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Forest Vegetation and Site Relationships in the Central Portion of the Great Smoky Mountains National Park

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To the Graduate Council:

I am submitting herewith a dissertation written by Michael Stanley Golden entitled "Forest Vegetation and Site Relationships in the Central Portion of the Great Smoky Mountains National Park." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Botany.

H. R. DeSelm, Major Professor

We have read this dissertation and recommend its acceptance:

F. H. Norris, M. E. Springer, A. M. Evans

Accepted for the Council:
<u>Dixie L. Thompson</u>

Vice Provost and Dean of the Graduate School

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

February 14, 1974

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Major Professor

We have read this dissertation
and recommend its acceptance:

A. Murray Evans

Fred H. Norris

M. E. Springer

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

FOREST VEGETATION AND SITE RELATIONSHIPS IN THE CENTRAL PORTION OF THE GREAT SMOKY MOUNTAINS NATIONAL PARK

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee

Michael Stanley Golden
March 1974

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ABSTRACT

The primary objectives of this study were (1) to apply recently developed quantitative vegetation analysis procedures to the problem of describing the forest vegetation of the central portion of the Great Smoky Mountains National Park, (2) to group samples into forest types based on the importance of a large number of taxa and to compare the results with studies using types defined by relative density or basal area of canopy dominants, (3) to assess and further define the relationships of vegetation pattern with elevation and with topographic characteristics, (4) to examine possible relationships between soil characteristics and vegetation pattern, and (5) to examine the successional status of the forest types.

Data were analyzed from 266 sample locations ranging from 759 to 1585 m elevation in the central portion of the Great Smoky Mountains National Park, in the vicinity of Mt. LeConte, Greenbrier Pinnacle, and Thomas Ridge.

The 266 sample soils were tentatively classified as: Typic Dystrochrepts, 51%; Lithic Dystrochrepts, 14%; Typic Haplumbrepts, 15%; Umbric Dystrochrepts, 10%; Lithic Histosols, 4%; Lithic Umbric Dystrochrepts, 3%; Fragmental, 2%; and Lithic Umbrepts, 1%.

Simple linear correlations among the soil, site and vegetation characteristics were computed. The highest number

of significant vegetation-soil correlations occurred with clay content of the A and B horizons and with pH_W. Most of the general vegetation characteristics were significantly correlated with microtopographic position.

Canopy sample plots were grouped into forest types based on taxa importance values with the aid of the agglomerative minimum dispersion clustering procedure. The types were: Spruce-Yellow Birch, Yellow Birch-Hemlock, Hemlock, Silverbell-Hemlock, Beech, Buckeye, Sugar Maple, Hemlock-Buckeye, Basswood, Northern Red Oak, Red Maple-Sweet Birch, Red Maple-Northern Red Oak, Yellow-Poplar, Chestnut Oak, Oak-Pine, Table-Mountain Pine-Pitch Pine and Table-Mountain Pine. The discreteness of the plot groups (types) was tested by canonical analysis. Vegetation, site and soil characteristics of the 17 forest types were described.

Relative densities of tree taxa in the canopy, sapling and seedling strata were compared to judge the successional stability of the types. Types which had no evidence of past disturbance appeared to be relatively stable, although periodic reproduction apparently had occurred in some plots. *Acer rubrum*, *Quercus prinus*, *Q. rubra* and *Oxydendrum arboreum* were the most common tree taxa which had replaced American chestnut.

A "topographic site gradient" was constructed based on combinations of potential solar irradiation classes (based on

aspect and slope angle) and microtopographic slope positions. Each position along this gradient was assigned a number, termed the "site gradient index" (SGI), which increased toward mesic sites. The samples of each forest type were plotted on axes of elevation and SGI. A composite diagram was made portraying the pattern of most of the types on the SGI-elevation axes. Observable patterns were noted when Umbrepts, Umbric Dystrochrepts and Lithic Dystrochrepts were plotted on the site diagram. Other characteristics showing patterns on the diagram were: percent clay in the B horizon, total vascular taxa, percent shrub cover, tree sapling density, and canopy basal area.

The combined vegetation-site summary contained in the composite site diagram suggests that the Mt. LeConte area departs significantly in detail (if not in basic outline) from the mosaic chart of Whittaker. This suggests that further local studies are needed in the Park to further verify or redefine its outline and/or details.

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I. INTRODUCTION

Large areas of forests which have never been cut are extremely rare in the eastern Deciduous Forest. The Great Smoky Mountains National Park of eastern Tennessee and western North Carolina encompasses some of these rare areas, scattered as islands among secondary and selectively-cut forests. Some of the largest of these areas are located near Mt. LeConte and on ridges to the east, in the central section of the Park.

The existence of undisturbed and little-disturbed forest makes the Smokies an area of great importance in the study of natural vegetation. Here, where man's effects have been small, the interrelationships among organisms and environment can be examined.

Many persons have studied the various aspects of the vegetation of the Smokies. The most significant extensive studies of forests were those of Cain (1931, 1935, 1937, 1943, 1945) and Whittaker (1948, 1952, 1956, 1966). It is the intention of this study to both complement and supplement these previous studies. Different scope, vegetation sampling approaches and analysis techniques as well as additional environmental measurements differentiate this study from those earlier. The scope of this study is wider than those of Cain's (1937, 1943), in which samples were primarily from the Greenbrier area and some of the north slopes of Mt. LeConte. It is narrower than Whittaker's (1948, 1956), which purported to include the "whole of the vegetation pattern of the Great Smoky Mountains," and involved samples as much as 48 km away from the area involved here. This study is restricted to only a limited portion of the Park and to a limited elevation range in order to reduce the amount of variation involved.

In the summers of 1969 and 1970, forest stands were sampled in the central portion of the Great Smoky Mountains National Park at elevations between 759 and 1585 m (2490 to 5200 ft). Tree, shrub and herb strata were sampled and soil and site characteristics were measured or determined at each plot. Soil samples were taken for laboratory analysis.

The primary objectives were (1) to apply already developed quantitative vegetation analysis procedures, which have been applied to relatively simple vegetation in the nearby Great Valley of eastern Tennessee (Grigal and Goldstein, 1971), to the problem of describing the vegetation of the central Smokies; (2) to base groups of samples into forest types on the relative importance (as measured by importance value) of a large number of taxa and to compare the results with studies using types defined by relative density or basal area of canopy dominants (Cain 1937, 1943; Whittaker, 1956); (3) to assess and further define the relationships of vegetation pattern with elevation and with topographic characteristics such as topographic shading and those characteristics related to potential solar irradiation (Frank and Lee, 1966); (4) to examine possible relationships between soil characteristics and vegetation pattern, which except for pH (Cain, 1931) have not previously been examined in detail for this area; and (5) to examine the successional status of the forest types, especially that due to the death of American chestnut (*Castanea dentata*), which was studied earlier by Woods and Shanks (1959).

II. REVIEW OF SELECTED LITERATURE

Forest Vegetation Analysis Techniques

Introduction. The problem of relating plant community composition to environment is necessarily related to the question of how to describe or classify communities. Few subjects in plant ecology have stirred as much controversy as that of the description and classification of naturally-occurring vegetation. Historically, a number of schools of methodology of classification of vegetation have arisen throughout the world, each with its vigorous proponents. In an excellent comprehensive review of natural community classification, Whittaker (1962) recognized seven major ecological traditions. Within each of these he traced numerous varying trends of thought and applications.

A comprehensive treatment written over 50 years ago by Du Rietz (1921) took 267 pages to review the field of vegetation classification up until that time. Since then, as Whittaker (1962) put it, "the literature of natural communities has become an almost unlimited expanse of uncounted thousands of papers, on which the unwary scholar may drift interminably to no destination." A recent work by Shimwell (1971) provides a review and discussion of classification approaches and describes selected methodology.

Two major trends have been evident in approaches to the classification and description of vegetation. One approaches vegetation as composed of well-defined and recognizable units somewhat analogous to species and having more or less distinguishable boundaries (Braun-Blanquet, 1932, 1951). This approach has historically dominated vegetation studies in Europe, and in practice includes a variety of specific methods and concepts. The contrasting major trend has been to consider vegetation as a continuum and not differentiable into sociological entities, except arbitrarily (McIntosh, 1967). This trend has been especially important among modern American ecologists.

Classification approaches. Classification approaches to vegetation description have typically resulted in abstract vegetation classes or types. Each type has consistent distinguishing characteristics, and is composed of concrete units which are recurring, closely similar plant assemblages with closely equivalent environments (Daubenmire, 1966). In this approach, the relation of environment to community composition consists primarily of measuring and describing environmental variation involved within all the units of a "type" or "association." The major problems involve the definition of the vegetation types.

World-wide, the most influential school of vegetation classification has been that referred to as the Zurich-Montpellier or "Southern" Tradition (Whittaker, 1962; Shimwell, 1971). Although there has been considerable variation within this tradition, the concepts of Braun-Blanquet (1932, 1951) have had the widest following.

The major emphasis of Braun-Blanquet and his followers is put upon floristic composition. Rather than considering only the dominant species, communities are theoretically to be classified by consideration of their entire species composition. In practice the use of character-species and differential species is the primary technique for defining communities (Whittaker, 1962; Shimwell, 1971).

Homogeneity of each stand-sample with regard to floristic makeup <u>and</u> environment is critical to the field technique of this and the other classification approaches (Braun-Blanquet, 1951; Becking, 1957; Shimwell, 1971).

In other important classification approaches, emphasis has been placed on physiognomy (Warming, 1909; Raunkiaer, 1934; Küchler, 1967) or on stratal structure and constant-species (DuRietz, 1921; Cajander, 1949). In these approaches as well as in that of the Zurich-Montpellier School, the major purposes have been the study of plant communities primarily for the sake of classification (Whittaker, 1962).

Other classification approaches have placed a greater emphasis on the habitat-community interrelationship. A number of Russian ecologists have arranged vegetation units in "ecological series" related to environmental gradients (Ramensky, 1932; Sukatschew, 1960).

