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Prediction of Forest Type and Productivity Index on Disturbed Sites in Great Smoky Mountains National Park

Charlotte Pyle
University of Tennessee - Knoxville

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I am submitting herewith a thesis written by Charlotte Pyle entitled "Prediction of Forest Type and Productivity Index on Disturbed Sites in Great Smoky Mountains National Park." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Edward R. Buckner, Major Professor

We have read this thesis and recommend its acceptance:

John C. Rennie, Edward E. C. Clebsch

Accepted for the Council:

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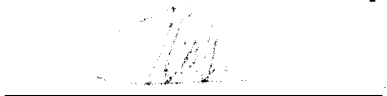
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PREDICTION OF FOREST TYPE AND PRODUCTIVITY INDEX
ON DISTURBED SITES IN
GREAT SMOKY MOUNTAINS NATIONAL PARK

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Charlotte Pyle

August 1988

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ABSTRACT

A study was conducted in a portion of the permanent vegetation plots established by Uplands Field Research Laboratory in Great Smoky Mountains. The plots were located in the northwestern portion of the park in the vicinity of Cades Cove and Tremont on sites previously disturbed by chestnut blight, logging, fire, farming activities, and livestock grazing. Estimated plot productivity, and data on vegetation, soils, and topographic parameters were available from previous study of these plots. The purpose of the present study was to develop methods to predict forest cover type and plot productivity index score using site and disturbance history-related factors.

On a gradient ranging from generally xeric to generally mesic, eight forest cover types were delineated: (1) Yellow Pines, (2) White Oak - Oak, (3) Chestnut Oak - Oak, (4) Mixed Sub-xeric Hardwoods, (5) White Pine - Hardwoods, (6) Chestnut Oak - Yellow-poplar, (7) Yellow-poplar, and (8) Mixed Mesic Hardwoods. Elevation, broad scale topographic factors, mean plot age, the degree of even-aged conditions within a plot, and the thickness of the organic and B soil horizons were the most important predictors of forest cover type.

Plot productivity index score was based on the volume increment of all trees in a plot over 30 cm dbh. A broad scale categorization of landform and total soil depth were the best predictors of plot productivity index score.

In general, broad scale topographic measurements derived from maps were better predictors of forest cover type and plot productivity index score than were categorizations of topography based on the investigator's perception of topography from within the plot itself. The effects of topography-related variables on forest cover type were more important at low elevation.

Disturbance history was found to be correlated to elevation. Topographic factors related to site moisture supply interacted with disturbance, particularly at low elevation. Thus, a given disturbance history did not always lead to the same forest cover type. Furthermore, a given forest cover type was found to be the result of more than one type of disturbance history scenario.

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CHAPTER I

INTRODUCTION

Description of the Study Problem

A system for site classification of forested areas is desirable for the comparison of potential land uses or to help evaluate the monetary value of forest tracts. It is useful to be able to describe an area in terms, such as forest cover type or site productivity, that are applicable to resource management. When large holdings are involved, it is very time consuming to get detailed field information on every hectare (ha) in the forest. Thus, it is further desirable to find a method of assessing units of forest land that can be applied within large tracts with a minimum of field work.

The present study, concerning the forest vegetation of disturbed sites, is a sequel to a study made by R. M. Callaway (1983, Callaway et al. 1987) in Great Smoky Mountains National Park (GSMNP). Callaway (1983) assessed vegetation plots in two ways: (1) by forest type classification and (2) by a plot productivity index score. He classified the forest cover type of his study plots by two different methods. In this process Callaway (1983:33) noted that misclassification (i.e., inconsistency between the results of the two classification systems) was most frequent for forest types "that had experienced human disturbance" or were dominated by pines (Pinus

spp.). Plants will hereafter be referred to by common name. A list of common names and corresponding scientific names is in Appendix F.

Both yellow-poplar and yellow pine forests typically result from disturbance. Yellow-poplar and yellow pines are species that require mineral soil and large amounts of sunlight for seed germination and successful establishment and growth (Fowells 1965). Regeneration of these species may follow disturbances ranging in size from the gap in the forest canopy cover left by the death of a single large tree to the large openings in the forest created by farm fields or logging. Callaway et al. (1987) discussed literature concerning the influences of human disturbance on forest cover types in GSMNP, and concluded that disturbance acted synergistically with topography, soil characteristics, and elevation to determine vegetation distribution.

The estimate of plot productivity made by Callaway (1983), hereafter referred to as "plot productivity index score," was based on the estimated annual volume of the bole wood (m^3/ha) produced per year. Callaway's purpose in estimating the annual bole wood volume increment was to describe plots by a single variable that could be tested for a response to site factors (E. E. C. Clebsch, personal communication to C. Pyle, March 1988). The response of the variable "productivity" to site factors was analyzed with regression analysis involving edaphic and topographic factors measured for each plot. When Callaway used a subset of his data, consisting of information

for only the undisturbed plots, the amount of variation in the plot productivity index score explained by the regression equation was increased by nearly 50%. Thus, Callaway's results showed that differences in disturbance history explain part of the variation in productivity observed on similar sites.

The hypothesis of the present study was that in disturbed forests, both site factors and disturbance history provide explanations of differences observed in (1) forest cover type and (2) productivity. The present study builds on the conclusions of Callaway (1983) and Callaway et al. (1987). As did the studies of Callaway 1983 and Callaway et al. 1987, the present study also builds on the GSMNP vegetation database, which initially was established by Uplands Fields Research Laboratory in GSMNP (Uplands Lab), and subsequently was augmented by the soils, topography, and productivity data of Callaway. To address the hypothesis of the present study, disturbance history and further site data were collected for the subset of Callaway's plots considered disturbed and located in northwestern GSMNP.

Objective of the Present Study

The objective of the present study was to find ways to predict (1) forest cover type classification and (2) plot productivity index score from site variables and disturbance history for disturbed sites in northwestern GSMNP.

CHAPTER II

LITERATURE REVIEW

Introduction

Research relevant to the present study includes both (1) baseline disturbance history data specific to Great Smoky Mountains National Park and (2) studies concerning the effects of disturbance or site factors on forest cover type and site productivity. Frequently, disturbance and site factors interact with one another. Thus, no attempt will be made to discuss their effects separately.

Among the disturbance-related topics included in a recent bibliography of GSMNP plant ecology research were pine beetle, fire, debris avalanche, intense rain storm, gap dynamics (i.e., how forest stands respond to holes in the overstory canopy that allow light to reach the forest floor), native wildlife, logging, Native American land use, settlement land use, balsam woolly adelgid, European wild hog, chestnut blight, grassy balds, and recreational impacts (White 1987). I will draw references from some of the above categories, and from other sources, to present the discussion below. Literature specific to the spruce-fir forest type will not be included. Pertinent details of historical disturbance in GSMNP will be further discussed in the study area description to follow.

Baseline Disturbance History Data Available for
Great Smoky Mountains National Park

Studies involving, or relevant to the park's baseline disturbance history data set include both general information and site specific information. Both categories of information include maps. General information has been compiled for logging, farming, and fire. Chiles (1978) compiled a geographic index of GSMNP place names which included a list of the currently used names for the place names used prior to the acquisition of certain areas by the National Park Service (NPS). Tape recordings and transcripts have been made of the recollections of persons who lived and worked in the Great Smoky Mountains prior to logging and prior to the acquisition of the land by the National Park Service. These recordings include information on land use practices and pre-logging forest cover species and size ranges.

Watershed by watershed Robert S. Lambert (1958) gave an overview of logging practices, corporate ownership, and the dates of cutting in GSMNP. Refinements of his initial work include a history of logging on the Little River (Lambert 1961b) and a short overview of logging in the Smokies (Lambert 1961a). Lambert deposited research notes and oral history tape recordings in the GSMNP Archives. M. R. Chiles' transcriptions of McCracken's (1974-1975) interviews with people involved in logging operations in the park are a major primary source of information on logging history and pre-logging forest

conditions. McCracken's interviews form the basis for discussions of the logistics and equipment use in pre-GSMNP logging operations (McCracken 1978, Trout and Watson 1986). McCracken's interviews and Lambert's notes were the main source of information for Cullom's (1983) chronology of Little River Lumber Company logging history.

In general, farming activities in GSMNP were of a subsistence nature. Farming activities included the use of broadcast burning of the forest to promote cattle forage, reduce underbrush, kill insects, and promote the growth of blueberry bushes (Clark 1923, Shields 1981, R. G. Cardwell, personal communication to C. Pyle, May 1988). Lambert (1957) is an important source of general information on GSMNP farming activities. Shields (1981) and Dunn (1976) also include material on historical land use practices in Cades Cove.

Fires of the last hundred years in GSMNP have been most frequently of human origin. Park fire records have been compiled and analyzed as to fire frequency, size, cause, elevation, and season of the year (Barden 1974, Barden and Woods 1974, and Harmon (1981). General information on fire and grazing effects was summarized in 1905 for the major districts of the Southern Appalachians, including watersheds in the Great Smoky Mountains (Ayres and Ashe 1905).

Livestock grazing practices involved both the pasturing of animals on cleared agricultural land or in wooded areas (R. G. Cardwell, personal communication) and the use of high elevation areas

("grassy balds") managed exclusively for grazing. Site specific information concerning livestock grazing on grassy balds and associated general information on settlers' livestock management practices was compiled from oral history sources by Lindsay (1976).

The single most important baseline source of mapped information on GSMNP logging, farming, and fire history is the work of Frank H. Miller (see Miller 1938; and maps in the GSMNP Archives). From Miller's vegetation map (the "Miller Map"; GSMNP Archives), fires, cutting boundaries, and areas likely to have been cleared for farming can be discerned. Miller's "Wilderness Overlay" map (in GSMNP Archives) aids in interpretation of the vegetation map. In addition, the Miller Map provides the only parkwide source of information of the pre-Chestnut blight distribution of the oak-chestnut forest cover type.

Other mapped sources of baseline disturbance history information include small scale maps depicting the general location of areas used by Native Americans in GSMNP (Bass 1977; site descriptions are also given). Pyle (1985, 1988) presented a map oriented summary of pre-park land use. Preliminary to this work, maps found in the GSMNP Archives were reviewed with respect to their potential usefulness in disturbance history work (Appendix A of Pyle 1985). In addition, disturbance history information from many sources was collated onto 1:24,000 USGS topographic maps (located at Uplands Lab; see Appendix B of Pyle 1985).

Effects of Disturbance History and Site Variables on Forest Cover Type

Research concerning the effects of disturbance on forest canopy species that is pertinent to the present study includes studies made on chestnut blight, logging, farming, grazing, and fire. In terms of areal extent, corporate logging was the most important disturbance in GSMNP (Pyle 1985, 1988). However, with oak-chestnut forests covering approximately one-third of GSMNP prior to the blight (Miller Map; GSMNP Archives), chestnut blight can be viewed as an important disturbance as well.

Pyle (1985, 1988) categorized chestnut blight and grazing as diffuse disturbances because (except where livestock were herded on grassy balds) the effect of these disturbances was diffused; i.e., neither chestnut blight nor livestock killed every tree in a stand. Selective logging was also considered a diffuse disturbance. Oliver (1981:154) distinguished between "minor" (i.e., diffuse) disturbances and "major" disturbances which he defined as "those which knock over or kill all living tree stems in an area large enough to ensure that most trees beginning growth after disturbance do not encounter competition from surrounding undisturbed trees."

Marks (1974) described two modes of stand regeneration following disturbance: (1) a reorganization of existing vegetation and (2) establishment of new individuals. The reorganization of existing individuals included the lateral growth of tree crowns adjacent to an

opening in the forest canopy, stump sprouts, and the release of advance regeneration. Marks noted that the periodicity of good seed years, the weight of seeds (related to how and how far seeds can be transported), and long-term seed viability are important factors in determining which species will become established following disturbance.

"Site" is used by foresters to mean both locale (i.e., position in space) and the sum of the factors (climatic, edaphic, topographic, and biological) that act on vegetation at a given locale (Spurr and Barnes 1973). Site factors important to forest cover type in the mountains of the eastern United States are elevation, topographic features (slope position, percent slope, slope shape, slope aspect), and soil characteristics (texture, structure, pH; Ashe 1922, Braun 1950, Spurr and Barnes 1973). In a study of forest cover patterns in the central Smokies, Golden (1981) concluded that elevation, topographic factors, prior disturbance, pH of the A soil horizon, and percent clay in the B soil horizon were the most useful variables for discriminating between forest cover types.

Boring et al. (1981) listed the following site variables that affect patterns of colonization and succession following disturbance: the season of the disturbance, the size of the disturbed patch, the site's [topographic] shape and aspect, the amount of leaf and canopy debris on the site, the degree of disturbance to litter and topsoil, the species present before disturbance, and the intact plants left

after disturbance. Disturbance during the growing season has been shown to give herbs and sprouts an advantage over yellow-poplar (Boring et al. 1981, Smith 1963 [cited in Boring et al., 1981], Trimble 1973).

White (1979) suggested that the colonizing ability of early successional species is a trade-off against specialization. He went on to say that in frequently disrupted communities, the species are often tolerant of wide environmental extremes; and, the composition of such communities is not predictable from site characteristics.

Several approaches have been taken to the quantification of "topography". Whittaker (1956) did a study of GSMNP vegetation involving direct gradient analysis. He plotted the relationship of forest cover types to one another in a diagram that had elevation on the vertical axis and a "moisture gradient" on the horizontal axis. The moisture gradient was made by aligning various topography classes from most mesic to most xeric along the horizontal axis. Individual topographic classes represented characteristics of topography seen in the field. The system of ordering was derived from the study of changes in the importance of various species as topography varied.

Whittaker (1956) termed his moisture gradient a "complex-gradient" because he considered it to be an integrator of many interrelated factors that affect plants. Other researchers in GSMNP have found the concept of a complex moisture gradient to provide a

satisfactory explanation of portions of the variation in forest cover type (DeYoung 1979, Harmon 1980, Arends, 1981).

North of GSMNP, Rheinhardt (1984) compared the forest cover pattern of the Virginia Balsam Mountains to that of the upper elevations (including the spruce-fir zone) of the Smokies. Overall, the Virginia Balsams were considered more mesophytic, but the trends along the gradients of vegetation change were, to some extent, similar to the Smokies. In detrended correspondence analysis, examination of the first axis suggested that the vegetation pattern of the Virginia Balsams was determined by the combined effects of elevation and moisture. The second axis was correlated to soil calcium levels.

Elevation was considered the major determinant of the forest cover pattern in the Black Mountains of western North Carolina, while topography, soil richness, and disturbance history affected the distribution species within elevational belts (Davis 1930). With decreasing elevation, a greater influence of topography on forest cover type appears to exist. At the elevation of the plateau forests (1000 - 2500 feet; about 300 - 760 m), topography "markedly influences the distribution of associations" (Davis 1930:316).

Lee (1963) indirectly measured sunlight input into a site in terms of the site's slope and aspect and the angle of the sun at a given latitude and day length. Golden (1974) expanded upon this

measurement in development of his topographic "site gradient index." Golden's site gradient index was an attempt to quantify Whittaker's (1956) moisture gradient; and involved the combination of potential sunlight input (derived from plot aspect and slope angle, using the tables of Frank and Lee [1966]) and the plot's position in terms of the vertical distance (0% to 100%) from a ridge to a valley bottom.

In Golden's (1974) composite diagram of forest types shown in relation to elevation and the site gradient index, the chestnut oak forest cover type was found on all but the most mesic and xeric sites at low elevation. Above 3000 feet (ca 915 m) elevation, it was restricted to the more xeric half of the diagram. In contrast, in Whittaker's (1956) diagram, as elevation increased, chestnut oak forests expanded their range to include more mesic sites. Since the two diagrams had different moisture scales, it was hard to determine the relative magnitude of the diagrammed changes. However, in both diagrams, the relative ranking of forest cover types on the topographic moisture gradient, from mesic to xeric, was from cove hardwoods, hemlock dominated forest cover types, chestnut oak dominated forest cover types, to pines.

Davis and Ward (1966) found that the angle (derived from a map) to the highest point of nearby topographic features south (i.e., South 85 degrees East to South 85 degrees West) of a plot was related to the growth of black cherry. Callaway (1983) made a similar, but considerably more involved, measure of topography which he termed

"protection." Protection was based on measurements of the slope and distance to sheltering landforms in eight fixed directions from the plot (Callaway 1983, Callaway et al. 1987). Protection was found to be significantly correlated to the second axis derived from an ordination of the plots' species composition ($r=-0.49$, $P=.001$).

Specific Effects of Disturbance and Site Factors on Forest Cover Type

Chestnut Blight

Chestnut blight (Endothia parasitica (Murr.) Anderson), was believed to have begun killing trees in GSMNP around 1925-1926 (Woods and Shanks 1957, 1959). By 1938, it had killed or affected 85 percent of the chestnut trees in the park (Miller 1938). Prior to the blight, the chestnut tree had had a wide ecological amplitude ranging from coves to ridges. In the mountains of western North Carolina, chestnut was present in every forest cover type except spruce (Holmes 1911; also see Arends, 1981, Shanks 1954b, Whittaker 1956). In the Smokies, the distribution of individual chestnut trees was highly concentrated in some locales and absent in others (Woods and Shanks 1959).

Chestnut blight killed trees gradually (Aughanbaugh 1935 (cited in Woods and Shanks 1959). In stands where chestnut crowns occupied less than 30 to 40 percent of the canopy, gradual enlargement of adjacent codominant tree crowns occurred in response to chestnut decline. In other stands, the decline and death of chestnut trees

led to the release of advance reproduction including hemlock, chestnut oak, and northern red oak seedlings and saplings. Elsewhere, in large gaps, species intolerant of shading were established by seed rain (e.g., yellow-poplar, sweet birch, and black locust). Seed rain from adjacent stands was also important for the establishment of red maple and hemlock (Woods and Shanks, 1957, 1959). In the eastern United States, studies (reviewed by Arends 1981 and Woods and Shanks 1957, 1959) indicate that red maple, northern red oak and chestnut oak were the most frequently found species in areas formerly occupied by stands containing chestnut. The oaks commonly occur as persistent large trees. However, particularly when stems down to 10 cm dbh are considered, yellow-poplar, silverbell, and sourwood were important on some sites (Arends 1981, Flora 1977, Golden 1974, Greenlee 1974, Nelson 1955, Whittaker 1956).

Both predicted and measured changes in forest species composition following chestnut blight in the Smokies indicated that forest succession was affected by site factors. On mesic sites, silverbell and hemlock increased in importance. On sites of intermediate moisture conditions, oaks increased in importance, while on xeric sites sourwood increased in importance. Red maple, a species tolerant of a great range in site conditions, was important in successional forest types ranging from mesic to xeric (Arends 1981, Woods and Shanks 1957, 1959).

The interaction of site factors with forest composition prior to chestnut blight was a factor in determining subsequent vegetation. For example, on north facing sites, where chestnut was more likely to be found in pure stands, large gaps were created by the death of many chestnut trees. The abundance of light on the forest floor and the mesic nature of such sites led to the establishment of yellow-poplar. In contrast, on sites occupied by pine - chestnut forests with an evergreen shrub understory, intolerant species (such as yellow-poplar or pines) were not likely to become established because the shrub layer shaded the soil surface. Tolerant species (such as hemlock and site-demanding hardwoods) were not suited to the dry site conditions. Thus, in former pine-chestnut-heath stands, chestnut blight led to no replacement at all in the canopy (Woods and Shanks 1959).

While the assemblage of replacement species at a given locale was influenced variously by site conditions and by the availability of seeds of adventitious species from outside the stands, the typically reported stand response to chestnut blight, throughout the eastern United States, was replacement of chestnut by its associated species (Arends 1981, Aughanbaugh 1935 (cited in Woods and Shanks 1959), Braun 1950, Illick 1921, Korstian and Stickel 1927, Nelson 1955, and Woods and Shanks 1957, 1959). Over time, some of the relatively intolerant species such as black cherry and oaks have been found not able to reproduce well enough to maintain the importance they initially gained in the forest following chestnut blight (Good

1968, Mackey and Sivec 1973). Also, as was predicted by Keever (1953), hickory is reported to have greatly increased in importance in some areas of former oak-chestnut forest (Johnson and Ware 1982, McCormick and Platt 1980).

Finally, the results of a forest modelling study concerning the long term changes following the elimination of chestnut suggest that the change in species composition after 50 years is not necessarily a good predictor of the long term change in forest cover (Shugart and West 1977).

Logging

A study of forest cover types following logging, done by McCracken (1978), included one of the areas in which plots of the present study are located (the Middle Prong of the Little River). Loggers were known to have cultivated gardens in two flat areas at 1800 feet and 2000 feet (ca 550 and 640 m) elevation. The regeneration of those logged, then cultivated, flats was compared to nearby logged slopes. Yellow-poplar and black locust were found in the upper canopy of the garden flats. Yellow-poplar and black locust, only, were found on one slope, while the upper canopy of the other also included sassafras, northern red oak, red maple, yellow birch, and sourwood. In all cases, in these low elevation cleared sites, yellow-poplar was the dominant species, comprising 71% - 91% of the upper canopy basal area. According to information provided by

people who worked as loggers in the area, prior to logging the sites supported mixed mesophytic forests.

McCracken (1978) also studied a steep slope believed to have been forested with a mixture of hemlock and hardwoods prior to logging. After logging, yellow-poplar was found to comprise the majority of the basal area. The fraction of basal area in yellow-poplar varied from 50% at 3200 feet (ca 975 m) elevation on the upper portion of the slope to 65% at 2800 feet (ca 855 m) elevation on the lower portion of the slope. On the upper slope position, red maple was the major associate, comprising 32% of the upper canopy basal area. On the lower slope, a combination of four other species (sassafras, northern red oak, red maple, and yellow birch) each contributed between seven and 11 percent of the upper canopy basal area. Prior to logging by the Little River Lumber Company in the Middle Prong, yellow-poplar in the Smokies was considered by Ashe (1913:7) to occur "only irregularly" above 3500 feet elevation.

In the mountains of western North Carolina, south of GSMNP and near Joyce Kilmer Memorial Forest, regeneration 15 to 20 years following logging was studied in a cove hardwoods stand located around 2500 feet (ca 760 m) elevation (Greenlee 1974). Eighty-seven percent of the basal area for trees (> 10 cm dbh) was found in a single species, yellow-poplar.

In comparison to the unlogged control site, located in Joyce Kilmer Memorial Forest, the species richness of the logged area was low. Basswood, sugar maple, beech, mockernut hickory, white ash, buckeye and northern red oak were lacking in the logged site. From examination of the topographic maps included in the manuscript, it appears that although the logged site was at the same elevation as the control site, there was less topographic protection from surrounding land features south of the logged site. The interaction of site factors with disturbance was not discussed by Greenlee.

Frothingham (1931) described the reproduction in cut-over hardwood forests in the Southern Appalachians as a mixture of seedlings and sprouts, with sprouts especially characteristic of logged and burned areas. Smaller trees sprout more prolifically when cut (Frothingham 1931, Boring et al. 1981). Thus, following disturbance, the pre-disturbance presence of smaller trees may contribute to a larger number of trees and greater biomass on sites which did not initially support large trees (Boring et al. 1981). In White Pine - Oak and White Pine - Hickory stands near Highlands, North Carolina, four years after logging, red maple was observed to have increased in importance in the stands by means of stump sprouts (Horn 1980).

Grapevines were considered sparse in undisturbed stands of a watershed studied in the forest surrounding Coweeta Hydrologic Laboratory (Williams 1954, cited in Boring et al. 1981). However,

following logging, grapevines were found to dominate localized sites at Coweeta and elsewhere (Boring et al. 1981, Shutts 1968 (cited in Boring et al. 1981), Trimble 1973). It was noted that vines utilize woody debris and competing vegetation for support (Boring et al. 1981).

Farming Activities

Farming activities in GSMNP included more than the clearing and ploughing of fields. As discussed below, intentionally set fires and livestock grazing in the woods outlying from cleared areas were important components of the pioneer lifestyle. In a general description of the Southern Appalachians, Ayres and Ashe (1902:45) described the woodland connected with farms as "largely culled and is in part covered with trees of second growth."

Ayres and Ashe (1902:58) stated that bottomlands were the first to be cleared and described them as "nearly all in cultivation." However, population pressures led to clearing on slopes above the bottomlands. Ayres and Ashe noted the regeneration of young pines on abandoned fields on mountain slopes.

Prather (1967) documented the forest cover and site characteristics of four historically cleared areas in Cades Cove. The dates of farmers' abandonment of these areas were believed to have been 1931 to 1935. The percentage of yellow pine stems counted in the canopy of the four plots was 46%, 52%, 84%, and 100%. Yellow-

poplar and red maple contributed 48% and 49%, respectively, to the first two of the four plots. In contrast to the other three plots, the plot with the canopy composed wholly of yellow pines was believed to have been a pasture, rather than a ploughed field.

It was noted that the plot dominated by yellow-poplar and yellow pines was not topographically homogenous. Yellow-poplar was found in the draw position, while the pines were found on the upper slope and top of a small ridge. Soil pH and moisture were found to be higher in the yellow-poplar draw than on the ridge or in the other plots.

In the Piedmont region of North Carolina, Billings (1938) investigated a series of old fields believed to be on comparable sites. All were of the same soil series. All were level or nearly so. If sloping, all had a south-facing aspect. The stands differed in age class from nine year old seedlings to 110 year old mature shortleaf pines.

GSMNP is in the Southern Blue Ridge mountains rather than in the Piedmont region. However, a review of the changes in the shortleaf pine structure and composition may lead to understanding of changes in the old fields dominated by yellow pines (mainly Virginia and pitch pines) in GSMNP.

The major change Billings (1938) found in the overstory was the decrease in the density of dominant pines in successively older stands. By age 50-60, hardwoods began to be important in the

understory; and pine reproduction was no longer found. Billings concluded that the pines would eventually give way to hardwoods.

Billings (1938) also investigated the soil profiles of the pine stands. Although plough furrows were still clearly evident in a 31 year old stand, the ploughed soil horizon, seen in younger stands, had been replaced by the development of an A1 horizon. With increasing stand age, thicker A1 horizons were found. Also, the organic horizons became more complex (i.e., they could be divided into litter, fermentation, and humus layers). With increased organic matter additions, the A1 horizon increased in water holding capacity. Billings concluded that over time, in an old field initially regenerated to a pine forest, the pines influenced soil conditions to the point that they became hospitable to hardwoods.

Livestock Grazing

Oral history accounts of pre-park livestock grazing activities indicated that although Tennessee had passed a fencing law in 1913, cattle, hogs, and sheep continued to be allowed to roam free, particularly in the woods outlying from areas of concentrated settlement (untranscribed taped interviews of former Park residents recorded by C. Pyle and C. D. McCarter, Lindsay 1976). That "woods pasturing" was not restricted to GSMNP is evident in the several articles written on the ill effects of grazing on timber production (Biswell 1945, Behre et al. 1929, Day and DenUyl 1932, DenUyl and Day 1934, Haasis 1926, Lutz 1930).

In western North Carolina, Biswell and Hoover (1945) found that cattle favored the foliage of yellow-poplar, black locust, ash, sourwood, sweet birch, sassafras, and dogwood over that of oaks and hickories. In areas lacking grass in the Piedmont region of North Carolina, cattle ate yellow-poplar (Biswell 1945). Day and DenUyl (1932) mentioned the complete elimination of yellow-poplar under farm woodland grazing conditions in Indiana.

Biswell and Hoover (1945:675) observed many trees 12 to 15 feet (ca 4-5 m) tall which were killed by "being ridden down and defoliated." Other damaging activities of livestock included browsing, trampling of small trees and tree roots, rubbing against trees, pulling out seedlings, uprooting saplings up to 3 inches (7.5 cm) in diameter, soil compaction, and destruction of litter and humus layers (Behre et al. 1929, Day and DenUyl 1932, DenUyl and Day 1934, Johnson 1952, Lutz 1930). Behre et al. (1929) noted that grazing might be beneficial for the control of hardwoods in old fields being managed for conifers.

Day and DenUyl (1932) described the pattern of gradual conversion of farm woodlands into pasture through grazing coupled with the removal of mature trees through death and decay or by farmers for fuelwood and other purposes. Lutz (1930) found that grazing injury stimulated root suckers in beech. Reduced growth of yellow-poplar in the 3-9 inch (7.5-22.5 cm) class in grazed versus ungrazed plots at Coweeta Hydrologic Laboratory was attributed to

soil compaction and exposure of roots through erosion initiated by cattle trampling (Johnson 1952).

Haasis (1926:534) stated that cattle "tend to travel the coves and ridges, neglecting the slopes between.". Johnson (1952) noted that cattle, which were allowed to range over an area that included both hardwood coves and pitch pine - oak ridges, spent most of the time in the cove hardwoods forest type. He attributed this to the presence of preferred forbs and grasses. Gershmel (1970) draws attention to the presence of flat land on ridgetops and springs near the ridgeline at high elevation.

Fire

Fire as an ecological factor in GSMNP is believed to be largely the product of people's activities (Barden 1974, Barden and Woods 1974, Harmon 1981). In contrast to Whittaker's (1956) assertion, dry site conditions and fires resulting from summer thunderstorms are not believed to be the sole explanation for the maintenance of table-mountain pine (Barden and Woods 1976).

