12-1972

An Evaluation of Control Techniques for the European Wild Hog (*Sus scrofa*) in the Great Smoky Mountains National Park of Tennessee

James Ronald Fox
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by James Ronald Fox entitled "An Evaluation of Control Techniques for the European Wild Hog (*Sus scrofa*) in the Great Smoky Mountains National Park of Tennessee." 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 Wildlife and Fisheries Science.

Michael R. Pelton, Major Professor

We have read this thesis and recommend its acceptance:

Ralph W. Dimmick, George M. Merriman

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Harry R. DeYoung entitled "The White Pine-Hardwood Vegetation Types of the Great Smoky Mountains National Park." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology.

H. R. DeSelm

H. R. DeSelm, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

L. Evans Roth

Vice Chancellor
Graduate Studies and Research

THE WHITE PINE-HARDWOOD VEGETATION TYPES OF THE GREAT SMOKY MOUNTAINS NATIONAL PARK

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Harry R. DeYoung

March 1979

ACKNOWLEDGMENTS

I would like to express my sincere appreciation for the guidance and encouragement throughout this project offered by Dr. H. R. DeSelm, Department of Botany, who served as major professor. His help was invaluable. Thanks are also extended to Dr. Clifford C. Amundsen, Department of Botany, and Dr. Dewey L. Bunting, Department of Zoology, for their suggestions, critical reading of the manuscript, and for serving on my committee.

Appreciation is extended to the Graduate Program in Ecology for providing financial assistance and material support. Thanks also go to the staff of the Great Smoky Mountains National Park for providing information and research materials. Sincere thanks go to Paul Schmalzer who graciously gave of his time to help with both collection and analysis of the field data, and to Mr. Don Broach of the University of Tennessee Computer Center for his consulting services.

For their time and assistance in collecting field data, I wish to thank Mr. Al Krusen, Mr. Art Enrico, Ms. Julie Thomas, and Mr. Henry Hastings.

I especially thank Mrs. Dan Kinsinger for her help and advice in the preparation of the manuscript.

I would like to acknowledge the interest and assistance given by Dr. A. R. Shields, recently retired Professor of Biology at Maryville College. Through personal contact with him, I was able to unravel portions of the disturbance history of the Cades Cove area. As a professor, Dr. Shields insisted that one learn to ask the "proper question," and

in so doing, he instilled in me a long-lasting appreciation of the science of ecology.

Appreciation is extended to my mother, Mrs. Eleanore DeYoung, for her interest, support, and encouragement.

A special note of appreciation is extended to my wife, Sarah, for her encouragement, help, and patience during this project and during all phases of my studies.

ABSTRACT

The white pine-hardwood type was described by Miller in 1938; however, subsequent researchers of the vegetation of the Great Smoky Mountains National Park have not described this type. A field study of white pine-hardwood vegetation was conducted in the Park from June to October, 1977. The objectives were to relocate and plot sample the white pine-hardwood stands to 1) group samples into vegetation types based upon the importance of white pine and its associated taxa, 2) use quantitative vegetation analysis procedures to describe the white pine-hardwood vegetation types, 3) assess the relationship of the vegetation types to environmental characteristics, 4) examine the successional status of the types, and 5) provide a basis for further ecological studies of these types in the Park.

Data were analyzed from 144 sample plot locations in the western portion of the Park in Tennessee at low to middle elevations (312 to 716 meters). Circular 0.0406 hectare (1/10 acre) plots were located in areas which had been previously mapped by Miller in 1941. Canopy (over 10 cm), sapling (2.5 to 10 cm), subsapling (2.5 cm diameter and one meter high), and herbaceous data were tallied in each plot. Site properties were collected in each plot. Laboratory determinations of soil pH and texture of both the A and B horizons were made.

Canopy data were used to group plots into vegetation types using an agglomerative clustering technique (Orloci, 1967). The seven communities identified were: white pine-Virginia pine, white pine-red maple, white pine-hemlock, white pine-chestnut oak, white pine-white

oak, white pine-northern red oak, and white pine types. Relative densities of tree taxa in the canopy, sapling, subsapling, and seedling strata were compared to determine the reproductive success of each type.

Disturbance evidence and historical accounts were analyzed to assess the successional status of the types. Most types have been disturbed through cultivation, logging, and fire although portions of the white pine-chestnut oak, white pine-white oak, white pine-northern red oak, and white pine types occurred on sites of limited human disturbance. The absence of chestnut stumps and the low proportion of sprouts indicated that it had a minimal former presence in the white pine-hardwood types.

Simple linear correlations among and between site, soil, and vegetation characteristics were computed. Significant correlations among soil characteristics indicated that slope angles increased as microtopographic position increased such that steep slope angles occurred predominantly downslope. Site and soil correlations indicated that stone volume was negatively correlated with elevation: lower elevations had an increase in stone material. The increased acidity of litter and the increased leaching due to additional precipitation at higher elevations contributed to a decrease in soil pH.

Discriminant analysis of the community types using vegetation data indicated that 95 percent of the types were distinct as classified by the cluster procedure. Discriminant analysis using selected environmental variables indicated that some types were not as distinct environmentally as they were vegetationally. Discriminating factors related to soil moisture conditions such as stone percentages, horizon thickness,

and total available water were important on the first discriminant axis. The second discriminant function appeared to be related to both soil moisture phenomena and slope position, which contributed to the concept that the white pine-hardwood types were segregated by available soil moisture. The classification success was low with only 41 percent of the plots correctly classified. The inability of the measured environmental variables to exactly distinguish the types may be attributed to the successional relationships among the types.

Canonical analysis was used to display the arrangement of the seven vegetation types along the first two canonical axes. The centroids of each type were arrayed along the first axis in an order which closely corresponded to the first and second axes in the discriminant analysis of the environmental variables. From the canonical analysis, it is inferred that soil moisture was important in segregating the white pine-hardwood types.

The diameter distribution of white pine may be of considerable value in inferring the age distribution and stand history of a forest. A direct sampling of white pine increment cores was conducted. Regression analysis was used to determine the best fit of the collective white pine-hardwood type as well as the individual types. The white pine-Virginia pine, white pine-red maple, white pine-hemlock, and portions of the white pine type were represented by relatively even-aged stands resulting from large scale disturbances. The white pine-oak types and portions of the white pine type more closely represented all-aged forests.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The geographic range of white pine (*Pinus strobus* L.) includes the southern Appalachians; the size and longevity of the taxon insure its being a dominant, codominant, or at least an important component of several plant communities (Fowells, 1965). Early descriptions and enumerations of southern Appalachian vegetation types in areas which include the Great Smoky Mountains mentioned several white pine-hardwood types and the wide ecological amplitude of white pine (Sudworth and Killebrew, 1897; Spaulding and Fernow, 1899; Ayres and Ashe, 1905; Miller, 1938; Braun, 1950; Patton, 1955; and Thomas, 1966).

Miller's (1941) map of the Principal Vegetation Types of the Great Smoky Mountains National Park included the white pine-hardwood types. He mapped the occurrence of the type in 40 separate locations in the western portion of the Park in Tennessee and in the Cataloochee area of North Carolina. Subsequent vegetation studies in the Great Smoky Mountains National Park (Whittaker, 1956; Golden, 1974) have not dealt with this vegetation type. In the forty-year period since Miller identified the type (1938), no one has described the subtypes of the white pine-hardwoods, nor their disturbance history, environmental characteristics, nor successional position.

The field work was accomplished June to October, 1977, and subsequent analyses were conducted during 1977 and 1978. Park archives were used to determine original plot locations and descriptions from

Miller's white pine-hardwood type. Thirteen plot data sheets were recovered and their locations mapped on present day topographic quadrangle maps. Canopy, understory, sapling, and herb strata were sampled, and soil and site characteristics were recorded, or laboratory determined, for each of 144 plots. Tree cores were taken from white pines (up to 55 cm in diameter) at most plot locations to estimate tree ages and to interpret stand dynamics. This analysis redefines Miller's white pine-hardwood vegetation type and establishes a foundation for mapping and management of this complex by the U.S. National Park Service in the Great Smoky Mountains National Park.

CHAPTER II

AUTECOLOGY AND SILVICULTURE OF WHITE PINE

Introduction

Pinus strobus (white pine), a tree mainly of northern distribution, occurs along the eastern mountain ranges as far south as northern Georgia. In its southward extension white pine occurs chiefly at progressively higher elevations. The climate over the range of white pine is cool and humid, and there is generally ample moisture in all seasons. The precipitation and the long growing season in the southern Appalachians (Georgia to Maryland) are well suited to white pine growth. In the southern Appalachians and the Pennsylvanian Alleghenies white pine generally occurs on northerly aspects in coves and on stream bottoms but has a wide ecological amplitude. In Georgia, North Carolina, and Tennessee it grows under a wide variety of conditions from moist river bottoms to upper slopes and ridge tops; on some sites it has rapid growth.

Pinchot and Ashe (1897) described the distribution of white pine in North Carolina. The forests in which white pine was dominant were not extensive but occurred in small conspicuous sections of the oak-chestnut forest generally below 3,000 feet. Single specimens and groups of white pine were described as being widely dispersed throughout the broadleaf forests (predominantly oak types) of the mountainous regions (Pinchot and Ashe, 1897). Fowells (1965) reported that white pine grew in a band along the mountains between 1,200 and 3,500 feet, occasionally reaching 4,000 feet. Pinchot and Ashe noted the potential value of

scatttered white pines as seed sources for the reforestation of cut-over land. Apparently old field sites with pure white pine were uncommon at that time. Since the turn of the century, white pine in the southern Appalachians has taken up an important role in secondary succession similar to that which it had attained in New England (Patton, 1955).

Soil and Topography

Soils within the range of white pine are derived predominantly from granites, gneisses, schists, and sandstones; phyllites, slates, shales, and limestones are less common. White pine is capable of growth in practically all the soils in its range, but in the northerly regions it is clearly associated with well-drained sandy soils. In the southern Appalachians, white pine grows well on sandy loams, loams, and silty loams with either good or impeded drainage. Clayey or poorly drained soils are not generally considered as favorable white pine habitat (Fowells, 1965). Minckler (1946) found that white pine growth in plantations at Norris, Tennessee, decreased as the clay content of the B horizon increased.

In the southern Appalachians, the site quality of white pine has been related to combinations of soil and topographic characteristics such as texture and thickness of the A and B horizons, topographic position, slope percent, and aspect (Fowells, 1965). Doolittle (1958) compared site index and growth of 10 southern Appalachian species. White pine had unequalled growth except on the best sites, where yellow poplar was ranked superior in height only. The structure and distribution of the white pine root system varies with soil characteristics, but in the southern Appalachian mountains, several (three to five) large roots

spread out and down into the soil, while smaller lateral roots spread horizontally in all directions (Fowells, 1965).

Lutz et al. (1937) attempted to determine the distribution of white pine roots in the various soil horizons. Compactness of the soil inhibited root distribution because of the resistance to penetration. The texture of the soils was important; root development was superior in loamy sands, sandy loams, and loams. Most roots occurred in the A or B horizons, and greater development occurred in the upper soil layers. The upper soil root concentration appeared to result from higher moisture values because of increased organic matter and a higher total exchange capacity.

Moore (1926) described the humus under the white pine type as somewhat decomposed, with a thickness of about three to four cm and a generally dry surface. The mineral soil under the white pine type was generally porous. Moore conducted germination tests of white pine on humus and mineral soils. He concluded that germination was better on mineral soil, as is the case with many conifers. Successful white pine germination on coniferous humus occurred when the seeds fell in the autumn before the annual needle drop. The needles covered the seeds and were "packed in" by winter snow. Germination proceeded the following spring if the surface remained moist long enough.

The maximum water-holding capacities of certain soils in New England were used to establish vegetation relationships by Colvin and Eisenmerger (1943). The mean water-holding capacities of the soils associated with dominants of the Smokies' white pine-hardwood types exhibited a small range. The canopy dominants ranged from white oak (76 percent) to red maple (89 percent). White pine grew on soils that

varied widely in their moisture-retaining properties, from dry sites on ridges to soils under either permanent or partial influence of the water table (stream banks).

A study at the Coweeta Hydrologic Laboratory reported that soil moisture stream flow volume was altered when mixed, mature hardwoods were replaced by plantation white pine. Interception loss was due to the year-round needle surface of white pine; thus the stream flow was decreased. The conclusion of Swank and Miner (1968) was that if water is a primary resource, the implications of the conversion of hardwoods to white pine should be considered.

Life History

White pine trees may begin to bear female cones when five to ten years old, but male cones generally do not appear during these years. The staminate and pistillate flowers are produced separately on the same tree. The cone production pattern is irregular in that, although the female cones are produced in about the same numbers each year, the male cones appear less regularly (Spaulding and Fernow, 1899; Fowells, 1965). Seed production is variable, with high production occurring every three to five years, with lower production in the interim. Most of the seeds are dispersed within the month following cone maturation. Seed fall was analyzed by Graber (1970) in Pennsylvania on three stands of mature white pines of variable densities. The stand with the intermediate density had the maximum seed production with nearly 50 percent more seed than the other stands. The period of seedfall was variable from one year to another and was negligible after November. Seed losses were due to birds and small mammals, and Graber

considered that a significant portion of the seeds was consumed.

White pine seed consumption by white-footed mice and red-backed voles was studied by Abbott and Quink (1970). They found that seed caches made in the fall of the year contained from 20 to 30 white pine seeds. The seeds were buried beneath the pine litter in contact with the mineral soil. Many of the caches were consumed before winter or by spring; however, some of the caches escaped destruction and produced seedlings.

Seed dispersal of white pine was researched by Rudis et al. (1978). The distribution of seedlings around isolated seed trees was analyzed, and densities were found to vary significantly in different directions from the seed source. The differences in dispersal were attributed to specific wind patterns, and seedling density was reduced sharply at greater distances from the source tree. Fowells (1965) reported that white pine seed may be wind-borne at least 200 feet within a white pine stand and more than 700 feet if in the open.

Dormancy of the embryo is general; it requires a moist, cool stratification period (40° to 50° F) of 30 to 60 days. Seed bed requirements are fairly specific. In full sunlight, some moderate cover and moist mineral soil are most advantageous, while dry mineral soil, pine litter, or thin canopy covers are generally unfavorable. Shade from overstory species provides protection during the early stages of growth, but after establishment, dense shade can severely limit the growth of white pine seedlings. Young seedlings can withstand several weeks of drought (Fowells, 1965). During the first three years, the white pine seedling is inconspicuous as a single straight stem with a small tuft of needles. Branching generally starts about the fourth year. During

this stage sufficient light and moisture are critical.

Growth

White pine is a long-lived tree, commonly reaching 200 years of age if undisturbed. The maximum age is about 450 years. On an average site white pine will add an inch to its diameter every five to six years (Fowells, 1965). White pine has been classified as intermediate in tolerance and is capable of dominance in competition with less shade tolerant species such as Virginia and pitch pine. If white pine fails to obtain an upper canopy position, more shade tolerant species will suppress its development. The seedling stage is very susceptible to competition because its initial height growth is comparatively slow. Once the sapling stage is reached, white pine growth rate increases. The relative great shade tolerance of white pine (compared with other pines) permits regeneration where the hardwoods are thinned by disturbance. In the case of second growth from clear cutting or on old fields, white pine acts as a pioneer species and often dominates the site and survives as a long-lived component of the stable forest. White pine may be a long term dominant on dry, sandy soils, and it is a long term component of many stable, mesic forest types throughout its range (Fowells, 1965).

White pine growth studies have been conducted on natural second growth sites and on plantations. Cope (1932) stressed the greater size and growth rate of white pine in the southern Appalachians in comparison with trees in New Hampshire. Fowells (1965) indicated that white pine grew more rapidly and to larger dimensions at the southern extremes of its range than elsewhere. Kimberly (1933) conducted a comparison of

growth rates between white pine sites in the mountains of north Georgia and in the Yale Forest in New England. He concluded that the differences between diameter and height growth were significant and that white pine growth was greater in the extreme southern portion of its range.

Early work with white pine occurring in combination with other species indicated that it grew more rapidly than its associates. Barrett (1933) obtained data from Georgia and North Carolina where white pine occurred in mixture with hardwoods. Increment borings, diameter at breast height, and height measurements were taken on the dominant and codominant individuals within sample plots. All were assumed to have been subjected to the same site conditions, and age-diameter curves were plotted for each. White pine had a significantly higher diameter growth than its nearest competitor, tulip poplar.

The Biltmore Estates near Asheville, North Carolina, began experiments with plantations of mixed taxa in 1890. The Tennessee Valley Authority (T.V.A.) utilized old field property near Norris Lake (20 miles north of Knoxville, Tennessee) to conduct mixed plantation growth studies on a wide range of topographic and soil-site conditions (Minckler, 1946). Examinations of the plots were conducted at the end of the first, third, and fifth growing seasons. The fifth season results were described by Minckler (1946). White pine plantations exhibited suppressed growth on soils with shallow A horizons and dense B horizons, and it was concluded that the more friable and porous the B horizon, the less importance attributed to the A horizon depth. Minckler suggested that dense and stiff B horizons restricted root growth, limiting the surface area available for moisture and nutrient

absorption. White pine had consistently better growth on northerly aspects because of the more porous subsoils associated with that exposure. In terms of competition, white pine was more tolerant than shortleaf pine and failed only under extremely dense cover (Minckler, 1946). It was reported that by the sixth growing season, white pine had overtopped most of its competitors on favorable sites.

Burton (1964) conducted a twenty-year growth analysis of T.V.A.'s Norris plantations. Various experimental mixtures of species with replicate plots had been initially established by Minckler. When white pine and tulip poplar were planted together, tulip poplar had superior growth only on the "best" sites. White pine was sensitive to aspect, but no consistent differences in survival, diameter growth or density were associated with aspect. Three species were successful survivors in the mixed plantation study: white pine had the greatest diameter and total height; tulip poplar was the most sensitive to site conditions; and shortleaf pine was the least sensitive, placing white pine as intermediate in its site requirements. Height growth of white pine was more affected by aspect than by soil properties (Burton, 1964). The rapid height growth of white pine at early ages was responsible for the relative failure of the hardwoods in the mixed plantations.

Bates and Thor (1970) specifically analyzed the mixed groups of shortleaf pine, tulip poplar, and white pine on the Norris plantation after 25 growing seasons. White pine was dominant when mixed with these species and had substantially greater diameters and better survival. Bates and Thor also found high variations in white pine diameter growth which was interpreted as a result of its tolerance of suppression and its ability to sustain small growth increments even when suppressed.

The rapid growth of southern Appalachian white pine was noted by Wright et al. (1976). Experiments were conducted in southern Michigan with seeds collected from sites ranging from Maryland south to north Georgia. The most successful test plantations in Michigan were obtained from seed collected from the North Carolina and Tennessee border area to north Georgia. Seeds collected from this location were able to withstand southern Michigan winter conditions. These white pine plantations also grew 10-20 percent taller than the trees grown from seed collected from Virginia northward. The preliminary results led to the intensive sampling of white pine seeds from the southern extremes of its range. Within any particular site in the southern Appalachians, Wright et al. (1976) found that there were no clear relationships between elevation of origin and the growth rate, except for seeds collected from east Tennessee. Among Tennessee sources, trees from middle elevations grew fastest. As a result of the proven winter hardiness of white pine in southern Michigan, Wright et al. converted the test plantations into seed orchards by removing the slowest growing progenies.

Research on white pine growth has included seasonal trends in photosynthesis and respiration, adaptability to light intensities, and growth pattern changes under suppression. McGregor et al. (1963) tested the seasonal variation of white pine photosynthetic rates in Durham, North Carolina. In white pine seedlings, the February photosynthetic rate increased slowly until April and then rapidly rose to a peak between July 15 and September 15, followed by a gradual autumn decline. The early increase in photosynthesis was the result of an increased capacity of needles already present. This may have been due to a seasonal periodicity in the rate of photosynthesis per unit of

chlorophyll, where peaks occurred in July and fell to a minimum in January. Several explanations for the winter decline in photosynthetic rates per unit of chlorophyll were examined by McGregor et al. (1963). One mechanism was a reversible disorganization of the chloroplasts associated with cold weather. In spring a partial reverse would occur, accounting for the increase in photosynthesis prior to the appearance of the new needles. Another cause might have been a seasonal change in resistance to carbon dioxide uptake possibly related to changes in the mesophyll cells or to stomatal behavior.

Bourdeau and Laverick (1958) worked on white pine tolerance in relation to light intensity. Tolerance may be defined as the ability to maintain relatively high photosynthetic efficiency at low light intensity. White pine seedlings were grown under four light intensity regimes. The rates of photosynthesis and respiration were measured at six-month intervals. Seedlings growing in shade had fewer, but longer and narrower needles that were more efficient in weak light than were sun-grown needles. Needle chlorophyll content increased with shading.

Bormann (1965) determined that white pine undergoing suppression was capable of investing a high proportion of its decreasing energy supply into primary growth, but missing rings occurred. This was a morphological modification which contributed to white pines' more efficient use of low light intensities. A reduction in diameter growth occurred early in suppressed trees in contrast to their continued height growth. This shift, favoring new productive tissue at the expense of conducting tissue, permitted a higher energy return per unit of photosynthate. Bormann found that if missing rings occurred in white pine, water and minerals were able to pass through older, previously formed

xylem. This ability is of considerable ecological significance in that suppressed trees under competition are capable of directing energy supplies into upward growth, thus prolonging the individual's survival and increasing the possibility of release. Spaulding and Fernow (1899) cited a case in which a completely girdled white pine was able to continue nutrient and water movement after two years; presumably, "a significant amount can pass through the dead wood of the trunk...." The tree continued height growth although the growth was reduced by half.

Principal Enemies

Spaulding and Fernow (1899) reported over one hundred insects which attack white pine. All structures of the pine are susceptible to attack. There are species that infest bark or wood (borers), roots, branches and twigs, and cones; some act as defoliators. Pine bark beetles were found infesting white pine on sites sampled by Kuykendall in the Smokies (personal communication, 1978). One species is considered the most notorious of all insect pests (Spaulding and Fernow, 1899 and Fowells, 1965). The white pine weevil (*Pissodes strobi*) kills the terminal leader and thus affects two or three years of growth. Eggs are deposited on the terminal shoots, and the hatched larvae bore into the pith. When the larvae attain full growth at the end of the summer, they hibernate until spring, after which they pupate into the mature beetle form. The terminal shoot starts to wilt and dies by the end of the summer. The tree is seldom killed; however, lateral branches from the highest whorls develop new terminal shoots, creating a crook in the bole and temporarily reducing height growth (Fowells, 1965). Cope (1932) cited the activity of downy woodpeckers in the southern

Appalachians as possibly contributing to natural weevil control.

White pine blister rust (Cronartium ribicola) is a vigorous fungus that exists throughout the range of white pine and attacks seedlings as well as mature trees (Fowells, 1968). Spaulding and Fernow (1899) did not mention this fungus in their work since it was introduced from Europe about 1900. The fungus spends part of its life cycle on white pine and the rest on plants of the genus Ribes (currants and gooseberries). The fungus grows directly from the infected needles into the main stem and can completely girdle infected seedlings. Control methods have primarily involved the removal of Ribes bushes from the desired area. Extremely large scale Ribes eradication programs have been conducted in an attempt to control white pine blister rust in potentially favorable white pine locations. Ball (1949) examined the status of the white pine blister rust control in the southern Appalachian region. White pine was recognized as an increasingly important forest component and a prolific seeder with the potential to develop within many forest communities. It was recognized that white pine was becoming established on a wide variety of sites with many other tree species. As a result of this trend, an examination of the distribution of white pine and Ribes within the forest community was undertaken. In the southern portion of its range white pine naturally occurred between 1,200 and 3,500 feet. Ribes was seldom located below elevations of 3,000 or 3,500 feet. Extensive areas of white pine in the southern Appalachians are free of Ribes and are not attacked by the white pine blister rust.

There are three species of Ribes native to the southern Appalachians according to Cope (1932). They are Ribes rotundifolium,

Ribes cynosbati, and Ribes glandulosum. Over 3,000,000 acres of white pine in the southern Appalachian control area were found to be either naturally Ribes free or protected from infestation by the removal of Ribes. The Ribes-bearing areas were predominantly in Maryland, Virginia, and West Virginia (Ball, 1949). The rest of the southern Appalachians were relatively Ribes free in the white pine regions because they do not occur together, being separated by different altitudinal requirements.

Fire

White pine has a relatively thin bark during the first thirty to forty years. As a result, surface fires may cause significant damage. Mature trees have a bark which becomes progressively thicker with age and is increasingly capable of withstanding all but the hottest fires. The regions in the northeastern U.S. dominated by white pine have been related to some previous large-scale disturbance, notably fire. Catastrophic fires have been recognized as components of some forest ecosystems but the role of fire in virgin vegetation types has not been adequately determined. Maissurow (1935) attempted to determine the role of fire in the perpetuation of the "virgin" forest by conducting age structure studies of white pine in mixed hardwood stands in Wisconsin. The critical analysis centered around the fact that white pine was essentially absent under the hardwood forest canopy. Where white pine occurred in even-aged groups, it was generally possible to ascertain that fire had eliminated the hardwood overstory. The occurrence of white pine in the mixed hardwood forest was attributed primarily to some sort of disturbance which could be dated through the

investigation of the even-aged remnants of white pine scattered throughout the "virgin" forest (Maissurow, 1935).

Wood (1932) explored white pine reproduction by following the seed dispersal from a group (11 individuals) of large specimens which dominated a younger hardwood stand. The old white pines survived a fire in 1907; they had burn evidence on the trunk and charring on the lower limbs. The purpose of this study was to determine the distance of seedling establishment from the group of seed trees. The number of established seedlings was largest in the direction of the prevailing wind and decreased with distance from the seed trees in all directions. After the fire, the seed bed conditions were favorable for white pine germination, but here the ages of the hardwoods (not the pines) corresponded to the date of the fire (Wood, 1932). It is conceivable that there was not adequate seed production or that the early seedlings were unable to survive.

Release

Forests have been subjected to many disturbances in different areas and at variable intensities. Whenever disturbance occurs, there are alterations in stand densities. As a result of decreasing density, changes in air and soil temperature, soil moisture, and light intensity occur. These new conditions affect the development of the residual stand and the subsequent regeneration. Downs (1943) investigated white pine release in Georgia on five uneven-aged hardwood stands which had an understory of white pine reproduction ranging in size from year-old seedlings to trees 16 feet tall. Pine was released on three of the plots by killing the overstory (girdling), and the other two plots were

used as controls. The release of white pine resulted in a 17 to 62 percent greater height growth compared to the control plots after three years.

Drought conditions could be responsible for an alteration of stand densities permitting white pine establishment. Hursh and Haasis (1931) reported drought conditions in the southern Appalachian region during the summer of 1925. During August and September of 1925 the leaves of many trees on ridges and upper slopes fell prematurely. Hursh and Haasis contended that drought conditions in the southern Appalachians have been an important factor in determining the composition of natural forest stands. Repeated drought years either directly eliminated hardwoods from ridge and upper slope positions or did so indirectly through the increased incidence of fire. The subsequent openings could then be available to released or invading white pine.

Wind damage may cause localized disturbances involving a single tree or it may be widespread and catastrophic. Curtis (1943) summarized the literature on wind behavior in an attempt to explain the composition of those forests in New England which were composed of relatively intolerant species. White pine was the primary forest constituent investigated by Curtis. White pine was determined to be more resistant to wind damage than other conifers, but hardwoods were twice as resistant due to superior root anchorage and more open crowns. However, old white pine characteristically overtops the canopy which undoubtedly makes these trees more susceptible to windthrow. There may be several advantages to white pines' excessive domination of the canopy. Increased photosynthesis and growth may increase seed production among the larger white pine. Potential openings due to white pine blowdowns could contribute

to canopy openings thus releasing white pine seedlings and exposing mineral soil used in seed germination.

Breeding

Breeding programs have been initiated to develop blister rust-resistant and white pine weevil-resistant white pine (Wright, 1970). White pine breeding programs have also been instituted to develop strains that are both susceptible and resistant to air pollutants. Berry (1961) described emergence tipburn on white pine as a needle blight assumed to be caused by atmospheric ozone or some other pollutant. Ellertsen et al. (1972) outlined the Tennessee Valley Authority's research into the white pine blight that occurred in portions of Morgan and adjoining counties in Tennessee. DeYoung (1973) studied the visible damage to white pine in controlled fumigation experiments with different pollutants. Sulfur dioxide damage to white pine was variable for individuals from the same fumigation regime. Breeding programs to determine white pine response to air pollutants could preserve both native and nursery stocks. Sensitive white pine specimens could be utilized as indicators of air pollutant concentrations.

CHAPTER III

SYNECOLOGY OF WHITE PINE

Northern Range of White Pine

Numerous plants considered characteristic of the forests of the northern United States also occur in the middle to high elevation forests of the southeast. The status of white pine in northern climax forests and its role in plant succession have been discussed by Spring (1905), Cooper (1922), Grant (1934), Lutz and McComb (1935), and Nichols (1935).

Throughout its range, white pine has become more important in the vegetation after catastrophes that eliminated the preceding stands. Indian settlements, windthrow, and forest fires following droughts all contributed suitable areas for white pine establishment. Pure stands of white pine were often located in areas that underwent major disturbances. It also commonly occurred as a minor component in other types following minor disturbances that did not completely eliminate the canopy. Fowells (1965) described white pine as a major dominant in four Society of American Forester types: White Pine-Northern Red Oak-White Ash; White Pine-Hemlock; White Pine-Chestnut Oak; and White Pine. White Pine is an integral component of 14 other types (Fowells, 1965).

Ineson and Ferree (1948) reported two white pine community types in northeastern Pennsylvania. A white pine-hemlock type was found on well-drained slopes and on the sides of ravines. Some virgin white pine-hemlock stands were attributed to the moist site conditions which were assumed to have inhibited fire. Another community was a

white pine-white oak-red oak type which occurred on rolling foothills within agricultural sections. The proportion of white pine was high compared to the associated species which included white oak, red oak, black oak, chestnut oak, and some red maple. This type occurred on sites that were more mesic than the oak types of the region. Ineson and Ferree (1948) described a chestnut oak type which occurred on poorer sites along southern slopes and ridges in which white pine was an associated species.

Throughout its northern range, white pine occurs in numerous types within the White Pine-Hemlock-Hardwoods of the Lake States and the Northern Hardwoods of New England. The Hemlock-White Pine-Northern Hardwood Region included the Lake States area and comprised the largest region of the Deciduous Forest Formation as understood by Braun (1950). Within the region, white pine occurred on a wide variety of sites and was also associated with the tolerant species of the Northern Hardwoods (Barrett, 1962).

In an analysis of the climax species of the White Pine-Hemlock-Hardwood forest in the Upper Peninsula of Michigan, Graham (1941) explored the literature in an attempt to determine true climax species. It was the white pine from the types in this area which was actively pursued by the loggers of the original forests. The white pine was reputed to tower over the surrounding mature hardwoods by as much as 50 feet. Most ecologists reported white pine as a climax forest component, but Graham (1941) rejected its climax status since it is incapable of regeneration under hardwoods without some form of disturbance. The evidence was that communities which had contained high percentages of white pine eventually underwent a conversion to essentially

hardwood-dominated types. Barrett (1962) reported that white pine may become a climax dominant on xeric sites.

White pine as a component of the Northern Hardwood forest extended from low elevations in New England through gradually increasing elevations southward along the southern Appalachian mountains. White pine and hemlock also continued south and mixed with the typical nothern associates maintaining the characteristic Northern Hardwoods composition (Forthingham, 1915). In the southern region of the Northern Hardwoods, white pine occurred sporadically and occurred primarily on xeric sites (Barrett, 1962).

Southern Range of White Pine

Barrett (1962) included the Allegheny Mountains of Pennsylvania in his Appalachian Highland Region and cited white pine as a codominant in mixtures of hemlock and hardwoods. This portion of Pennsylvania had been considered a transition zone between northern and southern floristic areas (Frothingham, 1915 and Ashe, 1922). In the Alleghenies, white pine occurred mainly on rugged terrain and formed pure stands, or combined with hemlock and northern hardwood species. In the middle of the eighteenth century the rafting of shipmast timbers was in progress in eastern Pennsylvania. The tall and straight white pine from the watersheds of the Susquehanna and Delaware Rivers were in great demand by coastal shipyards (Burnham et al., 1947).

In the southern portion of its range, white pine ranked similar to oaks and hickories in relative tolerance (Fowells, 1965). In the seedling stage, white pine benefited from some hardwood protection which improved its establishment when stand openings occurred. White pine

has the ability to grow successfully with hardwoods in the southern Appalachians, forming long term subclimax communities (Barrett, 1962).

The white pine of the southern Appalachians (Georgia to Maryland) has been a valuable lumber source and was subjected to selective logging which caused a minor reduction in its presence. White pine's presence was later drastically reduced by the repeated fires associated with the logging of associated hardwoods.