Among American ecologists, F. E. Clements (1928, 1936) was the most influential in promulgating classification approaches. He emphasized succession and regional vegetation units. The principal vegetation units are formations, which are composed of regional associations, defined by their dominant species or genera; associations are divided into consociations, characterized by single dominants, and these into societies characterized by subordinate species. These terms are applied to the "climatic climax," which is the ultimate stable community determined by the climate. Seral communities are but stages of development leading ultimately to the climatically-determined climax.

Braun (1950) described the Deciduous Forest Formation, dividing it into five major and four minor climax associations. She considered these as more or less artificial units which are variable but still controlled primarily by climate. She also recognized variants of associations, "association segregates," which are due to shifting dominance or importance of species and often related to local environmental differences.

Continuum approaches. A distinctly contrasting trend in vegetation description developed mainly among American ecologists. This is usually termed the "continuum concept," and is a development of the individualistic hypothesis most often attributed to Gleason (1926, 1939).

The individualistic concept holds that each plant species responds to environmental factors according to its own characteristics, no two species being exactly alike. Communities, formed by the overlap of species distributions, are essentially individual phenomena which may only arbitrarily and artificially be grouped into associations (Gleason, 1926; Whittaker, 1956). The continuum approach has been reviewed by McIntosh (1967).

Gleason's hypothesis was met by severe criticism or indifference by most of the association theory proponents (Cain, 1934; Phillips, 1934; Whittaker, 1962), and lay somewhat dormant until it was revived by Curtis and his associates (Curtis and McIntosh, 1951; Brown and Curtis, 1952; Curtis, 1959), who described vegetation continua in the vegetation of Wisconsin. An objective approach, as contrasted to the admittedly subjective approach of the association theorists, was stressed in stand selection and methodology (Brown and Curtis, 1952).

A new set of field and analytical methods was developed by those who followed the continuum concept. Plotless sampling methods were employed, obtaining data for basal areas, frequencies and stem densities of each tree species. An importance value was derived for each species in each stand, composed of the sum of relative dominance (basal area), relative frequency, and relative density. Each relative value was the species' percentage contribution to the total of the characteristic values (basal area, frequency, or density) of all species of the stand. Based on relative importance of species, each stand was assigned a continuum index number, which represented its position in a vegetational continuum. This continuum was then related, where possible, to an environmental gradient, the procedure being referred to as "ordination."

The one-dimensional continuum analysis of Curtis' earlier studies (Curtis and McIntosh, 1951; Brown and Curtis, 1952) was developed further into a multi-dimensional continuum approach (Bray and Curtis, 1957) which resulted in ordination of stands along more than one gradient, each of which could then be related to environmental factors.

These studies generally involved the ordination of stands or vegetation samples by vegetation characteristics, followed by an attempt to relate environmental data to these vegetational gradients.

Whittaker's (1956, 1967) gradient analysis approached the problem from the opposite direction. Gradients of environmental factors were first established, then vegetation characteristics were related to these. In the Great Smoky Mountains (Whittaker 1952, 1956), the Siskiyou Mountains

(Whittaker, 1960) and the Santa Catalina Mountains (Whittaker and Niering, 1965), two-dimensional ordinations of moisture and altitude were constructed, then compositional gradients related to them.

Many variations of multidimensional ordination have been used. Bakuzis and Hansen (1965) used a method of "synecological coordinates" to plot habitat attributes such as soils in two-dimensional gradients of synthetic environmental factors. Loucks (1962) derived synthetic "scalars" of moisture, nutrients and local climate, and found good correlation between these and gradients in vegetation composition. Similarly, Waring and Major (1964) derived synthetic indices of moisture, nutrients, light and temperature to which compositional gradients of species were related. Beals and Cope (1964) related the distributions of species to two-dimensional patterns of soil calcium and organic matter.

Computer-based approaches. In recent years, rapid advances in computer technology have led to greatly-increased computer use in handling biological data. Both mathematical and statistical approaches have been developed by ecologists to take advantage of the capabilities of computers for performing large numbers of complex calculations with great speed. Many techniques have been developed which were out of the question with hand calculators.

Consequently, widespread recent emphasis is placed on "mathematical ecology" (Pielou, 1969) or on "statistical plant ecology" (Goodall, 1970). Complex mathematical techniques for both classification and ordination of vegetation have been developed or adapted from other disciplines.

Any considerable amount of data from natural plant communities will usually involve many species and can include several different environmental measures from each sample location. Such data with multiple variates naturally lend themselves to some type of multivariate analysis, a general term for a number of statistical techniques used extensively in certain sciences, particularly psychology and sociology. Computational details for a number of these techniques can be found in texts by Seal (1964) and Morrison (1967).

Principal components analysis has been one of the most commonly used multivariate procedures for purposes of ordination. Basically, principal components analysis (PCA) seeks to reduce a complex set of data to a small number of orthogonal (perpendicular) axes which will account for most of the variation in the data. This in effect produces a multi-dimensional ordination with axes representing gradients of whatever characteristics were used as input data. These axes can then be related to environmental measurements or observations. Goodall (1954) was the first to apply PCA to a plant ecology study. He applied the technique to cover values of species from 256 quadrat samples of Victorian Mallee vegetation in Australia. Orloci (1966) analyzed data from sand dunes and dune slacks in British Columbia and found that the first three principal components accounted for more than 40% of the variance. Greig-Smith, Austin and Whitmore (1967) used a PCA to achieve a three-dimensional ordination of rain forest vegetation in the British Solomon Islands.

Austin and Orloci (1966) compared PCA to the technique of Bray and Curtis (1957), and considered PCA superior due to distortions caused by Bray and Curtis' use of oblique axes and non-Euclidean measures of distance. However, several evaluators of the PCA approach (Greig-Smith, 1964; Ivimey-Cook and Proctor, 1967; Austin, 1968; Anderson, 1971) have cautioned that its use is best when the range of variation among samples is not large, and that its use in complex vegetation of wide variability leads to a significant loss in interpretability.

Computer-based multivariate techniques have also been widely used for the classification of vegetation. The earliest of these techniques were similar to techniques which had been developed in numerical taxonomy (Sokal and Sneath, 1963). These numerical methods for community classification are generally referred to as "cluster analysis," and are discussed by Williams (1971) and by Pritchard and Anderson (1971).

Most of these clustering techniques compare pairs of samples by use of a measure of similarity or dissimilarity ("distance"), and cluster those which are most similar (or least dissimilar). Examples are the pair-group method (Sokal and Sneath, 1963), agglomerative least squares or minimum dispersion method (Orloci, 1967), group average clustering (Pritchard and Anderson, 1971), furthest neighbor clustering (Pritchard and Anderson, 1971), and centroid clustering (Gower, 1967).

Another clustering approach which has been widely used is association analysis (Williams and Lambert, 1959). This method attempts to produce homogeneous subdivisions of a group of vegetation samples by dividing them on the presence or absence of species showing a high degree of association. Greig-Smith, Austin and Whitmore (1967) and Allen (1971) used association-analysis to group vegetation data into more homogeneous units for subsequent principal component analyses, thus avoiding one of the weaknesses of PCA.

Vegetation-Site Studies in the Southern Appalachians

Many of the earlier studies of the vegetation of the Southern Appalachians are primarily descriptions of the vegetation and do not relate in any detail to site or soil characteristics. Included in this category are several papers by Cain on vegetation in the Great Smoky Mountains. These deal with the heath balds (Cain, 1930a), floristic affinities (Cain, 1930b), cove hardwoods (Cain, 1943), subalpine forests (Cain, 1935), Raunkiaer life-forms (Cain, 1945), and bryophyte unions (Cain and Sharp, 1938).

Cain (1931) related plant distribution to soil pH, and in an unpublished guide to a nature trail in the Greenbrier area (Cain, 1937) he described eight forest types and included some discussions of their site characteristics, primarily topographic position, soil depth, and elevation.

Russell (1953) concluded that beech gaps of the central Smokies persisted due to the ability of beech (*Fagus grandifolia*) to withstand the severe wind and ice storms which funnel through the gaps. The soils of the beech gaps were less acid than those of the adjacent spruce-fir forests, but it was not clear whether this was a result or a cause of the vegetation difference.

In his extensive analysis of the vegetation of the Smokies, Whittaker (1948, 1956) performed a gradient analysis in which he plotted relative densities of individual species on axes of elevation and a moisture "complex-gradient" based primarily on topographic position. He also located 15 vegetation types (13 of them forest vegetation) on the same "mosaic chart." No soils data were taken.

Crandall (1958) described a total of 13 site-types based on ground vegetation within five forest types of the spruce-fir forests of the Smokies. She loosely related these site-types to topographic position, aspect, and in some cases, soil moisture level and bedrock type.

Woods and Shanks (1959) found that tree species associated with dead American chestnut (*Castanea dentata*) in the Smokies varied with elevation, aspect and slope steepness. *Quercus coccinea* occurred primarily on southern aspects, whereas *Halesia carolina*, *Liriodendron tulipifera*, *Tsuga canadensis*, *Cornus florida*, and *Fagus grandifolia* were primarily on north-facing slopes.

A virgin hemlock (*Tsuga canadensis*) forest at 4400 ft elevation in southwestern North Carolina was composed of two types according to Oosting and Billings (1939), based on shrub and understory differences. A type characterized by dominance of *Rhododendron maximum* in the shrub layer occurred in coves and along streams. The interstream low ridge sites were characterized by the shrub dominance of *Polycodium* (*Vaccinium*) *stamineum* (L.). Soil differences between the two types were interpreted as due to the effects of the different vegetation, and consisted primarily of increased organic matter in the *Rhododendron* type.

Virgin hemlock stands in the Joyce Kilmer Memorial Forest of the mountains of western North Carolina were studied by Oosting and Bourdeau (1955). Two segregates were recognized on the basis of differences in the shrub strata. These were a *Rhododendron* type, characterized by dominance of the shrub *Rhododendron maximum*, and an herb type which lacked Rhododendron but had numerous herbaceous understory species. Although detailed soil data were obtained, no consistent soil differences were found between the two types. Habitat differences were related only to topography, the Rhododendron type being found on flats, along streams and on lower slopes. The herb type occurred higher on the slopes. Comparing the Kilmer segregates with those found earlier to the southeast in Ravenel's Woods (Oosting and Billings, 1939), they concluded that a total of four segregates were represented. Differences between the segregates of the two areas were attributed to the higher precipitation and lower temperatures at Ravenel's woods, which was at generally higher elevations.