Intentionally set fires in GSMNP were related to the woods pasturing of cattle (Ayres and Ashe 1905). Other intentionally set fires were set to promote the growth of blueberries (Shields 1981), and to burn off farm fields (R. G. Cardwell, personal communication). Further reasons for historical woods burning include reduction of

fire hazard, destruction of insect larvae and habitat, and killing of snakes (Clark 1923, Shea 1940).

The frequent use of fire by settlers in the Southern Appalachians was deplored for its damage to timber and reproduction (Ayres and Ashe 1902, 1905, Frothingham 1943, Hall 1910, Holmes 1911, Price 1902). Fires killed trees directly and also indirectly, through initiation of basal wounds that provided entry for fungi. Thin barked trees such as beech, birch, and maple are more susceptible to basal and root injuries from fire (Jemison 1944, Sims 1932, Stickel 1935). Seedlings and saplings are more affected by fire than are mature trees (Ayres and Ashe 1902, McCarthy and Sims 1935).

Fires also affected site quality. Burning of the litter layer destroyed the soil's source of both nutrients and protection from erosion (Ayres and Ashe 1902, McCarthy 1928).

The effects of fire were worse on south facing slopes because they were drier and more easily ignited fuels (i.e. pines) were present. On south facing slopes, thin undergrowth, excessive sprouting, and the presence of mountain laurel and rhododendron were attributed to the effects of fire (Ayres and Ashe 1902, Hall 1910).

Fire intensity is affected by topography and the amount, dryness, and inflammability of fuels (Buckner et al. 1987, Clark 1923). Regeneration following fire is affected by fire intensity.

In a study of a fire that burned in GSMNP in 1986, Buckner et al. (1987) found that Vaccinium sprouting increased with increases in the depth of the unburnt organic layer. In contrast, two thirds of the pine seedlings, which germinated following the fire, were found where mineral soil had been exposed.

Harmon (1984) found that tree survival following low-intensity surface fires in western GSMNP increased with bark thickness. With frequent fire, fast growing, thick-barked species would be favored. However, the ability of trees to sprout following fire must also be considered. Killed-back individuals of pitch pine, chestnut oak, scarlet oak, red maple, blackgum, and sourwood were observed sprouting by Buckner et al. 1987.

A distinction must be made between frequent low-intensity fires and the conflagrations that resulted when logging slash was ignited. Miller mapped the boundaries of fires which had altered the condition, age class, or species composition of the forests in GSMNP (Miller Map, GSMNP Archives). Nearly all of the fires Miller mapped occurred where there had been logging. Pyle (1988) reported that 87% of the area known to have burned intensely prior to park establishment had been logged.

Estimation of Site Productivity

Productivity is defined in terms of biomass produced per unit area per unit time (Barbour et al. 1987, Spurr and Barnes 1973).

Whittaker (1975:192-193) described productivity as "the most significant single attribute of a natural community." Likewise, Forman and Godron (1986:28) stated that biomass is "sometimes considered as an index of the 'information' in a system". Ecologists' use of productivity estimates as a means to express the integrated effects of site variables at a given locale may be contrasted with foresters' use of productivity estimates to predict the yield of timber (or merchantable biomass) at a given locale under specified stocking levels, species groups, and tree age. A source of examples of typical foresters' use of productivity estimates is found in the bibliography of hardwood growth and yield literature by Marsinko et al. (1987). In the present study, productivity estimates are used only in the ecologists' sense, to express the integrated effects of site variables.

Productivity studies in GSMNP have been concerned with using estimates of plot productivity as ecosystem indices rather than for the prediction of timber yield (Whittaker 1961, 1962, 1963, 1965, Whittaker 1966, Callaway 1983). In the paper that culminated his series of productivity studies in GSMNP, Whittaker (1966) reported the results of several estimates of stand biomass, woody plant dimensions, and productivity, including (a) total biomass, (b) annual biomass production, (c) total basal area of woody plants, (d) annual basal area increment, and (e) annual wood volume increment. Wood volume estimates were done on trees and arborescent shrubs. Biomass

estimations involved the bole wood, bark, branches, and leaves of trees and arborescent shrubs, and herbaceous plants. The results were discussed in relation to (1) forest cover type and (2) an environmental moisture gradient composed of elevation and topographic factors. Whittaker noted large basal area and volume increments in stands previously affected by farming (old fields), chestnut blight, and fire. These stands were characterized as unstable.

Callaway (1983) used an estimate of average annual bole wood production as an index to the response of the forest to site factors. Using site variables measured for each plot, he developed regression equations to predict the average annual production of bole wood in a plot. He found protection (a measure of a plot's position relative to the surrounding topography) to be the most important predictor of average annual bole wood volume production. Callaway's work will be discussed further in relation to the results of the present study.

Rodriquez (1973:9) listed two aspects of the measurement of growth for site evaluation:

- (1) scrutiny of the factors of the environment to learn how they relate to growth rates of forest trees as well as to distribution and succession of forest communities;
- and (2) the use of site ratings for actual management purposes.

Through site index studies, environmental factors have been related to growth. A short review of environmental factors that have been found to affect tree growth follows.

Ike and Huppuch (1968) found that the best predictors of site index for 10 species in the north Georgia mountains were site factors that influence moisture conditions through climate and soil moisture supply. Examples of such factors are elevation, slope position, and slope steepness.

Virginia pine, white oak, chestnut oak, black oak, white pine and yellow-poplar all grew better on more mesic sites (Ike and Huppuch 1968). Slope position was important to yellow-poplar growth (Auten 1945, Ike and Huppuch 1968, Smalley 1964). Ike and Huppuch also found that yellow-poplar growth was correlated to soil series. Mowbray and Oosting (1968) found the ratio of (clay/sand in the B horizon) to be a way to express soil aeration and moisture availability.

Yellow-poplar was considered more sensitive to site change than were oaks and pines (Auten 1945, Doolittle 1958, Ike and Huppuch 1968). Yellow-poplar was seldom found on southeast to southwest aspects except on the lower one third of a slope (Ike and Huppuch 1968).

In contrast to yellow-poplar, Virginia pine had the widest amplitude in topographic moisture tolerance, being found in sites ranging from lower slopes of sheltered coves to upper slopes of ridges. However, it grew best in moist, sheltered coves at 2000 feet (ca 610 m) elevation or lower. Topography class, slope position, and

slope steepness were important factors for Virginia pine site index (Ike and Huppuch 1968).

Smalley (1967) and Gaiser (1951) found that slope position was the most important predictor of white oak site index. In north Georgia, white oak grew best on low elevation (2000 feet; ca 610 m), gentle, north facing slopes. The influence of slope position on site index of white oak was stronger at high elevations (e.g., 3200 feet; 975 m) than at low elevations (Ike and Huppuch 1968).

A secondary site factor for white oak site index was the depth of the A horizon (Ike and Huppuch 1968, Gaiser 1951). McClurkin (1963) developed a regression model to predict white oak site index based on basal area, slope position, percent clay in the surface horizon.

Slope position was more important to the site index of chestnut oak than was slope steepness (Ike and Huppuch 1968). Slope position and percent clay in the A2 horizon were the only site characteristics found by Ike and Huppuch (1968) to be closely related to black oak site index. Within a range of 10% to 30% clay, the higher the clay content the better black oak grew. Doolittle (1957) found the best predictors of black oak site index to be the depth of the A horizon, slope position, and percent sand in the A horizon. Percent sand was negatively correlated to growth.

White pine made its best growth on bottoms in sheltered coves at low elevations. White pine is not considered as sensitive to site quality as yellow-poplar. Although both have high site indexes on good sites, yellow-poplar will do better than white pine on good sites, while white pine will grow better than yellow-poplar on poor sites (Ike and Huppuch 1968).

A different approach to site classification has been taken by Smalley (1984) for sites in the interior uplands of Tennessee, Kentucky, and Alabama. Smalley based his classification system on a hierarchy of regions, subregions, landtype associations, and landtypes (i.e., broad scale landforms). Descriptions derived from a review of pertinent literature are given for the soils, geology, vegetation, and productivity of each landtype. Productivity is expressed in terms of the site index of selected species. Overall, the works of Whittaker (1966), Callaway (1983), Ike and Huppuch (1968), and Smalley (1984) are in general agreement that topographic features are important indices of site productivity.

CHAPTER III

THE STUDY AREA

Physical Characteristics of the Study Area

The study area is located in the northwestern portion of GSMNP between Indian Flats Prong and Pine Mountain (Figure H-1; all numbered figures are in Appendix H; all numbered tables are in Appendix G). Within this amorphously bounded area, vegetation plots are generally clustered in and around Cades Cove and in a portion of the upper Middle Prong of the Little River. Plots in the Middle Prong watershed are found on Lynn Camp Prong, Indian Flats Prong, and Davis Ridge. GSMNP is bisected by the North Carolina/Tennessee state line at about 35 degrees 37 minutes 30 seconds latitude, between about 83 and 84 degrees longitude (United States Geologic Survey [USGS], 1949). The Great Smoky Mountains are the best known of a series of mountain ranges in the Unaka chain, a group of mountain ranges which diverges southwestward from the Blue Ridge in southwestern Virginia. The Unakas form the western front of the Southern Appalachian Mountains, and generally follow the North Carolina/Tennessee state line southwest to Georgia (Braun 1950, Fenneman 1938).

In geological contrast to the Blue ridge, the Great Smoky Mountains and vicinity are a "region of sedimentary rocks and their metamorphosed equivalents" (King et al. 1968:11). Most of GSMNP is

included in the Ocoee Series, a series of later pre-Cambrian rock, greater than 175 miles (ca 280 kilometers) in length, which follows the same geographical trend (northeast to southwest) as do the Unaka Mountains. The Ocoee Series is much folded and faulted, and includes a thrust sheet over the Ordovician limestones and shales of the Appalachian Valley to the west. In infrequent places, the older overthrust rock has eroded away, exposing the underlying limestone rock. Cades Cove is one such area (Fenneman 1938, Keith 1902, King et al. 1968, King and Stupka 1950).

The topography of Cades Cove is atypical of the remainder of the park. Within the loop road around Cades Cove lies an area that is essentially flat. Outside the loop road, gently sloping terrain steepens suddenly into a rim of mountains. The mountains rise some 900 feet (ca 275 meters) above the valley floor to the north, and about 2600 feet (ca 800 meters) up to the state line crest on the south (USGS 1964a). West of Cades Cove is a series of narrow, steep-sided ridges trending northeast to southwest (USGS 1964a, 1964b). East of Cades Cove, and more typical of the remainder of the Smokies, the Middle Prong of the Little River runs through a river gorge that is fed by numerous streams which drain steep sloped, V-shaped valleys (USGS 1964c). Within the general boundaries of the study area, elevation varies from 1200 feet to 5040 feet (ca 365 m to 1535 m). Elevations of sample plots range from 1470 feet to 5010 feet (ca 450 m to 1525 m, USGS 1964a, 1964b, 1964c).

The soils in the Middle Prong are of the Ramsey Series. Formed in place, they are derived chiefly from quartzite and slates. Rapid geological erosion, caused by steep slopes, creates indistinct soil profiles in these soils. West of Cades Cove, the same soil series is found. In contrast, Cades Cove is typified by soils formed from colluvial material composed of quartzite, slate, sandstone and shale particles, influenced to some extent by limestone (Elder et al. 1959, Hubbard et al. 1956).

Following the climatic classification system of Thornthwaite (1948), the Smokies were categorized by Shanks (1954a) as to temperature and rainfall. The study area falls within the mesothermal perhumid category (i.e., a warm, wet climate). Average temperatures, recorded at a station near Gatlinburg, Tennessee, ranged from an average daily minimum of 27.8 degrees Fahrenheit (ca - 7.6 degrees Centigrade) in January to an average daily maximum of 87.8 degrees Fahrenheit (31.0 degrees Centigrade) in July. Average annual precipitation was 54.05 inches (ca 137 cm, United States Dept. of Commerce, Weather Bureau 1963).

The prevailing winds of the Southern Appalachians are moist and warm, originating from the southwest. When these moist warm winds encounter the mountains, clouds form (Keith 1902) as the rising air is cooled. According to a study done during 1946-1950, temperatures in the Smokies decrease an average of 2.23 degrees Fahrenheit for each 1000 feet (1.2 degrees Centigrade for each 300 meters [m]) gain

in elevation (Shanks 1954a). Precipitation was found to increase about 9 inches for each 1000 feet (ca 22.5 centimeters for each 300 m) gain in elevation during another study done during 1946-1950 (Smallshaw 1953). Curves of average monthly precipitation versus potential evaporation, prepared by Shanks (1954a), suggest that drought stress occurs infrequently at low elevations, and not at all, at high elevations, in the Smokies. Shanks, did not examine day to day variation and microsite differences. However, Stephens (1969, cited in Callaway 1983) found precipitation to be more consistent at higher elevations.

Disturbance History of the Study Area

Disturbance History Overview

The major impacts on pre-Park forests were chestnut blight and disturbances, such as farming, logging, and fire, associated with Euro-American use of the area (Pyle 1985, 1988). Evidence of Native Americans' presence at hunting camps and villages in Cades Cove, and elsewhere in GSMNP, has been documented by Bass (1977). Other than the mention of cattle grazing along Abrams Creek in Cades Cove (Dunn 1976, p. 21), I found no site specific accounts of Native American land use practices within the study area. Davidson (1983) speculated that dramatic increases of pine pollen in Cades Cove occurring from 1900 to 165 years before present were an effect of Native American activities. However, as E. Clebsch pointed out to the present

author, 165 years before the "present" (i.e., 1983) is 1818. This suggests that the change in pine pollen may be attributed to pioneer settlement activities.

Because chestnut was a common species on sites that had not been farmed, its virtual elimination (in the 1930s) by chestnut blight was generally important throughout GSMNP. Within the study area, Cades Cove disturbance history is typified by farming activities such as ploughing, pasturing of livestock in fields, and firewood cutting. In historically forested areas outlying from Cades Cove, chestnut blight, fires, and woods pasturing of livestock were the most common disturbances.

Logging on Laurel Creek can be viewed as a transition from early-style logging to mechanized logging. Early-style logging was generally characterized by small scale operations and selectivity for valuable trees in terms of species and size. Very large trees were hard to mill on the portable mills frequently used and were hard to bring out of the woods without mechanized equipment. Very small trees were not economically worth the effort required to bring them to a mill. In the Middle Prong of the Little River, logging, involving railroads and steam powered skidders and loaders, was neither small scale nor selective.

Disturbance History of Cades Cove and the Extreme Western Smoky Mountains

The first permanent white settler in Cades Cove arrived in 1818 (Dunn 1976) or 1821 (Shields 1981). By 1830 there were 44 households. Most residents of the cove were subsistence farmers. Each household provided for its own material needs through activities such as ploughing fields and planting crops, establishing orchards, harvesting wild fruits and chestnuts, harvesting hay for cattle, hunting, hog husbandry, and firewood cutting. Buildings were initially made of logs and later of sawn lumber (Dunn 1976, Shields 1981).

The population of Cades Cove fluctuated widely between 1830 and 1930. The high of 132 households in 1850 was followed by the low of 45 households in 1860. Between 1860 and 1900, the number of households rose back up to 125. By 1917, it was down to 116. Beginning in 1916, large numbers of jobs associated with construction for Calderwood Dam (Brewer and Brewer 1975:239) and the opening of the aluminum plant in Alcoa (Shields 1969) may have drawn off some of the population. Many additional families moved away with the beginning of land acquisition procedures for the National Park in 1928 (Shields 1981). Park Ranger, Charlie Dunn, estimated there were 20 to 30 families living in Cades Cove when he arrived in 1931 (McCracken 1974-1975). For no population level is there full information on the extent of wood cutting and clearing associated with the subsistence lifestyle of Cades Cove farm families.

In addition to subsistence farming, early land use activities around Cades Cove included dike building, iron ore digging, charcoal making, and sawmilling operations. Peter Cable, who died in 1866 (Shields 1981), designed and supervised the building of a system of dikes, sluices, and log booms placed across creeks to drain the swampy lower end of the cove. In 1827, Daniel David Foute built an iron forge which was operated until 1847 (Dunn 1976). Iron ore was dug at various places within the cove. Charcoal was produced in what was known as the "coalin' grounds," located in a flat on Coalen Ground Branch, southwest of Cades Cove (Russie Whitehead, personal communication to C. Pyle and C. D. McCarter 1984).

During the 1840's Frederick Shields built a mill (at the Cable Mill area in Cades Cove) which included a sash saw (Dunn 1976). Although there were never any highly mechanized logging operations in Cades Cove, some lumber was manufactured with portable mills and shipped out of the cove. The use of portable mills (operated by John Post) on the holdings of the Morton Butler Company is cited by Charlie Dunn (McCracken 1974-1975) and corroborated by Russie Whitehead's recollection of sawmilling operations undertaken by "Old Man Post" (personal communication, 1984) in areas owned by Morton Butler Company. In 1925, in particular, portable mills were said to be operating in Cades Cove (Maddox 1925). During 1904-1906, poplar and sugar maple were cut from Lawsons Sugar Cove and above Mill Creek Falls. This lumber was shipped out via the railroad associated with

the Shea Brothers on Laurel Creek (Lambert 1958).

Open range was legal in Tennessee until 1913 when the fence law went into effect. Community pressure, rather than the enactment of the state law made East Tennesseans begin fencing livestock in the years after 1913 (R. G. Cardwell, personal communication to C. Pyle, 1988). In answer to a question concerning where people had their cattle graze on Coalen Ground Ridge (one and one half miles southwest of Cades Cove), Russie Whitehead said that they "let them go where they pleased" (personal communication to C. Pyle and C. D. McCarter 16 January 1985).

That the foraging of cattle outside of cleared areas was important in the local economy of GSMNP can be inferred by the frequent mention by Ayres and Ashe (1905) of grazing and burning of the forest. Many details on the effects of fire are given in the description of forest conditions in the Cades Cove district which included the area drained by tributaries of Abrams Creek in Cades Cove and upstream. The description of forest conditions by Ayres and Ashe (1905:176-177) included such comments as

Humus and litter. - Usually light, owing to repeated fires and much grazing. . . .

Cutting. - There has been very little cutting, except for local use. The large proportion of the timber has been burned in clearing.

Fire. - Fires are set whenever they will run, and the forest shows the effect of this practice. The brush is subdued; the timber is frequently scorched at the butt, often killed.

Reproduction. - Seedlings are kept down by cattle and fires, except on a few old fields, where thrifty pines and

oaks are abundant. . . .

Undergrowth. - Reduced by burning and grazing.

Ayres and Ashe (1905) also mention fires and grazing in their description of the Abrams Creek District which comprised all the land drained by Abrams Creek below Cades Cove. Oral history accounts of pre-Park land use primarily west of Cades Cove detail the setting of fires to promote cattle forage, to encourage huckleberry growth, and to expose fallen chestnuts (C. Pyle and C. D. McCarter, unpublished data). Likewise, vegetation plot notes for F. H. Miller's vegetation map mention repeated fires and burning for grazing in the extreme western portion of GSMNP (GSMNP Archives files).

Modifications to the forest environment did not stop upon the establishment of Great Smoky Mountains National Park in 1934. It was during the time of park establishment that the Civilian Conservation Corps (CCC) built roads and trails, cut dead chestnut trees to reduce fire hazard, suppressed fires, and planted trees in old fields. A CCC camp was located in Cades Cove from 1933 to 1942. The CCC rebuilt, upgraded, and in places re-routed, historical access routes to Cades Cove including Cooper Road, Parsons Branch Road, and the road to Happy Valley (Eakin 1933, Pyle 1979; CCC files and Superintendent's Monthly Reports 1933-1942 both located in GSMNP Archives).

After the CCC era ended, GSMNP Maintenance crews were responsible for roads, trails, and forestry-related projects. White

pine blister rust (Cronartium ribicola) surveys were done in GSMNP beginning in 1937, in Haywood County (Atlas of white pine rust control information, in GSMNP Archives). GSMNP Maintenance crews were involved in attempts to control the spread of white pine blister rust by eradicating currant bushes (Ribes sp.). Earl Franklin described the procedure for a one mile wide area that he worked on in 1946 from the picnic area in Cades Cove to the head of Parsons Branch:

'N' ever' ten chains [about 200 meters], we run a cross strip, back 'n' forth. Wherever a currant bush w's found, right there's where the plow stopped. We went an' got our mattocks 'n' shovels we dug that thing out then took put (sic) about a handful of salt right in th' hole where we dug 'im up. (McCracken 1974-1975:137-138).

During the southern pine beetle (Dendroctonus frontalis Zimm.) outbreaks of the 1950s, sanitation cuts were made. A southern pine beetle control map (dated 1950, in the GSMNP Archives) had circles around Cades Cove, White Oak Sinks, and in the vicinity of Sugar Cove, near Big Spring Cove, on Laurel Creek. Until 1958, the Chief Ranger Monthly Narrative Reports to the Superintendent (in GSMNP Archives) give information on the number of pines cut and treated (with ortho and fuel oil) by Park personnel. In 1958, the pine beetle suffered high winter mortality. Kuykendall (1978) summarized reports on a southern pine beetle outbreak from 1967-1975 in GSMNP. GSMNP Maintenance did not do sanitation cuts during this period.

Disturbance History of Laurel Creek

The Laurel Creek watershed has a long history of pre-Park land use, particularly in the Big Spring Cove area, where an Indian campsite/village was located (site report of McPherson 1936 in Bass 1977). Historically, the access to Big Spring Cove was via a wagon road from Dry Valley which went through Schoolhouse Gap to some homesites on Laurel Creek. The present day road up Laurel Creek from Townsend (in Tuckaleechee Cove) into Cades Cove was put under construction by CCC and Works Progress Administration crews (Shields 1969). For the pre-Park farmers in Cades Cove, the Rich Mountain Road, through Dry Valley, had been the main access from Tuckaleechee Cove into Cades Cove.

On Laurel Creek, the first record of timber cutting involves the shipment of lumber on wagons via Schoolhouse Gap. During the 1880's, Captain Duncan McDonald was sawing mostly yellow-poplar in the vicinity of Tuckaleechee Cove. At one point, the location of his "[portable mill] set was on the Smoky Mountain side of Laurel Creek" (information taken from a paper written for Inez Burns by McDonald's great-grandson, in 1933, cited in Burns 1952:56). Based on field work done 1900-1901, Ayres and Ashe (1905:176), reported that in the Laurel Creek Basin (Blount County, Tenn.), a "small mill has been operated about 4 miles from the head of this stream, but at little or no profit. Several hundred thousand feet of lumber have been sawed." The land use classification (timber stocking) map included with the

report showed a cleared area in the vicinity of Big Spring Cove. The flat area cleared by logging around Big Spring Cove was subsequently grazed (Arnold Thompson, personal communication to Brien Ostby).

Ayres and Ashe (1905:176) also reported that "Many fires have been set along the road, and much of the forest near it has been killed. The remote portions are but slightly injured." Reproduction was described as "Free where fires are not repeated." Depicted as burned, on the map of Ayres and Ashe (1905), were two areas near the road to Schoolhouse Gap in the vicinity of what I interpreted to be Pinkroot Branch and Spence Branch. (It should be noted that the topography on the base map of Ayres and Ashe [1905] is frequently quite different from that depicted on the current USGS maps.)

Ayres and Ashe (1905:175) considered the access to Laurel Creek (via a "rough and hilly wagon road") to be "Difficult." This difficulty was overcome soon after the Little River Railroad Company was chartered in 1901. The Little River Railroad Company had standard gauge track laid up the West Prong of the Little River and part way up Laurel Creek. From 1904-1907, the Shea Brothers, working under contract to the Little River Lumber Company (LRLC), used horse teams and wooden slides (up to two and a quarter miles long) to bring logs to the railroad. An incline (rail car powered by means of a winch) went across from Laurel Creek to Cades Cove, just west of the present day road into Cades Cove. This gave easy market access for Cades Cove lumber. According to Louis McCarter, the Shea Brothers

mainly cut yellow-poplar, maple, cherry, and birch. However, Lambert (1961b) also reports hemlock and ash were milled by the LRLC during this period. Lambert (1958:53) concluded that the area cut 1904-1907 was "pretty thoroughly cut over by the methods of that day."

Although Lambert (1958) says that no unusual burning took place during the Shea Brothers' logging, Charlie Dunn mentions a fire that "burned out the West Prong out (sic) in 1910. Hell of a fire....the whole West Prong. And Laurel Creek." (McCracken 1974-1975:17). (Information on the Shea Brothers operation was drawn from Cullom 1983, Lambert 1958, 1961b, McCracken 1974-75, and interviews by R. S. Lambert on file in the GSMNP Library and Archives.)

Disturbance History of the Middle Prong of the Little River

Logging was the major pre-Park human activity in the Middle Prong of the Little River. The logging practices used by the Shea Brothers on Laurel Creek (team logging and wooden slides) can be considered early-style logging (Lambert 1961a). Other early-style logging practices include the use of splash dams. From 1896-1900, J. L. English was in charge of logging operations in Blount County that included two splash dams on the Middle Prong (Burns 1952, Lambert 1961b). One dam was near the mouth of Spruce Flats Branch (in the vicinity of a bluff referred to, locally, as "Wildcat" [Foster 1970-1974] located in the vicinity of the area mapped [USGS 1964c] as "Spruce Flats"). The other dam was at the mouth of Marks Creek. According to Earl Franklin, whose uncle worked on the Marks Creek

operation, the Shea Brothers brought logs to the dam. They built a skid road (for teams) down Marks Creek to the dam. Franklin speculates that the Sheas also brought logs down Lynn Camp Prong from "maybe a half mile" upstream of the dam (McCracken 1974-1975). At the mouth of Marks Creek there was a logging camp associated with the Shea Brothers operation.

Marks Creek was also the site of a limited amount of settlement. In the early 1900s, in conjunction with news from Meigs Mountain, there are references made to people living on Marks Creek. Marks Creek is said to be named for an early settler in the area, who according to Andy Gregory (in 1925), lived in a cabin adjacent to a grist mill on Marks Creek some 80 years earlier. That cabin was extant in 1925. In 1927, A. K. Gregory described a LRLC possession cabin located on Marks Creek as having some 20 acres of land and the appearance of a very old place. He described the cabin as well known, occupied by tenants, and located on a public passway. (Marks Creek details are from the place name notes of Mary Ruth Chiles.) The old cabin may have been known to Arnold Thompson, who, while standing across from the mouth of Marks Creek, mentioned that there was a house over there somewhere. "I believe twenty-five acre cleaned up there. It's Marks Creek." (McCracken 1974-1975:15). (Note that throughout this study area description, otherwise unreferenced information on the Middle Prong of the Little River is

drawn from the transcriptions of McCracken's [1974-1975] interviews with former loggers.)

The Middle Prong of the Little River was the site of the last logging operation in GSMNP. Early-style logging was small scale and generally selective in contrast to the "second era of logging in the Smokies" (Lambert 1961a) which involved large scale clearing and railroad construction made possible by corporate investments into large tracts of land and capital intensive equipment (Lambert 1961a, Pyle 1985, 1988). Between 1904-1907 when the Shea Brothers contracted to log Laurel Creek, and the winter of 1925-1926 when the Little River Lumber company began constructing railroad lines in the Middle Prong watershed, highly mechanized logging practices suited to mountainous terrain had been perfected in the East Prong of the Little River (Elkmont area; Lambert 1961b). Used in the East and Middle Prongs of the Little River, overhead skidders (made by Clyde Iron Works), were said to be capable of reaching 5000 feet (about 1525 m), although the practical distance was generally considerably less; e.g., 2600-3000 feet (roughly 800-900 meters). In addition to skidders, which were set next to the railroad lines, inclines were built straight up and down steep slopes on quickly constructed trackage to enable logs to be brought to the railroad lines constructed up the East and Middle Prongs and their tributaries. Incline roads were used by a machine with railroad wheels and a steam powered winch. Some incline machines had the winching system and a

log loader together. The incline machine known as the "Sary Parker" did not have a log loader on it. The Sary Parker could be used to winch a log loader up to a loading site. Then the winch was used to bring a railroad car up to be loaded and winched back down to the railroad (see Joe Barnes, p. 3, in McCracken 1974-1975). In addition, inclines were used to winch a Clyde skidder up to a point where it could be set in order to save the time and cost of constructing a railroad grade and switchbacks to bring in the skidder on a train (Testimony of J. P. Murphy, Sevier County Circuit Court 1930). Thus, by means of inclines, skidders were set up and operated in areas where there is now no evidence of railroad grade construction.

Although the Middle Prong operation was the most highly mechanized logging ever done in the Smokies, early logging practices were still used where expedient. For example, horse team operators contracted to bring logs out of the headwaters of coves in which the topography had uneven breaks that would not allow the overhead skidder lines to remain above the ground. Team loggers dragged logs directly to an incline road terminus, or to within reach of a skidder, or to a point where the logs could be slid down the mountainside to be picked up by the skidder.