Cope (1932) conducted a state-by-state assessment of white pine in the southern Appalachians. The Cumberland Plateau of middle Tennessee was included since it formed the western boundary of the Southern Appalachian Province. Records indicated that white pine was once well represented in the Plateau forests, particularly in the mountain section. Braun (1950) noted the wide habitat distribution of white pine in the northern section of the Cumberland Plateau and considered stands dominated by it as secondary. Sherman (1958) studied five gorges on the Cumberland Plateau, and only Little Piney Gorge had white pine as a dominant constituent. Caplenor (1965) did not find white pine in the Fall Creek Falls gorge. Smith (1977) described a white pine community in which white oak and hemlock were important associates on upper draw positions. The plots were predominantly located on north-facing, level slopes. Schmalzer (1978) reported a white pine-chestnut oak type in Little Piney gorge and in a few plots along the Obed River. The type occurred on relatively steep upper and middle slope sites as well as on streamside sites, but the aspects were variable. Chestnut sprouts and fire occurred on a fourth of the plots, but no evidence of recent logging was discernible. Hinkle (1978) combined all of the white pine plots from the Cumberland Plateau studies of Smith (1977) and Schmalzer

(1978) into a single white pine-dominated community type. The type included red maple, chestnut oak, and hemlock as codominants of approximately equal importance; white pine was represented in most size classes. The soils were variable and were derived from sandstone colluvium with textures ranging from sandy loam to silt loam. Hinkle suggested that, with time, hemlock was the most likely associate to increase in importance within this type.

Thomas (1966) studied the vegetation of the Chilhowee Mountains in the foothills of the Smokies and described a hemlock-white pine type. The type was restricted to deep ravines and moist coves, generally occurring on alluvial soils at the base of steep slopes. He concluded that the higher percentage of hemlock over white pine resulted from previous cuttings of the valuable white pine. The hemlock-white pine type had the highest vascular species diversity compared to the other community types of that area.

Edens and Ash (1969) examined the development of a white pine stand in a bog environment in West Virginia. A single 26 year old white pine tree was reported in Big Glade of Cranberry Glades in 1942. White pine characteristically occurred on deep porous sandy loam soil along slopes and on well-drained sites in West Virginia. Herbaceous genera such as Gaultheria and Vaccinium, which are indicators of xeric white pine sites of low productivity, were commonly found in the open bog areas. The original white pine self-pollinated some time after 36 years, and seedling production fluctuated with successful seed years producing an uneven-aged stand. The single white pine tree developed a stand composed of 339 individuals, although the environmental conditions were not optimal for it. With the maturation of the offspring the stand size

will probably increase, making white pine the dominant woody plant in Big Glade.

Patton (1955) described the role of white pine in secondary succession in the mountains of North Carolina. Land that had been formerly cultivated and had reached the limit of profitability was converted to pasture. With fire control, the adjacent woodlot white pines frequently seeded into the pastures, making white pine more abundant on old fields than it was in the original forest. The name "old field pine" dates from the establishment of white pine in even-aged subclimax stands in New England. These stands resulted from an economic depression, war, and the eventual migration to manufacturing centers (after 1860) which led to the abandonment of the farms (Patton, 1955). Patton located old field stands of various ages and studied the floristic composition, soil characteristics, and stand structure of each age. Patton also studied a single stand of white pine-hardwoods in which white pine was self-perpetuating. The land had not been cleared, and cutting had only occurred on a few oak, chestnut, and white pine trees which had died from natural causes. Fires were traced back through local accounts to a serious ground fire (60 years previously) and a light fire within the preceding 25 years. The fires were attributed to lightning which Patton described as being "frequently attracted to this ridge." White pine had a very high seedling frequency under this canopy. Patton cited lightning strikes and fires as examples of erratic sources of disturbance which permitted white pine to grow through hardwood canopies and survive as a typical component of the upland deciduous forest of the southern Appalachians. The natural increase of white pine has been enhanced by the control of most forest

fires which had previously inhibited regeneration.

Well-documented records indicate that white pine once dominated a number of areas in the southern Appalachians due to a catastrophic disturbance that exposed mineral soils over substantial areas (Patton, 1955 and Barclay, 1957).

Relatively little research has been done using secondary vegetation as site indicators of community types. Hazard (1937) utilized ground vegetation to study old field successional forests in New Hampshire. She hypothesized that the ground vegetation in the pure white pine stands might indicate trends towards succeeding forest types and the eventual climax forest. Most of the white pine was found in pure second-growth stands, and some occurred in the original forests with hemlock and hardwoods. Hazard distinguished five indicator types progressing from infertile xerophytic sites to fertile mesophytic sites. Species lists accompanied each of the indicator types, and many of the species mentioned were common to the white pine-hardwood types described in Chapter VI.

Duppstadt (1972) recorded the flora of Bedford County, Pennsylvania, which is in the Ridge and Valley Province. The flora was reported by community, and a white oak-white pine type and white pine type were described. Some small areas of pure white pine were found, but most of the areas had white pine occurring variously with mixed mesophytic species. Duppstadt reported that the shrubs and herbs that occurred in the mixed types were generally characteristic of the hardwood communities with which the white pines were associated. The white oak-white pine type occurred on low ridges just above the valley floor. Dogwood was present as an understory species and Gaylussacia baccata

(huckleberry) was a common shrub. *Gaultheria procumbens* (teaberry) and *Chimaphila umbellata* (pipsissewa) were frequently encountered growing on the forest floor. Seedlings of red maple and other oak species were also growing under the white oak-white pine type.

CHAPTER IV

THE STUDY AREA

Location

The Great Smoky Mountains National Park is comprised of 227,076 hectares (508,000 acres) in Blount, Cocke, and Sevier Counties, Tennessee, and in Haywood and Swain Counties, North Carolina. The white pine type was identified as centering around Cades Cove and extending along Abrams Creek and its tributaries in Blount County, Tennessee; this study was conducted there (Figure 1). The area is mapped on the Blockhouse, Cades Cove, Calderwood, Thunderhead, and Wear Cove 7.5 minute topographic quadrangle maps of the U.S. Geological Survey.

The study area is in the Great Smoky Mountains which are a part of the Blue Ridge Province (Fenneman, 1938). The main ridge of the Smokies is oriented in a northeast to southwest direction and extends for approximately 50 miles within the Park. The Little Tennessee and the Big Pigeon Rivers are the major tributaries that drain the Smokies. Abrams Creek constitutes the major tributary of the Little Tennessee River and is the predominant stream in the western portion of the Park.

Climate

East Tennessee lies in the region of prevailing westerly winds. Weather originating in the interior of the continental United States and the Gulf of Mexico is the primary source of moisture (Fribourg et al., 1973). The Great Smoky Mountains have a diversity of climate that is

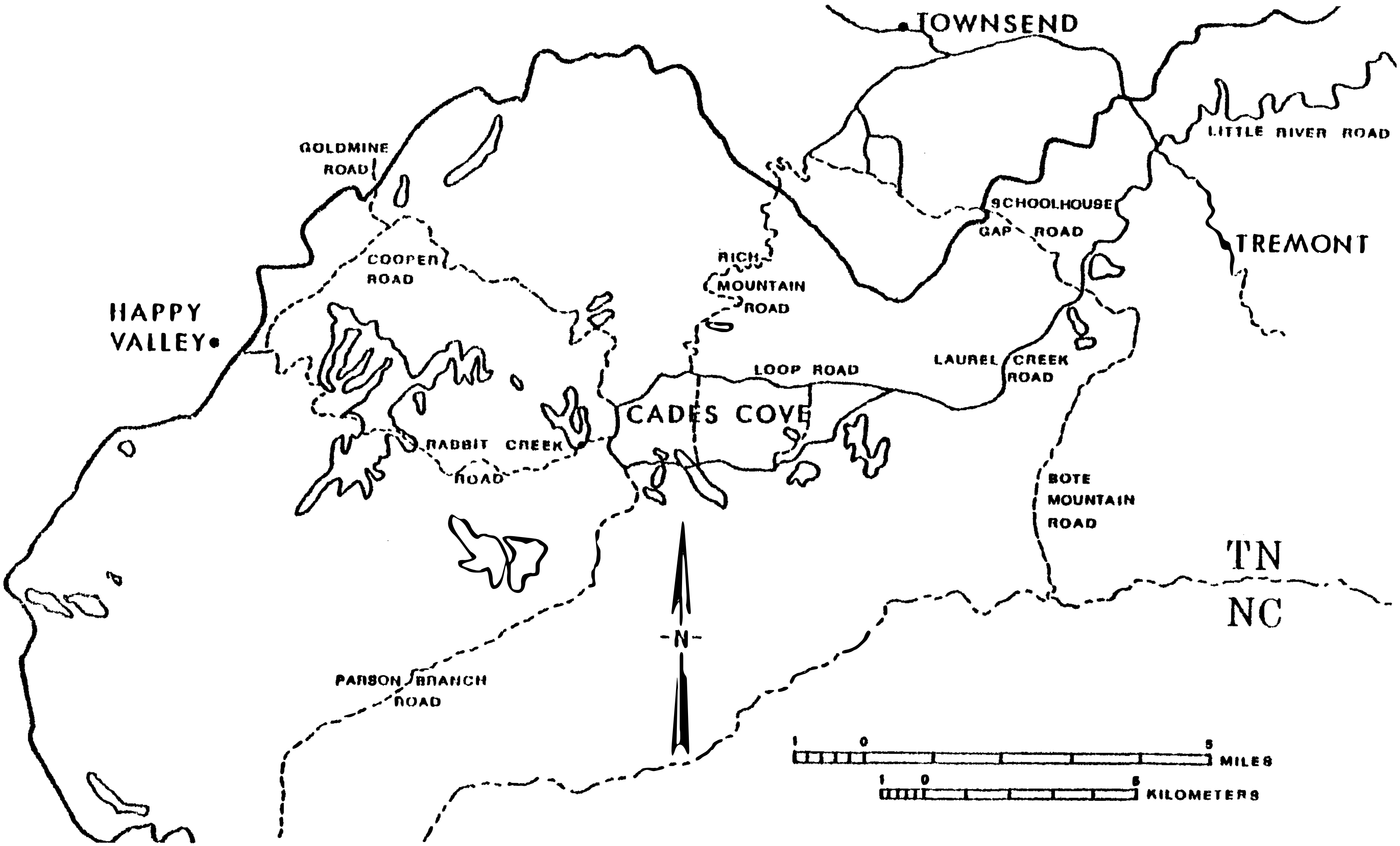

Figure 1. Location of the White Pine-Hardwood Stands in the Western Portion of the Great Smoky Mountains National Park (after Miller, 1941).

characteristic of the southern Blue Ridge Mountains. Variations in temperatures and precipitation, combined with topographic variability, contribute to the wide array of microclimatic habitats (Shanks, 1954; Stephens, 1969; and Bogucki, 1972).

The lower elevations of the Smokies have a humid-temperate climate with relatively moderate winters and short cold periods. Summers are generally hot and humid. Temperature data from Gatlinburg indicate a mean annual temperature of 56.8 degrees Fahrenheit (USDC, 1965). Wide variations in temperature and precipitation can occur within the Park due to the variable topography. The high mountains have an increased precipitation (including snow), generally lower temperatures, more fog and cloudiness, and a shorter frost-free period (Dickson, 1959). Altitudinal gradients affect temperature and precipitation patterns and therefore affect species distributions. Shanks (1954) found that the decrease in temperature per thousand foot increase in elevation averaged 2.23 degrees Fahrenheit. The average frost-free season of the low elevation Gatlinburg station is 180 days--generally from April 14 to October 13.

Although precipitation is fairly well distributed throughout the year, it is slightly depressed in the autumn (September and October) and peaks in late winter and spring (May) (Stephens, 1969). Excessive rainfall can occur with high frequency, but the majority of rainfall is light to medium-heavy (Bogucki, 1972). Hailstorms and tornadoes occur infrequently.

No glaciers reached or formed in the Smokies during the Pleistocene, but the climate approached glacial conditions, and there may have been a timberline at 4,000 or 5,000 feet. The climatic

fluctuations resulted in migration and modifications of both plant and animal populations, and it is suspected that this influenced the present biotic diversity of the Smokies (King and Stupka, 1950).

Physiography and Geology

Since the late Paleozoic, the Smokies have been subjected to erosional forces which have considerably reduced the original height of the mountains, and the peaks became rounded and exposed outcrops rare. Steep slopes comprise a large percentage of the Park's surface area, and the topography is rugged with numerous V-shaped valleys and narrow ridge crests. The land is so steep that less than 10 percent of the surface area of the Park is of slopes less than 10 degrees (Message from the President, 1902; cited in Whittaker, 1956). The variability of terrain is a scenic asset and forms the structural framework on which the biological diversity is distributed.

The pioneer investigations into the bedrock geology of the Smokies were conducted by Safford (1869); however, very little geologic work continued in the Smokies until after World War II. Three main groups comprise the bedrock material of the Smokies: (1) the metamorphic rocks of the Precambrian basement complex, (2) the sedimentary rocks of the later Precambrian which underlie the great majority of the Park, and (3) the sedimentary rocks of the Appalachian Valley which are of Paleozoic (Ordovician and younger) age (King et al., 1968).

Most of the Smokies and surrounding foothills are underlain by late Precambrian rocks which make up the Ocoee series. A shallow sea covered large regions and sediments from the weathered basement complex were constantly being deposited (King et al., 1968). They were later

complexly folded and faulted, although they were chiefly hard rocks resistant to erosion and were fairly uniform in their weathering response. The Ocoee series was named by Safford (1856, 1869) for the outcrops that occur along the Ocoee River. The Ocoee series has been divided into three groups. The groups are: the Great Smoky group which is represented by Elkmont and Cades Sandstone, the Snowbird group by Metcalf Phyllite, and the Walden Creek Group by the Wilhite Formation. The Cades sandstone of the Ocoee Series represents the predominant sandstone encountered in the study area. It consists of coarse-grained to conglomerate sandstone interbedded with argillite and siltstone. The sandstones of the Cades have a wider range of grain sizes than the fine-grained Elkmont type. The Cades resembles the Elkmont in general appearance but is predominant in lower mountainous country. Quartz is the most abundant mineral of the sand fraction, with up to 30 percent represented by feldspar. Associated soils are thin and are susceptible to down-hill creep due to slope steepness.

The Snowbird Group is represented by Metcalf phyllite which underlies the eastern margin of Cades Cove. The formation was named for Metcalf Bottoms along the East Prong of the Little River. It is a light to medium-gray phyllite with some fine-grained sandstone (Neuman and Nelson, 1965). Fragments of Metcalf phyllite, when separated from outcrops, are subject to alluvial and colluvial transport.

The Walden Creek group (Wilhite Formation) is made up of a large number of intergrading bedrock constituents including feldspathic sandstone, siltstone, and limestone. The sandstone component is less feldspathic than the Cades. The limestone beds are uniformly fine-grained and contain some carbonate. The Wilhite Formation occurs in

highly dissected topography with a limited vertical relief and sandstone projecting higher on the ridges.

The Chilhowee group has been classified as early Cambrian in age. It is a sequence of quartzites and interbedded siltstone and shales commonly found on Chilhowee Mountain. The Nebo Quartzite occurs predominantly along most of Chilhowee Mountain as exposed cliffs. The quartzite is medium to coarse-grained (Neuman and Nelson, 1965).

Representing the lower Ordovician is the Knox group containing Jonesboro limestone. Neuman and Nelson (1965) explained that the Jonesboro limestone is exposed in windows of the eroded Great Smoky Mountain thrust sheet. Within the study area the Jonesboro limestone was predominant on the valley floor of Cades Cove. The Great Smoky Mountain thrust fault lies at the northern edge of the foothills of the Great Smoky Mountains bordering the Appalachian Valley. It is a low angle thrust fault which carries older rock material over younger. The leading edge of the fault dips beneath Chilhowee Mountain and arises in the foothills. It has been exposed by erosion in several places such as Wear Cove and Cades Cove which are floored by Ordovician rocks. A smaller window occurs in the Calderwood area near the Little Tennessee River. The windows eroded to open valleys which were subsequently settled prior to the formation of the Park.

Soils

Detailed soil mapping was not available for the study area. General soil descriptions were based on the 1953 Blount County soil survey (Elder et al.). Most ridges and middle to upper slopes were mantled with residual Ramsey series soils, and lower slope positions

were covered with colluvial materials of the Jefferson series (Elder et al., 1953). Alluvium occurred in restricted areas predominantly in steep ravines and along major stream floodplains.

The Ramsey series of the upland soils were derived from sandstone, quartz, and slate. There were several series represented in the study area: Ramsey slaty silt loam, steep phase (25 to 50 percent slopes), Ramsey slaty silt loam, very steep phase (50 percent plus slopes), and Ramsey stony fine sandy loam, very steep phase (50 percent plus slopes). The Ramseys varied in depth and horizon thickness, but were generally shallow and weakly developed, and bedrock outcrops and rock fragments were abundant. The soils were light yellowish brown with textures that varied from fine sandy loams to silt loams.

The Rockland series was represented in the study area and was derived from slate and quartzite and had very steep slopes from 50 to 75 percent. Soil accumulation was minimal and the profiles were quite thin.

The Jefferson and Hayter soils were derived from Ramsey soils. They were colluvial soils that occurred at the base of slopes. The Jefferson series was a fine sandy loam occurring on mild slopes (5 to 12 percent). The Jefferson series occurred along the foot slopes of Chilhowee Mountain in the alluvium or colluvium that washed from the sandy Ramsey soils. The soil of the Jefferson series was well drained, the available water-holding capacity was high, and a large area of this series had at one time been under cultivation.

The Hayter series was a silt loam or stony silt loam occurring on very mild slopes (2 to 5 percent). The Hayter series was derived from the upland Ramsey series but lay adjacent to limestone or

was underlain by it. Large portions of this series occurred in Cades Cove. The soil has high available water-holding capacities, and large areas of it were cultivated.

Flora

The Smokies support a rich flora because of their history, age, and habitat diversity. The wide biological spectrum is partially attributed to numerous combinations of climatic, topographic, and edaphic conditions which increase habitat diversity. King and Stupka (1950) reported that there were 32 fern, 230 lichen, and 330 moss and liverwort taxa that occurred within the Smokies. Of the vascular flora, Hoffman (1964) listed a total of 1,450 taxa within the Park. Hesler (1962) reported that the Smokies contained at least 1,975 species of fungi.

The floristic affinities of 248 woody taxa from the Great Smoky Mountains were classified by Cain (1930b). He found 172 intraneous species (near the center of their range) and 76 extraneous species (near their range limit). Thirty species were considered as endemic to the southern Appalachians. The high rate of endemism was hypothesized to occur due to the extreme age of the land surface. In the mountains, the northern elements appeared in increasing importance with increasing elevation.

In 1945, Cain worked on over 1,000 flowering plant taxa that occurred in the Smokies and classified them, using the Raunkiaer (1934) life form system. The life forms of plants are a measure of the environmental conditions of a region. Hemicryptophytes comprised 52 percent of the taxa, 19.5 percent were phanerophytes, 15.5 percent were cryptophytes, 11.5 percent were therophytes, and 1.7 percent were chamaephytes.

Cain separated 113 taxa which occurred in the "cove hardwood" communities and found that the phanerophytes (36.3 percent) and the cryptophytes (25.8 percent) constituted higher percentages than when all vegetation types were considered.

Whittaker (1956) applied his field work in the Smokies to the theory of community units using the complex patterns of species distribution. He concluded that vegetation types were continuous with one another as the floristic composition shifts in response to environmental gradients. Whittaker reported that although species are distinct, each grades in and out of communities according to its own physiologic and genetic pattern.

Vegetation

The Great Smoky Mountains contain a wide variety of habitats attributable to the variable topography and elevation. The establishment of the Smokies as a National Park preserved large portions of the forests from lumbering and uncontrolled burning. As a result, the Smokies became a center of investigation into the study of Southern Appalachian vegetation.

The first large scale vegetation survey of the Great Smoky Mountains National Park was done in the 1930's under the leadership of Frank Miller. The study design was conducted in 27 watersheds with a total of 1500 one-fifth acre plots. Miller's types were broadly classified, based upon the 1931 Society of American Foresters types. Twelve vegetation types were discerned by Miller in 1938, and a map of the vegetation type boundaries was drawn in 1941.

Coniferous forests are prevalent at the higher elevations in

the northeastern portion of the Smokies. These forests are dominated by mixtures of Picea rubens (red spruce) and Abies fraseri (Fraser fir). Heath balds and grass balds commonly occur, interspersed among the higher mountains particularly on ridges (Camp, 1931; Wells, 1937; Cain, 1930a; Gant, 1978).

Braun (1950) and Shanks (1954b) described a high elevation northern hardwood type that occurred on mesic sites and in coves. The northern hardwood type contained the following important dominants: Fagus grandifolia, Betula alleghaniensis, Aesculus octandra, and Acer saccharum. As segregates of the high elevation northern hardwoods, beech gaps occurred as islands between the spruce-fir predominantly on south-facing slopes (Russell, 1953; Fuller, 1978).

Cove hardwood forests occur typically in low and middle elevation coves (Cain, 1937, 1943; Shanks, 1954b; Whittaker, 1956). Braun (1950) referred to the forests as typical mixed mesophytic communities similar to those she described in the Cumberland Mountains. Whittaker (1956) suggested that the cove hardwoods were located in more mesic habitats than Braun's mixed mesophytic forests of the Cumberlands. The dominants of the cove hardwoods as understood by Cain (1943) are a mixture of the following taxa: Tsuga canadensis, Aesculus octandra, Tilia heterophylla, Halesia carolina, Acer saccharum, Betula alleghaniensis, and Fagus grandifolia.

In 1956 Whittaker stated that the chestnut oak-chestnut forest was a forest type that had aerially dominated lower and middle elevations. With the demise of Castanea dentata (chestnut) by the chestnut blight (Endothia parasitica) there has been a drastic change in forest composition. Woods and Shanks (1959) studied the replacement of

chestnut by other species and found that *Quercus prinus* (chestnut oak), *Quercus rubra* (northern red oak), and *Acer rubrum* (red maple) were the most abundant replacement species. Whittaker (1956) also recognized other forest types that occurred at the same elevations as the chestnut oak-chestnut type, except that they were situated on sites ranging from sub-mesic to xeric. They were the northern red oak-pignut hickory type and the yellow pine type.

Miller first described the White Pine-Hardwood type in 1938, but subsequent vegetation studies in the Park have both failed to identify white pine as occurring in local concentrations and as a type dominant. Miller mapped the occurrence of the white pine-hardwood type which occurred predominantly in the western end of the Park in Tennessee. Two small stands occurred in the eastern end of the Park near Cataloochee. The white pine-hardwoods occurred at low to middle elevations (1,000 to 2,500 feet) and generally centered around Cades Cove and extended along Abrams Creek to Chilhowee Reservoir.

Human History

The Great Smoky Mountains were inhabited by the Cherokee Indians who had established semi-permanent villages throughout the adjacent lowlands. Primitive agriculture was practiced on the alluvial bottomlands, and periodic hunting trips penetrated the higher mountains. With the advent of Appalachian Valley immigration after the Revolutionary War, the establishment of numerous mountain settlements was initiated. Wear Cove and several other areas were cleared and settled around 1795 but not without some bloodshed over land conflicts with the Cherokees. The higher mountain sections were secured by land grants from North Carolina.

North Carolina had issued several land grants in the early 1800's, but legally the land belonged to the Cherokees until 1819 when they relinquished their claim by treaty. Cades Cove was a prominent feature within the land titles and was discriminated as an area which was capable of large-scale cultivation (Shields, 1977). Initially, the Cades Cove property was held by a few grantees but subsequently the larger tracts were divided and sold. The first comers took the bottom lands where the soil was adequate for cultivation. By 1838 the Cherokees had been relocated to Oklahoma by the infamous "Trail of Tears" (Kephart, 1936), although a few remained in western North Carolina.

White settlements such as Cades Cove expanded in the mountains; isolated communities were established, and the farm land was cleared. Lumber was used for the construction of cabins, barns, and the other necessary out-buildings. Numerous such settlements (most smaller than Cades Cove) were established throughout the western portion of the Smokies wherever subsistence farming was practical. Settlements adjacent to present-day white pine-hardwood stands were: Happy Valley, Cain Creek, Scott Gap, Rich Mountain, and Panther Branch. The areas under cultivation in these settlements varied in size as well as time of establishment.

Population fluctuations occurred in Cades Cove; between 1821 and 1850 the population tripled from 271 to 685 and newcomers expanded into nearby small coves and hollows. In 1860, the population fell to a much reduced level, only to increase again until 1920. The 1920 crash was caused by the local employment opportunities with Alcoa Aluminum which induced people to leave the Cove (Shields, 1977). In the early

20th century, the productive timber land was purchased and plans were initiated for a large-scale sawmill operation. The William Butler Tract was the potential lumber source, but the plans were never finalized, partly because of the intended purchase of the Park by the National Park Service. Although large tracts of the Park were logged by lumber companies, no large-scale logging operations were conducted in the Cades Cove region. Most of the western end of the Park was not extensively logged. The Calderwood region was subjected to small-scale logging during the 1900's; here a railroad extended four miles up Panther Branch for hauling mined slate. Limited logging occurred along the river valley.

In the western portion of the Park, the most significant logging disturbances were the numerous small tract operations. Logging during the period of 1880 to 1900 concentrated on small tract clear-cutting or selective cutting in the easily accessible areas (Lambert, 1960). Small tract logging was conducted in the Cades Cove area by steam-powered sawmills, and the lumber cut was usually restricted to community construction in the cove itself (Shields, 1977). Shields (1977) indicated that white pine was sought for construction framing. White pine was always in ready supply at the Shields' place in Cades Cove exclusively for the construction of coffins. Adjacent to Cades Cove was Coalen Ground Ridge which was clear-cut for the making of charcoal to fuel the forge in the Cove. In summary, the impact of habitation on the vegetation of the Park was observed in 1902 by Ayres and Ashe who examined the forest conditions. The lower north slopes were often cleared for pasturage and suffered some burning, while the southerly slopes were especially affected by indiscriminant fires. In spite of the various disturbances,

there were still considerable concentrations of fine timber left undisturbed in the elevations above 3,000 feet.

CHAPTER V

DATA COLLECTION AND PREPARATION

Introduction

Field work for this study was conducted from June through October, 1977. Prior to the field work, preliminary investigations were made of Miller's stand locations of the white pine-hardwood type. The original field topographic quadrangles in the Park archives were used to transpose stand boundaries to present day U.S.G.S.-TVA 7.5 minute topographic quadrangle maps.

The stands used were on the Cades Cove, Calderwood, Wear Cove, Thunderhead, and Blockhcuse topographic quadrangles. Stands were selected to obtain a broad sample from the white pine-hardwood areas and to secure a distribution of plots along a variety of elevations, aspects, and topographic positions.

In the field, stand boundaries were subjectively determined once it became obvious that the mapped stand location was accurate and that the type containing white pine existed. Plot centers were then randomly distributed throughout the stand. One hundred and forty-four plots in approximately 34 stands were sampled. The plots ranged in elevation from 312 to 716 meters (1,000 to 2,350 feet) above sea level, and a wide variety of aspects was represented.

Environmental Measurements

Circular plots 0.0406 hectares were used which had been adjusted for slope angle according to the method of Bryan (1956). Plots were

situated on various slope positions which were designated as ridge, upper slope, upper-middle slope, middle slope, draw, flat, and floodplain. A pre-numbered and identified aluminum rod was driven into the soil at the plot center. Flagging was used to demarcate the plot borders at four points. Distances from the center to trees near the plot edge were measured in cases of doubt about tree inclusion. The elevation of each plot was determined to the nearest 25 feet by a pocket altimeter which was checked frequently against topographic landmarks. The plot number and location were recorded on the topographic quadrangle map. Aspect was measured to the nearest 10 degrees using a hand-held Silva rangefinder compass. The slope angle was measured (to the nearest 5 percent) from the plot center to each of the previously flagged boundaries using an Abney level. Horizontal and vertical slope shape was subjectively designated as convex, flat, or concave. Canopy closure and surface rock cover were estimated to the nearest 5 percent.

Evidence of disturbance was recorded in each plot in order to assist in the determination of the past history and potential successional nature of the stand. The various disturbance phenomena noted were fire scars, logging, human settlement, old fields, wind damage, and present and/or past grazing. Other relevant information such as the presence and size of chestnut stumps or sprouts was noted at each plot.

A soil pit was dug to at least 50 cm (20 inches) near the center of each plot. The litter layer was recorded by its dominant component (broad leaves and/or needles), and the thickness was measured to the nearest cm. The volume of stones over eight cm wide and eight cm to two mm wide in the A and B horizons was estimated to the nearest

5 percent. The thickness of the A and B horizons was measured, and samples were bagged and labeled for laboratory analysis. The depth to consolidated material was estimated from the total depth the soil probe penetrated. The profile colors were noted.

Vegetation Measurements

In each .0406 hectare (1/10 acre) plot, the canopy was comprised of all stems greater than 10 cm (four inches) in diameter at breast height (DBH) which were tallied by taxon in five cm (two inch) size classes. Saplings, in the 2.5 to 10 cm (one to four inch) DBH size class, were tallied by taxon in the one-tenth acre plot. A diameter tape was used until accuracy in estimating diameters was developed. Unusually large stems were measured as they were encountered.

Subsaplings from four feet tall and under 2.5 cm (one inch) DBH were sampled on two six-foot wide transects across the plot center. The total area was equivalent to one-forty-ninth of an acre. The presence and relative abundance of the larger shrubs and woody vines was recorded concurrent with the subsapling transects.

Shrubs, vines, seedlings, and herbs were inventoried in two separate one-meter square plots that were randomly selected within the one-tenth acre plot. Stem counts and cover estimates to the nearest 5 percent were made by taxon. Appendix B, Table 43 contains a sample field data sheet.

Taxonomic determinations were made in the field when possible. Unknown or uncertain species were collected for later determination. The University of Tennessee Herbarium provided aid in determining unknown specimens. Trees were determined using the Summer Key to

Tennessee Trees by Shanks and Sharp (1950). Shrubs and woody vines were determined using Stupka's Trees, Shrubs, and Woody Vines of the Great Smoky Mountains National Park (1964). Herbaceous species were determined using a variety of manuals, but Radford et al. (1968) was used as a final authority for determination and nomenclature of all species. The reference collection is included in the Ecology Program Herbarium.

Tree cores were taken from white pines of various sizes throughout the study area. A total of 209 cores was collected and mounted; the ages were estimated to provide baseline information on DBH-age relationships and on the periods of pine invasion.

Laboratory Methods

Soil samples were air dried after their removal from the field. Soil pH measurements were obtained using a Leeds and Northrup meter with glass electrodes which was calibrated with standard buffer solutions. A soil and water solution (1:1 ratio) as well as a ratio of 1:2.5 soil and water solution with 1 N KCL added (Jackson, 1958) was tested to determine the pH for both the A and B samples of each plot. The KCL samples were consistently 1.0 pH unit lower than the water samples; the 1:1 soil to water pH values were used in subsequent analysis.

Soil samples from the A and B horizons were sieved to determine the fraction of coarse fragments (greater than two mm in diameter). Fourteen plots were selected for laboratory soil texture determination. The hydrometer method of Day (1956) as modified by Springer (M. E. Springer, personal communication) was utilized to determine the percentage of sand, silt, and clay in both the A and B horizons. These laboratory-determined textures became the standards, and the other

samples were analyzed (to the nearest five percent) by the "feel" technique recommended by the Soil Survey Staff (1951). The textural class, percent coarse fragments, and percent stone volume were utilized in establishing the available water holding capacity (AWHC) of both the A and B horizons. By combining the available water holding capacity and the horizon thicknesses in each plot, the total available water was calculated.

Aspect measurements were transformed on each plot datum following the method of Beers et al. (1966). This transformation resulted in a maximum value of 2.0 for northeast aspects, a minimum value of 0.0 for southwest aspects, and a value of 1.0 for both the northwest and southeast aspects. Average daily potential radiation was determined from the tables by Frank and Lee (1966) which utilizes latitude, aspect, and percent slope information.

The distance of the plot from the nearest small ridge and draw (microtopographic position) was measured directly from topographic quadrangle maps. The distances were summed, and the distance from the plot to the ridge was divided by the total distance to give a relative (percentage) microtopographic position, with the ridge equal to one, and the draw equal to 100. The procedure was also used with respect to the predominant (large or main) ridge and draw and is referred to as the macrotopographic position.

Computer Analysis

All data were punched on computer cards. The vegetation data were submitted to a computer program prepared by the University of Tennessee Computer Center staff. The program calculated, for each

species on each plot, the absolute and relative densities, basal areas, and importance values (IV = RD + RBA).

Statistical analyses were performed at the University of Tennessee Computer Center utilizing the IBM 360/65 and the DEC-10 computer. A variety of packaged computer programs have been utilized in this study. The Statistical Package for the Social Sciences (SPSS) program (Nie et al., 1975) was utilized extensively for descriptive statistics and data manipulation. The SAS program (Barr et al., 1976) was utilized to manipulate and manage stored data.

Vegetation types based upon 33 canopy taxa importance values from plots were determined using an agglomerative clustering technique developed by Orloci (1967). The classification technique of Orloci (1967) is based upon a heirarchial and agglomerative clustering procedure. Plots are grouped using the reduction of within-group variance and a maximized variance between groups. The group units may be considered vegetation types.

Correlations among and between vegetation and environmental variables were calculated using the Pearson Product-Moment Correlation procedure from SPSS (Nie et al., 1975). Discriminant analysis was conducted on both environmental and vegetation data using the procedure from Nie et al. (1975). Canonical analysis was performed using the program developed by Grigal and Goldstein (1971) to array the centroids of the vegetation types.