In the gorges of Fall Creek Falls State Park at the western side of the Cumberland Plateau of Tennessee, Caplenor (1965) distinguished six forest community types. These were mixed mesophytic, hemlock, hemlock-yellow birch, hemlock-basswood, oak-hickory, and chestnut oak. He described differences in soils and topographic position among the types.

In Thompson Gorge in the southern Blue Ridge (793 m elevation) of North Carolina, Mowbray and Oosting (1968) distinguished four major plant communities based on canopy dominance. These were: (1) a mixed bottomland community, occurring on the flat, moist bottomland, and dominated by Liriodendron tulipifera, Betula lenta and Magnolia fraseri;

(2) an upland oak community, dominated by Quercus borealis and Q. prinus, and occurring mainly on the north slope; and (4) oak-pine and pine-oak communities of Quercus coccinea and Pinus rigida predominating on the south slope.

They found the distributions of individual species strongly related to aspect and slope position. Quercus prinus was a significant component of stands on north slopes, but was infrequent on the south slope. Q. borealis was restricted to north-facing slopes, with maximum importance values on the lower mid-slope positions. Liriodendron tulipifera, Betula lenta, Magnolia fraseri, and Halesia carolina were restricted primarily to the bottom and lower north-facing slope. Pinus rigida was the most xerophytic species of the gorge, being restricted to the top of the north slope and the upper half of the south slope.

On the north slopes of Bluff Mountain, North Carolina, Whigham (1969) recognized three canopy associations which he related to elevation and aspect changes. He considered these clearly discrete, repeatable vegetation units that were part of a vegetational continuum which varied with aspect and with elevation.

A number of vegetation studies have been reported from gorges of the southern Blue Ridge escarpment, located in the border area of North Carolina, South Carolina, and Georgia (Cooper, 1963; Rodgers, 1965; Rodgers and Shake, 1965;

Mowbray, 1966; Racine, 1966; DuMond, 1969). These gorges range in elevation from about 670 to more than 1060 m and are characterized by high annual precipitation, generally exceeding 200 cm (Cooper and Hardin, 1970). The studies related forest communities primarily to topographic position, most not measuring or describing soil variables.

The vegetation patterns of these gorges fell generally into eight communities; (1) shrub thickets dominated by *Alnus serrulata*, restricted to river and creek banks; (2) the formerly cleared floodplains of the larger streams, occupied by a heterogeneous mixture of clearly successional species, primarily *Pinus virginiana*, *P. strobus*, *Liquidambar styracuflua*, *Liriodendron tulipifera*, *Acer rubrum*, *Betula lenta*, and *Tsuga canadensis*; (3) "mixed mesophytic" forests of coves, composed of a varying mixture of mesophytic species; (4) a slope segregate of mixed mesophytic forests, occupying lower slopes and having a greater variety of canopy species than the cove forests; (5) chestnut oak forests, occurring on open east and north-facing slopes at low elevations and on all slopes near 900 m; (6) mixed oak-hickory forests with *Quercus alba* and *Carya* sp. as common co-dominants with other oaks, occurring on the drier, open south- and west-facing slopes at lower elevations; (7) pine-oak forests composed of mixtures of *Pinus rigida*, *P. virginiana*, *P. echinata*, *Quercus coccinea* and *Q. prinus*, and occupying less xeric ridges, south-facing slopes and higher elevation knobs; and (8) pine forests where hardwoods have less than one-third dominance, occupying the driest ridges below 854 m elevation.

Safley (1970) described 22 forest types on the watershed of the Big South Fork of the Cumberland River. The types were dominated primarily by *Quercus alba*, except on shallow soils where pines had established and in protected coves where *Tsuga canadensis* was prevalent. He distinguished among types on the basis of aspect, slope position, soil depth, and proximity to streams.

Relation of Tree Growth to Site and Soil Characteristics

A number of studies have been conducted to determine the quantitative relationship between measurable site and soil characteristics and tree growth (usually measured as height or site index). Most such studies have used regression as the statistical tool for predicting these relationships.

In Thompson Gorge, North Carolina (Mowbray and Oosting, 1968), linear regression analysis indicated that the most important environmental factors affecting growth and importance values of *Liriodendron tulipifera* were the ratio of clay to sand in the B horizon, percent sand and percent clay in the B horizon, soil moisture at 12 inches, and vapor pressure deficit. Curvilinear equations of the clay to sand ratio resulted in R^2 values greater than 0.9 for most species and best fit the patterns of both growth and importance values of all species tested. They concluded that the clay to sand ratio was not a single factor, but an integrated expression of many factors having effect through soil moisture availability and soil aeration. They concluded that the environmental factors influencing the slope of the species population curves were soil moisture availability, soil aeration and the climatic factors influencing the rate of water loss from plants.

Doolittle (1957) studied the influence of soil and site factors on the growth of scarlet oak and black oak on the Bent Creek Experimental Forest near Asheville, North Carolina. He found that accurate estimates of the site index of these two species could be predicted from the depth of the A horizon in inches, slope position expressed as percent of total distance from the bottom of the slope to the ridge, and sand content of the A horizon.

Smalley (1961) reported on the growth of five-year-old yellow-poplar (Liriodendron tulipifera) which had been planted near the southern end of the Cumberland Plateau in Alabama. He found the relation of yellow-poplar height to topographic position to be very pronounced. The five-year heights ranged from an average of 18.2 ft in the bottoms to 11.8 ft on the upper north slopes and 6.3 ft on the upper south slopes. In a follow-up study (Smalley, 1964), he attempted to determine the underlying causes of the height differences through data relating to the soil moisture regime of the sites. Physical properties of the soil on the study sites and the ridges above them were not consistently related to topographic position. He concluded that availability of soil moisture was strongly affected by topography-related factors such as subsurface moisture recharge rather than by physical properties of the soil.

On the Piedmont of southern Virginia, North Carolina and South Carolina, Della-Bianca and Olson (1961) found that good estimates of site quality of white, scarlet and black oaks and yellow-poplar were difficult to obtain. They ascribed this difficulty to the gently rolling topography of the Piedmont, which had only slight changes in relief over long distances. This resulted in weak correlations between growth of the study species and site characteristics. However, yellow-poplar site index was related to slope position and to the organic matter content and thickness of the A_1 horizon.

Smalley (1967) found white oak tree height in northern Alabama associated strongly with slope position (percent distance from ridge to stream) and to total slope length plus distance from plot center to ridge. Mixed red oak (black, northern red, scarlet and southern red) tree heights were correlated most strongly with slope position and aspect. In the presence of these variables and tree age, the additions of soil factors did not significantly improve the regression equations. Smalley concluded that the effect of topographic variables was indirect, through its influence on soil moisture and structure, nutrients and microclimate. Soil thickness variables did not affect the height of the oaks studied.

Ike and Huppuch (1968) studied soil and site factors affecting groth of ten tree species in the Blue Ridge Mountains of Georgia. They concluded that topographic features were more closely related to site quality than were physical or chemical soil properties. The most reliable characteristics in site quality prediction were those which influence local climate and moisture supply. These were elevation, position on slope (expressed as percent of total distance from ridge to stream), aspect, and slope steepness.

Some other weaker but discernible relationships were noted. Site quality of yellow-poplar, white pine, and shortleaf pine was related to soil series, A horizon thickness was correlated with height of yellow-poplar, white oak, scarlet oak, black oak, and shortleaf pine. Soil fertility was a weak but fairly consistent indicator of site quality. The sites with higher growth usually had higher levels of exchangeable calcium and magnesium in their surface horizons than did the lower growth sites. Concentrations above 30 to 40 ppm in the A_p or A_2 horizons generally indicated a good site, whereas levels below 20 ppm usually indicated an infertile soil. They concluded that inherent soil fertility did make a difference with respect to site quality and tree growth, but that they lacked an adequate measure of soil fertility which could be used as a reliable predictor of site index.

In studies of soil-site factors related to site quality of white and black oaks in southern Indiana, Hannah (1968) found that the depth of the surface soil was the most important environmental factor measured. Decreasing stone content of the B_2 and increased distance from the ridge were correlated with increased site quality. Although site index of white oak was higher on north-facing slopes, aspect was not related to black oak site quality.

In western Tennessee, Hebb (1962) found that topographic position was the variable most consistently correlated with site index of individual trees. It was the most important factor for sweetgum and yellow-poplar. He found very low correlation of growth of white and southern red oak with any combination of site variables.

In northern Mississippi and western Tennessee, McClurkin (1963) found that slope position was significantly correlated with height growth of white oak, with height increasing on middle and lower slopes. Similarly, Gaiser (1951) found that site index of white oak in southeastern Ohio was higher on lower, north-facing slopes. He also found that A horizon thickness was positively related to white oak site index.

Several studies have reported significant site index variations across parent material types. Yawney (1964) reported that oak site index in West Virginia was higher on soils from limestone than on soils from shale and sandstone. Aspen in Minnesota grew faster on calcareous than on non-calcereous drift (Stoeckeler, 1960). In Ontario, Chrosciewicz (1963) found higher jack pine site indexes on glacial drift which had a high concentration of basic minerals. Studying ponderosa pine in the Black Hills, Myers and Van Deusen (1960) reported that soils derived from limestone had higher site indexes than soils derived from crystalline rocks.

The importance of climate other than microclimate has been shown by a number of studies. Latitude was significantly correlated with the site index of shortleaf pine (Coile and Shumacher, 1953) and that of Douglas-fir (Choate, 1961), presumably due to more favorable temperature conditions and possibly higher soil moisture levels due to higher precipitation. Zinke (1959) reported that the site index of Douglas-fir and ponderosa pine was related to average annual precipitation in northwestern California. When Hill, et al., (1948) compared similar soils in adjacent counties of

Washington, they reported that although both received abundant precipitation, the sites with somewhat greater rainfall had a Douglas-fir site index about 30 ft higher than those in the other area. Carmean (1954) also reported that Douglas-fir site index increased with increased precipitation in southwestern Washington. Stoeckeler (1960) concluded that aspen in the Turtle Mountains of North Dakota grew more slowly than in northern Minnesota because of substantially less precipitation. Choate (1961) and Steinbrenner (1965) both found that elevation influenced site index, presumably through its influence on temperature and precipitation. Jack pine site index in Ontario differs from one climatic region to another (Chrosciewicz, 1963).

