

Dellinger

Dark Copy
DO NOT
REMOVE

TO HAR
TO HAR
TO HAR



Southeast Region

The Southeast Region (SER) of the National Park Service (NPS) is the central administrative office for park units in eight states: Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Kentucky and two United States territories, Puerto Rico and the Virgin Islands. The diversity of parks and their resources is reflected in their designations as national parks, seashores, historic parks, recreation areas, military parks and rivers. The Office of Natural Resource Management and Science, Southeast Regional Office (SERO), administers scientific research, monitoring and consultation efforts in these parks and territories, involving a wide range of biological, physical and social sciences. SERO is the established in-house medium for distributing scientific information to park superintendents, resource management specialists and other National Park Service Personnel in the parks.

The NPS disseminates the results of biological, physical, and social science through the SER Natural Resources Technical Report Series. This series supersedes the previous SER Research/Resources Management Report Series but retains a consecutive numbering system. Natural resources inventories and monitoring activities, scientific literature reviews, bibliographies, and proceedings of technical workshops and conferences are also disseminated through this series. Documents in this series usually contain information of preliminary nature and are prepared primarily for internal use within the National Park Service. This information is not intended for use in open literature. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the National Park Service.

Copies of this report are available from the following. To order from the National Park Service, Technical Information Center, use the reference number on the bottom of the report's last page.

**National Technical Information Service
(NTIS)
5285 Port Royal Road
Springfield, VA 22161**

**National Park Service
Technical Information Center
Denver Service Center
P.O. Box 25287
Denver, CO 80225-0287**



LTERM:

LONG-TERM MONITORING AND RESEARCH
IN GREAT SMOKY MOUNTAINS NATIONAL PARK
Technical Report NPS/SERGRSM/NRTR-93/10

VEGETATION MONITORING
AND
AN ASSESSMENT OF PAST STUDIES

A Report in Partial Fulfillment of
Amendment No. 1 to Subagreement No. 8
Cooperative Agreement CA-5000-3-8025

Peter S. White

and

Richard T. Busing

North Carolina Botanical Garden
and
Department of Biology
University of North Carolina at Chapel Hill
Chapel Hill, NC 27599-3280

May 24, 1993

INTRODUCTION

The vegetation of Great Smoky Mountains National Park has attracted much research interest, both within and outside the National Park Service (White, 1987). This activity has also generated data sets that are useful to future understanding of the park's vegetation and for assessing the changes that are taking place in it. This past work has also provided some lessons about how to design future studies. This report both reviews past work and outlines a program for future research.

Given the regional setting (e.g., the presence of several Universities, Oak Ridge National Laboratory, the Tennessee Valley Authority, Coweeta Hydrologic Laboratory, several National Forests, Highland Biological Laboratory, Blue Ridge Parkway, and the Southern Appalachian Man and the Biosphere program), the national importance of park resources, and the critical research questions in such arenas as air quality impacts and climate change, the park has a great potential for attracting both future research and outside funding. However, vegetation monitoring is so important as a central agency need that the basic elements of this work (for example, integration with GIS and remote sensing projects, data management, and site selection and maintenance) should be done by the National Park Service itself. This will also allow the park to play a role in channeling outside interests to park needs and in integrating diverse studies to produce greater overall understanding of park resources.

Monitoring is currently carried out by park scientists, outside scientists, and resource managers. A key mechanism for tracking such work is the research activity permit system by which all workers must request permission for studies within the park and must make annual investigator reports (see White 1987 for an assessment of plant ecology related research 1972-1987). This system can be used to get maximum benefit from, attract, and even help guide outside research interest.

This report is organized into three major sections. Section I discusses the general purposes for long-term vegetation monitoring in Great Smoky Mountains National Park. This section will amplify our earlier contribution on vegetation monitoring under this Cooperative Agreement. Section II develops our ideas on the design of permanent vegetation plot monitoring for the park. Section III reviews past studies that provide useful data for future vegetation monitoring projects. An assessment of past data sets is a critical data management issue for the park (see also Peine et al., 1985). We therefore set out to document those past studies. Section III also provides an index to and data documentation for permanent vegetation plots established by scientists at Uplands Field Research Laboratory. An earlier report under the terms of this project (Busing and White, 1991) presented a detailed report on the establishment of three large permanent plots in an old-growth watershed. We will draw on that work in Sections I, II, and III.

Because of the need to address immediate issues and acute changes, species- and threat-specific monitoring will always be a key need in the park. However, the disadvantage of such work is that it is not the best approach for generating basic understanding of park ecosystems or of integrating monitoring across disciplines (e.g., with aquatic systems, water quality, and animal population studies). The design of such projects is usually closely tailored to the problem at hand and the protocols may not be useful for long-term monitoring because the community and ecosystem are not assessed *per se*. Further, in cases where the target species is or becomes ecologically unimportant after its decline (and the species-specific threat therefore becomes less of an agent of direct change in the system), such projects may not lead to long-term monitoring or enhanced understanding of park resources as more generally considered. For example, a

project targeted specifically at American chestnut trees and detection of the blight organism in the 1930s that did not include the permanent plot-based ecosystem-oriented approach advocated here would not be useful for assessing the great changes that took place in park vegetation as a whole (although such a project would certainly have documented changes to the chestnut population and allow us to better assess the significance of the remnant gene pool and levels of blight that now exists in the park).

This report outlines a plan for the long-term monitoring of the vegetation of Great Smoky Mountains National Park from the community or ecosystem (in the sense of ecosystem structure and dynamics) perspective. Some protocols for monitoring of particular species (e.g., endangered plant populations) or specific and acute threats (e.g., dogwood anthracnose, butternut canker, and ozone injury) have been developed separately within the park (Table I-1) and will not be discussed here. Rather, our focus is the park's vegetation cover defined by its composition, structure, dynamics, and environmental relations, rather than by species- or threat-specific issues. We believe that the park needs a basic vegetation monitoring program, although, in the short-term, there is always a danger that such a project will be outcompeted, when funds are inadequate, by projects focused on acute threats. A basic vegetation monitoring program should, of course, include the collection of data that are useful in the evaluation of specific threats. It would also be desirable to design projects focused on acute threats in a way that would contribute to basic understanding of community composition, structure, and dynamics.

SECTION I

PURPOSES FOR LONG-TERM VEGETATION MONITORING IN GREAT SMOKY MOUNTAINS NATIONAL PARK

Long-term monitoring, ecosystem dynamics, and the NPS mission

The mission of the National Park Service, as determined by the 1916 Organic Act, is to manage the national parks so that the natural resources they contain will survive 'unimpaired' and thus be available for the enjoyment of future generations as part of the nation's natural heritage. To determine whether resources are surviving implies the ability to detect change; in this sense, monitoring is essential to the basic agency mission.

There is another fundamental reason for monitoring in the national parks: change, both human-caused and natural continues even after legal protection of ecosystems within park boundaries. The founders of the National Park system may have assumed that park resources would survive as long as they were protected from direct exploitation within park boundaries (at least as long as visitor impacts were not allowed to degrade them). However, it is now clear that a variety of threats persist in parks or permeate them from outside their boundaries (White and Bratton 1980). These threats include exotic species invasions and changes to air and water quality. Further, human influence before the park was created sometimes causes successional changes that continue after the park has become established. Common examples are pre-park grazing, farming, and logging, losses of large animals (e.g., in Great Smoky Mountains National Park, the mountain lion, woodland bison, elk, and wolf), increased populations of native grazers (e.g., white tailed deer) and changes in fire or flooding regime. Monitoring allows the development of an understanding of these changes, can be used to evaluate the significance of the changes, and can help trigger studies that sort out natural and human sources of change. The parks can then better defend themselves against human influence and can undertake mitigation of undesirable change.

Natural dynamics, heterogeneity, and scale

Even without human sources of change, however, it is clear that nature is not a static object. Natural dynamic processes are present even in undisturbed, pristine wilderness areas, if only because of the processes of individual birth and death. When the individuals are large trees within a forest stand, population turn-over causes dramatic local patchwise change. The age and size of the dominant trees in each patch determine how that patch changes over time--for example, the expected values of such parameters as growth rates, probability of windfall or fire, and, importantly, response to human influences such as air pollution. Where some large, synchronizing natural process occurs (e.g., large fires), these patches can be quite large. Whether in large (many tree) or small (few tree) patches, local heterogeneity can be expected in vegetation composition, structure, and response to the overlay of human influence. For example, growth and death rates of trees will vary with tree size and age and patch conditions, as well as with such influences as air pollution.

Given the fact that parks can only protect a portion of the original wilderness landscape, 'scale effects' can be important in conservation management even if no other human influences are present. If a landscape is much larger than the typical size of the

individual patches in natural dynamics, differences among the patches may average out over these larger areas. This is the 'shifting mosaic' view: for example, the places that burn in a particular year shift across a landscape from one year to another, but the total amount of burned land per year may be constant. An overall landscape equilibrium made up of separately dynamic patches would only hold if the disturbance regime is constant.

For biomass stability, Shugart (1984) has suggested that a landscape needed to be at least 50 times larger than the characteristic patch size. Thus, while local change is an intrinsic part of nature, some parameters (biomass, leaf area, density, species composition) can be in equilibrium if the scale of the preserved land is large relative to patch size. The important lesson to be learned, however, is that heterogeneity in structure and function is likely to be important.

The concept of 'unimpaired' natural resources, then, can be and has been applied to these larger scales: we can be less concerned about natural change within a part of a landscape if the natural process that causes that change also produces stability at larger scales. Thus, 'unimpaired' can include much local change produced by natural processes that are intrinsic to the function of a natural landscape and determine stasis at other scales. The size of a park or an ecosystem within a park relative to natural processes is critical.

