Long-Term Ecological Monitoring Plan

Great Smoky Mountains National Park

February 1993

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

Great Smoky Mountains National Park (GRSM) is internationally recognized for its biological diversity. This diversity is expressed at all levels: genetic diversity within populations, species richness, and variety of ecosystems. The park has been a key research site for issues centering on biodiversity and environmental impacts to its natural biotic resources. Some of the greatest contributions to plant ecology regarding distribution of plants and plant communities were based upon work conducted in GRSM (Whittaker 1956). The diversity of its natural resources has attracted scientists and researchers the world over. Over 1,700 journal articles and books are known to have been published based upon research focused at GRSM. In recent years, GRSM has been the site of intensive studies on the potential impacts of air pollution and acidic deposition to biotic systems (Johnson and Lindberg 1992). A large number of federal agencies, research institutions, and universities have participated in contributing to research efforts at GRSM.

The diverse natural resources and environments of the park obviously represent a unique landscape within the National Park System, and long-term monitoring is important to park management for preserving it. Additionally, long-term monitoring in GRSM offers valuable opportunities to address critical monitoring questions from which information can be used on a more general basis for monitoring and preservation of environmental values in other geographic locations.

This Long-term Monitoring Plan describes the major features of the park's long-term ecological monitoring program and provides a strategic outline of intended park efforts and priorities for the next 5 years. The strategic section of the plan includes role and function information and funding information. It also includes a schedule for monitoring protocol development and implementation. The strategic section of the plan will be updated annually.

II. OBJECTIVES OF LONG-TERM ECOLOGICAL MONITORING PROGRAM

1. Establishment and implementation of a monitoring program to measure change over time in the biotic condition of selected key populations, communities and systems.

2. Analysis and presentation of data in a manner which will provide managers with practical information to help them preserve park natural resources.

3. Archiving of measurements into an accessible data management system which will encourage a broad spectrum of scientific investigators to do research in the park.

4. Establishment and implementation of a prototype monitoring program from which information can be gained to develop valid monitoring programs in other National Park Service managed areas.

III. LONG-TERM MONITORING THEMES AND SCALES

Components selected for inclusion in the GRSM long-term monitoring program are reflections of the needs expressed in the park's Resources Management Plan (RMP) and the priorities assigned therein. The program is very specific regarding the monitoring activities that are addressed, i.e., monitoring activities in subject areas for which there are management concerns for resource preservation, for which inventories are fairly complete, and for which sampling protocols are well developed. Levels of effort are identified for each subject area which will meet essential monitoring needs and which will also encourage additional inventory and monitoring endeavors by other agencies and external researchers.

The focus of the GRSM inventory and long-term monitoring program is to provide information important for preserving the biodiversity of this great natural resource. Maintenance of biodiversity is the primary resource-related goal of park management. Toward this end, monitoring efforts are aimed at: (a) assessment of changes in park biota; and (b) identification and assessment of environmental impacts which threaten the status of park biotic systems.

The program biodiversity paradigm is scale, by which is meant the area or spatial extent over which the activities take place. The plan recognizes five such scales:

1. The <u>landscape scale</u> encompasses components that are described at regional and parkwide spatial extents.

2. The <u>ecosystem scale</u> encompasses studies that describe a particular ecosystem type throughout its entire range in the park.

3. The <u>watershed scale</u> encompasses a variety of ecological studies that include studies at the population, community, and ecosystem levels of organization. The Noland Divide Research Watershed (NDRW) is the watershed receiving this treatment.

4. The <u>community scale</u> encompasses studies that focus on particular biological communities in selected areas of the park other than the research watershed.

5. The <u>species-population scale</u> encompasses studies that focus on populations within particular communities for rare or otherwise important species.

Biological components at the landscape scale include vegetation and disturbance history and land use maps. Geophysical components include various topographic characterizations, geology maps, hydrologic resources and meteorology. Chemical components include stream chemistry, wet deposition, gaseous pollutants, atmospheric particulates and accumulated trace elements. A great deal of the landscape level monitoring activity relates to air pollution. A long-term goal is to gain the capability to utilize satellite imagery to effectively monitor forest structural changes due to agents such as fire, gypsy moth defoliation, Fraser fir mortality and, ultimately, shifts in distribution of forest types on the landscape due to climatic change.

At the ecosystem level, the major emphasis has been on the spruce-fir ecosystem of high elevations. The isolated spruce-fir forests are extremely vulnerable to an exotic insect infestation, to air pollution, and to climatic change. Work in the spruce-fir ecosystem has focused on biodiversity, as well as on chemical deposition and ecosystem processes. Plots have been established to monitor woody and herbaceous plants, Fraser fir populations, lichens, rare plant populations, hog damage, small mammals, breeding birds, and the northern flying squirrel. The other focus ecosystem in this plan is the cave ecosystem. This work focuses on biological diversity, including related physical and chemical monitoring. Caves harbor many endemic species requiring special attention. These are studied at the population and community organization levels.

The watershed level activities are oriented to the study of community dynamics, ecosystem processes, and the interrelationships of biological diversity. To the extent practical, monitoring activity is conducted within the context of the research watershed in order to capitalize on the cumulative information base associated with it. The GRSM monitoring effort on the NDRW includes work on permanent vegetation plots, rainfall, stream flow, aquatic biota, and soil and stream chemistry.

The community scale monitoring activity in this document relates to exotic forest insects and diseases, European wild hogs, and large streams and the recreational fisheries that they support. The latter also includes the monitoring of physical and chemical parameters and macroinvertebrates. The species-population scale activities seek to describe and monitor the status of species of special concern, such as those that are endangered, endemic, heroic, exotic, or otherwise of value as bioindicators.

A unifying theme is the focus of monitoring activities on management concerns. Annual reporting will stress the development of information that will help answer related questions. Each of the activity descriptions in Section V. discusses such related management questions.

The second unifying theme is integration of the monitoring program with efforts to build and refine predictive models. Some models such as forest dynamic models for spruce-fir, black bear and exotic wild hog population models, ecosystem process models, and models that predict susceptibility to gypsy moth have been developed. The park will be able to work with researchers to further test and refine these models as monitoring data are collected. Other models will require separate research projects for development. As a general principle, the monitoring projects described herein will be used to attract such research, and monitoring and modeling will be an ongoing, iterative process.

The third unifying theme consists of perturbations that impact park resources widely, such as floods, drought, fire and exotic organisms. At present, the NDRW is being used for studies of the impact of the balsam woolly adelgid and air pollution on the spruce-fir ecosystem. Such studies will contribute to a better understanding of how these perturbations affect park resources.

All components of the long-term monitoring program possess established protocols and were selected because of their potentially wide applicability.

Monitoring effort reflects significant ongoing involvement with land management agencies and other cooperators throughout the southern Appalachian region. The program provides important opportunities involving data collection and analysis, resource study, cost sharing, expansion of existing programs to meet critical monitoring needs, quality control and quality assurance for geographic regional programs such as fisheries and bear management, and similar endeavors involving funding from non-park sources.

IV. NATURAL RESOURCE INVENTORY

The following tables describe the status of the park's natural resource inventory. The chart lists abiotic resource categories, natural communities, and higher taxonomic groups of organisms. During the park's 60 years of existence, much progress has been made on vertebrates and vascular plants, but most of the park's biodiversity is not in these groups and progress has been spotty elsewhere.

NATURAL RESOURCE INVENTORY PRIORITIES:

A large, biologically rich reserve such as Great Smoky Mountains National Park requires a long-term effort just to get to the "checklist" stage for all groups. The following list of natural resource inventory needs is in approximate priority order and was rated according to:

(a) pressing park management need;

(b) the degree to which the park is believed to harbor rare, endemic, and/or undescribed species;

(c) the degree to which the taxonomy of the group is known or at least "stabilized";

TABLE 1. BIOLOGIC INVENTORY STATUS, Great Smoky Mountains National Park, February 1993

TAXONOMIC GROUP	NUMBER OF TAXA DOCUMENTED IN PARK	ESTIMATE OF ACTUAL NUMBER IN PARK	ABUNDANCE/ RARITY KNOWN FOR TAXA IN GROUP	HABITAT KNOWN FOR TAXA IN GROUP	SOURCES	REMARKS
KINGDOM MONERA (Bacteria, "Blue-green Algae")	?	?	0%	Almost nothing known	--	--
KINGDOM PROTISTA (Protozoans, Algae, etc.)	?	Several hundred to several thousand	0%	Almost nothing known	Park staff	Some cataloging of algae may have gone on unofficially.
KINGDOM FUNGI	2,250	20,000	General abundance known for "macro fungi"	Poorly known, even for "macro fungi"	Univ. of TN Botany Park staff	20,000 species of fungi in GRSM is probably conservative when considering the aquatic, subterranean and "micro fungi" - Dr. R. Peterson, Univ. of TN.
KINGDOM PLANTAE VASCULAR	1,617	1,700 to 1,800	Yes; well known	Well known for most spp.	P. White Park staff	Each year 10-15 new taxa are discovered in the park incidental to other tasks.
NON-VASCULAR -Bryophytes	435	450-500	Yes, fairly well known	Fairly well known; most rare spp.	Univ. of TN	Some extreme disjunctions between the park & India (!) & Europe have been discovered in the past 3 years.
-Lichens	303	450-500	Fair-Poor	Fair	Wetmore	The Crustose group are poorly known.
KINGDOM ANIMALIA INVERTEBRATES -Lepidoptera	700+	1,500	Fair for those known	A few well known, others fair to unknown	Univ. of TN	Only 2 of the park's 12 forest types have received extensive, regular collecting.
-Plecoptera	125	175-250	Poorly known	Fair-Poor	Park staff	Aquatic.
-Trichoptera	150	250-300	Poorly known	Fair-Poor	Park staff	Aquatic.
-Ephemeroptera	50	150-200	Poorly known	Fair-Poor	Park staff	Aquatic.