Because of their economic importance, southern pines have been studied extensively in their relationships to site factors. Coile (1948) found that the thickness of the A horizon, ratio of silt-plus-clay to moisture equivalent of the B horizon, and imbibitional water value of the B horizon were variables related to site index of loblolly and shortleaf pine on the North Carolina Piedmont. He stated that the imbibitional water value was fairly characteristic of the conventional soil series as mapped and was better correlated with site index than the ratio of silt-plus-clay to moisture equivalent. Although he also tested topographic position and total depth to C horizon, they were not significantly correlated with site index. He concluded that site index of the species in his study area could be estimated from the thickness of the A horizon and the imbibitional water value of the B horizon.

In the Virginia Piedmont, Kormanik (1966) found that the site index of *Pinus echinata* was related to texture and thickness of the B_2 horizon, generally being higher on thin B_2's with clay loam textures. *Pinus virginiana* site index was directly related to the texture of the A_2, whereas *P. taeda* site index varied with thickness and clay content of the B_2 horizon (highest on thick loams) and soil drainage class. Coile and Schumacher (1953) found that site index of *P. taeda* and *P. echinata* decreased with increasing clay content of the solum in the Piedmont in the Carolinas, Georgia and Alabama. Zahner (1958) found that *P. taeda* site index increased with clay content to 35% in zonal soils.

In a study of 113 loblolly pine and slash pine plantations the Alabama Piedmont, Goggans (1951) included only tree age and depth of the A horizon in his final regression equation predicting tree height, although texture and moisture equivalent of the A horizon, xylene equivalent of the A and B horizons, and moisture equivalent of the B horizon were tested. He did not state the correlation coefficient or R^2 obtained. No topographic variables were tested. In the same area, Livingston (1972) found that 39 year old planted *P. taeda* averaged 19 ft taller on flats than on hilltops on the same soil series.

Nash (1963) studied the relationship of soil and site factors to shortleaf pine site index in southern Missouri. He assumed that soil moisture was the limiting factor in the growth of shortleaf pine, and studied factors which presumably affected it. Using empirically-derived ratings of two topographic (topographic location and slope position) and three soil (texture, stone content and consistence) characteristics, he found great variation in multiple correlation coefficients among areas having different geologic histories. Topographic location, slope position and texture of the B horizon were significant in all three geographic areas; stone content in one, and consistence of the B horizon in two. In all three areas, estimating site index by the two topographic factors resulted in a lower correlation coefficient than that of the three soil factors.

III. THE STUDY AREA

Location

The crest of the Great Smoky Mountains forms the Tennessee-North Carolina border between 35°29' and 35°47' N latitude, 83°05' and 83°55' W longitude. The National Park comprises 227,076 ha (508,000 acres) in Blount, Sevier and Cocke Counties, Tennessee, and Swain and Haywood Counties, North Carolina. Gatlinburg, Tennessee, and Bryson City and Cherokee, North Carolina, are small cities located at the Park boundaries.

This investigation was limited to that area of the Park drained by the East and West Prongs of the Little Pigeon River in Sevier County, Tennessee, and the Thomas Ridge area in Swain County, North Carolina, comprising a total area of approximately 26,000 ha (64,000 acres). This area includes Mt. LeConte, Mt. Kephart, Mt. Mingus, Thomas Ridge, Shot Beech Ridge, Beetree Ridge, the northeast slopes of Sugarland Mountain, the south slopes of Greenbrier Pinnacle, Greenbrier Cove, and the west slopes of Mt. Chapman and Mt. Guyot (Figure 1).

The area is mapped on the Mt. LeConte, Gatlinburg, Mt. Guyot, and Clingman's Dome 7.5 minute quadrangles of the U. S. Geological Survey.

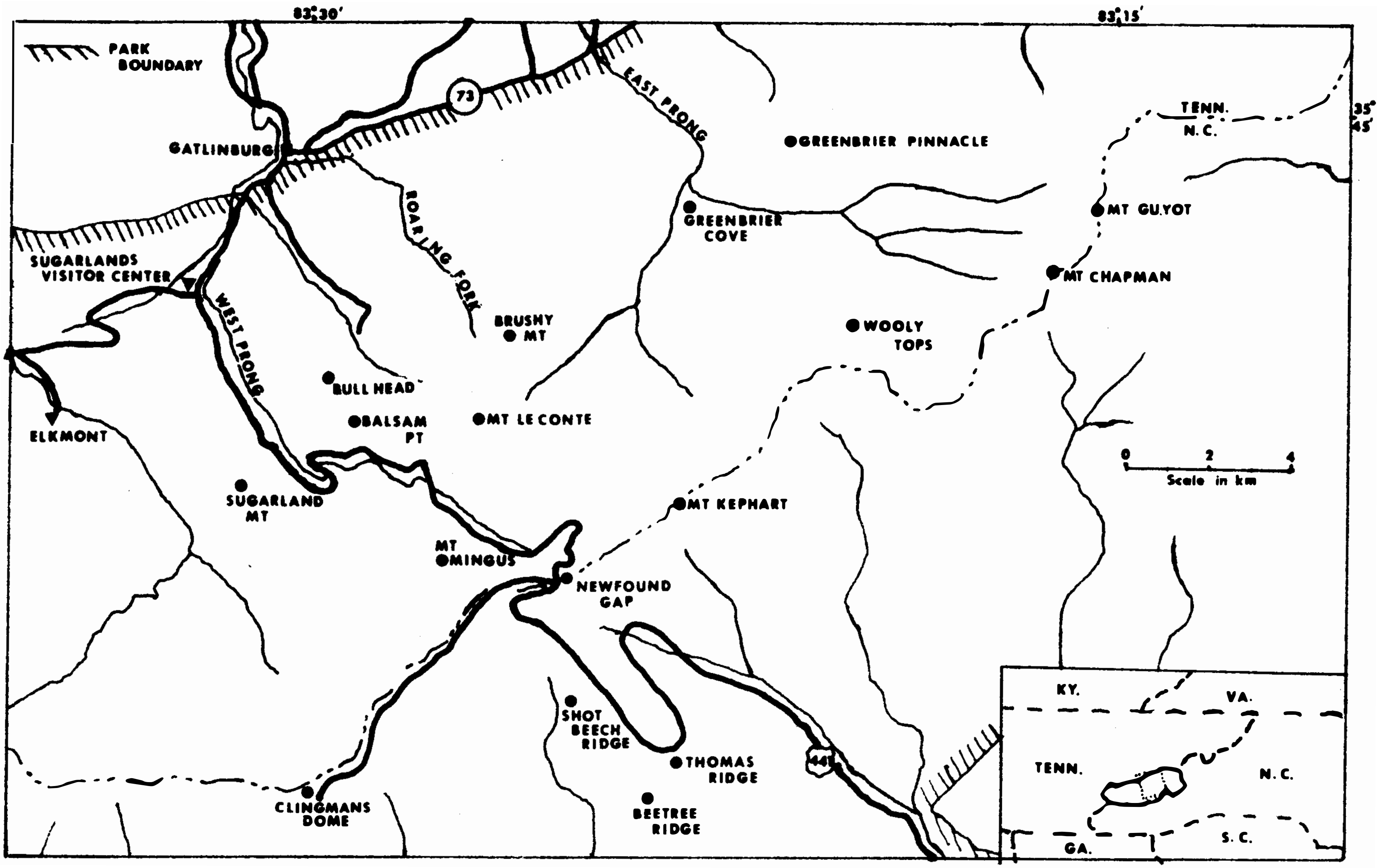

Figure 1. Location of study area.

Climate

Considerable climatic variation exists within the Smokies, due primarily to effects related to elevational change. Using Thornthwaite's (1948) classification, Shanks (1954a) placed stations at 445 m (1460 ft), 1158 m (3800 ft), and 1524 m (5000 ft) elevation in the humid mesothermal, perhumid mesothermal, and perhumid mesothermal categories, respectively, while a 1920 m (6300 ft) station was more humid than the perhumid microthermal category.

Weather patterns result in precipitation maxima in the late winter-early spring and in July-August. The winter primary maximum results from depressions moving from northwestern North America into Texas, picking up moisture from the Gulf of Mexico, then moving northeastward and depositing the accumulated moisture (Trewartha, 1966; Dickson, 1960). The midsummer secondary precipitation maximum results from showers and thunderstorms generated by the interaction of midtropospheric troughs and ridges located over Florida with a mid-continent pressure ridge (Dickson, 1960). Intense rainfall (defined as more than 1 inch in one hour or more than 3 inches in 24 hours) is most common during June, July and August. Frequency of intense rainfall increases with increased elevation (Bogucki, 1972). A precipitation minimum generally occurs in September or October (Stephens, 1969).

Weather data from four stations within the study area showed that precipitation increased with elevation, with annual averages of 147 cm (57.8 inches), 177 cm (69.5 inches), 200 cm (78.8 inches), 226 cm (89.0 inches) and 231 cm (90.9 inches) at elevations of 445 m, 762 m, 1158 m, 1524 m and 1920 m, respectively (Shanks, 1954a). The annual mean number of days with snowfall increased from 6.75 at the 445 m elevation to 25.9 at the 1920 m elevation, while the vapor pressure deficit decreased (Stephens, 1969).

As elevation increased, temperatures decreased at a curvilinear rate. As elevation increased, the lapse rate decreased. The overall average lapse rate was 2.23°F/1000 ft (0.41°C/100 m) (Shanks, 1954a), but this varied with season, being lowest (1.28°F/1000 ft) in December and highest (3.86°F/1000 ft) in July. February was the coldest month and July was the hottest month at all elevations, with monthly mean ranges being 40.0° - 71.7° F (4.4° - 22.0°C) at 445 m and 28.7° - 56.3°F (-1.8° - 13.5°C) at the 1920 m elevation. Mean maxima ranged from 53.0° - 86.5°F (11.7° - 48.0°C) at 445 m and from 37.7° - 65.2°F (3.2° - 18.4°C) at 1920 m with mean minima being 27.7° - 60.5°F (-2.4° - 16.8°C) and 22.2° - 51.2°F (-5.4° - 10.7°C) for the same elevations (Stephens, 1969).