Permission was granted by the Park Service to collect increment cores from white pine trees. Cores were replaced with tight fitting stems to minimize the possibility of entry by insects or fungi. Increment cores were mounted and sanded to reveal growth rings, and staining

was unnecessary. When the increment borer did not penetrate the tree center, an overlay was used to estimate its approximate age. The whorls of white pine may be used to estimate tree age, and the average age at breast height was determined to be approximately six years, allowing total age estimation rather than using the age at breast height.

CHAPTER VI

VEGETATION DESCRIPTION

Vegetation Classification

Classification of vegetation has been one of the major goals of plant ecology. Braun-Blanquet used floristic lists to observe the presence of "character species" in order to determine plant communities (Mueller-Dombois and Ellenburg, 1975). Clements (1928) stated that climate determined formation boundaries in which seral stages develop over time towards a climax (monoclimax theory). He and other ecologists proposed that communities were distinct entities and were replicated over the landscape. Gleason (1926) introduced the then radical concept of "individualism" which proposed that communities were a result of the random spread and successful establishment of individual plants. In other words, each species sorts out along a complex environmental gradient. The lines were drawn in the controversy between the discrete community supporters (Clements, 1928 and Daubenmire, 1966) and those supporting a continuum approach (Gleason, 1926; Whittaker, 1956; and McIntosh, 1967).

Curtis (1959) extended Gleason's individualistic hypothesis and proposed that there is a continuous variation from one stand to another in such a way that the further apart they are ecologically and geographically, the greater the differences among them. Whittaker (1956) viewed plant communities as a continuum with a complex gradational pattern of populations. Species distribute themselves individualistically according to physiology and genetics to form a continuum along

environmental gradients. McIntosh (1967) reviewed the continuum concept and stated that vegetation patterns were not random but were directly related to environmental gradients. He further noted that abrupt vegetation boundaries may occur because of soil conditions, historical treatment, or extreme microclimatic effects. E. L. Braun (1950) took a non-committal view and defined a community as a general term for any unit of vegetation regardless of rank or development.

Classification Techniques

Computer use in handling vegetation data has been expanding, enabling mathematical approaches involving large numbers of complex calculations to be accomplished with great speed. The mathematical approach has increased in popularity also because of its potential for exact replication of procedures. Mathematical ecology has grown increasingly important in plant ecology, and classification techniques have been developed which may be applied to vegetation data (Pielou, 1977). Computer-based vegetation classification essentially started with cluster analysis and developed into other multi-variate techniques.

There are many numerical classification procedures that have been utilized in the classification of vegetation (Pielou, 1977). Golden (1974) applied Orloci's (1967) clustering procedure to vegetation data from the Great Smoky Mountains National Park in order to segregate and classify plant communities. Various numerical classification techniques were analyzed by McCarthy (1976) on data collected by the Tennessee Valley Authority for Fentress County, Tennessee. Using his own contrived data, McCarthy determined that Orloci's technique (1967) based on minimum dispersion was successful in recognizing plant community assemblages.

Cluster analysis compares samples (plots), by use of a measure of similarity or dissimilarity "distance," and clusters those which are most similar or least dissimilar. The cluster procedures separate samples into groups based upon the discreteness of the vegetation structure. No two samples are considered to be exactly alike even when in close proximity; thus deviations are certain to occur even within equivalent habitats (Mueller-Dombois et al., 1974). McCarthy (1976) tested several numerical classification techniques because different clustering methods can produce variable results. Numerical techniques have inherent disadvantages that must be considered, and subjective judgement is generally required to determine the classification scheme. Another disadvantage is the broad variability in the results obtained from different classification techniques. Much of the disagreement regarding classification techniques exists because of the controversy over the nature of plant communities.

Cluster procedures separate plots into groups based upon the discreteness of the vegetation structure. A continuous vegetation pattern separated under this technique may become fractionalized and may distort the composition of the actual groups. Depending upon the intensity of sampling, the species assembled may vary dramatically throughout the range of a particular community type. A discrete vegetation pattern contains recurring species which may be easily clustered into distinguishable groups.

The agglomerative heirarchical classification technique designed by Orloci (1967) can be used to group sample plots into types. McCarthy (1976) cited that Orloci's (1967) agglomerative cluster procedure was one of the most commonly used agglomerative methods. In an agglomerative

classification, the procedure starts with each sample plot representing the initial n clusters. Initially, each sample plot is considered as a separate group. At each successive step the clusters are joined based upon the smallest "distance" between them, up to n-1 where all sample plots are united into a single cluster. During each cycle, the average within-group dispersion is calculated for each newly formed group. The cluster groups are united in a hierarchical fashion where clusters at any level are subgroups of groups at a higher level. The graphical representation of the hierarchy is a dendrogram in which relationships are easily interpreted and the operational level for cluster group discrimination can be discerned (Figure 2).

The vertical axis represents the percentage of total dispersion among all samples. The dispersion level on the vertical axis can be interpreted as an information level in which a high dispersion percentage represents a loss of information as more sample plots are combined into a single cluster group. The number at the base of each stem on the horizontal axis represents the number of sample plots included in each group at the zero percent dispersion level. To determine the actual classification from the vertical dispersion level, one may 1) decide on the number of classes to be recognized, 2) select the amount of heterogeneity desired, 3) select reasonable approximations based on field reconnaissance. All that can be expected from a procedure is that groups will intuitively reflect actual ecological phenomena (Pielcu, 1977). Cluster analysis has been used by Golden (1974) in the Smokies, McCarthy (1976) on T.V.A. forest records in Fentress County, and Hinkle (1978) on the Cumberland Plateau.

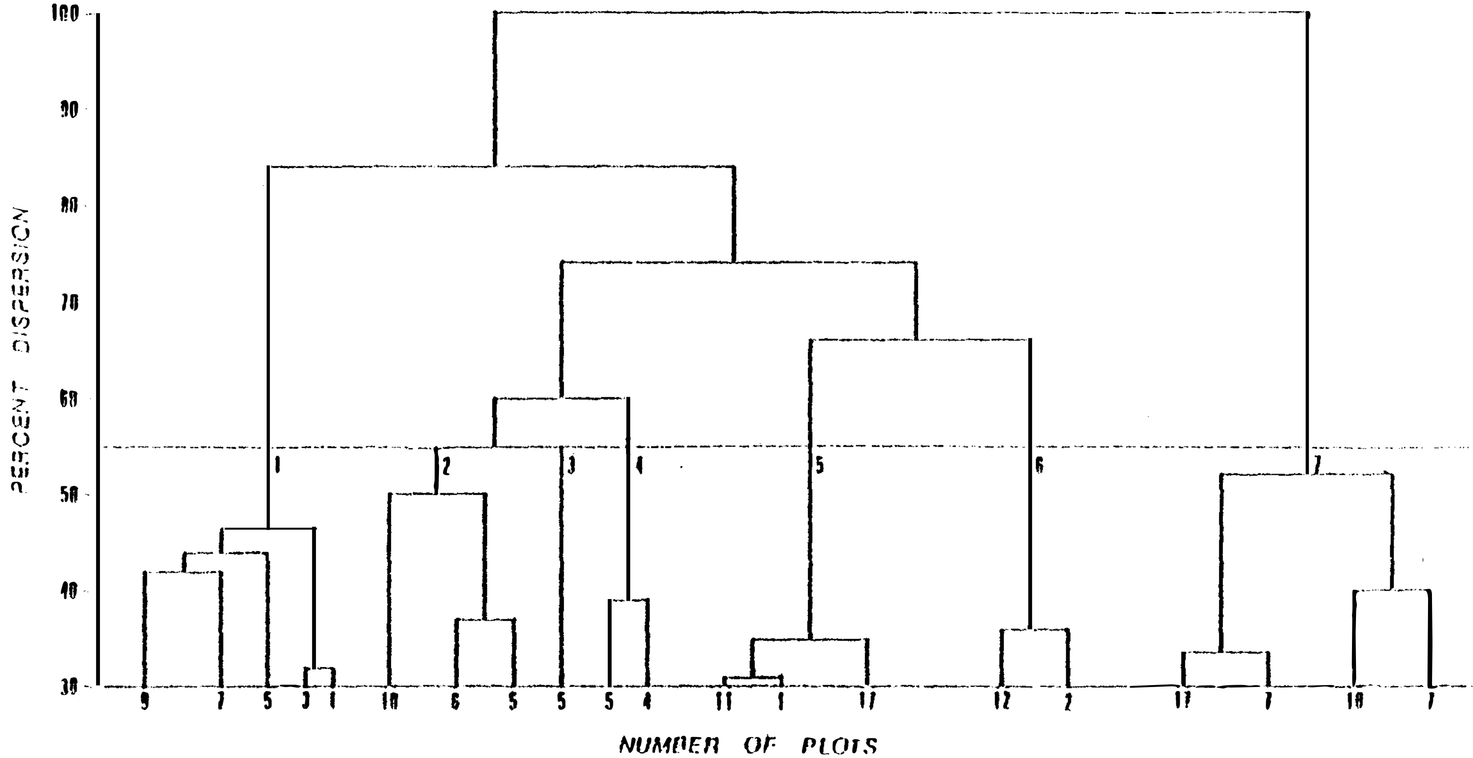

Figure 2. Classification dendrogram of the white pine-hardwoods. Vertical axis is within-group dispersion (Orloci, 1967) expressed as percent of total dispersion. Communities are defined at the 55 percent dispersion level. Key: 1=white pine-Virginia pine, 2=white pine-red maple, 3=white pine-hemlock, 4=white pine-chestnut oak, 5=white pine-white oak, 6=white pine-northern red oak, and 7=white pine.

Methods

Community types can be classified based upon any number of properties. In this analysis, floristic characteristics were utilized based upon the dominant species in terms of species importance values (determined by relative basal area and relative density).

A 55 percent dispersion level was subjectively selected for determining the community types in this study. Although Miller broadly defined this type as white pine-hardwood, it was determined that segregates were necessary to adequately describe and detail the occurrence of white pine vegetation in the Smokies. A higher dispersion level would have obscured some of the unique features of the vegetation, while a lower level would have fractionalized the vegetation into numerous components of less significance. Seven community types were distinguished at the 55 percent level, and the mean importance value for each taxon was calculated. The type name was based upon the one or two taxa which had the highest mean importance values.

Results

The seven groups that were obtained from the cluster analysis appear in Figure 2. Occurring on the dendrogram from left to right are the: white pine-Virginia pine, white pine-red maple, white pine-hemlock, white pine-chestnut oak, white pine-white oak, white pine-northern red oak, and white pine vegetation types. The classification and subsequent determination of types was primarily for the purpose of convenience and communication. Included within the discussions of each community type are tables containing information on the composition of the vegetation strata, disturbance history, and the environmental

characteristics that define the individual type. The first time a species name enters the discussion, scientific nomenclature is used, but thereafter it is referred to by its common name.

The White Pine-Virginia Pine Type

The white pine-Virginia pine community type contained 40 of the 43 tree taxa represented in this study. Pinus strobus (white pine) was the leading dominant and Pinus virginiana (Virginia pine) was also an important dominant; these had a combined mean importance value (100 maximum) of 54 percent. Important associated species included Pinus rigida (pitch pine), Acer rubrum (red maple), Quercus prinus (chestnut oak), Quercus rubra (northern red oak), and Liriodendron tulipifera (tulip poplar) which occasionally attained an importance value of 15 percent or more (Table 1).

This type occurred predominantly on northwestern aspects, although it occurred on all other major aspects except south facing slopes. Plots occurred in the Cades Cove area on north facing slopes at elevations of 381 to 640 meters (1,250 to 2,100 feet). Slope angles were slight to moderate (averaged 25 percent) and the average daily potential solar radiation was very high (256 Langleys).

The composition of the white pine-Virginia pine type typically consisted of moderate-sized overstory trees with a very open canopy (68 percent cover) and a well-developed understory including shrub and vine and herb layers (Tables 1, 2, 3).

Soil depths were moderate; they averaged 46 cm (18 in) and ranged from 36 to 84 cm. The A horizon averaged the thickest of any type sampled (16 cm) and an Ap horizon was noted in several plots. The

Table 1. Overstory Composition of the White Pine-Virginia Pine Type. N=25.

Taxa	Mean Relative Density[a]	Mean Relative Basal Area[b]	Mean Importance Value[c]
Acer rubrum	10.0 ± 1.7	4.5 ± 0.8	7.4
A. saccharum	0.1 ± 0.1	0.01 ± 0.01	0.1
Amelanchier laevis	0.1 ± 0.1	0.01 ± 0.01	0.1
Betula lenta	0.3 ± 0.2	0.1 ± 0.1	0.2
Carya cordiformis	0.1 ± 0.1	0.02 ± 0.02	0.1
C. glabra	1.3 ± 0.6	0.5 ± 0.2	0.9
C. tomentosa	0.7 ± 0.4	0.2 ± 0.1	0.4
Cornus florida	0.6 ± 0.4	0.2 ± 0.1	0.4
Fraxinus americana	0.3 ± 0.2	0.2 ± 0.2	0.3
Ilex opaca	0.2 ± 0.2	0.1 ± 0.1	0.2
Liquidambar styraciflua	0.3 ± 0.2	0.2 ± 0.1	0.3
Liriodendron tulipifera	3.1 ± 1.4	3.2 ± 1.4	3.2
Magnolia fraseri	0.1 ± 0.1	0.03 ± 0.03	0.1
Nyssa sylvatica	1.1 ± 0.4	0.6 ± 0.2	0.9
Oxydendrum arboreum	6.0 ± 1.4	1.9 ± 0.5	4.0
Pinus echinata	0.3 ± 0.1	0.2 ± 0.2	0.3
P. pungens	0.2 ± 0.2	0.5 ± 0.5	0.4
P. rigida	6.6 ± 1.4	9.6 ± 1.9	8.1
P. strobus	27.0 ± 2.1	37.0 ± 2.0	32.0
P. virginiana	22.0 ± 2.1	22.0 ± 2.1	22.0
Platanus occidentalis	0.3 ± 0.3	0.1 ± 0.1	0.2
Prunus serotina	0.7 ± 0.4	0.4 ± 0.2	0.6
Quercus alba	4.4 ± 1.4	4.0 ± 1.4	4.2
Q. coccinea	0.3 ± 0.2	0.2 ± 0.2	0.3
Q. falcata	0.2 ± 0.2	0.2 ± 0.2	0.2
Q. marilandica	0.1 ±	0.05 ±	0.1
Q. prinus	4.9 ± 1.3	6.8 ± 2.0	5.9
Q. rubra	4.8 ± 0.9	6.0 ± 1.3	5.4
Q. velutina	1.0 ± 0.4	0.8 ± 0.4	0.9
Robinia pseudoacacia	0.3 ± 0.1	0.3 ± 0.2	0.3
Sassafras albidum	0.1 ± 0.1	0.03 ± .03	0.1
Stewartia ovata	0.2 ±	0.04 ±	0.1
Tsuga canadensis	1.9 ± 0.7	0.8 ± 0.4	1.4
Total Density (stems/ha)	1096		
Total Basal Area (m^2/ha)		59.4	

a = MRD ± S.E. = mean relative density ± standard error.

b = MRBA ± S.E. = mean relative basal area ± standard error.

c = MIV = mean relative importance value (MRD + MRBA/2).

Table 2. Sapling and Subsapling Mean Relative Densities and Seedling Taxa Frequency in the White Pine-Virginia Pine Type. N=25.

Taxa	Mean Relative Density Saplings[d]	Mean Relative Density Subsaplings[e]	Frequency Seedlings[f]
Acer pensylvanicum	0.1 ± 0.1	0.01	
A. rubrum	29.0 ± 2.6	1.32	72
A. saccharum	0.3 ± 0.3	0.01	
Amelanchier laevis	0.2 ± 0.1		
Betula lenta	0.1 ± 0.1		
Carya glabra	2.6 ± 0.8	0.01	
C. tomentosa	0.1 ± 0.1	0.01	
Castanea dentata		0.03	
Cornus florida	5.0 ± 1.7	0.28	4
Crataegus sp.	0.1 ± 0.1		
Fagus grandifolia		0.01	8
Fraxinus americana	0.4 ± 0.3		
Hamamelis virginiana		0.04	
Ilex opaca	0.8 ± 0.6	0.04	4
Liquidambar styraciflua		0.02	
Liriodendron tulipifera	0.8 ± 0.5	0.02	16
Magnolia fraseri	0.3 ± 0.3	0.03	
Nyssa sylvatica	5.9 ± 1.4	0.12	
Ostrya virginiana		0.02	
Oxydendrum arboreum	19.0 ± 2.5	0.28	8
Pinus rigida	0.4 ± 0.3		
P. strobus	15.0 ± 3.5	1.04	92
P. virginiana	2.2 ± 1.0	0.02	
Prunus serotina	0.2 ± 0.2	0.01	8
Quercus alba	3.4 ± 1.1	0.02	16
Q. prinus	2.2 ± 0.7	0.04	16
Q. rubra	0.4 ± 0.3		20
Q. velutina	0.6 ± 0.3	0.01	
Q. spp.			20
Robinia pseudoacacia		0.01	
Sassafras albidum	1.0 ± 0.8	0.04	24
Stewartia ovata			8
Tilia heterophylla	0.3 ± 0.3		
Tsuga canadensis	9.9 ± 2.3	0.56	8
Total Density (stems/ha)	944	1985	

d = Saplings 2.5-10 cm (1-4 inches).

e = Subsaplings less than 2.5 cm and one meter tall.

f = Seedlings from two one-meter square plots and under one meter.

Table 3. Frequency of the Shrubs, Vines, and Herbaceous Taxa in the White Pine-Virginia Pine Type. N=25.

Shrub and Vine Taxa[g]	Frequency
Epigaea repens	4
Euonymus obovatus	8
Gaylussacia baccata	60
Kalmia latifolia	36
Mitchella repens	16
Parthenocissus quinquefolia	8
Rhododendron maximum	24
Rhus radicans	8
Rubus spp.	4
Smilax glauca	76
Vaccinium stamineum	4
V. spp.	24
Viburnum acerifolium	4
Herb Taxa[h]	
Allium tricoccum	4
Aster cordifolius	4
Chimaphila maculata	20
Cypripedium acaule	4
Desmodium laevigatum	4
Galax aphylla	24
Gaultheria procumbens	16
Goodyera pubescens	8
Hexastylis arifolia	4
Microstegium vimineum	8
Phlox stolonifera	8
P. spp.	4
Polygonatum biflorum	4
Polystichum acrostichoides	4
Potentilla canadensis	16
Pteridium aquilinum	8
Thalictrum thalictroides	4
Viola spp.	8

g = Shrubs and vines from two one-meter square plots (those over one meter as observed in .0406 hectare plot).

h = Herbs from two one-meter square plots.

O horizon was thick (6 cm) and was comprised predominantly of needles with a few leaves of broadleaved plants. Textures were generally loams and sandy loams in the A horizon. B horizon textures were generally silty clay loams, loams, and clay loams. The residual and colluvial soils of the Wilhite Formation and the Cades Sandstone underlay 80 percent of the plots. The total stone volume ranged from four to 50 percent with a mean of 46 percent in the A and B horizons. The soil was extremely acid (pH of 4.5) with no major difference between horizons. The total available water was intermediate (4.8 cm) among the other types analyzed (Appendix A, Tables 35 and 36).

To gain insight into type stability, the mean relative densities among the various strata were compared. The mean relative densities in Tables 1 and 2 provide information on the reproduction of tree taxa and those which may attain canopy size. The canopy was dominated by white pine, Virginia pine, pitch pine, and red maple; *Oxydendrum arboreum* (sourwood) was a common understory species which occasionally attained overstory size. Overstory basal areas averaged 59.4 m^2/hectare and stem densities averaged 1,096 stems hectare (Table 1).

Sapling (2.5 to 10 cm) species with high mean relative density values were red maple, sourwood, white pine, and *Tsuga canandensis* (hemlock). The total stem density of the understory was 944 stems/hectare. The highest mean relative density values among the subsapling layer were those of red maple, white pine, and hemlock (Table 2).

Included within the herbaceous samples were seedling counts. The highest frequency values were those of white pine, red maple, and *Sassafras albidum* (sassafras). Seedling density was high in all but one plot in which cattle grazing occurred (Table 2). Virginia and pitch

pine reproduction was reduced in the understory and was virtually nonexistent in the sapling or seedling strata. Virginia pine on deep soils is considered to be an old field pioneer or successional species following extensive forest damage (Fowells, 1965). Fowells also noted that Virginia pine is shade intolerant and relatively susceptible to fire damage. It is assumed that the yellow pines will be replaced by the more tolerant species such as red maple, hemlock, and white pine. Hemlock was increasing in importance through the various strata and red maple reproduction was consistent throughout. White pine was maintaining its dominance by strong representation within each stage. Tree taxa which were unique to this type were Quercus marilandica and Stewartia ovata.

The associated tree taxa suggest the successional nature of the type. Included are numerous species which may become codominants with white pine in the future. Based on the above data, it is believed that the white pine-Virginia pine type may be transitional to a white pine-red maple type or a white pine-hemlock type.

The frequency calculations of shrubs and vines and herbaceous vegetation are listed in Table 3. Characteristic shrub taxa were Gaylussacia baccata (huckleberry), Kalmia latifolia (mountain laurel), and Rhododendron maximum (rhododendron). Mountain laurel was generally associated with plots that had fire evidence, and rhododendron occurred predominantly on lower slope sites.

Eighteen herbaceous and fern taxa occurred among the samples (Table 3). Characteristic taxa with a 15 percent or higher frequency were Galax aphylla, Chimaphila maculata, Gaultheria procumbens, and Potentilla canadensis.

The white pine-Virginia pine type occurred on sites of relatively recent disturbance. It is probable that most or all of the plots were influenced by human use prior to the establishment of the Great Smoky Mountains National Park. Half of the plots were probably cultivated in the past. The remainder were probably logged, selectively cut and grazed, periodically burned, or some combination of the three. Chestnut sprouts (3 stems) occurred in a single plot of this type indicating its minimal former presence.

There were two subtypes pooled in this type, one of which was derived as a result of old field invasion and represented a majority of the plots. The old field white pine-Virginia pine plots were situated in the Cades Cove area at low elevations on slopes with slight to moderate angles. With the establishment of the Park, numerous old fields in the Cades Cove area were abandoned and subsequently invaded by white pine and Virginia pine. The greatest age obtained from the old field segment of this type was 35 years.

Upper slopes and ridges were vegetated by a second subtype of the white pine-Virginia pine type. Fire scars were evident in each plot within the subtype, although the plots were widely scattered. The plots were of variable ages with several pronounced groups possibly representing different fire years. The two main fire plot ages were dated approximately 1902 and 1927.

The Society of American Foresters (1954) does not recognize a white pine-Virginia pine type. In the southern Appalachians the S.A.F. white pine type (number 21) may have white pine associated with Virginia pine and shortleaf pine on drier sites.

The white pine-Virginia pine type has not been described

previously in the southern Appalachians although stands in which Virginia pine was a dominant have been observed by other investigators in the Smokies. Cain (1937) attributed the maintenance of Virginia pine dominated stands to periodic fire and indicated that it may be an edaphic climax on dry, exposed sites. Whittaker (1956) stressed the importance of fire in maintaining Virginia pine and thought that, under some conditions, they were self-maintaining. However, in this analysis few of the white pine-Virginia pine plots occurred on extremely xeric sites, and the type is herein considered seral under present conditions. Of course, fire may have been responsible for the original establishment of the stands although there were relatively few indications of recent fire in the plots of this type.

Safley (1970) described a Virginia pine-white pine type in the analysis of the vegetation of the Big South Fork of the Cumberland River. It generally occurred on upper slopes of south facing gorges, and the understory was dominated by red maple and dogwood. There was abundant understory reproduction of all the major taxa. The proximity of the stands to the gorge crest had permitted easy access for logging, and there was evidence of recent (30 years) logging disturbance, suggesting that the type was temporary.

Without fire, apparently red maple, hemlock, and sourwood begin to increase in the understory and can be expected to become more important in the canopy. Except for extremely xeric or fire prone sites, Virginia pine is a temporary species. With the continued importance of white pine, it is possible that the type will develop into white pine, white pine-red maple, or white pine-hemlock types depending upon site conditions.

The White Pine-Red Maple Type

The white pine-red maple type contained 35 of the 43 tree taxa used in this analysis. White pine was the leading dominant, and red maple was the second most important species; the two had a combined mean importance value of 58 percent. Important associated species included tulip poplar, hemlock, northern red oak, and white oak.

Elevations ranged from 335 to 655 meters (1,100 to 2,150 feet). This type occurred on aspects ranging from northwest to northeast. Slopes were moderately steep (averaging 32 percent), and the average daily potential solar radiation was very low (243 Langleys). The low elevation and lower slope position of this type probably resulted in shading from nearby ridges. The combination of aspect, low elevation, and shading contributed to the mesic nature of the white pine-red maple type.

Soil depths ranged from 15 to 91 cm and averaged 49 cm (19 inches). No Ap horizons were observed. The O horizon was one of the thinnest of all the types (five cm) and was primarily composed of leaves of broadleaved plants with low to equal portions of needles. Textures were generally loams and sandy loams or loamy sand in the A horizon. B horizon textures were commonly clay loams and sandy loams. The soils were derived from a variety of bedrock materials. The Wilhite Formation, Cades Sandstone, and Metcalf Phyllite underlay 91 percent of the plots with each type representing approximately one-third. The stone volume ranged from 5 to 70 percent with a mean of 44 percent in the A and B horizons. The soil was very strongly acid (mean pH of 4.6) with no major difference between horizons. The total available water was

intermediate compared with the other types in the study (Appendix A, Tables 35 and 37).

The white pine-red maple type generally had numerous small to intermediate red maples and abundant, large white pine in the canopy. The canopy consisted of several layers that were well-developed, having a 78 percent closure.

The canopy was typically dominated in terms of importance value by white pine and red maple. Other integral components were: tulip poplar, hemlock, northern red oak, and white oak. Sourwood and *Betula lenta* (sweet birch) were common understory species which occasionally reached canopy size (Table 4).

Sapling species with high mean relative densities were red maple, sourwood, dogwood, hemlock, and *Ilex opaca* (American holly) (Table 5). The highest mean relative density values among subsaplings were those of hemlock, dogwood, white pine, and red maple, in order of importance.

Seedling estimates based upon the frequency of occurrence are included in Table 5. The seedlings with the highest frequency values were: red maple, white pine, hemlock, American holly, and *Fagus grandifolia* (American beech). Understory reproduction was inhibited only under dense canopies of rhododendron. Red maple density exhibited a slight decline in the subsapling level but maintained a high level in all other strata. Its density and frequency suggest that it will remain as part of the composition of this type for a long period of time. Red maple has a very wide ecological amplitude in the Smokies (Whittaker, 1956 and Golden, 1974). Although it was found in all of the community types of this analysis, it occurs most commonly as a pioneer on disturbed sites at middle and lower elevations. Tulip poplar was present

Table 4. Overstory Composition of the White Pine-Red Maple Type. N=21.

Taxa	Mean Relative Density[a]	Mean Relative Basal Area[b]	Mean Importance Value[c]
Acer rubrum	26.4 ± 2.5	16.2 ± 1.7	21.3
A. saccharum	0.5 ± 0.3	0.2 ± 0.1	0.4
Amelanchier laevis	0.4 ± 0.3	0.2 ± 0.1	0.3
Betula lenta	2.8 ± 0.9	1.6 ± 0.6	2.2
Carya cordiformis	0.2 ± 0.1	0.1 ± 0.1	0.2
C. glabra	1.0 ± 0.5	0.7 ± 0.4	0.9
C. tomentosa	3.6 ± 1.2	2.4 ± 0.8	3.0
Cornus florida	2.8 ± 0.8	0.7 ± 0.2	1.8
Fagus grandifolia	0.5 ± 0.4	0.2 ± 0.2	0.4
Fraxinus americana	0.2 ± 0.2	0.02 ± 0.02	0.1
Ilex opaca	0.6 ± 0.4	0.1 ± 0.1	0.4
Liquidambar styraciflua	1.1 ± 0.7	0.6 ± 0.5	0.9
Liriodendron tulipifera	5.9 ± 1.6	6.8 ± 1.7	6.4
Magnolia fraseri	1.4 ± 0.7	0.7 ± 0.4	1.1
Nyssa sylvatica	1.6 ± 0.5	0.7 ± 0.2	1.2
Ostrya virginiana	0.2 ±	1.5 ±	0.9
Oxydendrum arboreum	7.4 ± 1.0	2.5 ± 0.6	5.0
Pinus pungens	0.1 ± 0.1	0.1 ± 0.1	0.1
P. rigida	0.9 ± 0.4	0.9 ± 0.4	0.9
P. strobus	24.6 ± 2.3	48.6 ± 3.3	36.6
P. virginiana	2.1 ± 0.7	1.6 ± 0.6	1.9
Prunus serotina	0.4 ± 0.2	0.2 ± 0.1	0.3
Quercus alba	3.4 ± 0.9	3.7 ± 1.0	3.6
Q. falcata	0.2 ± 0.2	0.6 ± 0.5	0.4
Q. prinus	2.4 ± 0.8	1.5 ± 0.5	2.0
Q. rubra	2.7 ± 0.7	4.9 ± 1.5	3.8
Q. velutina	0.9 ± 0.6	0.7 ± 0.4	0.8
Robinia pseudoacacia	0.5 ± 2.6	0.5 ± 0.5	0.5
Sassafras albidum	0.2 ± 0.2	0.2 ± 0.2	0.2
Tilia heterophylla	0.1 ± 0.1	0.1 ± 0.1	0.1
Tsuga canadensis	4.8 ± 1.0	2.8 ± .7	3.8
Ulmus rubra	0.1 ±	0.04 ±	0.1
Total Density (stems/ha)	902		
Total Basal Area (m^2/ha)		61.8	

a = MRD ± S.E. = mean relative density ± standard error.

b = MRBA ± S.E. = mean relative basal area ± standard error.

c = MIV = mean relative importance value (MRD + MRBA/2).

Table 5. Sapling and Subsapling Mean Relative Densities and Seedling Taxa Frequency in the White Pine-Red Maple Type. N=21.

Taxa	Mean Relative Density: Saplings[d]	Mean Relative Density: Subsaplings[e]	Frequency: Seedlings[f]
Acer pensylvanicum	0.6 ± 0.4	0.095	
A. rubrum	25.0 ± 3.7	0.524	52
A. saccharum	0.9 ± 0.6	0.095	
Amelanchier laevis	0.1 ± 0.1		
Betula lenta	1.9 ± 1.3	0.095	5
Carpinus caroliniana	1.6 ± 1.1		
Carya cordiformis	0.2 ± 0.2		
C. glabra	0.9 ± 0.5	0.095	5
C. tomentosa	1.5 ± 0.7	0.095	
Castanea dentata		0.019	
Cornus florida	14.0 ± 3.2	0.857	5
Fagus grandifolia		0.190	10
Ilex opaca	9.8 ± 3.9	0.238	14
Liquidambar styraciflua	0.6 ± 0.6	0.048	
Liriodendron tulipifera	0.7 ± 0.6	0.019	5
Magnifolia fraseri	1.8 ± 0.8		
Nyssa sylvatica	3.9 ± 1.0	0.190	5
Ostrya virginiana		0.048	5
Oxydendrum arboreum	15.0 ± 2.3	0.476	5
Pinus strobus	6.5 ± 1.7	0.571	48
P. virginiana	0.2 ± 0.2		
Quercus alba	0.4 ± 0.3	0.048	5
Q. prinus	1.2 ± 0.8		5
Q. rubra	0.1 ± 0.1	0.019	
Q. velutina	0.3 ± 0.2		
Q. spp.			10
Sassafras albidum	0.5 ± 0.3		5
Tsuga canadensis	13.0 ± 2.9	1.100	19
Ulmus rubra	0.6 ± 0.6		
Total Density (stems/ha)	730	1373	

d = Saplings 2.5-10 cm (1-4 inches).

e = Subsaplings less than 2.5 cm and one meter tall.

f = Seedlings from two one-meter square plots and under one meter.

in the canopy as large scattered individuals, but its density was low in all other strata. However, it is a long-lived species, and it may persist in the canopy as a minor associate. Northern red oak and white oak were present in the canopy as intermediate-sized individuals, but these too were not reproducing successfully. Hemlock importance varied in the various stages. White pine was well represented in the seedling and subsapling size classes. Tree taxa which were unique to this type were *Carpinus caroliniana* and *Ulmus rubra*. The diversity of taxa in the type reflects its successional character; present are potential replacement species that may assume dominance in future years. The author believes that the white pine-red maple type had a disturbance history (predominantly old field) similar to that of the white pine-Virginia pine type. The vegetational differences may be attributed to a longer period of establishment (70 years) based upon the tree core analysis, as well as more mesic site conditions. With time, red maple and hemlock may continue to increase in importance, and white pine will probably survive as a long-lived species enduring into the replacement type.

Table 6 includes the percent frequency of the shrub and vine, and herbaceous taxa taken from subplots within each plot. The rhododendron canopy had a pronounced effect on reproductive success of all but the most shade-tolerant species. *Gaylussacia baccata* occurred most frequently with mountain laurel but both were absent under full rhododendron coverage. *Smilax glauca* (greenbriar) had the highest vine frequency.

The diversity of the herbaceous and fern taxa was highest in the white pine-red maple type (Table 6); this may be attributed to the mesic

Table 6. Frequency of the Shrubs, Vines, and Herbaceous Taxa in the White Pine-Red Maple Type. N=21.