Not only was the scale of a mechanized operation much larger than that of early-style logging, the effects on the forest were much more severe. LRLC mill records include some 12 species groups

(Lambert 1958). Various forms of utilization involved a wide range of size classes, from very large trees down to 12 inches in diameter (about 30 cm), or even to six or eight inches in diameter (about 15 to 20 cm) for basswood. Although overhead skidders were designed to keep logs from becoming entangled with objects on the ground, the ends of logs frequently dragged on the ground, wearing in lines still visible on the landscape (McCord 1968, Pyle and Schafale 1988). Clyde skidders were described as leaving areas that resembled a big field growing up. "But you, you hardly ever left a, a tree of any size standing and all the the little (sic) was tore down." (R. Brackin, in McCracken 1974-1975:7). Such areas were subject to slash fires (Pyle 1985 1998). Because skidder sets were the vortex at which all skidding paths met, these areas suffered the greatest site degradation from skidders as well as from subsequent erosion along skid paths (Arnold Thompson, personal communication to E. R. Buckner). Other heavily impacted areas included the area along the railroad tracks which was heavily used by stationary log loaders and by the loggers' families who lived adjacent to the tracks.

Altogether, the most likely pre-Park disturbance to the study plots in the Middle Prong of the Little River was the highly mechanized logging done between 1926 and December 1938. In the area where the vegetation plots are concentrated (Figure H-1), logging was generally uncomplicated by any other form of land use. Severe logging slash fires, such as those which burned on the lower reaches

of Sam's Creek and Thunderhead Prong, are not reported for Indian Flats Prong or Davis Ridge. Prior to logging, the major farming settlement in the vicinity of Walker Valley was well downstream of the plots. In general, the gardens and livestock of loggers and their families were found in areas close to the railroad track; and there are no plots in which this appears to be a relevant disturbance.

For a few plots, other forms of disturbance not yet discussed may have been important. Areas burned prior to LRLC logging were shown by Ayres and Ashe (1905). One burned area, perhaps associated with the Shea Brothers logging, or with the pre-LRLC settlers on Marks Creek is found on both sides of Lynn Camp Prong near the mouth of Marks Creek. The others are on Mellinger Death Ridge, east of Indian Flats Prong. These are conceivably associated with cattle grazing that took place in the vicinity.

Ayres and Ashe (1905:175) discuss the forest conditions of the Middle Prong in conjunction with the West Prong of the Little River. They make several references to fire, viz,

Fire. - Nearly all the ridges have been burned over every year, killing much of the underbrush, injuring many timber trees, and deadening large areas.

Reproduction. - Free on cuttings that have not been burned. The burns are pastured, and seedlings are kept down.

This is a reasonable characterization of portions of the West Prong and of the pine ridges in the vicinity of Walker Valley which were

described by Joe Barnes (McCracken 1974-1975:42) as "huckleberry timber", which LRLC did not cut. In contrast, the presence of pines is neither biologically reasonable nor included in descriptions of pre-logging forest vegetation in the portion of the Middle Prong in which the study plots are located. However, the practice of burning and grazing in areas outlying from Walker Valley, including Thunderhead Prong, is corroborated by local people's recollections.

The area on the state line, both to the east and to the west of Davis Ridge, between the Little River and Hazel Creek, was used by livestock. In 1904, there was a drift fence across the state line east of Davis Ridge which separated the grazing area of Taylor and Crate from that associated with the Halls Cabin. (The drift fence is depicted on an untitled map prepared by G. S. Tennent in 1904, located in GSMNP Archives; Taylor and Crate was the name of a logging company from Buffalo, New York, which in 1894 cut and floated yellow-poplar logs from Hazel Creek to Chattanooga [Northwestern Lumberman, March 31, 1894, from notes of R. S. Lambert, in GSMNP Archives]). West of Davis Ridge, where the Derrick Knob trail shelter is now located, the Halls Cabin had been built around 1890 by a Hazel Creek resident for cattle herding purposes (Parris 1978). Cattle that grazed in the vicinity of Halls Cabin were driven up from Hazel Creek (O. R. Reagan, personal communication to C. Pyle and C. D. McCarter 1985). As late as 1927, the cabin was leased by the Calhouns, a North Carolina family (Place name notes of M. R. Chiles). At one

point, Granville Calhoun's grazing area extended from west of the Halls Cabin to Silers Bald (Lindsay 1976). Once the cattle were driven up as far as the Halls Cabin, there is no topographic barrier to the flat crest of Davis Knob and Davis Ridge. Thus, the unlogged "virgin forests" of upper Davis Ridge may have have been subjected to cattle foraging and herder-set fires.

Natural Vegetation Pattern of the Study Area

In general, the natural vegetation types of the Smokies are determined by the interaction of elevation with other site variables related to moisture (Braun 1950, Whittaker 1956). Braun (1950), who classified the deciduous forests of the eastern United States, put the Great Smoky Mountains into the Southern Appalachian section of the Oak - Chestnut Forest Region. This region includes mountainous areas from New York to Georgia. In the Southern Appalachian section, which includes the mountains south of Roanoke Gap, Virginia, Braun recognized five dominant forest communities. Cove hardwoods were characterized by having a mixture of mesophytic trees (such as buckeye, basswood, sugar maple, silverbell, yellow-poplar, beech, yellow birch, hemlock, or occasionally, chestnut), with from six to eight dominant species in any given stand. Above the coves (mountain valleys), on slopes at moderate elevations, a community of chestnut or oak-chestnut was found. Except on good sites, the oak-chestnut forest was characterized by a heath understory. A third community, found on outlying spurs and plateaus of the Blue Ridge physiographic

province (see Fenneman 1938), was comprised of oak and oak-pine forests. In GSMNP, specifically, Braun noted that forests of pine and heath occurred on some dry south slopes of lower ridges and locally at moderate elevations, not always on southern slopes. In general, in the Southern Appalachian section, at higher elevations, a transition was made from oak-chestnut forest species to the northern hardwoods forest type. This type is typified by sugar maple, yellow birch, beech, and buckeye, but other species may be present. Particularly in the Great Smoky Mountains, the transition to northern hardwoods may be from cove hardwoods species. Also, occurring at high elevation, though not found within the present study area, is the spruce-fir forest type.

Forests mapped as oak-chestnut by Frank H. Miller comprised 31 percent of the Park (refer to map dated 1938 with notes dated 1953 mounted on the wall at Sugarlands Visitor Center, GSMNP). Even in 1938, Miller estimated that 85 percent of the chestnut trees were affected by chestnut blight (Miller 1938). By the 1950's, the oak-chestnut types of Braun (1950) and Whittaker (1956) were based on dead or almost dead trees. Nonetheless, a useful overview of the natural vegetation pattern of the study site is provided by the basic framework of cove hardwoods, oak-(chestnut), oak-pine or pine-heath, and northern hardwoods seen against major site moisture and elevational gradients. Variants of these basic groupings of species may be attributable to fine scale variations in elevation, aspect, or

other environmental factors, and proximity to other forest types (Braun 1950, Whittaker 1956; also see review of literature on site-vegetation relations in the preceding chapter). More important to the present study (and, reviewed in the preceding chapter), species composition may be influenced with varying results by past disturbance.

CHAPTER IV

MATERIALS AND DATA COLLECTION

Previous Data Collection

The present study builds on (1) vegetation data collected by Uplands Lab personnel who used the methods of Bratton (1978) and (2) site data collected by Callaway (1983). Beginning in 1978, Uplands Lab personnel sampled and permanently marked the boundaries of some 300 vegetation plots in Great Smoky Mountains National Park. Callaway (1983) studied about half of those plots. The present study was limited to the subset of Callaway's plots, located in western GSMNP, which Uplands Lab personnel had identified as containing disturbed vegetation. Variable names, detailed parameter descriptions, and sources for all data used in the present study are listed in Appendix A. Described below are (1) the procedures used by Uplands Lab personnel to collect the vegetation data used in the present study, and (2) the methods of Callaway (1983) for data used or discussed in the present study. Data collection procedures specific to the present study are described in a separate section.

The vegetation data set of Uplands Lab was based on sampling done in 20 m by 50 m plots. For the present study, the "overstory" data of Uplands Lab were used. The "overstory" included all individuals with at least a 10 cm dbh. Within each plot, the

overstory was tallied by species to the nearest centimeter. No record was made of tree crown class position.

Data collected by Callaway (1983) included the variables "topography class," "drainage area," and "protection". (See RT, DRA, and PRO in Appendix A.) These variables were all obtained from 1:24,000 scale topographic maps.

The topography variable was used to characterize the landform on which a plot was situated. Topography classes were arranged on a gradient from xeric to mesic. Ridge tops, considered the driest sites, were assigned the value "1" and mesic flats were assigned an "8".

Drainage area referred to the size of the catchment area from which runoff rainfall and snowmelt could drain into the plot. Drainage area was estimated in hectares using a planimeter and gridform (Callaway et al. 1987).

The protection variable was used to characterize the landforms surrounding the plot in an effort to quantify the degree of exposure of the site. Calculation of protection was based on the weighted average of eight measurements, taken on fixed azimuths, of the (ratio of slope elevation change to distance) from the plot to the closest landform of greater altitude (Callaway et al. 1987).

The soils data of Callaway (1983:11) were based on the analysis of samples from one soil pit dug within each plot. In the field, the volume of large stones and the thicknesss of the A, B, and organic soil horizons were recorded. The total soil depth was measured "from the top of the organic horizon to the deepest point penetrated by a metal probe". In the laboratory, texture (percent sand, silt, and clay) and pH of both the A and B horizons were determined.

Callaway (1983) expressed productivity in terms of the cubic meters of bole wood produced per hectare per year by all the trees within a plot that were 30 cm (ca 12 inches), or greater, in dbh (see VOL, Appendix A.) Productivity was estimated in each plot using five randomly sampled trees 30 cm in dbh, or greater. A series of random numbers was used to determine a distance down the plot centerline and direction (right or left) to the sample tree in each of five 20 m by 10 m subsections of the plot. The first tree greater than 30 cm dbh encountered after turning from the center line was sampled. One increment core per tree was taken. The last 10 years of radial growth on the extracted increment core was measured in the field to the nearest 0.01 inch (N. S. Nicholas, personal communication to C. Pyle, March 1988). Dbh (outside bark) of the tree was measured to the nearest 0.1 centimeter. Tree height was measured in feet.

The periodic annual volume increment was defined as the amount of bole wood accumulated by a tree in a year (Callaway 1983). Periodic annual volume increment was equal to one tenth of the

estimated volume increment of the past 10 years. For wood volume calculations, a cone was used to model tree bole shape (volume = $[\text{Pi} * \text{radius}^2 * \text{height}]/3$). For the calculation of the wood volume current at the time of sampling, the bole radius was estimated by taking half the tree diameter measured in the field; and the height was that recorded at the time of sampling. For calculation of the estimated bole volume 10 years before, the current height (recorded at the time of sampling) was used. The 10 year increment was subtracted from half the current diameter to estimate the bole radius 10 years before. The 10 year volume increment was calculated by taking the difference between the estimated current bole volume and the bole volume estimated for 10 years before. The data were input into the following formula:

$$\text{MAVI} * \text{TREES} * 10$$

where

MAVI = the mean of the periodic annual volume increment of five
trees per plot

TREES = the number of trees 30 cm dbh or greater in a plot

10 = a factor to convert the plot data into hectares

For the present study, the result of this equation was termed the "plot productivity index score." No additional plot productivity data were collected.

Data Collection for the Present Study

Both site data and data related to disturbance history were collected for the present study. Disturbance history evidence was systematically noted in each plot using a checklist of items indicative of historic vegetation disturbance (Appendix B).

A systematic search for charcoal was made in each plot using a 25 cm by 25 cm frame. The frame was placed randomly in each of 40 five meter by five meter sections of the plot. To reference the sampling position within the plot, a 50 m tape was laid between the permanently placed stakes that mark the center of each 20 m end of the plot. The two five meter by five meter plot subsections on either side of each five meter section of the center line were located by pacing at right angles from the centerline. After the frame was tossed into each subsection, the soil organic layer was removed to expose the mineral soil surface within the area enclosed by the frame. The presence or absence of charcoal in four size classes was recorded. The size classes, measured on the longest dimension of the charcoal fragments, were (1) <5 mm, (2) 5 mm to 10 mm, (3) >10 mm to 100 mm, and (4) >100 mm. A charcoal measuring template was made by marking the edge of the data sheet with points for 0 mm, 5 mm, 10 mm, and 100 mm.

In order to estimate the mean stand age and range of tree ages within each plot, increment borings were made to the pith of five

selected canopy trees. Where present, intolerant species were selected for coring to determine if there was an even aged component within the stand. In addition, the largest tree was cored to estimate the age of the oldest tree in the stand. Canopy trees included three crown classes: dominants, codominants, and gap fillers. Gap fillers were trees (of smaller diameter than the average codominant tree) which had been left free to grow by the death of the surrounding trees. The gap fillers cored had a straight formed, vigorous appearance, and were as tall as, or as nearly tall as, the average canopy height. One core per tree was taken. All trees were cored at the level of one meter height on the uphill side of the tree. However, the increment borer itself was inserted on the side of the tree from which it was judged that the pith could be most reliably hit.

For the cored trees, species, diameter, crown class, and position in the plot relative to the plot centerline were recorded. Diameter was measured with a diameter tape to the nearest 0.1 cm at one meter height on the uphill side of the tree. Distance down the centerline was read to the nearest one meter and distance right or left of the centerline was estimated by pacing. The total number of growth rings was counted and recorded in the field. The cores were saved in soda straws for a recount in the office.

The topography in the vicinity of the plot was characterized in four ways. Within the plot, the plot terrain was rated (from 1-5) on

a gradient from dry to moist based on slope shape (MG, Appendix A). The plot orientation was measured as an azimuth with a hand held compass. Plot slope was measured in percent with a clinometer along the line of the plot azimuth. Nine landform descriptions were arranged on a gradient from mesic to xeric. Based on the local topography seen from the perspective of the plot, each plot was given a landform score from 1-9 (LAND, Appendix A).

To categorize the average slope and aspect of the landform on which a plot was situated, the slope and aspect (measured as an azimuth) were derived from 1:24,000 scale topographic maps. Slope was measured as the ratio of elevation change to horizontal distance. Elevation was read off the contours of the map in 40 foot intervals. Horizontal distance was measured between 40 foot contours where the slope appeared to be constant (i.e., where the map contours were evenly spaced). Distance was estimated to the nearest 10 feet using an engineer's scale on which 1/20 inch equals 100 feet at the 1:24,000 map scale.

CHAPTER V

DATA ANALYSIS

Introduction

The study area included 70 plots used by Callaway (1983) in which the forest was considered disturbed by Uplands Lab personnel. For the present study, seven plots were dropped from the analysis: two for lack of internal topographic homogeneity, one for lack of internal homogeneity in disturbance history, and four for being outliers in terms of species composition. Three of the four vegetational outliers were samples from forest types commonly found in GSMNP that were not well enough represented to be analyzed. (One was in a hemlock stand and two were in hemlock - yellow-poplar stands.) The fourth outlier, dominated by sweetgum, represented the forest cover of a periodically inundated swamp, a rare forest situation in GSMNP. After elimination of the outliers, the final analysis involved 63 plots.

Assignment of Forest Cover Types

Prior to the analysis of the data, forest cover types were assigned to the plots based on basal area of dominant and codominant trees rather than all individual stems in the "overstory." Because the vegetation data of Uplands Lab did not include crown position of "overstory" (i.e., ≥ 10 cm in dbh) stems in a plot, a system (detailed

in Appendix C) was employed to designate individuals likely to be found in the upper crown canopy (i.e., dominants and codominants).

The upper crown canopy data were subjected to analysis by Two-way Indicator Species Analysis (TWINSpan; Hill 1979b, Gauch 1980), a computer program designed to group plots by making a hierarchy of successive dichotomous divisions of the plots based on differences in species composition. As will be discussed later, a hierarchy of divisions does not necessarily lead to homogenous groups of plots. Therefore, the methods used to develop the Society of American Foresters (SAF) forest cover types (Eyre 1980), were used to develop a second vegetation classification.

This approach was chosen as an alternative to computerized techniques which treat all species as equally different. In contrast, the SAF method allows the investigator to apply silvical knowledge concerning similarities among species. For example, with a non-computerized technique, during the classification process the fact may be considered and used that Virginia pine and pitch pine are more similar in growth habit and response to site factors than are Virginia pine and southern red oak. It should be noted that the objective of subsequent discussion of the two methods of classification used in the present study will be to explain how the choice was made between the two within the confines of the present study. Thus, the analysis and discussion should not be construed to be an attempt to review all available classification techniques.

The SAF approach to the naming of forest cover types is based on the following rules (Eyre 1980):

- Forest cover type is based on the present (not potential) occupancy of an area by tree species.
- Forest cover types are named after predominant tree species.
- Predominance is based on basal area.
- To be used in the type name, a species must comprise at least 20 percent of the total tree basal area in a plot.
- Forest cover types may be described as pure (stocked 80 percent or more by a single species), a majority (the species in the name comprise more than half the stocking), or a plurality (the species in the name comprise the largest proportion in the stand).

For each plot in the present study, species basal area was calculated and converted to percent of the total plot basal area. Because only six of the 88 SAF forest cover types in the eastern United States are described as pluralities (Eyre 1980), pluralities were not used for the present study. Rather, names were assigned to the vegetation that comprised at least 50% of the plot basal area. An arbitrary rule was made that to be retained in the analysis, a forest cover type had to be represented by at least four plots. For plots named by a type name given to fewer than four plots, similar forest cover types were aggregated into a cover type derived by assigning a more general description to the plots. For example, the

Scarlet Oak - Pitch Pine (which also included 21% table-mountain pine), Virginia Pine - Pitch Pine, and Pitch Pine forest cover types each included less than four plots. So, a new cover type, named "Yellow Pines" (a generality) was created to group together plots in which the combined basal area of Virginia, pitch, table-mountain, and shortleaf pines constituted a majority (at least 50%) of the basal area of each plot.

Summarization of Site and Disturbance History-Related Variables

Field evidence of disturbance history was augmented with information from the vegetation map of Frank Miller (located in the GSMNP Archives; Miller 1938) and by photo-interpretation of photo-mosaics dated 1939 (in GSMNP Archives) and aerial photographs of Cades Cove dated 1946 (in GSMNP Resources Management). The final categorization of plot disturbance was subjective.

The charcoal data were summarized into nine categories. Each of the 40 subsections of a vegetation plot was weighted equally, and all plot summaries were expressed in terms of the total number of subsections within which a designated size class or combination of size classes of charcoal was present. The nine categories were based on the original size classes sampled: A = <5 mm, B = 5 mm - 10 mm, C = >10 mm. Because there was only one plot in which charcoal over 100 mm was found, this size class was dropped from further analysis. Additional charcoal categories (SUMD - SUMI, Appendix A) were

combinations of the three size classes, A, B, and C. For example, charcoal category D (SUMD, Appendix A) was used to tally the presence of charcoal without respect to size class (i.e., the presence of either A, B, or C).

Two recounts of the number of rings on each tree core were made in the office under bright light, using a hand lens. One side of each of the cores was planed smooth with a razor blade and was wetted with vinegar to darken the latewood. If the increment borer appeared to have missed the pith by a few rings (i. e., there was a point in the core where the rings curved in a tight arc), then the remaining number of rings to the pith was estimated.

If there was no indication that the end of the core was near the pith (as was the case with very large, hollow, or rotten trees), the number of rings to the pith was calculated based on the assumptions that the estimated radius of the tree (calculated as one half the measured diameter) represented the expected distance from the bark to the pith and that the observed growth rate (rings per centimeter) of the last available part of the core represented the growth rate of the missing part of the increment core. The length of the missing part of the core was estimated by taking half the estimated radius minus the length of the core. Where the counted number of rings varied, tree age was taken to be the average of the two counts made in the office. No allowance was made for the number of years a tree might have taken to reach the one meter height. The tree age data

were summarized by plot. Mean age, standard deviation, and variance were calculated. Maximum and minimum age were tallied.

For the topographic data, the moisture gradient and landform scores of the present study and the topography gradient rankings of Callaway's data were treated as continuous variables after the manner of Harris (1985). Both the plot azimuths taken in the field and the azimuths derived from maps were transformed following the method of Beers et al. (1966). This method uses a cosine transformation to give southwest aspects low ratings and northeast aspects high ratings (based on the fact that, given other factors are equal, tree growth has been observed to be greater on north and east facing sites in the northern hemisphere).

NOTE: Site and disturbance history-related variables taken together will be hereafter referred to as site/disturbance history variables.

Examination of the Relationship Between Site/Disturbance History Variables and Vegetation

Detrended Correspondence Analysis (DCA; Hill 1979a, Hill and Gaugh 1980) was used to arrange the plots on a mathematical gradient based upon their species composition. Species composition was expressed in terms of percent of the total plot basal area. When plots are ordinated, the first axis provides the greatest separation between individual plots. The ecological rationale behind creating

ordination gradients is the belief that vegetation is distributed along ecological gradients (e.g., a moisture gradient) which are composed of complex interactions between many variables. Thus, it is to be hoped that the position of plots along the gradient of species composition change is indicative of their relation to each other along an environmental gradient. More details on how DCA works and why it is useful are found in Appendix D.

The plots were graphed (in an ordination diagram), against two axes, based upon their plot scores on the first two vegetation gradients produced by DCA. Plots were labelled as to forest cover type (Figure H-2). Lines were drawn to indicate the different forest cover types in the DCA diagram.

If plots of the same forest cover type are generally clustered together in the DCA diagram, then the relationships between the DCA axis and site/disturbance history variables may be examined to gain insights into the relationships between site/disturbance history variables and forest cover group. Correlation analysis between plot scores and site/disturbance history variables was done to quantify the strength of the relationship between the gradients of vegetation change and individual site/disturbance history variables (Table G-1). Correlation analysis also provided information on the relationships among site/disturbance history variables (Table G-1).

Using site/ disturbance history variables that were significantly correlated to the first two DCA axes, an analysis of variance was done to measure the strength of the relationships between forest cover type and site/disturbance history variables. Student-Newman-Keuls multiple range tests were used to determine which variables resulted in significant separation of forest cover type (group) means (Table G-2). To provide further information on the relationship between forest cover type and disturbance history, the ordination diagram was relabelled with disturbance history information (Figure H-3).

Prediction of Forest Cover Type

The initial workplan for the present study involved the prediction of forest cover type by means of regressions based on the values of site/disturbance history variables to predict the position of the plot in ordination space. Although plots of the same forest cover type were generally found adjacent to one another in the ordination diagram, one forest cover type was not discrete. That is, the plots of this forest cover type were found at a considerable distance from one another and were separated by plots of other forest cover types (Figure H-2). Thus, the initial plan was abandoned; and forest cover type was predicted using discriminant analysis (PROC DISCRIM of SAS Institute, Inc. 1985; computer programs used in data analysis are listed in Appendix E.)

Discriminant analysis is a classification technique used to create the greatest degree of separation among class (i.e., group) means. The discriminant technique used involves taking a set of variables, applying weights to each variable, and summing the total of the weighted variables for each plot. The optimum solution is one that results in the greatest possible separation of group means. A plot is then classified according to which group (i.e., forest cover type) it has the highest probability of being found in. The probabilities are based on the comparison of the plot's weighted variables with the distribution of the values of those variables around the mean of each group. In the present study, forest cover type was the classification variable. Site/disturbance history variables were used as discriminatory variables (i.e., the variables to which weights were applied). Individual plot scores were calculated as the sum of the weighted variables. Class means were the average plot score for all plots in a given forest type.

Stepwise discriminant analysis was used to determine which of the site/disturbance history variables best separated the different forest cover type means. Variables significantly correlated ($P=.05$; Table G-1) to the first two DCA axes were included in the stepwise analysis. With the 10 best predictors, a discriminant model was made using seven tenths of the data set. This portion of the data set was derived by taking a random two thirds to three fourths of each of the forest cover types. To see how well site/disturbance history

variables predict forest cover type, the model was validated with the remaining three tenths of the data set. The stepwise procedure and test of the model were repeated using only variables which could be derived from a map.

Prediction of Plot Productivity Index Score

Correlations (Table G-1) were examined for (a) the plot productivity index score and the natural log of the plot productivity index score (Callaway 1983) versus (b) site/disturbance history variables. Variables significantly correlated ($P < .1000$) to productivity were entered into a stepwise regression program using the maximum R^2 improvement technique. In stepwise order, the best five variables were entered into a general linear model. The sequential sum of squares was examined for each variable. Only those variables for which the F statistic was significant ($P = .05$) were retained for further analysis. Regressions involving interaction and quadratic functions were done.

CHAPTER VI

RESULTS

Forest Cover Type Designations

The eight forest cover types assigned by the SAF methodology were (1) Yellow Pines, (2) White Oak - Oak, (3) Chestnut Oak - Oak, (4) Mixed Sub-xeric Hardwoods, (5) White Pine - Hardwoods, (6) Chestnut Oak - Yellow-poplar, (7) Yellow-poplar, and (8) Mixed Mesic Hardwoods (Figure H-4). The 19 clusters of plots created by TWINSpan were named according to the species common among all the plots (Figure H-5). For each TWINSpan cluster type, the plots were listed by the percentage of plot basal area accounted for by all the species that the plots in that cluster type had in common (i.e., those species included in the cluster name). For comparison to the forest cover types derived from the SAF methodology, the percentage of the plot basal area accounted for by the species in the TWINSpan cluster name, is followed by an abbreviation for the SAF forest cover type to which the plot was assigned (Figure H-6). As will be discussed later, the TWINSpan clusters and the SAF method forest cover types do not always result in similar groupings of the plots.

To avoid having forest cover types composed of less than four plots, the TWINSpan clusters were combined (results not presented). As already described, the forest cover types assigned by the SAF methodology represented combinations of forest cover types. In

addition, the Virginia Pine forest cover type (which included exactly four plots) was combined with the Yellow Pines forest cover type because all of the Virginia Pine plots included other yellow pines in addition to Virginia pine; and, in two of the plots, other yellow pines comprised more than one third of the basal area. The eight forest cover types assigned by SAF method were used in all subsequent analysis because in comparison to any possible combination of the TWINSpan clusters, the SAF forest cover types had a greater internal homogeneity (i.e., the plots included in a given SAF type had a greater basal area of the same species or species groups in common than did the TWINSpan groups).

Relationship of Site/Disturbance History Variables
to the Gradient of Plot Species Basal Area Composition

When the plots, labelled according to forest cover type, were examined in relation to their position along gradients of change in species composition shown on the DCA ordination diagram (Figure H-2), it was apparent that all of the forest types included some variation in plot species composition. To some extent, the White Pine - Hardwoods were mixed in with the White Oak - Oak, Yellow-poplar, and Chestnut Oak - Yellow-poplar groups. Less than half the Mixed Sub-xeric Hardwoods were clustered together. The remainder were found as outliers to the White Oak - Oak, Chestnut Oak - Oak, and Mixed Mesic Hardwoods forest cover types. Six types (Yellow Pines, White Oak - Oak, Chestnut Oak - Oak, Chestnut Oak - Yellow-poplar, Yellow-poplar,

and Mixed Mesic Hardwoods) were clustered closely enough that lines could be drawn in the ordination diagram to include almost all members of each type in a separate cluster. However, plots of a given forest cover type were not tightly clustered about their mean species composition. In fact, in many cases, individual plots of one forest cover type were found closer to individuals of another forest cover type than they were to the other plots of the same type. When the ordination diagram was viewed as a whole, without reference to the lines that separated the plots into their assigned forest cover types, the overall arrangement of plots indicated a gradual change in species composition along the DCA axes.

Correlations between site/disturbance history variables and the DCA axes (Table G-1) were studied to gain understanding of which variables appear to control the gradients of species composition. Elevation showed the greatest correlation to the plot scores of the first DCA axis ($r=0.78$, $P=0.0001$). The correlation suggested that some of the differences in species composition along the first DCA axis could be attributed to site differences associated with elevation. Other variables correlated ($P \leq 0.01$) with the first axis were percent clay in the A horizon ($r=0.58$), percent clay in the B horizon (-0.61), percent sand in the A horizon (0.46), percent sand in the B horizon (0.44), thickness of the A horizon (0.42), protection (0.44), plot slope taken in the field (0.33), plot slope derived from a map (0.37) drainage area upslope of the plot (0.36 ;

DRA, Appendix A), and the Beers' transformation of the plot azimuth derived from a map (0.38; BEERSOFF, Appendix A). Based on these results, the first DCA axis appeared to represent a gradient of the combined effects of elevation, soils factors (texture and topsoil thickness), and topography. These effects taken together suggest that a moisture gradient controls changes in species composition.

The factors included in a complex-gradient do not necessarily contribute equally at all points on the gradient. Therefore scatterplots of the first DCA axis versus the significantly correlated variables were made to allow the examination of the nature of the relationships. From the scatterplots, the strength of the correlations between elevation, drainage area, and transformed map azimuth (Figures H-7, H-8, H-9) appears to depend upon the fact that one of the ends of the DCA axis is strongly correlated with higher or lower values of the site/disturbance history variables, rather than that there exists a constant trend in relation to the gradient of DCA scores.