TABLE 1. BIOLOGIC INVENTORY STATUS, Great Smoky Mountains National Park, February 1993 (cont'd)

TAXONOMIC GROUP	NUMBER OF TAXA DOCUMENTED IN PARK	ESTIMATE OF ACTUAL NUMBER IN PARK	ABUNDANCE/ RARITY KNOWN FOR TAXA IN GROUP	HABITAT KNOWN FOR TAXA IN GROUP	SOURCES	REMARKS
INVERTEBRATES						
-Odonata	40	75-100	Fair	Fair	Park staff	Limited work by park staff in progress.
-Diptera	Several hundred-?	2-3,000	Unknown	Unknown	Park staff Univ. of TN	A very large and taxonomically difficult order.
-Coleoptera	A couple hundred	1-4,000	Unknown	Extremely poorly known	Park staff Univ. of TN	Incredibly rich group; a few taxa are known to be extreme endemics for park.
-Hemiptera	Scores	Several hundred?	Unknown	Unknown	Univ. of TN	--
-Homoptera	A couple hundred	Several thousand?	Scale insects-fair; others unknown	Some host plants for scale insects; otherwise unknown	Univ. of TN	--
-All Other Insect Orders	Several hundred	5-8,000	Unknown	--	Park staff Univ. of TN	This includes Hymenoptera as its largest group and about 15 other orders.
-Arachnids	Approx. 300	Up to 800	Poorly known for most groups	Habitat fairly well known for a few, others not	W. Carolina Univ.	So. Appalachians are a center of biodiversity for North America?
-Nematodes	35	400 +	Very poorly known	Somewhat for plant parasitic types	Univ. of TN	Probably 200 soilborne and 200 plant-animal parasites.
-Molluska	Approx. 100	150-?	Bivalves well known, land snail lesser, others poorly	Poorly known	TN Tech. Univ. Park staff	Land snails and bivalves have received most attention.
-Crustacea	25	100-?	A few well known; otherwise no	Fair to poorly known	Park staff	Extreme endemic cave species in park.
-All other invertebrates	?	Several hundred to several thousand	--	--	--	Groups such as earthworms and millipedes probably have endemic taxa in higher elevations, special habitats.

TABLE 1. BIOLOGIC INVENTORY STATUS, Great Smoky Mountains National Park, February 1993 (cont'd)

TAXONOMIC GROUP	NUMBER OF TAXA DOCUMENTED IN PARK	ESTIMATE OF ACTUAL NUMBER IN PARK	ABUNDANCE/ RARITY KNOWN FOR TAXA IN GROUP	HABITAT KNOWN FOR TAXA IN GROUP	SOURCES	REMARKS
VERTEBRATES						
-Fish	72	58	Well known	Well known	Park staff	Extant taxa 58 due to habitat alteration.
-Amphibians	37	37-40	Well known	Fairly well known	Park staff	Park is well known as a center of diversity of salamanders (26 species).
-Reptiles	36	36-38	Well known	Well known	Park staff	A few pineland species not seen for half-century.
-Birds	240	245-?	Well known	Well known	Park staff	--
-Mammals	67	<70	Well known	Well known	Park staff NC State Univ. Univ. of TN	--

TABLE 2. ELEMENT INVENTORY STATUS, Great Smoky Mountains National Park, February 1993

ELEMENT	NUMBER DOCUMENTED IN PARK	ESTIMATED NUMBER IN PARK	TOTAL RARITY KNOWN FOR PARK/REGION	LOCATIONS ACCURATELY MAPPED?	SOURCES	REMARKS
NATURAL COMMUNITIES						
TERRESTRIAL	19	About 20	Yes	Yes, for most forest types accuracy 80-90%	MacKenzie TNC Park staff	Classification used: The Nature Conservancy USFS Ecological Community classification for the SE U.S., Nov. 1990.
PALUSTRINE	6	6	Mostly	No	Park staff	Classification used: The Nature Conservancy USFS Ecological Community classification for the SE U.S., Nov. 1990.
SUBTERRANEAN	2	Several	Yes	Yes	Park staff	There are 10 known limestone caves. (Note: 65 specific sites in the park are delineated as Special Protection Zones.)
NON-BIOTIC RESOURCES						
GEOLOGY-FORMATION	25	About 25	Yes	Only 75% of park mapped	USGS	Southwest corner of park (NC) not mapped.
GEOMORPHIC-TYPES	10-15	10-15	Well known	No, only a few incidental to other mapping	USGS Park staff	Landform types are of interest in general and because higher peaks appear to have evidence of peri-glacial features.
SOILS-TYPES	Several	20-50?	No	No	SCS Oak Ridge Park Staff	Large-scale, non-agricultural soil surveys are only now starting to be used in So. Appalachians.
HYDROLOGIC SYSTEMS	Several	<20?	Not well understood	Surficial streams well known/ mapped on GIS, other systems less known	USGS Park staff	Hydrologic systems vary in size, character (reservoir vs. first order stream vs. ground water), chemical/physical properties.
AIR QUALITY	N/A	N/A	N/A	Partially	Park staff	Refers to air quality as it varies spatially and seasonally.

(d) an estimate of the relative number of workers (in and outside the NPS) skilled in that particular group.

Arachnids. Important predators, several authorities in park area, habitat-specific, rare species, including one species park has officially proposed to U.S. Fish and Wildlife Service as being in dire risk of extinction, and extreme endemics associated with caves.

Terrestrial Natural Communities. The park uses a "vegetation" map developed in 1988 from LANDSAT imagery using 90-meter pixels. It is about 85 percent correct. Needed is a fine-grained classification of these communities based on recent classifications developed by The Nature Conservancy, North Carolina Department of Conservation, and U.S. Forest Service.

Soils. Forest soil classifications for the southern Appalachians have recently been developed and are needed for the park. Only a small percentage of the park has been typed, and that using old agricultural systems. This element relates to almost all other natural resources in the park.

Insects: Ephemeroptera/Plecoptera/Trichoptera/Odonata. These orders, primarily aquatic, are at risk due to acid precipitation. New species and a new genus have been discovered in the last several years by park staff. Their association with water makes this group discrete.

Mollusks. Sporadic work on bivalves and land snails needs to be reinforced with comprehensive collections by terrestrial habitats. In 1992 in 1 day a specialist found several very rare species heretofore unknown from this part of the southern Appalachian region. Land snails and slugs are important intermediate hosts of mammalian parasites.

Insects: Hymenoptera. This is a vast and diverse order. Ants received parkwide survey in a 1940s study, little work since. Bees have received little attention in the park. There are about 700 species in the eastern United States. Many of these are solitary, rare native species that visit a single species or genus of plant (Mitchell 1960). These plant-pollinator relationships need to be elucidated before further extensive impacts (e.g., gypsy moth, hemlock woolly adelgid, dogwood anthracnose) occur in the park. Some sections of Order Hymenoptera are poorly known taxonomically, especially the parasitic wasps and related groups. This should not prevent work but may mean the groups are given lower priority.

Insects: Lepidoptera. A 3-year study of oak forest associated species combined with sporadic work earlier resulted in over 700 species being documented with specimens. This is believed to be about one-half the taxa of the park. Almost no work has been done on the "micro moths," a section of Order Lepidoptera with fewer experienced workers. One of these workers (R. Brown, Mississippi State Entomological Museum) feels that GRSM could hold many heretofore undescribed endemic species. All

Lepidopterans would be at risk to applications of Bacillus thurengensis, (the most widely used control agent for gypsy moth) should it ever be considered for use in the park.

Insects: Coleoptera. This is an enormous order. In this park several extreme endemics are known and most of the groups haven't even been surveyed yet. Some families such as the Coccinellidae (ladybugs) are important predators of injurious insects, including some of the devastating exotic insects now starting to infest this region.

Fungi. The Kingdom Fungi, formerly considered part of the Plant Kingdom, is very diverse at GRSM. This is probably due to the high diversity of vascular plants, which are directly or indirectly a food source, and the relatively high precipitation. Approximately 150 species types are known from the park. The most diversity comes from the moist cove forests where some genera are known only from single sites in the park and Southeast Asia or Polynesia. While several publications are available on the "macro fungi," additional work or inventorying remains and the aquatic fungi are almost totally unknown.

Insects: Diptera. Although the true flies are listed here, any of several other orders/ classes of invertebrates could just have easily been listed. The flies are a very species-rich order that, as with other such orders, must be tackled in sections and as a long-term project. Perhaps 2-3,000 taxa are in the park. Taxonomy at the species level is not fully worked out in some families. No doubt many endemic forms exist. Some flies are important pollinators, others are parasites/vectors of vertebrate diseases.

V. NATURAL RESOURCE LONG-TERM MONITORING COMPONENT DESCRIPTIONS

As described below for each GRSM monitoring component, the natural resource inventories are extensive and provide a sound foundation to support the long-term monitoring activities.