The average length of growing season (based on occurrence of 0°C) varied from 144 days at the 1524 m elevation to 156 days at 445 m (Stephens, 1969).

Physiography

The Smokies are a part of the Unaka Mountains of the Blue Ridge Province (Fenneman, 1938). They lie to the northwest and parallel to the main divide of the southern Blue Ridge Mountains, and are bordered on the northwest by the Ridge and Valley Province. The valleys of the Big Pigeon and Little Tennessee Rivers terminate the Great Smokies on the east and west and separate them from other ranges of the Appalachian highlands. These two rivers and their tributaries drain all of the Smokies, then both ultimately flow into the Tennessee River (the Pigeon first joins the French Broad River).

The main ridge of the Smokies, oriented generally northeast to southwest, winds for approximately 113 km (70 miles) within the Park, connecting a series of high peaks, with large ridges radiating to each side. The Smokies include 21.4 km (13.3 miles) of ridges above 1830 m (6000 ft) elevation, including 24 peaks (Ramseur, 1960). The highest of these are Clingman's Dome (2024 m), Mt. Guyot (2018 m), and Mt. LeConte (2010 m). The main ridge of the Smokies from Mt. Guyot to Mt. Collins, along with Mt. LeConte and its connecting ridge with Mt. Kephart fall within the study area. Valleys in the central portion of the Park range to as low as 418 m elevation along the Little Pigeon River.

Since a period of mountain building in the late

Paleozoic, the Smokies have been continuously eroded (King, *et al.*, 1968), their form becoming physiographically subdued (Fenneman, 1938). The peaks are generally rounded, and bare cliffs are rare. However, steep slopes make up most of the surface area with less than 10% having less than 10 degrees slope (Message from the President, 1902). The slopes surrounding Mt. LeConte are among the most rugged and steep in the Park. The summit of Mt. LeConte rises more than 1600 m above valleys less than 8 km away. The average slope gradient from the top of Mt. LeConte to the Roaring Fork Valley is 35%, and that of the south slope of Greenbrier Pinnacle is 40%. Some of the broad valley bottoms are flattened by alluvial-colluvial fan deposits of shallow to great depth (Bogucki, *et al.*, 1973).

Geology

Most of the Great Smokies and surrounding foothills are underlain by late Precambrian rocks which make up the Ocoee Series. These are complexly folded, metamorphosed sedimentary rocks which are resistant to erosion and fairly uniform in their reaction to it. Three formations in the study area, the Anakeesta, Thunderhead Sandstone, and Elkmont Sandstone are part of the Great Smoky Group, whereas a fourth formation, the Roaring Fork Sandstone, is part of the slightly older Snowbird Group, all of the Ocoee Series (King, 1964). The Thunderhead Sandstone and Anakeesta Formations underlie most of the study area, while the Elkmont Sandstone and Roaring Fork Sandstone occur along the northwestern edge, chiefly in Greenbrier and Roaring Fork Valleys.

Rocks of the Anakeesta Formation underlie most of the higher elevations in the study area, including most of the state line ridge and Mt. LeConte. Dark silty and argillaceous rocks metamorphosed to slate, phyllite or schist are predominant, forming steep slopes and sharp peaks such as the Chimneys. Small amounts of free carbon and iron sulfides produce dark and rusty weathered surfaces. Although dark fine-grained rocks are the most common components of the Anakeesta Formation, sandstone layers like those of the underlying Thunderhead Sandstone are commonly interbedded with them, and the two formations intertongue extensively (King, et al., 1968).

Both the Thunderhead Sandstone and the older underlying Elkmont Sandstone are somber gray, thick bedded, and composed principally of quartz and potassic feldspar grains, with some plagioclase feldspar and scattered pebbles of light colored granite and quartzite. Conspicuously blue tinted quartz grains are characteristic of the Thunderhead Sandstone, although such grains are present in less abundance in the underlying Elkmont Sandstone. Sandstone conglomerate with pebbles 3 - 12 mm is common in the Thunderhead Sandstone, compared to the fine grains of the Elkmont Sandstone, which are rarely larger than sand size (King, _et al_., 1968).

The Roaring Fork Sandstone is composed of dark fine-grained sandstone in beds 2 - 20 m thick, alternating with nearly equal thicknesses of mostly phyllitic silty and argillaceous rocks (King, _et al_., 1968).

A low angle thrust fault, the Greenbrier fault, lies along the contact between the Great Smoky Group and the underlying Snowbird Group. Two minor faults, the Oconaluftee and the Mingus faults, occur in the study area, primarily within the Thunderhead Sandstone and Anakeesta Formations.

No glaciers reached the Smokies during the Pleistocene, but there may have been a timberline above 1500 m elevation (King and Stupka, 1950). Most of the stream valleys in the central Smokies have mantles of boulders and alluvial-colluvial material which range from a few centimeters to five meters or more in diameter. Most of this material, particularly the large boulders, probably was loosened by frost action during the period when the upper elevations were less forested than presently, although massive debris slides have occurred during the last century (Bogucki, 1970).

Soils

Only very limited detailed information has been reported on soils in the central Smokies (Hubbard, _et al_., 1956, McGinnis, 1958; Ritchie, 1962; McCracken, _et al_., 1962; Wolfe, 1967). Generalizations presenting an overall picture of soils in the study area are presented here. More detailed descriptions based on data of this study are presented in later sections.

Colluvial and residual soils cover almost all of the area. Very narrowly restricted areas of alluvium occur along some of the streams. Much of the colluvium occurs as rocks and boulders, particularly in small narrow coves and ravines. In many such coves, the ground surface is totally covered by rock and fragments of varying sizes. A buried soil exists in most of these instances, and tree roots are able to extend through the overlying rock layer to the buried fines below (M. E. Springer, Personal Communication). Higher moisture conditions due to topographic position, along with an available, though buried, deep soil enhance the development of high-biomass stands of mesic trees (Whittaker, 1966). Colluvial rock also occurs frequently on gentle lower slope positions and on gentle slopes immediately below very steep slopes. Most ridges and middle to upper slopes are mantled with residual soils which are usually deeper than 50 cm, being shallow on narrow ridges and very steep slopes.

In the elevation range of this study, mull humus types are most common, as deciduous hardwoods are the most predominant tree cover. More layers occur under pine, hemlock and spruce-dominated stands, but are usually less than 7 cm thick. McGinnis (1958) found unincorporated organic layers averaging 23,370 kg/ha under *Pinus pungens* stands, 15,000 kg/ha under *Tsuga canadensis*-hardwood stands, and 7850 kg/ha under mixed hardwoods. Organic horizons were most commonly 2 - 6 cm thick, but occasionally exceeded 12 cm. Histosols, and soils with histic A horizons, consisting of litter and humus directly over decomposing rubble occurred at higher elevations under forests and heaths on steep slopes and ridgetops.

Inceptisols predominate in the study area, Ultisols occur rarely and only below 1000 m elevation. Spodosols occur occasionally at elevations above 1800 m (Oosting and Billings, 1951; McCracken, *et al.*, 1962; Wolfe, 1967), but few occur in the elevation range studied here. Weak horizon development is typical, and argillic horizons are very rare, usually occurging below 1000 m elevation. Wolfe (1967) found that Umbric Dystrochrepts were most common at higher elevation. He noted that some of the soils had been placed in the Porters-Ashe soil association, and he considered most of the soils he studied to be like those of the Ashe series except for the absence of gneissic bedrock. Hubbard, *et al.*, (1956) placed most of the mountain slope soils in the Ramsey series, while designating some of the lower slope soils as being of the Jefferson series. Typic Dystrochrepts (Sols Bruns Acides) are most common in the elevation range studied, although Umbric Dystrochrepts and Haplumbrepts are also common. Loamy-skeletal particle-size classes occur commonly on sites where colluvial rock is abundant.

Soil pH is acid to strongly acid. Cain (1931) found that pH generally decreased with elevation, and varied with vegetation type. Values as low as 2.9 occurred under high elevation spruce-fir stands. In the area of this study, he reported pH values from 3.8 to 6.8 under forest stands.

Flora

As a result of their great age and diversity of habitats, the Smokies support a very rich flora. Hoffman (1964, 1966a) lists 126 families of vascular plants, 531 genera, and a total of 1450 species, varieties and hybrids which occur in the Park. Of these 126 families, 38 are represented by only one species (Hoffman, 1966b).

At least 1975 species of fungi (Hesler, 1962), 32 ferns, 330 mosses and liverworts, 230 lichens and 131 native tree species occur within the area (King and Stupka, 1950). The Smokies are widely noted for the size reached by many of the native trees. Examples are a *Liriodendron tulipifera* with a circumference of 732 cm, a *Tsuga canadensis* of 602 cm and an *Aesculus octandra* of 465 cm (King and Stupka, 1950).

Cain (1945) classified 1142 flowering plant taxa occurring in the Smokies according to their life form as defined by Raunkiaer (1934). He found hemicryptophytes the predominant life form, constituting 52% of the taxa, 19.5% were phanerophytes, 15.5% were cryptophytes, 11.5% were therophytes, and 1.7% were chamaephytes. When 113 taxa occurring in "cove hardwood" communities were examined separately, phanerophytes and cryptophytes constituted much higher percentages than when all vegetation types were considered. Phanerophytes comprised 36.3%, cryptophytes 25.8%, hemicryptophytes 30.1%, chanaephytes 4.4%, and therophytes 3.4%.

In a study of the floristic affinities of plants of the Great Smokies, Cain (1930b) classified 248 woody taxa as intraneous (near the center of their range) or extraneous (near the limit of their range). He considered 69% (172 species) intraneous and 31% (76 species) extraneous. Thirty species (12%) are endemic to the Unaka range in eastern Tennessee and western North Carolina. The high endemism was attributed to the extreme age of the land surface. Of the extraneous species, 64 (25.6% of the total) species are northern in their distribution, including 17 native to southeastern Canada and 9 which are Canadian transcontinental in distribution.