If a park is not large enough to contain all of the relevant natural processes to the survival of its resources (e.g., not large enough to contain its water sources, sources of ignition for natural fire, or seasonal ranges of native animals), managers will always be dealing with resources that are subject to change because of events outside the boundary. This is one kind of 'scale effect'. In addition, if a park is small relative to the patch size of a dominant natural disturbance, then the natural process itself may cause disequilibrium (net trajectories of resources in a particular direction) within the park. An example is fire: if natural fire size is larger than the preserve, then the entire preserve will potentially be in a single successional state. Species not tolerant of that state will be driven to extirpation by a natural process because of scale effects. We raise these issues because they suggest that monitoring is important even in areas dominated by natural processes because we will still be attempting to understand change and to assess the way that human-generated changes interact with natural ones.

In sum, monitoring provides the ability to detect change in vegetation, allows a first assessment of the significance of human and natural sources of change, and builds understanding of the dynamics and natural processes that are intrinsic to nature itself. Understanding natural change and patchiness is a key to building understanding of human-influenced change. Natural systems are likely to have considerable spatial heterogeneity. We must understand natural variation and change in order to understand human influence and predict future change. We must establish the trajectory of change. Some monitoring will be designed around issues of local interest; because the national parks represent some of the finest surviving examples of pre-settlement North American landscapes, monitoring will also address issues of interest at a national (e.g., air pollution effects) or global (e.g., climate change) level.

The importance of vegetation monitoring in Great Smoky Mountains National Park

Unique resources. The vegetation of Great Smoky Mountains National Park is central to resource management issues, possesses international renown in the scientific and conservation communities, and is a key element in visitor appreciation and education. Among the distinctive features of Great Smoky Mountains National Park vegetation are

its high diversity, complex pattern, large area of old-growth forest, and major vegetation ecotones. The diversity of vascular plants is the highest of all US 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 by ecologist R. H. Whittaker 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, a major marker of paleo- and contemporary climatic change. 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-third of the park was never subject to direct human disturbance and within this area are some of the largest blocks of old-growth forests remaining in the southeastern United States, including stands in which trees surpass 2 m dbh. The vegetation cover of the Smokies landscape is of obvious importance to visitors.

Monitoring terrestrial vegetation in Great Smoky Mountains National Park 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 influences aquatic ecosystems. Ideally, vegetation monitoring will be integrated with studies of the animal populations, ecosystem process (nutrient flow), and aquatic systems.

While the prevailing forest types and those that are most diverse are dominated by broad-leaved deciduous trees, the park also possesses the largest area of old-growth high elevation spruce-fir forest in the southern Appalachians and the largest area of virgin red spruce forest anywhere on earth. Further, the ecotone between deciduous forest and spruce-fir forest is a critical ecosystem boundary, representative of the continental transition from temperate to boreal forest in Canada. Also prominent is the transition at mid-elevations from tall and shady cove forests on moist sites to low stature and open-crowned pine-oak forests on dry sites, an ecotone that is sensitive to changes in temperature, moisture, and fire regime.

Sources of vegetation change in the Park. Although the forests of Great Smoky Mountains National Park 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, and exotic diseases like dogwood anthracnose and butternut canker are examples of more recently identified vegetation changes. The gypsy moth, another exotic species, is expected to invade the park within the coming decades. Air pollution is suspected to be influencing soil chemistry and growth in red spruce, although levels of mortality have not yet approached those that the northern populations experienced in the 1960s and 1970s.

Past human history influences park ecosystems in watersheds that were logged or farmed. For example, the most severely damaged watersheds have a much higher cover of heath balds than old-growth watersheds, probably due to logging fires and severe soil erosion. Some logged areas also seem to be the sites of grape vine dominance (grape is a native species but may be slowing succession in these areas). Where disturbance was less drastic, successional change is proceeding more rapidly. While succession is generally seen as a beneficial change, the invasion of grassy balds by woody plants, taking place since the 1930s with the removal of grazing animals when the park was created, has been considered undesirable, at least on some sites.

Changing fire regime is also a concern in the park. Research has shown a decrease in fire frequency since park establishment, but it is unclear whether the pre-park fire regime was artificially high due to the influence of people. The decrease in fire frequency has meant that pine dominated forests are on a net trajectory towards oak-dominated forests. As the established hardwoods grow into fire resistance size classes, the effect of a fire of a given intensity will change. Regardless of the cause of the change in fire regime, vegetation change is occurring in these ecosystems.

A contributing factor in mature pine stands is the influence of the native insect, the southern pine beetle. This insect periodically causes large waves of mortality and thus, if no subsequent fire occurs, can hasten succession to oak forest. If a hot fire occurs, however, the burning of the organic litter layer of forest soils on dry sites allows regeneration of pine forest.

If climatic warming occurs, all forests of the Smokies will be affected to some degree simply because site environment is so important in determining vegetation composition, structure, and growth rates. Further, climate change has the potential to influence natural processes (e.g., fire regime) and the outbreak of native insects (e.g., the southern pine beetle). The complex topography and diverse ecosystems of the park lend themselves to the opportunity to establish gradients in site environment (e.g., elevation, slope aspect, and slope shape) and to monitor response to change in temperature and moisture.

The Resources Management Plan. The resource management issues of highest concern in the park (White 1987) are ones that often involve substantial potential for vegetation change: air pollution and climate change; rare species populations; exotic species invasions; fire management; and locally large deer populations. Monitoring data can provide a key defense against continued encroachment on the park's air quality. Further, many of the other resource management issues are dependent on an assessment of the degree of vegetation change. More specifically, this vegetation monitoring program can 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 insect balsam woolly adelgid.

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

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

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

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.

The need for vegetation monitoring is contained in a number of resource management issues (White 1987). Vegetation monitoring is described in a recent version of the Resource Management Plan in project GRSM-N-151 (Establish Long-term Ecosystem Monitoring). This monitoring is also required under GRSM-N-99 (Continue Protection of Fraser fir), -105 (Determine High Elevation Beech Decline), -144 (Establish Remote Watershed Monitoring), and -154 (Impacts of Gypsy Moth on Old-growth Forests). The work proposed here will develop information that will aid in the resolution of other issues described in the Resources Management Plan, such as fire management and air quality impacts (see also Table I-1).

Summary

In sum, the forests of the park have changed in the past and will change in the foreseeable future. This will include alterations in composition, structure, growth, mortality, and disturbance regime. The basic purpose of a vegetation monitoring plan is to allow a structured assessment of these changes. Long-term monitoring is important to park management, the park represents a unique landscape within the National Park system, and the diverse natural resources and environments of the park present an opportunity for addressing important questions. Vegetation monitoring can and should be integrated with other monitoring studies aimed at understanding ecosystem processes, animal populations, and aquatic systems.

Table I-1. Special vegetation monitoring projects in Great Smoky Mountains National Park. Ongoing projects in both Resource Management and Science have addressed these situations.

Special Vegetation Monitoring Projects

Airborne pollutants--Accumulator species--lichens
Airborne pollutants--Ozone injury to plants
Endangered species--Threatened, endangered, endemic, and rare plants
Exotic species impacts--Balsam woolly adelgid spraying program
Exotic species impacts--Butternut canker
Exotic species impacts--Dogwood anthracnose
Exotic species impacts--Gypsy moth invasion
Exotic species impacts--Exotic plant control
Exotic species impacts--Wild hog rooting damage
Fire--Fire incidence reports
Hazard tree assessments
Plant gathering--Ginseng
Plant gathering--Illegal poaching
Plant gathering--Wild ramps
Succession--Grassy balds management
Visitor impacts
Wildlife populations--Mast crop size

SECTION II

STRUCTURE AND DESIGN FOR PERMANENT VEGETATION PLOTS IN GREAT SMOKY MOUNTAINS NATIONAL PARK

An overview of vegetation monitoring in Great Smoky Mountains National Park

One of us (P. White) has been involved in vegetation studies in the park since 1978. The other (R. Busing) has reestablished a number of permanent sample plots (see Section III of this report). Together we have designed and tested the sampling methodology that we will describe below (see also Busing and White, 1991). In this section we will briefly describe some past vegetation monitoring in the park (Section III presents greater detail on these subjects).

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 the park. Including updates to the 1987 report, there are some 20 separate efforts that have some usefulness in vegetation monitoring; 12 of these allow relocation of specific plots (see section III of this report). Among the most extensive studies are the following:

S. P. Bratton, M. E. Harmon, and P. S. White. Counting 54 plots established in conjunction with hog exclosures, 410 permanent plots were established in western Great Smoky Mountains National Park from 1977-1985. The bulk of the plots were sampled at the western end of the park on the Tennessee side and were 0.1 ha in size.

S. M. Zedaker, N. S. Nicholas, C. C. Eagar, and P. S. White. 66 permanent 0.04 ha plots and 26 permanent transects were established in spruce-fir forest beginning in 1984 with funding from the US Forest Service and the National Acid Precipitation Assessment Program.

Finally, in the summer of 1990, the field methods proposed here were tested in Roaring Fork Watershed, one of the Research Watersheds proposed in this document. Three 1 ha plots and 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 (Busing and White, 1991). This work tested the effect of change in plot size on the sample mean and variance of vegetation data and showed that traditional plot sizes in the eastern United States (0.1 ha) were too small for Great Smoky Mountains National Park old-growth forests; that project recommended a plot size of at least 0.5 ha for estimating biomass and density for these forests and concluded that, in general, minimum plot size would vary across ecosystems because of variation in the size, density, and diversity of canopy trees.

Purposes of general vegetation monitoring in Great Smoky Mountains National Park

The work described here is a general, ecosystem- and landscape-based, vegetation monitoring program. The general objectives of this monitoring program are:

- to describe the rate and trajectory of vegetation change, including change in vegetation structure, composition, and dynamics;
- to assess the impacts of particular threats;
- to assess the response of sensitive resources;
- to assess the condition of unique resources;
- 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 build an understanding of ecosystem processes so that future changes can be better predicted;
- to establish field research sites that will attract additional research studies;
- and
- to promote the park's participation in regional and international monitoring networks.

Monitoring design: general issues

The plan presented here is based on the establishment and remeasurement of permanent plots. The design includes, however, broader spatial scales than the plots themselves, including the integration of field work with remote sensing. We will begin this section with a description of the major, structuring, ideas that are reflected in the monitoring design chosen. We will then describe methods for plot sampling.