CAVE MONITORING: GRSM has 10 known caves, all developed by solution in limestone strata. All are on the Tennessee side of the park and there are several complex caves, including Bull Cave, the deepest cave in Tennessee. In the past 50 years, sporadic documentation of cave invertebrate fauna led to the discovery of several amphipods, spiders and other invertebrates that were new to science and unique to one or two caves in the park. About 10 years ago, a cave exploring biologist inventoried all known cave species in the park's caves and produced an annotated species list (Wallace 1984). Wallace also conducted a periodic, qualitative monitoring program until 1991. Some of the species which were reported over 50 years ago were not reported by Wallace, indicating that there have been dramatic declines, extirpations or even extinctions of species. In the long-term monitoring program, monitoring will be conducted on 10 sampling days per year in Gregory Cave.

Management questions to be answered. The program addresses the following management questions: (1) What are the population trends in vulnerable macroinvertebrate groups? and (2) What physical factors, such as hydrology and temperature, affect survival of troglobite fauna?

VEGETATION MONITORING: The vegetation of GRSM is central to resource management issues. It is of international renown in the scientific, ecological and conservation communities (e.g., see general discussion and bibliography in McCrone et al. 1982) and is a key element in visitor appreciation and education. Inventories began shortly after authorization of the park in the late 1920s. Early work also included establishment of a vascular plant herbarium, drafting of a vascular plant checklist, the sampling of some 1,300 non-permanent vegetation plots, and the creation of a vegetation map. From the time of these early studies to the present, GRSM has continued to be a popular site for research on vegetation. Among the distinctive features of GRSM vegetation are its high diversity, complex pattern, large area of old-growth forest, and major vegetation ecotones. The diversity of vascular plants in GRSM is the greatest of all U.S. national parks. Dominant topographic gradients and disturbance history produce a landscape that is rich in vegetation types, even at local scales (the forest vegetation pattern has been called the most complex in all of North America). The ecotone between deciduous forest and spruce-fir forest encapsulates the continental transition from temperate to boreal forest in Canada, and the transition at mid-elevations from cove forests on moist sites to low stature and open-crowned pine-oak forests on dry sites is sensitive to changes in climate and fire regime. Approximately one-fourth of the park was never the subject of direct human disturbance, and within this area are some of the largest blocks of old-growth forest remaining in the southeastern United States, including stands in which trees surpass 2 m dbh.

Although the forests of GRSM contain trees that are capable of living more than 400 years, the landscape is rich in both natural and human-caused change. Many of the most important changes have been measured primarily as changes in the vegetation, particularly an acceleration of tree mortality, a change in ecosystem structure and composition, and an initiation of successional change. Among the most important causes of these changes have been chestnut blight, an exotic fungus (ca. 1925-1945); the balsam woolly adelgid, an exotic insect (ca. 1960-present); increases in air pollution (after ca. 1960); periodic outbreaks of the native insect southern pine beetle; a reduction of fire frequency after about 1900; grassy balds succession; the impact of European wild hogs on forest understories; and pre-park logging (White 1987). In addition to these causes, beech decline, dogwood anthracnose, and butternut canker are examples of more recently identified vegetation changes.

Several recent treatments have summarized historic information and extended the inventories with new field work. Recent inventories have been completed for vascular plants (White 1982), bryophytes (Smith, McFarland, and Davison, 1991), and fungi (Petersen 1978). Bibliographies summarizing past research have been prepared for vegetation studies (DeYoung et al. 1982). This work lists over 1,000 studies, including several classic works in plant ecology; vascular plant systematics (Wofford and White, 1981; Evans et al. 1981); and lichen ecology and systematics (DePriest 1984). Pyle (1985) presented a map-based analysis of all past human disturbance in the park which has been made part of the park's Geographic Information System (GIS). Yurkovich (1984) summarized research on geology (also a theme on the GIS) and geomorphology. The park's GIS and new remote sensing-based vegetation map contain critical inventory data that play a vital role in vegetation plot location and analysis.

White (1987) presented a synthesis of past research in terrestrial plant ecology, prioritized future research and monitoring needs, and described past establishment of permanent vegetation plots in GRSM. Including a few recent updates to the 1987 report, there are some 12 separate efforts that established permanent plots (P. White and R. Busing, personal communication). Among the most extensive studies are the following:

> Bratton, Harmon, and White. Over 300 permanent 0.1-ha plots were established in western GRSM from 1977-1980.
>
> Zedaker, Nicholas, Eagar, and White. Sixty-six permanent 0.04-ha plots were established in spruce-fir forest from 1984-1985 with funding from the U.S. Forest Service and the National Acid Precipitation Assessment Program.

As the current long-term monitoring program is implemented, the park will take advantage of these past studies where possible by using already existing permanent plots. P. S. White and R. Busing (personal communication) have completed a project to organize extant permanent plot data sets, as well as the 1930s non-permanent vegetation data set.

Finally, in the summer of 1990, the field methods developed to support this effort were tested in Roaring Fork Watershed. Three 1-ha plots, associated plot clusters and nested biodiversity plots were established in old-growth cove hemlock-hardwood forest. A report on this work, including monitoring design, plot establishment, data collection, and data management, has been completed and presented to the park (R. Busing and P. White, unpublished).

Long-term terrestrial vegetation monitoring in GRSM will furnish valuable information for the study of ecosystem processes, animal populations, and aquatic systems. Primary productivity is the basis of ecosystem energy flow. Fundamental pathways of nutrient cycling include uptake by vegetation, deposition through leaching and through mortality of plant parts, and decomposition of plant organic matter. Ecosystem structure, which plays an important role in maintenance of biological diversity, consists of the arrangement of living and dead organic matter in the vegetation. Vegetation produces key food items for many animal species in this landscape (e.g., hard mast crops). The shading of mountain streams, vegetation influence on soils, and the production of organic debris greatly influence aquatic ecosystems.

The long-term monitoring work intended here is a general, ecosystem- and landscape-based vegetation monitoring program. It is based on the establishment and remeasurement of permanent plots. The general objectives of the program are to describe the rate and trajectory of vegetation change; to gauge the significance of vegetation changes for park management goals; to help define research questions that will assess causes of change and, where appropriate, to help define research that will evaluate alternative management strategies; to establish field research sites that will attract additional research studies not funded by this program; and to promote the park's participation in regional and international monitoring networks.

Management questions to be answered. Understanding vegetation change is central to many management problems, including air pollution effects, the impacts of exotic species, landscape changes due to reduced fire frequency, dynamics caused by the southern pine beetle, and impacts to biological diversity. More specifically, this vegetation monitoring program will develop data on:

- Long-term changes in the biological diversity of high elevation spruce-fir forests under the influence of pollutant deposition, climate change, and the exotic balsam woolly adelgid.

- Decline of beech-northern hardwood forests and impacts of the exotic European wild hog.

- Impacts of the cyclic outbreaks of the southern pine beetle as these relate to forest succession, fuel loads, and fire management.

- Forest composition, structure, dynamics, and biological diversity in unique remnants of old-growth temperate forest.

- Changes in landscape dominance of oak and pine forests due to changes in climate and fire regime.

- Shifts in the spruce-fir-deciduous forest ecotone with climate change.

EXOTIC FOREST INSECT AND DISEASE MONITORING: From 1986-1992 GRSM spent an estimated $20,000 to $30,000 per year on monitoring the pest/pathogen and host status of three devastating infestations: balsam woolly adelgid, dogwood anthracnose, and butternut canker. Inventories of hosts and pests/pathogens are essentially complete although some gaps in our knowledge are likely to remain. Monitoring efforts have been published (Windham et al. 1989) or are in preparation.

The park has suffered several unnatural disasters in this century that are the direct result of infestations of exotic (usually East Asian or European) insects or fungi. A growing number of pest/pathogen species are infesting the diverse montane forests of the southern Appalachians. This project will quantitatively monitor all significant infestations of forest trees in the park.

Management questions to be answered. Management questions that need to be addressed include: how the pest/pathogen population varies in abundance on host from year to year; what the quantifiable impact of pest/pathogen is on host trees, and the demographic groups or habitats that are particularly sensitive or resistant; and whether intervention is warranted or practical and, if undertaken, the effectiveness of the intervention.

WATERSHED AQUATIC BIOTA MONITORING: Several inventories of GRSM invertebrates have been accomplished over the years, including some that deal specifically with aquatic insects. Since 1986, the park Research Aquatic Biologist has conducted continuing surveys of aquatic invertebrates in the park, resulting in a lengthening list of species known to occur in GRSM springs, streams, and rivers. Several hundred species of Trichoptera, Plecoptera, Ephemeroptera, and other insects are now confirmed. Surveys have been conducted in the watersheds at Noland Divide and Roaring Fork, and the invertebrate fauna of both areas are well known. Additional species not presently known to occur, and some not yet known to science, are likely to be encountered in the monitoring sites and throughout GRSM; however, the initial inventory phase in the research watersheds is complete (Parker, unpublished). Lists of specimens from the watersheds are maintained by the Research Aquatic Biologist, and reference specimens are deposited in the park's research museum and specimen catalog for permanent archiving. The long-term monitoring program will monitor aquatic invertebrates on a long-term recurring basis at the NDRW.

Management questions to be answered. (1) Are the benthic macroinvertebrate populations in GRSM adversely influenced by acidic deposition? (2) Do benthic macroinvertebrate populations display trends indicative of ecosystem stress?