Vegetation

The complex topography and wide range of elevations provide habitats which support a rich variety of forest vegetation, and limited areas of non-forested vegetation as well. Large areas of both virgin and secondary vegetation adds to the diversity of existing vegetation types. Braun (1950) placed the Smokies in the Oak-Chestnut Forest Region of the Eastern Deciduous Forest Formation. Deciduous forests are indeed the most prominent plant cover of the Smokies, but these are forests of great diversity. The high elevations in the northeastern half of the Smokies are dominated by coniferous forests similar to those of southeastern Canada. Treeless areas dominated by grasses and/or sedges or dominated by ericaceous heath are also a part of the vegetation (Camp, 1931; Wells, 1937; Cain, 1930a).

Mesic forests of low to middle elevation coves and lower slopes have been most frequently termed cove hardwoods (Cain, 1937, 1943; Whittaker, 1956; Shanks, 1954b). Collectively, Cain (1943) considered the cove hardwood forests of the southern Appalachians a faciation of the maple-beech-hemlock-birch association of the eastern deciduous forest formation. Braun (1950) referred to them as typical mixed mesophytic communities and post-climax representatives of the mixed mesophytic association she described as predominant in the Cumberland Mountains. Whittaker (1956) found the cove hardwoods less diverse in composition and more mesic in habitat than the mixed mesophytic forests of the Cumberlands. He noted that Braun's (1950) samples of the mixed mesophytic forests frequently included open slopes.

The cove hardwoods complex (Cain, 1943) has been typified as mixtures of a number of mesic taxa, most notably

Tsuga canadensis, *Aesculus octandra*, *Tilia heterophylla*, *Halesia carolina*, *Acer saccharum*, *Betula allagheniansis*, and *Fagus grandifolia*. Varying mixtures of those and several other taxa dominate cover and sheltered slopes up to about 1450 m elevation (Shanks, 1954b; Whittaker, 1956).

Whittaker (1956) stated that the most extensive forests of the middle and lower elevation slopes were the chestnut oak-chestnut forests, dominated by *Quercus prinus* and *Castanea dentata*. The canopy-size chestnut are now dead, and these forests contain a mixture of the old chestnut oak and a number of other taxa which have replaced chestnut.

The near-extinction of *Castanea dentata* by the chestnut blight (*Endothia parasitica*) caused drastic changes in large areas of eastern North America. In the Smokies, Woods and Shanks (1959) found that the most abundant species replacing chestnut were *Quercus prinus*, *Q. rubra*, and *Acer rubrum*.

Whittaker (1956) recognized a number of other forest types as occurring on sub-mesic to xeric sites of middle and low elevations. These include red oak-pignut hickory, chestnut oak-chestnut heath, Virginia pine, pitch pine heath and table-mountain pine heath. He named two high elevation (1200 m to 1800 m) oak types, red oak-chestnut and white oak-chestnut. Cain's (1937) types for the same sites were less specific, and he referred to them as an oak-pine complex.

Northeast of Double Springs Gap most of the ridges and high elevation slopes in the Smokies are dominated by mixtures of *Picea rubens* (red spruce) and *Abies fraseri* (Fraser fir). Crandall (1958), based on differences in the shrub and herb layers, differentiated eight site types within the spruce-fir forests. Whittaker recognized five subtypes among spruce forests, and four among the fir forests. In the central and northern sections of the Park, *Picea rubens* becomes important on slopes and ridges at about 1450 m elevation. These form mixtures with *Abies fraseri* to about 1890 m elevation, where *A. fraseri* becomes predominant.

Braun (1950) and Shanks (1954b) distinguished a northern hardwoods type in coves and mesic sites at elevations above 1450 m. The important dominants named were *Fagus grandifolia*, *Betula alleghaniensis*, *Aesculus octandra*, and *Acer saccharum*. Russell (1953) described the beech gaps which occur as islands in the spruce-fir at elevation above 1500 m. These occur mostly on the south-facing slopes of local dips in ridges, and are dominated by small, poorly formed *Fagus grandifolia*, with *Betula alleghaniensis* and *Aesculus octandra* commonly associated.

Two non-forest vegetation types occur at high elevations in the Smokies. The heath balds are on many of the steep, rocky ridges and slopes. Some mixture of *Kalmia latifolia*, *Rhododendron maximum*, *R. catabiense*, or *R. minus* with various other shrubs form generally treeless thickets on many of these exposed sites above 1300 m elevation (Cain, 1930a; Whittaker, 1956). The shrub canopy of these "slicks" may vary from one to four meters and are usually almost impenetrable.

Grass balds occur in the southwestern half of the Park on several exposed broad ridges. These are usually open meadows dominated by *Danthonia compressa* (mountain oat grass) and/or by *Carex* spp. (Camp, 1931; Wells, 1937; Mark, 1958). (None of these grass balds occur in the area of this study).

History of Land Use

The first human residents of the Great Smoky Mountains were the Overhill tribes of the Cherokee Indians. They lived in semipermanent villages on alluvial bottoms of the larger streams of the foothills. They practiced primitive agriculture on these bottomlands, but penetrated the higher mountains only on occasional hunting forays (King, 1964). Fire!

White settlers arrived in east Tennessee during the Revolutionary War, settling in the large Appalachian Valley. The mountains were settled soon thereafter. Wear Cove was settled in 1795 and White Oak Flats (later Gatlinburg) soon after that (King, 1964). Most of the early mountain settlers were of Scotch or Scotch-Irish ancestry. Many bloody encounters occurred between the whites and Indians during the period the settlers were occupying and *clearing* the land formerly claimed by the Cherokees (Frome, 1966). Most of the Cherokees were forcefully removed to Oklahoma in 1838 on the infamous "trail of tears" (Kephart, 1936).

The white settlers occupied the large valleys and farmed them, but many isolated communities, farmsteads and cabins were established in valleys and little coves back in the mountains. Except for clearing land for farming, timber was cut by mountaineers only for cabin logs, cabinet wood and other valuable lumber; most of the forest remained relatively undisturbed (King, 1964). It was not until several decades after the Civil War that the rugged mountainous areas were even approached by commercial loggers.

Logging in the Great Smokies passed through two distinct phases. The first occurred from 1880 to 1900 and was characterized by peripheral logging, or selective cutting in areas most easily reached by the loggers (Lambert, 1960). The first timber trees sought were black cherry (_Prunus serotina_), black walnut (_Juglans nigra_) and ash (_Fraxinus_ spp.), but yellow-poplar (_Liriodendron tulipifera_) also became important. This type of logging depended heavily on oxen and stream transportation.

The first phase of logging resulted in stripping most of the lower creeks of their choice poplar and the upper reaches of the more accessible black walnut, cherry and ash. This type of operation did little to destroy the character of the mountain forests. Fires were rare and no large areas above the streams were completely denuded of timber (Lambert, 1960).

The second phase began about 1900 with a flurry of timber land purchases by large lumber companies. An 18-mile long railroad was built from a sawmill in Townsend, Tennessee to the east prong of the Little River. Maximum utilization of timber in the Smokies occurred during the First World War. Nearly 200 miles of railroads were in use in the general area. Cable logging, powered by steam engines, was used in some areas (Lambert, 1960).

Most of the area (on the Tennessee side) of this study was an exception to the widespread integrated logging operations. No railroad was built and loggers continued to use teams to bring logs to portable mills and to haul lumber to the shipping point at Sevierville (Lambert, 1960). Most of the land at the higher elevations in the study area was owned by Champion Fiber Company. They had ceased most of their logging by 1930, finding it cheaper to import wood from Canada than to build the necessary railroads to continue logging in the Smokies (Frome, 1966).

A bill providing for the establishment of the Great Smoky Mountains National Park was passed on January 25, 1925, but land purchases were not completed for almost 15 years. The Park was officially dedicated in 1940.

IV. METHODS

Collection of Field Data

Specific areas for sampling were selected on topographic maps. The chief consideration in choosing a sample area from the maps was to obtain a distribution of plots among all elevations, aspects, and topography types. The exact location of each plot center was determined subjectively in the field. Relative homogeneity (determined visually) of topography and canopy vegetation were the criteria used in selecting a sample stand. Two hundred eighty-three plots were sampled during the summers of 1969 and 1970; they ranged in elevation from 695 to 2038 m (2260 to 6490 ft) above mean sea level. Later analyses were concentrated on the 266 samples taken between 759 and 1585 m (2490 to 5200 ft).

Vegetation data. Each stand was sampled using concentric circular plots of 0.08, 0.04 and 0.004 ha (1/5, 1/10 and 1/100 acres). Only one set of nested plots was inventoried in each forest stand. Plot radii were established after first determining the slope angle using an Abney level. The radii were adjusted for slope angle using the procedure described by Bryan (1956).

Cover estimates to the nearest 10% were recorded for the tree, shrub, herb and moss strata. Cover was considered actual vertical projection of plant parts to the ground surface. In each 0.08 ha plot, all stems greater than 12.7 cm (5 inches) dbh (diameter at breast height or 137 cm) were tallied by taxon in 5 cm (2 inch) size classes. All stems 2.5 to 12.7 cm (1 to 5 inches) dbh were tallied by taxon in 2.5 cm diameter classes in the 0.04 ha circular plot. Seedlings, shrubs, and herbs were inventoried in the 0.004 ha circular plot. Seedlings, shrubs and woody vines were counted by taxon. The percent ground cover of each herbaceous taxon (including pteridophytes) was recorded to the nearest 10%.

Evidence of _Castanea dentata_ (American chestnut) was noted on each 0.08 ha sample. The number of stumps, down logs, sprouts and snags which were judged to be _C. dentata_ were recorded.

Taxonomic determinations were made in the field where possible. Unknown or uncertain specimens were collected and later identified. Nomenclature follows Little (1953) for trees, and Radford, _et al._, (1968) for non-tree taxa.

Soil and site data. Slope azimuth was measured to the nearest degree using a hand held compass. Slope angle was determined with an Abney level to the nearest 5%. Lateral and vertical slope form was classified as concave, straight or convex.