Permanent plot focus. Assessing vegetation change can be accomplished with either permanent sample plots or non-permanent samples. The advantages of permanent plots are the investigator's ability to follow the fate of individual stems and directly observe birth, growth, and death rates. This also allows a more detailed view of mechanisms of change. This is particularly important in the Smokies vegetation where individuals are long-lived.

The choice for permanent plots does represent a choice for intensive (versus extensive) work: that is, for the same sampling effort in terms of money and time, a greater spatial distance can usually be covered with non-permanent plot sampling. This is because permanent plots must be carefully monumented and surveyed; in addition, with time spent on the relocatability of these plots, there is an added incentive to increase the detail and quality control for the vegetation measurements. Extensive, non-permanent plot surveys have the disadvantage of less resolution in terms of natural processes and mechanisms of change. Intensive plots provide a great deal of information about a relatively small loca-

tion in the landscape. It is therefore essential that the plot locations are optimized and that the plots be used in conjunction with more spatially extensive assessments (e.g., remote sensing and survey transects--we will return to these subjects below, but this report does not describe these projects in detail).

Another disadvantage of permanent plots is that the findings at some time in the future are dependent on the state of the plot in the past--the two samples are not independent in a statistical sense. This disadvantage is, in fact, brought about by the very advantages noted earlier--the ability to follow the fate of individuals. We discuss this point because it does have the consequence that the value of the data from permanent plots is dependent on the way these plots were initially established. Clear criteria for site selection, randomization at some point in the process, and replication are essential.

An example will illustrate the potential problems with plot location. When samples are placed subjectively, they are often placed in 'homogeneous' stands of older trees without recent disturbances like treefalls. Essentially, this means that plots may have a higher mean basal area, higher canopy tree age, and a reduced variance compared to truly random samples in the same area. Relatively small plots (e.g., 0.1 ha in old-growth hardwood stands) placed around large trees give much higher estimates of biomass than random or larger plots (larger plots inevitably include a better average size for the trees sampled). This kind of problem occurred on some of R. H. Whittaker's plots in the Smokies and probably resulted in overestimates for standing crop, biomass, and stored carbon in these forests, numbers that have been much used in the international literature (R. T. Busing, E. E. C. Clebsch, and P. S. White, unpublished data). Plots that are large relative to the patchiness (e.g., 1 ha plots in old-growth hardwood forests) cannot avoid the heterogeneity that is present in stem sizes and ages. The problem could also be avoided by having large numbers of plots; randomization is important in all cases.

Another example of problems with subjective plot locations is that plots put around the oldest trees will have a different expected mortality rate than those in younger patches. Plots put around unhealthy trees (to study the course of a disease, for example) will have much higher mortality rates than random plots (unless, of course, all possible sample trees are unhealthy). Thus, the use of permanent plots requires that replication and randomization be part of the design and that tests be made of the effect of plot size and number. The study by Busing and White (1991) was the first to look explicitly at these issues in the park. We will show how these plots can be embedded in a scheme that supplies a greater spatial context and extent.

Adequate monumenting of plots and careful surveying of directions to the plot from landmarks and points of access is critical. Three lessons emerge from the past use of permanent plots in the park:

(1) A failsafe system of plot markings

Vandalism and animals can affect plot markers. Bears have been observed to knock over stakes and bear and deer hair has been found on stakes. Small mammals have been found to gnaw on PVC stakes. Aluminum tree tags glitter in the sun and attract animal disturbance.

As a consequence of this, the 0.1 ha plots sampled through Uplands Lab in the late 1970s involved eight unique markers on each plot, any one of which would allow relocation of plot boundaries. These included four stakes, each of a different color and each referenced with a tree tag on a nearby tree chosen for its uniqueness in

the stand (see Appendices).

Permanent plot markers must be periodically inspected (e.g., at least every 5-10 years) and replaced when necessary.

Tree tags must be replaced, as well; for example, the bands and nails that fix the tree tags to the trees may allow only 10-20 years of growth. After that there is a danger that the tree tags will be lost.

Plot markings are critical to the relocation of plots; much value and past effort is lost if these are not inspected and replaced (best done in conjunction with resampling the plot).

(2) Careful survey of plot locations from landmarks and points of access

Plots must be surveyed by compass and distance from reference points. All plots should be mapped onto a standard set of USGS 7.5' quadrangle maps. Global positioning systems currently allow relocation only within some 30-50 m. Their accuracy must be more like 3-5 meters before conversion to this system will be desirable.

(3) Data management and archiving

Individual investigators have devised their own systems, often documented only in their own notes, for data management. The park should make a special effort to have a centralized data management system. This should include not only data collected by park staff, but also data collected by others under the Resource Activity Permit system. We encountered several sources of confusion in assembling the index to raw permanent plot data that we report here.

Vegetation properties vary by site and disturbance history. The structure, composition, and dynamics of the park's vegetation varies with site factors, disturbance history, and other factors. Site factors that influence relative warmth and moisture include elevation, slope shape, slope aspect, slope steepness, slope position, and topographic shading. In addition, geology and soil properties vary across sites. Disturbance history often varies with elevation (lower elevation had more agricultural disturbance) and by watershed (some watersheds were heavily disturbed by logging). As a consequence, plot locations must be chosen after stratification to control this variation.

As implied, vegetation change occurs sharply with change in topography--from low to high elevations and from moist coves to dry ridges. This means that natural disturbances and responses to human influence will vary along these gradients (Harmon et al. 1983). For example, climatic warming will be accompanied by shifts of species along topographic gradients. Further, these changes are likely to be non-linear along the gradient--that is, change will be more dramatic on certain portions of the gradient. Because of the expectation of change along gradients, we have established a sampling design in which each permanent plot is also the starting point of transects that establish the gradient context of each plot.

Vegetation properties show geographic variation. The characteristic landscape types and the dominance by certain kinds of vegetation varies geographically in the park. The western part of the park has limestone windows and an average lower elevation than the eastern part of the park. Pine ridges are ubiquitous and closely spaced. By contrast, the

eastern part of the park has an average elevation that is higher and pine forests tend to be more distantly spaced. The spruce-fir forest ends abruptly west of Clingmans Dome, although high enough elevations are found westward still. The north facing Tennessee side of the park appears to have higher dominance by hemlock and rhododendron than the dominantly south facing North Carolina side, with the exception of the Raven Fork watershed. The Raven Fork watershed has the character of a high average elevation and a deeply entrenched creek valley, possibly due to geologic substrate. The distribution of heath balds and understory heath shrub layers seems uneven in neighboring watersheds on remote sensing images.

Some of these differences may be due to difference in environment, while others may be due to past human disturbance or other factors. Whatever the cause, the lesson for vegetation monitoring is that no one watershed in the park is identical to or represents the whole. This suggests the establishment of research watersheds throughout the park.

Vegetation properties show scale dependence. As we have demonstrated in an earlier phase of this project, scale dependence is important in any vegetation monitoring project. Scale dependence is the phenomenon by which vegetation parameters vary with the scale of the sample. Scale can be separated into two components: grain size (the size of the quadrat, plot or pixel--the unit of resolution) and extent (the area over which the samples are arrayed). Change in grain size and change in extent both influence the observed characteristics of the vegetation, ranging from species richness to such vegetation properties as density and basal area.

Data should be collected in a way that promotes comparisons with other studies. We have chosen a plot design in which 10 x 10 m quadrats are treated as modules of a larger plot that can be 20 x 20 m, 20 x 50 m, or larger (including 100 x 100 m in old-growth hemlock-hardwood forests). This design allows easy comparison to the 20 x 50 m Uplands Lab plots (data often collected in 10 x 10 m units as well), the 20 x 50 North Carolina Vegetation Survey Plots (data collected on 10 x 10 m units), and the 20 x 20 m spruce-fir plots sampled under NAPAP (data collected on 10 x 10 m units). Further, the 100 x 100 m plot size is compatible with the basic design of Smithsonian Institute biodiversity plots (the 1 ha plot is treated also as the center of a 500 x 500 m area for animal studies).

How many plots should be established?

The discussion above suggests that variation in site types, disturbance history, and geography should be used to determine the location and number of permanent sample plots. The park is large and heterogeneous; the next question is, then, how many plots should be used to capture the natural variation that is present? Although having more plots is better than having fewer, the sample design also needs to be efficient. We will discuss two solutions. First, we will describe the stratification of sites for sampling; we will then show how to reduce the sampling effort by focusing on certain sites and ecosystems, with spatial context and gradient position supplied by remote sensing and plot transects.

Stratification blocks. Two major gradients, elevation and site moisture class, are essential. Ideally, each of these would be segmented in such a way that the classes were several times narrower than the distribution of dominant species. For example, to model and understand the response of hemlock trees, one would want a minimum of 3-5 classes along the gradient from one of its limits to the other. This implies approximately 10 elevation classes (500 ft; 150 m widths) and five moisture classes (these have been determined subjectively in the past but should now be determined by quantitative algorithms using digital terrain maps), yielding 50 stratification blocks. However, as

elevation increases, the effect of site moisture decreases so that in the upper four elevation classes, the number of site moisture classes could be reduced to three, yielding a total of 42 stratification blocks. Given the need for stratification by disturbance history, geographic coverage, and replication this is still a fairly large number.

There are at least two classes of previous direct human disturbance (not including burning and such indirect effects as chestnut blight): none and disturbed. Human disturbance should be further separated into agriculture and logging. Agricultural impacts include: cleared-not plowed; cleared-plowed; not cleared-grazed (with occasional tree cutting). Some areas had drainage ditches cut. Logging impacts include: clear cut-no fire; clear cut-severe fire; other. Not all of these disturbances occur on all sites and some of them have such limited consequences within the park that they should not be fully entered into the stratification scheme. Since most watersheds were either logged or not and much of the agricultural disturbance occurred at low elevations, two stratification blocks are proposed for the bulk of the park forests: logged and old-growth. Special studies can be added for severe post-logging fires or agricultural impacts on a subset of the sites.