WATERSHED HYDROLOGY AND NUTRIENT CYCLING MONITORING: Due to its extensive elevational range and geographic location, GRSM embraces the largest area of the remnant red spruce-Fraser fir ecosystem in the world. This high elevation forest, however, is being subjected to air pollution, acidic deposition, and insect infestation. Evidence now exists for high elevation ecosystem disaggregation as evidenced by fir mortality, spruce decline, and accelerated nutrient loss from the terrestrial components of the system. In addition, potential global warming could exacerbate presently recognized problems and force the upward migration of the spruce-fir forest with the resultant loss of most or all of that community type. Terrestrial impacts and acidic deposition may also be placing high elevation aquatic organisms at increasingly greater risk of mortality and extirpation due to chronic and episodic acidification of the stream environment.

The spruce-fir forests at GRSM have been shown to receive some of the highest rates of acidic deposition measured in North America (Lindberg and Lovett 1992). Not only are these forests receiving high rates of deposition inputs, they are also experiencing accelerated rates of export of acid substances (H^+ and Al^{3+}) associated with the accelerated loss of nitrate from these ecosystems (Johnson et al. 1991; Van Miegroet et al. 1990). The accelerated exports may be related to: (1) high nitrogen deposition rates and (2) increased internal nitrogen mineralization associated with (a) the high incidence of Fraser fir mortality due to woolly adelgid infestations (mortality of Fraser fir in some parts of the park exceeds 90 percent), and (b) a general deterioration of crown condition of spruce trees observed in permanent plots monitored at GRSM since the mid-1980s (Peart et al. 1992).

The high rates of acidic deposition and the mobilization of acidic substances from the soil in the spruce-fir forests place high elevation GRSM streams at great risk of both episodic and chronic acidification. Past studies have observed episodic declines in the pH of high elevation streams at GRSM (Silsbee and Larson 1981; Olem 1986; Cook et al. 1990). Studies on Raven Fork at GRSM suggested that declines in stream pH within the park were associated with fish mortality at an adjacent fish hatchery (Jones et al. 1983).

Routine stream monitoring of Noland Creek is currently being instituted as part of the NDRW program. Early results show that the stream has near-zero buffering ability (alkalinity as measured by Gran titration). Particularly high levels of acidic anions (nitrate and sulfate) provide further evidence that Noland Creek may be near chronic acidification and is likely subject to episodic acidification events.

This monitoring program is designed to track key indicators of ecosystem health within this important yet fragile high elevation forest system and to meet monitoring needs as described in the GRSM RMP.

The location of the NDRW at the former site of the Integrated Forest Study (IFS) on the Effects of Acid Deposition on Forest Ecosystems provides the significant advantage of an extensive 3-year data record of atmospheric chemistry and deposition, forest nutrient content/status, and biogeochemical cycling.

Parameters which were previously measured as part of the IFS program and related programs include: soil solution chemistry; total, wet, cloud, and dry deposition estimates; precipitation and throughfall chemistry; biomass and nutrient stock estimates for vegetation and upper soil for the IFS plot; cloud chemistry; tree physiology; soil temperature; and meteorologic parameters including wind speed and direction, air temperature, and solar radiation.

In addition to the IFS work, a number of vegetation plots for spruce-fir monitoring are located adjacent to the watershed and these plots provide up to 6 years of data on forest health and condition relevant to vegetation within the watershed.

Present watershed instrumentation includes a hydrologic instrumentation site, one wet deposition site and one throughfall monitoring plot, a soil-solution monitoring station, and a 33-m high meteorologic tower located at the former IFS research station (at 1,740 m). For stream flow monitoring, GRSM has installed hydrologic devices where Noland Creek crosses the Noland Divide Trail Road. The stream is braided at the crossing point and each of two streamlets passes through a structure consisting of concrete wingwalls, a concrete approach section, and a fiberglas 3-foot H-flume. Stage height and discharge are recorded continuously on a Campbell CR-10 data logger from Stevens water level gauges on the stilling wells of each H-flume. A biotic monitoring station has been established 20 m upstream of the flume on one of the streamlets for sampling of drift and seston.

The long-term monitoring program includes the following at the NDRW: the wet deposition monitoring station contains one Aerochemetrics wet-dry collector for the collection of wet-only precipitation, a Belfort recording precipitation gauge, and a solar panel array located on a platform from which vegetation is kept cleared; throughfall monitoring is maintained at a nearby below-canopy site via a network of passive collection devices and a second Belfort gauge; the Belfort gauges allow for continuous data recording on a Campbell data logger; the soil-solution station is located adjacent to the throughfall site and consists of a network of underground porous glass lysimeters attached to a tension generating hanging-drop assembly; the 33-m tower provides access for meteorologic sampling at 5-10 m above mean canopy heights. The following is a partial list of equipment which was previously maintained on the tower as part of the IFS project: cloud water sensor, anemometer, wind vane, solar radiometer, humidity and temperature sensor, tipping bucket precipitation gauge, and cloud water drip monitor. The tower was utilized to measure cloud chemistry, atmospheric concentrations and particle fluxes.

Management questions to be answered. Individual issues discussed above, including acidic deposition, tree decline, air pollution and global change impacts, have all been identified as important resource management issues for GRSM. Due to the interrelated nature of these problems, GRSM has developed an integrated watershed approach toward the comprehensive long-term monitoring of ecosystem health and environmental impacts to the fragile spruce-fir ecosystem.

The NDRW has been established by GRSM to monitor the following ecosystem parameters in the high elevation spruce-fir zone:

- trends in precipitation chemistry
- trends in wet deposition and total deposition (via throughfall)

- changes in stream chemistry
- changes in net nutrient export from the forest ecosystem
- trends in frequencies and magnitudes of stream episodic acidification events
- changes in the status and health of stream organisms
- chemical and physical information for background relative to forest health monitoring in nearby spruce and fir plots

LARGE STREAM FISHERIES MONITORING: Historically, fishery studies in the park have concentrated on changes in salmonid populations and have attempted to relate these data to angling success and the need for changes to fishing regulations. Some of these studies have also provided excellent information on the relative abundance and distribution of game and non-game fish species. Due to lack of a long-term funding commitment, these efforts have been sporadic and non-systematic in nature, and although providing a good base inventory, they cannot be used to predict the short- and long-term effects of environmental perturbations or man's activities on the aquatic systems.

During the 1970s and early 1980s, U.S. Fish and Wildlife Service field crews established inventory sites in most of the park's major watersheds. In 1986, utilizing this historic database, six representative streams (Abrams Creek, Deep Creek, Little River, Oconaluftee River, Hazel Creek and Cataloochee Creek) were selected for monitoring. Intensive monitoring has continued since on Little River and on Cataloochee Creek, benefiting from strong outside interest and support. Three to four years of data is available for the remaining streams.

Data analyses of game and non-game fish numbers and total weight indicate significant declines in fish populations in Little River from 1986-1989 and in Cataloochee Creek from 1986-1990 (Moore, unpublished). The data seems to indicate that droughts and floods are responsible. The data also documents some changes in stream chemistry but are insufficient to draw conclusions about impacts to aquatic biota. Data on recreational fishing in the park indicate that the annual average number of angler use days from 1974-1984 was 46,095 days, but from 1985-1990, the annual average was 70,800 days (Moore, unpublished). This trend is consistent with the loss of recreational fishing opportunities outside of parks and other preserves due to regional development activities, plus an increase in the overall number of anglers. Concurrent with this is an increase in other water-related activities, such as swimming, tubing, kayaking and whitewater canoeing, that result in habitat alteration due to visitors channelizing or damming stream segments to support these activities.

Comparative analysis of changes in sportfish and non-game fish numbers and biomass and species diversity due to increased angling and other water-based recreation and effects of natural phenomena such as droughts and floods cannot be made for streams other than Little River and Cataloochee Creek due to lack of replicative work on a recurring basis. As part of the long-term monitoring program, sampling will be conducted annually on Little River and Cataloochee Creek to ensure continuity in existing databases. One of the following streams (Abrams Creek, Deep Creek, Hazel Creek or Oconaluftee River) will also be sampled each year and a 4-year rotational schedule established. These data will be compared to the annual samples to provide a more complete picture of changes across the park. There is great public interest in the management and preservation of GRSM's fish populations.

Management questions to be answered. This program addresses the following management questions: (1) What is the extent of annual variation in sport and non-game fish populations? (2) What is the extent in variations of physical, chemical and biotic parameters that affect fisheries in the park? (3) What is the extent of angler use of the fishery resource of GRSM? (4) Can these data be used to develop a predictive model of the fishery resource of GRSM?

LARGE STREAM BENTHIC MACROINVERTEBRATE MONITORING: Biotic sampling has been carried out systematically by the North Carolina Division of Environmental Management in Cataloochee Creek at the USGS hydrologic benchmark site since 1984 (North Carolina Division of Environmental Management 1989). These surveys have demonstrated that the excellent water quality of Cataloochee Creek is reflected in the diversity and health of the biota. Over 100 invertebrate taxa are known to occur at the site, of which almost 50 percent are Ephemeroptera, Plecoptera, and Trichoptera, species which indicate good water quality. Numerous other collections have also been made as part of specific studies in the past (e.g., Green 1975, Mathews 1978, Silsbee and Larson 1983). Within the long-term monitoring program, benthic macroinvertebrates will be monitored annually at each large stream fishery survey site and at the brook trout monitoring sites on Bunches Creek using the Benthic Monitoring Ambient Network (BMAN) approach developed by the North Carolina Division of Environmental Management (1989).