Shrub and Vine Taxa[g]	Frequency
Euonymus americanus	5
E. obovatus	10
Gaylassacia baccata	43
Kalmia latifolia	33
Leucothoe editorum	19
Mitchella repens	19
Parthenocissus quinquefolia	19
Rhododendron maximum	71
Smilax glauca	29
Vaccinium spp.	5
Vitis rotundifolia	14
Herb Taxa[h]	
Agrimonia rostellata	5
Amphicarpa bracteata	10
Arundinaria gigantea	5
Asplenium platyneuron	5
Aster cordifolia	5
Carex complanata	5
Chimaphila maculata	5
Cypripedium acaule	5
Dennstaedtia punctibula	5
Desmodium laevigatum	24
Dioscorea spp.	5
Galax aphylla	33
Galium circaezans	14
Gaultheria procumbens	10
Goodyera pubescens	5
Heuchera villosa	5
Hexastylis arifolia	19
Luzula echinata	5
Panicum microcarpum	5
P. spp.	10
Phlox stolonifera	5
Polystichum acrostichoides	24
Potentilla canadensis	10
Sedum ternatum	5
Thelypteris noveboracensis	10
Tradescanthia virginiana	5

Table 6. (Continued)

Herb Taxa	Frequency
Trillium spp.	5
Unknown #1	10
Unknown #2	5
Unknown #3	5
Viola spp.	19

g = Shrubs and vines from two one-meter square plots (those over one meter as observed in .0406 hectare plot).

h = Herbs from two one-meter square plots.

nature of the type. Taxa with a 10 percent or higher frequency were *Galax aphylla*, *Desmodium laevigatum*, *Polystichum acrostichoides*, *Asarum arifolium*, *Viola* spp., and *Galium circaezans*.

The white pine-red maple type occurred on disturbed sites in several sections of the Park. Many of the plots occurred near old roadways or major trails where logging, grazing, and burning evidence was noted. The type was widely scattered in the Cades Cove area but occurred predominantly on marginal old field sites on lower slope positions. Historical evidence supports the settlement of the upland sites and their subsequent release when their marginal benefits were extinguished (Shields, 1977). The ages of the tree cores obtained from this type support the concept that the white pine-red maple type was released prior to the previously mentioned white pine-Virginia pine type.

The Cane Creek area had a small settlement on fairly level terrain which was cleared and probably clear cut in more remote sections. The Calderwood area had several kinds of disturbance. Some portions were once settled and were released approximately 80 years ago. A railroad extended up Panther Branch for hauling slate, and portions of the area were clear cut. This area also had some fire evidence, possibly resulting from slash fires or, more recently, from arson by displaced citizenry who formerly lived in the area. The oldest tree cores obtained from this section were 60 years old.

The final section of the white pine-red maple type occurred along Laurel Creek Road which was once a part of the Little River Railroad. The Little River Lumber Company logged up Laurel Creek to Crib Gap, just above Cades Cove (personal communication: A. R. Shields, 1978; personal communication: W. McCracken, 1978). The oldest white

pine cores available for this section ranged from 45 to 60 years, which may be the span of time over which cutting took place. Chestnut sprouts (one stem) occurred in only one plot, indicating a minimal former presence.

The Society of American Foresters (1954) does not recognize a white pine-red maple type. Red maple occurs as an associate species with white pine in the following S.A.F. types: white pine-northern red oak-white ash (number 20), white pine (number 21), white pine-hemlock (number 22), and white pine-chestnut oak (number 51).

Canopy composition resembled that of the previously discussed white pine-Virginia pine type in having some of the same leading taxa, but it was distinguished by the presence of such mesophytes as Ostrya virginica, Tilia heterophylla, and Ulmus rubra. Tulip poplar was the major associate of the white pine-red maple type. There were stands dominated by tulip poplar in the Smokies which Cain (1937, 1943), Braun (1950), and Whittaker (1956) described as successional predominantly on old fields. Red maple was strongly associated with each white pine type in this analysis.

Red maple is very susceptible to fire injury; however, fire-killed trees are capable of vigorous sprouting, thus increasing beyond their original importance in the stand (Fowells, 1965). It is possible that the cultivation and logging history plus the phenomena of fire could have been responsible for the importance of red maple in the composition of this type. The lack of reproduction in most of the canopy species except for white pine, red maple, and hemlock suggests this community may ultimately develop into one dominated by hemlock, similar in composition to the white pine-hemlock community type.

The White Pine-Hemlock Type

The white pine-hemlock type was characterized by 17 tree taxa. White pine was the leading canopy dominant and hemlock was also an important dominant. Associated species included Virginia pine, red maple, and sourwood which may achieve an importance value of 10 percent or greater (Table 7).

The elevational range of this type was 450 to 533 meters (1,475 to 1,750 feet). Plots dominated by white pine and hemlock occurred on northwesterly and northeasterly aspects predominantly on lower to middle slope positions and on protected ridges and flat slopes. One plot had a southwestern exposure but occurred in a steep, shaded ravine. Slopes were moderately steep (averaging 34 percent) and the average daily potential solar radiation was fairly high (250 Langleys).

Soils were shallow and ranged from 15 to 64 cm and had an average thickness of 33 cm (13 inches). The A and B horizons were the thinnest encountered in the analysis. The organic horizon was moderate in thickness and was composed of mixed broad leaves and needles. Textures were generally sandy loams in the A horizon, and both silty clay loams and sandy loams in the B horizon. The Wilhite Formation was the predominant bedrock type in 80 percent of the plots. The stone volume ranged from 5 to 59 percent with a mean of 73 percent in the A and B horizons. Stone volumes averaged the highest for any type in the study. The soil pH was extremely acid; it averaged 4.4 in both horizons. As a result of the stone volume and the shallow profile, the total available water was very low, only 2.3 cm (Appendix A, Tables 35 and 38).

The white pine-hemlock type was typically composed of tall white pine and small to intermediate sized associated overstory trees with a

Table 7. Overstory Composition of the White Pine-Hemlock Type. N=5.

Taxa	Mean Relative Density[a]	Mean Relative Basal Area[b]	Mean Importance Value[c]
Acer rubrum	8.8 ± 2.4	4.1 ± 1.2	6.5
Amelanchier laevis	0.5 ± 0.5	0.1 ± 0.1	0.3
Betula lenta	3.2 ± 2.1	0.9 ± 0.6	2.1
Carya tomentosa	2.3 ± 2.3	2.4 ± 2.4	2.4
Cornus florida	1.9 ± 1.4	0.5 ± 0.3	1.2
Fagus grandifolia	0.7 ± 0.7	0.1 ± 0.1	0.4
Liriodendron tulipifera	2.5 ± 1.1	1.5 ± 0.9	2.0
Nyssa sylvatica	3.0 ± 1.5	1.6 ± 1.0	2.3
Oxydendrum arboreum	6.1 ± 2.0	2.1 ± 0.6	4.1
Pinus strobus	23.0 ± 5.3	58.0 ± 5.1	41.0
P. virginiana	6.4 ± 4.0	6.7 ± 3.8	6.6
Quercus alba	1.3 ± 0.9	2.3 ± 1.9	1.8
Q. rubra	1.4 ± 0.9	0.9 ± 0.6	1.2
Sassafras albidum	0.5 ± 0.5	0.4 ± 0.4	0.5
Tsuga canadensis	38.0 ± 4.5	18.0 ± 2.8	28.0
Total Density (stems/ha)	968		
Total Basal Area (m^2/ha)		55.7	

a = MRD ± S.E. = mean relative density ± standard error.

b = MRBA ± S.E. = mean relative basal area ± standard error.

c = MIV = mean relative importance value (MRD + MRBA/2).

closed canopy. The shrub layer was poorly developed, and the herbaceous diversity was the lowest of any type. The overstory was typically dominated by white pine and hemlock, but white pine was consistently larger. Associated species were generally intermediate in stature. The sapling species with high mean relative densities were hemlock, sourwood, red maple, and white pine. The understory was composed almost entirely of saplings of the canopy taxa except for Virginia pine. The highest mean relative densities among the subsaplings were for the following species: hemlock, *Ilex opaca* (American holly), and red maple (Table 8). The seedlings with the highest frequency values were: red maple, *Prunus serotina* (black cherry), sassafras, American holly, and hemlock (Table 8). The seedling stratum contained a few small taxa which were not inhibited by the dense shade produced by the canopy taxa, notably hemlock. None of the overstory taxa, with the exception of hemlock, occurred as seedlings.

White pine occurred in the canopy and sapling layers but was not in the subsapling or seedling strata. The shade undoubtedly inhibited white pine establishment. Hemlock was predominant in every strata although the seedling frequency was low. Red maple was well represented in all of the reproductive stages due to vigorous sprouting and frequent seed production (Fowells, 1965). The size class distribution of currently important taxa shows the stable pattern of hemlock and supports the predication of its continued and increased dominance, along with white pine. The type may further progress toward the eventual dominance of hemlock with a few long-lived white pine as associates. The lack of diversity in the taxa of the white pine-hemlock type may be attributed to the small sample size (five plots) representing the type.

Table 8. Sapling and Subsapling Mean Relative Densities and Seedling Taxa Frequency in the White Pine-Hemlock Type. N=5.

Taxa	Mean Relative Density		Frequency
	Saplings[d]	Subsaplings[e]	Seedlings[f]
Acer rubrum	11.0 ± 4.1	1.0	60
Betula lenta	2.1 ± 1.7		
Cornus florida	6.2 ± 2.3	0.4	
Ilex opaca	6.0 ± 4.2	2.2	20
Magnolia fraseri	3.8 ± 1.4	0.2	
Oxydendrum arboreum	13.0 ± 4.2	0.8	
Pinus strobus	7.7 ± 7.7		
Prunus serotina			20
Quercus alba	1.6 ± 0.9		
Sassafras albidum			20
Tsuga canadensis	49.0 ± 14.0	15.4	20
Total Density (stems/ha)	944	1961	

d = Saplings 2.5-10 cm (1-4 inches).

e = Subsaplings less than 2.5 cm and one meter tall.

f = Seedlings from two one-meter square plots and under one meter.

Shrub frequencies were low, and only two species occurred in the type. The frequency of shrubs and vines and herbs are listed in Table 9. *Rhododendron maximum* and *Gaylussacia baccata* each occurred in only one plot. *Rhododendron* was prominent on low slopes, and *Gaylussacia baccata* occurred on a drier upland slope. The vines *Smilax glauca* and *Mitchella repens* had a frequency of 60 percent. Braun (1950) noted that *Mitchella repens* was a common species occurring with hemlock and was indicative of her hemlock-mixed mesophytic community. Under the canopy of white pine and hemlock, herb growth was totally absent in certain places.

The white pine-hemlock type occurred on sites that had been selectively logged or clear cut and pastured, and also on sites that were relatively undisturbed except for periodic ground fires. The Cades Cove area contained one plot which had been subjected to logging and grazing. Another plot occurred along Rabbit Creek Road where there may have been small tract logging. Three plots occurred along Abrams Creek on low and middle slope sites and represented various types of disturbances. One plot occurred upslope from a broad and level oxbow which had once been settled and cleared, according to a local resident (personal communication: Grady Whitehead, 1978). It is conceivable that selective cutting or small tract logging took place on the slope above the clearing. The other two plots along Abram's Creek were on fairly steep (50 percent) middle slope positions in a remote section three to four miles downstream from Abrams Falls. The disturbance history of these plots was unclear, but fire scars were found on large white pines in one plot. There were also several large Virginia pines that occurred in these plots. Possibly fire opened these sites, permitting the

Table 9. Frequency of the Shrubs, Vines, and Herbaceous Taxa in the White Pine-Hemlock Type. N=5.

Shrub and Vine Taxa[g]	Frequency
Gaylussacia baccata	20
Mitchella repens	60
Rhododendron maximum	20
Smilax glauca	60
Herb Taxa[h]	
Chimaphila maculata	20
Dennstaedtia punctilobula	20
Galax aphylla	40
Goodyera pubescens	20
Polystichum acrostichoides	20

g = Shrubs and vines from two one-meter square plots (those over one meter as observed in .0406 hectare plot).

h = Herbs from two one-meter square plots.

invasion of Virginia pine. No chestnut sprouts were found in any of the white pine-hemlock plots.

Type 22 of the Society of American Foresters (1954) is white pine-hemlock. It is considered a northern forest type that is relatively rare in the mountains of Tennessee and North Carolina. Hemlock is most productive in a climate which is humid and cool, and in the southern Appalachians it occurs on the cooler locations such as ravines, shaded aspects, and north facing slopes (Fowells, 1965).

The S.A.F. described a hemlock type (number 23) which also occurs in the southern Appalachians and has white pine as an associated species. Fowells (1965) cited hemlock as occurring with white pine in disturbed stands and exhibiting some characteristics of pioneer species. However, hemlock is usually categorized as a climax species because of its shade tolerance and strong development under established stands. Hemlock is capable of self-perpetuation under dense canopies if suitable seedbed conditions are available. Hemlock can withstand long-term suppression, but it is vulnerable to fire damage and is incapable of sprouting (Fowells, 1965).

Braun (1950) considered the white pine-hemlock type as an association-segregate of the mixed mesophytic. She also noted that white pine had a wide habitat distribution in the southern Appalachians and considered any stand dominated by it as secondary. Whittaker's (1956) eastern hemlock type did not contain white pine. Barclay (1957) described a hemlock-white pine type which was synonymous to the S.A.F. white pine-hemlock type. The area Barclay described was a minor forest component of Johnson County, which ultimately suffered commercial exploitation. Sherman (1958) studied five gorges on the Cumberland

Plateau. Little Piney Gorge was the only one in which white pine occurred as a codominant in combination with hemlock. Hinkle (1978) described a white pine-hemlock type on the Cumberland Plateau in Pickett County, Tennessee. He hypothesized that hemlock would increase in importance due to its greater shade tolerance.

Thomas (1966) described a hemlock-white pine type on Chilhowee Mountain which was restricted to deep ravines and moist coves. The hemlock-white pine type had the largest number of vascular plants of any type sampled on Chilhowee Mountain. Numerous herbaceous plots were taken within the type, which would partially account for the increased number of species compared to the white pine-hemlock type in this analysis. The hemlock-white pine canopy contained 28 tree taxa compared to 15 from the white pine-hemlock type in this analysis, and the two types had an overstory presence Jaccard Similarity Index value of 39 percent.

The sample plots previously described represent disturbed remnants of one or more unknown community types. The cumulative disturbance evidence leads the author to believe that white pine-hemlock is a successional type. The successional trend of this type is well documented in the literature. The continued strong reproduction of hemlock will insure its dominance with white pine as a long-lived associated species.

<u>The White Pine-Chestnut Oak Type</u>

The white pine-chestnut oak type occurred predominantly on steep upper slopes and ridge tops on a variety of aspects. There were 22 tree taxa in this type; white pine was the major canopy dominant and chestnut oak was an important dominant. Their combined mean importance value was

57 percent. Associated species which occasionally attained an importance value of 10 percent or greater were red maple and sourwood.

The elevational range for this type was 343 to 686 meters (1,125 to 2,250 feet). This community occurred along a wide range of aspects but occurred predominantly on southeasterly aspects. The mean slope angle was 38 percent which was the steepest slope encountered on any type. Although the slopes were relatively open, the average daily potential solar radiation was very low at 237 Langleys.

The soils were of moderate average depth (48 cm or 19 inches) but varied from 10 to 91 cm. The organic layer was thin (four cm), and was composed of an equal mixture of broad and needle leaves. Textures were generally sandy loams but a few clay loams occurred. No Ap layers were observed. A broad range of textures comprised the B horizon. Stone volumes in the A and B horizons averaged 47 percent. The total available water was quite high (5.4 cm). The soil pH was extremely acid; pH values of 4.5 and 4.4 occurred in the A and B horizons, respectively. Cades Sandstone, Wilhite formation, and Metcalf Phyllite underlay the white pine-chestnut oak type (Appendix A, Tables 35 and 39).

The white pine-chestnut oak type consisted of tall white pines and medium to tall chestnut oaks with broad canopies. The associated species were generally small trees that, in combination with the overstory, produced 75 percent canopy closure. Other layers were moderately well developed.

In several plots chestnut oak actually occurred as the dominant species. Integral components of the canopy were red maple and sourwood. Sapling, subsapling, and seedling components of the understory contain significant members of the canopy group of taxa.

Type stability, suggested from the mean relative densities of Tables 10 and 11, shows the consistence of white pine which ranked high in relative density in all strata. Red maple was consistent in all strata, indeed abundant in the sapling, subsapling, and seedling classes. Sourwood, dogwood, and hemlock were sporadic in various strata. Woods and Shanks (1959) found that following the demise of *Castenea dentata* (chestnut), red maple ranked third after chestnut oak and white pine in abundance as a replacement species. Virginia pine and pitch pine here had a minimal presence and occurred in only a few plots. The mean canopy closure percentage was great in this type, and chestnut oak reproduction was low in the sapling and seedling strata. Fowells (1965) considered chestnut oak as intermediate in shade tolerance; thus reproduction under the canopy may die back but is capable of resprouting until released in a new canopy opening. These facts suggest that the white pine-chestnut oak type may be stable and relatively self-maintaining. It may retain a red maple component.

The shrub stratum was often two-layered, with an upper one of small stands of *Rhododendron* and *Kalmia* and a dense lower stratum of *Gaylussacia* and *Vaccinium*. These often occurred with *Smilax* (Table 12). *Galax* and *Chimaphila* occurred in Golden's (1974) chestnut oak type herbaceous layer. The low diversity here is believed to be due to the small and disturbed nature of the samples.

The white pine-chestnut oak type occurred on sites that had been selectively logged or clear cut and then pastured. Partly because of the varying intensities of past disturbance, the plots themselves were varied in composition. Canopy closure varied from 63 percent on south-facing upper and middle slopes to 72 percent on north-facing lower

Table 10. Overstory Composition of the White Pine-Chestnut Oak Type. N=9.

Taxa	Mean Relative Density[a]	Mean Relative Basal Area[b]	Mean Importance Value[c]
A. pensylvanicum	0.3 ±	0.1 ±	0.2
Acer rubrum	18.0 ± 2.1	13.0 ± 2.7	16.0
Carya glabra	2.6 ± 1.5	2.8 ± 2.1	2.7
C. tomentosa	0.4 ± 0.4	0.2 ± 0.2	0.3
Cornus florida	1.5 ± 1.0	0.3 ± 0.2	0.9
Fraxinus americana	0.6 ± 0.6	0.4 ± 0.4	0.5
Liriodendron tulipifera	0.8 ± 0.8	1.2 ± 1.2	1.0
Nyssa sylvatica	5.2 ± 2.4	2.4 ± 1.0	3.8
Oxydendrum arboreum	13.0 ± 2.2	4.5 ± 1.0	8.8
Pinus rigida	0.8 ± 0.8	0.3 ± 0.3	0.6
P. strobus	27.0 ± 4.6	38.0 ± 4.7	33.0
P. virginiana	0.4 ± 0.4	0.4 ± 0.4	0.4
Quercus alba	1.0 ± 0.4	1.6 ± 0.8	1.3
Q. coccinea	1.0 ± 0.5	1.6 ± 0.8	1.3
Q. prinus	19.0 ± 2.5	29.0 ± 6.1	24.0
Q. rubra	1.7 ± 0.8	1.7 ± 1.0	1.7
Q. velutina	0.4 ± 0.4	0.9 ± 0.9	0.7
Robinia pseudoacacia	0.2 ± 0.2	0.4 ± 0.4	0.3
Sassafras albidum	0.6 ± 0.4	0.2 ± 0.1	0.4
Tsuga canadensis	6.0 ± 3.3	1.9 ± 1.1	4.0
Total Density (stems/ha)	1048		
Total Basal Area (m^2/ha)		56.7	

a = MRD ± S.E. = mean relative density ± standard error.

b = MRBA ± S.E. = mean relative basal area ± standard error.

c = MIV = mean relative importance value (MRD + MRBA/2).

Table 11. Sapling and Subsapling Mean Relative Densities and Seedling Taxa Frequency in the White Pine-Chestnut Oak Type. N=9.

Taxa	Mean Relative Density Saplings[d]	Mean Relative Density Subsaplings[e]	Frequency Seedlings[f]
Acer pensylvanicum	1.0 ± 0.6	0.222	
A. rubrum	25.0 ± 5.7	2.220	66
A. saccharum	4.4 ± 0.5		
Carya glabra	0.9 ± 0.7	0.333	
C. tomentosa	1.2 ± 1.2		
C. spp.			11
Cornus florida	11.0 ± 3.5	1.550	11
Fraxinus americana	0.5 ± 0.5		
Hamamelis virginiana	1.5 ± 1.5		
Ilex opaca		0.333	11
Liriodendron tulipifera			22
Magnolia fraseri	0.6 ± 0.6	0.222	11
Nyssa sylvatica	5.0 ± 2.3	0.555	
Oxydendrum arboreum	14.0 ± 2.6	2.110	22
Pinus strobus	14.0 ± 5.1	1.660	55
P. virginiana			11
Quercus alba	1.0 ± 0.9		
Q. prinus	3.9 ± 2.0	0.333	44
Sassafras albidum	2.6 ± 1.5	0.333	
Tsuga canadensis	17.0 ± 7.8	1.440	
Total Density (stems/ha)	661	1613	

d = Saplings 2.5-10 cm (1-4 inches).

e = Subsaplings less than 2.5 cm and one meter tall.

f = Seedlings from two one-meter square plots and under one meter.

Table 12. Frequency of the Shrubs, Vines, and Herbaceous Taxa in the White Pine-Chestnut Oak Type. N=9.

Shrub and Vine Taxa[g]	Frequency
Gaylussacia baccata	77
Kalmia latifolia	22
Mitchella repens	11
Parthenocissus quinquefolia	11
Pyrularia pubera	11
Rhododendron maximum	33
Rhus radicans	11
Smilax glauca	33
Vaccinium stamineum	11
V. spp.	33
Vitis rotundifolia	11
Herb Taxa[h]	
Amphicarpa bracteata	11
Chimaphila maculata	11
Galax aphylla	33
Hexastylis arifolia	44
Panicum spp.	11
Polystichum acrostichoides	11
Smilacina racemosa	11
Uvularia pudica	11

g = Shrubs and vines from two one-meter square plots (those over one meter as observed in .0406 hectare plot).

h = Herbs from two one-meter square plots.

slopes. Six of the nine plots occurred in the Cades Cove area and were relatively remote from the present-day cleared portions of the Cove. The plot closest to the Cove was along the Pine-Oak Nature Trail which loops through a former farm woodlot. The white pine persists there because the original owner, Uncle Andy Shields, refused to have his big trees cut. The other plots occurred on sites that may have been logged and possibly pastured. Most of the Cades Cove area plots occurred on relatively high slope positions (from upper middle to upper slopes) but seldom occurred along ridge crests.

Three plots occurred in the Calderwood area. There was a plot along Tabcat Creek adjacent to a large flat area dominated by old field Virginia pine. It is conceivable that this site was selectively logged and then pastured. The oldest white pine tree cored was 88 years old. Two plots were taken along Abrams Creek. One was upslope from the ox-bow settlement described in the preceding type. Both plots were situated below major ridge crests, and the occurrence of tip-up mounds suggests that blowdowns occurred in addition to selective cutting which had perturbed the sites. No evidence of chestnut was seen in any plot of this type.

The Society of American Foresters (1954) recognized a white pine-chestnut oak type (number 51) that dominates considerable areas in the southern Appalachians. The other S.A.F. type that contains chestnut oak as a dominant was the chestnut oak type (number 44); this was also seen by Golden (1974) in the Smokies. No white pine occurred in Golden's samples. Woods and Shanks (1959) hypothesized that the white pine-chestnut oak community was probably a part of the oak-chestnut community which was common prior to the chestnut blight; however, no evidence

of chestnut was discovered in the plots comprising this type.

Whittaker (1956) described two types with chestnut oak as a dominant: chestnut oak-chestnut and chestnut oak-heath. Many of the large chestnuts were alive or standing dead at the time of Whittaker's field samplings. The chestnut oak-heath is probably equivalent to Golden's chestnut oak type. Braun (1950) also described the chestnut oak-chestnut community in the Smokies and in the southern Appalachians. Braun suggested that chestnut oak would be favored as a replacement, so it seems to be reasonable that this community type could have originated through the decreased importance of chestnut logging or after the blight. Contrary to this is the absence of chestnut evidence found here, and found by Hinkle in the chestnut oak type in the Cumberland Gap National Historic Park (Hinkle, 1974).

Schmalzer (1978) described a white pine-chestnut oak type which occurred on the Cumberland Plateau in Little Piney Gorge and along the Obed River. White pine and chestnut oak had equal importance values, and hemlock, red maple, and tulip poplar were important canopy associates. Soil textures were silt loams, loams, and sandy loams and the soil was extremely acid (pH of 4.4). Chestnut sprouts occurred in one-fourth of the plots and fire evidence was also found in a quarter of the type. Schmalzer considered the type to be stable, based upon the successful reproduction of the canopy components.

This vegetation type appeared to be stable as evidenced by the relatively successful reproduction of white pine and the persistence of chestnut oak. The Society of American Foresters (1954) contended that the successional nature of this type was not known. It appears that this type, barring major disturbance, will develop into a mature climax

forest with a similar composition to the present one, except that the shortleaf and pitch pines will ultimately be eliminated.

The White Pine-White Oak Type

The white pine-white oak type contained 32 of the 43 tree taxa represented in this study. White pine and white oak had a combined mean importance value of 63 percent. Red maple, northern red oak, and Virginia pine were also important. Plot elevation ranged from 312 to 663 meters (1,025 to 2,175 feet), and stands occurred on all aspects. The white pine-white oak type had the highest average daily potential solar radiation (258 Langleys); slopes averaged only 25 percent.

Soil depths ranged from 38 to 91 cm and averaged 63 cm (25 inches). The B horizon had the greatest average thickness of any type sampled at 44 cm. An Ap horizon was noted in a single plot where a settlement had occurred along Rich Mountain Road. The O horizon was moderately thick and was composed of varying proportions of broad and needle leaves. Textures were generally sandy loams and loams in the A horizon; B horizon textures were silty clay loams, loams, and sandy loams. The residual and colluvial deposits of the Cades Sandstone and Wilhite Formation underlay 79 percent of the plots within this type. Stone volumes in the A and B horizons ranged from 4 to 68 percent and averaged 38 percent which was the lowest mean value of any of the community types in this analysis (Appendix A, Tables 35 and 40).

The soil pH was strongly acid with pH values of 4.7 and 4.6 in the A and B horizons respectively. Due to both deep and "low" stone volume soils, the total available water was the highest of any type in this analysis (6.1 cm).

The white pine-white oak type overstory had moderate to large sized trees with a relatively open canopy (73 percent closure). The understory was well developed, the shrub layer was well stocked, and there was an intermediate level diversity of herbaceous taxa.

The canopy was typically dominated by white pine and white oak; red maple and northern red oak were conspicuous components. Virginia pine and sourwood were common species in the lower portion of the canopy (Table 13). Most taxa of the overstory were well represented in the sapling, subsapling and seedling layers; red maple was especially well represented in the sapling layer. Hemlock was also better represented as a sapling than as an overstory component.

White pine, red maple, American holly, northern red oak, and white oak had the highest seedling frequencies (Table 14). Understory reproduction was progressing in all plots. White pine reproduction was significant in all size categories, characteristically occurring as one of the three species with the highest relative densities in each stratum. Red maple was consistently reproducing and appeared to be a potentially strong codominant with white pine and white oak. Halesia carolina (silverbell) is characteristic of mesic cove hardwood communities and was a minor component of the white pine-white oak type.

White oak seedling production was relatively low and mortality was moderate, yet the small number of individuals was well distributed through the various size classes. White oak is considered as intermediate in shade tolerance (Fowells, 1965). Its ability to survive as a shade tree, its quick response to release, and its longevity combine to make it a stable component on favorable sites. White oak has optimum growing conditions in the southern Appalachians, and it grows

Table 13. Overstory Composition of the White Pine-White Oak Type. N=29.

Taxa	Mean Relative Density[a]	Mean Relative Basal Area[b]	Mean Importance Value[c]
Acer rubrum	10.2 ± 1.2	4.5 ± 0.8	7.4
Betula lenta	0.3 ± 0.2	0.1 ± 0.1	0.2
Carya cordiformis	0.2 ± 0.1	0.1 ± 0.1	0.2
C. glabra	1.6 ± 0.6	0.8 ± 0.4	1.2
C. tomentosa	1.7 ± 0.6	1.7 ± 0.7	1.7
Cornus florida	0.8 ± 0.5	0.2 ± 0.1	0.5
Halesia carolina	0.1 ±	0.02 ±	0.1
Liquidambar styraciflua	0.1 ± 0.1	0.03 ± 0.03	0.1
Liriodendron tulipifera	1.5 ± 0.6	1.6 ± 0.6	1.6
Magnolia fraseri	0.1 ± 0.1	0.02 ± 0.02	0.1
Nyssa sylvatica	1.6 ± 0.4	0.8 ± 0.2	1.2
Oxydendrum arboreum	6.6 ± 1.1	2.2 ± 0.4	4.4
Pinus echinata	0.2 ± 0.1	0.4 ± 0.3	0.3
P. pungens	0.3 ± 0.2	1.0 ± 0.7	0.7
P. rigida	2.2 ± 0.7	2.6 ± 0.8	2.4
P. strobus	39.0 ± 2.0	49.0 ± 2.2	44.0
P. virginiana	5.4 ± 1.0	4.1 ± 0.8	4.8
Platanus occidentalis	0.2 ± 0.2	0.2 ± 0.2	0.2
Quercus alba	16.6 ± 1.8	20.3 ± 2.0	19.0
Q. coccinea	0.4 ± 0.4	0.4 ± 0.4	0.4
Q. falcata	0.3 ± 0.2	0.5 ± 0.3	0.4
Q. prinus	1.4 ± 0.6	0.9 ± 0.4	1.2
Q. rubra	5.1 ± 0.8	6.4 ± 1.0	5.8
Q. velutina	0.7 ± 0.3	0.4 ± 0.3	0.6
Robinia pseudoacacia	0.1 ± 0.1	0.1 ± 0.1	0.1
Tsuga canadensis	3.2 ± 1.1	1.8 ± 0.9	2.5
Total Density (stems/ha)	963		
Total Basal Area (m^2/ha)		64.3	

a = MRD ± S.E. = mean relative density ± standard error.

b = MRBA ± S.E. = mean relative basal area ± standard error.

c = MIV = mean relative importance value (MRD + MRBA/2).

Table 14. Sapling and Subsapling Mean Relative Densities and Seedling Taxa Frequency in the White Pine-White Oak Type. N=29.

Taxa	Mean Relative Density Saplings[d]	Mean Relative Density Subsaplings[e]	Frequency Seedlings[f]
Acer pensylvanicum	0.2 ± 0.1		
A. rubrum	29.0 ± 3.1	1.480	67
A. saccharum	0.3 ± 0.3		
Betula lenta	0.2 ± 0.2		
Carya cordiformis	0.1 ± 0.1		
C. glabra	1.9 ± 0.7	0.021	
C. tomentosa	0.8 ± 0.3		
Castanea dentata		0.021	4
Cornus florida	8.5 ± 2.0	0.138	4
Fagus grandifolia	0.3 ± 0.3	0.034	7
Halesia carolina	0.1 ± 0.1	0.021	
Ilex opaca	0.6 ± 0.4	0.069	25
Liquidambar styraciflua	0.1 ± 0.1		
Liriodendron tulipifera	0.1 ± 0.1	0.021	11
Magnolia fraseri	0.7 ± 0.3		11
Nyssa sylvatica	9.4 ± 2.3	0.379	7
Oxydendrum arboreum	18.0 ± 3.7	0.379	11
Pinus pungens	0.1 ± 0.1		
P. rigida	0.1 ± 0.1		
P. strobus	12.0 ± 2.5	0.517	7
P. virginiana	0.4 ± 0.2		
Quercus alba	3.8 ± 1.5	0.069	14
Q. prinus	0.7 ± 0.3	0.069	4
Q. rubra	0.5 ± 0.3	0.034	18
Q. velutina	0.5 ± 0.2		
Q. spp.			14
Sassafras albidum	0.2 ± 0.2	0.138	
Tsuga canadensis	12.0 ± 2.4	0.103	
Total Density (stems/ha)	832	755	

d = Saplings 2.5-10 cm (1-4 inches).

e = Subsaplings less than 2.5 cm and one meter tall.

f = Seedlings from two one-meter square plots and under one meter.

particularly well on northerly and easterly lower slopes and in coves. Fowells (1965) further reported that white oak develops best on deep, well-drained, loamy soils which were characteristic of the white pine-white oak type. White oak acorn crops are irregular and the dispersal range is limited; however, seedling sprouts have accounted for much of the second growth white oak following cutting or fire (Fowells, 1965). White oak replacement seems sufficient to insure continued dominance in this type. Since the important overstory species were reproducing, this community type is probably a time-stable one.

Gaylussacia baccata had the highest frequency of occurrence and generally covered extensive areas in most plots (Table 15). It had a patchy distribution when associated with dense stands of Rhododendron maximum and Kalmia latifolia. Smilax glauca, Euonymus obovatus, and Mitchella repens also commonly occurred within the type. Twelve herbaceous and fern taxa occurred in the ground stratum (Table 15). Taxa with a frequency of 10 percent or higher were Galax aphylla, Gaultheria procumbens, Chimaphila maculata, Aster cordifolius, and Polystichum acrostichoides.

