLIA), seeks to inventory the estimated 100,000 species of living organisms in Great Smoky Mountains National Park. The project will develop checklists, reports, maps, databases, and natural history profiles that describe the biology of this rich landscape to a wide audience. The species level of biological diversity is central to the ATBI, but the project is developed within an ecological and conservation context and encourages understanding at other levels of organization, including genetic variation within species and ecosystem descriptions. As of September 17th 2005, ATBI has identified 569 species new to science and 3358 species previously not known to inhabit the Great Smoky Mountains National Park.

Extensive bacterial diversity in soils and waters of Great Smoky Mountains National Park: How many species are out there?

Seán P. O'Connell.
Western Carolina University

Recent estimates have raised the estimate of bacterial diversity from 10^3 species per gram of undisturbed soil to 10^6 species. While this estimate is "astronomically" large when one considers prokaryotes within Great Smoky Mountains National Park, it should not deter efforts to understand such diversity. Patterns of bacterial distributions should become clearer with repeated sampling. For the past four years, bacterial isolates have been obtained using R2A culture plates inoculated with samples from Kephart Prong and Oconaluftee River sites. The goal of this work is to determine whether the same species occur in attached and unattached life stages at each site and whether species would be common to both sites. Sequencing of ≈550 bp of 16S rDNA and functional testing have been used to classify species. Results include the characterization of representatives from seven phyla, 39 genera, and 66 species. No overlap at the level of both sequences and functional traits (metabolic/physiological testing) has been seen. The proteobacteria dominated Kephart Prong soils while the High and Low G+C Gram Positive bacteria dominated Oconaluftee soils. Oconaluftee waters were dominated by the Cytophaga/Bacteroides/Flavobacteria and secondarily by the betaproteobacteria, the latter of which codominated at Kephart Prong aquatic sites, along with both gram positive groups. These disparities in diversity between samples from two similar sites indicate either microhabitat differences or small sample size. Long-term collection from these sites continues and a picture of the extent of diversity will hopefully emerge to allow predictive hypotheses to help explain the differences observed in these sites.

Heterozygosity in *Artomyces pyxidatus* from the Great Smoky Mountains National Park

Edgar B. Lickey[1], Shannon M. Tieken[2], Karen W. Hughes[1], and Ronald H. Petersen[1]
[1]University of Tennessee and [2]Rose-Hulman Institute of Technology

Basidiomycete fungi from the Great Smoky Mountains National Park (GSMNP) often show heterozygosity for DNA insertion/deletion events in the nuclear ribosomal ITS region. We investigated this heterozygosity in *Artomyces pyxidatus* (= *Clavicorona pyxidata*). Within North America, two distinct haplotypes were observed: a southwestern US/Mexico/Costa Rica haplotype and a northeastern haplotype. These two haplotypes are thought to represent progeny from different refugia existing during the Wisconsin glacial period, which ended 20,000 years ago. The haplotype distributions presently overlap forming a broad cline from southwest to northeast and hybrids between the two haplotypes have been found in nature. The GSMNP shelters both haplotypes. Three separate coves in the GSMNP were intensively sampled. Haplotype frequencies were examined to determine if cove forests sheltered reproductively isolated populations of *A. pyxidatus* and if the two haplotypes were in Hardy-Weinberg equilibrium. There were no significant differences between GSMNP populations with respect to gene frequencies; however, the two haplotypes are not in Hardy-Weinberg equilibrium in the GSMNP because, in this species, there is a heterozygote deficiency. Such a deficiency can occur if individuals are largely self-fertilizing or if there are genetic or environmental barriers to interbreeding. Since both haplotypes were sometimes found on the same log, it appears unlikely that inbreeding by isolation is responsible.

Tree canopy biota in the Great Smoky Mountains National Park

Harold W. Keller
Central Missouri State University

The first survey and inventory of tree canopy biota is part of the All Taxa Biodiversity Inventory in Great Smoky Mountains National Park. Student climbers used the double-rope climbing technique to obtain tree-canopy bark samples of ferns, lichens, liverworts, mosses, macrofungi, and myxomycetes up to 40 meters. A fern, *Polypodium appalachianum*, was discovered growing as a canopy epiphyte 40 m above ground level on the upper surface of a horizontal branch on a champion-sized *Liriodendron tulipifera* tree. A soil-forming mat of humus supported four species of mosses typically associated with ground habitats, but were absent from bark samples taken at various heights from the vertical tree trunk. Tree-canopy bark samples analyzed have yielded 37 moss species and 28 liverworts species, all previously known from ground sites. Approximately 84 lichen species from the tree canopy represented new records for the Park, but were also known from ground sites. Five basidiomycete species (macrofungi) were collected from the tree canopy; none were new records. Ninety-five myxomycete species were recorded from the tree canopy, including 52 new records for the Park. *Diachea arboricola* was restricted to the upper canopy of living trees and represented the only myxomycete species new to science discovered in the Park. Myxomycetes represent the only group collected that have species only known from the tree canopy. Financially supported by National Science Foundation, Biodiversity Surveys and Inventories, Awards DEB-0079058 and 0343447, Discover Life in America 2001-26 and 2002-17, and National Geographic Committee for Research and Exploration 7272-02.

Diatom species (Bacillariophyceae) from subaerial habitats in the Great Smoky Mountains National Park

Rex L. Lowe[1] and Jeffrey R. Johansen[2]
[1]Bowling Green State University and [2]John Carroll University

Diatoms and other algae have been collected and identified from subaerial habitats in the Great Smoky Mountains National Park as part of a larger biodiversity survey of the park. Algal collections were made across a range of moisture gradients and bedrock mineralogies with pH ranging from 4 to greater than 7. None of the communities collected were totally submerged in water, but were often associated with moist mosses and cyanobacterial mats. Some of the collections are from cliff faces wetted only periodically. To date, 52 diatom genera and over 160 species have been identified from these habitats. Several of these genera are widely distributed across aquatic habitats. However, several of the genera are "subaerial specialists" and possess morphological features such as reduced size, reduced external openings in the cell wall, or additional external siliceous membranes that allow them to survive in relatively dry habitats. Widely distributed species with high fidelity to subaerial habitats occur in the genera *Decussata*, *Diadesmis*, *Fragilariaforma*, *Luticola*, *Melosira*, *Nupella,* and *Orthosira*. Many of the species constitute new park records, national records, or are new to science.