Management questions to be answered. This program is designed to address questions including: (1) Are changes in benthic macroinvertebrate populations reflective of changes in water quality parameters? (2) Do changes in benthic macroinvertebrate populations affect or reflect changes in fish populations? As indicated by the first question, this effort relies on data from the program on large stream water quality and, as indicated by the second question, is closely tied with the program elements on large stream fisheries and brook trout.

LARGE STREAM WATER QUALITY MONITORING: Currently, two streams in the park, Cataloochee Creek and Little River, are monitored for discharge and water quality parameters by the USGS as part of that agency's network of hydrologic benchmark stations. Stream discharge has been monitored since 1933, and water quality parameters have been recorded at Cataloochee since 1963; discharge and water quality have been monitored at Little River since 1964. Based upon the USGS data, both sites have excellent water quality. No long-term water quality record exists for any other stream in the park, although sporadic records of various duration exist for many sites (Peine et al. 1985).

Monitoring sites selected in the long-term monitoring program are designed to provide water quality data needed by the biological components of community scale monitoring, as well as by the brook trout monitoring component of species scale monitoring. One monitoring site will be located on the East Prong of Little River near Elkmont to provide data useful to the biological components of the community scale monitoring program in that drainage. A second water quality monitoring site will be established on Abrams Creek near the ranger station. The justification for this site includes: (1) Abrams Creek is the largest single watershed in the park (Parker and Pipes 1990); (2) the geology of the watershed is unique in GRSM because of the presence of large deposits of limestone, which in turn has made the water chemistry of the watershed unique (Mathews 1978, Larson et al. 1986); (3) the species richness of the aquatic fauna in this watershed is greater than in any other drainage in the park (Lennon 1962, Mathews 1978); and (4) three threatened and endangered fish species (smoky madtom, yellowfin madtom, spotfin chub) have been reintroduced to the Abrams Creek drainage since 1986. A third water quality monitoring site will be located on Bunches Creek. This site will benefit the brook trout component of species scale monitoring.

Management questions to be answered. This program is designed to provide background information essential to three related programs: Large Stream Fisheries Monitoring, Large Stream Benthic Macroinvertebrate Monitoring, and Brook Trout Monitoring.

RARE PLANT MONITORING: An inventory of rare plants was conducted by Bratton (1979b). Peter White and Susan Bratton have published several peer-reviewed articles on rare plant issues in the Smokies (Bratton and White 1980). A recently concluded status report (Rock and Langdon, in preparation) inventories all vascular and non-vascular plants rare enough to be of management concern. Currently the park has 519 taxa of plants known from five or fewer locations, 167 of which are listed as declining, rare, threatened or endangered by either state or federal agencies. Of these, 15 are now believed to be extirpated from the park since its creation.

This component of the long-term monitoring program consists of setting up baseline, quantitative plots at approximately 45 population locations of the rarest species of plants in the park. Species priorities have been determined by use of Natural Heritage rarity rankings. After baseline measurements of site, associated species and the target species, an analysis will be completed on potential and demonstrated threats that influence survival of each rare taxon. Primary focus is on detecting and tracking population declines and increases in rare plants and the factors that cause them. Periodic re-visits are scheduled that vary in frequency from several per year to once every several years. Subsequent visits accumulate data toward development of predictive, demographic population models; identification and efficacy rating of pollination agents (where applicable); and testing the impact of stewardship activities that may be implemented to prevent extirpation.

Management questions to be answered. (1) What are threats to and current survival status of each of the 45 targeted populations? (2) What are the trends in population viability, as opposed to "background" modulations in population numbers? (3) What are the biotic and abiotic factors and management actions (if any) that influence changes? (4) What are the breeding systems employed by these populations, how does reproductive success vary, and what ecological or genetic factors influence these variances? (5) Can demographic models of populations be developed that can predict growth and decline?

RARE FISH MONITORING: Fishery surveys by the U.S. Fish and Wildlife Service in the 1950s and 1970s revealed that 30 species of fish have been extirpated from the park. A large majority of these were lost in 1957 during an attempted renovation of Abrams Creek, from Abrams Falls downstream to the park boundary (Simbeck 1990). Three of the extirpated species (smoky madtom, yellowfin madtom, and spotfin chub) have subsequently been federally listed as endangered or threatened, primarily because of the impacts of impoundments, pollution, habitat modification and other human-related impacts on these populations (Smoky Madtom Recovery Plan 1985, Yellowfin Madtom Recovery Plan 1983, Spotfin Chub Recovery Plan 1983). As part of the long-term monitoring program, monitoring of the yellowfin madtom, smoky madtom, and spotfin chub will occur annually, preferably in late spring or early summer, within their historic range throughout the 8-mile segment of Abrams Creek. Physical, chemical, and habitat data will be collected for analysis at each sample of the reintroduction sites. Backpack electrofishing and/or snorkeling will be used to collect or observe spotfin chubs. Yellowfin and smoky madtoms will be monitored by visual observations via snorkeling.

The park's Fishery Management Plan identifies six other species that are proposed for listing at the state or federal level and that need to be reintroduced. Monitoring protocols will be developed for each of these six species as they are reintroduced.

Management questions to be answered. The monitoring program is designed to address the following management questions: (1) Have the introduced rare fish survived the reintroduction? and (2) Will they expand in numbers sufficiently to become viable populations?

BROOK TROUT MONITORING: Fishery studies in the 1930s, 1950s and 1970s (King 1937, Lennon 1967, Kelly et al. 1980) have provided historical inventories on the distribution of native brook trout populations, and non-native brook trout stocking has been thoroughly documented in the park (King 1937; Lennon 1967; Kelly et al. 1980). These studies have demonstrated that native brook trout range has declined approximately 75 percent since 1900 in the area now encompassed by the park. Logging and exploitive fishing practices have been cited as the cause of the initial declines. As a consequence of the reductions in brook trout populations, non-native rainbow trout were stocked into every major watershed beginning about 1910 (Larson and Moore 1985). After the creation of the park in the early 1930s, non-native strains of brook trout from New England were also stocked in an attempt to reclaim lost brook trout range, and one official stocking of brown trout occurred in the park in the 1960s. State agencies and others accomplished other brown trout stocking adjacent to the park in streams flowing out of the park. Consequently, brown trout as well as rainbow trout and non-native brook trout have now established viable populations in many of the park's watersheds. Early park managers believed that as reforestation occurred, the brook trout would reclaim lost range. However, just the opposite has occurred--the exotics have thrived in the streams of GRSM and have moved upstream into previously unstocked areas and have outcompeted brook trout. From the 1930s to the 1970s, brook trout range declined from 157.8 km to 63.6 km (59.7 percent) in 59 streams, as documented by studies conducted during those intervals, while rainbow trout range expanded by 94.2 km (Larson and Moore 1985). Additional monitoring of brook trout range has continued on a small scale since the completion of these early studies and has documented further losses of brook trout range.

As part of the long-term monitoring program, monitoring brook trout population distribution in the park will be accomplished by establishing sampling sites (two-three) along the length of all streams known to contain mixed populations of rainbow and brook trout downstream of allopatric brook trout populations. The following established sampling design will be followed to ensure the credibility and continuity of the databases: (1) all sites will be sampled on a 10-year rotation (one-three watersheds per year, depending on size); (2) physical, chemical and habitat data will be collected during each sample for each stream; (3) established backpack electrofishing techniques will be used to collect fish; (4) three electrofishing depletions will be performed in each sampling site and the MICROFISH computer program (Van Deventer and Platts 1985) will be used to calculate population parameters; (5) the downstream and possibly the upstream limits of allopatric brook trout populations will be mapped with the GIS system in order to monitor any long-term changes in distribution; (6) summary information and results of analyses will be incorporated into the overall data management program for the park.

Management questions to be answered. The management questions addressed by this monitoring activity include: (1) Is the brook trout range continuing to decline? (2) What factors are most influencing any decline in range that may be occurring?

BLACK BEAR POPULATION MONITORING: The American black bear is a symbol of GRSM and generally of a much larger portion of the southern Appalachian region. It is considered an indicator species from a regional management perspective in that population changes relate well to changes in land use patterns. Currently the 400-600 black bears that inhabit the park serve as a "core" population for the southern Appalachian region. GRSM is critical to the preservation of the black bear population.

It provides the best protection for breeding age females to survive and reproduce. As a result, between 50-100 surplus animals are produced annually, many of which disperse outside the park (M. Pelton, pers. comm.).

As human activities and development expand, habitat for bears shrinks and populations decline. As a result, southeastern bear populations, including those in GRSM, are not continuous but are relatively small, disjunct populations scattered throughout the region. Development along the park's boundary has created a situation where the "buffer zone" for protection of bear habitat has been internalized within the boundary.

In 1969, Dr. Michael Pelton of the University of Tennessee Forestry, Wildlife and Fisheries Department began extensive black bear monitoring efforts in the northwest quadrant of the park. His intensive monitoring effort documents the black bear populations to be near or at carrying capacity in the study area. However, a concern with this project has been the geographical limitation of Dr. Pelton's work. For many years, a bait-station survey conducted by the park documented extremely low visitation rates by bears in the southwest quadrant (Lake Subdistrict), indicating an extremely low density of bears. Ironically, the southwest quadrant contains what is believed to be better habitat than other areas in the park due to significantly higher mast production. If habitat is not limiting, then some anthropogenic factor is possibly responsible for the difference in these bear densities. To substantiate and quantify this concern so that it can be addressed by management, the long-term population dynamics and ecology monitoring effort currently being conducted by Dr. Pelton needs to be expanded to include this park quadrant (Lake Subdistrict).