Elevation of each plot was determined with a pocket altimeter which was checked frequently against topographic maps at features of known elevation. Each plot location was carefully marked on topographic maps. TVA 7.5 minute quadrangles with 40 ft contours were used for plot location and for later topographic measurements.

Yearly total potential solar beam irradiation was determined for each plot from the tables of Frank and Lee (1966).

Litter type was recorded as mull, mor or mixed, and its thickness measured to the nearest centimeter. Litter cover was estimated to the nearest 10%.

The plot surface area covered by exposed rock was estimated to the nearest 10%. Any evidence of disturbance, such as blowdown, cutting or fire was noted.

Where possible, a soil pit was dug to at least 50 cm (20 inches) depth near the center of each plot. Some of the plots were completely covered with boulders, making a soil fines collection impossible. The soil profile was described and discernible horizons were measured. Soil samples were usually taken from each horizon for laboratory analyses. Large-stone volume within the soil profile was estimated to the nearest 10%. Where possible, the nature of the soil parent material was recorded as sandstone, phyllite or slate.

Laboratory Analyses

Both dry and moist color determinations were made on each soil sample by comparing the uncrushed sample with Munsell (1954) soil color charts.

The percent (by weight) of gravel-sized particles (greater than 2 mm diameter) in each oven-dried soil sample was determined by sieving and weighing.

Soil phosphorus and potassium content and soil pH were determined for each sample by the Tennessee State Soils Testing Laboratory. Soil pH was measured to the nearest 1/10 pH unit in a 1:1 soil to water solution. Phosphorus and potassium were extracted using 1% $(NH_4)_2SO_4$ in 0.05N H_2SO_4. Potassium concentrations in the soil extract were determined with a Perkin-Elmer flame photometer. Phosphorus concentration was determined by the selective reduction of the phosphomolybdic complex in an acid medium (Page, 1965).

The total available phosphorus and potassium in the top 50 cm and top 30 cm at each site was estimated by first converting the laboratory values (pounds per acre per six inches) of each horizon sample into kilograms per hectare per centimeter, multiplying by the horizon thickness, multiplying by a correction factor for horizon bulk density, correcting for horizon gravel content, adding the two horizon totals, then correcting for soil pit stone content. Bulk density correction factors were obtained by averaging the horizon values reported by McGinnis (1958) and Ritchie (1962) for Smokies soils, then expressing this as a fraction of a standard soil bulk density of 1.47 g/cc. A bulk density correction factor of 0.531 (1.47 g cm^{-3}/0.78 g cm^{-3}; 0.78 g cm^{-3} was the average of the bulk densities reported by McGinnis and Ritchie) was used for the A horizon, and 0.707 (1.47 g cm^{-3}/1.04 g cm^{-3}) for the B horizon.

Textures of the mineral horizons were determined using the "feel" method as described in the Soil Survey Manual (1951). The percentages of sand, clay and silt were estimated to the nearest 5%. Frequent checks were made using standards of known particle size distributions provided by Dr. M. E. Springer of the University of Tennessee.

Available water-holding capacity of the solum (if shallow) or top 50 cm of each soil was estimated by using textural constants reported by Longwell, Parks and Springer (1963), corrected for soil depth, stone, and gravel.

Map Measurements

Topographic position. The complex topography of the Smokies results in small ridges leading from larger ridges which may lead from still larger ridges. As a result, determination of only the "local" topographic position of a site (its position relative to the nearest upslope ridge) may present an inadequate picture of its topographic relationships. Because of this, slope position was measured in two ways.

Macrotopographic position was measured as the percent distance of the sample plot from the large ridge most affecting the plot topographically to the nearest down-slope stream represented as a blue line on the topographic map. Necessarily, subjective judgment was involved in the selection of the large ridge most affecting the plot.

Microtopographic position was measured as the elevational distance of the plot from the nearest upslope convexity (ridge top) expressed as a percent of the total elevational distance from the convexity to the bottom of the nearest downslope concavity. Measurements were made perpendicular to contour lines. A ridge position was 0%, a midslope position 50%, and a valley or cove bottom 100%.

Topographic shading. Topographic shading at each plot was estimated using measurements from topographic maps. Two pairs of dates were selected for consideration: April 19 and August 25, and June 1 and July 12. The sun angle is the same on both days of each pair.

The solar altitude and azimuth were determined for each half hour of each of the pairs of dates. Data were taken from Table 170 of the _Smithsonian Meterological Tables_ (List, 1971). The tangent of the sun's angle at each half hour was then determined. Using a protractor and an architect's rule, the amount of time the sun's direct rays were shaded from each plot was estimated by finding the azimuth and the tangent of the angle from the plot to each nearby ridge. Shading was determined to the nearest half hour during the morning and during the afternoon on each plot on each date.

A growing season daily average morning shading and afternoon shading was computed by averaging the April - August and the June - July values. The sum of these two averages (morning and afternoon) was then considered the mean total daily shading during the growing season at each site.

Computer Analyses

The IBM System 360/65 Computer at the University of Tennessee was used extensively in performing statistical analyses of the data.

Basal areas, stem densities, relative basal areas, relative densities, importance values and diameter distributions were computed for each taxon in each sample using a program written by Mrs. Virginia Patterson of the University of Tennessee Computing Center.

All computations of means, ranges, standard deviations, frequencies and simple correlations were performed through the use of packaged programs of the Statistical Analysis System (Barr and Goodnight, 1971). These programs perform all calculations in double precision.

Programs used for the computations of the agglomerative classification and the canonical analysis were from Goldstein and Grigal (1972).

V. FOREST VEGETATION AND ITS RELATION TO SITE AND SOIL CHARACTERISTICS

General Site, Soil and Vegetation Characteristics

Although the original 283 sample plots were taken at elevations ranging from 695 m (2260 ft) to 2038 m (6490 ft), study was concentrated on those within the range 759 m to 1585 m (2490 ft to 5200 ft). This eliminated nine samples from elevations higher than 1646 m and six samples from elevations below 759 m. Two additional samples were omitted from final analyses due to their isolation in the agglomerative procedure (see later). Descriptions and discussions of site and soil characteristics are based primarily on the remaining 266 samples, grouped into 17 forest types (by the agglomerative clustering procedure which is explained later), with exceptions noted.

Site. The 266 sample plots were fairly well distributed in elevation, 37% between 759 m and 1000 m, 30% between 1000 m and 1250 m, and 33% occurred between 1250 m and 1585 m. The Yellow Birch-Hemlock type had the widest elevation range, 750 m (Table 1), and the Oak-Pine type occurred across the narrowest elevation range, 134 m.

Elevation change is a fairly easily measured characteristic which even to the most casual observer is related

Table 1. Site Characteristics of the Forest Types, Means and Ranges of Data

Taxa	N	Elevation (m)	Aspect[a]	Microtopographic Position[b]	Macrotopographic Position[b]	Slope Angle (%)	Annual Potential Insolation[c]	TMS[d]
Buckeye	15	1197	1.20	97	71	35	229	2.2
		939-1524	.29-1.97	90-100	20-100	15-56	151-310	1.2-3.5
Hemlock-Buckeye	5	1120	1.33	93	70	33	252	1.6
		860-1372	0-1.91	80-100	20-90	12-56	213-302	0.7-2.2
Basswood	3	1116	.52	93	83	52	272	2.8
		820-1317	.18-1.09	90-100	80-90	39-60	255-302	2.5-3.0
Yellow-Poplar	5	888	.70	80	84	29	261	1.6
		774-975	.02-1.42	70-90	80-90	20-50	229-292	0.8-2.5
Sugar Maple	11	1191	1.37	75	50	45	230	1.5
		942-1442	.03-2.0	20-100	10-100	14-85	124-282	0.5-3.0
Silverbell-Hemlock	18	1051	1.30	72	75	29	244	1.7
		792-1433	0-1.98	20-100	10-90	10-53	212-292	0.3-3.7
Hemlock	56	1070	1.16	68	74	34	244	1.5
		866-1463	0-2.0	0-100	20-100	10-67	177-311	0-4.3
Yellow Birch-Hemlock	29	1280	1.27	61	60	42	219	1.5
		829-1579	0-1.99	0-90	0-90	5-80	124-310	0-3.5
Red Maple-Sweet Birch	5	932	1.40	54	46	33	224	1.5
		792-1070	0-2.0	0-80	0-80	20-47	168-286	0.8-2.5
Beech	8	1411	.91	51	31	53	236	1.6
		1122-1585	.09-1.97	0-100	0-80	25-68	161-302	0-3.5
Red Maple-Northern Red Oak	7	1041	.73	57	59	36	271	1.6
		832-1402	.09-1.98	10-90	20-90	5-75	213-312	0.5-2.5
Spruce-Yellow Birch	19	1453	1.06	50	55	53	248	2.2
		1219-1561	.03-1.99	0-80	10-90	19-82	146-313	0.3-3.2
Chestnut Oak	46	946	.57	39	50	37	285	1.2
		759-1356	0-2.0	0-80	0-90	16-58	195-332	0-2.5

Table 1 (continued)

Taxa	N	Elevation (m)	Aspect[a]	Microtopographic Position[b]	Macrotopographic Position[b]	Slope Angle (%)	Annual Potential Insolation[c]	TMS[d]
Northern Red Oak	19	1364	.34	39	35	52	294	1.3
		988-1512	0-1.82	0-80	0-90	23-69	226-317	0-2.3
Oak Pine	5	917	.50	6	36	46	291	1.1
		847-981	.01-1.06	0-10	10-80	36-60	255-310	0.8-1.3
Table-Mountain Pine	7	1126	.69	5	26	42	273	0.9
		853-1475	.02-1.26	0-20	0-60	29-65	195-317	0.2-1.3
Table-Mountain Pine-Pitch Pine	8	1017	.11	7	7	35	296	0.8
		771-1317	.02-.29	0-30	0-40	22-56	282-304	0-2.3

[a] Transformed by method of Beers, et al., (1966), 0=SW, 2.00=NE.

[b] Percent vertical distance ridge to draw or valley. 0=ridge, 100=draw.