For scores below 300 on the DCA axis, over half of the vegetation plots were situated between 1800 and 2200 feet (about 550-670 m) elevation. Below a DCA axis score of 300, only one plot was situated over 2500 feet (about 760 m) elevation. Above a score of 300, the plot elevations (with the exception of two plots) are above 2850 feet (about 870 m); and an upward trend (elevation versus DCA axis score) can be seen (Figure H-7).

Very small drainage areas are consistently associated with plot DCA axis scores below 50. These plots were all in Yellow Pines forest cover type (#1). Between 50 and 200 on the first DCA axis, the drainage areas were small (generally less than 2 hectares). Above a score of 200, Yellow-poplar (forest cover type #7), plots had exceedingly high values for drainage area; and the Mixed Mesic Hardwoods plots (type #8) had a higher than average size drainage area. Altogether, the upward trend was not uniform for drainage area along the first DCA axis (Figure H-8).

High values for the transformation of the plot azimuth derived from a map were seen above a score of 300 on the first axis for 14 of the 21 plots (Figure H-9). In tabulated plot data (not presented here) 14 of the 21 plots had transformed azimuths of 1.71 or more. Transformed azimuths of 1.71 or greater include compass azimuths from 0 to 90 degrees (i.e., north to east aspects).

Site variables negatively correlated ($P=0.01$) with the second DCA axis were the pH of the A horizon ($r=-0.48$), pH of the B horizon (-0.61), thickness of the A horizon (-0.41), total soil depth (-0.37), drainage area (-0.35), and topography type (-0.37). Because pH indicates the negative logarithm of the hydrogen ion (H^+) activity in the soil, as pH values decrease, H^+ (i.e., acidity) increases. Because topographic type was organized on a gradient from xeric to mesic, a negative correlation of topographic type and the DCA axis means that as the DCA axis score increases, the topographic type

becomes less mesic. The depth of the soil organic horizon and three measures of tree age (MAX, MEAN, and STDEV, Appendix A) were positively correlated to the second DCA axis ($P=0.01$; respectively, $r=0.48, 0.40, 0.36, 0.43$). This combination of correlations suggests a gradient composed of site quality factors relating to soils, topography, and historically open stand conditions. High site quality (thick A horizons and mesic topography) and historically open conditions were at the lower end of the axis. Historical differences in sunlight conditions are deduced from the presence of stands now generally classed as young and even-aged versus older, uneven-aged stands.

When site variables were plotted against the second DCA axis (scatterplots not presented), the variables with the most uniform rate of change across the DCA gradient were the depth of the organic horizon, thickness of the A horizon, and pH of the B horizon. Except on the highest portion of the second DCA axis, increases in stand age-related variables (i.e., older trees, greater deviations of tree age within a plot) were seen with increasing DCA scores. Topography class and the pH of the A horizon showed pronounced differences between the lower and upper ends of the second DCA axis. However, these variables had inconsistent rates or directions of change along the DCA axis.

The DCA ordination done for the present study included four axes. Few site/disturbance history variables were significantly

(0.0999) correlated to the third and fourth axes (Table G-1). The third and fourth axes also were not correlated to forest type; and they will not be discussed further.

Relationship of Site Variables to Forest Cover Type

Relationships of site variables to forest cover type may be seen in a summary table (Table G-3). Yellow-poplar and Mixed Mesic Hardwoods types are more likely to be found on soils of lower clay content, higher sand content, and deeper A horizons than are other types. (Refer to Table G-2 for information on which forest cover type means are significantly different based on examination of individual site variables.)

Both the Yellow-poplar and Mixed Mesic Hardwoods also show something of an affinity for mesic aspects (as measured by high values of Beers' transformed aspect). The mean elevation of the Mixed Mesic Hardwoods plots is about 4000 feet (about 1220 m) with a standard deviation of 913 feet (about 280 m). This separates the Mixed Mesic Hardwoods from all other forest cover types.

Among the other forest cover types, there are not significant differences based on elevation. Although not significantly different from other forest cover types, the Yellow-poplar had the highest mean pH in both the A and B soil horizons. The Yellow-poplar forest cover type had the shallowest organic horizon, while Yellow Pines and Mixed Sub-xeric Hardwoods had generally deeper organic layers. Depth of

organic layer is important in separating the Mixed Sub-xeric Hardwoods from other forest cover types.

Higher values for protection characterize the Chestnut Oak - Yellow-poplar forest cover type. The Yellow Pines, White Oak - Oak, and White Pine - Hardwoods forest cover types have the lowest means for protection (PEO, Appendix A). However, there is considerable overlap in the ranges of these three types. Additionally, there is overlap with the ranges of the other forest cover types.

According to forest cover type means, the most mesic topography was found in the White Pine - Hardwoods, while the most xeric topography occurred in the Yellow Pines and Mixed Sub-xeric Hardwoods. The White Oak - Oak forest cover type was more xeric on the average than the Chestnut Oak - Oak type, but this difference was not statistically significant. Altogether, as may be expected, the means of different pairs of forest cover types are able to be statistically separated when different site variables are examined (Table G-2). However, no single variable is significantly different for every pair of forest cover types.

Relation of Disturbance History-Related Variables to Forest Cover Type

Examination of the correlations between disturbance history related variables and the gradient of change portrayed by the DCA axes suggests that relationships between some disturbance history-

related variables and individual forest cover types are to be expected. The relationship of disturbance history to forest cover type is presented graphically in Figure H-3. Comparisons among forest cover type means with respect to age-related variables and the presence of charcoal are included in Table G-3. Only the differences in age-related variables are statistically significant (Table G-2).

Young, even-aged stand conditions were typical of the Yellow Pines and Yellow-poplars (Figures H-3, H-10, H-11). The degree of even-aged conditions is estimated by the measure of standard deviation of the age of the cored trees within a plot. For the present study, plots with a standard deviation of less than 11 years were considered even aged (Figure H-3). Mixed Mesic Hardwoods plots had a wide range in mean stand age, but on the average had lower values for the standard deviation of the mean stand age (i.e., had a greater proportion of even-aged plots) than did the White Oak - Oak, Chestnut Oak - Oak plots, Mixed Sub-xeric Hardwoods, and Chestnut Oak - Yellow-poplar forest cover types (Figures H-3, H-10, H-11). The White Oak - Oak, Chestnut Oak - Oak, and Chestnut Oak - Yellow-poplar forest cover types were characterized by older trees (Figure H-10). The forest cover type (group) mean for the mean plot age was over 100 years for these three cover types (Table G-3).

In a total of 31 plots charcoal was present in at least five out of the 40 samples taken per plot and/or there were charred stumps, logs or snags in the plot. The presence of charred material or

charcoal in five out of 40 samples was considered strong evidence of fire.

All of the Chestnut Oak - Oak and the Chestnut Oak - Yellow-poplar plots and a portion of the Yellow Pines and Yellow-poplar plots had strong evidence of fire. Signs of former occupation by chestnut trees were seen in 15 plots, including all of the Chestnut Oak - Yellow-poplar forest type. With one exception each, the Yellow Pines, White Oak - Oak, and Yellow-poplar cover types were lacking in evidence of former chestnut presence. Within the Chestnut Oak - Yellow-poplar forest cover type, all plots had sign of both fire and chestnut blight.

All 17 of the plots located in the Cades Cove area above the confluence of Abrams and Forge Creek and within one kilometer of the Cades Cove loop road (Figure H-1) were found at or below an elevation of 2000 feet. None had indications of former chestnut presence. Only one had strong evidence of fire. The 17 Cades Cove perimeter plots were classified in the Yellow Pines, White Oak - Oak, White Pine - Hardwoods, and Yellow-poplar forest cover types.

The disturbance history checklist data for Chestnut Oak - Oak plots did not include any evidence of clearing of the sites for farming activities (Figure H-3). Neither was evidence of historical clearing found in the White Oak - Oak plots. Evidence of historical clearing for farming included signs seen in the plots (rock piles,

rock walls). Also, the examination of historical aerial photographs indicated that, in 1939, some of the plots were situated in clearings completely devoid of trees. All of the Yellow Pines plots except one had been cleared, mostly through farming-related activities. The Yellow Pines plot that was not cleared had signs of both fire and former chestnut trees. All but one of the Yellow-poplar plots had been previously cleared through farming or logging. In the logged Yellow-poplar plots, evidence of fire was more common than in the farmed Yellow-poplar plots (Figure H-3).

Examination of tabulated plot data (not presented), revealed that where yellow-poplar trees were important in the White Pine - Hardwoods forest cover type, the plots included signs of farming. And, where the Mixed Mesic Hardwoods had stumps or an even aged appearance, logging, rather than farming activities, was indicated.

Forest Cover Type Prediction

In order of selection by stepwise discriminant analysis, the 10 best predictors of forest cover type were: 1) elevation, 2) protection, 3) mean plot age, 4) topography class, 5) transformation of the plot azimuth derived from a map, 6) depth of the soil organic layer, 7) thickness of the B horizon, 8) transformation of the plot azimuth taken in the field, 9) variance of the mean plot age, and, 10) maximum age of the trees cored in a plot. The averaged squared canonical correlation of forest cover type to the 10 variable linear

function was 0.41. This means that when the plots are described by the 10 variables taken together, 41% of the variation among plot forest cover type will be accounted for. These 10 variables represent a complex of elevation, topography, plot age, and soils parameters that cannot be simply described. The function will be referred to as a site quality - tree age gradient.

A second stepwise discriminant analysis was done using the six site variables that could be derived from maps: 1) elevation, 2) protection, 3) topography class, 4) transformed plot azimuth, 5) drainage area, and, 6) slope. The first five variables (of those listed above), were included in the stepwise model, with a total average squared canonical correlation of 0.25. This function is simply described as a topographic moisture gradient.

When all 63 plots were used to construct the discriminant functions, the 10 variable model was 100% successful in grouping the plots into the correct forest cover types. The five variable model classified 90% (all but six) plots correctly. Using the same sets of discriminating variables, new weighted linear functions were derived from seven tenths of the plots. These functions were tested on the remaining three tenths of the plots. The 10 variable model correctly classified 13 of the 19 test plots (68%), while the five variable model classified eight plots (42%) correctly.

Plot Productivity Index Score Predictions

Plot productivity index score was significantly correlated ($P=0.0001$) with topography type, total soil depth, and the pH of the B horizon (Table G-1). According to the results of a stepwise regression done with all site/disturbance history variables with a correlation significance of $P=0.0999$ (Table 1), the best five predictors of plot productivity index score were 1) topography, 2) total soil depth, 3) sand in the A horizon, 4) Beers' transformed azimuth of the plot azimuth taken in the field (BEERSAZ, Appendix A), and 5) landform class (LAND, in Appendix A).

When the natural logarithm of the plot productivity index score was used as the dependent variable, the best five predictors were 1) topography, 2) total soil depth, 3) pH of the B horizon, 4) the Beers' transformed mapped plot azimuth (BEERSOFF, Appendix A), and 5) the minimum age of cored trees in the stand. For prediction of both plot productivity index score and its log, examination of the sequential sum of squares indicated that only topography and total soil depth were significant additions to the models.

Scatterplots of topography versus plot productivity index scores (Figures H-12, H-13), and total soil depth versus plot productivity index scores (Figures H-14, H-15) show some relationship to productivity for both of these site variables. However, it is evident that neither variable alone explains all the variance in

productivity. The portion of the variance in plot productivity (R^2) explained by topography and total soil depth taken together was 40% and 43%, respectively, for the plot productivity index score and its log. Models with quadratic terms and/or an interaction did not result in a significant increase in R^2 . The model used involves topography class and total soil depth:

$$\hat{Y} = a + b_1X_1 + b_2X_2$$

where

\hat{Y} = the predicted volume increment

a = the intercept

b_1 = the regression coefficient of X_1

b_2 = the regression coefficient of X_2

X_1 = the first variable; topography

X_2 = the second variable; total soil depth

CHAPTER VII

DISCUSSION

Relationship of the Forest Cover Types Identified in the Present Study to Those of Other Studies in the Great Smoky Mountains and to Types Described by the Society of American Foresters.

(1) YELLOW PINES Forest Cover Type

Whittaker (1956) separated the yellow pines of GSMNP into three groups, by elevation, with Virginia pine at the lower elevations, pitch pine at mid elevations, and table-mountain pine at both upper elevations and on more exposed ridges. Virginia pine stands were found both in old fields and in what Whittaker considered climax pine stands on south facing slopes. He noted pitch pine and scarlet oak as associates in climax Virginia pine stands. Shrub coverage was generally 10%-40% in contrast to the 40%-70% ericad cover in pitch pine stands. The yellow pines of the present study included three of Callaway's Scarlet Oak - Yellow Pine plots, only two of which could have been named as such by the SAF methodology used in the present study. These three plots were on xeric topography, rather than in old fields or in other areas known to have been historically cleared. In contrast, all but one of the remaining Yellow Pine plots of the present study were included in the Yellow Pines cover type of Callaway (1983) and were similar to the Successional Yellow Pines described by Harmon (1980) and Thomas (1966).

Three pine forest cover types, Pitch Pine, Virginia Pine, and Virginia Pine - Oak, described by the SAF (Eyre 1980), are relevant to the present study. Note that the types described by the SAF were developed according to the SAF rules outlined earlier; i.e., for a species or species group to be included in the forest cover type name, it must comprise at least 20% of the stand basal area, and, a majority (at least 50%) of the stand basal area must be accounted for by the species given in the type name.

As described by the SAF, both the Pitch Pine type and the Virginia Pine type include pure stands or majority stands. Associated with the Pitch Pine and Virginia Pine types are Virginia and pitch pines (respectively) and xeric oaks, hickories, red maple and other pines. Both the pitch pine and Virginia pine types are said to be found on old fields and following fire.

The third SAF type, Virginia Pine - Oak includes a basal area majority composed of Virginia pine and oaks. Associated species are pitch pine, table-mountain pine, hickories and red maple. This cover type is found on both old fields and upland sites. Yellow-poplar is mentioned as an associate for the Virginia Pine and Virginia Pine - Oak types, but not for the Pitch Pine type.

(2) WHITE OAK - OAK Forest Cover Type

In the present study, all but two of the nine White Oak - Oak plots were found in Cades Cove upstream of the junction of Abrams and

Forge Creeks. In GSMNP, this forest cover type seems to be mostly restricted to Cades Cove (personal observation); and, in that respect is similar to the White Oak - White Pine type of Callaway (1983). Whittaker (1956), however, described a White Oak - Chestnut Oak forest found on some exposed, southwest facing ridges above 4500 feet (ca 1370 m) elevation. White oak, along with northern red oak and chestnut oak, was a component of Thomas' (1966) Mixed Oak Flats forest cover type. This type was found in areas formerly occupied by almost pure stands of chestnut. Only one of the White Oak - Oak plots of the present study had evidence of former chestnut presence. In the Mixed Oak type of Harmon (1980), white oak was one of five oaks that could be dominant in western GSMNP. In contrast to the way in which the plots of the present study would be ranked on a xeric to mesic gradient (based on the topography classes assigned by Callaway [1983]), Harmon (1980) considered the sites in his study, on which white oak was dominant, to be more mesic than those on which chestnut oak was dominant. This does not appear to be the case in the present study.

The SAF (Eyre 1980) describes the White Oak forest cover type as pure. Associates that may comprise up to 20% of the stand basal area include northern red, black, chestnut, scarlet, post, and bur oak, as well as hickories, blackgum, yellow-poplar, maples, white pine, and hemlock. Two of the plots of the present study could be considered pure white oak.

Other SAF forest cover types with white oak in the name are (1) White Oak - Black Oak - Northern Red Oak and (2) Yellow-poplar - White Oak - Northern Red Oak. In these types the three species included in the name comprise a majority of the stocking. The relative percentage of white oak and the other species varies with site moisture. On a gradient from xeric to mesic, black oak is found on the drier sites, and northern red oak and yellow-poplar tend toward the more mesic sites. White oak is found on both dry and mesic sites. If the rule that a species must comprise at least 20% of the stand basal area is strictly adhered to, then only one of the White Oak - Oak plots of the present study could be classified as White Oak - Black Oak - Northern Red Oak. Altogether, all three species were found in but two plots. None of the White Oak - Oak plots of the present study included yellow-poplar.

(3) CHESTNUT OAK - OAK Forest Cover Type

Chestnut oak is a common species in GSMNP, and within the study site is found under a wide range of site conditions. The study includes no Chestnut Oak - Oak sites over 2240 feet (ca 680 m) elevation. In the 1930s, one third of the park was mapped as "Oak and Chestnut" forest by Miller (framed copy of Miller Map with acreage tally, in Sugarlands Visitor Center, GSMNP). Whittaker (1956) described Chestnut Oak - Chestnut forests as the most extensive forests of middle and lower elevations in the Smokies. In the present study, the lack of Chestnut Oak - Oaks in the middle

elevations may be an artifact of the sampling scheme, in that there are few plots in the 2500 - 3500 feet (760 - 1070 m) elevation band.

Chestnut oak is a component of various forest cover types described for GSMNP; e.g., Chestnut Oak (Callaway 1983), Closed Oak (Shanks 1954b), Mixed Oak, Mixed Oak Flats, Oak - Hickory (Thomas 1966), Oak and Chestnut (Miller 1938), Mixed Oak (Harmon 1980), and Chestnut Oak (Arends 1981). Golden (1981) noted that in the central Smokies, two of the three forest cover types in which chestnut remains were most abundant were Chestnut Oak - Red Maple and Chestnut Oak. Two other forest cover types included by Golden (1981) in a chestnut oak complex were Chestnut Oak - Northern Red Oak and Scarlet Oak - Chestnut Oak.

(4) MIXED SUB-XERIC HARDWOODS Forest Cover Type

All plots in the Mixed Sub-xeric Hardwoods forest cover type contain both oaks (ranging from 6% to 62% of the plot basal area) and red maple. Chestnut oak basal area ranges from 6% to 44%, while red maple basal area ranges from 2% to 21% of the total plot basal area. Other species (not common to all plots) include hickories, yellow pines, and blackgum. As noted before, there is a wide range in species composition of the plots included in the Mixed Sub-xeric Hardwoods forest cover type. The Mixed Hardwood type of Harmon (1980) was described as quite variable, with 47 species seen in a total of 16 plots. Dominant species were red maple, dogwood, pignut hickory, mockernut hickory, silverbell, yellow-poplar, northern red

oak, black oak, and black locust. These plots were also frequently characterized by the former presence of chestnut and the current presence of grape vines and a herbaceous (rather than ericaceous) understory.

The Red Maple - Oak forest, a chestnut replacement type described by Arends (1981), included red maple, chestnut oak, northern red oak, sourwood, pitch pine, blackgum, black locust, sweet birch, Fraser magnolia, yellow-poplar, and black oak. Only two of the Mixed Sub-xeric Hardwoods plots in the present study had signs of former chestnut trees, but all, except one, had indications of historical disturbance by fire.

The Oak - Hickory cover type of Thomas (1966) is descriptive of two of the Mixed Sub-xeric Hardwoods plots of the present study; and the Pitch Pine - Scarlet Oak Scrub cover type is somewhat applicable to one other Mixed Sub-xeric Hardwoods plot. The Pitch Pine - Scarlet Oak Scrub cover type had droughty conditions and evidence of fire (Thomas 1966).

Shanks' (1954b) Open Oak And Pine Stands forest cover type is applicable to one of the Mixed Sub-xeric Hardwoods plots. Open Oak And Pine Stands are described as "of dry, exposed slopes and ridges, often rocky, on which the scattered short trees do not form a closed forest canopy; the essentially continuous tall shrub layer, [is] dominated by Kalmia..." (Shanks 1954).

The associated species of the SAF Chestnut Oak forest cover type (Eyre 1980) include all the species that comprise the majority composition in the various Mixed Sub-xeric Hardwoods plots of the present study. Rosebay rhododendron and mountain-laurel are included as shrub associates in the Chestnut Oak forest cover type and were found in some of the plots of the Mixed Sub-xeric Hardwoods. The SAF Chestnut Oak type, similar to the Mixed Sub-xeric Hardwoods type, is usually associated with dry, upland sites. None of the Mixed Sub-xeric Hardwoods plots of the present study have a majority of basal area comprised by chestnut oak. Nonetheless, the Chestnut Oak forest cover type description provides a better overall generalized description of the plots than does either any other SAF type or any other single type derived from study of GSMNP forests.

(5) WHITE PINE - HARDWOODS Forest Cover Type

The White Pine - Hardwoods forest cover type included some plots in which pitch pine or hemlock were important in addition to white pine and hardwoods. The most important associated hardwoods (by species basal area) were white oak and yellow-poplar. The White Pine - Hardwoods of the present study are found only in Cades Cove. In the present study, pitch pine and yellow-poplar were important associated in old fields, while white oak and hemlock were important in areas with no evidence of farming.

In GSMNP, white pine is important only in the western Smokies and in Cataloochee (located in the extreme eastern end of the park;

see Miller Map, GSMNP Archives). Miller's (1938) description of the White Pine - Hardwoods type included stands in which white pine was the predominant species in various mixtures with yellow pines and some 15 species of hardwoods including white oak and yellow-poplar.

DeYoung (1979) studied the white pine complex in western GSMNP and classified 144 white pine stands into seven forest cover types, including White Pine - White Oak and White Pine - Hemlock. Although DeYoung did not include a white pine - yellow-poplar forest cover type, he mentioned that yellow-poplar was sometimes an important associate within cover types of the white pine complex that occurred on old fields.

Harmon (1980) attributed the high variation in species composition of the White Pine forest cover type to its juxtaposition with several other cover types. He noted that "[s]light variations in slope position, concavity and aspect shifted the white pine cover type from mesic associates (e.g., hemlock) to more xeric associates (e.g., Virginia pine)" Harmon (1980:108).

(6) CHESTNUT OAK - YELLOW-POPLAR Forest Cover Type

Although other authors have not segregated the Chestnut Oak - Yellow-poplar type, yellow-poplar has been included in descriptions of Chestnut Oak forests in GSMNP. Callaway (1983) mentioned yellow-poplar as a component of his Chestnut Oak type. The Closed Oak forest cover type, described by Shanks (1954b:11) as "of intermediate

to dry slopes dominated by oaks, or originally by oaks and chestnut..." may include yellow-poplar as one of 27 associates. In the Chestnut Oak - Chestnut forests of the central Smokies, Whittaker (1956) found 75% or more of the canopy to be dominated by chestnut oak and dead chestnut. Yellow-poplar was one of six associates. It was not, however, an associate in the more xeric Chestnut Oak - Chestnut - Heath forest of Whittaker (1956). Miller (1938) considered yellow-poplar as an occasional associate of the Oak And Chestnut type. Golden (1974) found yellow-poplar as a canopy tree (> 12.7 cm dbh) in 16% of the plots he classified into the Chestnut Oak forest cover type. Overall, the tendency of yellow-poplar to be found on mesic sites, while chestnut oak is most commonly found on more xeric sites, makes dominance by this pair of species unlikely in most situations.

(7) YELLOW-POPLAR Forest Cover Type

The Yellow-poplar type of the SAF is described as "probably determined primarily by [high] site quality and previous stand disturbance" (Eyre 1980). In GSMNP, Yellow-poplar is a well recognized forest cover type. Similar to the Second Growth Yellow-poplar cover type found in the foothills of GSMNP around Chilhowee Mountain (Thomas 1966), the Yellow-poplar forest cover type of the present study is the result of clearing, either by logging in plots at mid elevations (as low as 2450 feet [ca 750 m]), or by farming activities at lower elevations. The one exception to a history of

clearing was a plot in which Chestnut Oak comprised 20% of the basal area. This plot, which straddled an intermittent stream in a narrow hollow, was more similar to Thomas' Lowland Coves type, in which yellow-poplar predominates. Thomas described the Lowland Coves cover type as occurring in areas that had been lumbered, but not clear cut. In contrast to his Second Growth Yellow-poplar, Thomas considered the Lowland Coves type "probably" to be climax forest. Although yellow-poplar comprised the majority plot basal area, this plot (with 20% chestnut oak) was more topographically akin to the present study's Chestnut Oak - Oak and Chestnut Oak - Yellow-poplar plots than to the remainder of the yellow-poplar plots.

The Yellow-poplar cover type of Callaway (1983) included both old fields and sites with sheltered topography. On very mesic sites, such as ravines, Callaway found the Hemlock - Yellow-poplar forest cover type. As noted before, two of the disturbed plots initially included in the present study were classified as Hemlock - Yellow-poplar. One was in a deep ravine on a mesic flat prone to flooding during high water. The other was in a streamside area currently prone to flooding as a result of historical attempts to re-route the stream channel. Golden (1974) included two successional plots and one old growth plot in his Yellow-poplar forest cover type. He mentioned fire, stumps, and chestnut blight in relation to the successional plots. The old growth plot was located on a gentle

lower valley slope and included hemlock in addition to yellow-poplar and other mesic hardwoods.

(8) MIXED MESIC HARDWOODS Forest Cover Type

Included as dominant species in the Mixed Mesic Hardwoods forest cover type of the present study are basswood, beech, black cherry, buckeye, fire cherry, Fraser magnolia, northern red oak, red maple, silverbell, sugar maple, sweet birch, and yellow birch. This forest cover type is similar to both the "cove hardwoods" and the "northern hardwoods" of other authors. For example, Braun's (1950) Northern Hardwoods forest cover type included sugar maple, yellow birch, beech, and buckeye as the most important species. Also present were white ash, black cherry, silverbell, cucumber magnolia, chestnut, and occasionally, basswood. In addition, the Northern Hardwoods of Braun include the beech and chestnut orchards of Cain (1931). Cain described the orchard forest type as woodlands of stunted form at high altitudes. The chestnut orchard type was composed almost exclusively of chestnut, chestnut oak, northern red oak, and buckeye. One plot in the present study was probably a former chestnut orchard, being currently dominated by northern red oak with many dead chestnut snags and a red maple component.

The important species of Braun's Cove Hardwoods forest cover type were basswood, silverbell, yellow-poplar, hemlock, chestnut, and the four major Northern Hardwoods species (sugar maple, yellow birch, beech, and buckeye). Other species Braun listed as typical

associates of the Cove Hardwoods, but did not list with the Northern Hardwoods, were red maple, bitternut hickory, Fraser magnolia, and serviceberry. Braun described Cove Hardwoods as characterized by the dominance of six to eight of the important cove species (with no particular species or species combination consistently dominant in the landscape).

Whittaker (1956) listed six species that share dominance in most of the cove forests he studied in GSMNP: hemlock, silverbell, buckeye, basswood, sugar maple, and yellow birch. In addition, he found yellow-poplar and beech important in some stands. Altogether, these eight species comprised 80%-90% of the canopy of Whittaker's cove forests. Although no particular species was consistently found to be dominant, certain combinations of species were locally dominant. Except for the Gray Beech forest cover type (which was analogous to the beech orchards of Cain [1931] and to the beech gaps of Russell [1953]), Whittaker did not separately describe any "northern hardwoods" forests. However, in a discussion of what he referred to as "the so-called northern hardwoods," Whittaker noted that with increasing elevation, buckeye, basswood, and yellow birch increased in importance, while yellow-poplar and hemlock were often absent from coves. Whittaker regarded these upper cove forests as a subtype of the Cove Hardwoods, in which the same dominants were found in different proportions.

Shanks (1954b) described a Cove Hardwoods forest cover type found below about 4500 feet (1370 m) elevation and a Northern Hardwoods forest found above 4500 feet elevation. In his list of Cove Hardwoods dominants, he included all the trees Braun (1950) listed as important plus black cherry, white ash, cucumber magnolia, and northern red oak. Shanks described Northern Hardwoods as "Plants of deciduous forests in [the] spruce-fir altitudinal belt above 4500 feet, dominated principally by beech and yellow birch; typically mull type humus layer." The complete list of Northern Hardwoods canopy species given by Shanks was quite similar to the list of species given for the Mixed Mesic Hardwoods of the present study. However, Shanks included an additional four species (hemlock, serviceberry, Fraser fir and red spruce), and did not include northern red oak, sweet birch, or basswood. Cain (1931) described a sweet birch forest community, found at elevations of 4500 - 5500 feet (ca 1370 - 1675 m), in which the formation of raw peat at the surface of the soil "may be attributed in some way to the abundance of evergreen undershrubs." In the present study, in the two plots of the Mixed Mesic Hardwoods forest in which sweet birch was important, an ericaceous understory was present. These plots had wet, slow to decompose humus.

The most mesic deciduous forest cover type of Harmon (1980) was the Cove Hardwoods, in which dominance was shared by red maple, buckeye, sweet birch, beech, yellow-poplar, white pine, rosebay

rhododendron, and hemlock. Arends (1981) described the Northern Red Oak - Silverbell type as a replacement forest cover type found following disturbance by chestnut blight at elevations of 3500 - 4000 feet (ca 1065 - 1220 m) in the central Smokies. The plots of this forest cover type were characterized by small trees (particularly silverbell and red maple) with frequently scattered larger individuals (mainly northern red oak).