In the long-term monitoring program, the current monitoring work will be expanded to the southwest quadrant of the park. Bears will be caught annually utilizing Aldrich spring-activated foot snares along established sampling routes. Animals will be immobilized by chemical injection. While immobilized, each animal will be tagged, lip-tattooed, weighed, sexed, examined for ectoparasites, and notations made regarding body condition. Gross measurements, blood, hair, fecal samples, and a non-functional tooth will be collected as part of the biological work-up. Blood serum will be collected and banked at the University of Tennessee for current and future research. Teeth will be sectioned to determine age. Selected animals will be fitted with radio-transmitting breakaway neck collars. The monitoring effort will be repeated annually, allowing for mark-recapture analysis to determine bear population densities in the study area. This long-term monitoring effort is intended to result in precise population estimates with high confidence limits and low standard deviation.

During winter periods, reproductive status of denning females will be assessed. Female black bears will be radio-tracked beginning in late November to determine dates of den entry. During mid-winter, dens will be visited and the reproductive condition of the females determined (with newborn cubs, with yearling cubs, or without offspring). Litter sizes and sex ratios will be determined for those litters that are accessible.

Another aspect of the monitoring effort will be determining home ranges and habitat utilization. Locational information on radio-collared bears will be obtained by triangulation from an airplane. Ground azimuths will be determined by the loudest signal method. Locations obtained on the ground will be made from the intersection of at least two azimuths. Periodically, diel sampling will be carried out to determine hourly movement and activity patterns. Home ranges will be estimated by two techniques: (1) the bivariate or elliptical model, and (2) the convex polygon or maximum area polygon method (McLean 1991).

The second long-term monitoring program component of black bear monitoring in GRSM is a hard mast food availability survey. Hard mast is the most important food source for many wildlife species inhabiting eastern mountainous areas such as the park. The availability of hard mast relates directly to food habits, movements, habitat preference and reproduction, and thus affects population densities of black bears. Whitehead (1969) developed a survey technique for evaluating annual oak mast yield. The park and the states of Tennessee, North Carolina and Georgia utilize the Whitehead tree count survey during August/September for determining fall mast production. Routes chosen are representative of the major habitat types and elevations present in the park.

The third component of the park's long-term monitoring program relating to black bear monitoring is a black bear bait station survey. The survey method was developed by the University of Tennessee after 7 years (1972-1978) of research. Visitation rates to bait stations significantly correlate with annual Jolly-Seber density estimates based upon Dr. Pelton's work (Johnson 1990).

At each bait station, three partially open cans of sardines are hung with nylon string at least 10 feet high in a small tree and are spaced at 0.5-mile intervals along survey routes. (Survey routes over the entire park were selected to systematically represent the park, with an overall density of approximately 1 bait site/1 square mile.) After 5 nights, the baits are checked and the percentage of visitation by bears is developed as a comparative index value (Johnson 1990). The same routes are sampled in the same manner and at the same time each year.

Bait station surveys are conducted during July because bear activity is highest during this period. A relatively stable social structure also exists at this time, ensuring sampling of the "resident" bear population.

Management questions to be answered. Specific management questions include: (1) What is the status of the black bear population in the park? (2) What are the key factors that influence population dynamics? (3) Can we use monitoring techniques to detect poaching of the bear population in various quadrants of the park? (4) Can a predictive model be developed to quantify the cumulative relationships of factors affecting black bear population dynamics?

CADES COVE DEER POPULATION MONITORING: The white-tailed deer herd in Cades Cove provides one of the most prized viewing opportunities for visitors to the park. Approximately 2,000 acres of pasture land surrounded by wooded mountains are managed as an historic district. Deer populations in this area are significantly more dense than in other areas of the park. Since the late 1960s, several studies of the Cades Cove deer herd have indicated significant variations in population density. In 1971, researchers reported an 84 percent reduction in the herd due to an epizootic hemorrhagic disease (EHD) die-off. This disease is known to be a problem in high-density deer populations. Also, 11 domestic cattle in the area under special use permit were reported to have died from the disease (Fox and Pelton 1973). Negative social impacts from overpopulation can also be expected.

In the early 1980s, investigators determined the Cove's herd to be one of the most dense populations in the Southeast (Kiningham 1980). Since then, information from sporadic monitoring has indicated that population levels may be on the decline. Although coyotes migrated into the park in 1985, no predator/prey relationships have been determined.

High deer population levels have impacted native floral communities, many of which are threatened or endangered (Warren, in press). In 1979, a vegetation study conducted in the park documented a reduction in the number of plant species, a loss of hardwood species, and a predominance of conifer species in an area heavily populated by deer. Overbrowsing by deer is known to alter plant communities and influence plant succession (Bratton 1979a). For example, overbrowsing by deer during high population cycles is considered to be the cause for extirpation of the Virginia chain fern (*Woodwardia virginica*) from the park and is suspected as being the cause for the loss of the purple fringeless orchid (*Plantanthera peramoena*) (K. Langdon, pers. comm.).

Cades Cove is also one of the most heavily visited areas in the park. Public safety (e.g., deer-vehicle collisions, Lyme disease issues, etc.) is a concern that can be exacerbated when deer populations are high.

Since the 1960s, periodic monitoring efforts have been conducted in Cades Cove to assess deer population densities, herd welfare, herd behavior, movements, habitat utilization and infectious diseases. In order to properly assess the herd's status, document population fluctuations over time, and quantify impacts to native flora, a systematic long-term monitoring effort is required. Otherwise, the park can only speculate as to the nature and significance of these population fluctuations. Also, an endangered red wolf reintroduction program underway in this area of the park is adding much significance to the need for long-term monitoring of the Cades Cove deer herd. Collected data from such monitoring will contribute to an understanding of the wolves' prey requirements.

Adequate monitoring of the Cades Cove deer herd requires utilization of systematic, biologically sound monitoring techniques. Several methods (e.g., pellet counts, mark-recapture, drive counts, etc.) have been used in Cades Cove to estimate population status/density (Kiningham 1980). The two methods chosen to adequately monitor the population on a long-term basis include roadside night counts and abomasal parasite counts (APC). These two methods will continue as part of the long-term monitoring program.

Roadside night counts were first used in Cades Cove by Fox and Pelton (1973), and Kiningham (1980) provided a detailed description of the methodology. The roadside counting technique used differs from traditional roadside counting methods (King method, Frye's strip census, and Hayne's method). It is actually a modification of the drive count method (Overton 1971). An imaginary drive line is projected perpendicular to both sides of the road. As this line sweeps through both fields and wooded areas, all of the deer that pass through it are counted. Density estimates are derived by dividing the total number of deer observed by the total area surveyed. As part of the long-term monitoring program, roadside night counts will be conducted biweekly throughout the year.

The APC technique will serve as an additional tool for determining deer herd health in relation to habitat. Annually, during the last week of August or the first week of September, 10 deer will be removed, abomasal parasites collected, and the samples analyzed by the Tennesssee Wildlife Resources Agency laboratory in Nashville, Tennessee. The APC technique is a standard monitoring technique for land management agencies throughout the southeastern United States for assessing herd health in relation to habitat.

Management questions to be answered. The program addresses the following management questions: (1) Can we predict white-tailed deer population dynamics? (2) What is the status of the Cades Cove deer herd in relation to the occurrence of hemorrhagic disease and abnormal parasites? (3) Does the Cades Cove deer herd threaten rare plant populations? (4) How significant a prey base is the Cades Cove deer herd for the reintroduced red wolf?

VI. DATA MANAGEMENT

Background. A comprehensive, state-of-the-art data management system is seen as the central support system of the park's I&M program, and the park has undertaken many steps toward a comprehensive data management strategy. For several years, a consistent effort has been made to identify, obtain, and catalog existing data sets of natural resource value. These efforts have resulted in the production of a report that summarizes existing data sets (Peine et al. 1985), and the development of a research data management protocol for use by resource management and research personnel in the park (MacKenzie 1987). This protocol covers all aspects of a monitoring or research project from designing field data sheets and developing data entry programs and data validation, to data set documentation and archiving of data sets. The protocol is flexible enough to incorporate database spreadsheets, ASCII, and other forms of data storage.

Natural Resource Database (NRDB). The park has appointed the Research Aquatic Biologist as Data Manager for the I&M program. The Data Manager is assisted by a Computer Specialist, and the development of the NRDB is under their direction. The specifics of the system are worked out in meetings involving interested parties. The resource managers and scientists who are actively generating data as part of this project are responsible for the validity of their own data, and QA/QC of the original data are described in the protocols and are the responsibility of the PIs. Data entry for each project is accomplished by the PIs using their own resources.

The NRDB possesses the following characteristics:

(1) The NRDB is an integrated database management system having a graphical user interface, and that eventually will contain copies of data generated by each project, organized by data type, and classified and indexed in such a way as to permit rapid retrieval of related data sets.

(2) In order to assure data integrity and to protect the priority rights of PIs who generated the data, different levels of security are provided that permit access in a controlled manner.

(3) Provisions exist for updating and changing data files; however, only PIs responsible for the data are permitted to update or change data. Standard data manipulations that do not change the original files are permitted by any qualified investigator who has been granted access to the data. These manipulations include sorting and printing, as well as statistical and graphical analysis.