The white pine-white oak type occupied both sites that had a variety of perturbations and those in which no disturbance effects were discerned. Old field invasion typically occurred on the plots within the periphery of Cades Cove and around remote home sites. The tree cores taken from old field white pines averaged about 60 years of age. Upper and middle slopes in the Cades Cove area were affected by selective logging or clear cutting, depending on the site location. Fire scars were evident in several of the plots which had also been logged. Several plots contained sapling-sized white pine which were either dead or

Table 15. Frequency of the Shrubs, Vines, and Herbaceous Taxa in the White Pine-White Oak Type. N=29.

Shrub and Vine Taxa[g]	Frequency
Epigaea repens	11
Euonymus obovatus	14
Gaylussacia baccata	77
G. ursina	7
Kalmia latifolia	53
Leucothoe editorum	4
Mitchella repens	14
Pyrularia pubera	4
Rhododendron maximum	53
Rhus radicans	4
Smilax glauca	56
Vaccinium spp.	42
Vitis rotundifolia	11
Herb Taxa[h]	
Aster cordifolius	7
Chimaphila maculata	11
Desmodium laevigatum	14
Dioscorea spp.	4
Galax aphylla	7
Gallium spp.	39
Gaultheria procumbens	4
Hexastylis arifolia	35
Polystichum acrostichoides	11
Potentilla canadensis	4
Trillium spp.	4
Viola spp.	4

g = Shrubs and vines from two one-meter square plots (those over one meter as observed in .0406 hectare plot).

h = Herbs from two one-meter square plots.

stunted, probably due to shading. The diversity of sites, the broad area, and the variability in periods of disturbance made it difficult to estimate the time of release.

There were six plots in the Calderwood area that were undisturbed by the events of man; however, there was evidence of fire in several remote locations. The plots that appeared to be undisturbed contained some very large white pines. The oldest white pine cored in the white pine-white oak type was 183 years old and had a diameter of 55 cm. Three plots in the Calderwood area occurred along Panther Branch and had been subjected to logging.

In the Blockhouse area, both selective cutting and old field cultivation occurred. The old field tree cores averaged 64 years of age on the level sites near Gold Mine Road and Cooper Road. A single chestnut sprout occurred in a single plot, which suggested its limited former presence in the area.

There were three Society of American Forester (1954) types that contained white oak as a dominant, although none of the descriptions included white pine as an associated species. These types all occurred in the southern Appalachians and were generally considered as stable climax types. White oak was listed as an associate in the S.A.F. white pine type (number 21), white pine-hemlock type (number 22), and the white pine-chestnut oak type (number 51). It also occurred in all the community types in this analysis. White oak is a common associate in numerous types within the southern Appalachians (Fowells, 1965).

Braun (1950) described areas in the Alleghenies of West Virginia where secondary stands of white pine "mingled" with white oak. These secondary white oak-white pine stands occurred in valleys and on

adjacent slopes. Human occupancy in the Smokies caused numerous disturbances that may have permitted white pine access in logged, selectively cut, or burned areas, especially on lower elevation sites.

The minimal presence of chestnut sprouts in the white pine-white oak type did not indicate that the community structure was altered by the chestnut blight. It would be difficult, based only on the sample taken, to predict changes in species composition within the white pine-white oak type. The lack of information available for this type from other studies added to the problem of determining its future status. With the climax potential of white oak and the longevity of white pine, the white pine-white oak community type may remain stable for a long period of time.

The White Pine-Northern Red Oak Type

The white pine-northern red oak community type contained 29 of the 43 tree taxa represented in this study. White pine was the leading dominant and northern red oak was an integral dominant in the type. These two species had a combined mean importance value of 60 percent. Important associated species included red maple, pitch pine, and chestnut oak which occasionally attained an importance value of 15 percent or more. This type occurred predominantly on large ridges and middle to upper slopes on northwestern and southeastern aspects but rarely occurred on northeastern or eastern exposures. No stands were seen on southwestern or west-facing aspects. Elevations ranged from 450 to 671 meters (1,475 to 2,200 feet); slopes were moderately steep (averaging 26 percent), and the average daily potential solar radiation was low (244 Langleys) (Appendix A, Tables 35 and 41).

Stands of this type generally consisted of large specimens of white pine and northern red oak widely distributed among smaller individuals of several other species. The canopy closure was intermediate among the types (74 percent). This type had a well developed understory with a large diversity of taxa. The shrub layer was variable with few taxa represented. The diversity of the herbaceous flora was also quite low (Tables 16-18).

Soil depths were moderate and ranged from 19 to 86 cm and averaged 46 cm (18 inches). The O horizon was the thickest of any type in the analysis (seven cm) and was composed primarily of broad leaves with few needles. Textures were loams and sandy loams in the A horizon; an Ap horizon was noted in one plot. B horizon textures were generally loams and sandy clay loams. The residual and colluvial materials of the Cades Sandstone (43 percent) and the Wilhite Formation (57 percent) constituted the soil-forming materials of this type. The stone volume averaged 50 percent in the A and B horizons. Both horizons were extremely acid; the A horizon had an average pH of 4.5, and the B horizon had an average pH of 4.6. The mean total available water was intermediate (4.5 cm) among the types studied (Appendix A, Tables 35 and 41).

The canopy was dominated by white pine, northern red oak, red maple, pitch pine, and chestnut oak (Table 16). Sapling species with high mean relative density values were red maple, sourwood, white pine, and black gum. The highest frequency values were for white pine and red maple seedlings followed by northern red oak and sourwood (Table 17). Understory reproduction would probably replace white pine and most of the associated species, but northern red oak reproduction was moderate

Table 16. Overstory Composition of the White Pine-Northern Red Oak Type. N=14.

Taxa	Mean Relative Density[a]	Mean Relative Basal Area[b]	Mean Importance Value[c]
Acer rubrum	10.9 ± 2.3	3.5 ± 0.8	7.2
Carya glabra	0.6 ± 0.4	0.4 ± 0.3	0.5
C. tomentosa	0.5 ± 0.3	0.6 ± 0.5	0.6
Magnolia fraseri	0.2 ± 0.2	0.04 ± 0.04	0.1
Nyssa sylvatica	2.3 ± 1.1	0.7 ± 0.4	1.5
Oxydendrum arboreum	6.2 ± 1.3	2.3 ± 0.5	4.3
Pinus rigida	4.6 ± 1.9	8.2 ± 3.1	6.4
P. strobus	34.0 ± 3.1	39.0 ± 1.9	36.5
P. virginiana	3.8 ± 1.3	2.7 ± 1.0	3.3
Quercus alba	5.0 ± 1.5	4.5 ± 1.5	4.8
Q. coccinea	2.2 ± 1.3	3.2 ± 1.9	2.7
Q. falcata	0.2 ± 0.2	0.3 ± 0.3	0.3
Q. prinus	5.4 ± 1.5	6.3 ± 2.3	5.9
Q. rubra	21.0 ± 2.0	26.0 ± 1.9	23.5
Q. velutina	0.9 ± 0.6	1.5 ± 1.2	1.2
Robinia pseudoacacia	0.3 ± 0.2	0.4 ± 0.3	0.4
Sassafras albidum	1.4 ± 0.8	0.3 ± 0.2	0.9
Tsuga canadensis	1.0 ± 0.7	0.6 ± 0.5	0.8
Total Density (stems/ha)	990		
Total Basal Area (m^2/ha)		55.9	

a = MRD ± S.E. = mean relative density ± standard error.

b = MRBA ± S.E. = mean relative basal area ± standard error.

c = MIV = mean relative importance value (MRD + MRBA/2).

Table 17. Sapling and Subsapling Mean Relative Densities and Seedling Taxa Frequency in the White Pine-Northern Red Oak Type. N=14.

Taxa	Mean Relative Density		Frequency
	Saplings[d]	Subsaplings[e]	Seedlings[f]
Acer pensylvanicum		0.214	
A. rubrum	39.0 ± 4.7	2.210	42
Amelanchier laevis	0.9 ± 0.9	0.014	
Carya glabra	0.1 ± 0.1	0.057	
C. tomentosa	0.4 ± 0.3	0.057	
Castanea dentata		0.014	
Cornus florida	1.1 ± 0.8	1.070	
Fagus grandifolia		0.029	7
Ilex opaca	1.1 ± 0.8	0.143	
Liquidambar styraciflua		0.029	
Liriodendron tulipifera		0.029	7
Magnolia fraseri	0.4 ± 0.4	0.143	
Nyssa sylvatica	10.0 ± 1.6	0.286	
Ostrya virginiana		0.014	
Oxydendrum arboreum	16.0 ± 2.6	0.929	
Pinus strobus	14.0 ± 2.7	0.929	42
P. virginiana	0.8 ± 0.3		
Prunus serotina	4.3 ± 1.4		
Quercus alba		0.043	14
Q. prinus	3.9 ± 1.6		14
Q. rubra	1.6 ± 0.7		28
Q. velutina	0.4 ± 0.4	0.014	
Robinia pseudoacacia	0.1 ± 0.1		
Sassafras albidum	3.6 ± 1.5	0.071	28
Stewartia ovata		0.029	
Tsuga canadensis	1.7 ± 0.8	0.929	
Total Density (stems/ha)	999	4288	

d = Saplings 2.5-10 cm (1-4 inches).

e = Subsaplings less than 2.5 cm and one meter tall.

f = Seedlings from two one-meter square plots and under one meter.

Table 18. Frequency of the Shrubs, Vines, and Herbaceous Taxa in the White Pine-Northern Red Oak Type. N=14.

Shrub and Vine Taxa[g]	Frequency
Gaylussacia baccata	84
Kalmia latifolia	56
Leucothoe editorum	7
Mitchella repens	7
Rhododendron maximum	28
Smilax glauca	70
Vaccinium stamineum	7
V. spp.	35
Herb Taxa[h]	
Galax aphylla	7
Gaultheria procumbens	42
Hexastylis arifolia	79
Unknown #4	7
Uvularia sessilifolia	7

g = Shrubs and vines from two one-meter square plots (those over one meter as observed in .0406 hectare plot).

h = Herbs from two one-meter square plots.

in the seedling layer and was poor or absent in the subsapling and sapling strata. Perhaps this is a function of its periodic seed production (Fowells, 1965). Its importance in the canopy is probably due to sprouting after logging.

Hemlock and white oak were also variously represented among the strata. Hemlock was an unimportant canopy and sapling species and was more prevalent in the subsapling layer, but was not observed as a seedling. White oak was a minor associate in the canopy, was absent in the sapling layer, and was present in the subsapling and seedling strata. It appears likely that red maple will continue to increase in importance value. Northern red oak will probably remain as a codominant over a long period of time. Pitch pine was an associate species which most frequently occupied upper slope and ridge positions in the Calderwood region. They occurred in a variety of size classes and some were quite large. The majority of plots in which pitch pine occurred had no visible evidence of disturbance, but this could result from the length of time obscuring any disturbance effects. Also the xeric conditions of the site may have been sufficient for pitch pine regeneration. White pine was represented in many size classes and had a strong presence in all of the reproductive layers. Based upon the stand composition of white pine it appeared to be a long term dominant in this vegetation type. Shrubs and herbs (Table 18) were similar to those of the previous types.

The white pine-northern red oak type occurred on sites of limited human disturbance. Only four of the 14 plots had evidence of human influence. One plot on the periphery of Cades Cove may have been cultivated and was certainly pastured. Another cultivated plot occurred

in the settled area along Rich Mountain Road. Two plots had evidence of logging, and the area in which they occurred was probably clear cut for the production of charcoal. Coalen Ground Ridge was a site of hardwood cutting for charcoal production (personal communication: A. R. Shields, 1978). Four of the plots were on ridge crests and had obvious evidence of blowdowns or remnant tip-up mounds. The final six plots were in the Calderwood area near Scott Gap and were relatively undisturbed. Chestnut sprouting occurred in only one sample plot within this type (one stem).

The Society of American Foresters (1954) recognized a white pine-northern red oak-white ash type (number 20). The type had red maple as chief associate and was generally found on steep, fertile, and well-drained soils. This type often followed "old field" white pine in New England but also occurred on sites that had never been cultivated. The S.A.F. described the type (number 20) as permanent in some areas but as successional toward a white pine-hemlock type or the northern hardwood-hemlock types.

No white pine-northern red oak types have been delineated in vegetation studies of the Smokies. Braun (1950) discussed Oak-Chestnut communities from middle elevation positions in the southern Appalachians but did not cite northern red oak as an important forest dominant.

In the northern red oak-basswood-white ash type (number 54) of the Society of American Foresters (1954), white ash was considered an unimportant species in the southern Appalachians. The white pine-northern red oak type did not have white ash as a component possibly due to its relative absence in the Smokies.

Whittaker (1956) described two vegetation types that contained

northern red oak as a dominant species. A red oak-pignut hickory type and a red oak-chestnut type were delineated by Whittaker as occurring in the Smokies. In his red oak-chestnut type, Whittaker reported that the majority of the chestnuts were dead but had comprised 70 to 80 percent of the original canopy with northern red oak. He also cited that no other canopy associate reached a large percentage in the type, but that red maple was an important understory component. Golden (1974) recognized a northern red oak type in the Great Smoky Mountains National Park. He described the major associated taxa as Quercus velutina, Q. coccinea, Q. prinus, and tulip poplar which all occurred in this analysis, although they were not all canopy components.

The influence of human disturbance on the white pine-northern red oak type was only discerned on a few plots, and the majority of plots had no visible evidence of disturbance. The type may be considered permanent and/or subclimax. One hypothesis is that the type would be successional toward a white pine-hemlock type. A second hypothesis is that the type may be successional toward one or more northern hardwood-hemlock types. There were several northern hardwood components (Acer pensylvanicum, Fagus grandifolia, tulip poplar, and Prunus serotina) in the understory, but oaks were predominant in both the canopy and the understory. Hemlock had a minimal importance in the canopy, sapling, subsapling, and seedling strata of the white pine-northern red oak type, which discounts both replacement hypotheses. The continued importance of white pine, northern red oak, and red maple will contribute to the permanence of the type.

The White Pine Type

White pine dominated stands were very abundant and widely distributed throughout the western portion of the Tennessee side of the Great Smoky Mountains National Park. The white pine type contained 32 of the 43 tree taxa represented in this study. Although sample plots of this type were diverse in site and vegetation characteristics, plots were generally dominated by very large trees of white pine, which also had a high density. One sample plot contained a white pine which had a diameter at breast height of 85 cm (34 inches). White pine was the leading dominant, with a mean importance value of 58 percent. The white pine type had a wide range of slope positions but seldom occurred in coves or on floodplains. Associated species included red maple, Virginia pine, northern red oak and chestnut oak, but these had mean importance values of only 5 to 7 percent. Individual plots varied widely in the importance of the various associated taxa (Table 19).

Elevation ranged from 373 to 716 meters (1,225 to 2,350 feet). This type occurred predominantly on northwestern aspects (12 plots), although it also occurred on western (seven plots), northern (five plots), and northeastern (five plots) aspects. Slopes were quite steep (averaged 36 percent); the average daily potential solar radiation was moderate (245 Langleys). Most topographic positions were represented but ridge sites predominated (32 percent).

Soil depths ranged from 20 to 91 cm, and the average was 51 cm (20 inches). Ap horizons were noted on two old field plots. Surface rock cover was typically low, although several lower slope and cove sites had an average cover of 10 percent.

The 0 horizon was moderate in thickness and was composed

Table 19. Overstory Composition of the White Pine Type. N=41.

Taxa	Mean Relative Density[a]	Mean Relative Basal Area[b]	Mean Importance Value[c]
Acer rubrum	9.8 ± 1.1	4.4 ± 0.5	7.1
Amelanchier laevis	0.1 ± 0.1	0.01 ± 0.01	0.1
Betula lenta	0.1 ± 0.1	0.01 ± 0.01	0.1
Carya glabra	0.4 ± 0.2	0.3 ± 0.2	0.4
C. tomentosa	0.6 ± 0.3	0.4 ± 0.3	0.5
Cornus florida	0.5 ± 0.3	0.1 ± 0.04	0.3
Fraxinus americana	0.04 ± 0.04	0.02 ± 0.02	0.03
Ilex opaca	0.2 ± 0.1	0.1 ± 0.1	0.2
Liriodendron tulipifera	1.2 ± 0.6	1.0 ± 0.6	1.1
Magnolia fraseri	0.3 ± 0.2	0.1 ± 0.1	0.2
Nyssa sylvatica	1.2 ± 0.3	1.0 ± 0.4	1.1
Oxydendrum arboreum	5.8 ± 0.7	2.2 ± 0.3	4.0
Pinus echinata	0.5 ± 0.3	1.0 ± 0.7	0.8
P. rigida	3.3 ± 0.8	5.2 ± 1.3	4.1
P. strobus	53.0 ± 1.7	63.0 ± 1.6	58.0
P. virginiana	7.1 ± 1.2	5.2 ± 0.9	6.2
Platanus occidentalis	0.3 ± 0.2	0.2 ± 0.2	0.3
Quercus alba	1.6 ± 0.5	1.2 ± 0.5	1.4
Q. coccinea	0.6 ± 0.3	0.7 ± 0.4	0.7
Q. falcata	0.4 ± 0.2	0.3 ± 0.2	0.4
Q. prinus	4.4 ± 0.8	4.7 ± 1.0	4.6
Q. rubra	5.2 ± 0.8	6.7 ± 1.0	6.0
Q. velutina	0.9 ± 0.4	0.6 ± 0.2	0.8
Robinia pseudoacacia	0.4 ± 0.3	0.3 ± 0.2	0.4
Sassafras albidum	0.4 ± 0.2	0.2 ± 0.1	0.3
Tsuga canadensis	1.6 ± 0.5	0.6 ± 0.2	1.1
Total Density (stems/ha)	1099		
Total Basal Area (m^2/ha)		60.8	

a = MRD ± S.E. = mean relative density ± standard error.

b = MRBA ± S.E. = mean relative basal area ± standard error.

c = MIV = mean relative importance value (MRD + MRBA/2).

predominantly of needles with few broad leaves. Textures in 76 percent of the plots were loams and sandy loams in the A horizon. B horizon textures were variable; sandy loams, loams, silty clay loams, and clay loams occurred. The Cades Sandstone and the Wilhite Formation underlay 75 percent of the plots within this type. The stone volume averaged 47 percent in the A and B horizons. The A horizon averaged extremely acid (pH of 4.5), and the B horizon was very strongly acid with an average pH of 4.6. The total water availability was medium (five cm) (Appendix A, Tables 35 and 42).

The vegetation of the white pine type consisted of tall overstory trees (especially white pine) with a well developed understory. The canopy had several layers and closure averaged 72 percent. Understory, shrub, and herbaceous density and cover was variable depending upon site moisture conditions and on the density of the *Rhododendron* stands.

Sapling and subsapling species with high mean relative density values were red maple, white pine, sourwood, and hemlock (Table 20). The highest frequency values were those of red maple and white pine. Understory reproduction was high in all plots except those with dense heath canopies and a single plot in which a recent fire (within six months of sampling) had occurred. When the strata were compared, the white pine type had a wide diversity of canopy associates, but only red maple and hemlock were successfully reproducing and represented in the various strata. Virginia pine, northern red oak, and chestnut oak were canopy associates which were marginally represented in the sapling, subsapling, and seedling strata.

White pine occurred with various species on different sites.

Table 20. Sapling and Subsapling Mean Relative Densities and Seedling Taxa Frequency in the White Pine Type. N=41.

Taxa	Mean Relative Density		Frequency
	Saplings[d]	Subsaplings[e]	Seedlings[f]
Acer pensylvanicum	0.5 ± 0.30	0.073	
A. rubrum	35.0 ± 3.20	0.756	60
A. saccharum		0.015	
Amelanchier laevis	0.1 ± 0.10		2
Betula lenta	0.2 ± 0.20	0.005	7
Carya glabra	1.6 ± 0.60	0.010	5
C. tomentosa	1.5 ± 0.70	0.049	
Castanea dentata	0.1 ± 0.01	0.005	
Cornus alternifolia		0.010	
C. florida	2.8 ± 1.20	0.171	2
Crataegus sp.	0.3 ± 0.30		
Fagus grandifolia	0.6 ± 0.60	0.010	
Fraxinus americana	0.2 ± 0.10		
Ilex opaca	0.8 ± 0.40	0.098	19
Liriodendron tulipifera	0.9 ± 0.50	0.010	12
Magnolia fraseri		0.049	
Nyssa sylvatica	7.1 ± 1.30	0.220	2
Oxydendrum arboreum	16.0 ± 2.20	0.244	2
Pinus rigida	0.2 ± 0.20		
P. strobus	19.0 ± 2.60	0.171	53
P. virginiana	1.8 ± 0.70		
Platanus occidentalis	0.1 ± 0.04		
Prunus serotina	0.2 ± 0.10		2
Quercus alba	1.4 ± 0.60	0.015	5
Q. prinus	1.0 ± 0.40	0.024	10
Q. rubra	0.5 ± 0.30	0.005	10
Q. velutina	0.1 ± 0.10	0.015	5
Q. spp.			17
Sassafras albidum	0.4 ± 0.20	0.049	12
Tsuga canadensis	8.8 ± 1.50	0.463	17
Total Density (stems/ha)	835	1393	

d = Saplings 2.5-10 cm (1-4 inches).

e = Subsaplings less than 2.5 cm and one meter tall.

f = Seedlings from two one-meter square plots and under one meter.

Many of the old field and xeric ridge samples included Virginia pine. The sites on which white pine occurred with northern red oak and chestnut oak generally occupied middle to upper slopes and protected ridges. White pine was maintaining its dominance throughout all diameter classes and the type appeared to be stable.

Fifteen shrub and vine taxa occurred in the white pine type (Table 21). There were thirteen herbaceous and fern taxa represented in the type (Table 21). The white pine type occupied sites which had a variety of disturbances. There were two major areas which comprised this type: the Cades Cove and the Calderwood areas. Two plots near the Laurel Creek Road were probably subjected to logging between 1901 and 1939 by the Little River Lumber Company. Half of the 20 plots were taken in the Cades Cove region which had been previously cultivated or pastured. The oldest white pine among these plots was 55 years. Other plots on steeper slopes may have been selectively logged and pastured. Still other more remote plots were on small tracts that had been clear cut.

Human activity had far less impact in the Calderwood region than in Cades Cove. Seven plots of 19 taken there may have experienced selective cutting as suggested by their proximity to homesites or old roads. Two plots that were close to the oxbow homesite previously described had some pronounced differences in composition compared to the other plots within the white pine type. Carya tomentosa (mockernut hickory) and scarlet oak occurred as prominent subdominants on these plots.

Fire damage was observed on five widely scattered plots throughout the Calderwood and Cades Cove regions. Adjacent plots often had no

Table 21. Frequency of the Shrubs, Vines, and Herbaceous Taxa in the White Pine Type. N=41.

Shrub and Vine Taxa[g]	Frequency
Crataegus spp.	2
Epigaea repens	17
Euonymus obovatus	7
Gaylussacia baccata	67
Kalmia latifolia	55
Mitchella repens	10
Parthenocissus quinquefolia	7
Pyrularia pubra	2
Rhododendron maximum	31
Rhus radicans	2
Rubus spp.	2
Smilax glauca	77
Vaccinium staminium	5
V. spp.	22
Vitis rotundifolia	5
Herb Taxa[h]	
Chimaphila maculata	7
Cypripedium acaule	2
Daucus carota	2
Desmodium laevigatum	2
Galax aphylla	48
Gaultheria procumbens	19
Goodyera pubescens	2
Hexastylis arifolia	2
Microstegium vimineum	5
Polygonatum biflorum	2
Polystichum acrostichoides	7
Potentilla canadensis	7
Viola spp.	2

g = Shrubs and vines from two one-meter square plots (those over one meter as observed in .0406 hectare plot).

h = Herbs from two one-meter square plots.

evidence of fire. It is possible that fires were small and localized or that evidence was no longer visible. On those plots in which fire evidence was available, the species composition was somewhat different because pitch pine was present and often had relatively high importance values. However, the vegetation of some plots that appeared to be undisturbed also included pitch pine. Half of the 20 plots in the Calderwood region were thought to be undisturbed, but it was conceivable that fire evidence was overlooked or was no longer present. Chestnut sprouts occurred in two strata of a single plot in the white pine type. Within the plot, three stems were of subsapling size.

The Society of American Foresters (1954) described a white pine type which occurs throughout the Northern Forest region of Canada, northern New England, the Lake States, and extends south along the Appalachian Mountains to northern Georgia. In the southern Appalachians, the moist sites contain tulip poplar, hemlock, northern red oak, and white oak as the major associates, while the drier sites contain chestnut oak, pitch pine, and Virginia pine (S.A.F., 1954).

The white pine type has frequently been described as an early type to occupy abandoned agricultural land. The white pine type in the southern Appalachians occupies mountain slopes, flats, and valleys; soil characteristics range in texture from sandy to clay loam and in moisture from mesic to xeric (S.A.F., 1954). The A horizon textures of the white pine type in the Smokies were predominantly loams and sandy loams, and the total available water ranged widely. Barclay (1957) attributed the abundance of pure white pine stands in Johnson County, Tennessee, to the occurrence of forest fires and hardwood cutting. He thought that fires occurred at different times on the mountain slopes, creating

openings and favorable seed beds for white pine germination. The thick bark of mature white pine protects it from fire while other species are killed (Ayres and Ashe, 1905). In the present study, white pine survived fire while other species did not in the burned plot described previously.

In the original forests of east Tennessee, white pine was an important forest component. Sudworth and Killebrew (1897) noted the abundance of white pine in various localities of east Tennessee. They explained that large portions of the best white pine timber had been previously cut by portable sawmill operations. Sudworth and Killebrew (1897) described the adaptability of white pine in Tennessee to varied soil and moisture conditions.

The white pine type has been described as a long-lived temporary type that is usually subclimax but is capable of long term occupation and even permanence on sandy soils (S.A.F., 1954). The role of disturbance in perpetuating the white pine type has been examined, and the consensus indicates that large stands of white pine were associated with large-scale disturbances. Old field abandonment in North Carolina was analyzed by Patton (1955). Variously aged old field stands were investigated to monitor changes in associated flora, white pine composition, and successional trends. Patton concluded that after 30 years, naturally seeded stands of white pine have closed canopies, numerous dead stems, scattered hardwood reproduction, and an open forest floor with a moderate density of herbaceous taxa. After 50 years, an understory of hardwoods had less than 5 percent of the total basal area. Patton conceded that the white pine overstory would be succeeded by the associated hardwood species.

Patton (1955) also investigated a "self-perpetuating" white pine type in which there was an understory of hardwoods, but repeated catastrophes (lightning strikes, wind-throw, the chestnut blight, and fire) opened the canopy and permitted the successive periods of pine establishment which created an uneven-aged stand. Patton described a dense shrub population in the stand and cited Gaylussacia baccata as unique to his analysis. In this study, Gaylussacia baccata was also a very common shrub component of all the white pine-hardwood types described from the Smokies.

The disturbance history of the white pine type was inferred from field observations, but detailed analysis of some additional characteristics may have been useful in determining the origin of the type and its probable successional history. Lutz and McComb (1935) analyzed two virgin white pine stands that differed in white pine density. They compared the stem and basal branch features of white pines growing on clear cut or old field areas to natural forest stands with open canopies. Results indicated that stand origin could be discriminated based upon the measured characteristics. Lutz and McComb concluded that pure or nearly pure white pine stands are often even-aged and generally originate on open sites after a major disturbance. Where white pines are locally abundant in a forest one may infer that they developed in small canopy openings.

Based upon the known disturbance history of half of the plots of the white pine type, the importance of white pine may be attributed to human-induced large-scale perturbations. The other half of the plots of the type occurred predominantly on upper slopes and ridge crest positions and may represent a climax type based upon the long-lived nature of

white pine, its ability to survive moisture stress on xeric sites, and the frequency of natural disturbance insuring successful regeneration.

CHAPTER VII

CORRELATION ANALYSIS

Introduction

Correlation analysis was used to examine the relationships among environmental (site and soil) and vegetation variables. While not implying a causal relationship, correlations were useful in (1) providing an overview of the data set, (2) identifying subtle associations, and (3) lending statistical support to hypothesized interactions. Environmental variables used in the correlation analysis appear in Table 22 along with their abbreviations and units of measure.

This type of analysis has been used extensively in ecological studies in the southern Appalachians region as an interpretive tool for vegetation analysis (Safley, 1970; Martin, 1970; Hinkle, 1975; Smith, 1977; and Wade, 1977).

Correlation matrices were developed among and between site, soil, and vegetation variables using the Pearson product moment procedure from the SPSS program (Nie et al., 1975). Correlations significant at the P=.001 and .005 levels are included in the matrices.

Site Correlations

The strong negative correlation between the transformed aspect and total daily average solar radiation was to be expected since aspect was utilized for determining the insolation values for each plot (Table 23).

Plot position was correlated with other position measures

Table 22. Variables Used in Correlation Analysis.

Abbreviation	Variable Name	Units or Transformations
Vegetation		
CORF	*Cornus florida*	Importance Value (IV)
FRAA	*Fraxinus americana*	IV
LIQS	*Liquidambar styraciflua*	IV
LIRT	*Liriodendron tulipifera*	IV
MAGF	*Magnolia fraseri*	IV
NYSS	*Nyssa sylvatica*	IV
OXYA	*Oxydendrum arboreum*	IV
PINR	*Pinus rigida*	IV
PINS	*P. strobus*	IV
PINV	*P. virginiana*	IV
PLAO	*Platanus occidentalis*	IV
PRUS	*Prunus serotina*	IV
QUEA	*Quercus alba*	IV
QUEP	*Q. prinus*	IV
QUER	*Q. rubra*	IV
ROBP	*Robinia pseudoacacia*	IV
TILH	*Tilia heterophylla*	IV
TSUC	*Tsuga canadensis*	IV
Site		
ELEV	Elevation	meters
ASPTRAN	Aspect transformed from Beers et al. (1966)	SW=0 NE=2
PLOTPOS	Plot position	1=ridge 8=flood plain
HORPLSH	Horizontal slope shape	1=convex 3=concave
VERPLSH	Vertical slope shape	1=convex 3=concave
SLANGUP	Up slope angle	%
SLANGDO	Down slope angle	%
SLANGM	Average of the up and down slope angle	%
ACCSLSH	Across slope angle	1=ridge 40=draw
INSOL	Average daily potential solar radiation	Langleys
CANCLO	Canopy closure	%
MICRORG	Distance to the nearest small ridge	meters
MICRODR	Distance to the nearest small draw	meters

Table 22. (Continued)

Abbreviation	Variable Name	Units or Transformations
Site		
MICROTP	Relative position 1=ridge, 100=draw (small ridge)	%
MACRORG	Distance to the nearest major ridge	meters
MACRODR	Distance to the nearest major draw	meters
MACROTP	Relative Position 1=ridge, 100=draw (major ridge)	%
Soil		
THICO	Thickness of the organic layer	cm
THICA	Thickness of the A horizon	cm
THICB	Thickness of the B horizon	cm
THICT	Total profile thickness	cm
STVOLA	Stone volume of the A horizon (over three inches)	%
STVOLB	Stone volume of the B horizon (over three inches)	%
STCOV	Stone cover	%
SANDA	Sand in the A horizon	%
SANDB	Sand in the B horizon	%
SILTA	Silt in the A horizon	%
SILTB	Silt in the B horizon	%
CLAYA	Clay in the A horizon	%
CLAYB	Clay in the B horizon	%
TEXTA	Texture of the A horizon	(1=high AWHC)
TEXTB	Texture of the B horizon	(9=low AWHC)
PH20A	Water measured pH in the A horizon	pH
PH20B	Water measured pH in the B horizon	pH
PHKCLA	KCL measured pH in the A horizon	pH
PHKCLB	KCL measured pH in the B horizon	pH
AWHCA	Available water holding capacity in A horizon	cm/cm
AWHCB	Available water holding capacity in B horizon	cm/cm
STFRACA	Stone fraction in A horizon (under three inches)	%
STFRACB	Stone fraction in B horizon (under three inches)	%
H20A	Total water in the A horizon	cm
H20B	Total water in the B horizon	cm
H20T	Total water in the profile	cm

Table 23. Matrix of Simple Linear Correlations Among Site Variables.

	ASPTRAN	PLOTPOS	HORPLSH	VERPLSH	SLANGUP	SLANGM	HORSLSH	MICRORG
INSOL	-0.54**					-0.37**		
MICRORG		0.53**					0.28**	
MICROTP		0.66**			0.27**	0.29**		0.76**
MACROTP		0.35**				-0.23*		
HORPLSH		0.28**						
ACCSLSH			0.85**	0.32**				
SLANGDO				-0.27**				

**Significant at P=.001.

*Significant at P=.005.

(microrg, microtp, and macrotp). Position was also correlated with horizontal slope shape, suggesting that more concave slope shapes occur on lower plot positions. Horizontal slope shape was very highly correlated (+0.85) with "across" slope mean angle which was expected since horizontal shape was grouped and the angle was measured across the same line in the field. Vertical slope shapes were positive on horizontal shape, suggesting that vertical and horizontal shapes were correlated. Vertical shape was negative on down-slope angles, suggesting that steeper angles (up-slope) are more likely to be convex.