Geographic variation suggests that old-growth and logged watersheds be selected from both the Tennessee and North Carolina sides of the park and from the western end (with its lower average elevations and its importance of fire) to the eastern end. Thus, if we pick three watersheds on each side of the park, one each in the eastern, middle, and western part of the park, we have 6 Research Watersheds. However, because of the abrupt western boundary of spruce-fir forest and because of the distinct nature of Raven Fork watershed, 9 seems more ideal (these names are approximate only and would have to be further refined by GIS analysis): Lower Abrams Creek (Tennessee--fire historically more frequent), Mt. Forge Creek-Gregory Ridge (Tennessee--old-growth), Tremont (Tennessee--logged), Elkmont (Tennessee--logged), Mt. LeConte-Cosby (Tennessee--old-growth), Cataloochee (North Carolina--old-growth and logged), Raven Fork (North Carolina--old-growth), Noland Creek-Deep Creek (North Carolina--old-growth and logged), and Hazel Creek (North Carolina--logged).

At this point we have the potential for 42 sites, 9 watersheds, and, thus, 378 plots, not counting special studies on a subset of the potential sites nor replication (some of the replication would be subsumed within the 9 watersheds). Many of the plots could be based on existing permanent plots (particularly in Abrams Creek, Gregory Ridge, Tremont, and the spruce-fir forest), but our recommendation is for sampling that would improve and extend these plots (i.e., expand the size of the plots and add transects for gradient context), so that the work is still significant. We turn next to the question of how to reduce the number of potential sampling sites to produce a more efficient and focused design.

Focusing the design

It seems unlikely that the park will be able to afford the large number of permanent plots derived above, at least not in the near future. Further, it seems unlikely that watershed-based studies that would integrate research on ecosystem processes and aquatic systems will occur at more than a very few sites. We therefore turn to landscape types, unique resources, and key management questions as devices for subsetting the scheme outlined above. We will outline the situations for vegetation monitoring below:

Old-growth temperate forests. These forests are unique and internationally significant resources. Some sites lacked significant numbers of chestnut trees, have been only lightly disturbed by wild hogs, have not been burned, and have not been invaded by exotic plants.

However, they are threatened by such exotic species as the gypsy moth and the hemlock adelgid and some species are sensitive to air pollutants. Old-growth oak forests are unique and vulnerable to gypsy moth invasion. Seven sites (Forge Creek, Mt. LeConte, Greenbrier, Cosby, Cataloochee, Raven Fork area, Deep Creek area) would be sampled, some with multiple plots, for a total of some 50 plots.

Pine, pine beetles, and fire. Fire frequency has decreased during the past 60 years. Mature pine stands are vulnerable to large-scale outbreaks of the native insect, the southern pine beetle. Both through ongoing succession and after the pine beetle, pine stands are on a net trajectory to oak dominance. Some lightning fires (as well as some arson fires) have been hot enough to regenerate pines. Some oak stands on somewhat moister sites than the stands of current pine dominance may be vulnerable to the gypsy moth. Some species in these systems are sensitive to air pollution. Pine stands are more frequent and closer together in the western end of the park (Tennessee side) and more isolated eastward. The western end of the park has been well-covered by existing permanent plots. Ten sites in the western end and ten additional sites in the middle and eastern ends of the park would be sampled for a total of 30 sites with plot clusters.

Spruce-fir forests. A set of 66 permanent plots was established under the NAPAP Spruce-fir Cooperative (Section III). These forests receive high pollutant deposition and contain many rare species. An ecosystem monitoring site has been established within these forests; the park should continue to document changes in these forests, although the nature of the initial plot design is an important question. A minimum of 20 existing plots would be chosen for expansion.

Northern hardwood forests. Beech gaps are a unique community type within the park. Beech gaps and other high elevation hardwood stands have been severely impacted by wild hogs in the past. An existing exclosure system (see Section III) and previous data collection are assets. Some beech stands appear to be in decline (P. White and Keith Langdon, personal observations). Some 10 sites would be chosen from the full distribution of these forests, with some 30 plots established.

This scheme suggests roughly 70 sites (equivalent to Landscape Reference Areas below) and 200 permanent plots. The value of these plots can be increased through two innovations. We developed a method to incorporate spatial and gradient context around the focal permanent plot. Spatial context is provided by remote sensing, with gradient context supplied by the nature of the field sampling itself. This recommendation does not preclude the establishment of plots for other threat- or hypothesis-specific reasons.

Methods

The design elements discussed above have been incorporated in the vegetation monitoring methods presented below. It is suggested that permanent plots be located in larger areas called Landscape Reference Areas and these be located within Research Watersheds. Permanent plots are embedded along transect lines that give a gradient context to detecting change and employ nested grain sizes to allow assessment of scale dependence. All sampling employs a base unit of 10 x 10 m to allow easy comparison to similar studies. Basic selection of the permanent plot sites is stratified-random, where stratification is accomplished by major site features, as described above. Ideally, three replicates per stratification block per Research Watershed would be established.

Research watersheds. Research watersheds should be picked to represent the geographical variation within the park and, where possible, because of the potential for

overlap with studies of animal populations, aquatic systems, or issues of particular management concern.

Landscape Reference Areas. Within each Research Watershed, Landscape Reference Areas, each at least 1 km x 1 km, will be identified. These will include the sites for permanent plot establishment and will be randomly located within stratification cells. Available aerial imagery and other remote sensing data will be used to map ecosystem types and determine canopy tree mortality (e.g., due to such acute effects as the southern pine beetle, balsam woolly adelgid, fire, and other disturbances). These areas will be mapped, retrospectively, at as close to a decade interval as possible. The areas will be remapped as new imagery becomes available every 10 years, except when acute threats and rapid changes require remapping on a 1-5 year time frame.

Biological Diversity Reference Areas. Full 1 ha biodiversity (presence-absence) plots within the Landscape Reference Areas are proposed. These can be expanded to large grids sizes as needed by other researchers (e.g., studying bird populations), as in the 500 m x 500 m (25 ha) design of the Smithsonian Institution Biodiversity Program, refined in a joint Smithsonian-Great Smoky Mountains National Park workshop in 1989.

Species number is always an artifact of quadrat size (sample grain) if only a single size is used. We propose nested plot sizes in order to model the relationship between species richness and grain size, rather than relying on species number at an arbitrary grain size. Our plot clusters, transects, and replication will also allow us to examine the dependence of species richness on the other aspect of scale, spatial extent (distance between samples).

Permanent plots, plot clusters, and transects. Permanent plots are proposed in the major ecosystem types within the Landscape Reference Areas. These will be based around existing permanent plots where possible. Within the ecosystem types, a central plot will serve as the focal plot; each of the four sides of this plot (each 90 degrees from the preceding side) will be extended 200 m (or more where special problems such as change along the spruce-fir-hardwood ecotone exist) into the surrounding topography to create a plot cluster--that is, a focal plot sampled in the context of local gradients. Eight satellite plots (every 100 m on each line emanating from the focal plot) will be sampled along these transects. Where possible, plots will be located in areas that have trail access (e.g., trails within 1 km).

The proposed permanent plots will vary from 0.01 ha (small habitats such as seepage areas) to 0.04 ha (some special habitats such as rock outcrops and wetlands; high density forests) to 0.1 ha (intermediate density forests) to 1 ha (old-growth forests). Regardless of overall plot size, all data will be collected on subplots of 10 x 10 m within the permanent plot to provide a common scale (grain size) of resolution.

Plots will be slope corrected. A basic description of each plot will characterize topography, canopy height, geology, and past disturbance. All data below will be recorded by species. All data will be collected at the same time or phenologic stage from one year to the next during monitoring.

Data to be collected in the plots is outlined in Table II-1. Remeasurement schedules are outlined in Table II-2.

Past data sets have been assessed for future usefulness in Section III. It is expected that permanent plots from these past efforts will be evaluated for incorporation into the scheme proposed here.

Table II-1. An outline of data to be collected in permanent plots.

Data to be Collected in Permanent Plots

Trees > 2 cm dbh: mapped to the nearest 0.5 m; dbh recorded to nearest mm at a fixed distance from a tree tag. Condition, height, and crown height recorded.

Trees 1-2 cm dbh: within 10 x 10 m modules, diameter recorded to the nearest mm.

Trees < 1 cm dbh and > 1 m tall: Density in up to two (one in plots ≥ 0.1 ha; two in plots < 0.1 ha) 2 x 2 m subplots within each 10 x 10 m module; substrate recorded.

Trees < 1 m tall (seedlings): Density in up to five (two in plots ≥ 0.1 ha; five in plots < 0.1 ha) 1 x 1 m subplots within each 10 x 10 m module; substrate recorded; first year germinals distinguished from older seedlings.

Shrubs and woody vines: Cover on up to two (one in plots ≥ 0.1 ha; two in plots < 0.1 ha) 2 x 2 m subplots within each 10 x 10 m module.

Herbs: Cover on up to five (two in plots ≥ 0.1 ha; five in plots < 0.1 ha) 1 x 1 m subplots within each 10 x 10 m module.

Summed bryophyte and lichens: Cover on up to five (two in plots ≥ 0.1 ha; five in plots < 0.1 ha) 1 x 1 m subplots within each 10 x 10 m module.

Substrate types: Cover on up to five (two in plots ≥ 0.1 ha; five in plots < 0.1 ha) 1 x 1 m subplots within each 10 x 10 m module.

Standing dead trees > 10 cm dbh: Mapped, dbh to nearest mm, height recorded.

Coarse woody debris: Fallen logs > 10 cm dbh mapped in 10 x 10 m modules.

Gaps (< 20 yr old) and other disturbances: Mapped across plot in 10 x 10 m modules.

Physical features (streams, boulders, rock outcrops): Mapped across plot in 10 x 10 m modules.

Soils: Two pooled samples per plot, one from each of two depths (surface soil just below leaf litter and 30 cm depth) in each of the 10 x 10 m module.