(4) The NRDB contains standards for formatting of commonly used variables (i.e., project codes, date and time, elevation, temperature, location in the park, etc.). While some of these formatting conventions are straight-forward and already agreed upon, a suitable area subdivision code is still under development.

(5) Individual data sets are documented with complete descriptions of data origin, PIs, variable and file formats, reference to related data sets and special purpose programs used to produce and to analyze the data, and citations of publications in which the data have been used.

(6) All data, programs, and documentation are backed up weekly. Data are stored on magnetic tape as the economically most feasible solution. Two back-up copies of the data are stored at different locations, one at

Headquarters, the other in the Botany building of Uplands Research Laboratory. Once a year, an additional copy is sent to the SE Regional Office in Atlanta. As volume of data and frequency of retrieval increase, other storage media will be considered.

(7) Initial hardware and software provisions necessary for data archiving and remote communications are in place but, with the growing volume of data, will be upgraded in the near future.

(8) Provisions are being made for transfer of suitable data between the NRDB and the Natural Heritage Datacenter as well as the park's GIS. Protocols and programs to allow routine movement of data from and to the NRDB will be developed. Programs have been developed for data transfer from the Natural Heritage Datacenter to the GIS.

Data set inventory. The process of identifying, locating, validating, and archiving data sets remains a priority of the NRDB. The Data Manager is surveying all existing monitoring data that may need to be incorporated into the NRDB, including historical as well as ongoing and planned projects. Whenever necessary, the Data Manager will consult with appropriate PIs to determine whether a particular data set should be incorporated into the NRDB, and if so, determine the priority for its inclusion.

VII. QUALITY ASSURANCE AND QUALITY CONTROL

The GRSM long-term monitoring program collects and maintains data on the health and functioning of populations, communities, and ecosystems within the Great Smoky Mountains National Park. Periodically, the data are subjected to trend analysis by park staff or collaborators to assess long-term changes in the health of natural components of GRSM. In addition, data in the GRSM database are in the public domain and may therefore be obtained for use in external scientific studies, regulatory processes, and legal proceedings.

The usefulness of any data set is limited by the accuracy and precision of the information obtained. Even if the data are collected using the best possible methodology available at the time of collection, the data usefulness will still be limited if both the collection and analysis protocols and the data quality are not carefully documented. The program therefore strives to meet these needs through the following mechanisms:

(1) Each project leader seeks to implement modern field and laboratory collection and analysis procedures that provide the best possible data accuracy and precision within the limitations of resources available to implement those procedures.

(2) Each project leader develops Quality Assurance/Quality Control (QA/QC) procedures designed to (a) detect sampling and analytical errors, (b) allow for the re-sampling and/or re-analysis of data determined to lie outside of acceptable quality limits, and (c) quantify the quality and limitations of data sets produced from the program.

(3) Each project leader documents sampling, analysis, and QA/QC procedures utilized in their portion of the monitoring program. GRSM integrates the information into a protocols document which is peer-reviewed and submitted to the NPS I&M program for publication (see IX. Reports and Publications).

(4) Data submissions to the Natural Resource Database (NRDB) by the project leaders include not only the quality checked monitoring data but also information on the quality of the data. Precision and accuracy data are either incorporated as a part of the monitoring data set or provided as a separate data set. With each data submission, project leaders provide the Data Management Coordinator (DMC) with (a) a narrative statement on the overall quality of the monitoring data set and (b) a description of the QA/QC data that are included with the data set.

(5) When data are requested from the NRDB, the DMC will provide the monitoring data, the QA/QC data, and any narrative statements on data quality associated with each data set.

(6) Non-technical and technical reports that are produced by participants and collaborators in the monitoring program (see IX. Reports and Publications) will include summary statements on the quality of data being discussed in the reports. Where appropriate, data quality statements will also be incorporated into writings produced for publication in management and scientific journals.

VIII. 5-YEAR IMPLEMENTATION STRATEGY

The three tables in this section outline the long-term monitoring program strategy for GRSM through FY97 (Table 3 is for FY93 only but will be annually updated for current year). Included by fiscal year is a monitoring schedule for the various components (projects) in the program and for funding utilized in the program. All funding is expressed in FY93 dollar value. No allowance is made for inflation through the life of this 5-year strategy. Although significant FTE is consumed by the program, few permanent positions are being added to the park staff to carry it out. This is because most of the management and supervision is accomplished by existing staff, thus allowing the long-term monitoring program funding to go into component (project) work.

This section of the plan will be revised annually. However, once the program is fully implemented, there should be little change from year to year except for updating funding

TABLE 3. Schedule of Monitoring Component Implementation (FY)

MONITORING COMPONENT	MONITORING IMPLEMENTATION STATUS (FISCAL YEAR)		PROTOCOL PEER REVIEW COMPLETE	SCALE
	PARTIAL	FULL		
Cave Monitoring	92	94	94	Community
Vegetation Monitoring	94	95	94	Community
Exotic Forest Insect and Disease Monitoring	93	94	94	Species
Watershed Aquatic Biota Monitoring	92	94	93	Watershed Community Species
Watershed Hydrology and Nutrient Cycling Monitoring	91	95	94	Watershed
Large Stream Fisheries Monitoring	92	93	93	Community
Large Stream Benthic Macroinvertebrate and Large Stream Water Quality Monitoring	92	94	93	Community Ecosystem
Rare Plant Monitoring	92	92	93	Species
Rare Fish Monitoring	--	93	94	Species
Brook Trout Monitoring	92	93	93	Species
Black Bear Population Monitoring	92	94	93	Species
Cades Cove Deer Population Monitoring	92	93	93	Species

TABLE 4. Projected 5-Year Expenditures by Monitoring Component/Function (in thousands) [1]

MONITORING COMPONENT/FUNCTION	FY93	FY94	FY95	FY96	FY97
Cave Monitoring	$ 0.0 ($ 0.0)	$ 8.0 ($ 2.0)	$ 8.0 ($ 2.0)	$ 8.0 ($ 2.0)	$ 8.0 ($ 2.0)
Vegetation Monitoring	$ 0.0 ($ 0.0)	$ 48.0 ($ 1.0)	$ 48.0 ($ 4.0)	$ 48.0 ($ 4.0)	$ 48.0 ($ 4.0)
Exotic Forest Insect and Disease Monitoring	$ 22.0 ($ 4.0)	$ 21.5 ($ 3.0)	$ 21.5 ($ 3.0)	$ 21.5 ($ 3.0)	$ 21.5 ($ 3.0)
Watershed Aquatic Biota Monitoring	$ 18.0 ($ 6.0)	$ 19.5 ($ 6.0)	$ 19.5 ($ 6.0)	$ 19.5 ($ 6.0)	$ 19.5 ($ 6.0)
Watershed Hydrology and Nutrient Cycling Monitoring	$ 96.6 ($ 34.0)	$113.5 ($ 34.0)	$113.5 ($ 34.0)	$113.5 ($ 34.0)	$113.5 ($ 34.0)
Large Stream Fisheries Monitoring	$ 19.0 ($ 20.0)	$ 18.5 ($ 20.0)	$ 18.5 ($ 20.0)	$ 18.5 ($ 20.0)	$ 18.5 ($ 20.0)
Large Stream Benthic Macroinvertebrate and Large Stream Water Quality Monitoring	$ 38.0 ($ 12.0)	$ 43.0 ($ 12.0)	$ 43.0 ($ 12.0)	$ 43.0 ($ 12.0)	$ 43.0 ($ 12.0)
Rare Plant Monitoring	$ 43.0 ($ 2.0)	$ 41.5 ($ 2.0)	$ 41.5 ($ 2.0)	$ 41.5 ($ 2.0)	$ 41.5 ($ 2.0)
Rare Fish Monitoring	$ 7.0 ($ 3.0)	$ 7.0 ($ 3.0)	$ 7.0 ($ 3.0)	$ 7.0 ($ 3.0)	$ 7.0 ($ 3.0)
Brook Trout Monitoring	$ 33.0 ($ 15.0)	$ 31.5 ($ 15.0)	$ 31.5 ($ 15.0)	$ 31.5 ($ 15.0)	$ 31.5 ($ 15.0)
Black Bear Population Monitoring	$ 31.4 ($ 4.5)	$ 60.0 ($ 4.5)	$ 60.0 ($ 4.5)	$ 60.0 ($ 4.5)	$ 60.0 ($ 4.5)
Cades Cove Deer Population Monitoring	$ 10.0 ($ 4.5)	$ 10.0 ($ 4.5)	$ 10.0 ($ 4.5)	$ 10.0 ($ 4.5)	$ 10.0 ($ 4.5)
Data Management [2]	$ 75.0 ($ 0.0)	$ 75.0 ($ 0.0)	$ 75.0 ($ 0.0)	$ 75.0 ($ 0.0)	$ 75.0 ($ 0.0)
Management and Administration [3]	$ 0.0 ($ 26.3)	$ 0.0 ($ 26.3)	$ 0.0 ($ 26.3)	$ 0.0 ($ 26.3)	$ 0.0 ($ 26.3)
TOTAL COSTS	$393.0 ($131.3)	$497.0 ($133.3)	$497.0 ($136.3)	$497.0 ($136.3)	$497.0 ($136.3)

[1] (a) All figures in FY93 dollar value (no allowance projected for inflation).
(b) Figures in parentheses indicate GRSM/SER funding source.