New algal records from Great Smoky Mountains National Park

Jeffrey R. Johansen[1] and Rex L. Lowe[2]
[1]John Carroll University and [2]Bowling Green State University

Since 1999, we have been involved in the effort to collect and identify all algal species in the Great Smoky Mountains National Park. This effort has been a part of a larger such effort for all phyla in the park known as the All Taxa Biodiversity Inventory (ATBI). As of 2004, we had reported 584 taxa of algae, including 108 Cyanobacteria, 97 Chlorophyta, 12 Tribophyta, 1 Chrysophyta, 2 Synurophyta, 3 Eustigmatophyta, 353 Bacillariophyta, 4 Dinophyta, 3 Rhodophyta, and 1 Eglenophyta. We have added over 200 new records to this list, including a number of new species. New records have been especially rich in Cyanobacteria (62), Chlorophyta (74), and diatoms (57). Distinctive habitats in the park include wet rock walls, seeps, and waterfall splash zones (subaerophytic epilithic communities) as well as tightly crustose communities on the rocks in streams. Particularly unusual findings include *Heribaudiella fluviatilis* (Phaeophyta), *Rhodospora sordida* (Rhodophyta)*, Arnoldiella* and *Drapernaldia* (new species, Chorophyta), and a number of new diatom species.

Pteridophyte distribution in the Great Smoky Mountains National Park

Patricia B. Cox[1] and Richard Schulz[2]
[1]TVA Heritage Program and [2]Great Smoky Mountains Nation Park

With the help of funding through the Hesler Grant from the University of Tennessee, the fern project began in the summer of 1999. There were four goals for the original study: 1. to locate and validate herbarium voucher specimens for all the species reported from the GSMNP, 2. to revisit known fern localities to verify the plant's occurrence in the GSMNP, 3. to search for new populations of species occurring in the park and also look for new additions to the pteridophyte flora of the GSMNP, and 4. to produce a database of current information on the pteridophytes of the GSMNP for the ATBI (All Taxa Biodiversity Inventory) project. These goals, or a portion of each, have been reached. In addition to the original goals, we also began mapping the distribution of ferns in the park.

To date, approximately 200 miles of 57 trails have been surveyed. We are using the trails as transects. Every 200 meters, we make a 15 m circular plot and record all the fern species present as well as population density for each species. We are also recording associated tree species found in each plot. Between the plots, we are making qualitative reports on the ferns present along the trail. These data have been input into an ACCESS program, and maps will be generated using GIS tools to relate these distributional data to various GIS layers such as vegetation, slope, and aspect. Once "all" the trails have been surveyed we hope to get a better understanding of the biogeography of fern species in the park.

Aquatic Oligochaeta (Annelida) in the Great Smoky Mountains National Park, North Carolina and Tennessee, USA

Mark J. Wetzel[1] and Peggy Morgan[2]
[1]Illinois Natural History Survey Center for Biodiversity, Champaign and [2]Florida Department of Environmental Protection, Tampa

The class Oligochaeta represents the most diverse and widely distributed group of annelids in freshwater habitats in North America. Oligochaetes are commonly an important and often dominant component of the benthic community, yet specimens rarely are identified beyond class or family level because of perceived difficulty in taxonomic resolution. To date, 209 species of freshwater oligochaetes representing 12 families and 75 genera occur in North America based upon published distributional records; over half of these species occur in the southeastern US. While numerous publications over the last 25 years have focused on the aquatic oligochaete fauna in North America, none has focused on oligochaetes occurring in the Great Smoky Mountains National Park (GSMNP). Funding received from Discover Life in America through the All Taxa Biodiversity Inventory program has supported our surveys for aquatic oligochaetes, other macroinvertebrates, and water quality at 136 streams, springs, seeps, lentic habitats, and cave pools in the GSMNP. To date, 24 species of aquatic oligochaetes representing 10 genera in the families Enchytraeidae, Haplotaxidae, Lumbriculidae, Tubificidae (including the subfamily Naidinae) have been identified from our collections; all represent new Park records, and four are reported as new state records (NC, TN). As expected, the abundance of oligochaetes collected in the moderate- to high-gradient streams was low. However, the low diversity at most of the sites we have surveyed is surprising, given the pristine water quality and variety of aquatic habitats present in the GSMNP, and the diversity of freshwater oligochaetes previously reported from the southeastern US.

Biodiversity explosion: Collembola of Great Smoky Mountains National Park (GRSM)

Ernest C. Bernard
The University of Tennessee, Knoxville

Collembola are the most abundant insects, sometimes numbering 50,000/m^2 in temperate deciduous forest. Previous to the ATBI, 55 species had been reported from GRSM, some of which were misidentifications. Currently, more than 200 species are recognized in GRSM, including more than 60 species new to science and more than 100 new records. In addition, reexamination of type specimens in collections dating to the 1940s has validated a number of species that had been synonymized with other taxa, such as in the genus *Morulina*. One new genus has been collected, and three new species belonging to previously non-North American genera have been found (two South American, one Mediterranean). Several new records are major range extensions: for instance, *Folsomia nivalis* known previously from the Canadian Maritime provinces and *Hypogastrura tooliki* described from Alaska. Digital imaging and videography of live springtails is being used to more accurately render appearance and coloration, and to document behaviors and interactions with other soil and litter biota. Molecular differentiation of *Tomocerus* spp. is underway in order to more reliably separate the many similar species of this common genus. A Lucid-based online key for identification of southern Appalachian Collembola is under construction; where possible, this key will use characters visible with a dissecting microscope to separate species.

The aquatic insect fauna of Great Smoky Mountains National Park

Oliver S. Flint, Jr.[1], Luke M. Jacobus[2], W. Patrick Mccafferty[2], Boris C. Kondratieff[3], John C. Morse[4] and Charles R. Parker[5]
[1]National Museum of Natural History, Smithsonian Institution, [2]Purdue University, [3]Colorado State University, [4]Clemson University, and [5]US Geological Survey

The Great Smoky Mountains National Park contains more than 3400 km (>2000 miles) of streams, numerous springs and seeps, as well as temporary ponds, bogs, and other specialized habitats. In addition, much of the south side of the park borders Lake Fontana, a large Tennessee Valley Association reservoir. The rugged topography of the park creates considerable habitat complexity. Combined with the moist, mild climate of the southern Appalachian region, a rich fauna of aquatic insects occurs within the Smokies. At this time, nearly 450 species of the orders Ephemeroptera (104 species), Plecoptera (116), Megaloptera (6), and Trichoptera (223) are known from the park.

Documenting beetle diversity in the Smokies; past the half-way point!