Scale dependence in plant diversity: Floristic Reference Areas of 1 ha will be established around all focal plots regardless of the size of the tree mapped plot. Presence and absence of all vascular plants will be recorded on a nested series of subplots within each 10 x 10 m module (each of these sizes is 10 times the area of the preceding size): 10 x 10 cm; 32 x 32 cm; 1 x 1 m; 3.2 x 3.2 m; and 10 x 10 m. The species richness of larger areas (0.1 ha and 1 ha) will be computed from contiguous 10 x 10 m plots up to full 100 x 100 m plot size (1 ha).

Table II-2. Remeasurement frequency for permanent plots.

Remeasurement frequency:

2/year: Herb layer (spring and summer); germinals and seedlings in cases of acute threats to populations.

1/year: Tree mortality in cases of acute mortality and where symptoms accompanying death are required.

1/5 year: Basic plot remeasurement schedule except in cases of acute mortality and rapid change. Missing plot stakes and tree tags will be replaced.

1/10 years: scale dependence in plant diversity; landscape reference areas remapped.

SECTION III

SUMMARY OF FOREST VEGETATION PLOT STUDIES
IN GREAT SMOKY MOUNTAINS NATIONAL PARK
WITH PARTICULAR REFERENCE TO PERMANENT PLOT STUDIES

An Overview of Forest Plot Studies

Forest vegetation studies in the Great Smoky Mountains involving plot sampling have been carried out since the 1930s. In this section we review these studies with particular reference to studies useful in long-term monitoring of forest vegetation. In this regard, the merits of each set of plots are weighed. The ideal set of long-term monitoring plots would include large (>0.5 ha) plots that are easily relocated. Large plots are advantageous because they allow the distinction between small scale dynamics (<0.1 ha) and large scale dynamics. The latter are particularly important in detecting subtle changes driven by exogenous factors. The ability to relocate plot boundaries is an important consideration as well. In some of the cases discussed below, the best that can be done is to relocate the stands where plots were placed, rather than the individual plots themselves. Tagging of individual trees for future identification and remeasurement, as well as careful monumenting of the stands, is particularly helpful here. In addition, quantitative information on all vegetation strata is desirable. Ultimately, the suitability of a set of plots for long-term monitoring depends on the problem at hand. Some plot sets are restricted to a specific forest type, while others span a range of types. The former may be more appropriate for the study of stand dynamics in a given forest type, and the latter may be more suitable for the study of changes at the landscape level. These distinctions are considered as well in the following assessments.

The most extensive vegetation study was completed in the late 1930s by F. H. Miller. The study was a park-wide survey of vegetation types within the park boundary as it existed at that time. More than 1300 plots were sampled, and a vegetation map was drawn from the data. Unfortunately, the Miller plots were not permanently marked in the field, and for this reason they cannot provide detailed information on vegetation dynamics. Original plot locations were marked on a topographic map of the park and the original plot data, including shrub layer composition, tree layer composition and size-class structure, are on file at Great Smoky Mountains National Park. Although exact plot sites cannot be located in the field, some of the cove forest stands sampled by Miller's crews were sampled again in the mid-1970s by Walker (1978). Walker successfully relocated 21 stands in coves based on elevation, relation to streams and stand characteristics including composition and disturbance history. New, 0.1-ha plots were established at these sites. They were mapped and marked for future reference. The data are on file at Western Carolina University. Because of the difficulty in accurately relocating Miller's stands on remote sites in difficult terrain, the data set as a whole is considered to be of little use in the kind of long-term monitoring advocated here despite the large number of plots.

A variety of other vegetation plot sampling studies have been completed in addition to Miller's survey. However, their areal coverage has not been as broad (Table III-1). The following is a brief discussion of each study, presented in chronological order. Table III-1 provides information on each study including the principal investigators, forest types, plot permanence, the number and size of plots, data collected, and pertinent reports or

publications. Plot permanence in Table III-1 is an indicator of relocatability. Plots that are listed only as "mapped" probably cannot be relocated exactly; however, forest stands (rather than individual plot boundaries within the stands) may be readily relocated, particularly if they are near trails or other landmarks. Plots listed as "marked" have permanent tree tags or stakes at specified plot corners or centers. If these markers can be found, then the plot boundaries can be reestablished accurately. For this reason, directions to each plot from landmarks are very useful. Tagging all trees in a plot is helpful for several reasons. First, plots can be found easily and their boundaries located with confidence. Second, individual trees can be identified for demographic data. Third, diameter measurements can be made in the same place on each tree during resampling. With these and other considerations in mind we rate the usefulness each plot study for long-term monitoring as poor, fair, good or excellent.

In the 1930s, S.A. Cain intensively sampled several forest stands in the Greenbrier area (Little Pigeon River watershed), documenting vascular plant composition. The original data are not available; however, data summaries are found in Cain (1937, 1943). Because many of these sites are along trails and their elevation is specified, the stands can be relocated for resampling (e.g. Busing 1989). The usefulness of the original plot data in long-term monitoring is considered only fair because plots cannot be relocated exactly. See below for a description of R. Busing's reestablishment of permanent plots in Cain's stands.

As part of a comparative study of southern and northern Appalachian spruce-fir forests, Oosting and Billings sampled nine high-elevation stands within Great Smoky Mountains National Park in 1946. Composition and size-class structure of the stands was subsequently published (Oosting and Billings 1951). Saunders (1979) consulted Billings to determine the locations of each stand on topographic maps and sampled the same nine stands in 1975 with 10, 0.01 ha plots per stand. The original data are on file at Duke University. Because the exact plot locations cannot be relocated and because the plots are of relatively small size, the usefulness of these plots in the long-term monitoring of spruce-fir vegetation is considered poor to fair; probably only Saunders can relocate the plot positions.

Two research groups were involved in ecosystem studies in the 1950s and 1960s. Whittaker and Becking established a series of 0.1 ha plots in the Greenbrier area, the Mt. LeConte area, and along the Smokies' crest between Mount Guyot and Clingmans Dome. Data were gathered on stand composition, production and biomass (Whittaker 1966). Several of these plots were relocated in the 1970s in a study of forest compositional dynamics and potential responses to climate change (Becking & Olson 1978). Some new 0.1 ha plots were established by Becking at this time. Becking deposited the 1959-62 and the 1976-77 data from these plots at Great Smoky Mountains National Park. Several of these sites were sampled again in the 1980s by R.L. Graham at Oak Ridge National Laboratory. Directions were recorded and trees were tagged for the set of plots sampled in the 1970s. The plots represent a good data set for long-term monitoring of all vegetation strata in a variety of vegetation types. The only major drawback is the somewhat small size of plots (0.1 ha)--this is of greatest concern in old-growth plots with large trees. The fact that the plots span a wide range of elevations and topographic positions makes them useful in the study of vegetation dynamics on the landscape.

The second ecosystem research team was based at the University of Tennessee. Shanks and Clebsch sought information on forest ecosystem parameters using larger (0.4 ha) plots ca. 1961. Four of these were located in spruce-fir forest between Newfound Gap and Clingmans Dome, a fifth was located in a tulip poplar stand in the Greenbrier area, and a

sixth was located in an old cove forest along Dunn Creek, in what is now known as Albright Grove. Original data from these plots is on file at the University of Tennessee. All but one of these 0.4 ha plots have been relocated and sampled in the past decade (Busing et al. 1988, Busing & Clebsch 1988, Clebsch & Busing 1989). The large size of these plots make them particularly valuable for monitoring long-term stand dynamics in spruce-fir and cove forest. They are considered to be good long-term monitoring plots. The only major drawbacks are the paucity of plots and the lack of information on subordinate vegetation strata.

Oh studied beech gap vegetation with special reference to the maintenance of beech populations at six locations in the park. The stands are located along the Smokies crest between Newfound Gap and Double Springs Gap at elevations ranging from 1500 to 1800 m. Each stand contained 20 quadrats. Raw data on live and dead tree tallies are included in Oh's thesis (Oh 1964). Because of the detailed directions and maps in Oh's thesis, these plots are potentially good references for long-term monitoring of beech gap forests.

One of the most intensive studies of vegetation-site relationships in the park was done by Golden ca. 1970 under the supervision of H.R. DeSelm. Several hundred circular plots were sampled in the Mt. LeConte area across a variety of elevations (690-1980 m), slope aspects and soil types. Vegetation types were classified, gradient analyses were performed, and vegetation-site relationships were described (Golden 1974, 1981). The relocatability of these plots is unknown. Golden (1974) states that plot locations were drawn on USGS 7.5' quadrangle maps; however, the maps are not filed with the original data at the University of Tennessee (H.R. DeSelm, personal communication). Even if stand locations could be determined, the usefulness of these plots would be fair. The plots are widely distributed across the landscape, but the small size limits their usefulness in detecting subtle vegetation change resulting from exogenous factors.

A study of the ecotone between spruce-fir and hardwood forests at the southwestern end of the spruce-fir zone in the Smokies was also supervised by H.R. DeSelm in the early 1970s. In an attempt to determine why spruce-fir forests do not extend further west on peaks that are high enough to harbor such vegetation, the composition and size-class structure of stands at this ecotone was determined with a series of circular plots. D.C. West collected the field data. They were analyzed but not documented in the form of a report or publication. The plots are generally located between Silers bald and Newfound Gap, subtending the Smokies crest. The location of these plots near a major forest ecotone make them potentially valuable in the study of vegetation dynamics in response to climate change. Relocatability is critical here, however. Plot centers were staked permanently (D.C. West, personal communication) and plot locations were mapped. Approximately half of the plots are near maintained trails. The original data are on file at the University of Tennessee. The usefulness of these plots is considered fair to good. The major drawbacks in this case are the potential difficulties in plot relocation and small plot size.

In 1975, Ramseur established three vegetation plots in extensive open areas adjacent to spruce-fir forest to study the rate of forest invasion. The open areas were grass dominated vegetation at Andrews Bald, Mt. Buckley and Cherry Log Ridge. Invading trees were mapped and site photographs were taken. Photographs, maps and tree data are included in a management report (Ramseur 1976). Detailed directions and tree maps make these plots good references for the study of spruce-fir forest encroachment into grass dominated vegetation.