Slope angle (up) was positive on microtopographic positions; steep slope angles occurred predominantly down-slope. The mean slope angle was used in calculating potential insolation and the latter was maximized at a certain angle, which would account for the negative relationship. It was not clear why the mean slope angle was positive on the microtopographic position and negative on the macrotopographic position. The across slope mean was positively correlated with the distance to the nearest ridge, implying that the ridge positions generally had convex horizontal slopes. Strong correlations between the microtopographic position and the distance from the nearest ridge were expected.

Soil Correlations

Both horizons had total water values that correlated with numerous soil characteristics that were used in calculating the total water values themselves (Table 24). Positive correlations existed between the composite horizon's total water value (H2OT), thickness of the individual horizons and the available water holding capacities. The stone volumes (stones over three inches) and stone fractions (stones under three inches)

Table 24. Matrix of Simple Linear Correlations Among Soil Variables.

	H2OT	THICA	THICB	THICT	STVOLA	STVOLB	STCOV	SANDA	CLAYA	PH2OB	PHKCLA	PHKCLB	AWHCA	AWHCB	STFRACA	STFRACB
H2OA	.72**	.78**			-.49**								.64**		-.47**	
H2OB	.97**		.72**			-.52**								.70**		-.64**
H2OT	1.00**			.70**	-.54**	-.54**							.63**	.75**	-.51**	-.68**
THICO							-.26**									
THICA		1.00**		.48**												-.28**
THICB			1.00**	.94 **												-.30**
THICT				1.00**											-.26**	-.38**
STVOLA					1.00**					.29 **		.43**	-.63**		.33**	
STVOLB						1.00**						.34**		-.74**		.55**
STCOV							1.00**	.26*	-.28**				-.28**			
SANDA								1.00**					-.45**			
SANDB														-.33**		
PH2OA										.34**	.61**					
PH2OB										1.00**		.37**				
PHKCLA											1.00**	.55**				

**Significant at P=.001.

*Significant at P=.005.

for each horizon were negatively correlated with total water values in each horizon. The combined A and B horizon total water was similarly affected by the same soil variables, and their correlations need not be discussed further.

The thickness of the organic (O) horizon was negatively correlated with stone cover; that is, the thickness of the organic layer increased as the stone cover decreased. This may be due to more xeric conditions on plots with high stone cover due to low soil moisture capacity. The more xeric conditions could cause a reduction in vegetation productivity with subsequent reduced litter accumulation. Sites which contained deep humus layers were vegetated by ericaceous or mesic shrubs but generally had a reduced stone cover.

The total thickness of the profile was positively correlated with the A horizon thickness (.48), and a strong positive correlation occurred with components of the total thickness. The larger correlation coefficient of the B horizon points up the fact that it was generally the thicker component, comprised the largest portion of the solum, and had a greater overall influence over the total thickness. Negative correlations between horizon thickness and stone volume simply indicate greater distances to bedrock or parent material.

The stone volume of the A horizon was positively correlated with the soil pH as determined by water and KCL. The B horizon stone volume was also correlated positively with the soil pH (KCL) of the B horizon. It is probable that the stone fraction had a direct affect on soil pH.

The stone volume estimates from both horizons had a strong negative correlation with the available water holding capacity of the profile, due to the use of these volume estimates in the determination of

available water holding capacity. The profile stone volume estimates were positively correlated with the laboratory-determined stone fraction percentages. The A horizon had a correlation of .33 and the B horizon had .55, suggesting that A horizon stone volume was more variable.

The percentage of exposed stone on the plot surface was positively correlated with the percentage of clay in the A horizon. Sand content was evidently associated with the early stages of the weathering of rock material. As the clay content of the A horizon increased, the percent stone cover decreased. The stone cover was negatively correlated with the available water holding capacity of the A horizon. This acts through the percentage of stone as well as the sand, silt, and clay percentages. The sand percentages in the A and B horizons were negatively correlated with the available water holding capacity in each horizon. There were several positive correlations between different horizons and pH tests (water and KCL). Soil pH as measured in KCL and water were strongly correlated. KCL-measured pH was consistently a whole unit lower than that measured in water.

Site Versus Soil Correlations

Correlations between site and soil variables can be utilized to explain environmental characteristics that may have previously gone undetected. The negative correlation between stone volume and elevation meant that lower elevations had an increase in stone material (Table 25) due to the transporting of colluvium. Increasing elevation caused a decrease in various soil pH measures in both horizons as reported by McGinnis (1958). The increased acidity of the litter and the additional leaching due to increased precipitation at higher elevations contributed

Table 25. Matrix of Simple Linear Correlations Between Site and Soil Variables.

	ELEV	PLOTPOS	SLANGM
STVOLA	-.43**		.34**
STVOLB	-.36**		.38**
STCOV		.27**	
PH2OB	-.38**		
PHKCLA	-.26**		.24**
PHKCLB	-.36**		

**Significant at P=.001.

to the soil pH. The mean slope angle had a positive correlation with the soil pH. This could be attributed to a reduction in percolation which would limit leaching.

Vegetation Correlations

Correlations between vegetation variables and environmental (soil-site) variables delineated some obvious patterns but further revealed some interesting relationships. Hinkle (1975) reported that simple linear correlations of importance value, relative density, and relative basal area with environmental variables resulted in numerically similar correlation coefficients. Only importance values were utilized in determining relationships between vegetation and environmental characteristics. Selected overstory taxa and environmental variables were utilized to determine potential relationships.

Tulip poplar is an important forest dominant in the southern Appalachians. Fowells (1965) reported that it grows extremely well and quite abundantly in the lower Ohio River basin and in the mountains of North Carolina, Tennessee, Kentucky, and West Virginia. Tulip poplar importance value (IV) was positively correlated with the IV of dogwood, sycamore, sweet gum, wild cherry, and basswood, all of which are considered as mesophytic species (Table 26). White pine was negatively correlated with tulip poplar. These species apparently compete as pioneers when entering old field sites where they may selectively eliminate one another. Tulip poplar was positively correlated with surface stone cover (Table 27). This may be explained by its occurrence on lower slope sites where colluvial soil material is predominant. A negative correlation existed between the stone volume of the A horizon

Table 26. Matrix of Simple Linear Correlations Among Species.

	LIRT	QXYA	PINS	PINV	PLAO	PRUS	QUEP	QUER	TILH	TSUC
CORF	.30**							-.27**		
FRAA				.27**		.53**				
LIQS	.29**									
LIRT	1.00**		-.23**		.30**	.30**		-.26**	.26**	
MAGF									.63**	
NYSS		.25**					.28**			
PINR				.27**						
PINS			1.00**	-.31**						
PINV				1.00**		.46**				
QUEA							-.29**			
QUER								1.00**		-.24**

**Significant at P=.001.

Table 27. Matrix of Simple Linear Correlations Between Species and Environmental Variables.

	LIRT	QXYA	PINV	QUEP	QUER	TSUC	QUEA	CORF	ROBP
ASPTRAN	.22*								
PLOTPOS	.24**								
VERPLSH				-.28**					
SLANGDO	-.25**			.37**					
INSOL		.22*							
CANCLO			-.27**						
MICRORG									
MICRODR				.22*					
MACROTP	.22*								
THICO					.23*				
THICB							.22*		
THICT							.24**		
STVOLA	-.24**	-.25**							
STVOLB		-.25**							
STCOV	.33**							.40**	.29**
CLAYA				.24**		-.24**			
AWHCA						-.33**			
AWHCB						-.22*			
H2OA						-.25**			
H2OB							.22*		

**Significant at P=.001.

*Significant at P=.005.

and tulip poplar. This appears to be contrary to previous situations in which tulip poplar importance increased with higher percentage of exposed stone cover. The negative relationship may be explained by the occurrence of tulip poplar on old field sites in which there were limited amounts of stone in the A horizon. The best soils were chosen for cultivation and stones were removed from the field.

The correlation of tulip poplar with plot position and macrotopographic position are similar to a report by Day and Monk (1974) in that the positive correlation indicates that tulip poplar is most successful on lower slope positions. The positive correlation between tulip poplar and transformed aspect reveals that tulip poplar is more prominent on northern exposures. There was a negative correlation between tulip poplar importance value and the angle down slope which was also reported by Safley (1970) on the Big South Fork of the Cumberland River.

Sourwood had a positive correlation with blackgum. Both species were common understory components and were represented in most of the white pine-hardwood types. Sourwood importance values were negative with stone volume of the A and B horizons. When insolation values increased sourwood importance value increased, indicating that sourwood is more prevalent on south-facing exposures.

Virginia pine was positively correlated with pitch pine, which was an associate on old field sites and on ridge positions. Virginia pine was also positively correlated with other old field invaders, white ash and black cherry. These occurred predominantly in the white pine-Virginia pine, white pine-red maple and white pine types in which Virginia pine was also an important component. White ash and black cherry

had a strong positive correlation coefficient (.53). White ash generally occurs on abandoned farmland in the southern Appalachians but generally invades after pine establishment (Fowells, 1965). Black cherry is a member of the mixed mesophytic climax although it is intolerant. It was infrequent in the virgin forest but generally increased in importance after disturbance. It is more abundant in locations subjected to logging or fire (Fowells, 1965). Based upon the reported disturbances common to the types in which white ash and black cherry occur, it is suggested that they are indicative of seral stages of succession.

White pine had a strong negative correlation with Virginia pine. Both species are old field invaders; however, Virginia pine is less tolerant of shading and thus white pine can eliminate Virginia pine as a competitor. Canopy closure was negatively correlated with Virginia pine importance value. As the canopy closure increased, more shade was produced and the importance value of Virginia pine decreased.

Fowells (1965) suggested that chestnut oak reaches its best development in well-drained coves and competes best with other oaks on dry soils; it occurs widely on dry sites throughout the southern Appalachians. Chestnut oak was positively correlated with black gum. Black gum was a common understory component in the white pine-chestnut oak type. The vertical slope shape was negatively correlated with chestnut oak importance value. Chestnut oak increases in importance value on steep convex-shaped vertical slopes. As the distance from the nearest draw increases (approaching the nearest ridge) chestnut oak increases in importance value. Martin (1966) reported that the chestnut oak forest was best developed on upper south-facing slopes on Wilson Mountain. The slope angle and the distance from the draw support the

previous interpretation that steep slopes occur at upper slope positions. The chestnut oak type occupies mountain slopes, high valleys, and flat ridge tops (S.A.F., 1954), and in this analysis was found predominantly on upper slope and ridge positions. It was positively correlated with the percentage of clay in the A horizon. The relationship may be due to the increased water availability of the more clayey soils resulting in favorable growth. Golden (1974) reported a positive correlation between chestnut oak importance value and clay percentage in the higher elevation forests of the Smokies.

Northern red oak was negatively correlated with dogwood and tulip poplar; the latter two decreased in importance value as northern red oak increased. Northern red oak is intermediate in tolerance but is generally more tolerant than tulip poplar (Fowells, 1965). It responds favorably to release and is capable of becoming dominant early in its life cycle; this may account for the reduction of tulip poplar and may possibly contribute to the low importance value of dogwood as well. Safley (1970) and Day and Monk (1974) also found relatively few significant correlations between environmental variables and the importance values of northern red oak.

Fraser magnolia and basswood were strongly correlated (.63) with one another. Fraser magnolia occurred in several of the white pine types, and basswood only occurred in a single plot within the white pine-red maple type. The low occurrences probably account for the high correlation coefficient.

The distribution and importance of hemlock in the southern Appalachians has been reviewed by Braun (1950). Hemlock was negatively correlated with northern red oak. Hemlock is a mesophytic species

located predominantly on lower and middle slope positions. Northern red oak decreases in importance value as hemlock increases. Hemlock produces dense shade, and the moderately tolerant northern red oak may not compete successfully. Hemlock is capable of producing virtually pure stands. Its importance value decreased as the percentage of clay in the A horizon and the available water holding capacity of the profile increased. The fact that hemlock increases in importance value as the clay content and available water holding capacity decreases is contrary to the known occurrence of hemlock on moist sites. The resolution may be that, although the probable soil moisture level is low, the actual occurrence of hemlock is generally in draws and near drainage seeps.

Fowells (1965) reported that white oak is common throughout the eastern U.S. and is prevalent in the southern Appalachians where it grows on a broad spectrum of sites and soils. White oak was negatively correlated with chestnut oak. White oak is generally considered as a lower slope species while chestnut oak occurs predominantly on middle and upper slopes. White oak was positively correlated with the B horizon total water and the B horizon thickness and total profile depth. White oak develops best on deep, well-drained, loamy soils, and it is often located on northern and eastern lower slopes and open coves (Fowells, 1965).

Dogwood and black locust were positively correlated with stone cover (.40 and .29 respectively); as stone cover increased the species' importance value increased. Black locust is a relatively intolerant, shallow-rooted species (Fowells, 1965), which permits it to compete successfully on thin, rocky soils. Dogwood is a tolerant understory

species (Fowells, 1965). These weedy mesophytic to submesophytic taxa are at least temporarily surviving on these rocky sites.

CHAPTER VIII

DISCRIMINANT ANALYSIS

Introduction

Discrete and continuous schools of vegetation analysis share the common goal of determining the structure of vegetation. Numerical techniques such as cluster analysis have been developed to classify the vegetation into workable units. In cluster analysis the plots or stands are grouped according to vegetation similarities. Community types are determined from the vegetation grouping of plots in the cluster procedure. If the vegetation pattern is continuous, the cluster groups may be ambiguous. Discriminant analysis is a multivariate statistical technique which may be used to test the relative discreteness of the community types defined by cluster analysis. Discriminant analysis may also be utilized to measure the degree of segregation of plots based upon environmental characteristics.

Multiple discriminant analysis is designed to distinguish between two or more groups. A series of discriminating variables are selected to measure the characteristics on which the groups may differ. The mathematical objective is to weight and linearly combine the discriminating variables, such that groups are as statistically distinct as possible.

In determining the maximum group separation, the discriminant technique produces one or more linear expressions composed of the discriminating variables. The equation for the discriminant function is of the form:

$$D_i = d_{i1}Z_1 + d_{i2}Z_2 + \ldots + d_{ip}Z_p$$

where D_i is the discriminant score for axis i. The d's represent the weighting coefficients, and the Z's represent the standardized values for p discriminating variables used in the analysis (Nie et al., 1975). The maximum number of functions that can be calculated is equal to the number of discriminating variables or one less than the number of groups, whichever is smaller.

Discriminant functions are derived in their order of importance, and each represents a unique axis which can describe the location of a group relative to the others. The first function represents the axis along which maximum group separation occurs. The discriminant procedure provides three methods for judging the importance of succeeding discriminant functions. One method involves the relative percentage of the eigenvalue associated with the function. An eigenvalue is calculated when the function is produced, and the sum of all the eigenvalues is a measure of the total variance of the discriminating variables. The relative percentage is calculated by dividing a discriminant function's eigenvalue by the sum of the eigenvalues derived for all the functions. The relative percentage associated with any function is thus a measure of the total variance explained by that function (Nie et al., 1974).

A second method for judging the importance of discriminant functions is the canonical correlation which measures the association between a single discriminant function and the other functions. It is a measure of the function's ability to discriminate between the groups. The final method for determining critical discriminant functions is the Wilks' lambda calculations. The larger the lambda, the less information

remaining. A chi-square statistical test is calculated to determine the significance of the additional information that may be contributed by a function.

The discriminant technique can be utilized for various types of data interpretation. Analytical interpretations can be made with the standardized discriminant function coefficients in which the relative contribution of a particular variable is determined. The larger the coefficient (disregarding the sign) the greater the contribution of the variable to the discriminant function. The sign denotes whether the variable is making a positive or negative contribution to that particular function. The standardized coefficients can be used to characterize each function by identifying the most important variables on that function.

The group centroids (means), when plotted along an axis for each discriminant function, provide a visual display of the degree of separation of the groups on two axes. The group centroid represents the mean location of an individual vegetation plot from that group within the discriminant function space. The discriminant functions are arranged by decreasing order of importance. Plotting the group centroids along the most significant axes permits an examination of the degree to which groups are separated. If a pair of discriminant functions are plotted, a two-dimensional array is created and the overlap of groups can be observed. Statistical tests may be utilized to determine the significance of group separation (Nie et al., 1975).

Discriminant analysis is also a powerful classification procedure which is capable of identifying the most likely group membership of a vegetation plot. Classification functions are obtained after the

discriminant functions have been derived. The probability of group membership is discerned from the classification functions. Based upon the discriminating variables, even vegetation plots not originally organized into a group may be classified. The original groups from the cluster analysis may also be checked to determine the precision of the original classification procedure. If a large number of miscalculations occur, then the selected variables were poor discriminators. A classification table is produced by the discriminant procedure to provide information on where misclassification occurs (Nie et al., 1975).

Previous Use

Discriminant analysis has been used in several vegetation studies. Norris and Barkham (1970) used discriminant analysis to study the effects of various physical site conditions on the ground flora of several English Cotswold beech woodland areas. Interpretation of the discriminant procedure led to the conclusion that the Cotswold beech woodland vegetation contained a number of ground flora types with fairly distinct species assemblages. The primary discriminating variables were factors that were related to management practices that caused various disturbances, such as increased canopy openings, soil temperatures, and humidity variability. McCord (1976) used discriminant analysis to observe the separation of herbaceous plant r and k strategies. Mann (1977) reviewed the application of discriminant analysis in niche studies and utilized the procedure to examine the relationships of herb species occupying similar niches.

Grigal and Goldstein (1971) and Goldstein and Grigal (1972) conducted a vegetation study on Walker Branch watershed in Oak Ridge,

Tennessee, and used four clustering procedures to classify the vegetation. Those plots that were classified into the same vegetation type independent of the clustering technique became designated as the "core" groups. Kercher and Goldstein (1977) used the "core" groups with environmental data from Walker Branch in a discriminant analysis. The objective was to determine whether or not the environmental data set could discriminate the core groups created by the cluster procedures. Kercher and Goldstein found that using environmental discriminating variables provided high classification success for defining the core groups. The implication is that the core groups were distinct based upon environmental characteristics.

Methods

The SPSS Program Discriminant (Nie et al., 1975) was used to conduct the analysis. Discriminant analysis was used with vegetation data and environmental data to test group separation. The first step was to provide the group membership information. The groups used in the procedure were those determined by the cluster analysis. The vegetation variables were identical to those used in the cluster analysis (species importance values). The environmental variables were subjectively reviewed, and those variables that did not significantly differ between the seven groups were eliminated because they were poor discriminators. Variables which were highly correlated were examined and if they measured the same phenomena, they were subjectively eliminated.

The normal procedure in discriminant analysis is to generate a set of discriminant functions which provide maximum group separation for the previously defined groups. From the discriminant functions a set of

classification functions are calculated to predict group memberships. Plots were originally ordered into groups based upon the cluster classification. Bias may be introduced into the calculations because a predetermined vegetation grouping was used to derive the classification functions. Success of predicated group membership may be high since the classification functions were derived from the original groupings.

Discriminant-Vegetation Variables

Discriminant analysis was used to determine the classification success of community types (groups) based on vegetation data (species importance values). The groups were previously defined by cluster analysis using species importance values. Group membership information used in the discriminant analysis was based upon the groups discerned from the cluster procedure. The primary concern was to determine the classification success and to determine whether the groups were in fact distinct vegetationally.

The discriminant functions varied in their relative percentage of the eigenvalues which measure the variance explained by a single function. All of the canonical correlation values were high, meaning that each function successfully discriminated between groups. Based upon the small size of the Wilks' lambda for each discriminant function, there was a significant amount of information contributed by each function (determined by chi-square test).

All of the community types were distinct based on vegetation characteristics. Examination of the classification matrix (Table 28) indicated that the overall classification success was very high (95.14 percent). Most of the plots were correctly classified and only

Table 28. Matrix of Classification Success[a] from Discriminant Analysis of White Pine-Hardwood Community Types[b] Using Species Importance Values[c].

Actual Groups	Predicted Groups						
	WP-VP	WP-RM	WP-H	WP-CO	WP-WO	WP-NRO	WP
WP-VP N=25	88			4	8		
WP-RM N=21		100					
WP-H N=5			100				
WP-CO N=9				100			
WP-WO N=29			3.4		89.7		6.9
WP-NRO N=14						100	
WP N=41	2.4						97.6

a = Percent of "grouped" cases correctly classified: 95.14 percent.

b = Abbreviations: WP=white pine, VP=Virginia pine, RM=red maple, H=hemlock, CO=chestnut oak, WO=white oak, and NRO=northern red oak.

c = Values within the matrix are percentages of the plots in the community types.

seven plots were reclassified by the discriminant procedure. The best classification correspondence occurred in the white pine-red maple, white pine-hemlock, white pine-chestnut oak, and the white pine-northern red oak types. One plot from the white pine type was predicted to occur in the white pine-Virginia pine type. Both types were successional and were distinguished by the significantly lower importance values of white pine in the white pine-Virginia pine type.

Discriminant-Environmental Variables

The discriminant procedure was conducted using the groups previously defined by cluster analysis and selected site and soil variables. Environmental data were used in a discriminant procedure in an attempt to discern whether the community types were distinct environmentally. Table 29 contains the calculated F matrix, and the significance level at the .10 level with 12 and 126 degrees of freedom was 1.60. The white pine-red maple type was environmentally distinct from all other plots at the .10 significance level. Some environmental overlap occurred between the types. The white pine-northern red oak type was not significantly different from the white pine-Virginia pine or white pine-white oak types. The white pine-hemlock type was not significantly different from the white pine-chestnut oak type. Some overlap also occurred between the three white pine-oak types (white pine-chestnut oak, white pine-white oak, and white pine-northern red oak) indicating that they were not environmentally distinct.

The discriminant functions were reviewed for their contribution to segregating groups. The relative percentage of the eigenvalue for the first two discriminant functions was 54.9 percent, and functions one

Table 29. Matrix of F-values Between White Pine-Hardwood Types[a] from Discriminant Analysis[b] Using Selected Environmental Variables.

	WP-VP	WP-RM	WP-H	WP-CO	WP-WO	WP-NRO
WP-RM	1.61**					
WP-H	2.02**	1.89**				
WP-CO	1.97**	1.74**	1.00*			
WP-WO	1.68**	1.64**	1.93**	1.80**		
WP-NRO	1.14*	2.40**	1.87**	1.73**	1.26*	
WP	2.29**	1.96**	2.02**	1.12*	1.48*	1.27*

a = Abbreviations: WP=white pine, VP=Virginia pine, RM=red maple, H=hemlock, CO=chestnut oak, WO=white oak, and NRO-northern red oak.

b = Degrees of freedom 12,126 $\alpha.05 = 1.83$
$\alpha.10 = 1.60$

**Significant at the P=.10 level.

*Not significant.

through three explained 76 percent of the variance (Table 30). To determine the number of functions necessary to explain the maximum amount of variance, the canonical correlation values and the Wilks' lambda were examined. The canonical correlation values were quite high (Table 30), and the Wilks' lambda remained moderately small for the first three functions. A chi-square test on the Wilks' lambda values was utilized to determine which discriminant functions were significant discriminators among the groups. The chi-square test was significant for the first three functions at the .05 level.

The selected discriminant functions represent three orthogonal dimensions along which groups were significantly separated. The standardized discriminant function coefficients were analyzed to discern the variables that contribute most to the discriminant function. The prominent discriminating variables for the first function (Figure 3) appeared to represent a moisture axis where the soil texture components, stone percentages, horizon thickness, and total available water combine to distinguish group membership. The first function explained 29.5 percent of the total variance. The second discriminant function also appeared to be related to soil moisture phenomena and was additionally related to plot slope position which contributed to the concept of a moisture factor. The dominant discriminating variables for the second function were soil texture components, stone volumes, total water availabilities, the plot slope position, and the distance from the nearest draw. The discriminating variables in the third function were also related to soil moisture and topographic position. The total water availability, the horizon thickness, and the stone volume were directly related to a moisture index. The percent microtopographic position and

Table 30. Standardized Coefficients of Environmental Variables on the First Three Discriminant Functions from the Analysis of the White Pine-Hardwood Community Types[a].

	DF-1	DF-2	DF-3
Variable			
H2OT	1.29	0.61	0.55
SANDA	1.00	0.85	-0.01
THICB	-0.75	-0.24	-0.63
CLAYA	0.70	0.62	-0.11
STVOLB	0.65	0.55	0.52
STFRACA	0.59	-0.24	0.34
MICRODR	-0.15	-0.64	0.50
MICROTP	-0.05	-0.31	0.74
PLOTPOS	-0.07	-0.54	-0.56
SLANGUP	0.55	0.02	-0.59
THICO	-0.45	0.40	0.24
THICA	-0.44	-0.25	-0.20
Canonical Correlation	0.472	0.447	0.410
Relative Percentage	29.4	25.5	20.7

a = Abbreviations of environmental variables follow conventions from Table 22.

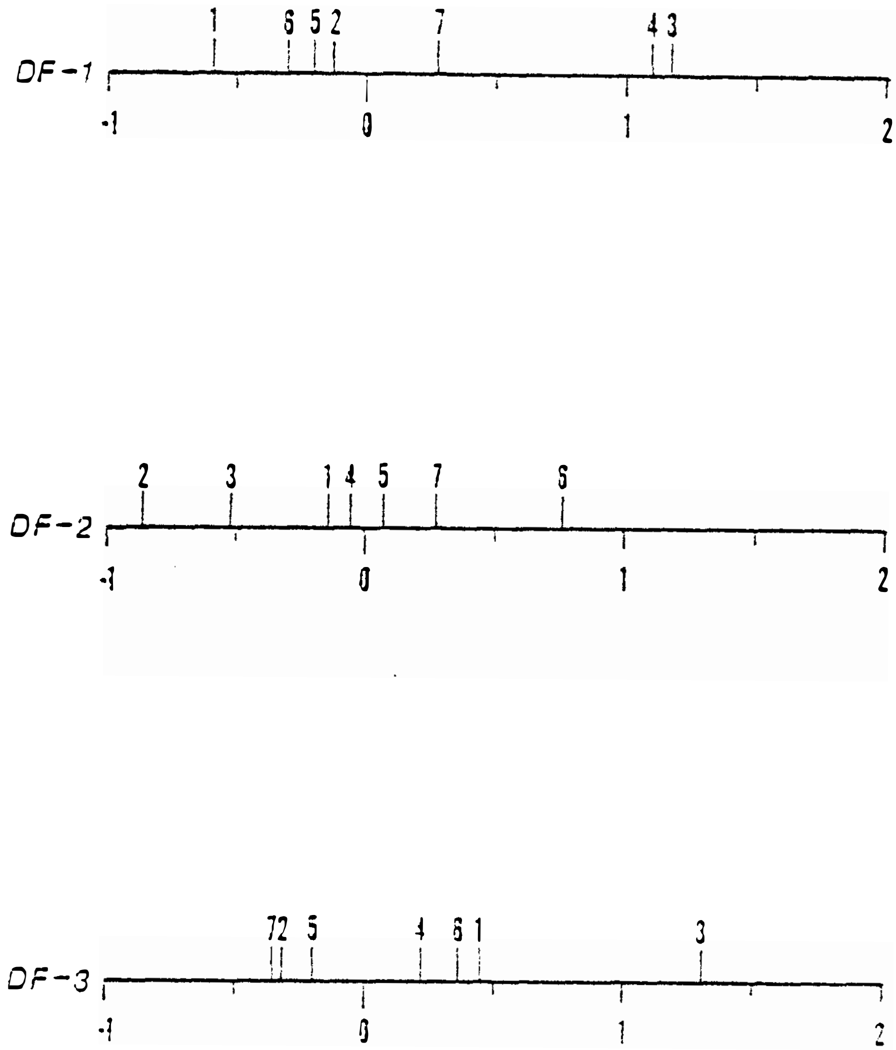

Figure 3. Centroids of the white pine-hardwood types along the first three discriminant functions from an analysis using selected environmental variables. Key: 1=white pine-Virginia pine, 2=white pine-red maple, 3=white pine-hemlock, 4=white pine-chestnut oak, 5=white pine-white oak, 6=white pine-northern red oak, and 7=white pine.

up slope angle were also indirectly related to a moisture index.

The classification matrix (Table 31) indicated that the overall classification success was low, with only 41 percent of the plots correctly classified. The white pine-red maple and the white pine-hemlock types were the most successfully classified groups with 52.4 and 60 percent respectively. The white pine-Virginia pine, the white pine-white oak, and the white pine types had the least successful classification.

The disturbance history of the vegetation in the Smokies represents a wide variety of perturbations which affected the original vegetation and influenced the composition of the second growth communities. White pine has a relatively wide ecological amplitude and occurs with many different species on quite diverse sites. The white pine-hardwood types were classified by cluster analysis into community types which occur on the landscape. Discriminant analysis on the environmental variables did not exactly confirm the classification scheme. The white pine-hardwood community types were not distinct environmentally and the successional nature of the types may account for the low classification success using environmental variables.

Table 31. Matrix of Classification Success[a] from Discriminant Analysis of White Pine-Hardwood Community Types[b] Based upon Selected Environmental Characteristics[c].

	Predicted Groups						
Actual Groups	WP-VP	WP-RM	WP-H	WP-CO	WP-WO	WP-NRO	WP
WP-VP N=25	36	12	8	4	12	16	12
WP-RM N=21	14.3	54.4	4.8	4.8	9.5	9.5	4.8
WP-H N=5			60	20	20		
WP-CO N=9		11.1	22.2	44.4	11.1		11.1
WP-WO N=29	17.2	17.2	3.4	6.9	37.9	6.9	10.3
WP-NRO N=14	21.4	7.1	7.1		7.1	42.9	14.3
WP N=41	2.4	14.6	4.9	12.2	9.8	19.5	36.6

a = Percent of "grouped" cases correctly classified: 41 percent.

b = Abbreviations: WP=white pine, VP=Virginia pine, RM=red maple, H=hemlock, CO=chestnut oak, WO=white oak, and NRO=northern red oak.

c = Values within the matrix are percentages of the plots in the community types.

CHAPTER IX

CANONICAL ANALYSIS

Introduction

The objectives of classification and ordination are to determine the underlying structure of a system and to compare systems along environmental gradients. Different techniques complement one another and, used in combination, they can contribute to a better interpretation than that based upon a reliance on a single technique. Ordination procedures can be helpful in condensing field data by arranging the plot information into a framework to display their interrelationships (Mueller-Dombois and Ellenberg, 1974).

After a classification procedure has been done, the relationships of the resulting cluster groups can be portrayed along the axes that exhibit most of the variance, thus providing a visual display of the degree of separation. In calculating the maximum group separation, the first and second axes represent the greatest variance.

Canonical analysis is an ordination technique used to array plot clusters or groups along axes based upon vegetation characteristics. A graphic representation of the group arrangement is made by plotting the distance between each of the groups in a two-axis system. The canonical procedure first requires the listing of plot membership by groups. The first procedure calculates the dimensions of variation, and the first axis is inclined in the direction of greatest variability between the mean positions of the groups. The second axis is perpendicular to the first axis and is inclined along the second level of variability. This

continues for each subsequent axis to a maximum of K-1, where K equals the number of groups. Golden (1974) reported that generally only the first several axes are capable of biologically meaningful interpretation.

Previous Use

Canonical analysis has been used in vegetation analysis by Grigal and Goldstein (1971). Vegetation of the Walker Branch watershed in Oak Ridge, Tennessee, was classified to distinguish the predominant types. Grigal and Goldstein classified the tulip poplar, oak-hickory, chestnut oak, and pine types as relatively distinct "core" groups based upon their consistent separation in each of four classification procedures. Canonical analysis completely separated each of the core groups along the first two canonical axes, indicating that the groups were distinct.

Canonical analysis was used in the central region of the Great Smoky Mountains National Park by Golden (1974). He classified a number of vegetation types which composed a complex vegetation pattern. Golden found that there was considerable overlap of some types. Certain types representing the Cove Hardwood forest community were clustered along the first two canonical axes.