Chris Carlton and Victoria Bayless
Louisiana State University Arthropod Museum

The current Coleoptera Taxonomic Working Group of the All Taxa Biodiversity Inventory (ATBI) has been active since June 2001. It consists of a core group of students and researchers who are headquartered at the Louisiana State Arthropod Museum, and is supported by a network of 28 specialists worldwide. Our starting point was ≈700 species based mainly on specimens collected prior to 2001 and deposited in the Great Smoky Mountains National Park (GSMNP) collection. Using our in-house Biota® relational database and periodic species accumulation analyses we have documented more than 1100 new species records for the park among the 10,352 specimen records to date, including 20 species new to science. Thus our current beetle species count for GSMNP is 1803 species from 97 families. We project total beetle diversity for the park will be ≈3000 species based on extrapolation of figures for the 20 largest families in eastern North America. Most additional records are expected to derive from taxonomic work on the following families: Staphylinidae, Curculionidae, Tenebrionidae, Scarabaeidae, Latridiidae, and Ptiliidae. Progress has been hampered by a lack of taxonomic expertise and logistical problems associated with large specimen volumes. The former problem is society wide and the latter has been partially solved. The vast majority of specimens processed to date were derived from structured protocols conducted during the initial phase of the ATBI. Current and future efforts will be focused on samples collected during organized beetle bioblitzes and/or using specialized techniques targeting taxa that cannot be accessed using mass-collecting methods.

Our journey through the Lepidoptera of Great Smoky Mountains National Park

David Wagner[1] and Brian Scholtens[2]
[1]University of Connecticut and [2]College of Charleston

The Lepidoptera TWIG of the Great Smoky Mountains ATBI has recorded over 1600 species of moths and butterflies from GSMNP, and compiled over 21,000 individual specimen records in just over 5 years of survey work. We have used bioblitzes as foci to encourage greater involvement from the systematic community and bolster our species list—more than 30 lepidopterists have participated in aspects of the inventory. We estimate the total number of species in the park to be between 2000 and 2500, with mostly microlepidoptera (especially Gelechioidea) still to be added to the list. We have recorded more than two dozen undescribed species from the Park, including a spectacular Park endemic geometrid moth. Our surveys of the Park's lepidopteran fauna have included considerable life-history work as well. In our last two bioblitzes, we expanded our efforts to include DNA barcoding, with the goal of obtaining a sequence from all species known from the Park. The survey has resulted in several publications, with others nearing completion. Support for these efforts has come from Discover Life in America and a variety of other sources.

Spatial diversity of forest ants in Great Smoky Mountains National Park, USA

Nathan Sanders[1], Robert Dunn[2], Jean-Philippe Lessard[1], and Melissa Geraghty[1]
[1]University of Tennessee, Knoxville and [2]North Carolina State Univeristy

Ants are ubiquitous in forests, especially in Great Smoky Mountains National Park (GSMNP), USA. However, much remains to be learned about the causes of spatial variation in ant species diversity. We sampled ants over several years in >30 sites to examine spatial patterns of ant diversity in GSMNP. In total, we have identified approximately 100 ant species, many of which are new records to GSMNP, if not entirely new to science. Species accumulation curves show that at many of the most-species-rich sites, we are only beginning to adequately sample the ant fauna. We find that species diversity declines sharply with elevation because ants are strongly limited by temperature.

Native bees (Hymenoptera: Apoidea) of the GSMNP

Adriean Mayor
Great Smoky Mountains National Park

In one of only five bee inventories conducted east of the Mississippi, the USDA-ARS Bee Biology and Systematics Laboratory located in Logan, Utah recorded 144 species of bees found in Great Smoky Mountains National Park, and anticipated a Park bee fauna of over 250 species. Conducted in 2002, the inventory reported 16 new state records and one of the bees (*Andrena* sp. 2) may be a new species to science. Since this inventory, an additional 56 species have been discovered, bringing the total to 200 bee species found in the Park.

Dragonflies and damselflies of the Smokies

Keith Langdon
Great Smoky Mountains National Park

The odonate fauna of Great Smoky Mountains National Park (TN/NC) is being systematically studied and documented for the first time as part of the Smokies' All Species Biodiversity Inventory (ATBI). With orientation and direction from scientific authorities and park staff, a team of citizen volunteers have undertaken to survey significant aquatic systems in the Park. Specimens, catch and release records, and reliable sight records are used in the survey, which emphasizes adult collections. Recent field guides for both dragonflies and damselflies and close-focusing binoculars are used. Data are captured in the ATBI database for analysis of distributions, phenology, abundances, etc. and for eventually use with many other geographic themes being developed in the park. To date, 92 taxa are reported from the park, but not all larger water bodies have been sampled and many that have, require multiple visits to effectively document each site's fauna. Several rare/unusual taxa are reported.

Pseudoscorpions of the Great Smoky Mountains—An introduction

Edward E.C. Clebsch[1] and James D. Cokendolpher[2]
[1]Greenback, TN and [2]Lubbock, TX

External morphological features of pseudoscorpions that are important in classification and useful in identification are briefly reviewed, as are a few aspects of feeding, life history, ecology, and behavior. The history of study of the group in the Smokies and in the region is reviewed, and the current state of our knowledge of the group in the region is evaluated.

Land snail surveys of the Great Smoky Mountains National Park

G. Thomas Watters[1] and Dan C. Dourson[2]
[1]Ohio State University and [2]Stanton, KY

The Great Smoky Mountains harbors one of the most diverse land snail assemblages in North America. At least 45 taxa are unique to the southern Appalachian Mountains, some occupying no more than a few counties. Although famous for its snails, the Great Smoky Mountains have never been systematically surveyed. The All Taxa Biodiversity Inventory and several independent projects have allowed the authors and their staff to begin a comprehensive survey of the Park. Now in its sixth year, over 300 sites have been examined, largely using leaf-litter samples. The inventory now includes over 140 taxa, many of which are new records for the Park, including several species perhaps new to science. The use of GIS technology has allowed us to map the distribution of each species and relate it to various habitat characteristics.

Influence of abiotic factors on a southern Appalachian crane fly (Diptera; Tipuloidea) fauna

Matthew J. Petersen and Jessica D. Davis
Iowa State University

The degree to which taxa create assemblages across a spectrum of habitats is dependant on numerous environmental factors including habitat heterogeneity and type, climate, elevation, and disturbance history. For species-rich insect groups such as crane flies (Diptera: Tipuloidea) these forces will act on both the larval and adult life stages, each separately working to determine species distributions. The adult crane flies of a southern Appalachian montane ecosystem were inventoried from October 2000–2001 to determine the extent to which they formed distinct assemblages between forest types and to identify abiotic factors influencing their distributions. Sampling locales showed moderate levels of beta diversity between closed canopy forest types as apposed to high levels of beta diversity between closed and open canopy types. Minimum and maximum temperatures, plot aspect, and canopy cover were significant predictors of fly community assemblage. Surprisingly, elevation was not a significant factor affecting fly community composition. The grouping of forest types with closed canopy indicates a heterogeneous crane fly fauna that is less affected by forest type than by degree of canopy insolation.