In the mid 1970s, Runkle placed transects in old cove forests in order to characterize

natural disturbance and forest response. Data on canopy structure were collected along transect lines, while data on canopy composition were collected using the point-centered quarter method along the same transects. The study sites were mid-elevation coves near Dunn Creek, Kalanu Prong and Roaring Fork. Several of these transects were re-sampled in 1983 and in 1990-1991, and they are a good source of information on cove forest canopy dynamics. Publications resulting from this work include Runkle (1981, 1982, 1985) and Runkle and Yetter (1987). The data are on file at Wright State University. Barden (1979, 1980, 1981) conducted similar studies on gap dynamics in cove forests. His sampling sites were not marked for future relocation, however.

Forest response to southern pine beetle infestation was investigated by Kuykendall in the mid 1970s. Circular plots were placed in 49 low to mid-elevation (<1370 m) pine stands subject to high overstory mortality ca. 1970. These stands were located in the middle and western areas of the park, north of the Smokies crest. Composition of recovering stands was related to site conditions (Kuykendall 1978). These plots represent one of the largest sets of information on pine stands in the park. Plot centers were marked, allowing the possibility of relocation. The original plot data are on file at the University of Tennessee. This is a good data set for long-term monitoring of all vegetation strata in pine stands. The only major drawbacks are potentially difficult relocation and small plot size.

By the late 1970s, an attempt to establish a park-wide system of permanent 0.1-ha plots was underway. Several series of plots were established primarily at the west end of the park by researchers associated with Uplands Field Research Lab. Some of the plots were located along elevational and topographic gradients in areas with contrasting disturbance histories. Others were located in areas with sharply contrasting soil types, fire histories, or impacts of interest. Some plots were established in conjunction with an exclosure study of wild hog impacts. The data set represents the largest data base for permanently marked plots within the park. It is potentially valuable information for the study of long-term vegetation dynamics in the Great Smoky Mountains. The usefulness of these plots in long-term monitoring of stand and landscape phenomena is considered good to excellent. Small plot size and the lack of tags on individual trees are the only drawbacks in this set. The Uplands Field Research Lab permanent plots are described in detail below.

In the 1970s and 1980s Fraser fir mortality increased sharply within the park following infestation by the balsam woolly adelgid. Infestation and subsequent mortality spread from the northeastern end of the park, southwestward to the Clingmans Dome area over this period. In order to study and monitor the impacts of the adelgid on fir and its associates, two sets of plots were established. The first set was sampled by Eagar and Johnson in 1976. Fir infestation was studied in stands at Mt. Sterling, Mt. LeConte, and several high peaks along the main Smokies crest from Mt. Guyot to Clingmans Dome. Plot centers were marked, but detailed directions to each plot were not recorded. The small plot size and questionable relocatability make these plots less valuable than some more recent spruce-fir plots. Their usefulness is rated as fair.

A second set of plots was established in spruce-fir forests on Mt. Sterling, Mt. Guyot, Mt. LeConte, Mt. Collins and Clingmans Dome by P.C. Durr in 1990 and 1991. These plots were designed primarily to provide baseline information on the status of Fraser fir and its potential for future survival. The original data are on file at Great Smoky Mountains National Park. These plots are a good to excellent set for long-term monitoring of all vegetation strata in spruce-fir forests. Small plot size is the only major disadvantage here.

An additional set of spruce-fir forest plots was sampled by Eagar and Nicholas in the mid 1980s on sites between Newfound Gap and Clingmans Dome. P.S. White and S. Zedaker were the principal investigators in this forest monitoring project. Data were collected over several years from each plot in order to assess the impact of acid rain and other pollutants on forest health. The condition of red spruce was a major focus of the study. This set of plots continues to serve as a basis for the study of forest response to pollution and other impacts (Nicholas et al. 1992, Nicholas & Zedaker 1992). The original data are on file at Great Smoky Mountains National Park. These plots are a good to excellent reference set for long-term monitoring of all vegetation strata. Again, small plot size is a disadvantage.

In conjunction with the 1980s spruce-fir plots, a series of 26 permanent transects were established in 1986-87 by S. Pilsk and E. Pauley to sample the condition of overstory vegetation in areas above 1520 m elevation. The study, supervised by Eagar and Nicholas, was primarily concerned with the status of red spruce at various elevations. The transects ran downslope from high peaks along the main ridgeline between Old Black and Mt. Buckley, and at Mt. LeConte. They contained ca. 100 Bitterlich variable radius plots. The original data are on file at Great Smoky Mountains National Park. If these plots can be relocated successfully, despite rugged terrain and dense underbrush, they would be a good basis for monitoring high-elevation tree-stratum dynamics. Considering the potential difficulties in plot relocation, however, the usefulness of these plots is rated as fair.

In the late 1980s and early 1990s Busing sampled several old-growth cove forests with large (0.6-1.0 ha) permanent plots. All of the plots were designed for long-term forest monitoring. Four of them were 0.6 ha in area and they were placed in stands that had been sampled previously (Busing 1989). These plots, located near Long Branch, Porters Creek and Dunn Creek, are good references for the study stand dynamics in mixed deciduous cove forests. Data on vegetation substrata were not collected at these sites.

The three 1.0 ha plots of White and Busing were located in hemlock-mixed deciduous stands near Roaring Fork. They were accompanied by a series of Bitterlich variable radius plots (26 total) along transect lines emanating from each 1.0 ha intensive plot. These plot clusters serve as a basis for long-term forest monitoring at a range of scales from 0.01 ha to the stand (1.0 ha) and landscape level (> 10 ha). With all trees tagged and mapped in each intensive plot, and detailed directions to surrounding Bitterlich plots (with three trees tagged near plot center), these sites are excellent for long-term monitoring of all vegetation strata. Data for these plots are on file at the University of North Carolina.

Our review treats all of the studies that we are aware of that used permanent, relocatable sample plots. Many other investigators have sampled vegetation in Great Smoky Mountains National Park using non-permanent sample plots (see bibliography by DeYoung et al. 1982 and White 1987). A few of these may have employed plots that were mapped on quadrangle maps or even marked in the field, but we have not been able to verify their status (the original reports are unclear and we have not been able to contact the original investigators). Some of these may prove useful in specific cases. Early plot-based research on spruce-fir forests included work by Cooley (1954), Crandall (1958), and Schofield (1960). We do not believe that these studies have yielded relocatable plots. Spruce-fir forest research in the 1980s by R. Bruck and S. McLaughlin under the NAPAP project were carried out on fixed sites, but the data collected were not community-oriented and fall outside our definition of vegetation permanent plots. Pauley and Clebsch (1990) and Wu (1988) marked sample sites in the field for later resampling, but, again, the data collected and the scope of the studies did not warrant inclusion here. Pine forest research by Zobel (1969), Barden (1974), and DeYoung (1979) involved plot sampling; however, it

is unlikely that these plots can be relocated.

An Index to Uplands Field Research Laboratory Permanent Vegetation Plots: 0.1 ha plots established 1977-1980

A vegetation survey of Great Smoky Mountains National Park was initiated in 1977 under the leadership of S. P. Bratton using permanently marked, 0.1-ha plots (Bratton 1978; see below for a description of individual projects and the Tables and Appendices for identification of study leaders and other information). Including plots from hog enclosure studies, a total of 410 plots were established by various researchers associated with Uplands Field Research Laboratory from 1977 to 1985 (Table III-2 and Appendix 4). The 400 plots established by 1983 were indexed using a BASIC program in that year by P. White (see Appendix 1). The 30 hog enclosure plots listed in Table III-2 and Appendix 1 have now become a data set of 40 active plots (Appendix 4).

For the raw data files, we present data on location, site conditions, vegetation data, and computer file access (Tables 2 & 3, see also Appendix 1). The data formats for the computer files of the raw plot data are given in Appendix 2 and the methods of data collection are outlined in Appendix 3. Of the 400 plots listed in Table III-2 (plots in the hog enclosure project established after 1983 are not included in that Table), 14 have incomplete site data (see also PLTDX.BAS in Appendix 1). These include 8 of the 31 CAMPSITE plots (see below for a description of the separate projects), 2 older hog enclosure plots, and 4 unidentified plots of S. Bratton. These plots are distinguished on the Tables because '0' has been entered for UTM coordinates. The raw data files are located at Uplands Lab and this information could be entered from field data sheets.

S. P. Bratton wrote guidelines for permanent plot establishment in 1977 and revised these in 1978. Bratton (1978) forms the basis of our Appendix 3, which gives basic methods for the permanent plots established through Uplands Lab. However, there were no data management guidelines in the early days of Uplands Field Research Lab; rather, individual researchers organized and analyzed their own data sets. After S. P. Bratton left Uplands Lab for the CPSU at the University of Georgia in 1982, P. White worked with Chris Eagar, Anne Stocum, and Mark MacKenzie, to begin to organize all raw data files, plot maps, and computer files. After P. White left Uplands Lab, Mark MacKenzie completed guidelines on data management and created a SAS data set of the live tree data from 312 of the 0.1 ha plots, with plots listed consecutively by the Section Number-Plot Number designation (MacKenzie, memo to the Uplands files, 5/1/86). This data set is archived at Uplands Lab (as part of MacKenzie's data management files) and is on computer tapes at the University of Tennessee.

Several factors made the organization of these data challenging. First, all data computerization and analysis was carried out with 80 column computer cards when most of the permanent plots were established. The cards were awkward to carry back and forth to the University of Tennessee computing center and were difficult to organize and store (further, storage conditions at Uplands Lab were poor because of humidity). Proofing and correcting data was a multi-step process: card-punching, printing of data, proofing against raw data sheets, and correcting at the card-punch. All of the Uplands 0.1 ha permanent plots were first put in card format. Many of these were later transferred to computer tapes at the University of Tennessee; again, this was usually done by individual investigators in blocks of plots, rather than in raw data files that included all plots. When we completed our analysis this year, we discovered that a few data sets had never been written to the tapes, but remain in card format at Uplands Lab (we will discuss this finding below). Also, data sets completed by three Master's students at the University of Tennessee (E. Arends,

N. S. Nicholas, and R. Callaway) were never added to the Uplands tapes. Obviously, every effort should be made to add the card format files to computer tape files.