Results

The white pine-red maple and the white pine-northern red oak types represent the extremes on the first canonical axis (Figure 4). The white pine-chestnut oak and the white pine-white oak types were distinct along the first axis. Complete overlap occurred between the white pine-hemlock and the white pine-red maple types indicating that they were not readily distinguished. The wide confidence interval of

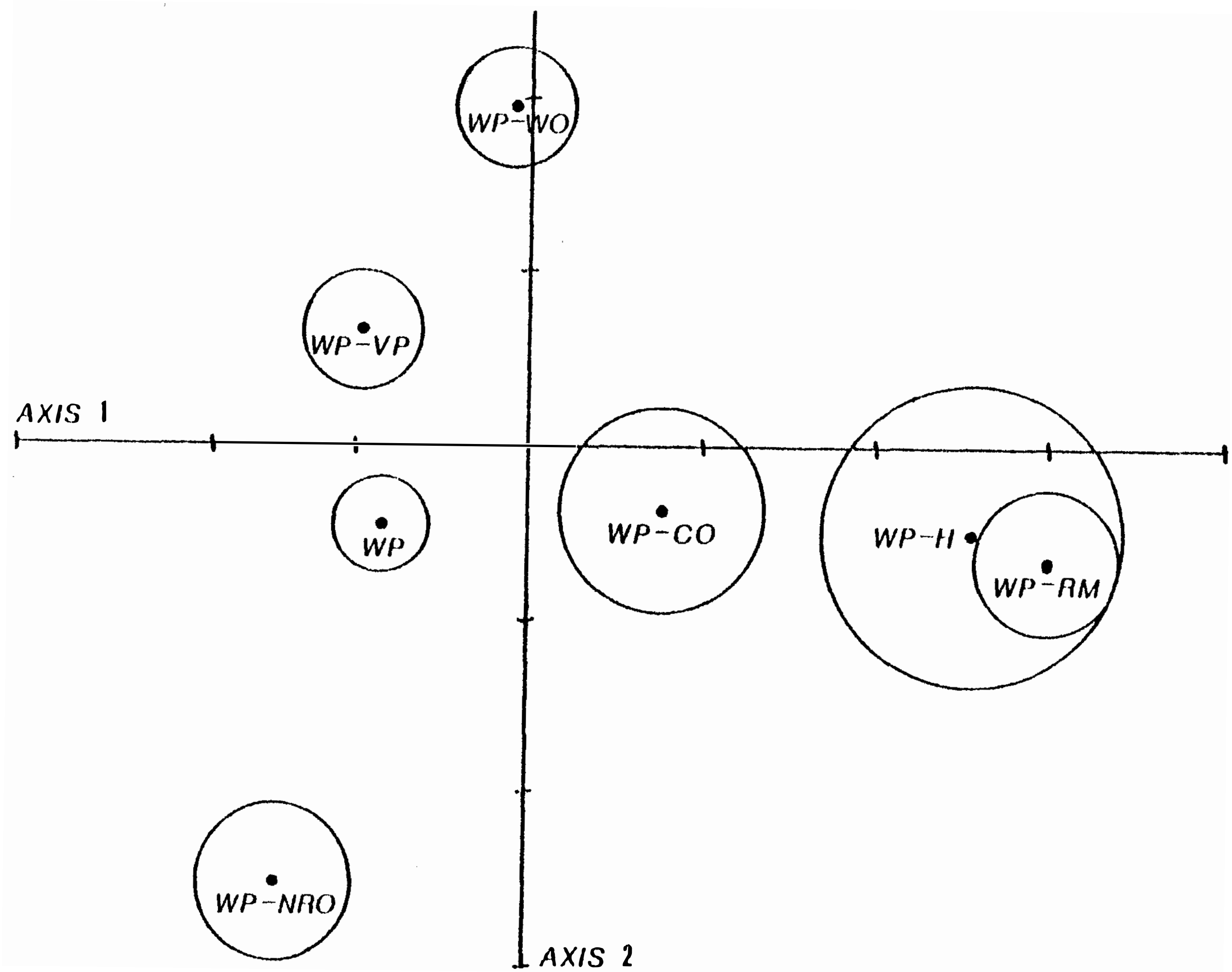

Figure 4. Centroid positions along the first two canonical axes of seven white pine-hardwood types. Circles represent 90 percent confidence intervals around group means.

the white pine-hemlock type was due to the small number of plots (five) which represented the type. The white pine-Virginia pine type overlapped with the white pine type, due to the similarity of species composition between the types. Both the white pine and the white pine-Virginia pine types were grouped close to the white pine-northern red oak type on the first canonical axis. The types in which northern red oak and Virginia pine were important components were not recognized as distinct entities along the first axis.

The sequence of community types on the first axis (x) ranged from white pine-red maple to white pine-northern red oak and may be inferred to be a moisture axis, although other factors may contribute to the differentiation between the groups. The first axis in the discriminant analysis of the vegetation variables contained the group centroids in an order (from left to right) which very closely corresponds to the canonical array of the vegetation types in Figure 4. When compared with the discriminant analysis of the environmental variables in Figure 3, the first canonical axis had some correspondence with the first and second discriminant axes, which were readily interpreted as a moisture scale.

The three vegetation types that were distinct along the second axis were the white pine-northern red oak, the white pine-Virginia pine, and the white pine-white oak types. Considerable overlap occurred on the second axis with the other four types being tightly clustered. The second axis was not environmentally interpretable.

Canonical analysis results displayed the arrangement of the seven vegetation types along the first two canonical axes. All the types were distinct except for the white pine-red maple and the white

pine-hemlock types which overlapped on both axes. This procedure demonstrated the value of canonical analysis in illustrating the level of distinctness of the groups determined by the cluster analysis classification scheme.

CHAPTER X

REGRESSION ANALYSIS OF WHITE PINE DIAMETER-AGE RELATIONSHIPS

Introduction

The diameter distribution of white pine may be of considerable value for inferring the age distribution and the stand history of a forest. It has been established for some species that even-aged stands have normal (bell shaped) diameter distributions (Baker, 1923 and Hough, 1932) around the mean diameter. Lorimer (1976) found that an all-aged forest often has a normal distribution of diameters with different means and variances for each age class. Assuming a balanced age structure, each successive class would have progressively fewer trees than the preceding class. Lorimer described the diameter distribution of an all-aged stand as a series of overlapping normal curves of decreasing height and increasing variance since variance in diameter growth increases with age.

Diameter distributions may be utilized to infer the type of age structure within a forest stand. However, Hough (1932) warned that care should be taken when including diameter distributions of suppressed or shade tolerant understory species. In order to accurately utilize diameter distributions, a direct sampling of ages is necessary for predicative purposes. Hough further advised that stands with few sample cores may not show a normal distribution, but a group of samples should provide adequate dispersion of sizes around an average diameter.

Regression procedures are descriptive statistics which are performed on sample data in order to generalize characteristics of a

population (Nie et al., 1975). Generally the first step in regression analysis is to find the best linear prediction equation and evaluate its prediction accuracy. In simple linear regression (with two variables) values of the dependent variable are predicted from a linear function of the form: $Y' = A+BX$ where Y' is the estimated value of the dependent variable Y, B is a constant by which all values of the independent variable X are multiplied, and A is a constant which is referred to as the Y-intercept (Nie et al., 1975). The difference between the actual and the estimated value of Y for each case is called the residual or the error in prediction and is represented by the expression: $Y-Y'$. The predicted Y' values fall along the regression line and the vertical distances of the points from the line represent the residuals $(Y-Y')$ or the errors in prediction.

The strength and direction of the relationship is explained by the correlation coefficient r and the coefficient of determination R^2. The sign of r indicates the direction of the relationship, and the absolute value of r can be used as an index of one's confidence in the relationship (Nie et al., 1975). However, since R^2 indicates the proportion of variation in age explained by diameter at breast height in this study, it has a clearer interpretation as an index of the relationship. The average size of the residuals are used as a basis for most of the summary statistics such as the R^2 and the standard error of estimate. A direct examination of residuals in a scatterplot provides a visible pattern of the actual variation within a data set where the vertical axis represents the residuals (age) and the horizontal axis (diameter) represents the variable against which the residuals are being plotted. For example, a wide scatter in the

residuals at the upper limits of diameter size would indicate that the cores from large trees were subject to greater age variability.

Underlying relationships may be analyzed through polynomial regression. Regression lines are fitted curves which simply represent the best mathematical fit calculated for an observed data set. In this approach, successive powers of the predictor variable are inserted into the equation along with the original predictor. The general form of a polynomial equation is: $Y' = A + B_1X + B_2X^2 + B_3X^3 + \ldots$. Polynomial regression equations are described by the number of exponents used in the equation. For example, if the cube was the highest exponent, then the equation would be a third degree polynomial. As increasing powers of X are used, the curve becomes more complex and may fit a given set of data increasingly well. The number of inflection points in the fitted line are related to the number of degrees in the polynomial equation. The maximum number of inflection points are one less than the degree of the polynomial equation. Additional degrees increase the R^2 coefficient, implying that the fit of the equation improves with additional exponents (Sokal and Rohlf, 1969). Increases in the R^2 coefficient may become inconsequential after a certain point, and it is advisable to check the significance of additional exponents to the polynomial. With each added power of X, the mean square over which the regression mean square must be tested loses another degree of freedom. The criteria used for selecting regression models for reliability is an F-test. For most biological work, terms of X no higher than the cube are used (Sokal and Rohlf, 1969 and Nie et al., 1975).

Results

Simple linear regression was first utilized on the total set of 209 white pine increment cores. The associated statistics are in Table 32. The coefficient of determination value was low ($R^2 = 0.209$) indicating that the age variance was large. Linear regression did not account for much of the variation in the age and diameter relationship based upon the R^2. If there is no indication about the functional form of the data set a polynomial equation may yield a good approximation of the relationship (Miller and Freund, 1965). The natural log transformation is also often used to improve the R^2 value. Table 32 contains the statistics for the third degree polynomial and the natural log transformation of the diameter for the total sample. There were no significant improvements of the fit over the original linear equation. The inference is that differences in tree size are attributed to corresponding differences in age, although trees of the same age may differ greatly in size when grown in different environmental conditions. A scatterplot of the residuals failed to discriminate any difference in residual age over the entire range of diameter distributions.

The high variance of the residuals and the relatively poor fit obtained from the regression analysis prompted the writer to break the data set into more easily interpretable and functional units. Seven white pine-hardwood types had been distinguished in this analysis based upon vegetation and environmental characteristics. In an attempt to improve the predictive potential of the age determined from diameter at breast height, the increment cores were grouped based upon their community affiliation.

Simple linear regression analyses were conducted on six of the

Table 32. Regression Analysis on the Total Increment Core Sample. N=209.

Analysis	A	B	S.E.E.	R^2
Simple Linear Regression $Y' = A + BX$	37.37	0.73	18.98	0.209
Polynomial Regression $Y' = A+B_1X^1+B_2X^2+B_3X^3$	35.42	B_1= .83 B_2= .00094 B_3=-.00004	19.05	0.211
Simple Regression natural log of diameter $Y' = A + B (\ln X)$	-04.41	19.39	18.94	0.212

seven white pine-hardwood types. Only three cores represented the white pine-hemlock community, so the type was eliminated from further analysis. Table 33 includes the simple linear regression statistics calculated for each white pine community type. The white pine-chestnut oak type sample contained only 10 cores of limited diameter range and the white pine-northern red oak type contained only 13 cores. Since the statistics of the regressions of the two types were very similar (Table 33), they were pooled to increase sample size. The types were distinct environmentally but had many site and soil similarities (Appendix A, Tables 35, 39, and 41). The simple linear regression for the pooled data gave an intermediate linear fit (Table 33).

The slope of the linear equations was similar for most of the types except for the white pine-red maple and the white pine-white oak types which were distinctly different. The white pine-red maple type had a slope of 0.32, indicating a suppressed growth rate in comparison with the other vegetation types. The reduced growth rate may be attributed to competition between white pine and the associated pioneer species (red maple and tulip poplar) in this type. The white pine-white oak type had a slope of 1.30 which was higher than the other types in the analysis. This type contained the oldest white pines cored (179 and 183 years old). The white pine-white oak plots occurred on a diversity of sites and had variable periods of establishment which may contribute to the superior growth rate.

Scatterplots of the increment core ages and diameters from several vegetation types suggested that there may be a curvilinear trend in the relationships. Several regression models were tested for each community type in order to determine the equation which supplied the

Table 33. Simple Linear Regression Analysis of Age and Diameter Relationships on Trees from the White Pine-Hardwood Types[a].

	N	Mean Diameter	Mean Age	A	B	S.E.E.	R^2
WP-VP	45	25.0	48	29.65	0.74	14.18	0.34
WP-RM	26	32.7	58	47.28	0.32	15.37	0.12
WP-WO	49	27.8	64	27.94	1.30	25.13	0.26
WP	63	25.6	57	41.18	0.63	16.10	0.19
WP-CO	10	24.0	57	37.88	0.80	11.51	0.35
WP-NRO	13	29.2	50	25.60	0.84	7.50	0.77
Pooled: WP-CO and WP-NRO	23	26.9	53	32.99	0.75	10.62	0.49

[a]Abbreviations: WP=white pine, VP=Virginia pine, RM=red maple, H=hemlock, CO=chestnut oak, WO=white oak, and NRO=northern red oak.

best fit, explained the maximum amount of variance, and best described the actual biological phenomena.

The white pine-Virginia pine type had a coefficient of determination of 0.38 calculated for the natural log transformation and 0.42 for the third degree polynomial (Table 34). The polynomial provided a superior fit, and it was significant at the P = .001 level. A plot of the residuals revealed that predicted age was most accurate among diameters ranging from 17 to 40 cm. The tree diameters under 17 cm were probably variously subjected to suppression from the canopy constituents and were thus quite variable. The larger cores (from 40 to 55 cm) had increased variance due to their greater age and variable growing conditions (Gates and Nichols, 1930). The oldest tree cored in this type was 86 years of age.

The linear equation and the natural log transformation for the white pine-red maple type had low R^2 values of 0.12 and 0.13 respecttively. Based upon the similarity of R^2 values, the linear fit was preferred because of its interpretability (Table 34). A plot of the residuals revealed that the predicted age was slightly more accurate in the 11 to 21 cm diameter class. The overall relationship contained a large variance for diameters over 21 cm. The white pine-red maple type had a low R^2 due to a variable period of release. The successional nature of the type was variable; sites originated from old fields, selectively logged areas, and burns. The oldest increment core obtained from this type was 87 years of age.

The pooled white pine-chestnut oak and white pine-northern red oak types had an R^2 of 0.49 calculated for both the linear equation and the second degree polynomial (Table 34). The polynomial equation

Table 34. Regression Analysis on the White Pine-Hardwood Types

	A	B_1	B_2	B_3	S.E.E.	R^2
White Pine-Virginia Pine Type (N=45)						
Polynomial $Y'=A+B_1X^1+B_2X^2+B_3X^3$	2.01	4.83	-0.16	0.002	13.69	0.42
Transformation $Y'=A+B\ (\ln X)$	- 4.52	17.29			13.83	0.38
White Pine-Red Maple Type (N=26)						
Transformation $Y'=A+B\ (\ln X)$	19.95	11.27			15.34	0.13
Simple Linear $Y'=A+BX$	47.28	0.32			15.37	0.12
White Pine-Chestnut Oak and White Pine-Northern Red Oak Types Pooled (N=23)						
Simple Linear $Y'=A+BX$	32.99	0.75			10.62	0.49
Polynomial $Y'=A+B_1X^1+B_2X^2$	35.73	0.55	0.003		10.87	0.49
White Pine-White Oak Type (N=49)						
Polynomial $Y'=A+B_1X^1+B_2X^2+B_3X^3$	- 1.66	7.27	-0.30	0.004	22.17	0.45
White Pine Type (N=63)						
Polynomial $Y'=A+B_1X^1+B_2X^2+B_3X^3$	-13.25	7.86	-0.28	0.003	15.46	0.28

was significant at the P = .001 level but failed to account for any additional variance beyond that of the linear equation. A plot of the residuals revealed that the predicted age was more accurate using diameter size classes greater than 20 cm. It is conceivable that the larger white pines grew in adequate light, but the smaller white pines in the understory were variously subjected to suppression.

The white pine-white oak type had the best fit with a third degree polynomial, giving an R^2 of 0.45. The equation was significant at the P = .001 level (Table 34). The plotted residual values of the type showed that the predicted age was most accurate in the 10 to 30 cm diameter class. There was greater variance in the larger white pine diameters. Several white pines were very old (124, 179, and 183 years of age) yet their diameters did not exceed 55 cm. Gates and Nichols (1930) referred to the fact that youthfulness in trees growing suppressed under a forest canopy can be misleading unless increment cores are analyzed. The extreme age differences contributed to the variance in the residuals of the larger tree diameters.

A third degree polynomial gave the best fit to the data from the white pine type. The R^2 was 0.28 and the equation was significant at the P = .005 level (Table 34). A plot of the residuals revealed that the predicted age was highly variable among all diameters but was least accurate among diameters ranging from 35 to 52 cm. The white pine type was widely scattered throughout the sampling area and had good regeneration in all strata, indicating the potential for all-aged stands. In an all-aged stand, variable suppression of each individual before it grows to canopy size would account for a large variance among diameters.

A third-degree polynomial provided the best fit for the following

types: white pine-Virginia pine, white pine-white oak, and white pine. The negative B_2 term in the regression equation of each type induced a downward inflection which leveled the fitted curve. The leveling of the fitted curve may represent suppression, and the eventual upswing may be attributed to the subsequent release. Segments of the white pine-Virginia pine and white pine types had successful reproduction throughout the various strata, and the all-aged stands were undoubtedly undergoing suppression. The white pine-white oak type contained the oldest increment cores of white pine which were obtained from trees under 55 cm in diameter at breast height. From the great age of these moderate sized white pine, it can be inferred that suppression had affected several of the white pine-white oak sample plots.

The equations from the white pine-hardwood types can be used to predict the approximate age of white pine from diameter measurements. The small R^2 coefficients among most of the vegetation types was due to the wide range of site and soil conditions, stand densities, and competing species. Natural genetic variability would also contribute to a reduced R^2 coefficient.

Kimberly (1933) and Barrett (1933) worked on age-diameter relationships on white pine in the southern Appalachians and found that it grows more rapidly and to larger dimensions in the southern extremes of its range. Gates and Nichols (1930) reported that second growth stands which exhibit a marked diversity of size classes may be found to belong to the same relative age class. Hough (1932) sampled white pine stands in northwestern Pennsylvania and found that they were predominantly even-aged in both second growth and in "virgin" stands. He hypothesized that the old growth white pine forests originated in relatively even-aged

stands through the operation of catastrophic events.

Based upon the regression analysis calculated for several of the white pine-hardwood types, it is clear that many factors contributed to the variability of diameter growth. The role of white pine as a natural replacement species in disturbed areas has been well documented. It is assumed that the white pine-Virginia pine, white pine-red maple, white pine-hemlock, and portions of the white pine type are represented by predominantly even-aged stands resulting from large scale disturbance. The white pine-oak types and portions of the white pine type may more closely represent an all-aged forest in which small scale disturbances permit the periodic release and the subsequent long-term persistence of white pine in the vegetation.

CHAPTER XI

SUMMARY AND CONCLUSIONS

This study involved the analysis of data from 144 sample plots at elevations ranging from 312 to 716 meters (1,025 to 2,350 feet) in the western portion of the Great Smoky Mountains National Park. Circular 0.0406 hectare (1/10 acre) plots were placed in areas which had been previously mapped by Miller in 1941. The vegetation of the canopy (over 10 cm), sapling (2.5 to 10 cm), subsapling (under 2.5 cm), and seedling-shrub-herb strata were tallied within each sample plot. Basal areas, stem densities, relative basal areas, relative densities, and importance values were calculated for the canopy and sapling strata. Site and soil data characteristics were determined from field measurements and laboratory analyses.

All of the white pine-hardwood types were represented by a variety of aspects, and no type was restricted to a particular exposure. Slope position was highly variable and white pine-hardwood types occurred on dry ridges, middle slope positions, and along floodplains. Forty-three tree taxa occurred in the analysis, and the canopy stem densities ranged from 963 stems/ha in the white pine-white oak type to 1099 stems/ha in the white pine type. Canopy basal areas ranged from 55.7 to 64.3 m^2/ha within the white pine-hemlock and white pine-white oak types respectively.

Evidence of disturbance was observed in 45 percent of the plots and was most common in the white pine-Virginia pine and the white pine-red maple types. Historically *Pinus strobus* has been one of the prime timber resources in the eastern United States, and with the long history

of settlement in the southern Appalachians, it is suspected that white pine was logged on a small scale by pre-Park settlers. In the Park, clearing occurred even into small coves, especially around homesteads to make fields. Since white pine was a favored species, it was undoubtedly sought where it occurred in abundance, specifically in the various white pine-hardwood stands.

Castanea dentata sprouts were noted in four percent of the plots and were absent in the white pine-hemlock and white pine-chestnut oak types. It does not seem likely that chestnut death is responsible for anything more than minimal white pine increases since the 1930's.

Canopy importance values were used to group the sample plots into vegetation types with the agglomerative clustering procedure suggested by Orloci (1967). Seven types resulted from separating groups at the 55 percent dispersion level and were named according to the one or two taxa with the highest average importance values. The types were: white pine-Virginia pine, white pine-red maple, white pine-hemlock, white pine-chestnut oak, white pine-white oak, white pine-northern red oak, and white pine.

The white pine-Virginia pine type occurred on northwestern aspects, and soil textures were loamy. The type occurred on sites of relatively recent disturbance. Half of the plots had been cultivated (Ap horizons were noted), and the remainder were probably logged or burned. There were two segments of the type, resulting from both old field abandonment and natural disturbance, notably fire. Virginia pine is a temporary species and will be replaced by red maple, hemlock, and sourwood which are all increasing in the understory. Portions of this type may develop into the white pine-red maple type.

The white pine-red maple type occurred on lower slope positions with aspects ranging from northwest to northeast. Textures were generally loams and sandy loams; no Ap horizons were observed. Red maple occurs as a pioneer on disturbed sites, and many of the sample plots had evidence of logging, grazing, and burning. Canopy composition resembled the white pine-Virginia pine type but was distinguished by a higher diversity and the presence of several mesophytes (*Ostrya virginica*, *Tilia heterophylla*, and *Ulmus rubra*). The continued reproduction of hemlock, red maple, and white pine suggests this community may ultimately be dominated by hemlock with a composition similar to the white pine-hemlock type.

Plots dominated by white pine and hemlock occurred on northwesterly and northeasterly aspects on steep and protected middle and lower slopes. The high stone volume and the shallow profile thickness contributed to the low total water availability. White pine occurred in the canopy and sapling layers but was not in the lower strata. Hemlock was predominant in each stratum, and the pattern suggests that it will continue to increase in dominance. The sample plots represent disturbed remnants of other community types, but with the cumulative evidence, it appears that hemlock will become the dominant with white pine as a long-lived codominant or associate species.

The white pine-chestnut oak type occurred on steep upper slopes and on ridge tops over a variety of aspects. Textures were generally sandy loams, and no Ap horizons were observed. White pine ranked consistently high in all strata, and chestnut oak reproduction was low in the sapling and seedling strata. The type occurred on sites that had been selectively logged or that were relatively undisturbed. The

vegetation type appeared to be stable, and the Society of American Foresters (1954) contended that the successional nature of the type was not known. The type may represent either a long-lived subclimax community or a mature stable forest.

The white pine-white oak type occurred on all aspects and soil textures were sandy loams and loams in the A horizon. Due to the profile thickness and the low stone volume soils, this type had the highest total water availability. White oak was well-distributed throughout the various size classes, and reproduction appeared sufficient to insure its continued dominance. White pine reproduction was significant in all strata, and it consistently had one of the highest relative densities in each stratum. The white pine-white oak type occupied sites that had a variety of perturbations, as well as sites that were undisturbed. With the climax potential of white oak and the longevity of white pine, this community type may be stable for long periods of time.

The white pine-northern red oak type occurred predominantly on large ridges and middle and upper slopes with northwestern and southeastern aspects. Soil textures were loams and sandy loams in the A horizon, and an Ap horizon was observed in a single plot. Based upon the prominence of white pine in all the strata, it will probably remain as a long-term dominant. Northern red oak reproduction was moderate in the seedling layer but was poor or absent in the subsapling and sapling strata, which may be attributed to its periodic seed production. It is likely that northern red oak will remain as a dominant within the type. The type occurred on sites of limited human disturbance, and the majority of sample plots contained no evidence of disturbance. The type may be considered as a long-lived subclimax type which may be successional to

either a white pine-hemlock or a northern hardwood-hemlock type.

The white pine type was dominated by white pine (importance values over 50) and occurred throughout the study area. The type covered a wide range of slope positions but seldom occurred in coves or along floodplains. Textures were loams and sandy loams in the A horizon. The white pine type had a wide diversity of canopy associates, but only red maple and hemlock were significantly represented in the various strata. White pine was maintaining its dominance throughout all diameter classes and appeared to be stable. The sample plots had variable levels of disturbance but most ridge sites were relatively undisturbed. Human-induced perturbations occurred on approximately one-half of the plots, and the other one-half occurred on upper slope and ridge positions. The type may represent a climax type based upon the long-lived nature of white pine, its ability to survive moisture stress and the frequency of natural disturbance (blowdown and fire), insuring successful regeneration.

The discreteness of the plot groups was tested by discriminant analysis using vegetation data, and 95 percent of the groups were correctly classified. Many of the types were less distinct on an environmental basis. Discriminant analysis using selected environmental variables indicated that some types were not as distinct, with only 41 percent of the plots correctly classified. The selected environmental variables did a reasonable job of discriminating group membership. The low level of classification may be attributed to the successional relationships of the types or perhaps due to the operation of unmeasured variables. The first and second discriminant functions (axes one and two) were related to soil moisture and plot position conditions. The

most discriminating environmental variables were soil texture, stone percentage, horizon thickness, total available water, plot position, and the distance from the nearest draw, which were all related to a moisture index.

The distinctness of the types was tested by canonical analysis. The white pine-chestnut oak and white pine-white oak types were distinct along the first axis of the canonical analysis. Complete overlap occurred between the white pine-red maple and the white pine-hemlock types on the first axis. The sequence of types along the first axis was similar to the array of types on the environmental discriminant analysis axes, suggesting that soil moisture condition was the major factor differentiating the white pine community types. Other gradient analyses that have been conducted in the Park have yielded similar results regarding the differentiation of vegetation types based on a moisture index (Whittaker, 1956 and Golden, 1974).

LITERATURE CITED

LITERATURE CITED

Abbott, H. G. and T. F. Quink. 1970. Ecology of eastern white pine seed caches made by small forest mammals. Ecology 51:271-278.

Adams, D. W. 1911. Report on the lands of the Shaefer estate, 21,000 acre tract, Johnson County, Tennessee. U.S. Forest Service. Unpublished manuscript.

Ashe, W. W. 1922. Forest types of the Appalachians and White Mountains. J. Elisha Mitchell Sci. Soc. 37:183-198.

Ayres, H. B. and W. W. Ashe. 1905. The southern Appalachian forest. U.S. Geol. Surv. Prof. Paper 37. 291 pp.

Baker, F. S. 1923. Notes on the composition of even-aged stands. J. Forestry 21:712-717.

Ball, J. C. 1949. Association of white pine with other forest tree species and Ribes in the southern Appalachians. J. Forestry 47:285-291.

Barclay, F. H. 1957. The natural vegetation of Johnson County, Tennessee past and present. Ph.D. Dissertation, Univ. of Tenn., Knoxville, 146 pp.

Barr, A. J., J. H. Goodnight, J. P. Sall, and J. T. Helwig. 1976. A user's guide to SAS. SAS Institute, Raleigh, N.C. 329 pp.

Barrett, J. W., C. E. Farnsworth, and W. Rutherford, Jr. 1962. Logging effects on regeneration and certain aspects of microclimate in northern hardwoods. J. Forestry 60:630-639.

Barrett, L. I. 1933. Growth rate of northern white pine in the southern Appalachians. J. Forestry 31:570-572.

Bates, A. L. and E. Thor. 1970. Mixed species plantations: Composition and growth as related to soil-site characteristics. J. Forestry 68:234-236.

Beers, T. W., P. E. Dress, and L. C. Wensel. 1966. Aspect transformation in site productivity research. J. Forestry 64: 691-692.

Berry, C. R. 1961. White pine emergence tipburn, a physiogenic disturbance. U.S.D.A. Forest Service Southeastern Forest Exp. Sta., Asheville, N.C. Station Paper 130, 8 pp.

Bogucki, D. J. 1972. Intense rainfall in the Great Smoky Mountains National Park. J. Tenn. Acad. Sci. 47:43-97.

Bormann, F. H. 1965. Changes in the growth pattern of white pine trees undergoing suppression. Ecology 46:269-277.

Bourdeau, P. F. and M. L. Laverick. 1958. Tolerance and photosynthesis adaptability to light intensity in white pine, red pine, hemlock and Ailanthus seedlings. Forest Science 4:196-207.

Braun, E. L. 1950. Deciduous forests of eastern North America. Blakiston Co., Philadelphia. 596 pp.

Braun-Blanquet, J. 1932. Plant sociology, the study of plant communities. Trans. by G. D. Fuller and H. S. Conard. McGraw-Hill, New York. 439 pp.

Bryan, M. B. 1956. A simplified method of correcting for slope on circular sample plots. J. Forestry 54:442-445.

Burnham, C. F., M. J. Ferree, and F. E. Cunningham. 1947. The white pine-oak forests of the anthracite region. U.S.D.A. Northeastern Forest Exp. Sta., Philadelphia, Pa. Station Paper 8, 35 pp.

Burton, J. D. 1964. Twenty years of growth of the Norris Watershed plantations. J. Forestry 62:392-397.

Cain, S. A. 1930a. An ecological study of the heath balds of the Great Smoky Mountains. Butler Univ. Bot. Studies 1:177-208.

Cain, S. A. 1930b. Certain floristic affinities of the trees and shrubs of the Great Smoky Mountains and vicinity. Butler Univ. Bot. Studies 1:129-150.

Cain, S. A. 1931. Ecological studies of the vegetation of the Great Smoky Mountains of North Carolina and Tennessee. I. Soil reaction and plant distribution. Bot. Gaz. 91:22-41.

Cain, S. A. 1937. Ecological work on the Great Smoky Mountains region. J. Southern Appalachian Bot. Club 1:25-32.

Cain, S. A. 1943. The tertiary character of the cove hardwood forests of the Great Smoky Mountains National Park. Bull. Torr. Bot. Club 70:213-235.

Camp, W. H. 1931. The grass balds of the Great Smoky Mountains of Tennessee and North Carolina. Ohio J. Sci. 31:157-164.

Caplenor, D. 1965. The vegetation of the gorges of the Fall Creek Falls State Park in Tennessee. J. Tenn. Acad. Sci. 40:27-39.

Clements, F. E. 1928. Plant succession and indicators. Wilson, New York. 453 pp.

Colvin, W. S. and W. S. Eisenmenger. 1943. Relationships of natural vegetation to the water holding capacity of the soils of New England. Soil Sci. 55:433-445.

Cooper, W. S. 1922. The ecological life history of certain species of Ribes and its application to the control of white pine blister rust. Ecology 3:7-16.

Cope, J. A. 1932. Northern white pine in the southern Appalachians. J. Forestry 30:821-828.

Core, E. L. 1938. Plant migrations and vegetational history of the southern Appalachian region. Lilloa 3:5-29.

Curtis, J. D. 1943. Some observations on wind damage. J. Forestry 41:877-882.

Curtis, J. T. 1959. The vegetation of Wisconsin. Univ. Wis. Press, Madison. 657 pp.

Daubenmire, R. 1966. Vegetation: Identification of typal communities. Science 151:291-298.

Day, F. P., Jr. and C. D. Monk. 1974. Vegetation patterns on a southern Appalachian watershed. Ecology 55:1064-1074.

Day, P. R. 1956. Report of the committee on physical analysis, 1954-1955. Soil Sci. Soc. Amer. Proc. 20:167-169.

DeYoung, H. R. 1973. The effect of air pollution on plants. Maryville College Independent Study. 79 pp. (Typed).

Dickson, R. R. 1959. Some climate altitude relationships in the southern Appalachian Mountain region. Bull. Amer. Meterological Soc. 40:352-359.

Doolittle, W. T. 1958. Site index comparisons for several forest species in the southern Appalachians. Soil Sci. Soc. Amer. Proc. 22:455-458.

Downs, A. A. 1943. Response of eastern white pine reproduction in the southern Appalachians to liberation. J. Forestry 41:279-281.

Duppstadt, W. H. 1972. Flora of Bedford County, Pennsylvania. I. Plant Communities. Castanea 37:86-94.

Edens, D. L. and S. W. Ash. 1969. The development of a white pine stand in a bog environment at Cranberry Glades, West Virginia. Castanea 34:204-210.

Elder, J. A., S. R. Bacon, R. L. Flowers, T. R. Love, J. A. Phillips, G. M. Thompson, and D. A. Tucker. 1953. Soil survey of Blount County, Tennessee. U.S.D.A Soil Conservation Service, Washington, D.C. 119 pp.

Ellertsen, B. W., C. J. Powell, and C. L. Massey. 1972. Report on study of diseased white pine in east Tennessee. Tennessee Valley Authority. 13 pp.

Fenneman, N. M. 1938. Physiography of eastern United States. McGraw-Hill, New York. 714 pp.

Fowells, H. A. (Ed.). 1965. Silvics of forest trees of the United States. U.S.D.A, Forest Service, Agr. Handbook 271. 762 pp.

Frank, E. C. and R. Lee. 1966. Potential solar beam irradiation on slopes: Tables for 30° to 50° latitude. U.S. Forest Serv. Res. Pap. RM-18. 116 pp.

Fribourg, H. A., R. H. Strand, J. V. Vaiksnoras, and J. M. Safley. 1973. Precipitation probabilities for east Tennessee. Univ. Tenn. Agri. Exp. Sta. Bull. 512. 40 pp.

Frothingham, E. H. 1915. The northern hardwood forest: its composition, growth, and management. U.S.D.A. Bull. 285. 17 pp.

Fuller, R. D. 1977. Why does spruce not invade the high elevation beech forests of the Great Smoky Mountains? M.S. Thesis, Univ. of Tenn., Knoxville. 65 pp.

Gant, R. E. 1978. The role of alletopathic interference in the maintenance of southern Appalachian heath balds. Ph.D. Dissertation, Univ. of Tenn., Knoxville. 123 pp.

Gates, F. C. and G. E. Nichols. 1930. Relation between age and diameter in trees of the primeval northern hardwood forest. J. Forestry 28:395-398.

Gleason, H. A. 1926. The individualistic concept of the plant association. Bull. Torr. Bot. Club 53:7-26.

Golden, M. S. 1974. Forest vegetation and site relationships in the central portion of the Great Smoky Mountains National Park. Ph.D. Dissertation, Univ. of Tenn., Knoxville. 275 pp.