[2] Data management included, although not considered a monitoring component.

[3] Management and Administration included is at Division level.

TABLE 5. FTE/Other Personal Services by Monitoring Component/Function (FY93)

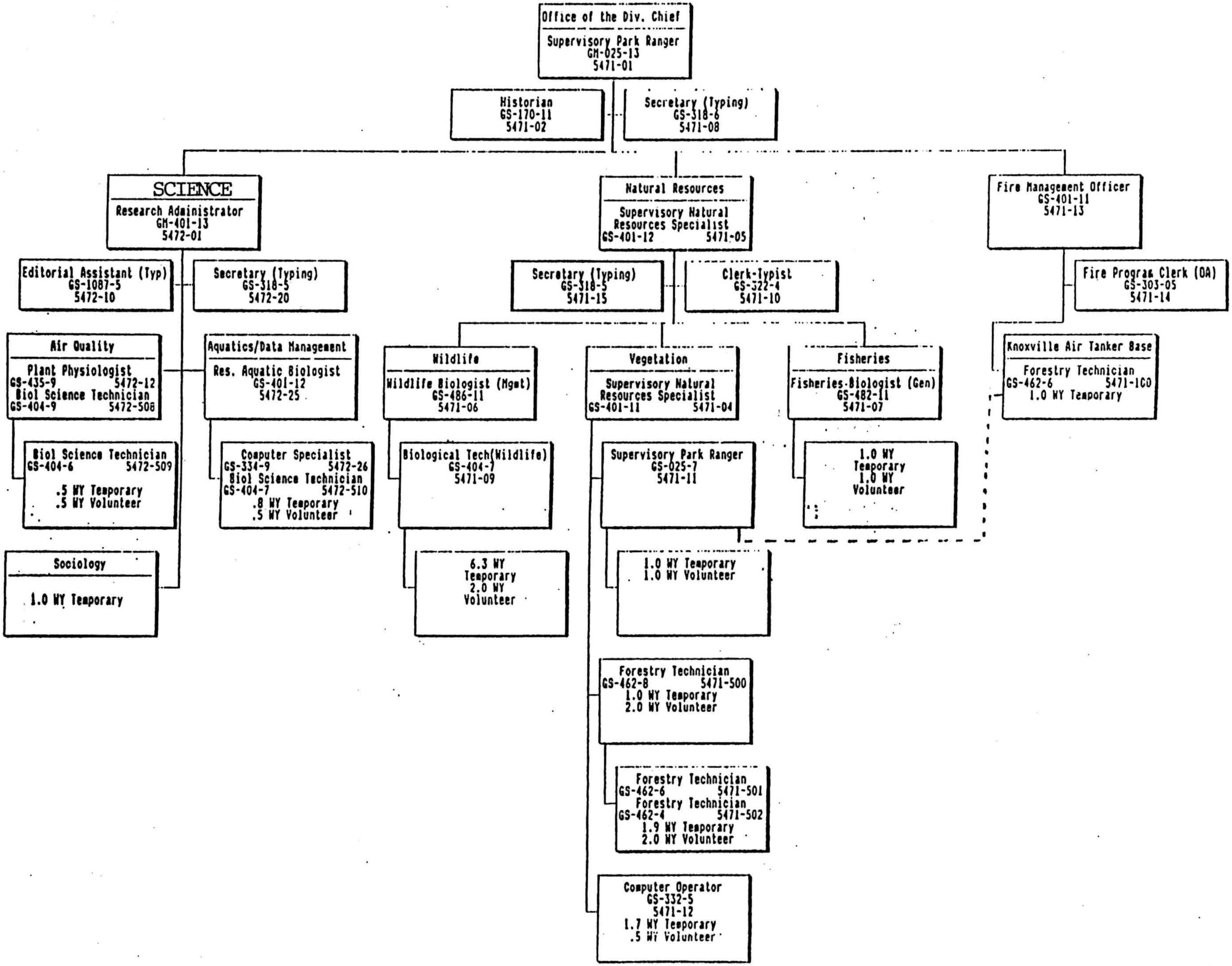
MONITORING COMPONENT	POSITIONS AND FTE UTILIZED		TOTAL NPS FTE
	NPS	OTHER	
Cave Monitoring	None.	None.	0.0
Vegetation Monitoring	None.	None.	0.0
Exotic Forest Insect and Disease Monitoring	.8 FTE GS-6 Forestry Technician	None.	0.8
Watershed Aquatic Biota Monitoring	.3 FTE GS-6 Biological Science Technician .1 FTE GS-12 Biologist	3 mo. Volunteer/SCA Assistant	0.4
Watershed Hydrology and Nutrient Cycling Monitoring	.4 FTS GS-13 Research Ecologist	12 mo. University Research Asst. (Field) 6 mo. University Research Asst. (Lab) 24 mo. University Senior Res. Tech. (2)	0.4
Large Stream Fisheries Monitoring	.4 FTE GS-4 Biological Science Technician	3 mo. SCA Assistant 3 mo. collaborator	0.4
Large Stream Benthic Macroinvertebrate and Large Stream Water Quality Monitoring	.6 FTE GS-6 Biological Science Technician .1 FTE GS-12 Biologist	6 mo. Volunteer/SCA Assistant	0.7
Rare Plant Monitoring	1.0 FTE GS-7 Biological Science Technician 1.0 FTE GS-5 Biological Science Technician	6 mo. SCA Assistant 3 mo. Volunteer	2.0
Rare Fish Monitoring	None.	9 mo. CPSU cooperative subagreement	0.0
Brook Trout Monitoring	1.0 FTE GS-7 Biological Science Technician	3 mo. SCA Assistant 9 mo. CPSU cooperative subagreement	1.0
Black Bear Population Monitoring	.1 FTE GS-22 Wildlife Biologist .3 FTE GS-8 Biological Science Technician .2 FTE GS-7 Biological Science Technician .4 FTE WG-5 Wildlife Handler	8 mo. SCA Assistant (5) 4 mo. Intern (volunteer) (2)	1.0
Cades Cove Deer Population Monitoring	.1 FTE GS-11 Wildlife Biologist .1 FTE GS-8 Biological Science Technician .1 FTE GS-7 Biological Science Technician .2 FTE WG-5 Wildlife Handler	3 mo. SCA Assistant (2)	0.5

TABLE 5. FTE/Other Personal Services by Monitoring Component/Function (FY93) (cont'd)

MONITORING COMPONENT	POSITIONS AND FTE UTILIZED		TOTAL NPS FTE
	NPS	OTHER	
Data Management	1.0 FTE GS-9 Computer Specialist .5 FTE GS-12 Biologist	None.	1.5
Management and Administration	.1 FTE GM-13 Supv. Park Ranger .1 FTE GS-12 Natural Resource Specialist .1 FTE GS-6 Secretary .4 FTE GS-5 Secretary (2)	6 mo. University Secretary	0.7
GRAND TOTAL FTE UTILIZED IN LONG-TERM MONITORING PROGRAM			9.4

January 1992

TABLE 6 - RESOURCE MANAGEMENT AND SCIENCE DIVISION



Recommended: ____ Chief, Res. Mgmt. & Sci.

Approved: ____

levels as a result of inflation or for actual base funding level changes. Also included is an organization chart for the park Resource Management and Science Division which, along with one scientist from the Cooperative Park Studies Unit at the University of Tennessee, is responsible for carrying out the program.

IX. REPORTS AND PUBLICATIONS

The GRSM long-term monitoring program strives for timely analysis and reporting of findings. The program places strong emphasis on managerial, scientific, and interpretive implications of monitoring results. In addition, the Servicewide program requires certain reports detailing financial and administraive aspects of the park's program. The park's long-term monitoring program coordinator is responsible for coordinating and compiling all reports.

Monitoring Protocols - The park is in the process of developing a handbook of monitoring methods that includes the protocols for each of the components. The protocols are the documentation that gives scientific credibility to the program and thus are of paramount importance. As each protocol is completed and reviewed, it is submitted to the park's long-term monitoring coordinator. When all protocols are finished, they will be published as a handbook of the monitoring methods used in GRSM.

A Mid-Fiscal Year Operations Report will be submitted to the WASO I&M coordinator each April. This 1- to 2-page summary will report on the financial and administrative aspects of the park's program for the ongoing fiscal year. This report may be delivered by electronic mail.

Annual Administrative Reports are submitted to WASO I&M in November of each year. These reports will follow the format of the Annual Investigator Reports.

The park's 5-Year Implementation Strategy will be updated each year and submitted as an appendix to the Annual Administrative Report.

Annual Technical Reports are submitted each November for each funded program component and are compiled by the park long-term monitoring coordinator into a single document. This document serves as a repository of data generated by the long-term monitoring program and is referenced in the Annual Administrative Report. These reports serve to assure the WASO I&M coordinator that the results of the long-term monitoring program are compiled regularly.

In addition to the Annual Technical Reports, each program component manager is encouraged to prepare manuscripts for publication in peer-reviewed journals as the data warrant. Journal types include Park Service-oriented (Park Science), management-oriented (Ecological Applications, Journal of Environmental Management), and academic-oriented (Ecology, Journal of Environmental Quality).

A State of the Park Resources Report is required each spring. This 2-page report will focus on different natural resources each year and is intended for distribution to Congressional and Executive Branch leaders as well as for use by park, regional, and WASO Park Service personnel.

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