Another factor that made the organization of these data sets initially difficult is the fact that the tapes hold not only the raw data sets, but also many files that represent steps in the analysis process. The problem here is that the available programs for this kind of analysis have evolved; thus, most of these files of output data are of marginal value. Researchers are much more likely to repeat the analyses using the raw plot data so that they can verify themselves how the data were used and so they can use more up-to-date programs. Researchers are also likely to want to use new kinds of analyses or tailor the data sets analyzed to particular problems. Although these output files take up much of the tapes themselves, we have not indexed or deciphered the formats of these files for the reasons mentioned.

Our emphasis here is the raw data files for basic characterization of the vegetation. For example, we did not assess the availability of site data (e.g., topography) since that can be readily captured from the USGS quadrangle maps bearing plot locations; in any case, this was usually computerized by individual project leaders during their analyses and is not present on the computer tape files we examined. Further, there were several ancillary studies that went on at the time of the permanent plot establishment which also fell outside our scope. For example, Mark Harmon studied wood decay, fuels, bark thickness, and other topics in conjunction with his study of fire effects (see study abbreviation "WEST" below). Again, we have focused on the basic permanent plot data set that will be valuable in future studies of vegetation change.

Except for the hog enclosure project, we also do not present lists of dates on which the permanent plots were sampled nor do we index data from those resamplings per se (see discussion below on the WEST project). Individual researchers should be contacted to further assess these data when and if the vegetation monitoring project is funded in the park.

Finally, we have not described nor listed here the data analysis programs that accompany the raw vegetation data on the computer tapes. These are documented on various tape indexes at Uplands Lab. Some of the programs are standard Cornell Ecology Programs. Others were written by researchers at Uplands for the particular data formats used in the raw data. With the advent of better and more accessible computer facilities, the park should be able to access the data with the help of our format statements. However, the data tapes should be examined for helpful supplementary information (e.g., the species code list for translating the six-letter species codes to full scientific names).

Plot identifications. A key identifier for the plots, on computer tapes, in the raw data files, and on maps showing the locations of plots, is the Section Number-Plot Number designation. The park was divided into 'Vegetation Survey Sections' (see Appendix 3 for a map of these) and all plots numbered within these sections. The plot numbers are sometimes consecutive and sometimes not (the available, pre-stamped tree tags often determined the availability of plot numbers to the field crews). The plots are listed in Tables 2 and 3 by the Section Number-Plot Number combination. These combinations were intended to be unique; however, there were occasional lapses because teams independently used the same plot number or misnumbered the Section when they were near a section boundary. The index file and program PLTDX.BAS (Appendix 1, see notes within the program listing) and the archival maps at Uplands Lab include clarifications of these occasional problems.

Permutations in data collection. It should be noted that several basic variations in field data collection were used during the four year span during which most of the plots were established; not all of these are described in Appendix 3. The several data file formats that result from these permutations of data collection are documented in Appendix 2. Thus, the file formats in Appendix 2 are critical to data interpretation; these can also be compared with the blank data sheets in Appendix 3 (note that the data sheets and file formats are based on an 80-column computer card). Not all of the data described in Appendix 3 was collected on each plot and not all of the data sheets were ever card punched. Again, our emphasis in this report will be the files that contain raw plot data on vegetation structure and composition.

Basic permutations in the data collection scheme included the following:

- (1) trees mapped by compass angle and distance ("TM" in Appendix 2);
- (2) trees not mapped--recorded in 10 x 20 m subplots ("TU");
- (3) trees not mapped--recorded in 10 x 10 m subplots (upper=above center line or lower=below center line of plot, ("TP");
- (4) shrubs recorded in three diameter classes ("SH"); and
- (5) shrubs recorded by cover only.

Tree mapping and shrub diameter classes were dropped from sampling on some plots to save time and increase the number of plots sampled, given available resources. In particular, shrub diameter classes were difficult to use in areas with dense colonial shrubs (e.g., Vaccinium).

Location of data. Raw data (including data for some plots not on the magnetic tapes--this includes card format data and the field data sheets in manual files) are stored at Uplands Field Research Lab. Original plot location maps, site characterization data sheets (e.g., topographic and disturbance features), directions to the plot, witness trees used, a sketch map of the sampling, and other supportive information (some of it never computerized) is also present in those files. The files are organized consecutively by the Section Number-Plot Number identifier (see below). A photocopy of these files was made under John Peine's tenure as Research Coordinator and these were stored separately from the original data files. All of the original data should be formally archived. Researchers wanting to use the data should check the original field data sheets and may need to contact the original field leaders of the sampling.

As described above, the magnetic tapes contain many secondary files based on the raw data. These represent summarized and analyzed data made by individual researchers. Since analysis and statistical programs change over time, these files are of questionable usefulness. In any case, the analyses were made on subsets (not always identified) of the raw data. The most important part of the data set is clearly the raw plot data; with access to that data (and its formats), researchers can perform new analyses or repeat old ones. We have included in this report documentation for the original, raw data only. Our report represents the first comprehensive data documentation for this valuable data set.

Initial goals of the permanent plot project, 1977-1980. S. Bratton initiated vegetation sampling in 1977 in the western end of the park (most of these plots are on the Tennessee side of the state line--few plots are in North Carolina) for several reasons. Important

management issues were prominent in this part of the park: European wild hogs had occupied this area for more years than eastward in the park; historic fire frequencies were high, particularly immediately around Cades Cove and in Abrams and other creek valleys west of Cades Cove; the deer population was higher in Cades Cove than in any other area in the park; there were several exotic plant species; and a number of rare plant species were known from Cades Cove. The western end of the park also presents areas of contrasting geologies (limestone vs. sandstone) and histories (old-growth, logged, and farmed). The western end of the park was also less well known in terms of vegetation since many researchers were attracted to the higher slopes of the central and eastern part of the park. The permanent plot network that began to form in 1977 in this area was established to address these issues and to cover the range of sites and vegetation present. Plots were established on approximately 400 ft elevation intervals and on a variety of slope positions, slope shapes, and aspects.

The density of plots established in the western part of the park would have resulted in 2,000 or more permanent plots if the same density was sampled throughout the park. This is a large number of plots to maintain (as discussed above, permanent plots should be monitored and plot markings and tree tags replaced). Whether or not such a large network of plots would ever have become an ongoing monitoring project is open to question. In any case, S. Bratton was to leave the park for the University of Georgia in 1981 and the funding and priorities subsequently did not permit monitoring of these plots nor establishment of new plots based on this design. The next substantial effort to establish monitoring plots would come in 1984 with the advent of the spruce-fir-air quality project (see above).

Although never part of a regular resampling schedule, some of these permanent plot sites have been revisited in subsequent studies. R. Callaway collected new data from 154 of the 0.1-ha sites in 1982. M. E. Harmon has continued to sample post-fire plots in the WEST data set. The data included soil samples and tree growth measurements (Callaway 1983). Effects of site variables on forest composition and growth were then analyzed (Callaway et al. 1987, 1989). In a study of fire fuel levels in contrasting forest types, N. S. Nicholas collected additional data from 93 of the 0.1-ha sites in 1982 and 1983. Dead wood volume and organic debris levels were estimated at each site (Nicholas 1984). New sites were visited in 1984-85 making a total of 279 samples. A Bitterlich prism plot was marked and mapped at each of the 186 new sites. Fuel levels were then related to forest type and site variables (Nicholas & White 1984, 1985).

Study descriptions. The abbreviated study titles listed in Table III-2 represent projects that had several different purposes. The general objectives and other pertinent information for each study are summarized chronologically below. References to reports and publications stemming from these studies are also listed. The focus on individual studies, often carried out by one or a few project leaders, is retained here because it is so prominent in the organization of tape data files. However, it should be noted that sometimes one plot was used in more than one study; in addition, our designations on Tables 2 and 3 are not always identical with file names used on the tape copies of the raw data, particularly for the study prefix "CC" (see below). Both our designations below and the tape file names should be considered simply a means of access to the raw data, rather than a definitive title for the plots themselves.

In 1977, permanent plot studies were initiated for plots labelled with the following abbreviations:

- (1) "WEST". This was a study of fire effects in the western Great Smoky Mountains

National Park (Harmon 1980, 1982, 1984). A total of 94 plots were established by M. E. Harmon in the western end of the park (Tennessee side) in conjunction with work at Uplands Lab and a Master's Thesis at the University of Tennessee. Harmon has resampled a number of these plots over the last 15 years. Harmon also established 3 plots in the Cades Cove area.

One of the practices adopted by Harmon was to add a number to the plot number to indicate the year since burn for the recently burned plots. Thus, plot 1-10 (Section Number 1, Plot Number 10) was the condition of the plot before burning (this was reconstructed from standing dead, fallen, and surviving trees), plot 1-110 was the plot the first year it was sampled after the burn, and plot 1-210 was the plot the second year after the burn. Some herb and shrub data were collected up to 5 years after the burn (hence, a plot in the herb data set might carry the designation 1-410--in other words, this is permanent plot 1-10 sampled for herbaceous plants 4 years after the burn). One must be careful not to confuse Harmon's numbering system with a valid plot number (in the example just cited, 1-10, not 1-410 is the correct plot designation used on plot maps and manual data sheet files).

(2) "CC" as a prefix. This was a study of site history, geological influences, and edaphic conditions, and deer browse on vegetation in Cades Cove and other low elevation sites in the western part of the park (a total of 51 plots: Bratton et al. 1980).