Both Callaway (1983, Callaway et al. 1987) and Golden (1974) described many separate groupings of the species lumped together in the Mixed Mesic Hardwoods of the present study. Both included Northern Red Oak and Beech forest cover types. Other types were (a) Northern Red Oak - Silverbell, (b) Hemlock - Silverbell - Beech, (c) Basswood - Buckeye, (d) Buckeye - Yellow Birch (Callaway 1983, Callaway et al. 1987), (e) Silverbell - Hemlock, (f) Buckeye, (g) Sugar Maple, (h) Basswood, (i) Red Maple - Sweet Birch, (j) Red Maple - Northern Red Oak, (k) Hemlock - Buckeye, and (l) Yellow Birch - Hemlock (Golden 1974). These types were derived from computer classification programs. (Recall that in the present study, the type names assigned to the plots were based on species, which individually comprised at least 20% of the plot basal area, and which, when taken together, comprised at least 50% of the total plot basal area.)

Of the type names initially assigned to the Mixed Mesic Hardwoods plots of the present study, only two (a Northern Red Oak and a Beech cover type) were the same as those type names (listed

above) from the work of Callaway (1983), Callaway et al. (1987), and Golden (1974). With the exception of the two plots mentioned above, the Northern Red Oak and Beech types of Callaway and Callaway et al. (represented by 11 and six plots, respectively) were found in stands classified as undisturbed. Thus, they were generally not comparable to those of the present study. Site characteristics of the Northern Red Oak and Beech plots of the present study were not similar to those of the forest cover types described by Golden.

The forest cover types of the SAF (Eyre 1980) include six types dominated by combinations of mesic hardwoods: (1) Sugar Maple, (2) Sugar Maple - Beech - Yellow Birch, (3) Sugar Maple - Basswood, (4) Black Cherry - Maple, (5) Beech - Sugar Maple, and (6) Red Maple. These types are listed as "northern hardwoods" forest cover types for the Northern Forest region of the eastern United States, where sugar maple is more common than it is in GSMNP. For the Mixed Mesic Hardwoods of the present study, the SAF forest cover types are applicable to two plots, one dominated by red maple, and the other by sugar maple - beech - yellow birch.

In the present study, the lack of replication of plots with similar arrays of dominant species led me to lump all the plots containing predominantly mesic hardwoods into a single forest cover type. Based both on field observations and the arrangement of the plots along the DCA axes (Figure H-2), I agree with Whittaker (1956) that mesic or "cove" hardwoods include combinations of species that

are locally dominant; and that in the upper coves, species are found in different proportions than at lower elevations.

Further Comments Concerning the Relation of the SAF Forest Cover Types to the Present Study

Except for the Yellow-poplar type, the forest cover types of the present study are not described by the SAF. This likely should have been expected in that the present study was specific to GSMNP rather than to the eastern United States. However, given the use of basically the same methods, the lack of overlap between the forest cover types of the present study and those of the SAF raises the question of how rules for naming species associations should be applied. While it is known that there are many combinations of species found in forest stands in the eastern United States, the designated forest cover types of the SAF are based on combinations that occupy a fairly large area in the aggregate (Eyre 1980). Thus, whether the forest cover type name assigned to the plot species composition is applicable to large areas in the aggregate should be considered.

Except for the Chestnut Oak - Yellow-poplar type, the forest cover types of the present study have been seen to be composed of groups or combinations of species that have been recognized by other workers in GSMNP. Therefore, it can be said that in the present study, the naming of the forest cover types in relation to plot species composition did lead to the designation of forest cover types

that may be considered descriptive of large areas in the aggregate in GSMNP.

The use of the SAF-derived rules (that a forest cover type must comprise at least 50% of the basal area, and, that for a species to be included in a name, at least 20% of the basal area had to be comprised by that species) contributed to the internal homogeneity of species or species groups composition in the forest cover types of the present study. These rules prevented the situation (found in the TWINSpan clusters, discussed below) in which plots were grouped together based on the occurrence of small amounts of basal area of distinctively different species but few other species in common.

Strict adherence to the 50% and 20% rules within the 20 m by 50 m plots may not always be the best approach in that it implies a uniformity of species distribution that is probably not realistic. That is, when the method is used by the SAF in description of its forest cover types (Eyre 1980), the descriptions are probably more representative of the average conditions found in large stands rather than literally descriptive of what is seen in every 20 m by 50 m tract within a large area.

A Comparison of the Use of TWINSpan Versus the Application of the SAF Methodology for Forest Cover Typing

TWINSpan creates clusters of plots by repeated hierarchical divisions (Figure H-5). Although the name TWINSpan is an acronym for

Two-way Indicator Species Analysis, the method is not based on indicator species. Rather, it is a form of "dichotomized ordination analysis" (Digby and Kempton 1987, Hill 1979b).

For the "primary ordination" of the TWINSpan procedure, the plots are ordinated by reciprocal averaging (a technique which is very similar to DCA). Based on their ordination axis scores relative to the mean of the axis, the plots are divided into two groups. Then a "refined ordination" is done using the "differential" species that are preferential to one group or the other (i.e., at least twice as likely to be found in one group as in the other). The refined ordination axis is divided at the score that puts the most plots into the same group as did the primary ordination. The same set of procedures is repeated within the first two groups to derive the clusters in the next tier of the dendrogram. This process is repeated again and again, until the final clusters are reached, which occurs when the groups are composed of less than five plots.

The important thing to note is that the TWINSpan procedure is basically a series of divisions of plots according to their score on an ordination axis. And, ordination scores organize the plots such that the greatest differences among plots species composition are revealed. Thus, the assumption underlying the clusters provided by the TWINSpan procedure is that when plots of the greatest dissimilarity in species composition are separated into two groups, the resulting groups will contain plots that are similar. This is

not a guaranteed result. For example, in the present study, in cluster "K", all four of the plots have chestnut oak, but only two of them contain all three of the species (chestnut oak, black oak, and white oak) that made this cluster different from the chestnut oak cluster (Figure H-5, Figure H-6).

The initial TWINSpan division put plots dominated by pines, oaks, and yellow-poplar (clusters A-M, Figure H-5) in one group. The other group comprised the plots dominated by mesic hardwoods and hemlock (clusters N-S, Figure H-5). Subsequent divisions of the mesic hardwoods resulted in groups that were distinctly different from other groups, but that were not necessarily internally homogenous. That is, all plots in a given group differed from other groups by including certain distinctive species, but that/those distinctive species did not necessarily make up the majority of the plot basal area. (For example, see cluster "O" [Black Cherry], Figure H-6).

On the oaks, pines, yellow-poplar side of the TWINSpan dendrogram (Figure H-5), the division of plots based on distinctive differences did not allow for application of silvical knowledge concerning similarities among species. For example, the computer has no way of knowing that pitch pine is more similar to table-mountain pine or Virginia pine than it is to white oak or chestnut oak. Furthermore, small groups of plots which were otherwise similar were subject to separation early in the hierarchy of divisions based on

the presence or absence of certain distinctive (indicator) species. Plots in these groups could not be brought together later by agglomeration of the TWINSpan clusters because they were not readily connected by combining the branches of the dendrogram. For example, clusters "A", "B", "C", and "D" were closely connected and were generally dominated by yellow pines. Cluster "E", which is composed of two plots with white pine and yellow-poplar in common, was tied through cluster "D" to the yellow pine dominated clusters. Other plots with large amounts of white pine and yellow poplar in common were found in a separate portion of the dendrogram (Figure II-5).

Some of the groupings of species on the oaks, pines, and yellow-poplar side of the TWINSpan dendrogram were associations recognized by other authors; e.g., the White Pine - White Oak type (cluster "H"). This type represents an intergradation between the White Pine - Hardwoods and the White Oak - Oak forest cover types of the present study. The other two plots in the White Pine - Hardwoods of the present study were found in yellow-poplar - pine clusters (D, E; Figure II-6). As noted before, the White Pine - Hardwoods had two principal hardwood associates: white oak and yellow-poplar. Examination of Figure II-6 reveals that the plots included by TWINSpan in clusters "D", "E", and "H" are aptly named; i.e., a majority of the plot basal area is comprised by the species in the cluster name. Thus, the White Pine - Hardwoods of the present study are shown to be

a diverse group, which, given a larger data set, would probably best be separated into subunits of greater internal homogeneity.

While, in the present study, the SAF methodology generally resulted in forest cover types of greater internal homogeneity than those derived from TWINSpan, the methodology is not without drawbacks. For example, if the majority of plot basal area is not clearly composed of one or two species, it is hard for an investigator to see all of the possible combinations of plots given the many possible different generalizations of species groupings (e.g., pine - oak versus pine - hardwoods versus pine - xeric hardwoods). Thus, even though the rules of the SAF methodology are unambiguously stated for the present study, application of the methodology may lead to results that would not be repeated by another investigator. In turn, it should be noted that agglomeration of the clusters of TWINSpan output also may result in choices made by one investigator that would not be repeated by the next.

Altogether, in a study area where species' silvical characteristics are well documented and the number of study plots is limited, a method of forest cover type assignment that allows the investigator to apply silvical knowledge of trees is to be preferred over one that does not. And, a method that has the facility to group plots based on similarities between majority plot basal area is more useful than one which uses differential species that (1) may or may not comprise a significant portion of the plot basal area, and (2) may

or may not indicate anything significant about the other associated species or the site on which the vegetation is found.

The Effects of Disturbance History and Site Variables on Forest Cover Type

For determination of plot disturbance history in the present study, both nominal variables (the checklist items) and continuous variables (tree age and charcoal) were used. Mean plot age was shown to be related to forest cover type (Tables G-1, G-2); and mean plot age was the third variable included in the 10 variable stepwise discriminant function. The number of times charcoal was encountered within a plot was not an important predictor of forest cover type. Nonetheless, examination of Figures H-2 and H-3 reveals that the Chestnut Oak - Oak and the Chestnut Oak - Yellow-poplar plots all had strong evidence of fire, while the Yellow Pines (with one exception) and the White Oak - Oaks (with three exceptions) were lacking in evidence of fire.

These results would appear to suggest a relationship between the presence of fire and presence of chestnut oak, and the absence of fire and the presence of white oak and yellow pines. However, another aspect of GSMNP disturbance history that must be considered is the proximity of a plot to areas of concentrated settlement. Almost all of the Yellow Pines and White Oak - Oak plots are found in Cades Cove, at or below 2000 feet (about 610 m) elevation, in an area mapped as "concentrated settlement" (Pyle 1985, 1988). These plots

were invariably in the proximity of historically farmed areas. In Cades Cove, at or below 2000 feet (ca 610 m) elevation, the Yellow Pines are on old field sites or previously cleared areas; and the White Oak - Oak plots are generally in areas believed to have been woodlots.

The grazing of woodlots was a common practice in the 1930s and before. Fires are known to have been set regularly on the piney slopes surrounding Cades Cove; and it was a common practice in GSMNP to burn off fields with no concern over keeping the fire confined to the field (Dwight McCarter, personal communication to C. Pyle 1985). On field sites, with fuels composed of grassy materials, fires would not have led to the formation of charcoal particles of a size large enough to have been found by the methods employed in the present study. In grazed woodlots, trampling and browsing inhibit fuel build ups (personal observation). So, fires hot enough to burn woody debris of a size large enough to leave charcoal fragments visible on the soil surface 50 to 60 years after the National Park Service acquired the land may be conceived to have been infrequent in grazed woodlots. Furthermore, any charred wood that was formed following fire in a grazed woodlot was subject to the effects of trampling.

All the plots of the Chestnut Oak - Oak and Chestnut Oak - Yellow-poplar forest cover types and some of the Mixed Sub-xeric Hardwoods were found in areas outlying from Cades Cove. In contrast to areas of concentrated settlement, grazing pressure would have been

more diffuse and fire probably not as frequent in these outlying areas. These circumstances would lead to a greater fuel build up in between fires. This, in turn, would result in fires that burned intensely enough to consume larger fuels. The death of trees from infection by chestnut blight also may be presumed to have resulted in additional fuels. Except for two Mixed Mesic Hardwoods plots, all plots with signs of former chestnut presence also had signs of fire.

All plots with evidence of clearing for agricultural purposes had even-aged stand conditions. These plots were classified in the Yellow Pines, Yellow-poplar or White Pine - Hardwoods forest cover types. Plots categorized as logged were found in the Mixed Mesic Hardwoods, Yellow-poplar, and Yellow Pines forest cover types. Within the Yellow-poplar and Yellow Pines types, even-aged conditions were seen in all the logged plots. Within the Mixed Mesic Hardwoods, even-aged conditions were not present in all the logged plots.

In logged plots, even-aged stand conditions were found more frequently than were sawn stumps. The species observed as stumps in the Mixed Mesic Hardwoods were red oak (Erythrobalanus subgenus) and chestnut. At lower elevations, white pine, yellow pines, and white oak (Leucobalanus subgenus) stumps were also seen. With the exception of hemlock, other species known to have been cut in the study area are believed to decompose too readily for stumps to be still evident 50 to 80 years after cutting.

Although certain disturbance history sequences are more likely to be associated with one forest cover type than another, there is no single pathway of succession from a given disturbance history to a given forest cover type. Furthermore, the interaction of site variables with disturbance history is important. The Yellow Pines and Yellow-poplar forest cover types are strongly associated with the clearing of land for agricultural purposes. However, on mesic sites (particularly those with large upslope areas that drain underground moisture into the plot), yellow-poplar predominates. Dominance by yellow-poplar or yellow pines is not found in areas where the disturbance was categorized as diffuse (Pyle 1985, 1988). In diffusely disturbed areas, at lower elevations, White Oak - Oak, Chestnut Oak - Oak, Chestnut Oak - Yellow-poplar, and Mixed Sub-mesic Hardwoods are found. In the diffusely disturbed areas of higher elevations, Mixed Mesic Hardwoods are found. (However, it should be noted that the sampling generally favored coves and/or north to east facing aspects at high elevation.)

Other than geographic location, which separates out the White Oak - Oak plots (generally restricted to Cades Cove), no site variables accounted for the species composition differences among plots of the White Oak - Oak, Chestnut Oak - Oak, and Chestnut Oak - Yellow-poplar forest cover types. A greater mean depth of the organic soil layer distinguished the Mixed Sub-mesic Hardwoods from

the White Oak - Oaks, Chestnut Oak - Oaks, and Chesnut Oak - Yellow-poplars (as well as from all other forest cover types).

To some extent, the relationship between site variables and historical settlement patterns may also be responsible for relationships between disturbance history and forest cover type. Concentrated settlement was found in areas where there was fertile flat land; e.g., Cades Cove. Settlement was not common in the more narrow, steep-sided mountain valleys of higher elevations adjacent to Cades Cove or in the drainage of the Middle Prong of the Little River. Thus, at lower elevations, disturbed mesic sites were generally farmed. In contrast, at higher elevations, where the topography was less suited to farming, the primary disturbance that occurred on mesic sites was logging. Therefore, the potential effect of elevation on species composition must be considered. For example, yellow birch is found on a wider range of site conditions at higher elevations; yellow-poplar, and most pines, are not found at higher elevations; fire cherry is not found at low elevations. Thus, fire cherry is not to be expected at low elevation regardless of whether the site was cleared by farming or logging; and, vice versa, yellow-poplar is not to be expected at higher elevations. The three logged yellow-poplar plots of the present study were found below 2880 feet (ca 875 m) elevation but above the upper limit of concentrated settlement (which, in Cades Cove, was generally 2000 feet [ca 610 m]).

As discussed above, the apparent relationship between a lack of fire and the presence of Yellow Pines is somewhat spurious. It may be attributed to the fact that with one exception the Yellow Pines plots were in areas that were in agricultural use until about the time the NPS acquired the land. In the one Yellow Pines plot not used for intensive agriculture, charcoal was found in 31 of the 40 samples taken in the plot. This plot was on one of the piney ridges above Cades Cove, and represents the only sample in the study area of this site-vegetation type, which is rather widespread at low elevations in the extreme northwestern end of the Smokies. (The presence of pine forests on ridges may be seen by examination of color infrared aerial photographs dated 1982 located at the National Park Service Cooperative Park Studies Unit, University of Tennessee, Knoxville).

With one exception, the Mixed Mesic Hardwoods of the present study were restricted to sites above 2440 feet (about 740 m) elevation. As noted before, this is to some degree an effect of historical settlement patterns. The Mixed Mesic Hardwoods include even-aged logged plots, uneven-aged, selectively logged plots, and two plots with no signs of disturbance other than their proximity to the area, along the Tennessee/ North Carolina state line, which was grazed before the NPS owned the land. (The two plots lacking in signs of disturbance have no coded disturbance in Figure H-3.)

Not only do the Mixed Mesic Hardwoods include variation in disturbance history and dominant species, they also include variation in patterns of age and size class distributions. Although frequent in the plot overstory at the time the data were collected, species such as fire cherry and Fraser magnolia are not likely to remain important. Fire cherry is shortlived and requires an abundance of sunlight to become established. It is unlikely that the logging disturbance, which created open stand conditions, will be repeated in GSMNP. Fraser magnolia is a small tree and may be expected to become uncommon in the upper canopy as the overstory increases in stature. As succession progresses in the Mixed Mesic Hardwoods plots, new species associations in the upper canopy will evolve, and perhaps relationships of these associates to site factors will emerge.

Prediction of the Eight Forest Cover Types

A discriminant function with a combination of site and disturbance history-related variables (the site quality - tree age gradient) was more successful at predicting forest cover type than was a function that used only the site variables available from maps. However, any claim of great success must be tempered with the fact that with the division of the data set into model and test groups, only two thirds of the test plots were correctly classified for the site quality - age model. An explanation for the relative lack of success in classifying the test plots is that with a total of 63

plots and eight forest cover types (two of which had only four plots each), the data set was too small to divide in the first place.

From the data at hand, it is not wholly clear whether a function based on a larger model data set would give better results. However, since certain forest cover types are quite different from others with respect to single site/disturbance history variables (Tables G-2, G-3), it seems reasonable to expect that a function derived from a combination of the variables that would successfully separate all the forest cover types should be found.

Because discriminant analysis is a multivariate technique, all the variables affecting forest cover type are examined simultaneously and the importance of otherwise unmeasured interactions among variables may be utilized. For example, although no variable taken alone would separate the means of the White Oak - Oak, Chestnut Oak - Oak, and Chestnut Oak - Yellow-poplar forest cover types, with simultaneous consideration of the variables in the discriminant function, confusion among these forest cover types was no more prevalent than among any other forest cover types. In fact, in the models which used the entire data set, there was completely successful prediction of these forest cover types.

Altogether, the multivariate approach seems useful; and further study on the nature of site/disturbance history - forest cover type relationships made with a larger number of plots is warranted. It is

believed that a larger number of plots would lead to greater precision in definition of the means and variation of site factors within forest cover types. More plots might also result in a better understanding of what is a reasonable extent of variation of species composition within a given forest type and/or might result in the recognition of more forest cover types with a greater internal species homogeneity within each type.

When the entire data set was included in the discriminant model, the function composed entirely of map variables had a 90% classification success (for the plots used to derive the function) versus the 100% classification success of the site quality - tree age model. In the site quality - tree age model, the primary topographic variables were those from maps. Only one field topographic variable (the transformation of the plot azimuth) was included in the 10 variables derived from stepwise discriminant analysis.

The difference between the field and map- derived measures of topography is a matter of scale, with the map variables measuring topography on a coarser scale than was done in the field within the plots. Correlations between map and field measures of similar topographic factors varied from 0.38 to 0.85 as follows (from Table G-1):

site moisture: drainage area vs. moisture gradient = 0.38,
aspect: map azimuth vs. field plot azimuth = 0.62,
landform shape: topography class vs. landform = 0.67,
slope: map slope vs. field plot slope = 0.85.

The inclusion of slope was not found to be a significant addition to the stepwise discriminant function when using either all the site/disturbance history variables or just the map variables.

The remaining correlations, although fairly strong, do support the contention that there is a difference between broad scale and fine scale topography. Both (1) the inclusion of the broad scale topographic variables to the general exclusion of the fine scale variables in the discriminant function and (2) the general lack of fine scale topographic variables in the group of variables that separate the means of the forest cover types (Table G-2), suggest that broad scale topographic features are more important in the determination of forest cover type than are fine scaled features.

Prediction of Plot Productivity

Two important observations concerning the prediction of plot productivity index score may be made when the results of the present study and those of Callaway (1983) are compared. First, in both studies, a combination of topographic and soils factors consistently was found to be the best predictor of plot productivity index score. In all cases, the topographic factors were the most important. Second, a wide range of success (R^2) of the productivity models was found. With undisturbed plots only, Callaway's model (protection plus depth of the soil organic layer) explained 83% of the variation in plot productivity (expressed as the natural log). For a

combination of undisturbed and disturbed plots, the predictors protection, topography class, and depth of the soil organic layer explained 63% of the variation in the log-transformed plot productivity index score (Callaway 1983). In the present study, using disturbed plots only, topography class and total soil depth explained 43% of the variation in the log-transformed plot productivity index scores. Thus, the results of this study confirm those of Callaway (1983); i.e., historical disturbance creates added variation in the relationship between site variables and plot productivity index scores.

In comparison to undisturbed stands, the age class structure of disturbed stands generally includes a greater proportion of younger trees in the upper canopy. Also, given a relationship between disturbance to the forest canopy and the increased incidence of sunlight, it is reasonable to believe that stands with a history of disturbance would include a greater proportion of species intolerant of shade. Therefore, in general, one would expect the mean age and species composition of disturbed and undisturbed stands to differ. Although Whittaker (1966) found higher volume increments in disturbed stands, the successional nature of disturbed stands (i.e., the presence of young, intolerant trees) may contribute both to increases and decreases in productivity. On the one hand, young trees have a faster growth rate than mature trees; and, in open sunlight, intolerant trees tend to grow faster than tolerant trees. On the

other hand, with crowding or overtopping by adjacent trees, intolerant trees (regardless of age) are not able to thrive (Spurr and Barnes 1973, Daniel et al. 1979). Taken together, differences related to seral stage of the plots in the present study may account for some of the unexplained variation in growth rates among trees within the same plot as well as among plots on similar sites. Perhaps the reason that the variables related to tree age were of little importance in the prediction of productivity index score on disturbed sites was that the effects of age were confounded by the effects of crown position.

Another factor that may account for a portion of the unexplained variation in the estimates of plot productivity is the number of trees cored per plot. Using plots of the same size as the present study, Whittaker (1966) cored 50 to 75 trees per plot. For Callaway's (1983) estimate of productivity, used in the present study, five trees per plot were cored. Given a consistent population size and variance, smaller samples are less precise in the estimation of the mean. However, it is important to note that although the plots were the same size, the populations for which Callaway estimated plot productivity were considerably smaller than those with which Whittaker was concerned. Callaway dealt only with trees 30 cm and above in dbh, while Whittaker, for the portion of his study concerned with woody individuals considered both trees and shrubs 1 cm and above in dbh.

Nonetheless, with a small sample size, strong control over sources of variation should be exerted. A major source of variation among the growth rates of individual trees is crown position. Codominant and dominant trees get more sunlight and tend to grow faster. Because intolerant trees do not thrive under shaded conditions, crown position is of the utmost importance for intolerant species. Furthermore, even extremely tolerant trees, such as sugar maple, exhibit periods of growth suppression and release attributable to whether or not their crowns were shaded (Canham 1985). Also, as may be inferred from a discussion of site index by Daniel et al. (1979), a secondary source of variation in growth rate among codominant trees is species differences. In the plot data provided by Uplands Lab for the present study and Callaway's (1983) study, no information was given on crown position. Therefore, stratification by crown position of those trees cored to provide estimates of growth was not an option for the reduction of variation in plot productivity index scores.

In both the present study and that of Callaway (1983), differences were seen among the average productivity index scores of the forest cover types. Such results may be interpreted in three ways: (1) species composition affects productivity, (2) the factors that affect species composition also affect productivity or (3) the productivity potential of a site affects the relative success of different species and thus affects the stand composition as well. If

productivity estimates within a plot were stratified by species, it could be determined whether species composition had an additional effect on plot productivity after the effect of site factors had been taken into account. However, given the strong effect of crown position on individual tree growth, any test of the effect of species would have to include the control of crown position.

Altogether, regardless of the lack of control over other factors, topographic variables have been shown to be consistently important in the prediction of plot productivity index scores for both undisturbed and disturbed plots. Consequently, it is recommended that investigators interested in the prediction of productivity should concentrate on refinements of the methods of quantifying topography. For example, the ordering of topographic classes along a theoretical moisture gradient should be compared to field measurements of site moisture. Further, any successful method of quantifying topography should be tested to see that it is repeatable by other investigators. Another approach to ensuring that methodology is repeatable is to develop computer algorithms to do the procedure. Development of a computer program to calculate the topographic protection of a plot from digital elevation models (computerized maps) is currently underway, under the direction of E. E. C. Clebsch, at the University of Tennessee (E. Burress, personal communication to C. Pyle).

CHAPTER VIII

SUMMARY

As a sequel to the study made by Callaway (1983) in disturbed and undisturbed vegetation plots in Great Smoky Mountains National Park, site and disturbance history-related variables were used in the development of mathematical predictions of forest cover type and plot productivity index score in 63 plots containing disturbed vegetation in western GSMNP. Prior to the prediction of forest cover type, the species in the upper crown canopy of each plot were classified as to forest type. Two systems of classification were used: (1) a methodology derived from the manner in which forest cover types are named by the Society of American Foresters (Eyre 1980) and (2) a computerized hierarchical, divisive method (TWINSpan; Hill 1979b). The constraints on the SAF methodology were that the species in a forest cover type name must comprise a majority (at least 50%) of the plot basal area; and, to be included in the cover type name, a species (or generalized species group, e.g., oaks) must comprise at least 20% of the plot basal area.

The application of the SAF methodology to the assignment of forest cover type names was preferred to TWINSpan because the SAF methodology allowed for the use of silvical knowledge and the grouping of plots based on similarities rather than grouping by differences among plots. When used in the present study, which had a

small number of plots with an overall wide variation in species composition, TWINSpan was faulted for dividing groups of plots based on the common presence in one portion of the group of differential species (i.e., species not common in the other portion of the group being divided). This was seen as a disadvantage because little regard was given to how much of the plot basal area was accounted for by the differential species. And, not infrequently, the differential species accounted for below 50% of the plot basal area.

The eight forest cover types assigned by the SAF methodology were (1) Yellow Pines, (2) White Oak - Oak, (3) Chestnut Oak - Oak, (4) Mixed Sub-xeric Hardwoods, (5) White Pine - Hardwoods, (6) Chestnut Oak - Yellow-poplar (7) Yellow-poplar, and (8) Mixed Mesic Hardwoods. The plots were displayed in a Detrended Correspondence Analysis (Hill 1979a) ordination diagram depicting the gradient of plot species composition. When the plots were labelled with the forest cover type names assigned by the SAF methodology, plots of the same forest cover type were generally located adjacent to one another. Consequently, the SAF methodology was judged relatively successful in grouping together plots of generally similar species composition. However, as was interpreted from the range of DCA scores for plots of a given forest cover type, within some cover types there was a wide range of species composition.

With a data set composed of all 63 plots, forest cover type was predicted with 100% success using a discriminant function that

included 10 variables. The function was referred to as a "site quality - tree age" function. The ten variables were: (1) elevation, (2) protection, (3) mean plot age, (4) topography class, (5) transformation of the plot azimuth derived from a map, (6) depth of the soil organic layer, (7) thickness of the soil B horizon, (8) transformation of the plot azimuth taken in the field, (9) variance of the mean plot age, and (10) maximum age of the cored trees in a plot. A 90% success in plot classification was achieved using five variables derived from maps: (1) elevation, (2) protection, (3) topography class, (4) transformed map azimuth, and (5) drainage area. For a more rigorous test of the usefulness of these sets of variables as predictors, three tenths of the plots were set aside, and new discriminant functions were calculated using the remaining seven tenths of the plots. When the discriminant functions were tested (on the three tenths portion of the plots), the site quality - tree age function correctly classified 68% of the plots while the map variables function correctly classified 42% of the plots. The difference in success between the models made with the full data set and those used in testing the discriminant variables was in part attributed to the small size of the data set.

Although the discriminant functions provided a way to predict forest cover type, they did not suggest the distribution of the forest cover types along simply explained gradients of change in site or disturbance history-related variables. Nonetheless, through

examination of the relationships among certain disturbance history-related variables, site factors, and forest cover type, vegetation patterns related to disturbance history and site factors were perceived. For example, agricultural clearing led to regeneration by Yellow Pines and Yellow-poplar forest cover types, while clearing for logging generally led to Mixed Mesic Hardwoods and Yellow-poplar types. In contrast, in plots now dominated by oaks or sub-xeric hardwoods, tree removal by fire, chestnut blight, or cutting was believed to have not resulted in the clearing of the stand. Rather, the historical disturbance was considered diffuse by virtue of the uneven-aged stand conditions presently encountered in the plots.

Within the study area, both the very broad scale pattern of historical disturbance in GSMNP and the relatively more fine scale interaction of disturbance with topography were important influences on the current forest cover pattern. The settlement patterns in GSMNP led to heavy use of mesic sites at low elevations. In the present study, mesic sites at low elevation were uniformly subjected to intense agricultural land use pressures which resulted in the clearing of the land. At high elevation, logging, rather than farming, was the major disturbance. Logging was both heavy (resulting in clear cut stands) and light (resulting in diffusely disturbed stands).

The cleared sites at low elevation, including some logged sites below 2880 feet (ca 875 m) elevation, regenerated to yellow-poplar.