Smoky bears: Tardigrada of the Great Smoky Mountains National Park

Diane R. Nelson[1] and Paul J. Bartels[2]
[1]East Tennessee State University and [2]Warren Wilson College

As part of the All Taxa Biodiversity Inventory (ATBI) in the Great Smoky Mountains National Park (GSMNP), we have collected a total of 592 samples from soil/decomposed leaf litter, lichens and mosses on trees, and stream sediment and periphyton within all 19 permanent ATBI plots. About 75% of these samples have been processed. We have collected some additional samples from caves, rock lichens, seeps, and bird nests. Recently we began taking new samples from deep soils and high elevation anakeesta rock formations. Tardigrades have been extracted from samples using centrifugation with Ludox AM™ and mounted on individual microscope slides in Hoyer's medium for identification under phase and DIC microscopy. Prior to our study, only three species of tardigrades had been previously reported from a few samples in the park. We have now examined over 7000 slides and recorded 69 species, 13 of which we believe may be new to science. We have also calculated species richness estimates using EstimateS 6 software for each of the major tardigrade habitats and for comparison of the number of tardigrade species in mosses on trees at breast height and at the base. We are developing a key to the species of tardigrades in the GSMNP, including photographs of the species and illustrations of all the characters and character states. This key will be available on the Internet.

Reptile richness of Great Smoky Mountains National Park

W.B. Cash[1], Jay Clark[2], Frank Van Manen[2], Jessica Daniel[3], Jon Davenport[4], Joshua Ennen[5], James Ramsey[3] and James Webb[1].
[1]Maryville College, [2]University of Tennessee, [3]Murray State University, [4]East Carolina University, and [5]University of Southern Mississippi

From 2000 to 2004, 1356 reptile individuals representing 33 species were encountered in Great Smoky Mountains National Park. Reptiles were sampled at 70 permanent sites and multiple random localities throughout the 2200-km^2 park. Various techniques were employed to encounter reptiles including visual search and seizure, temporary drift fences with screen mesh funnel traps, metal roofing tin arrays, turtle hoop trapping, spotting scopes, and collection of reptiles found dead on road surfaces. Multiple biotic and abiotic variables were measured at each point of encounter, including UTM coordinates, elevation, date, and general life-history notes (sex, life stage, and general morphological characteristics). Overall reptile species richness of Great Smoky Mountains National Park was increased to 38 species from the 36 confirmed historic records when the project began. The two new species were the Slider Turtle (*Trachemys scripta*) and the Common Musk Turtle (*Sternotherus odoratus*). The three most commonly encountered reptile species were the Eastern Garter Snake (*Thamnophis sirtalis*), Black Racer (*Coluber constrictor*), and the Copperhead (*Agkistrodon contortrix*). Conversely, the three least commonly encountered species were the Mole Kingsnake (*Lampropeltis calligaster*), the Southeastern Five-lined Skink (*Eumeces inexpectatus*), and the Eastern Hognose Snake (*Heterodon platyrhinos*). Five species known historically from the park were not encountered during the inventory (Coal Skink, *Eumeces anthracinus*; Scarlet Snake, *Cemophora coccinea*; Pine Snake, *Pituophis melanoleucus*; Southeastern Crowned Snake, *Tantilla coronata*; Eastern Slender Glass Lizard, *Ophisaurus attenuatus*). We will discuss our data in the context of conservation management of reptiles in the park and provide probability of distribution models for selected species.

Breeding bird inventories in Great Smoky Mountains National Park: Links to research and monitoring

Theodore R. Simons[1] and Susan A. Shriner[2]
[1]USGS Cooperative Research Unit, North Carolina State University and [2]Colorado State University

Forest songbirds provide a model system for studying and monitoring biological diversity. They comprise a diverse group with a wide range of ecological requirements that are easily interpreted to the general public. For these reasons we conducted an extensive inventory of breeding birds in Great Smoky Mountains National Park between 1996 and 1999. For all years combined, we established 4159 independent plots throughout the Park, and conducted a total of 7573 point-count censuses, recording 74,797 individuals of 115 species. We will illustrate how inventory data for birds has been incorporated into the Park's long term inventory and monitoring program, and how these data have been applied to: model species distributions and habitat associations across the Park, to estimate the importance of the Park as a regional population source for declining bird species, to predict the degree to which site disturbances due to development or management may affect particular breeding bird species, and to project the effects of large-scale changes in forest composition caused by exotic pests, diseases, and air pollution.

Mycetozoans of the Great Smoky Mountains National Park

John C. Landolt[1] and Steven L. Stephenson[2]
[1]Shepherd University and [2]University of Arkansas

During the period of 1998 to 2005, surveys for dictyostelids (cellular slime molds) and myxomycetes (plasmodial slime molds or myxogastrids) were carried out at numerous study sites throughout the Great Smoky Mountains National Park as one component of the All Taxa Biodiversity Inventory (ATBI) project. These study sites included examples of all major forest types along with the more common types of non-forest vegetation. Since the surveys began, the number of dictyostelids known from the Park has increased from 12 to at least 30, whereas the number of myxomycetes has increased from 88 to more than 220. The new records of dictyostelids from the Park include 10 species new to science. Many of these are "small" species that seem to be confined to marginal habitats at higher elevations. A number of species of myxomycetes appear to be restricted largely or exclusively to the red spruce-Fraser fir forests found at the very highest elevations in the Park. Some of these, including such examples as *Barbeyella minutissima*, *Elaeomyxa cerifera,* and *Lepidoderma tigrinum*, tend to be associated with the substrate complex represented by the decaying wood of decorticated spruce logs with a cover of leafy liverworts (particularly *Nowellia curvifolia*) present.

Small mammal population dynamics within the ATBI sites of the GSMNP

Edward B. Pivorun
Clemson University

This study was initiated in October 1999, and over 2500 small rodents and insectivores had been trapped up to December 2004. Seventeen ATBI sites and 48 additional sites were sampled with Sherman live traps and pitfalls. Mark-recapture techniques were used to assess population parameters. *Permoyscus maniculatus*, the deer mouse, is the dominant small rodent throughout the park. However, *Clethrionomys gapperi,* the red-backed vole, occasionally displayed dominance at altitudes above 4000 ft. *Sorex cinereus*, the masked shrew, is the dominant insectivore at higher altitudes and *Blarina brevicauda*, the short-tailed shrew dominates at lower altitudes. Rodent populations associated with specific ecosystems in the park display dynamic shifts in species composition and biomass. These population changes can occur on a seasonal basis or over a span of years. Highest "species diversity" is associated with some of the harshest environments at altitudes above 4000 ft. One example of the dynamic aspects of mammal population composition was noted at the Clingmans Dome ATBI site. In 1999, the red-backed vole was dominant in the fall trapping period. This was noted again in 2000, 2001, and 2002. However, in the spring and summer trapping periods of 2000–2002, the populations of voles and deer mice displayed comparable densities. The rock vole displayed relatively high densities in 1999–2000, but virtually disappeared in 2001–2002. At Indian Gap, voles and deer mice displayed comparable population sizes during 2000 and 2001. In 2002, the mice surpassed the vole populations.