Groups of the "CC" plots included: CCACID (Cades Cove, acid soil); CCCOLL (Cades Cove--Colluvium over limestone); CCCONT (Cades Cove controls); CCFLOOD (Cades Cove--seasonally flooded sites); and CCLIME (Cades Cove limestone soils). The computer tape files often group the individual files under different subcategories than used in the plot index, but the CC prefix is used in both approaches. We emphasize the use of the indexes (Tables 2, 3, and 4, Appendix 1) for access to location and raw data for individual plots, rather than particular groupings of the plots.

We have designated call Cades Cove plots with one of these modifiers after the "CC" prefix. However, several cautionary notes must be presented: (a) some plots were used for more than one of these categories (thus, a plot might be used both as a CCFLOOD plot and a CCLIME plot) and (b) some plots from other data sets (e.g., the WEST data set) were used in some of the Cades Cove analyses. Again, researchers using these data should check site conditions, plot maps, and raw data files for particular information required in their work.

The Cades Cove plots were also the nucleus of a project on deer browse impacts. This project also used plots from a variety of other projects described here (see notes in Appendix 1). This introduced two uses of the word 'control' or CCCONT for these plots--the controls for the deer browse study and the 'controls' for the limestone study.

(3) "HOG" as a prefix. This was a study of European wild boar impacts on vegetation (Tables 2 & 3; a total of 30 plots). Appendix 4 gives a fuller treatment to the active set of 40 plots associated with hog exclosures. Investigators on this project were S. Bratton and P. White. L. Renfro and R. Busing also were active in subcontracted data collection.

These studies continued in 1978 and a new study of logged and unlogged vegetation on

ridges south of Cades Cove was initiated by P. White:

- (4) "DAVIS", "LEDBTR", and "GREG". These plots were established in a study of the logged forest plots on Ledbetter and Davis Ridges and their contrast with unlogged plots on Gregory Ridge (together these studies total 117 plots):

In addition, L. Stromberg, an Uplands technician initiated in 1978:

- (5) "CAMPSITE". This was a study of human impacts on vegetation at backcountry campsites (a total of 32 plots) (Bratton et al. 1982). This is one of the data sets that seems to be found only on computer cards at Uplands Lab. We did not find it on the data tapes we assessed at Uplands Lab or the University of Tennessee.

In 1979, several studies on what were termed "Special Protection Areas" (unusual concentrations of rare plants) were initiated by P. White and S. Bratton:

- (6) "BC", "CG", and "WOS". This was a study of three limestone windows, Bull Cave (5 plots), Crib Gap (3 plots), and White Oak Sink (13 plots).

- (7) "ABRAMS". This was a study of Lower Abrams Creek to augment the WEST and CC data sets at the lowest elevations in the park (4 plots).

The computer tape files that contain the plots from the "ABRAMS" study also contain some other low elevation western end plots.

- (8) "LECONTE". This was a study of the summit of Mount LeConte (7 plots) to describe a high-elevation area of Fraser fir forest under attack by the balsam woolly adelgid, an exotic insect, and open habitats with rare plant populations.

The last major study involving the establishment of a series of 0.1 ha plots focused on vegetation in forests dominated by chestnut prior to the blight and were sampled by graduate student Ernesto Arends of the University of Tennessee in 1980:

- (9) "CHSTNUT". This was a study of stands formerly dominated by American chestnut 50 years after the blight (38 plots). Only tree data were collected (Arends 1981).

Of the projects listed above, WEST, CC, DAVIS, LEDBTR, GREG, BC, CG, WOS, and ABRAMS established plots in the western end of the park from near Tremont to the western boundary and almost all on the Tennessee side of the state-line. These studies total 287 of the 400 plots. The CAMPSITE and HOG plots are scattered throughout the park. The CHSTNUT plots are in the central and eastern part of the park.

In the study abbreviation descriptions above, 394 of the 400 plots from Tables 2 and 3 are accounted for. The remaining 6 plots are: CDOME (a plot on Clingmans Dome sampled by C. Eagar), UNKNOWN (3 plots sampled by S. Bratton for which location data could not be found), MAYNCR (a low elevation plot sampled by S. Bratton in 1977 in conjunction with the Cades Cove studies), and 'XXXXXX' (a plot file for a plot 8-35 found at Uplands Lab with no supporting data). Of these we found computer tape data only for MAYNCR. There are manual files of original data sheets for the rest of these plots at Uplands Lab.

Computer data files. Of the 400 plots established by 1983 and listed in Tables 2 and 3,

we found computer tape files of raw data for 291; additional plots have computer files at Uplands Field Research Laboratory (see below). This report documents the location and format of these files. The 291 plots had raw tree data; 81 of these plots lacked tape files of herb stratum data and 1 lacked shrub stratum data (a plot from the WEST study). All of the raw data files are on file at Uplands Fields Research Laboratory.

The LECONTE herb data (7 plots) are stored only on magnetic tapes at the University of Tennessee (these plots were not on tapes we had access to at Uplands Lab). The 74 remaining data sets with computerized tree data but no herb data on the tape files we examined, are in the CC, BC, CG, WOS, and ABRAMS categories. S. Bratton was the study leader for most of these plots. Her work took place during the times when the card format was the only one available, so it is likely that these herb files are stored at Uplands Lab as cards.

Seventy of the 109 plots for which no tape files (including no tree files) were found at Uplands Lab were in two studies: the CAMPSITE plots (32 plots) and the CHSTNUT plots (38 plots). Data sets from these files are stored at Uplands Lab (raw data files are likewise stored there), bringing the total of plots with computerized data to 361. CAMPSITE and CHSTNUT plots date from a time at Uplands Lab and the University of Tennessee when the only computer facilities available used card format data. The studies with prefix "HOG" in the Tables were also not found on the computer tapes we examined. However, the current set of hog enclosure plot data has been computerized and is already stored on diskettes at Uplands Lab (40 plots, including 16 plots established by 1983 and listed in Tables 2 and 3) (see below and Appendix 4). Some of the older hog impact plots (see plots with the 'HOG' prefix in the Tables), no longer maintained in the current enclosure system, also have card format data stored at Uplands Lab. Thus, a total of 401 of the 410 plots has been computerized at Uplands Lab.

This leaves 9 'problem' plots not found on the computer tapes (410 total plots with 401 represented by some computer tape or diskette data at Uplands). These 9 plots occur under the following study codes (see also above): CDOME (1 plot; another problem is that this bears a duplicate Section Number-Plot Number, 4-1, with one of the older hog enclosure plots--however, this is a plot which is no longer active), UNKNOWN (3 plots), XXXXX (1 plot), and CCPAST (4 plots of pasture vegetation in Cades Cove; these were probably not computerized because no trees were present). All of these are represented by raw data files at Uplands Lab (filed by Section Number-Plot Number).

Where data have not been found, an "NA" appears in Table III-3 indicating that a computer file for these data was not available to us.

How to use the plot data index and find plot locations and data

The index includes two tables. Table III-3 is a list of all plots and codes for corresponding raw, computerized data files. Different kinds of data from one plot usually appear in different files (e.g., trees in one file, shrubs in a second, and herbs in a third). The kinds of raw data available in computer tape files are given in Table III-3 with their Section Number-Plot Number code (e.g., plot 1-1 tree data is found in file C1). The actual name, format, and location of the data file is provided in Table III-4 (e.g., C1 is the code for computer file TREE1). File formats are explained in Appendix 2.

Lists of plots by USGS quadrangle can be generated with the PLTDX.BAS program described in Appendix 1. Quadrangle numbers are shown in Appendix 3. PLTDX.BAS also contains helpful comments on the plots (see comments within program listing in

Appendix 1).

After the potential user locates plots of interest, raw data print-out should be made for cross checking with the original field data sheets. The manual files must be used for plot location sheets, witness tree descriptions, and sketch maps of the plots and their surroundings. The original USGS 7.5' minute quadrangles should also be consulted and additional topographic or environmental data can be verified at that time. It would also be advisable to contact the individual who lead the original plot establishment. Some plots are relatively straightforward to find because they are precisely mapped from landmarks (however, plot markers are inconspicuous and tree tags positioned away from trails to avoid aesthetic impacts and attracting visitors, so that most plots require at least some searching). However, other plots are far from trails and landmarks and may require several hours of searching. Time makes the plots harder to find: animals and other agents (tree growth pushing against tree tags) may remove or obscure plot markings. This problem, again, argues that the plots be put on a 5-10 year remeasurement schedule. Some of the problems in relocating 0.1 ha plots lead to greater precision in plot locations in later projects, such as the 0.04 ha spruce-fir plots.

Hog enclosure project

Wild boar impacts on vegetation have been studied with plots in high elevation beech forests. Many of these high elevation sites, dominated by beech and other northern hardwoods, have been subject to boar rooting since the 1950's. Vegetation of beech forests has been studied by Russell (1953) and Oh (1964) without reference to wild boar impacts. Subsequent studies have concentrated on the effects of rooting on vegetation. Bratton (1974, 1975) and Huff (1977) sampled rooted and non-rooted areas to assess changes brought about by boar rooting. Of these studies, only Oh's work included relocatable plots useful in long-term monitoring (these plots have been discussed above).

A series of permanent plots including enclosure plots bordered by durable fencing and control plots outside the fence were established beginning in 1980. At the present time, the hog enclosure project consists of 12 sites (including two low elevation sites at Special Protection Areas in Cades Cove) and 40 plots (18 inside enclosures and 22 outside the fences). The sites used in the hog enclosure project are clustered by years of hog impact. There are 3 sites in the eastern end of the park (Balsam Mt 1, Balsam Mt 2, and Pretty Hollow Gap) with historically low and short-duration impact; 3 sites in the central part of the park (Beech Gap, Double Springs 1, and Double Springs 2) with historically high and moderate-duration impacts; and 4 sites in the western part of the park (Spence Field 1, Spence Field 2, Gregory Bald 1, and Gregory Bald 2) with historically high and long-duration impacts. A full description of this project is presented in Appendix 4. This Appendix replaces the data available on these plots in 1983 and contained in PLTDX.BAS (Appendix 1; Table III-2).