Where low elevation sub-mesic sites were subjected to intensive agricultural land use, yellow pines regenerated. Where low elevation sub-mesic to sub-xeric sites were subjected to diffuse disturbances, uneven-aged stands of oaks and other generally non-mesic species are now found. However, at high elevation except on sites of xeric topography, mesic hardwoods regenerated whether the disturbance was intensive or diffuse.

In the present study, the estimated plot productivity of trees > 30 cm dbh was used as an index variable; i.e., a variable which could be used to summarize the response of the forest to site factors. Thus, estimated plot productivity was referred to as the "plot productivity index score." For prediction of plot productivity, regression models were developed using either plot productivity index score or the natural log of plot productivity index score. Both measures of plot productivity index score were best predicted by an equation involving topography class and total soil depth. A comparison was made of the results of the present study (which involved disturbed plots only) versus the results presented by Callaway (1983) for a combination of disturbed and undisturbed plots and for undisturbed plots only. Using a combination of topographic and soils variables to predict log-transformed plot productivity index score, a coefficient of determination (R^2) was found of 0.83, 0.63, and 0.43, respectively, for undisturbed plots only, undisturbed and disturbed plots combined, and disturbed plots only. Thus,

confirmation was seen of Callaway's conclusion that historical disturbance creates added variation in the relationship between site variables and plot productivity index.

A review of literature suggested that sources of variation in the prediction of plot productivity index score from a sample of trees may include tree crown position, species, and age. A major source of the potential variation in the plot productivity index score could be eliminated, and the relevance of the productivity index to forest timber management could be increased, if the population sampled at each plot were limited to dominant or codominant trees.

CHAPTER IX

CONCLUSIONS

- (1) The effect on forest cover type of variables related to topography appears to be more pronounced at lower elevation.
- (2) There are multiple successional pathways following a given disturbance; e.g., depending on how mesic a site is, the successional forest cover following farming may be classified as Yellow Pines or Yellow-poplar, or, in some cases (not sampled adequately enough to be discussed as a separate forest cover type in the present study), White Pine - Yellow-poplar.
- (3) There are also multiple disturbance history scenarios that may lead to a given forest cover type. For example, both agricultural clearing and clearcut logging led to dominance by the Yellow-poplar forest cover type on mesic sites; and both agricultural clearing and intense fires lead to dominance by Yellow Pines on less mesic sites.
- (4) Topographic variables were important in the prediction of both forest cover type and plot productivity index.
- (5) The present study addressed topographic differences among plots at two scales: fine scale and broad scale. Fine scale topographic features include classification of the plot position in terms of its presence on small landforms observed in field

work, the apparent orientation (azimuth) and slope of the plot measured while standing in the plot, and the moisture collecting capability (concavity versus convexity) of the terrain within the plot. Broad scale topographic features include the plot position described in terms of the landform on which the plot is perceived to be located when the plot is mapped, the plot position in relation to surrounding landforms recognized from a map, the slope and azimuth of the map landform, and the amount of area upslope of the plot that is in the watershed of the plot (i.e., that contributes underground or overground moisture to the plot).

- (6) The broad scale characterizations of topography provided better predictors of both forest cover type and plot productivity index score than did the fine scale topographic features.
- (7) A direction for future work applicable to the prediction of both plot productivity index scores and forest cover type, is the refinement and testing of the methods of classification or quantification of map-derived topographic features to establish a well documented methodology that is repeatable by subsequent investigators.
- (8) From study of the SAF descriptions of the forest cover types of the United States and Canada (Eyre 1980), two conclusions are drawn: (a) species in the type name should be representative of the majority of the stand basal area and (b) a named forest cover

type should dominate large areas in the aggregate. These guidelines were observed in the naming and discussion of plot forest cover types of the present study.

- (9) It was recognized that mesic hardwoods are dominated by several species that share dominance and are found in different proportions at different localities. It is tempting to believe that with more plots in a sample, the mesic hardwoods could be separated into several forest cover types in each of which fewer species would share dominance. However, it is concluded (given the large number of species present, the frequently random nature of factors [such as seed source and presence of light gaps] that determine which species are regenerated, and the many possible combinations of elevation, topography, and aspect in mesic hardwood forests) that it is likely impossible to identify associations of a small number of species that dominate the species basal area of large areas in the aggregate.

- (10) Forest cover types composed of chestnut oak and other oaks have been frequently described by workers in GSMNP. In comparison to the results of other studies, recognition of the Chestnut Oak - Yellow-poplar forest cover type in the present study is believed to be reasonable because yellow-poplar is generally included in the group of associated species that have been described for the chestnut oak forests of GSMNP. However, the present study, which included four Chestnut Oak Yellow-poplar plots, does not provide

sufficient evidence that this forest cover type is widespread or dominates a large area in the aggregate in GSMNP.

- (11) The inclusion of chestnut oak in all the Mixed Sub-xeric Hardwoods plots and the overlap between the species of this forest cover type and the SAF Chestnut Oak forest type suggests that the Mixed Sub-xeric Hardwoods are a more xeric variant of the chestnut oak forests of GSMNP.
- (12) Based on species composition and comparison of their group means for topography class, the Chestnut Oak - Yellow-poplar, Chestnut Oak, and Mixed Sub-xeric Hardwoods may be viewed as an example of a mesic to xeric gradient within the general confines of a Chestnut Oak forest type.

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APPENDICES

APPENDIX A
NAMES, DESCRIPTIONS, AND SOURCES OF VARIABLES
USED IN COMPUTERIZED DATA ANALYSIS

-
- ¹ indicates the source of data is Uplands Lab (See Bratton 1978)
 - ² indicates the source of data is Ray Callaway's work (See Callaway 1983)
 - ³ indicates field was renamed by Pyle
 - ⁴ indicates Pyle's field sampling
 - ⁵ indicates Pyle's office work (from maps or calculations)
-

AGESSQ⁵ - s^2 of age; i.e., the variance of the mean of the ages of the cored trees within a plot

BEERSAZ⁵ - Beers' et al. (1966) transformed azimuth for plot azimuth taken in the field. In tables and elsewhere in this manuscript, this variable is referred to as field azimuth.

BEERSOFF⁵ - Beers' et al. (1966) transformed azimuth for plot azimuth (OAZ⁴) derived from a map. In tables and elsewhere in this manuscript, this variable is referred to as map azimuth.

CA² - Clay in the A soil horizon (in percent)

CB² - Clay in the B soil horizon (in percent)

DA² - Depth (thickness) of the A soil horizon

DB² - Depth (thickness) of the B soil horizon

DBH¹ - Diameter at breast height measured in cm, ca 1978, on all woody plants above 1 cm diameter within the 20*50 m plots

DBH² - Diameter at breast height measured in cm, ca 1983, on trees cored for growth measurements

DBH⁴ - Diameter measured in cm, in 1987, (actually taken at one meter height) on trees cored for age estimates in 1987

DO² - Depth of the soil organic layer

DRA² - Drainage Area in hectares (File BIG.AUD, DATA ENVAR2); based on planimeter and grid form measurements (off topographic maps) of the area from which rainfall would drain into the plot (Callaway 1983:12)

ELEV⁴ - Elevation of plot in feet as determined by the position of the center of plots marked on enlarged copies of USGS 1:24,000 scale topographic maps used in the field

FAZ⁴ - Field Azimuth taken from uphill to downhill within a plot along the line of the steepest slope. Note that BEERSAZ is the "field azimuth" referred to in the text.

FSL⁴ - Field Slope taken in percent from uphill to downhill within a plot along the line of the steepest slope

LAND⁴ - designation of topography as seen in the field; coded from xeric to mesic

- 1 = knob; or narrow ridge (<30 m wide before sloping off)
- 2 = wide ridge
- 3 = upper slope (ridge top can be seen from plot)
- 4 = upland flat; or gap in ridge
- 5 = midslope
- 6 = lower slope
- 7 = bottomland flat, lacking live stream
- 8 = draw (not wide enough for plot to sit in flat)
- 9 = live stream flat; or ravine wide enough for plot to sit next to creek

LNVL² - Natural logarithm of VOL²; i.e., natural logarithm of the plot productivity index

MAX⁵ - Maximum age of cored trees within a plot

MEAN⁵ - Mean age of cored trees within a plot

MG⁴ - Moisture Gradient; shape of landform within the plot, coded from xeric to mesic

- 1 = convex
- 2 = undulating convex
- 3 = smooth
- 4 = undulating concave
- 5 = concave

MIN⁵ - Minimum age of cored trees within a plot

OAZ⁵ - Azimuth of plot derived from map. Note that BEERSCFF is the "map azimuth" referred to in the text.

OSL⁵ - Percent slope of plot derived from a map.

PHA² - pH of the A horizon of the soil

PHB² - pH of the B horizon of the soil

PLOTNUM⁵ - plot number, the first digit of which is the section number of the area of GRSM in which the plot is located

PRO² - Protection; a variable calculated from measurements off topographic maps. Protection was designed to give a numerical value for the comparison of the plots in terms of their surrounding topography. Protection was measured as the ratio between the elevation change and distance from the plot to surrounding landforms. The distance to surrounding landforms was measured from each plot on eight azimuths (0, 45, 90, 135, 180, 225, 270, and 315 degrees, where 0 is the azimuth to the north and 180 is the azimuth to the south). Callaway (1983) refers to "sheltering" landforms, while Callaway et al. (1987) described the protection measurements in terms of "nearby landforms of greater elevation." N. S. Nicholas, who did field work with Callaway and who worked with the protection calculations said that the distance was taken to the top of the nearest ridge or peak of greater elevation regardless of the degree of protection from solar radiation offered by the angle between the plot and the landform (personal communication to C. Pyle March 1988).

For each azimuth, the ratio of elevation change to distance was calculated by means of the formula $(ER-EP)/D$, where ER = elevation of sheltering landform, EP = elevation of plot, and D = distance from plot to sheltering landform. For the south, southeast, and southwest azimuths (180, 135, and 225 degrees), the elevation-distance ratios were weighted by 1.5 because this gave the variable protection a better fit to the data (Callaway 1983). It was reasoned that the southern exposure is more significant (presumably because in the northern hemisphere, exposure to the sun comes more from the south than the north and this has an observed effect on tree growth [Beers et al. 1966]). After weighting, plot protection values were derived from the average of the eight elevation-distance ratios.

Protection values for all the plots of Callaway varied from .01 to .44 (file BIG.AUD, DATA ENVAR). It can be observed that in a geometric sense, with a given distance, the greater the elevation change, the larger the ratio of elevation to distance, and the greater the degree of topographic sheltering. This observation does not consider differences in distances to sheltering landforms, differences in the range (within a plot) of the eight ratios of elevation change to distance from the plot (measured on the eight azimuths), nor differences in the weights applied to southerly azimuths. But, the highest value for protection is believed to indicate the most surrounding land of higher elevation (Callaway et al. 1987, who converted the "protection" of Callaway [1983] into a scale from 0 to 100).

RT³ - Callaway's topographic class; renamed from T². (From discussion in Callaway [1983] the code appears to be numbered 1-8 from xeric to mesic.)

- 1 = ridge top
- 2 = gap
- 3 = open slope
- 4 = xeric flat
- 5 = protected slope
- 6 = cove
- 7 = ravine
- 8 = mesic flat

SA² - Sand in the A soil horizon (in percent)

SB² - Sand in the B soil horizon (in percent)

SIA² - Silt in the A soil horizon (in percent)

SIB² - Silt in the B soil horizon

SPECIES¹ - Species code (has six letters)

ST² - % volume of stone in soil

STDEV⁵ - Standard Deviation of the mean of the ages of the cored trees in a plot

SUMA⁴ - the number of times (out of 40 samples per plot) that charcoal < 5 mm (on the longest axis) was seen

SUMB⁴ - the number of times (out of 40 samples per plot) that charcoal 5 mm - 10 mm (on the longest axis) was seen

SUMC⁴ - the number of times (out of 40 samples per plot) that charcoal > 10 mm (on the longest axis) was seen

SUMD⁴ - the number of times (out of 40 samples per plot) that any charcoal at all was seen. Note that in the tables in this manuscript, "charcoal" refers to the variable "SUMD."

SUME⁴ - the number of times (out of 40 samples per plot) that charcoal of both size classes <5 mm and 5 mm - 10 mm was seen

SUMF⁴ - the number of times (out of 40 samples per plot) that charcoal of both size classes <5 mm and >10 mm was seen

- SUMG⁴ - the number of times (out of 40 samples per plot) that charcoal of both size classes 5 mm - 10 mm and >10 mm was seen
- SUMH⁴ - the number of times (out of 40 samples per plot) that charcoal of all three size classes (<5 mm, 5 mm - 10 mm, >10 mm) was seen
- SUMI⁴ - the number of times (out of 40 samples per plot) that charcoal of all three size classes (<5 mm, 5 mm - 10 mm, >10 mm) or the two larger size classes was seen
- TD² - Total Depth of soil (from top of O horizon to the deepest point penetrated by a metal probe [Callaway 1983])
- VOL² - Volume increment for each plot; referred to in the present study as the plot productivity index, and expressed in terms of the estimated annual volume increase in cubic meters per hectare based on the following formula: (the mean of the periodic annual volume increment of five trees per plot) * (the number of trees 30 cm in diameter and above) * (10 [because the plots were one-tenth hectare]). Sometimes less than five trees per plot were used (see plot data); and for plots with very small trees, the 30 cm lower diameter limit was reduced (E. Clebsch, personal communication).

The periodic annual volume increment of a tree was defined as the amount of bole wood accumulated in the course of a year (Callaway 1983). Annual volume increment was based on the annual mean of the estimated volume increment of a 10 year period. One increment core per tree was used to estimate the average radial growth of the previous 10 years. At the time of coring, tree height was estimated and current diameter (outside bark) was measured. The tree bole radius (= current measured diameter/2) minus the 10 year increment was used to estimate the tree radius of 10 years before. A cone was used to model the tree bole shape (formula = $[Pi * radius^2 * height]/3$). The 10 year volume increment of each cored tree was estimated by taking the difference between the volume of two cones: the first, calculated from the current diameter/2 and height, and the second, calculated from current height and estimated radius of 10 years past. Periodic annual volume increment was derived by dividing the 10 year increment by 10.

APPENDIX B

DISTURBANCE HISTORY CHECKLIST USED IN FIELD WORK

DISTURBANCE HISTORY CHECKLIST Plot # _____ Date _____

FARMING IN PLOT ___ >1 rockpile ___ plough lines > 50 m AWAY ___ >1 rockpile ___ plough lines

PAST GRAZING ___ parallel trails ___ moss on stairstep risers ___ exposed roots

LOGGING ___ cable, equipment in plot ___ cable, etc. within 50 m of plot ___ stump > 30 cm possibly cut
CLEARLY CUT STUMPS (>30 cm) WITH NO ADJACENT LOGS: ___ Chestnut ___not Chestnut

CHESTNUT BLIGHT (CHESTNUT ONLY) ___ logs >30 cm on ground ___ logs <30 cm on ground
___ snags >30 cm ___ snags <30 cm ___ stumps not evidently sawn ___ log next to cut stump

FIRE ___ healed over flat place in base of tree trunk ___ cat face ___ charred catface
CHARCOAL SEEN: ___ ground ___ log < 10 cm dbh ___ log > 10 cm dbh ___ snag ___ live tree

GENERAL PHYSICAL

IN PLOT: ___ chimney ___ square cornered rockpile ___ single shapeless rockpile
___ exposed rocks on ground non-aluminum/plastic artifacts (specify): _____
___ pit and mound topography ___ other misc. holes > .5 m wide (describe below) ___ levelled area
FENCE ___ posts ___ rails ___ wire ___ row of trees
ROAD (>1.5 m WIDE): ___ old rd ___ RR ties TRAIL: ___ <75 cm wide ___ >75 cm wide ___ >10 cm deep

<50 m AWAY: ___ chimney ___ square cornered rockpile ___ single shapeless rockpile
___ exposed rocks on ground non-aluminum/ plastic artifacts (specify): _____
___ pit and mound topography ___ other misc. holes > .5 m wide (describe below) ___ levelled area
FENCE ___ posts ___ rails ___ wire ___ row of trees
ROAD (>1.5 m WIDE): ___ old rd ___ RR ties TRAIL: ___ <75 cm wide ___ >75 cm wide ___ >10 cm deep

BIOLOGICAL

___ even aged appearance ___ grape vines in canopy in plot ___ grape vines in canopy >50 m from plot

OPEN GROWN TREES: ___ 1 or 2 ___ >2 species: _____

___ Synchronous Mortality in Pine

SPROUT CLUMPS: ___ Trees patterned as around old stump Species _____

___ >2 trees, no pattern Species _____

___ 5 or more *Rhodo* stems from ground level bole ___ 5 or more *Kalmia* stems from ground level bole

EXOTICS (or Walnut or Linder) IN PLOT (Specify): _____

EXOTICS (etc.) WITHIN 50 m OF PLOT (Specify): _____

ANIMAL SIGN: ___ Hog rooting ___ scat (from what? _____) Other: _____
___ browsed vegetation ___ browse line ___ currently accessible to cattle

STAND VIGOR: ___ excellent ___ unremarkable ___ poor ___ Canopy gaps

NOTES

APPENDIX C

DETERMINATION OF UPPER CROWN CANOPY

The vegetation data received from Uplands Field Research Laboratory, GSMNP listed each tree by plot number, species, and dbh. For the present study, the data were sorted by dbh class within each plot and printed one tree to a line. Each plot was examined as a unit without reference to the other plots in the data set.

First, for each plot, breaks in the diameter distribution were marked. Second, the diameter and species of each tree cored for age was compared to the listed diameter and species of all the "overstory" trees. To designate cored trees, an asterisk was placed beside the corresponding tree in the stand data array. In the 10 years between plot establishment and tree coring for age, the trees generally had grown one or two centimeters in diameter. When the relationship of a cored tree to the vegetation data array was ambiguous, a "worst case" assumption of growth stagnation and insignificant bole taper was used as a rule to match the cored tree to the vegetation data. For example, if a cored tree was a 39 cm black oak, and the data array showed 36, 39, 40, 41, 42 and 44 cm black oaks, the asterisk was placed beside the the 39 cm individual. The "worst case" rule was used because it was a repeatable method.

If the cored trees fell above the marked break in diameter distribution, the breaking point was taken as a cut off point between individuals of the codominant and intermediate crown classes. If there was no breaking point, the diameter of the smallest tree cored

was used as a guideline to the likely size of the codominants; and an arbitrary cut off point was set at a diameter less than that of the cored trees and divisible by five. The choice of the arbitrary point was also influenced by silvical characteristics. For example, if the cored trees were 37 cm dbh and above, and the individuals between 30 and 35 cm dbh were yellow-poplars (an intolerant species), the lower diameter level was set at 30 cm. In contrast, if the 30 to 35 cm individuals were oaks, then 35 cm was taken as the cutoff level. If there was a clear breaking point, but the cored trees were smaller in diameter (which happened in the case of gap fillers), the trees with diameters greater than the breaking point plus the cored trees were designated as the upper crown canopy.

After a data set composed of the upper crown canopy individuals had been created, the method was tested by comparing the calculated total plot basal area to what were considered reasonably expected levels of basal area for dominants and codominants. If the calculated basal area did not fall within the range of $1.4 \text{ m}^2/\text{plot}$ (about $60 \text{ ft}^2/\text{acre}$) and $3.2 \text{ m}^2/\text{plot}$ (about $140 \text{ ft}^2/\text{acre}$), the cut off point was reconsidered. For plots with low basal areas, the plot disturbance history data were examined to see if comments had been made concerning stand break-up or canopy gaps. After examination of the disturbance history data, the likely codominant cut off level was changed in one plot with an unreasonably low basal area and one plot with an unreasonably high basal area.

During the process of examining the data to designate the upper crown canopy, comparisons of the cored tree data versus the plot vegetation data indicated a few conflicts in species identification. The species of the cored trees in question were rechecked by examination of the core with respect to woody characteristics (Panshin and DeZeeuw 1980). The species in the vegetation data set were reassigned to reflect the identification of the core.

APPENDIX D

DETAILS ON DETRENDED CORRESPONDENCE ANALYSIS

Theory and Use in Plant Ecology

Detrended Correspondence Analysis (DCA or DECORANA; Hill 1979a, Hill and Gaugh 1980) is a method of ordination. Ordination is a non-hierarchical method of ordering multivariate data for the purpose of identifying the elements of underlying order that contribute to the differences among individual entities. In the present study, individual entities consisted of vegetation plots. The elements of underlying order are perceived as a simply described gradient, or trend, along which the characteristics of the individual entities change.

Most work done with ordination in plant ecology has been exploratory in nature. Objectives have been (1) to gain understanding of plant community structure (both for descriptive purposes and for making better mathematical models), (2) to show patterns of continuous relationships between vegetation (species composition) and environmental gradients, and (3) to generate (rather than to test) hypotheses (Gauch 1982:118, Barbour et al. 1987:225, Williams and Gillard 1971:245-246). However, Chang and Gaugh (1986) provide an example of using the gradients defined by ordination axes as dependent variables in multiple regression.

Ordination is a multivariate statistical technique. In general, multivariate techniques provide a means to work with and summarize numerous variables simultaneously. Variables measured for each

individual are assigned weights and an individual's ordination score is the sum total of the weights times the variables. For the present study, DCA was used to summarize plot species basal area. Weights were assigned to each species in the data set. For each plot, the sum of each species' basal area times the weight assigned that species was totalled to give the plot's ordination score.

In any ordination procedure, individuals in a data set are placed on an axis according to their ordination scores. With vegetation data, because different species have been assigned different weights, plots with similar species composition are likely to have similar ordination scores while those with very different species compositions are likely to have widely divergent scores. Thus the ordination axis represents a gradient of change in species composition. To identify the elements that contribute to the underlying order of plot species composition, similarities and differences among site factors associated with vegetation plots may be examined along the ordination axis.

Whittaker (1975:120) described a complex-gradient as the "assemblage of environmental factors that change together through the space along which a community gradient [the change in species composition] occurs and that influence its populations..." Correlations between site factors and plot scores may be done to see which site factors may contribute to the environmental gradient underlying the change in species composition along the ordination

axis. When the highly correlated factors are identified and considered as a whole, the investigator may be able to perceive the existence of an underlying environmental gradient.

It must be kept in mind that the gradient of change in site factors is generally complex. Thus different site factors may be of different degrees of importance for different species or communities. Furthermore, some site factors may be more important in their interaction than when taken singly. The underlying gradient is expected to express a higher level of organization and be something more than the sum of the individual site factors.

Mathematical Details

DCA is a refinement of reciprocal averaging (Hill 1973). Reciprocal averaging is analogous to correspondence analysis (l'analyse des correspondances). French statisticians have viewed correspondence analysis in terms of the matrix algebra of joint occurrences (correspondences) of individuals of like kind (Hill 1973:239) while plant ecologists have used the same algebra as the basis for the manipulation of vegetation plot data by means of weights assigned to species. The mathematical theory behind the use of reciprocal averaging for a matrix of species by plots data is the belief that when species are assigned the proper weights, plots will align themselves along a gradient in an order that best reflects the differences in species composition among the plots.

Reciprocal averaging is an iterative process, i.e., it does the same thing over and over again. The process involves two basic steps. As stated by Hill (1973:238), "the process may be called 'reciprocal' because the species-scores are averages of the stand-scores and reciprocally the stand-scores are averages of the species-scores." For a data set organized as a matrix with all the species in rows (designated by i) and all the plots in columns (designated by j), the value entered at the intersection of row i and column j represents the response of species i in plot j . In the present study, the species response is expressed in terms of basal area.

In a species by plots data set, the reciprocal averaging process begins with the assignment of an arbitrary weight to each species. A species weight is referred to as a species score. Plot scores are calculated for each plot based on the weighted average of the sum total basal area found in the plot. This can be expressed algebraically as:

$$y'_j = \sum_i a_{ij} x_i / c_j,$$

where

y'_j = the new value for the score for plot j

a_{ij} = the response of species i in plot j

(i.e., the basal area of species i in plot j)

x_i = the weight most recently assigned to species i

$c_j = \sum_i a_{ij}$ = the total of the response of all species i for plot j (i.e., the total basal area found in plot j)

In general, note that for this discussion of reciprocal averaging:

x refers to species

y refers to plots

i is used as a subscript to x , and refers to a row in a data matrix organized in $X * Y$ form (e.g., if $i = 3$ reference is being made to the species for which data has been recorded in row 3)

j is used as a subscript to y , and identifies columns (i.e., plots) in the data matrix

r_i is a row total for species i

c_j is a column total for plot j

Thus, when (for example) $j = 1$, the above formula applies to plot 1. A sum is totalled by taking (within an individual plot) the basal area for species 1 times the weighting for species 1, plus the basal area for species 2 times the weighting factor for species 2, and so on, until the weighted basal areas for all the species have been summed for the plot. Next, the plot score (which represents an average of the total weighted plot basal area) is gotten by dividing the weighted plot sum total (i.e., the $\sum_i a_{ij}x_i$) by the total plot basal area from the original (unweighted) data (i.e., c_j). The process is done for all plots. The plot scores can be used to order the plots on a gradient from low scores to high scores.

The next step in reciprocal averaging is to redefine the distribution of species scores in the light of the new plot scores.

Starting with the plot scores just calculated, new species scores (i.e., new weights for the species) can be calculated.

Algebraically, this is expressed as:

$$x'_i = \sum_j a_{ij} y_j / r_i,$$

where

x'_i = the new species score

a_{ij} = the response of species i in plot j

(Note that a_{ij} represents the actual basal area of species i in plot j , and does not change as the species scores change)

y_j = the plot score most recently assigned to plot j

$r_i = \sum_j a_{ij}$ = the total of the responses across all the plots for species i (Note that this total [and, also, c_j] represent the values initially measured for a_{ij} , and do not change when species scores [or plot scores] change)

Thus, beginning with $i = 1$ (i.e., beginning with the calculations for species 1), the new scores for the species are calculated in a manner inverse to the calculation for plot scores. Weighted basal area is summed over plots by species. Beginning with species 1, the summation is made for the basal area for species 1 in plot 1 times the plot score for plot 1, plus the basal area for species 1 in plot 2 times the plot score for plot 2, and so on, until all the plots have been included. The species score (which represents an average of the total weighted species basal area) is then gotten by dividing the weighted species sum total (i.e., the $\sum_j a_{ij} y_j$) by the total basal

area for that species as recorded in the original data set (i.e., r_1). The dual process described above is iterated using the new species scores to calculate another new set of plot scores, which, in turn, are used to calculate still another set of species scores.

Although it is hard to accept, intuitively, that this reciprocal averaging process leads to anywhere, ultimately, a stable point is reached where the calculated species scores change so little that the newest set of plot scores is virtually the same as the previous set. Though the mathematical processes by which the gradients for the plots are derived are not similar for reciprocal averaging versus principal components analysis, the graphed output looks similar. That is, both outputs, when graphed in two dimensions, have the appearance of an X-Y graph. Likewise, both sets of results lead to the geometric structuring of the data in a way that summarizes the variation between plots and helps a person think about what underlying factors may be responsible for the variation between plots.

It has been observed that both principal components analysis and reciprocal averaging lead to situations where the second or other subsequent axes, although mathematically uncorrelated to the previous axis, are not independent of it. Because of systematic, but uncorrelated, relationships between the ordination axes, tests of contrived data for which the ordination should have produced a horizontal line of points across the ordination space, resulted in a

representation of the plots in an arched configuration; i.e., a second axis was quadratically related to the first (Gaugh, et al. 1977). The same phenomenon was described as the horseshoe effect by Kendall (1971).

DCA is identical to reciprocal averaging except that it includes a rescaling of the axes and a detrending procedure designed to prevent the points from being placed in a curve where there is no curved relationship between the plots (Hill 1979a, Hill and Gaugh 1980). Detrending is done to all axes after the first one each time (except for the last time) the sample scores are calculated. The reason there is no detrending following the last calculation of sample scores is to preserve the relationship of the plot scores as the weighted means of the species scores.

Detrending the second axis involves dividing the first axis into segments. Within each segment, the values on the second axis are centered so that their mean variation from a straight line parallel to the first axis is zero. Running segments are used in the DCA program (Hill and Gaugh 1980). The rescaling of the reciprocal averaging axes done by DCA is to equalize the mean within-sample dispersion of species scores at all points along the gradient. Within-sample variance is standardized to unit deviation for the average species abundance profile.

Wartenberg et al. 1987 have criticised DCA both for the detrending and for the rescaling of the axes. They consider the arch effect to be an attribute of the data structure rather than a mathematical artifact. Thus, they argue that it should be interpreted rather than disguised by detrending. The rescaling is considered arbitrary by both Wartenberg et al. (1987) and Digby and Kempton (1987). The rescaling is based on the untested theory that species turnover takes place at a constant rate.

APPENDIX E

COMPUTER PROGRAMS USED FOR DATA ANALYSIS

For preliminary data organization and miscellaneous data reduction, VP Planner (a spreadsheet program) and DBASE III (a database manager program) were used. For the analyses discussed in this thesis, the programs listed in Table E-1 were used.

Table E-1. Computer programs used in data analysis.