Appendix 2. The text of the Science Plan for the Great Smokies Mountain National Park ATBI as it was written by the Science Committee.

The Science Plan for the All Taxa Biodiversity Inventory in Great Smoky Mountains National Park, North Carolina and Tennessee, Summer 2000.

Peter White (pswhite@unc.edu, University of North Carolina, 919-962-6939) and John Morse (jmorse@clemson.edu, Clemson University, 864-656-5049), Co-Chairs, Science Committee, Discover Life in America (www.discoverlife.org).

Committee Members: Frank Harris, Keith Langdon, Rex Lowe, Becky Nichols, Chuck Parker, John Pickering, Mike Sharkey.

Outline

Introduction to the Science Plan
Rationale for the ATBI
  Why do we want to do this project?
  Why the Smokies, why now?
  What questions will be addressed?
The Five Science Plan Themes
  Theme 1: Coordination across ALL taxonomic groups.
  Theme 2: Taxonomic Working Group (TWIG) organization.
  Theme 3: Taxonomic inventory in an ecological and conservation context.
  Theme 4: A Geographic Information System (GIS) as an organizing and analysis tool.
  Theme 5: Involvement of students of all ages and the public.

Introduction

The All Taxa Biodiversity Inventory, a project of Discover Life in America, seeks to inventory the estimated 100,000 species of living organisms in Great Smoky Mountains National Park and to develop checklists, reports, maps, databases, and natural history profiles that describe the biology of this rich landscape to a wide audience. The species level of biological diversity is central to the ATBI, but the project is developed within an ecological and conservation context and encourages understanding at other levels of organization, including genetic variation within species and ecosystem descriptions.

This *Science Plan* presents the rationale for this project and the organizing themes and objectives that structure the work. This plan was drafted by the Science Committee of Discover Life in America in collaboration with Taxonomic Working Groups that lead the effort for particular groups of organisms.

Rationale for the ATBI

We describe the rationale for the project under three headings: Why do we want to do this project?; Why the Smokies, why now?; and What are the questions to be addressed?

Why do we want to do this project?

The ATBI is important for the scientific community. The project is important to science because it will invent and test new paradigms for large-scale and long-term biological inventory.

The ATBI supports museums, universities, researchers, and students, and thus fosters the survival of these institutions and the taxonomic knowledge that is essential to society. By supporting museums and academia, we support the ability to know and to name and we enhance the taxonomic expertise of the nation.

The specimens from the ATBI can be used comparatively by researchers working elsewhere. In this way, the project indirectly benefits biological inventory beyond Park boundaries. The specimens and data will constitute an archive of information to be used by future generations, as well.

The ATBI supports the National Park Service and Great Smoky Mountains National Park. The ATBI supports and enhances the basic conservation mission of the National Park system. The project 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.

The ATBI is important for society at large. 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 likely.

Human beings have an innate love of distinguishing, identifying, and naming. 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 will draw 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 will bridge the gap between academic and public education.

Why the Smokies, why now?

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 supports the project through staff time, financial support, and facilities.

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 need to study the Park now to understand future change.

What questions will be addressed?

The habitats and taxonomic groups to be addressed are diverse, and research questions will often be specific to particular taxonomic groups and habitats. Nonetheless, we can express some generic project-wide questions that ATBI will address. We group representative questions under three headings: How should the ATBI be done?, What species are present: where are they and when are they present?, and What explains patterns of diversity and distribution?

How should an ATBI be done? Because the scope of this project is unprecedented, the first group of questions addresses overall approaches to inventory in the Park.

- Can we integrate traditional methods of taxonomic inventory with the establishment of a set of structured observations at biodiversity reference areas?
- How many biodiversity reference areas do we need and how do we select areas to represent the diversity of environments and histories within the Park? What is the trade-off between intensive (increase in effort at each location at the expense of number of locations) and extensive (increase in the number of locations at the expense of effort at each location) inventory at the biodiversity reference areas?
- Can we incorporate the public and volunteers into the taxonomic inventory through biodiversity reference areas, sampling protocols, and sorting centers?
- Can we use an integrated computer mapping system to structure the inventory and to register accumulating information?
- Can we use species-effort curves to estimate checklist completeness? How do we estimate how many species are yet to be discovered? Can we formulate stopping rules based on species-effort curves?
- Can we create a quantitative and repeatable estimate of diversity through documentation of the species-effort curve?
- How can we use new technologies to capture and transmit data?

What species are present: where are they and when are they present? The core questions of the project focus on the documentation of diversity in the Smokies.

- What species occur in the Park, where do they occur (for example, by community, habitat, and geography) and when do they occur (for example, by season and time of day)? Do access and the proximity of trails and roads influence what species are present?

- How complete are existing Park checklists? As the project progresses, how many of species are new Park records, new county records, new state records, new national records, and new to science?
- What species are endemic or nearly endemic to the Park?
- What rare or listed species occur in the Park? What habitats do they occur in and are they secure?
- What invasive exotic species occur in the Park? Are particular habitats vulnerable to exotic invasions? Are exotics expanding?

What explains patterns of diversity and distribution? As knowledge accumulates about the species present in the Park, we will seek to address questions about the pattern of species distribution, the factors which control that distribution, and the conservation implications of project results. Major factors that determine species distributions are the physical environment (warmth, moisture, geology and soils), disturbance history (human and natural disturbance), and spatial properties (how large or isolated a habitat is, the spatial location of habitats relative to other terrain features). Species with different niche characteristics, vagilities, and rates of gene flow will react differently to the Park's environments, histories, and spatial characteristics so that the answers to these questions will differ in interesting ways among taxonomic groups.

- What is the relationship between biological distributions and the physical environment and human and natural disturbance?
- What environmental and ecological factors correlate with diversity? Does diversity increase with warmth, moisture, and productivity and decrease with elevation? Is diversity higher in old-growth compared to second-growth areas? Is diversity higher in areas of large contiguous habitat than in small isolated habitats? Is there an effect on high-elevation species of the maximum local elevation (because climates were warmer in the past, it has been hypothesized that extirpation of high-elevation species was most intense on mountains which are lower than 5700–6000 ft)?
- How does environment and geography contribute to species diversity patterns in groups with different inherent vagilities and rates of gene flow?
- Are there hot spots of diversity within the Park?
- Can we use known locations to predict distributions from computer map data?
- Are some species limited to old-growth or second-growth areas?
- Is diversity correlated among groups? Can we use one group to predict diversity in another?
- How well do the umbrella-species approach and the indicator-species approach (in both of these a few taxa are used to index diversity in other taxa) work?
- Are particular habitats more vulnerable to exotic species invasions or to other kinds of change?
- What species and habitats are the most vulnerable to change?
- How do known threats overlay species distributions?