Goldstein, R. A. and D. F. Grigal. 1972. Computer programs for the ordination and classification of ecosystems. Ecol. Sci. Div. Publ. No. 417. Oak Ridge National Lab., Oak Ridge, Tenn. 125 pp.

Graber, R. E. 1970. Natural seed fall in white pine (Pinus Strobus L.) stands of varying density. U.S. Forest Serv., Northeastern Forest Exp. Sta. Research Note NE-119. 6 pp.

Graham, S. A. 1941. Climax forests of the upper peninsula of Michigan. Ecology 22:355-362.

Grant, M. L. 1934. The climax forest community in Itasca County, Minnesota, and its bearing upon the successional status of the pine community. Ecology 15:243-257.

Grigal, D. G. and R. A. Goldstein. 1971. An integrated ordination-classification analysis of an intensively sampled oak-hickory forest. J. Ecol. 59:481-492.

Hazard, H. B. 1937. Plant indicators of pure white pine sites in southern New Hampshire. J. Forestry 35:477-486.

Hesler, L. R. 1962. List of fungi of the Great Smoky Mountains National Park. Botany Dept., Univ. of Tenn., Knoxville. 83 pp. (Typed).

Hinkle, C. R. 1975. A preliminary study of the flora and vegetation of Cumberland Gap National Historical Park, Middlesboro, Kentucky. M.S. Thesis, Univ. of Tenn., Knoxville. 236pp.

Hinkle, C. R. 1978. The classification and ecological analysis of forest communities occurring on the Cumberland Plateau of Tennessee including flat to rolling upland and ravine topography. Ph.D. Dissertation, Univ. of Tenn., Knoxville. 262 pp.

Hoffman, H. L. 1964. Check list of vascular plants of the Great Smoky Mountains. Castanea 29:1-45.

Hoffman, H. L. 1966. Supplement to checklist, vascular plants, Great Smoky Mountains. Castanea 31:307-310.

Hough, A. F. 1932. Some diameter distributions in forest stands of northwest Pennsylvania. J. Forestry 30:933-943.

Hursh, C. R. and F. W. Haasis. 1931. Effects of 1925 summer drought on southern Appalachian hardwoods. Ecology 12:380-386.

Ineson, F. A. and M. J. Ferree. 1948. The anthracite forest region--a problem area. U.S.D.A. Miscellaneous Publ. No. 648, Northeastern Forest Exp. Sta. 71 pp.

Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 498 pp.

Kephart, H. 1936. The Cherokees of the Smoky Mountains. Westland Printing Co., Silver Springs, Md. 36 pp.

Kercher, J. R. and R. A. Goldstein. 1977. Analysis of an east Tennessee oak-hickory forest by canonical correlation of species and environmental parameters. Vegetatio 35:153-163.

Kimberly, J. T. 1933. Growth rate of white pine in the southern Appalachians and New England. J. Forestry 31:946-947.

King, P. B., R. B. Neuman, and J. B. Hadley. 1968. Geology of the Great Smoky Mountains National Park, Tennessee and North Carolina. U.S. Geol. Sur. Prof. Pap. 587. 23 pp.

King, P. B. and A. Stupka. 1950. The Great Smoky Mountains--their geology and natural history. Sci. Month. 61:31-43.

Kuykendall, N. W. 1978. Composition and structure of replacement forest stands following southern pine beetle infestations as related to selected site variables in the Great Smoky Mountains. M.S. Thesis, Univ. of Tenn., Knoxville. 122 pp.

Lambert, R. S. 1960. Logging in the Great Smoky Mountains. Report to the Park Superintendent. Typewritten manuscript. 12 pp.

Lorimer, C. G. 1976. Stand history and dynamics of a southern Appalachian virgin forest. Ph.D. Dissertation, Duke Univ. 201 pp.

Lutz, H. J., J. B. Ely, and S. Little. 1937. The influence of soil profile horizons on root distribution of white pine. Yale Univ. School of Forestry Bull. 44. 57 pp.

Lutz, H. J. and A. L. McComb. 1935. Origin of white pine in virgin forest stands of northwestern Pennsylvania as indicated by stem and basal branch features. Ecology 16:252-256.

Maissurow, D. K. 1935. Fire as a necessary factor in the perpetuation of white pine. J. Forestry 33:373-378.

Mann, L. R. 1977. Discriminant analysis of some east Tennessee forest herb niches. M.S. Thesis, Univ. of Tenn., Knoxville. 107 pp.

Martin, W. H. 1966. Some relationships of vegetation to soil and site factors on Wilson Mountain, Morgan County, Tennessee. M.S. Thesis, Univ. of Tenn., Knoxville. 134 pp.

Martin, W. H. 1971. Forest communities of the Great Valley of East Tennessee and their relationship to soil and topographic properties. Ph.D. Dissertation, Univ. of Tenn., Knoxville. 387 pp.

McCarthy, D. M. 1976. Numerical techniques for classifying forest communities in the Tennessee Valley. Ph.D. Dissertation, Univ. of Tenn., Knoxville. 164 pp.

McCord, R. A. 1976. The application of r- and k- selection concepts to herbaceous plants. M.S. Thesis, Univ. of Tenn., Knoxville. 119 pp.

McGinnis, J. T. 1958. Forest litter and humus types of east Tennessee. M.S. Thesis, Univ. of Tenn., Knoxville. 82 pp.

McGregor, W. H. D. and P. J. Kramer. 1963. Seasonal trends in rates of photosynthesis and respiration of loblolly pine and white pine seedlings. Amer. J. Bot. 50:760-765.

McIntosh, R. P. 1967. The continuum concept of vegetation. Bot. Rev. 33:130-187.

Miller, F. H. 1938. Brief narrative descriptions of the vegetative types in the Great Smoky Mountains National Park. Typewritten manuscript. 17 pp.

Miller, F. H. 1941. Vegetation type map: Vegetation cover types of the Great Smoky Mountains National Park. Sugarlands Visitor Center, Gatlinburg, Tennessee.

Miller, I. and J. E. Freund. 1965. Probability and statistics for engineers. Prentice-Hall, Englewood Cliffs, New Jersey. 432 pp.

Minckler, L. S. 1941. Forest plantation success and soil-site characteristics on old fields in the Great Appalachian Valley. Soil Sci. Soc. Amer. Proc. 6:396-398.

Minckler, L. S. 1946. Old field reforestation in the Great Appalachian Valley as related to some ecological factors. Ecol. Monog. 16: 88-108.

Moore, B. 1926. Influence of certain soil and light conditions on the establishment of reproduction in northeastern conifers. Ecology 7:191-220.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, Inc., New York. 547 pp.

Neuman, R. B. and W. H. Nelson. 1965. Geology of the western Great Smoky Mountains, Tennessee. U.S. Geol. Survey Prof. Pap. 349-D. 81 pp.

Nie, N. H., C. H. Hull, J. Jenkins, K. Steinbrenner, and D. H. Bent. 1975. Statistical package for the social sciences. McGraw-Hill, New York. 673 pp.

Nichols, G. E. 1935. The hemlock-white pine-northern hardwood region of eastern North America. Ecology 16:403-422.

Norris, J. M. and J. P. Barkham. 1970. A comparison of some Cotswold beechwoods using multiple-discriminant analysis. J. Ecol. 58: 603-619.

Orloci, L. 1967. An agglomerative method for the classification of plant communities. J. Ecol. 55:193-206.

Patton, E. G. 1955. The development of white pine forest and soil on abandoned farm lands in the North Carolina Blue Ridge. Ph.D. Dissertation, Duke Univ. 90 pp.

Pielou, E. C. 1977. Mathematical ecology. John Wiley and Sons, New York. 385 pp.

Pinchot, G. and W. W. Ashe. 1897. Timber trees and forests of North America. N.C. Geol. Surv. Bull. 6.

Radford, A. E., H. E. Ahles, and C. R. Bell. 1968. Manual of the vascular flora of the Carolinas. Univ. of North Carolina Press, Chapel Hill. 1183 pp.

Raunkiaer, C. 1934. The life forms of plants and statistical plant geography. Oxford Univ. Press. 632 pp.

Rudis, V. A., A. R. Ek, and J. W. Balsiger. 1978. Within-stand seedling dispersal for isolated Pinus strobus within hardwood stands. Canadian Jour. of Forest Research 8:10-13.

Russell, N. H. 1953. The beech gaps of the Great Smoky Mountains. Ecology 34:366-374.

Safford, J. M. 1856. A geological reconnaissance of the state of Tennessee. State Geologist 1st Bienn. Rept. 164 pp.

Safford, J. M. 1869. Geology of Tennessee. S. C. Mercer, Printer to the State, Nashville. 550 pp.

Safley, J. M. 1970. Vegetation of the Big South Fork Cumberland River, Kentucky and Tennessee. M.S. Thesis, Univ. of Tenn., Knoxville. 148 pp.

Schmalzer, P. A. 1978. Classification and analysis of forest communities in several coves of the Cumberland Plateau in Tennessee. M.S. Thesis, Univ. of Tenn., Knoxville. 207 pp.

Shanks, R. E. 1954a. Climate of the Great Smoky Mountains. Ecology 35: 354-361.

Shanks, R. E. 1954b. Reference lists of native plants of the Great Smoky Mountains. Botany Dept., Univ. of Tenn., Knoxville. Mimeographed. 14 pp.

Shanks, R. E. and A. J. Sharp. 1950. Summer key to Tennessee trees. Univ. of Tenn. Press, Knoxville. 24 pp.

Sherman, H. L. 1958. The vegetation and floristics of five gorges of the Cumberland Plateau. M.S. Thesis, Univ. of Tenn., Knoxville. 103 pp.

Shields, A. R. 1977. The Cades Cove Story. Great Smoky Mountains Natural History Association, Gatlinburg. 115 pp.

Smith, L. R. 1977. The swamp and mesic forests of the Cumberland Plateau in Tennessee. M.S. Thesis, Univ. of Tenn., Knoxville. 121 pp.

Society of American Foresters. 1954. Forest cover types of North America. Washington, D.C. 67 pp.

Soil Survey Staff. 1951. Soil survey manual. U.S.D.A. Handbook 18. 503 pp.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Company, San Francisco. 776 pp.

Spaulding, V. M. and B. E. Fernow. 1899. The white pine. U.S.D.A. Div. For. Bull. 22. 185 pp.

Spring, S. N. 1905. The natural replacement of white pine on old fields in New England. U.S.D.A. Bureau of For. Bull. 63. 32 pp.

Stephens, L. A. 1969. A comparison of climatic elements at four elevations in the Great Smoky Mountains. M.S. Thesis, Univ. of Tenn., Knoxville. 119 pp.

Stupka, A. 1964. Trees, shrubs and woody vines of the Great Smoky Mountains National Park. Univ. of Tenn. Press, Knoxville. 186 pp.

Sudworth, G. B. and J. B. Killebrew. 1897. The forests of Tennessee: Their extent, character, and distribution. Tennessee Industrial League. Publishing House of the M.E. Church, South. Nashville.

Swank, W. T. and N. H. Miner. 1968. Conversion of hardwood-covered watersheds to white pine reduces water yield. Water Resour. Res. 4:947-954.

Thomas, R. D. 1966. The vegetation and flora of Chilhowee Mountain. Ph.D. Dissertation, Univ. of Tenn., Knoxville. 355 pp.

U.S. Dept. of Commerce. 1965. Climatic summary of the United States--supplement for 1951 through 1960, Tennessee. Washington, D.C. 82 pp.

Wade, G. L. 1977. Dry phase vegetation of the uplands of the Cumberland Plateau of Tennessee. M.S. Thesis, Univ. of Tenn., Knoxville. 116 pp.

Wells, B. W. 1937. Southern Appalachian grass balds. J. Elisha Mitchell Sci. Soc. 53:1-26.

Whittaker, R. 1956. The vegetation of the Great Smoky Mountains. Ecol. Monog. 26:1-80.

Whittaker, R. H. 1962. Classification of natural communities. Bot. Rev. 28:1-239.

Wood, O. M. 1932. An example of white pine reproduction on burned lands in northeastern Pennsylvania. J. Forestry 30:838-845.

Woods, F. W. and R. E. Shanks. 1959. Natural replacement of chestnut by other species in the Great Smoky Mountains National Park. Ecology 40:349-361.

Wright, J. W. 1970. Genetics of eastern white pine. U.S.D.A. For. Serv. Res. Pap. WO-9. 16 pp.

Wright, J. W., W. A. Lemmien, J. N. Bright, and G. Kowalewski. 1976. Rapid growth of southern Appalachian white pine in southern Michigan. Michigan State Univ. Agric. Exp. Sta., East Lansing. Research Rep. 307. 8 pp.

APPENDICES

APPENDIX A

ENVIRONMENTAL VARIABLES

Table 35. Environmental Categorical Variables[a] by Community Type[b].

	WP-VP N=25	WP-RM N=21	WP-H N=5	WP-CO N=9	WP-WO N=29	WP-NRO N=14	WP N=41
Plot Position							
Ridge	28	5	20	22	28	29	32
Upper slope	36	14		33	14	43	15
Upper mid slope	12	14	20		7	14	12
Mid slope	12	24	40	33	21	7	15
Lower slope	4	29	20		17	7	17
Flat	8	5					2
Draw		5		11	7		7
Flood plain		5			7		
Texture of the A Horizon							
Silt loam	16	14		11	7		5
Silty clay loam	4					7	
Loam	32	48	20		17	43	32
Clay loam	8	5		22	3	7	12
Sandy loam	36	14	60	44	55	29	44
Sandy clay loam				11		7	2
Clay					3		
Loamy sand	4	14	20	11	10	7	5
Sand		5			3		
Texture of the B Horizon							
Silt loam	8	14		11	14	7	5
Silty clay loam	16	14	40	11	24	7	17
Loam	28	14	20	11	21	29	24
Clay loam	20	24		22	3	7	15
Sandy loam	8	19	40	11	21	14	29
Sandy clay loam	12	5		11	7	21	2
Clay	4			22	3	14	2
Loamy sand	4	5			7		5
Sand		5					
Bedrock Material							
Cades Sandstone	28	29	20	44	41	43	29
Metcalf Phyllite	12	29		22			15
Jonesboro Limestone	8				3		10
Nebo Quartzite		10			17		
Wilhite Formation	52	33	80	33	38	57	46

Table 35. (Continued)

	WP-VP N=25	WP-RM N=21	WP-H N=5	WP-CO N=9	WP-WO N=29	WP-NRO N=14	WP N=41
Observed Disturbance							
None	46	48	60	50	61	64	58
Fire	12	7	10		9	4	9
Logging	6	10	10	11	5	7	6
Flooding		5		6	2		
Blowdown	4	7	10	17		4	2
Grazing	10	5					4
Old Field	8	10		6	10	4	6
Old Road	14	10	10	11	14	18	15
Horizontal							
Convex	56	52	80	67	52	57	54
Flat	8	5				14	2
Concave	36	43	20	33	48	29	44
Vertical							
Convex	72	52	80	89	66	71	68
Flat	12	5				7	
Concave	16	43	20	11	35	21	32

a = Numbers are percent values.

b = Abbreviations: WP=white pine, VP=Virginia pine, RM=red maple, H=hemlock, CO=chestnut oak, WO=white oak, and NRO=northern red oak.

Table 36. Environmental Characteristics[a] of the White Pine-Virginia Pine Type. N=25.

Variable	Mean	St-Dev	Range
ELEV	533.0	68.0	381.0- 640.0
ASPTRAN	0.9	0.7	0.0- 2.0
H20A	1.9	0.9	0.3- 3.5
H20B	2.9	1.9	0.2- 8.0
H20T	4.8	2.6	0.5- 10.4
SLANGUP	25.8	17.9	0.0- 66.0
SLANGDO	23.0	16.6	0.0- 50.0
SLANGM	25.0	17.6	0.0- 58.0
ACCSLSH	21.0	9.9	2.0- 38.0
THICO	5.8	2.2	3.0- 10.0
THICA	15.8	6.0	5.0- 25.0
THICB	30.0	15.2	0.0- 61.0
THICT	47.0	18.2	13.0- 84.0
STVOLA	33.0	20.0	8.0- 72.0
STVOLB	33.0	20.0	4.0- 82.0
STCOV	2.0	7.2	0.0- 35.0
SANDA	48.5	17.8	15.0- 85.0
SANDB	46.8	17.0	15.0- 80.0
SILTA	35.7	13.6	10.0- 60.0
SILTB	31.8	11.1	10.0- 50.0
CLAYA	15.8	7.8	5.0- 30.0
CLAYB	21.7	9.8	7.0- 42.0
PH20A	4.5	0.9	1.2- 7.5
PH20B	4.6	0.3	4.0- 5.0
PHKCLA	3.9	0.6	3.3- 6.6
PHKCLB	3.9	0.2	3.6- 4.1
INSOL	256.0	31.4	150.0- 295.0
AWHCA	11.5	3.4	5.0- 17.0
AWHCB	9.0	4.4	0.7- 17.6
CANCLO	68.2	11.0	50.0- 99.0
STFRACA	6.4	7.0	0.0- 20.0
STFRACB	18.4	18.0	0.0- 50.0
MICRORD	51.3	54.9	0.0- 198.0
MICRODW	117.8	95.2	0.0- 427.0
MICROTP	31.0	30.8	0.0- 99.0
MACRORD	387.4	425.7	23.0-1829.0
MACRODW	180.6	209.4	0.0- 853.0
MACROTP	64.3	25.8	7.0- 99.0

a = Abbreviations of environmental variables follow conventions from Table 22.

Table 37. Environmental Characteristics[a] of the White Pine-Red Maple Type. N=21.

Variable	Mean	St-Dev	Range
ELEV	504.8	96.0	335.0- 655.0
ASPTRAN	1.2	0.7	0.0- 2.0
H2OA	1.4	0.7	0.4- 2.8
H2OB	3.4	2.5	0.4- 8.9
H2OT	4.8	3.1	0.8- 11.6
SLANGUP	33.7	20.6	2.0- 70.0
SLANGDO	30.7	20.0	3.0- 75.0
SLANGM	32.2	20.0	3.0- 73.0
ACCSLSH	24.6	8.8	6.0- 37.0
THICO	4.7	2.7	1.0- 13.0
THICA	14.3	7.2	5.0- 30.0
THICB	34.2	18.2	0.0- 71.0
THICT	48.5	22.0	5.0- 91.0
STVOLA	32.6	17.5	7.0- 66.0
STVOLB	30.2	18.1	5.0- 70.0
STCOV	7.4	10.1	0.0- 40.0
SANDA	53.0	20.9	19.0- 90.0
SANDB	46.9	21.0	15.0- 90.0
SILTA	33.1	15.4	5.0- 62.0
SILTB	33.8	13.6	5.0- 57.0
CLAYA	14.0	7.9	5.0- 30.0
CLAYB	19.8	10.5	5.0- 40.0
PH2OA	4.6	0.3	4.1- 5.1
PH2OB	4.6	0.2	4.1- 4.9
PHKCLA	4.0	0.2	3.4- 4.3
PHKCLB	3.9	0.3	3.4- 4.3
INSOL	242.7	35.7	160.0- 301.5
AWHCA	10.8	4.4	3.7- 19.2
AWHCB	9.3	4.3	2.7- 17.0
CANCLO	78.0	10.6	50.0- 99.0
STFRACA	8.1	10.2	0.0- 40.0
STFRACB	16.9	13.7	0.0- 40.0
MICRORD	99.4	111.9	0.0- 427.0
MICRODW	105.5	60.8	15.0- 229.0
MICROTP	41.5	30.9	0.0- 91.0
MACRORD	408.7	402.8	61.0-1768.0
MACRODW	120.3	70.6	15.0- 305.0
MACROTP	71.0	19.8	21.0- 95.0

a = Abbreviations of environmental variables follow conventions from Table 22.

Table 38. Environmental Characteristics[a] of the White Pine-Hemlock Type. N=5.

Variable	Mean	St-Dev	Range
ELEV	483.2	37.4	450.0- 533.0
ASPTRAN	0.6	0.8	0.0- 1.9
H2OA	0.8	0.6	0.2- 1.7
H2OB	1.5	1.4	0.3- 3.5
H2OT	2.3	2.0	0.7- 5.2
SLANGUP	33.8	15.8	19.0- 56.0
SLANGDO	33.4	17.2	11.0- 53.0
SLANGM	33.6	163.2	15.0- 54.5
ACCSLSH	19.0	11.6	1.0- 31.0
THICO	4.8	2.1	3.0- 8.0
THICA	11.2	5.3	5.0- 18.0
THICB	21.4	17.5	0.0- 46.0
THICT	32.6	19.9	15.0- 64.0
STVOLA	44.0	7.8	35.0- 52.0
STVOLB	50.6	7.7	40.0- 59.0
STCOV	7.0	2.7	5.0- 10.0
SANDA	63.8	12.2	49.0- 80.0
SANDB	59.4	10.8	47.0- 70.0
SILTA	26.8	12.2	15.0- 44.0
SILTB	27.0	11.5	15.0- 45.0
CLAYA	9.4	3.8	5.0- 15.0
CLAYB	14.0	5.5	5.0- 20.0
PH2OA	4.4	0.3	4.1- 4.7
PH2OB	4.4	0.2	4.2- 4.7
PHKCLA	3.8	0.2	3.4- 4.0
PHKCLB	3.8	0.1	3.7- 4.0
INSOL	205.0	36.6	194.0- 292.7
AWHCA	6.7	2.9	4.0- 10.2
AWHCB	5.0	2.8	1.9- 7.9
CANCLO	81.0	4.2	75.0- 85.0
STFRACA	19.0	13.9	5.0- 35.0
STFRACB	33.0	20.2	5.0- 55.0
MICRORD	115.6	80.4	15.0- 198.0
MICRODW	112.6	57.6	15.0- 152.0
MICROTP	50.8	28.4	9.0- 83.0
MACRORD	356.6	233.6	91.0- 701.0
MACRODW	134.0	19.6	107.0- 152.0
MACROTP	67.0	18.2	38.0- 84.0

a = Abbreviations of environmental variables follow conventions from Table 22.

Table 39. Environmental Characteristics[a] of the White Pine-Chestnut Oak Type. N=9.

Variable	Mean	St-Dev	Range
ELEV	569.9	118.6	343.0- 686.0
ASPTRAN	1.0	0.9	0.0- 2.0
H2OA	1.7	1.3	0.4- 3.9
H2OB	3.7	3.3	0.3- 8.4
H2OT	5.4	4.5	0.8- 12.4
SLANGUP	36.7	18.4	4.0- 68.0
SLANGDO	40.8	16.4	4.0- 58.0
SLANGM	38.4	178.8	4.0- 62.5
ACCSLSH	22.9	6.6	14.0- 34.0
THICO	4.1	1.1	3.0- 6.0
THICA	15.4	7.4	5.0- 30.0
THICB	32.2	26.1	0.0- 61.0
THICT	47.7	31.1	5.0- 91.0
STVOLA	31.6	16.9	12.0- 66.0
STVOLB	38.7	21.0	13.0- 68.0
STCOV	3.3	3.5	0.0- 10.0
SANDA	50.6	18.3	25.0- 90.0
SANDB	46.7	19.0	20.0- 85.0
SILTA	30.0	11.7	5.0- 50.0
SILTB	26.7	9.4	10.0- 40.0
CLAYA	19.4	10.7	5.0- 35.0
CLAYB	27.1	15.0	9.0- 45.0
PH2OA	4.5	0.2	4.1- 4.7
PH2OB	4.4	0.2	4.3- 4.8
PHKCLA	3.9	0.2	3.6- 4.1
PHKCLB	3.8	0.2	3.6- 4.2
INSOL	237.4	51.6	150.7- 300.4
AWHCA	10.8	5.1	3.5- 19.4
AWHCB	8.9	5.2	2.6- 13.9
CANCLO	74.9	12.8	55.0- 99.0
STFRACA	8.9	13.9	0.0- 40.0
STFRACB	15.0	19.4	0.0- 50.0
MICRORD	63.3	36.9	15.0- 137.0
MICRODW	116.0	85.9	23.0- 290.0
MICROTP	39.7	22.1	12.0- 77.0
MACRORD	392.7	446.6	30.0-1219.0
MACRODW	224.3	231.5	23.0- 610.0
MACROTP	59.4	20.7	20.0- 87.0

a = Abbreviations of environmental variables follow conventions from Table 22.

Table 40. Environmental Characteristics[a] of the White Pine-White Oak Type. N=29.

Variable	Mean	St-Dev	Range
ELEV	524.7	84.3	312.0- 663.0
ASPTRAN	1.0	0.7	0.0- 2.0
H20A	1.7	0.7	0.5- 3.2
H20B	4.4	2.5	1.0- 10.7
H20T	6.1	2.9	1.5- 13.3
SLANGUP	26.4	13.9	5.0- 58.0
SLANGDO	23.5	14.5	3.0- 58.0
SLANGM	24.9	13.9	6.5- 58.0
ACCSLSH	22.8	9.0	4.0- 35.0
THICO	5.3	1.7	3.0- 9.0
THICA	15.5	4.7	8.0- 30.0
THICB	44.2	17.7	15.0- 76.0
THICT	62.9	15.4	38.0- 91.0
STVOLA	27.2	16.0	6.0- 60.0
STVOLB	29.9	16.8	4.0- 68.0
STCOV	2.7	7.1	0.0- 35.0
SANDA	61.5	18.3	20.0- 90.0
SANDB	54.7	18.0	20.0- 80.0
SILTA	26.1	13.7	5.0- 65.0
SILTB	26.7	10.7	10.0- 55.0
CLAYA	12.5	6.6	5.0- 30.0
CLAYB	19.7	9.9	5.0- 45.0
PH20A	4.7	0.3	4.0- 5.1
PH20B	4.6	0.3	4.2- 5.2
PHKCLA	3.9	0.3	3.4- 4.9
PHKCLB	3.9	0.2	3.5- 4.3
INSOL	258.0	34.6	169.0- 311.2
AWHCA	11.1	3.2	3.5- 17.1
AWHCB	9.8	3.2	3.4- 15.0
CANCLO	73.1	9.6	60.0- 99.0
STFRACA	5.2	6.0	0.0- 20.0
STFRACB	12.2	11.6	0.0- 40.0
MICRORD	67.5	66.2	0.0- 244.0
MICRODW	84.8	63.3	15.0- 229.0
MICROTP	42.3	30.8	0.0- 91.0
MACRORD	273.1	327.8	0.0-1768.0
MACRODW	124.5	117.6	15.0- 549.0
MACROTP	63.9	25.4	0.0- 95.0

a = Abbreviations of environmental variables follow conventions from Table 22.

Table 41. Environmental Characteristics[a] of the White Pine-Northern Red Oak Type. N=14.

Variable	Mean	St-Dev	Range
ELEV	528.6	73.8	450.0- 671.0
ASPTRAN	1.1	0.5	0.4- 2.0
H20A	1.3	0.7	0.3- 2.5
H20B	3.2	2.4	0.1- 8.1
H20T	4.5	2.8	0.5- 10.3
SLANGUP	25.7	13.6	6.0- 46.0
SLANGDO	26.7	17.6	0.0- 55.0
SLANGM	26.2	15.3	40.0- 470.0
ACCSLSH	20.9	9.7	3.0- 36.0
THICO	6.7	2.7	4.0- 13.0
THICA	11.6	3.9	5.0- 18.0
THICB	34.9	18.8	0.0- 71.0
THICT	46.6	19.4	15.0- 86.0
STVOLA	37.0	14.4	13.0- 55.0
STVOLB	36.7	16.1	13.0- 65.0
STCOV	1.8	3.2	0.0- 10.0
SANDA	51.8	16.9	15.0- 85.0
SANDB	47.1	18.8	10.0- 80.0
SILTA	30.7	10.5	10.0- 50.0
SILTB	28.6	9.7	15.0- 50.0
CLAYA	17.5	8.5	5.0- 35.0
CLAYB	24.4	11.9	8.0- 45.0
PH20A	4.5	0.2	4.2- 4.9
PH20B	4.6	0.2	4.3- 5.1
PHKCLA	3.8	0.2	3.5- 4.1
PHKCLB	3.8	0.2	3.5- 4.1
INSOL	244.1	36.5	178.0- 296.0
AWHCA	11.0	3.2	6.2- 16.6
AWHCB	8.2	4.3	1.0- 15.0
CANCLO	73.9	11.1	60.0- 99.0
STFRACA	5.7	7.8	0.0- 25.0
STFRACB	20.0	20.6	0.0- 70.0
MICRORD	31.5	36.9	0.0- 137.0
MICRODW	106.1	68.1	15.0- 229.0
MICROTP	24.1	22.9	0.0- 69.0
MACRORD	193.6	140.1	15.0- 427.0
MACRODW	156.0	125.0	15.0- 427.0
MACROTP	53.6	22.8	18.0- 91.0

a = Abbreviations of environmental variables follow conventions from Table 22.

Table 42. Environmental Characteristics[a] of the White Pine Type. N=41.

Variable	Mean	St-Dev	Range
ELEV	544.6	92.5	373.0- 716.0
ASPTRAN	0.9	0.7	0.0- 2.0
H2OA	1.7	0.9	0.4- 4.2
H2OB	3.3	2.4	0.2- 10.7
H2OT	5.0	2.9	0.9- 14.4
SLANGUP	37.6	18.7	1.0- 74.0
SLANGDO	34.0	20.0	1.0- 70.0
SLANGM	35.8	19.0	1.0- 71.0
ACCSLSH	23.1	9.7	6.0- 40.0
THICO	5.3	2.1	1.0- 10.0
THICA	14.9	6.5	4.0- 30.0
THICB	35.7	19.0	0.0- 76.0
THICT	50.9	21.4	10.0- 91.0
STVOLA	34.0	14.7	11.0- 70.0
STVOLB	36.2	17.5	11.0- 80.0
STCOV	3.8	7.1	0.0- 35.0
SANDA	55.2	14.1	25.0- 85.0
SANDB	50.3	15.5	11.0- 80.0
SILTA	29.3	10.4	10.0- 60.0
SILTB	29.4	9.3	15.0- 53.0
CLAYA	15.5	7.7	5.0- 35.0
CLAYB	20.3	9.7	5.0- 45.0
PH2OA	4.5	0.6	1.8- 5.5
PH2OB	4.6	0.3	4.2- 5.8
PHKCLA	3.8	0.3	3.1- 4.2
PHKCLB	3.8	0.2	3.2- 4.2
INSOL	245.4	39.2	154.0- 314.8
AWHCA	11.1	3.0	4.3- 16.9
AWHCB	8.7	4.2	0.9- 16.9
CANCLO	71.8	12.9	25.0- 99.0
STFRACA	6.1	7.8	0.0- 35.0
STFRACB	17.4	15.3	0.0- 70.0
MICRORD	55.2	57.7	0.0- 198.0
MICRODW	84.5	53.9	8.0- 229.0
MICROTP	35.4	30.7	0.0- 94.0
MACRORD	468.3	544.2	15.0-1981.0
MACRODW	182.2	163.4	23.0- 762.0
MACROTP	64.1	22.9	7.0- 95.0

a = Abbreviations of environmental variables follow conventions from Table 22.

APPENDIX B

SAMPLE DATA SHEET

DATE ______________ PLOT # ____________________

STAND ______________ TOPO SHEET ______________

Harry DeYoung
Ecology Dept.
U.T.

% SLOPE UP __________ DOWN __________ ACROSS RIGHT _________ LEFT _______

ASPECT _________________ ELEVATION _______________ SLOPE POSITION ________

DISTANCE FROM RIDGE _____ SLOPE SHAPE VERTICAL ____ HORIZONTAL ___________

PARENT MATERIAL _________ BEDROCK _________________ DEPTH TO BEDROCK ______

LITTER LAYER ____________ % ROCK COVER ____________ % CANOPY CLOSURE ______

	O	A	B	C
THICKNESS				
COLOR				
% STONE				

EVIDENCE OF DISTURBANCE: fire scars___ browse___ pig___ stumps___
Ap___ gullies___ roads___ miscl.___________________________________

HERB PLOT

species	% cover	species	% cover

SUBSAPLING TRANSECT: All Species 2.5 cm. DBH

TREE SPECIES	# STEMS	SHRUBS-WOODY VINES	# STEMS

DATE ____________________ PLOT # ____________________

ADDITIONAL INFORMATION

ONE-TENTH ACRE SAMPLE

SPECIES	DBH CLASSES										
	2.5 10	10 15	15 20	20 25	25 30	30 35	35 40	40 45	45 50	50 55	55 60	60 65

VITA

Harry Rine DeYoung was born in Detroit, Michigan, on November 29, 1951. He attended elementary school in Detroit but moved to Princeton, New Jersey, in 1964. He was graduated from Princeton High School in 1969. The following September he entered Maryville College, Maryville, Tennessee, and was elected to the Beta Beta Beta Biological Honor Society in 1972. In June, 1973, he received a Bachelor of Arts degree in Biology.

In 1973, 1974, and 1975 he worked as chief instructional assistant for the Tremont Environmental Education Center in the Great Smoky Mountains National Park. During the summers of 1975, 1976, and 1977 he directed Tremont's Wilderness Program for young adults.

In 1975 the author entered the Graduate Program in Ecology part time while continuing administrative work at Tremont. In 1976 he taught at the University of Tennessee as a Graduate Teaching Assistant and in 1977 he worked for the Ecology Program on a research assistantship.

He is a member of the Ecological Society of America, the Association of Southern Biologists, and the Tennessee Academy of Science. He is married to the former Sarah R. Winbigler of Jackson, Mississippi.