Name	Reference	Use
DCA	Hill 1979a	Ordination of plots based on their species composition.
PROC CORR;	SAS 1985 ¹	Correlations among DCA axes, site/disturbance history variables, and forest cover type (with the forest cover types numbered from 1 to 8 corresponding to their rank order along the first DCA axis).
PROC DISCRIM;	SAS 1985	To develop a weighted linear function of site/disturbance history variables that best separate the forest cover types for the purpose of predicting forest cover type.
PROC GLM;	SAS 1985	For prediction of plot productivity index score, a series of models was made, beginning with one independent variable and continuing until the addition of more variables resulted in no significant increase in the sequential sum of squares. The variables were added in the order of importance derived from PROC STEPWISE.
PROC GLM; MEANS --/SNK;	SAS 1985	Analysis of variance with forest cover type and site/disturbance history variables testing the separation of forest cover type means for each site/disturbance history variable.

Table E-1. continued

Name	Reference	Use
PROC MEANS;	SAS 1985	(1) Tally of within plot minimum and maximum tree age; and calculation of within plot mean and standard deviation of tree age. (2) Calculation of means and standard deviations by forest cover type for selected site/disturbance history variables.
PROC STEPDISC	SAS 1985	Determination of the best predictors of forest cover type using a discriminant function. Stepwise selection was used.
PROC STEPWISE	SAS 1985	Determination of the best predictors of (a) plot productivity index score and (b) the natural log of plot productivity index score. The maximum R^2 improvement method of model selection was used.
TWINSpan	Hill 1979b	Cluster analysis of plot species composition.

¹ SAS 1985 = SAS Institute, Inc. 1985.

APPENDIX F

SCIENTIFIC NAMES OF PLANTS REFERRED TO BY COMMON NAME

basswood, white	<u>Tilia heterophylla</u> Vent. ¹
beech, American	<u>Fagus grandifolia</u> Erhr.
birches	<u>Betula</u> spp.
bitternut hickory	<u>Carya cordiformis</u> (Wangenh.) K. Koch
black cherry	<u>Prunus serotina</u> Erhr.
black locust	<u>Robinia pseudoacacia</u> L.
black oak	<u>Quercus velutina</u> Lam.
blackgum	<u>Nyssa sylvatica</u> Marsh.
buckeye, yellow	<u>Aesculus octandra</u> Marsh.
bur oak	<u>Quercus macrocarpa</u> Michx.
chestnut, American	<u>Castanea dentata</u> (Marsh.) Borkh.
chestnut oak	<u>Quercus prinus</u> L.
cucumber magnolia = cucumbertree	<u>Magnolia acuminata</u> L.
dogwood, flowering	<u>Cornus florida</u> L.
fire cherry = pin cherry	<u>Prunus pensylvanica</u> L.f.
Fraser magnolia	<u>Magnolia fraseri</u> Walt.
hemlock, eastern	<u>Tsuga canadensis</u> (L.) Carr.
hickories	<u>Carya</u> spp.
maples	<u>Acer</u> spp.
mockernut hickory	<u>Carya tomentosa</u> (Poir.) Nutt.
mountain laurel	<u>Kalmia latifolia</u> L. ²

¹ Except as noted, the names follow those of Little 1979.

² Name from Radford et al. 1968.

northern red oak	<u>Quercus rubra</u> L.
oaks	<u>Quercus</u> spp.
pignut hickory	<u>Carya glabra</u> (Mill.) Sweet
pinus	<u>Pinus</u> spp.
pitch pine	<u>Pinus rigida</u> Mill.
post oak	<u>Quercus stellata</u> Wangenh.
red maple	<u>Acer rubrum</u> L.
rhododendron	<u>Rhododendron</u> spp.
rosebay rhododendron	<u>Rhododendron maximum</u> L.
sassafras	<u>Sassafras albidum</u> (Nutt.) Nees
scarlet oak	<u>Quercus coccinea</u> Muenchh.
serviceberry	<u>Amelanchier laevis</u> Wieg. ³
short-leaf pine	<u>Pinus echinata</u> Mill.
silverbell, Carolina	<u>Halesia carolina</u> L.
sourwood	<u>Oxydendrum arboreum</u> (L.) DC.
southern red oak	<u>Quercus falcata</u> Michx.
sugar maple	<u>Acer saccharum</u> Marsh.
sweet birch	<u>Betula lenta</u> L.
sweetgum	<u>Liquidambar styraciflua</u> L.
Table Mountain pine	<u>Pinus pungens</u> Lamb.
Virginia pine	<u>Pinus virginiana</u> Mill.
white ash	<u>Fraxinus americana</u> L.
white oak	<u>Quercus alba</u> L.

³ Name from Braun 1950 and Shanks 1954b.

white pine, eastern	<u>Pinus strobus</u> L.
yellow birch	<u>Betula alleghaniensis</u> Britton
yellow-poplar	<u>Liriodendron tulipifera</u> L.

APPENDIX G

TABLES G-1 - G-3

Table G-1. Correlations¹ among DCA axes scores, forest type, and site/disturbance history variables

	DCA Axis 1	DCA Axis 2	DCA Axis 3	DCA Axis 4	forest cover type	plot productivity	LN, productivity	elevation	topography class	protection	drainage area	map azimuth	map slope	depth, O horizon
elevation	.78	+	.	.	.64	.	.	*	.	.	.	.	.34	.
topography class	.29	-.37	.	.	.33	.54	.53	.	*	.56	.52	.	.	-.37
protection	.44	.	-.26	.	.45	.42	.43	.	.56	*	.61	.	.27	.
drainage area	.36	-.35	.	.	.40	.44	.39	.	.52	.61	*	.	.	-.38
landform	.	-.31	.	.	.	+	.30	-.32	.67	.51	.48	.	.	-.38
moisture gradient	+	.	.	.	.	.	.	.	.41	.42	.38	.	.	-.40
field azimuth	.28	.	.	-.28	.27	.	.	.	.	.	.	.62	.	.
map azimuth	.39	.	.	-.27	.42	.	.	.	.	.	.	*	.	.
field slope	.33	+	.	.	+	.	.	.29	.	.27	.	.	.	.
map slope	.37	.	.	.	+	.	.	.34	.	.27	.	.	*	.
% clay, A horizon	-.58	+	.	.	-.53	-.34	-.37	-.44	-.35	-.50	-.46	.	-	.36
% clay, B horizon	-.61	.	.	.	-.54	.	-	-.45	-.27	-.41	-.46	.	.	.30
% sand, A horizon	.46	.	.	.	.44	.44	.43	.	.46	.54	.54	.	.	-.26
% sand, B horizon	.44	.	.	.	.41	.33	.34	.	.41	.48	.54	.	.	.
depth, O horizon	.	.48	.	.	.	-.27	-.41	.	-.37	.	-.38	.	.	*
thickness, A hor.	.42	-.41	.	.	.43	.44	.44	.35	.29	+	.35	.	.	-.36
thickness, B hor.	.30	-.28	.	.	.36	.38	.38	.	.34	.	.	.	.	-.28
total soil depth	.26	-.37	.	.	.27	.50	.54	.	.33	.	.	.	.	-.32

Table G-1. (Continued)

	DCA Axis 1	DCA Axis 2	DCA Axis 3	DCA Axis 4	forest cover type	plot productivity	LN, productivity	elevation	topography class	protection	drainage area	map azimuth	map slope	depth, O horizon
pH, A horizon	. - .48	.	.	.	.	.35	.38	-.31	.45	.35	.36	.	-.29	-.46
pH, B horizon	. - .61	.	.	.	.	.47	.49	-.32	.54	.31	.37	.	-	-.45
charcoal	.	.27	-.29	.	.	.	-.28	.	-.39	.	.	.	+	.29
min. tree age	.	.	.33	.	.	.	.	.	.	.	.	.	.26	.
max. tree age	.	.40	+	.	.	.	.	.	.	.	.	.	+	.
mean tree age	.	.36	.26	.	.	.	.	.	.	.	.	.	+	.
s.d. of tree age	.	.43	.	.	.	.	.	.	.	.	.	.	.	.
age variance	.	.30	.	.	.	.	.	.	.	.	.	.	.	.
forest cover type ²	.89	.	.	.	*	.45	.37	.64	.33	.45	.40	.42	+	.

¹ The following correlations are significant at .0500: elevation/pH, B horizon; total soil depth/ depth, O horizon. All other correlation coefficients (r) are significant as follows:

if $r \geq .48$, then $P = .0001$; if $.41 \leq r \leq .47$, then $P = .0100$; if $.32 \leq r \leq .40$, then $P = .0100$;

if $.25 \leq r \leq .31$, then $P = .0500$; if + or -, then $P = \pm .0999$.

² The forest cover types were assigned numbers based on their position along the first DCA axis.

Table G-2. Variables That Result in Significant (.05) Separation of Forest Cover Types by the S-N-R test

	Yellow Pines	White Oak - Oak	Chestnut Oak -Oak	Mixed Sub-xeric Hardwoods	White Pine Hardwoods	Chestnut Oak - Yellow-poplar	Yellow- poplar	Mixed Mesic Hardwoods
Yellow Pines	*** *** ***	MAX, ¹ MEAN	MAX, MEAN STDEV AGESSQ	DO MAX	RT DB	PRO,MIN MAX,MEAN STDEV	DRA	ELEV
White Oak - Oak	MAX MEAN	*** ***	-----	DO	RT, DB MEAN	-----	DRA MEAN	ELEV
Chestnut Oak - Oak	MAX, MEAN STDEV AGESSQ	-----	*** *** ***	DO	FSL, MEAN DB, AGESSQ MAX, STDEV	-----	DRA, CA CB, STDEV MAX, MEAN	ELEV CA CB
Mixed Sub- xeric Hdwda.	MAX DO	DO	DO	*** ***	RT, DB TD, DO	DO	DRA, CA DO	ELEV, CA CB, DO
White Pine - Hardwoods	RT DB	RT DB MEAN	FSL, MEAN DB, AGESSQ MAX, STDEV	RT, DO DB, TD	*** ***	PRO, DB TD, MAX	DRA DB	ELEV, DB FSL, CB
Chestnut Oak - Yellow- poplar	PRO, MIN MAX, MEAN STDEV	-----	-----	DO	PRO, DB TD, MAX	*** ***	DRA, DA MIN, MAX	ELEV DA
Yellow-poplar	DRA	DRA MEAN	DRA, MAX CA, MEAN CB, STDEV	DRA CA DO	DRA DB	DRA, DA MIN, MAX	*** ***	ELEV DRA
Mixed Mesic Hardwoods	ELEV	ELEV	ELEV CA, CB	ELEV, CA CB, DO	ELEV, CB FSL, DB	ELEV DA	ELEV DRA	*** ***

^{1/} Variables are AGESSQ = Variance of plot tree age, CA = Clay in the A horizon, CB = Clay in the B horizon, DA = Thickness, A horizon, DB = Thickness, B horizon, DO = Depth, O horizon, DRA = Drainage area into plot, ELEV = elevation, FSL = Plot slope taken in the field, MAX = Maximum age of trees cored in a plot, MEAN = Mean age of cored trees in a plot, MIN = Minimum age of cored trees in a plot, PRO = Protection, RT = Topography class, STDEV = Standard deviation of age of cored trees, TD = Total soil depth.

Table G-3. Summary of forest cover type site/disturbance history variables

Variable	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
	Yellow Pines		White Oak - Oak		Chestnut Oak - Oak		Mixed Sub-xeric Hardwoods	
Elevation	1991	300	1904	135	2048	218	2366	954
topography class	2.9	1.4	3.7	1.3	4.2	2.2	2.8	1.6
protection	0.14	0.05	0.15	0.04	0.23	0.09	0.16	0.09
drainage area	0.37	0.24	0.84	0.34	1.28	1.14	0.52	0.38
field azimuth	1.07	0.74	0.58	0.82	0.99	0.71	0.88	0.78
map azimuth	0.77	0.49	0.81	0.76	1.09	0.70	1.41	0.54
field slope	18.5	13.3	26.7	19.3	41.8	24.1	34.2	30.3
map slope	19.5	17.1	22.7	27.7	42.4	20.0	29.5	29.9
charcoal	9.3	11.9	4.3	5.9	14.8	5.6	15.3	9.5
minimum age	38.6	6.3	63.9	17.4	58.2	8.5	49.7	14.8
maximum age	64.4	21.6	154.0	27.6	170.8	47.7	144.2	70.6
mean plot age	51.0	9.0	110.6	15.7	118.9	27.0	88.0	35.9
s.d. within plot	9.7	7.7	37.9	15.2	53.6	22.9	41.2	26.1
	White Pine - Hardwoods		Chestnut Oak - Yellow-poplar		Yellow-poplar		Mixed Mesic Hardwoods	
Elevation	1831	74	2143	97	2203	407	4001	913
topography class	7.0	2.0	4.7	2.1	5.5	2.2	4.5	2.0
protection	0.14	0.02	0.28	0.09	0.27	0.10	0.23	0.09
drainage area	0.40	0.37	1.73	0.62	4.76	3.57	2.09	2.76
field azimuth	0.90	0.79	1.09	0.73	1.15	0.81	1.41	0.65
map azimuth	1.05	0.71	0.92	0.67	1.76	0.44	1.48	0.73
field slope	8.5	5.1	36.0	17.5	14.7	18.9	44.1	18.6
map slope	11.5	3.0	29.5	25.4	13.6	18.4	44.1	16.5
charcoal	2.3	2.1	9.0	4.8	9.0	11.7	6.7	9.4
minimum age	49.5	13.4	69.7	24.4	40.3	11.7	52.5	17.6
maximum age	83.7	39.7	165.5	59.7	77.9	47.8	108.3	62.9
mean plot age	64.6	25.8	104.6	39.3	62.0	27.7	77.2	37.1
s.d. within plot	13.7	11.0	44.1	23.1	14.6	20.8	24.4	22.3







Table G-3. (Continued)

	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
	Yellow Pines		White Oak - Oak		Chestnut Oak - Oak		Mixed Sub-xeric Hardwoods	
% clay, A horizon	27	6.6	25	6.2	31	6.3	30	4.3
% clay, B horizon	30	9.2	31	7.6	35	6.8	32	5.4
% sand, A horizon	23	10.1	23	9.6	27	8.6	22	5.1
% sand, B horizon	21	8.2	21	13.4	22	10.6	20	4.5
depth, O horizon	6	2.2	4	2.1	5	2.2	10	3.5
thickness, A hor.	15	4.6	12	4.2	11	3.1	11	3.9
thickness, B hor.	25	18.5	20	7.9	22	7.8	19	4.0
total soil depth	66	19.1	65	14.7	68	16.9	59	11.1
pH, A horizon	4.9	0.29	5.1	0.20	5.0	0.25	4.9	0.12
pH, B horizon	5.2	0.24	5.2	0.16	5.1	0.19	5.0	0.26
productivity index	1.53	0.96	2.03	0.64	1.47	0.94	1.40	1.50
<hr/>								
	White Pine - Hardwoods		Chestnut Oak - Oak		Yellow-poplar		Mixed Mesic Hardwoods	
% clay, A horizon	27	3.9	23	5.1	20	7.5	18	5.5
% clay, B horizon	33	2.1	28	4.0	22	8.4	20	6.7
% sand, A horizon	26	7.6	29	7.9	36	9.8	32	9.3
% sand, B horizon	20	8.3	26	5.3	34	11.0	29	7.7
depth, O horizon	5	1.0	5	0.6	3	2.5	5	3.3
thickness, A hor.	15	5.2	10	2.4	19	4.9	20	6.6
thickness, B hor.	47	10.0	24	8.4	32	13.6	33	5.9
total soil depth	85	0.0	60	17.0	73	11.2	75	11.4
pH, A horizon	5.1	0.24	5.1	0.30	5.3	0.34	4.9	0.25
pH, B horizon	5.3	0.18	5.1	0.25	5.4	0.26	5.1	0.25
productivity index	4.55	1.30	2.14	0.95	4.06	1.85	3.18	1.76

APPENDIX H

FIGURES H-1 - H-15

Figure H-1. Northwestern Great Smoky Mountains National Park.

-  Park boundary
-  public road
-  restricted road
-  stream
-  Davis Ridge
-  plot location

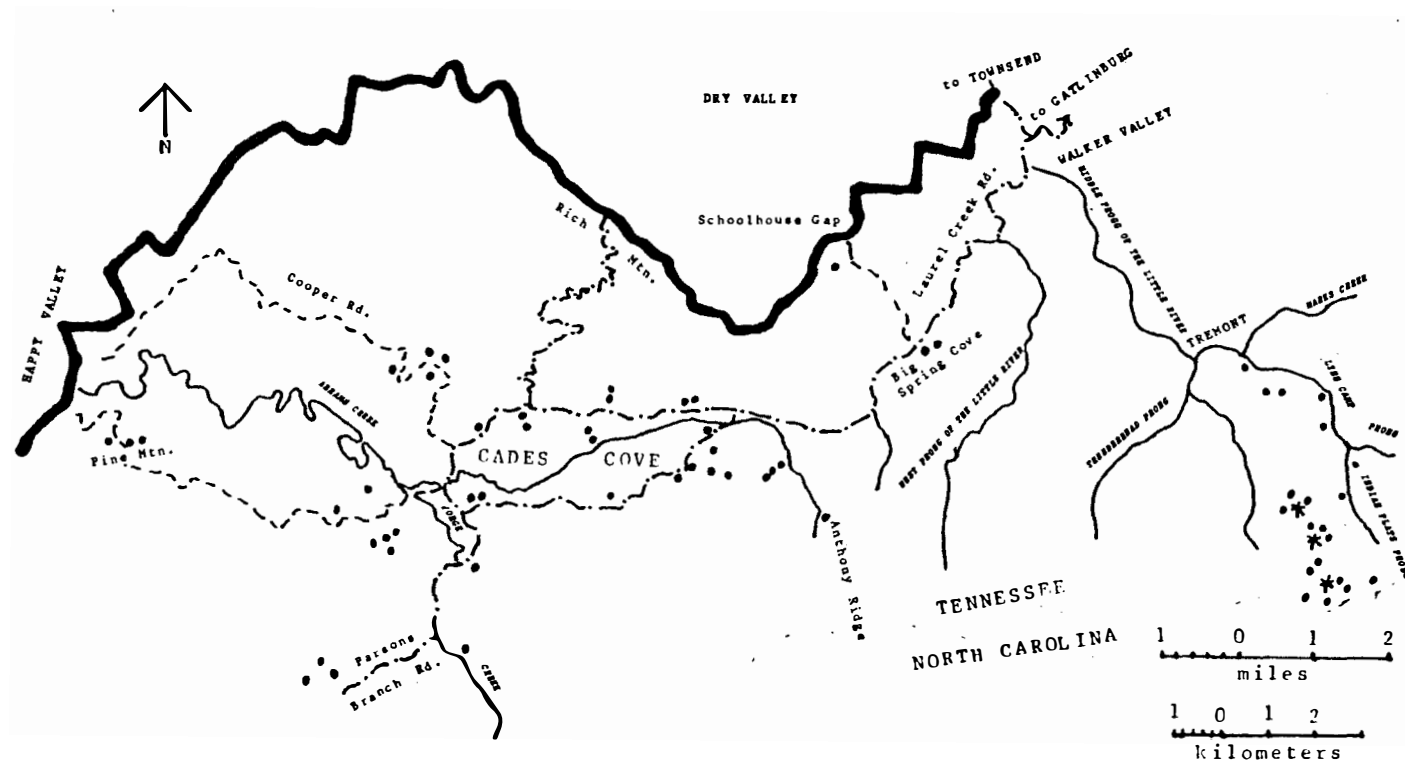


Figure H-1.

Figure H-2. Arrangement of forest cover types in ordination space.

- ☐ Yellow Pines
- ☒ White Oak - Oak
- ☒ Chestnut Oak - Oak
- ☐ Mixed Sub-xeric Hardwoods
- ☐ White Pine - Hardwoods
- ☒ Chestnut Oak - Yellow-poplar
- ☐ Yellow-poplar
- ☒ Mixed Mesic Hardwoods

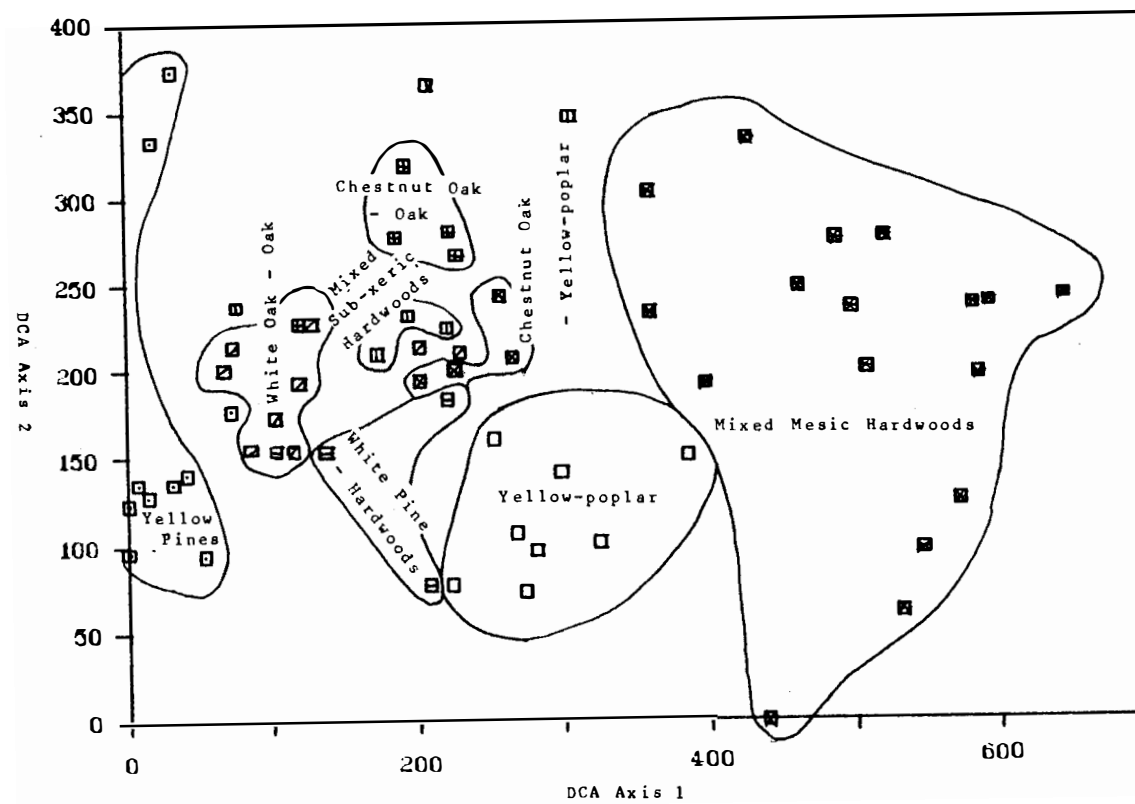


Figure H-2.

Figure H-3. Disturbance history by forest cover type.

- ☐ Cleared for farming activities
- ☐ Stumps seen in plot
- ☐ Even-aged
- ☐ Plot categorized as logged
- ☐ In Cades Cove $\leq 2000'$ elevation
- ☒ Evidence of former chestnut trees
- ☒ Strong evidence of fire

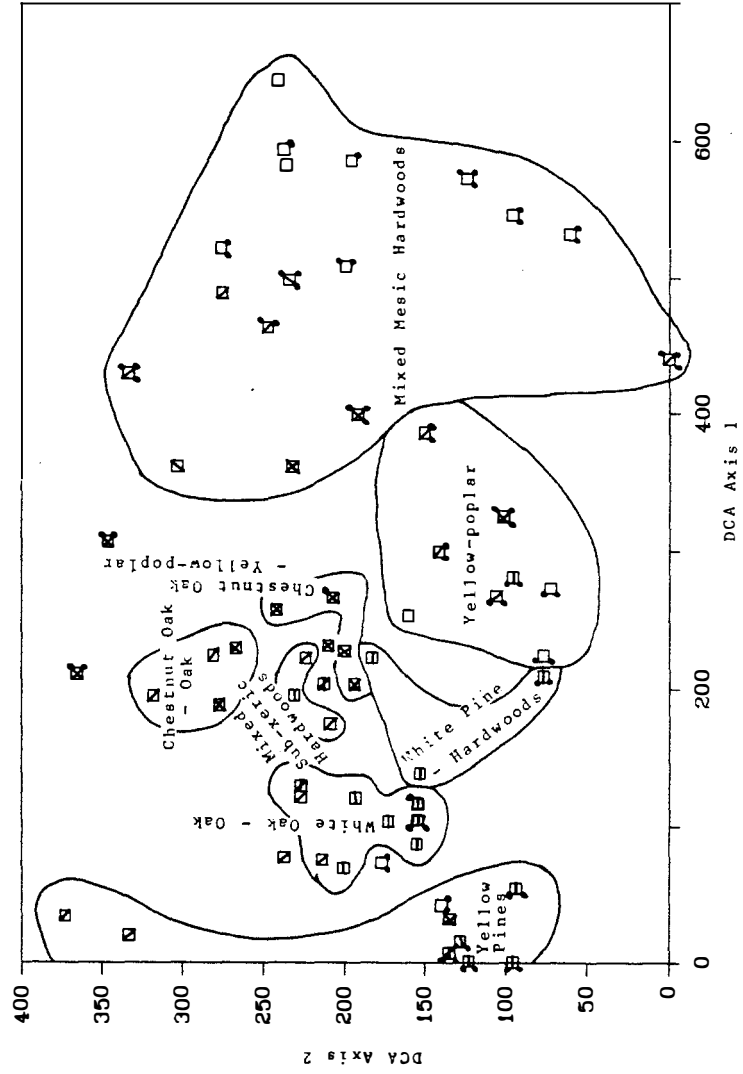


Figure H-3.

Figure H-4. Definition (and Summary) of Forest Cover Type Designations.

The number in parentheses following the forest cover type name is the number of plots assigned to that type. Total n=63.

#1 Yellow Pine (10): at least 50% of the basal area is composed of Virginia pine, shortleaf pine, or Table Mountain pine. (All but three plots assigned to this category had at least 78% yellow pine basal area.)

#2 White Oak - Oak (9): at least 50% of the basal area is composed of oaks including at least 20% white oak. (The basal area of white oak ranged from 21% to 92% of the total plot basal area. Total oak basal areas ranged from 51% to 92%.)

#3 Chestnut Oak - Oak (5): at least 50% of the basal area is composed of hardwoods including at least 20% chestnut oak. (Chestnut oak basal areas ranged from 59% to 84%. Total oak basal areas ranged from 59% to 91%.)

#4 Mixed Sub-Xeric Hardwoods (6): defined as plots in which at least 50% of the basal area is composed of some combination of sub-xeric hardwoods not fitting the classification criteria for any other forest cover type. (The composition of majority basal area in these plots ranged from Oak - Hickory to Black Gum - Red Maple - Hardwoods. All plots contained chestnut oak and red maple.)

#5 White Pine - Hardwoods (4): at least 50% of the basal area is composed of white pine or hardwoods, including at least 20% white pine. (White pine basal areas ranged from 29% to 50%. The most important associated hardwoods were either white oak or yellow-poplar.)

#6 Chestnut Oak - Yellow-poplar (4): at least 50% of the basal is composed of chestnut oak and yellow-poplar. (The basal area of chestnut oak ranged from 26% to 47%. The basal area of yellow-poplar ranged from 22% to 37%.)

#7 Yellow-poplar (8): at least 50% of the basal area is composed of yellow-poplar. (Yellow poplar basal areas ranged from 52% to 88%. Other species comprising greater than 20% of the basal area within a plot were chestnut oak and white pine. The species most frequently ranked second in plot basal area was red maple.)

#8 Mixed Mesic Hardwoods (17): at least 50% percent of the basal area is comprised of some combination of the following species: basswood, beech, black cherry, buckeye, fire cherry, Fraser magnolia, northern red oak, red maple, silverbell, sugar maple, sweet birch, yellow birch. (Basal areas of mesic hardwood species ranged from 61% to 100%. On the first round of assigning these plots into forest cover types, 17 type names were created using the species that individually comprised at least 20 percent of the plot basal area, and in combination comprised a majority (50% or more) of the plot basal area. Except for buckeye and sugar maple, all of the species listed above were included in at least one of the initial 17 forest cover type names.)

Figure R-4.