The Five Science Plan Themes

Central themes and a new paradigm for biological inventory

The southern Appalachians have attracted scientific exploration for over two centuries. Great Smoky Mountains National Park itself has been explored by taxonomists since it was established in 1934. Indeed, scientists were among those campaigning for a national park in the southern mountains in the early 1900s. All conservationists recognized the importance of the rich plant and animal life of this landscape as they argued for creation of the Park. The ATBI will document past scientific observations, expand and enhance ongoing interest, and develop a new, systematic approach to observation throughout the Park's landscape.

We define five themes for this Science Plan. These themes describe our basic approach and form the philosophical underpinnings of our objectives. Collectively they produce a new paradigm for biological inventory. After an overview of each theme, we list objectives for each.

Two appendices to this plan are included: Appendix A: The User's Guide, and Appendix B: Traditional and Structured Collecting and Observing.

The five Themes are:

- Theme 1: An inventory for all taxa and coordination across taxonomic groups;
- Theme 2: Taxonomic Working Groups (TWIGs) and the taxonomic inventory;
- Theme 3: Taxonomic inventory in an ecological and conservation context;
- Theme 4: A Geographic Information System (GIS) as an organizing and analysis tool; and
- Theme 5: Involvement of the public, schools, and volunteers.

Theme 1: An inventory for all taxa and coordination across taxonomic groups.

The first theme is that this inventory will address all taxonomic groups. This establishes Great Smoky Mountains National Park as the first site in North America and one of the first sites in the world to have a thorough and integrated inventory of its living things. Not only will this project add tremendously to the understanding of the Park and its conservation of biological diversity, but it will also stimulate the training of taxonomists by drawing attention to the importance of taxonomy and systematics as fields of human knowledge.

We seek to harness the interest that field biologists have always had in the Park and to stimulate an expansion of this work. We seek to reach all biologists who visit the Park with the goals and structure of ATBI and to enlist cooperation, capture information, and enhance information quality. The Park's collecting permit system is one vehicle for this communication. Information on ATBI can be distributed when collecting permits are applied for or issued and in mailings that request Annual Investigator Reports.

Taxonomic Working Groups (TWIGs) have been organized for major groups of living things. Through the TWIGs, the project seeks to reach professional societies and individual investigators to expand taxonomic effort in the Park. The TWIG organization is described below in more detail as our second theme. The Science Committee and the ATBI Coordinating Office will work with the TWIGs to create common protocols and guidelines across taxonomic groups.

Even with promotion of ATBI, there will be taxonomic groups that are receiving inadequate attention. The Science Committee must play a role in identifying understudied groups—groups that have no TWIG or for which the TWIG needs assistance in organizing, groups for which the methods for inventory are obscure within ATBI, and other special opportunities (e.g., bringing in an expert in a particular group to advise ATBI on how to approach that group). The Science Committee will seek to promote work in those problematic or poorly known groups. The Science Committee will seek opportunities to bring specialists to the Park to consult on inventory approaches and techniques. The Science Committee will recruit TWIG leaders for "orphaned" groups—groups without current leadership.

The Science Committee will seek the establishment of fellowships and sabbatical leave programs, as well as other forms of support (for example, travel and housing), that will give taxonomists and graduate students the opportunity to reside in the Park for varying periods of time—for a summer, six months or a full year or more to work on particular priority groups and problems.

Bioquests will be used to expand taxonomic work in the Park. Bioquests will bring groups of scientists and amateur naturalists to the Park for short but intense periods of work. The TWIGs and Science Committee will develop guidelines for Bioquests (including organization, support functions, and data capture) and for quality control and assurance for all data, including specimen labels and checklists.

We envision an ATBI central office that will be an information center for collectors, will operate the bulk sampling, sorting center, and volunteer programs, will coordinate TWIG Bioquests, and will serve as the interface between the Park's collecting permit system and field collectors. The office will maintain the running scoreboard of the taxonomic inventory, including working checklists and newsworthy statistics (e.g., species new to North Carolina and Tennessee, new to the Park, new to the five counties of the Park, and new to science). The office will track and archive the developing history of the project and will maintain the registry of participants.

The ATBI office will oversee support functions for field work, including housing, temporary work space, storage facilities (e.g., freezers), microscopes, cameras, bar-coding machines, software, computers, and transportation.

Objectives of Theme 1

- Objective 1-1: Establish an office in Great Smoky Mountains National Park that will provide information to field workers, operate the bulk sampling and sorting center protocols, archive samples from the sorting center if no TWIG is organized to work on those samples, archive information and data, coordinate TWIG Bioquests and other field activities of the TWIGs, oversee or coordinate the availability of support functions (housing, temporary work space, storage facilities, microscopes, cameras, bar-coding equipment, software, computers, and transportation), and maintain the volunteer program and registry of participants.
- Objective 1-2: Keep the project scoreboard: a running checklist of all organisms in the Park, including working checklists and newsworthy statistics of species new to North Carolina and Tennessee, new to the Park, new to the five counties of the Park, new to science, and estimates of inventory completeness.
- Objective 1-3: Describe and archive the field effort, history of the project, and observational methods in sufficient detail to permit repeat of these methods and to allow future detection of change for appropriate observations.
- Objective 1-4: Work with TWIGs and the Database Committee on protocols to capture data on collections and observations made in the Park, whether by independent investigators, TWIG projects, Bioquests, Park employees, or the public.
- Objective 1-5: Work with TWIGs to develop guidelines for Bioquests.
- Objective 1-6: Promote ATBI through, and capture information from, the Park's collecting permit system and Annual Investigator Reports.
- Objective 1-7: Expand taxonomic interest by assisting TWIGs in promoting ATBI to professional societies.

- Objective 1-8: Promote training of a new generation of taxonomic specialists in participating Universities by targeting grant dollars for graduate research assistantships in taxonomy and systematics.
- Objective 1-9: Improve job-market opportunities for newly-trained taxonomists and systematists, for example by demonstrating to universities and museums the availability of extramural support for inventories, collection improvement, and systematics research.
- Objective 1-10: Budget support for graduate fellowships, faculty sabbatical leave grants, and other financial assistance to facilitate intensive investigation of priority groups and problems by visiting specialists living temporarily in the Park
- Objective 1-11: Regularly review the organizational status and composition of TWIGs and aggressively seek specialists for understudied groups, funding the work on such groups appropriately.

Theme 2: Taxonomic Working Groups (TWIGs) and the taxonomic inventory

The fundamental work of ATBI will be done by Taxonomic Working Groups (TWIGs) organized around specific biological groups. The Science Committee depends on the work of the TWIGs to build the long-term Science Plan.

TWIGs have key tasks:

- enlisting the participation of, and communicate with, a network of taxonomists and professional societies;
- assessing the current state of knowledge about each taxonomic group (including drafting preliminary checklists and bibliographies, addressing synonymy, and identifying important holdings of specimens);
- producing running checklists, including, as appropriate, common names, synonymy, and status (for example, field-sighting record, specimen-based record, extant taxon, believed-extirpated taxon, most-recent record);
- planning field work and determining collection methods;
- participating in the effort to design and adopt structures for specimen label and observational data;
- writing an annual report, plan, and budget request; and
- propose the benchmarks for and moving each taxonomic group through a series of "Levels of Knowledge" from inventory of past research to checklists to distribution maps to synthetic natural history profiles.

The efforts of the TWIGs will generate important products, including:

1. Checklists, including synonymy and common names, as appropriate
2. Assessments of status of species in the Park (e.g., site record, specimen-based record, historic record, extirpated, extant, doubtful, abundance)
3. New species descriptions
4. New distributional records
5. Voucher specimens
6. Field guides, identification aids, interactive keys, drawings, and photographs
7. Information for web page profiles

The TWIG Theme includes three subthemes that are distinctive and original elements of this project:

1. Traditional and structured collecting and observing: the project will encompass two kinds of field work: we term these traditional and structured. The project will place heavy emphasis on expanding both kinds of taxonomic survey in the Park.

Traditional collecting and observing is here defined as field survey in its general sense. Collecting and observing will be accomplished by individual investigators based on their experience, knowledge, time constraints, and methods. ATBI will assist these investigators and capture their records for the accumulating database. ATBI will establish guidelines for collecting, including methods for promoting spatial resolution. ATBI will also establish guidelines for Bioquests: intense, short-term field experiences organized around particular biological groups. Traditional activities are based on the experience and intuition of scientists working directly in the field. Such activities are usually the most efficient means to building a checklist and discovering rarities. However, it is often difficult to document the effort expended and to describe the work in a way that makes it repeatable by future investigators.

Structured collecting and observing is here defined as those activities that take place at predetermined sampling points (Biodiversity Reference Points) chosen to represent the diversity of environments and histories of the Park's landscape. Structured sampling points will be available to all field workers and will be especially valuable for bulk sampling, particularly sampling done by the public and volunteers (groups that lack the experience and knowledge that is essential to traditional collecting and observing). Structured sampling points will be documented by ATBI, including latitude, longitude, soil, geology, topography, habitat and vegetation, and human history. Structured collecting and observing will allow comparisons among seasons and years, among habitats and places with different disturbance histories, and along environmental gradients. Structured sampling will allow documentation of species-effort curves and will allow estimates of species turnover and complementarity among sites, thus contributing to assessment of how many biodiversity reference areas are needed.

2. Sorting centers and bulk sampling: TWIGs will devise methods for bulk sampling for certain groups and set up centers for sorting and distributing them to taxonomic experts. ATBI will establish protocols for the Sorting Centers, including tracking specimens from the Park to specialists and museums or other institutions.

3. Estimating completeness: we will estimate completeness of effort for taxonomic groups, where appropriate and possible, through analysis of species-effort, species-area, and species-time curves. We will track the number of species new to the Park and new to science as a function of the number of individuals collected. We will seek to incorporate methods that will allow us to keep a running tally of species inventoried, including species new to science, as well as the locations and times of observation. We will develop and encourage use of methods such as species-area, species-individual, species-time, and species-effort curves so that completeness can be assessed. We will test our predictions about completeness through additional fieldwork using the stratification parameters for the Biodiversity Reference Points. We will estimate richness through methods that compare ratios between well-known and poorly-known taxonomic groups. We will seek ways of making the discovery of new species as efficient as possible as a function of the number of individuals or samples analyzed.

Objectives of Theme 2

- Objective 2-1: Develop, maintain, and document lists of all taxa in the Park, determine the percentage of species new to the Park and new to science, and estimate the total number of species in the Park and the completeness of the inventory for each taxonomic group; create bibliographies of past research and index the location of specimens in museums and other institutions.
- Objective 2-2: Expand and harness taxonomic interest in the Park by networking with professional societies, museums, and research centers.

- Objective 2-3: Define levels of knowledge and products: the stages for moving taxonomic groups from the incomplete checklist to final synthesis.
- Objective 2-4: Propose Bioquests as appropriate.
- Objective 2-5: Establish procedures for bulk sampling and for specimen sorting and processing centers for distribution of specimens to TWIG experts.
- Objective 2-6: Develop methods to estimate inventory completeness and efficiency.

Theme 3: Taxonomic inventory in an ecological and conservation context

Taxonomists typically assess a group across its entire distribution. Ecologists often collect quantitative data on multiple biota, but focus on particular study areas. Managers of conservation areas require information on threats to resources, need an ability to monitor and predict change, and must devise management actions to protect or restore natural ecosystems. The ATBI will seek to unite these activities by establishing an explicit ecological and conservation context for taxonomic inventory.

The principle ways that we will accomplish this are: (1) we will link field observation to location and environmental, historical, and geological factors that affect species distributions; (2) we will seek ways to facilitate the association of observations with community type (the ecological address of species); (3) we will seek ways to build knowledge about species interactions and associations; (4) we will document observation methods and index and archive findings to facilitate future detection of change; (5) where possible, we will link taxonomic inventories to long-term monitoring sites and projects; and (6) we will map species occurrences and model species distributions.

Objectives of Theme 3

- Objective 3-1: Using accumulating observations, map known locations, develop methods to predict the distribution of species in the Park, and be able to associate species with particular habitats and conditions
- Objective 3-2: Determine how richness and distributions of species (and important subsets of species such as endemics, threatened species, exotic/invasive species, and species with key ecological roles) are related to: the legacy of past human disturbance (e.g., logging, farming, hydrologic changes, fire, and exotic species invasions); environmental variables (community structure and composition, elevation, temperature regime, moisture, resource availability, energy flow); spatial characteristics such as the size and isolation of habitats and the relationship of the habitat to surrounding terrain; and organism characteristics (e.g., niche width, vagility, and gene flow).
- Objective 3-3: Seek opportunities to link field collecting with monitoring sites and management questions.

Theme 4: A Geographic Information System (GIS) as an organizing and analysis tool.