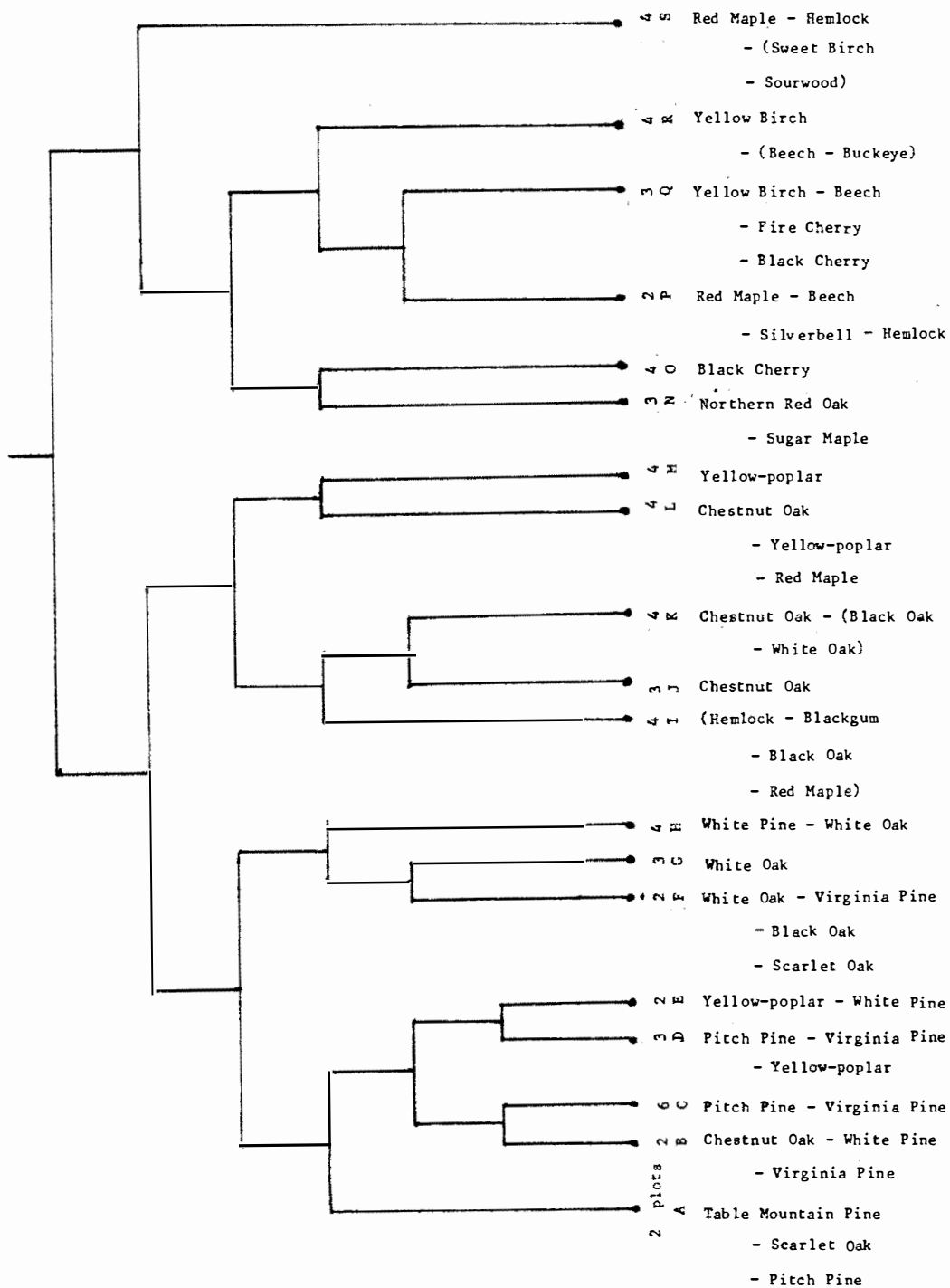


Figure 1'-5. Clusters derived from TWINSPLAN

Figure H-6. Plotwise Comparison of Forest Cover Types:
TWINSpan computerized, divisive system v s. SAF methodology

¹/ Name assigned to TWINSpan cluster based on species the plots have in common

²/ Percentage of plot basal area accounted for by the species the plots have in common

³/ Name of forest cover type to which the plot was assigned by the SAF methodology. Abbreviations are, CO-H=Chestnut Oak-Hardwoods, CO-Yp=Chestnut Oak-Yellow-poplar, MMH=Mixed Mesic Hardwoods, MSH=Mixed Sub-xeric Hardwoods, YP=Yellow Pines, Ypop=Yellow-poplar

⁴/ No species are common among all plots in this cluster

⁵/ Plot lacks one or more of the species in the assigned name

⁶/ Species in parenthesis are not common to all plots

- (A) Table Mountain Pine - Scarlet Oak - Pitch Pine¹ 97%² YP³, 89% YP
- (B) Chestnut Oak - White Pine - Virginia Pine 100% CO-O, 54% MSH
- (C) Pitch Pine - Virginia Pine 97% YP, 96% YP, 84% YP, 70% YP, 89% YP, 78% YP
- (D) Pitch Pine - Virginia Pine - Yellow-poplar 54% WP-H, 83% YP, 92% YP
- (E) Yellow-poplar - White Pine 66% WP-H, 91% Ypop
- (F) White Oak - Virginia Pine - Scarlet Oak - Black Oak 87% WO-O, 61% WO-O
- (G) White Oak 92% WO-O, 15% MSH, 82% WO-O
- (H) White Pine - White Oak 56% WP-H, 83% WP-H, 89% WO-O, 52% WO-O
- (I) (Hemlock - Blackgum - Black Oak - Red Maple)⁴ 52%⁵ WO-O, 39%⁵ MSH, 70%⁵ WO-O, 43%⁵ MSH
- (J) Chestnut Oak 84% COO, 37% CO-O, 65% CO-O
- (K) Chestnut Oak - (Black Oak - White Oak)⁶ 26%⁵ Ypop, 59% MSH, 64% CO-Yp, 67%⁵ WO-O
- (L) Chestnut Oak - Yellow-poplar - Red Maple 82% CO-Yp, 100% CO-O, 68% CO-Yp, 91% CO-Yp
- (M) Yellow-poplar 88% Yp, 77% Yp, 85% Yp, 68% Yp
- (N) Northern Red Oak - Sugar Maple 23% Yp, 77% MMH, 37% MMH
- (O) Black Cherry 26% MMH, 10% Yp, 21% MMH, 12% MMH
- (P) Red Maple - Beech - Silverbell - Hemlock 49% MMH, 96% MMH
- (Q) Yellow Birch - Beech - Fire Cherry - Black Cherry 33% MMH, 44% MMH, 73% MMH
- (R) Yellow Birch - (Beech - Buckeye)⁶ 100% MMH, 75%⁵ MMH, 82% MMH, 36%⁵ MMH
- (S) Red Maple - Hemlock - (Sweet Birch - Sourwood)⁶ 50%⁵ MMH, 100%⁵ MMH, 66% MMH, 52% MMH

Figure H-6.

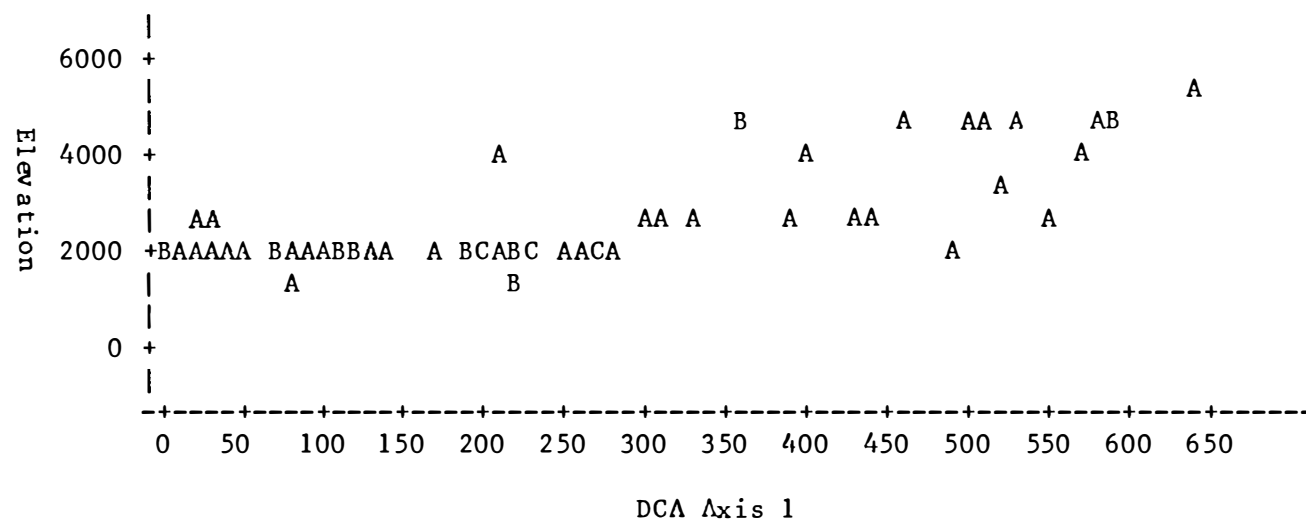


Figure II-7. The relationship of elevation to DCA Axis 1.

Symbols refer to number of observations where A = 1, B = 2, etc.

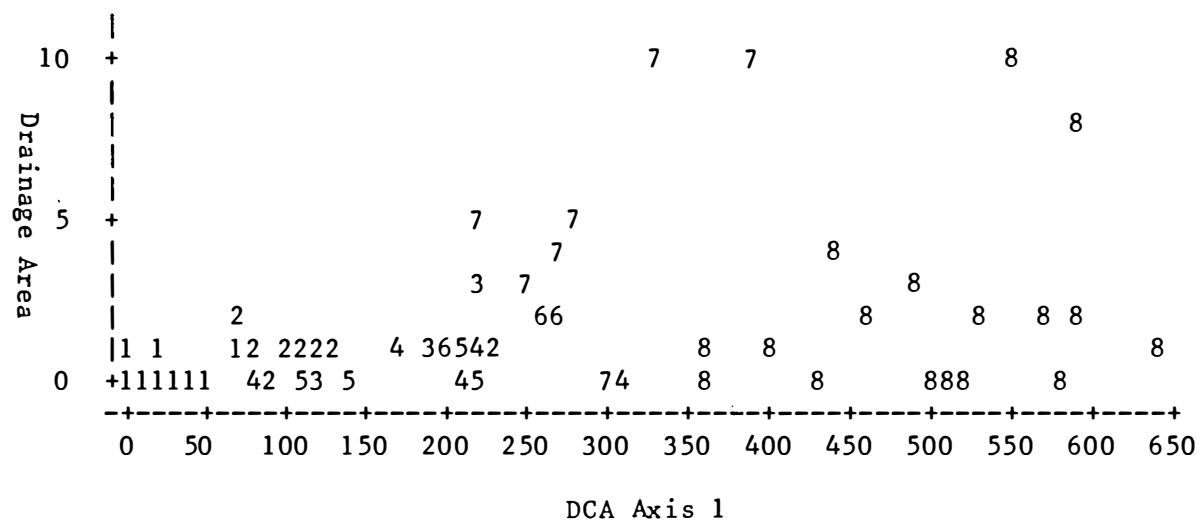


Figure H-8. The relationship of drainage area to DCA Axis 1.

Symbols refer to forest cover type: 1 = Yellow Pines, 2 = White Oak - Oak, 3 = Chestnut Oak - Oak, 4 = Mixed Sub-xeric Hardwoods, 5 = White Pine - Hardwoods, 6 = Chestnut Oak - Yellow-poplar, 7 = Yellow-poplar, 8 = Mixed Mesic Hardwoods. Seven observations are hidden.

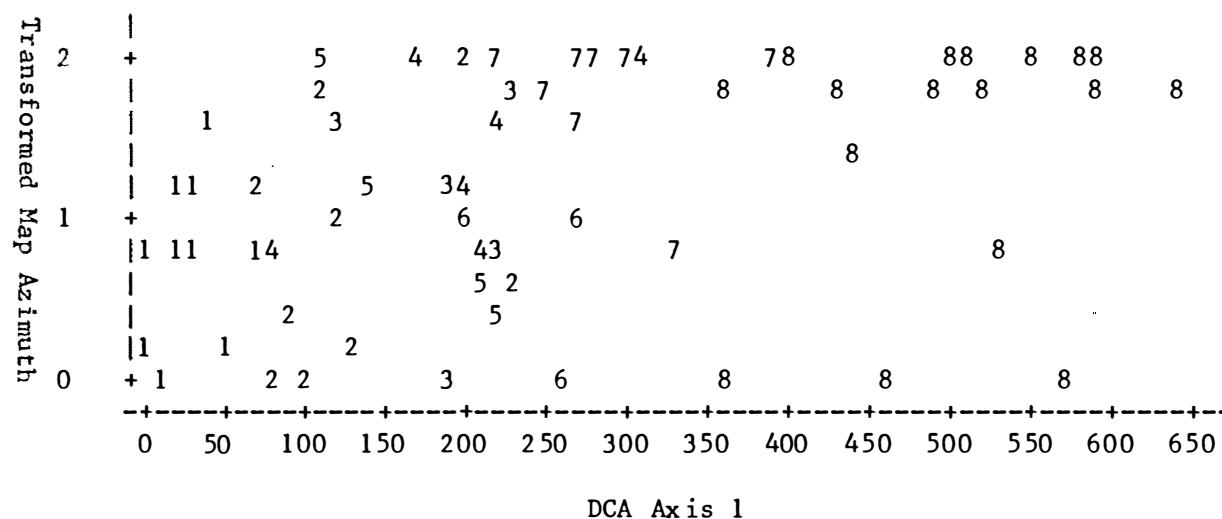


Figure H-9. The relationship of transformed map azimuth to DCA Axis 1.

Symbols refer to forest cover type: 1 = Yellow Pines, 2 = White Oak - Oak, 3 = Chestnut Oak - Oak, 4 = Mixed Sub-xeric Hardwoods, 5 = White Pine - Hardwoods, 6 = Chestnut Oak - Yellow-poplar, 7 = Yellow-poplar, 8 = Mixed Mesic Hardwoods. One observation is hidden.

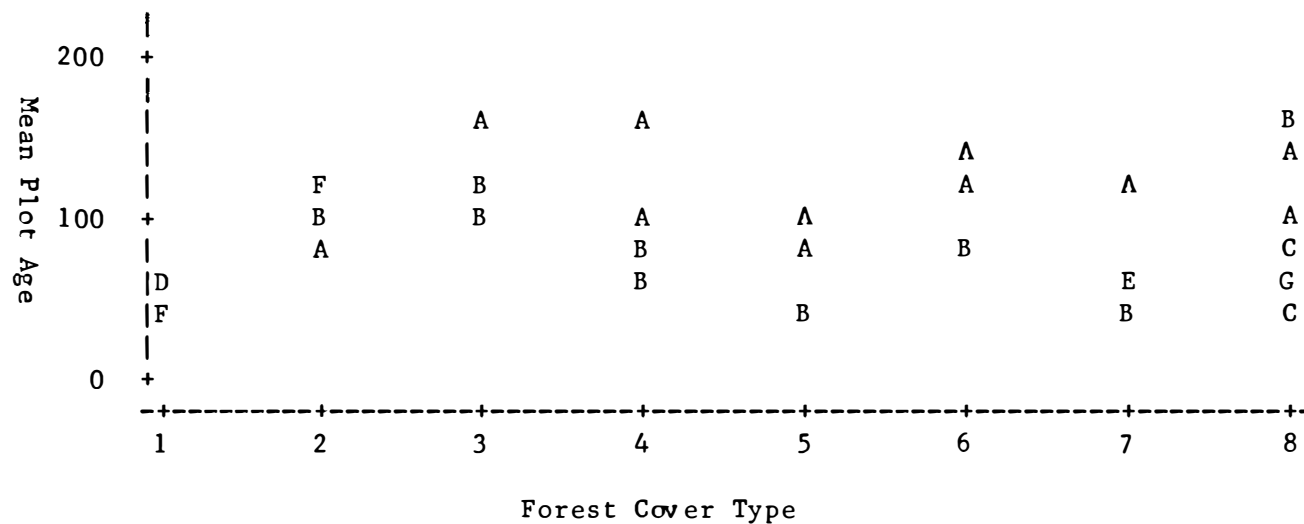


Figure H-10. The relationship of mean plot age to forest cover type.

Symbols refer to the number of observations where A = 1, B = 2, etc.

Numbers refer to forest cover type: 1 = Yellow Pines, 2 = White Oak - Oak, 3 = Chestnut Oak - Oak, 4 = Mixed Sub-xeric Hardwoods, 5 = White Pine - Hardwoods, 6 = Chestnut Oak - Yellow-poplar, 7 = Yellow-poplar, 8 = Mixed Mesic Hardwoods.

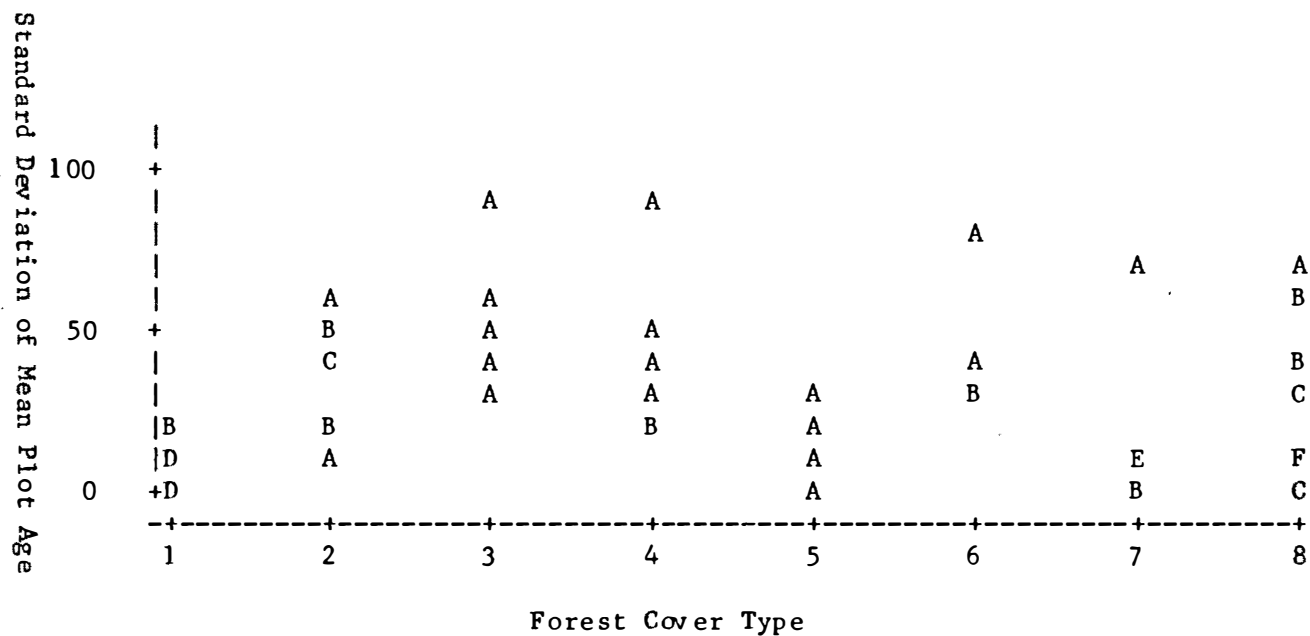


Figure H-11. The relationship of standard deviation of the mean plot age to forest cover type.

Symbols refer to the number of observations where A = 1, B = 2, etc.

Numbers refer to forest cover type: 1 = Yellow Pines, 2 = White Oak - Oak, 3 = Chestnut Oak - Oak, 4 = Mixed Sub-xeric Hardwoods, 5 = White Pine - Hardwoods, 6 = Chestnut Oak - Yellow-poplar, 7 = Yellow-poplar, 8 = Mixed Mesic Hardwoods.

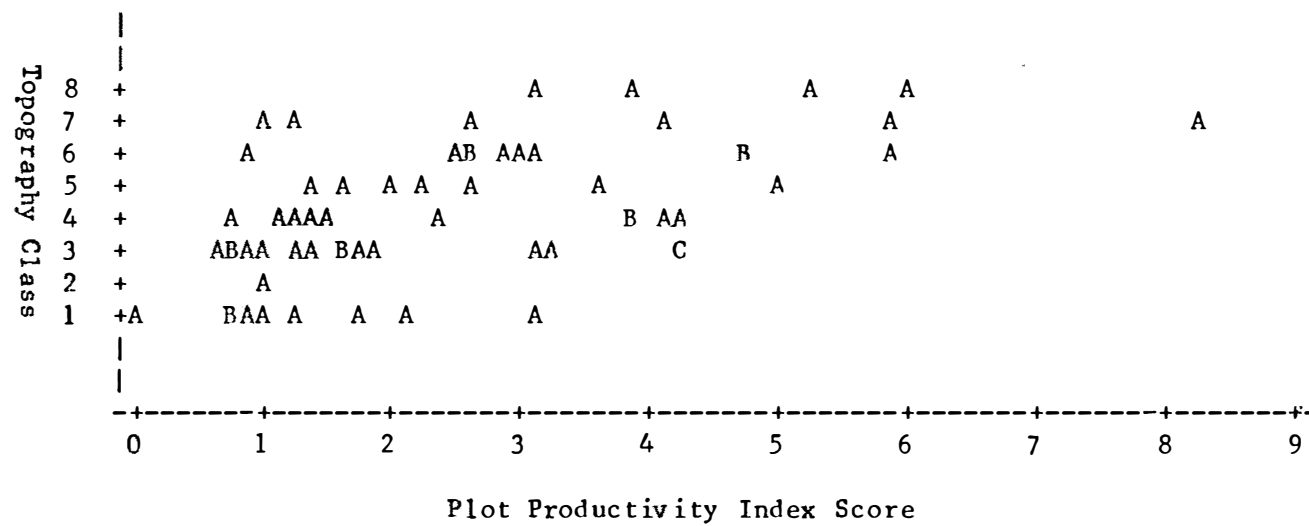


Figure H-12. The relationship of topography class to plot productivity index score.

Symbols refer to the number of observations where A = 1, B = 2, etc.

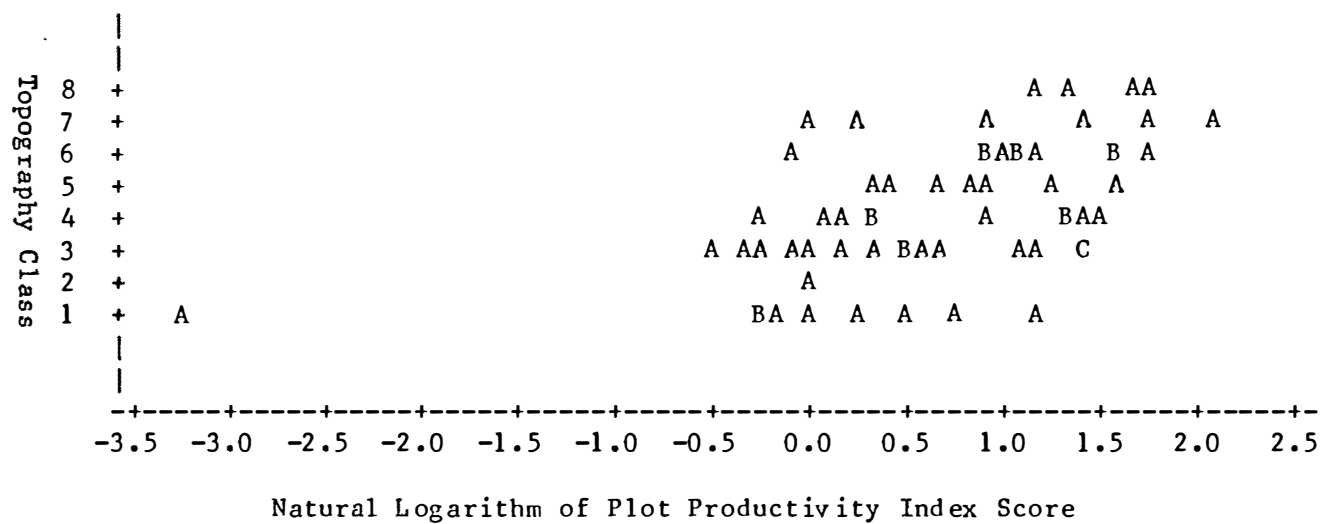


Figure H-13. The relationship of topography class to the natural logarithm of plot productivity index score.

Symbols refer to number of observations where A = 1, B = 2, etc.

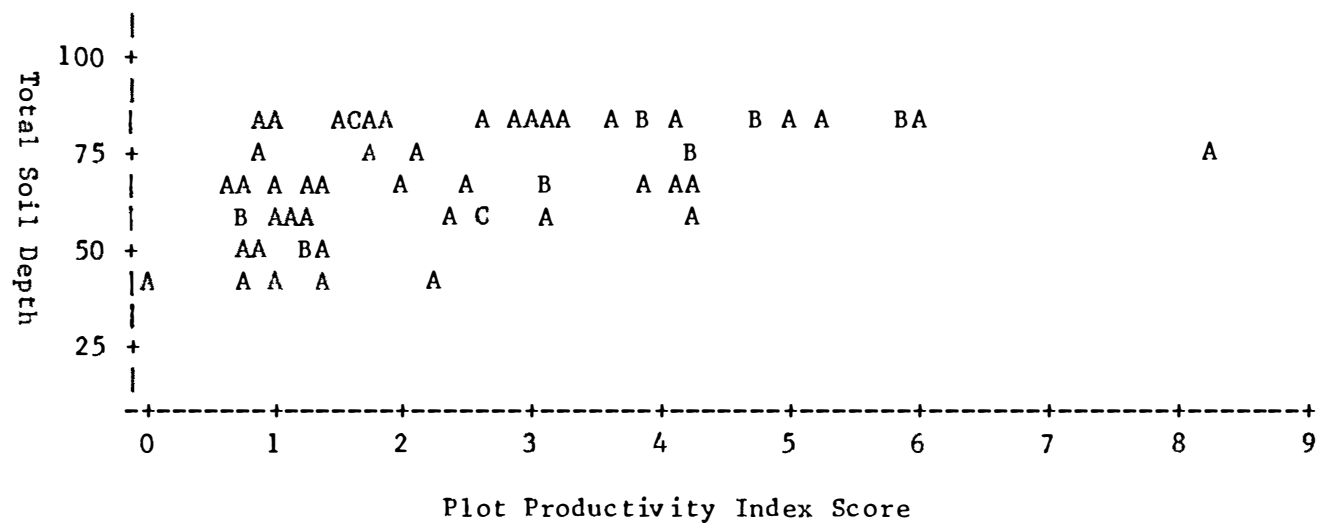


Figure H-14. The relationship of total soil depth to plot productivity index score.

Symbols refer to number of observations where A = 1, B = 2, etc.

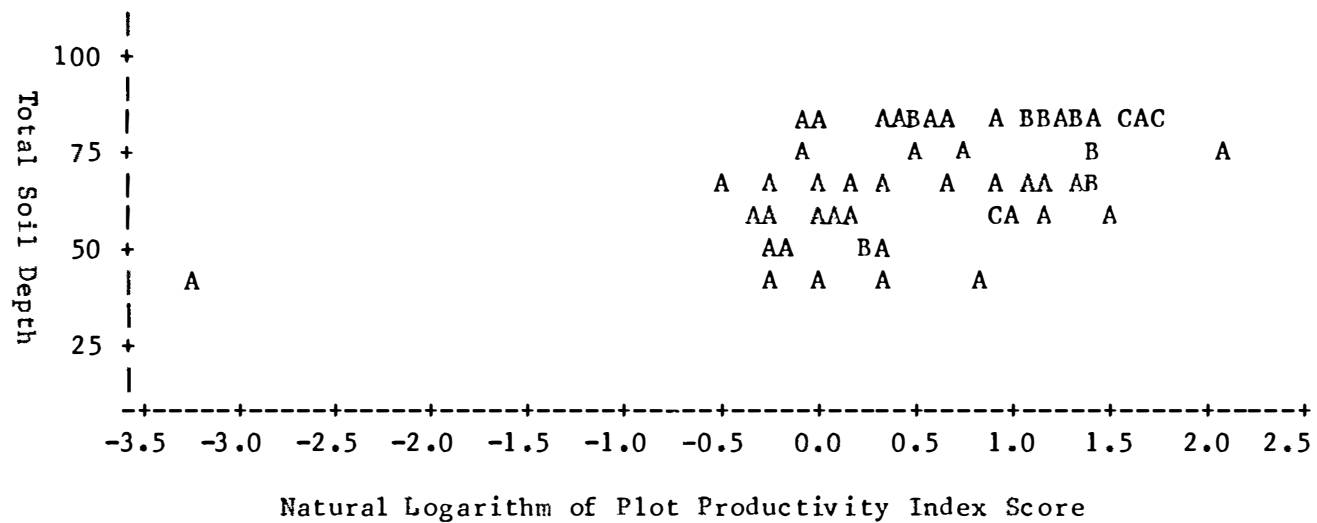


Figure H-15. The relationship of total soil depth to the natural logarithm of plot productivity index score.

Symbols refer to number of observations where A = 1, B = 2, etc.

VITA

Charlotte Pyle was born in California and graduated from Fio Americano High School in Sacramento. In 1976, she received a B.S. in Conservation of Natural Resources from the University of California, Berkeley. Following graduation she worked for the United States Forest Service in range management and with rare plants. In 1979, she began working at Uplands Field Research Laboratory, Great Smoky Mountains National Park. After acceptance into the University of Tennessee, Department of Forestry, Wildlife, and Fisheries, she attended school part time. While in school she continued to work, first at Uplands Laboratory, and later for the USDA, Forest Service-Environmental Protection Agency Spruce-fir Research Cooperative. She is a member of Xi Sigma Pi, the Society of American Foresters, and the Ecological Society of America. She married David Silsbee in 1985.