There are two essential features of all observations of species occurrences: place and time of observation. Time of observation is straightforward to record (nonetheless, guidelines should be established for the resolution and format of these data); on the other hand, spatial resolution can be difficult in these rugged mountains and yet is a key to associating observations with environmental factors, historical influences, communities, and management concerns. Mapping of observations is also key to modeling and predicting distributions and to understanding any distortions caused by overcollection in accessible areas and undercollection in inaccessible ones. As a result we must work to maximize spatial resolution for observations.

We will use a GIS for a variety of interrelated purposes. We will use a GIS to select a series of Biodiversity Reference Points clustered within larger blocks called Landscape Reference Areas. The Landscape Reference Areas will represent the Park's characteristic landscapes. The Landscape Reference Areas and Biodiversity Reference Points will cover environmental, historical, and geologic variation in the Park and are distributed across its full geography. The establishment of observation areas will enhance our ability to model species distributions. We will use a GIS as a general framework for keeping an ongoing record of all collecting activities and for mapping the locations for species collected and observed. We will also be able to identify over- and undercollected areas and compare more accessible to less accessible sites. We will use a GIS to identify hot spots of diversity and areas sensitive to change. We will use a GIS to model and predict species distributions, as well as to pick areas to test such maps in the field.

Objectives of Theme 4

- Objective 4-1: Use a GIS to produce a User's Guide to collecting in Great Smoky Mountains National Park to facilitate field work and to maximize cooperation of investigators.
- Objective 4-2: Use a GIS to track field observations, to register and prevent incompatible activities, to identify potential for overlap of activities, to identify under- and overcollected areas, and to select test plots for comparing accessible and inaccessible areas.
- Objective 4-3: Use GIS to produce a stratification of the Park's diverse environments, history, and geology in order to select Biodiversity Reference Points clustered within Landscape Reference Areas.

Theme 5: Involvement of the public, schools, and volunteers

One of the unique features of ATBI is the close involvement envisioned for the public. Volunteers will carry out bulk sampling, undertake taxonomic sorting, provide field assistance to specialists, and participate in intensive taxonomic forays. These volunteers may come for a day or serve for many years. They can be involved individually or as part of school groups, scout groups, clubs, or civic organizations. We seek to interweave the activities of scientists, Park service employees, public educators, interpreters, museums, and the public in this project. We seek to train a variety of "parataxonomists"—members of the public who have been trained to make critical natural history observations and collect specimens for evaluation by specialists.

Volunteers, school children, and parataxonomists: we seek to involve and train nonprofessionals in most aspects of the work, from field collection to specimen sorting and data processing. Younger children will be exposed to the project to excite and inspire them with biological exploration, while older children will be encouraged to participate in ways appropriate to age, experience, and available supervision.

Dissemination of knowledge to a wide audience: just as the project seeks to involve the public and nonprofessionals, it also seeks to make results of the project widely available to audiences ranging from schools to universities and from tourists to amateur naturalists.

Objectives of Theme 5

- Objective 5-1: Involve volunteers and non-scientists with inventory, sorting and specimen processing centers, data processing, and administration.
- Objective 5-2: Work with the Education Committee to make the results of research widely available in a variety of media and for people of all backgrounds, skills, and abilities.

- Objective 5-3: Work with the Education Committee to develop programs and activities that will provide learning opportunities about biodiversity for a full range of potential participants at all educational levels, including pre-schoolers, primary and secondary students and teachers, college, university, and post-doctoral students, and amateur naturalists and the general public.

Appendix A: The User's Guide

The User's Guide will depict and analyze environmental and historical factors that control the distribution of plants and animals in the Park, including factors important in terrestrial, aquatic, and subterranean ecosystems. Such factors include: elevation; topographic aspect; shape and position; geology; human and disturbance history; geographic position; and ecosystem structure and composition (e.g., vegetation type). Taxonomy and Collecting Committees, as well as all TWIGs, should help define requirements for the User's Guide.

The template of the User's Guide allows the assignment of an Ecological Address to each observation—as important as its geographic address.

The User's Guide will also depict and analyze information on Park access in order to allow efficient planning of field work, but also, in combination with information on collecting history, to identify over- and under-collected areas.

The User's Guide will also serve as the template for accumulating the history of the ATBI effort by registering field projects. This registration will also help identify areas in which overlap of fieldwork in time or space or both is desirable or to be avoided. The accumulating history will be a running scoreboard of taxonomic groups and the times and places of inventory. The User's Guide will help guide and register both structured and unstructured collecting and observing activities. The User's Guide can be cross-referenced to efforts to document existing checklists and past research efforts as defined by the Taxonomy Committee and TWIGs.

The User's Guide is not just a set of maps and lists, but provides useful summaries and analyses of the diversity of sites and histories in the Park. The underlying GIS database will be maintained for further analysis and queries.

Some version will be accessible through the Web site. The material will also be made available in hardcopy.

Appendix B: Traditional and Structured Collecting and Observing

Collecting and Observing will involve traditional collecting and observing and structured collecting and observing.

Traditional collecting and observing activities

These are defined as those activities that are not formally oriented around Landscape Reference Areas and Biodiversity Reference Points. The duration of the activities is anything from days to years and from ongoing to intermittent. These activities also include serendipitous and ad hoc observations—anything from chance discoveries by Park staff and the visiting public to visits by specialists or university classes. These activities include the relatively intense and short-term field investigations called Bioquests.

Structured collecting and observing activities

The User's Guide can also be used to publicize specific places in the Park that collectively represent the diversity of environments and histories of the whole Park and do so with replication. We suggest two scales for this analysis: Landscape Reference Areas (LRAs) and Biodiversity Reference Points. The selection of these areas should be done by running scenarios against GIS-based information for the Park.

Each LRA would be a representative piece of the Park's Landscape. The Biodiversity Reference Points would represent the local gradients and heterogeneity within LRAs and would offer a range of local observation points to investigators. The User's Guide would describe the LRAs at higher resolution than for the rest of the landscape—e.g., a high-resolution vegetation map would be made for each LRA from aerial images. The User's Guide would indicate what collecting activities were permissible at, or in the vicinity of, Biodiversity Reference Points.

Quantitative Sampling at Biodiversity Reference Points

Documentation of field activities is important for all activities, whether structured or not. For example, it will be important to know how long an investigator spent in the field, what trails and places were inventoried, at what season, time of day and weather conditions the observations covered, what sampling methods used, and so on. Beyond the capture of this information, species lists and estimates of diversity can be made quantitatively meaningful if some portion of the effort goes into construction of species-area, species-time, species-effort, or species-individual curves. By repeating methods in the future and by rebuilding these curves, we can track changes in diversity even when the inventory for the Park as a whole is incomplete.