[c] In 1000's Langleys, from tables of Frank and Lee (1966).

[d] Total mean shading, hours/day.

to significant vegetation changes. Vegetation studies which encompassed areas of significant elevational variation have generally found that elevation is one of the most important variables related to vegetation composition (Whittaker, 1956; Whittaker and Niering, 1965; Fonda and Bliss, 1969).

Overall sampling of slope aspects were reasonably balanced, as 53% of the samples had northerly aspects (north of due east or due west) and 47% had southerly aspects. A slight bias towards the NW - NE quarter occurred (29% of the samples), due to the configuration of Mt. LeConte in relation to surrounding mountains. Within the elevations 759 m to 1524 m, Mt. LeConte has a considerably larger slope area on the north side than on the south side, where the adjoining valley is higher than those to the northwest or northeast.

The azimuth transformation suggested by Beers, _et al._, (1966) assumes that northeast is the coolest and most moist aspect, and the southwest is the hottest and driest. Higher numbers, then, are more mesic, with the maximum 2.00 corresponding to northeast. The Hemlock-Buckeye type had the most mesic mean aspect and Table-Mountain Pine-Pitch Pine averaged the most xeric in aspect (Table 1, page 55).

The local topographic or microtopographic position (Table 1) of a sample not expressed its location relative to the ridge and valley closest to it across contour lines. It increased with increasing proximity to the valley or cove bottom, thus site conditions usually become more mesic with increasing slope position value. The types in Table 1, page 55, are arranged in order from most mesic to most xeric (as determined by the site gradient index which is discussed later) and with several exceptions, this is also the order of decreasing microtopographic position.

Slope angles of sample locations varied from 5% to 85%, with an overall mean of 36%. The slopes of Mt. LeConte and adjoining ridges are among the steepest in the park. Most of the coves and valleys slope greater than 20%, and are steeper at higher elevations. Almost all of the ridge sample plots were on ridges sloping greater than 20%. Six forest types had average slope greater than 45% (Table 1). At the study elevations in the central Smokies, most of the small valleys and coves have a steep gradient and are v-shaped, resulting in the fairly high average slope percent for the types found primarily in coves and on lower slopes.

Much of the influence of aspect and slope angle on vegetation is due to their effect upon the intensity and duration of solar insolation. The potential direct solar beam irradiation can be calculated for any location by taking into account the inclination of the surface relative to the sun's rays, which can be determined from the date, latitude, slope angle and slope azimuth. Tables containing these values for a range of latitudes and dates have been reported by

Frank and Lee (1966). Fribourg (1972) has developed a computer program which calculates potential direct beam insolation for any combination of latitude, slope angle, slope azimuth, and date. The annual total potential insolation provides a value which integrates somewhat the effects of slope angle and aspect, since, for the same latitude, this total is influenced only by these two variables. This is true for the potential irradiation, but it must be recognized that the actual irradiation is influenced by a number of other factors, including atmospheric attenuation, clouds and suspended particles. Other factors being constant, increased insolation should result in higher temperatures and higher evapotranspiration rates, increasing moisture stress on plants. Therefore, the potential insolation value integrates at least part of the complexly interacting effects of slope angle and aspect.

Potential annual irradiation varied from 124,000 to 332,000 Langleys among sample locations and most of the types had a wide variation in values (Table 1, page 55). The lowest mean value was that of the Yellow Birch-Hemlock type (219,000 Langleys/year), the other extreme occurring in the Table-Mountain Pine-Pitch Pine type (296,000 Langleys/year).

Topographic shading by nearby ridges was significant at many sites. The values obtained were estimates of daily shading of direct sunlight during the growing season, occurring in early morning or late afternoon, or both. The average total daily shading (the sum of the average morning and average afternoon shading) ranged from 0.8 hours in the Table-Mountain Pine-Pitch Pine type to 2.8 hours in the Basswood type (Table 1 , page 55). Individual plot averages ranged as high as 4.3 hours per day. The individual plot maximum morning shading was 3.0 hours, the maximum afternoon shading was 2.7 hours.

Simple linear correlations among the site variables were calculated, and those significant at the 0.001 probability level are reported in Table 2. Slopes generally become steeper near large ridgetops at higher elevations, accounting for the correlation between elevation and slope angle. The same explanation holds for the negative correlation between slope angle and macrotopographic and microtopographic position. The values for macrotopographic and microtopographic positions decrease as they approach the ridge top, accounting for the negative correlations. Greater topographic shading naturally occurs in coves and valleys than higher on slopes, leading to a positive correlation of microtopographic and macrotopographic positions with topographic shading values. Morning shading occurs due to ridges located to the east of the site and afternoon shading is due to ridges to the west. East-facing sites on long slopes were frequently shaded in the afternoon by the ridges at the top of the slope,

Table 2. Correlations[a] Among Site Characteristics of the Central Great Smoky Mountains

Site Characteristics	Elevation	Macrotopographic Position	Microtopographic Position	Aspect	Slope Angle (%)	Total Irradiation	Mean AM Shading	Mean PM Shading	Mean Total Shading
Elevation	1.00	-.34	-.21		.40				
Macrotopographic position[b]		1.00	.66		-.28		.37		.36
Microtopographic position[b]			1.00		-.21		.39	.20	.47
Aspect[c]				1.00		-.69	-.36	.34	
Slope angle (%)					1.00				
Total irradiation[d]						1.00			
Mean AM shading							1.00	-.20	.67
Mean PM shading[e]								1.00	.59
Mean total shading[e]									1.00

[a] Only correlations ≥.20 are reported (significant at .001 probability level).

[b] Percent vertical distance from ridge (0) to draw or valley (100).

[c] Cosine transformation of Beers, et al., (1966).

[d] Total annual potential solar irradiation in Langleys, from Frank and Lee (1966).

[e] Daily average during growing season, in hours.

which were to the west. The converse was true of the west-facing slopes in the mornings. Since the aspect value increases toward 2.00 at northeast and decreases toward 0.00 at southwest, the result was a positive correlation between aspect and afternoon shading (east-facing sites tend to be more shaded to the west) and a negative correlation between aspect and morning shading (west-facing sites tend to be more shaded to the east).

Soils. Of the 266 sample soils, a tenative classification is as follows: Typic Dystrochrepts, 51%; Typic Haplumbrepts, 15%; Lithic Dystrochrepts, 14%; Umbric Dystrochrepts, 10%; Lithic Histosols, 4%; Lithic Umbric Dystrochrepts, 3%; Fragmental, 2%; and Lithic Umbrepts, 1%. Only one sample soil could be fairly positively classified as an Ultisol - an Oak-Pine plot with a Lithic Hapludult profile occurring at 850 m (2780 ft) elevation. Twenty-three sample sites had soils in the loamy-skeletal particle size class. Rock fragments were usually colluvial.

The ten Lithic Histosols sampled were all under stands strongly dominated by Tsuga canadensis, Picea rubens, or Betula alleghaniensis, or of some mixture of two or three of these species at elevations above 1090 m (3580 ft). Five of the ten were dominated by P. rubens at elevations above 1400 m (4600 ft). Eight of the ten had shrub layers dominated by Rhododendron maximum or R. catawbiense, species which produce highly acid, slowly decomposing litter. These Histosols consisted of 3 to 45 cm of litter and mor humus above bedrock, with thickly-interlaced roots.

Fifty-six of the 266 sample plots had total soil depths less than 50 cm, thus taxonomically belonging to lithic subgroups. In most cases, sampling went only slightly below this depth, so that true total depth of most of the remaining 210 samples was not determined.

Shallow soils (less than 50 cm depth) occurred most frequently on ridges, upper slopes or in small coves or valleys filled with colluvial rocks and boulders. In the latter case, buried soils likely exist beneath the layer of rock fragments, and roots of large trees probably penetrate the overlying material and reach the fines beneath. Large individuals of mesic taxa frequently were found in these colluvium-filled coves, indicating a lack of severe moisture stress. The high frequency of shallow soils in samples of the Oak-Pine, Table-Mountain Pine and Table-Mountain Pine-Pitch Pine types (Table 3) are a consequence of predominant occurrence of these types on ridges or upper slopes (Table 1, page 55). The frequent shallow soils of the Spruce-Yellow Birch type result from their predominant occurrence on steep high elevation slopes over slates and phyllites of the Anakeesta Formation. These soils tend to be shallow and in many cases formed on unstable rubble.

Table 3. Soil Characteristics (Means and Standard Errors) of the Forest Types

Forest Types	N	% with Soil Depth <50 cm	Surface Rock Cover (%)	Stone Volume (%)	Water-Holding Capacity[a]	Total Available Phosphorus[b]	Total Available Potassium[b]	pH$_W$[c]	Clay in B Horizon (%)
Buckeye	15	27	28± 5.8	35± 7.7	3.61±0.71	8.05± 1.42	252.1±43	5.1(4.6-5.9)	8±0.8
Hemlock-buckeye	5	20	40± 9.5	44±11.7	3.68±1.78	8.21± 3.04	278.5±81	4.8(4.4-5.3)	10±2.2
Basswood	3	33	50±17.3	30± 5.8	3.99±1.52	7.21± 2.37	297.5±94	4.8(4.7-5.4)	18±6.1
Yellow-poplar	5	0	20± 8.4	5± 2.1	5.84±0.97	7.28± 0.97	339.0±42	5.4(4.8-5.3)	14±2.9
Sugar maple	11	18	16± 8.4	19± 5.3	7.70±0.91	15.19± 3.73	249.0±22	5.1(5.0-5.4)	16±1.8
Silverbell-hemlock	18	6	7± 2.9	16± 5.0	6.81±0.84	7.17± 0.64	263.5±44	4.7(4.0-5.4)	14±1.4
Hemlock	56	14	9± 2.4	11± 2.1	6.32±0.46	7.08± 0.41	222.0±19	4.5(3.8-5.7)	12±0.7
Yellow birch-hemlock	29	34	22± 5.9	36± 6.6	3.71±0.56	7.09± 1.59	157.7±19	4.4(3.9-5.0)	12±1.3
Red maple-sweet birch	5	0	12± 8.0	10± 5.5	5.94±1.63	6.13± 0.83	310.6±60	4.4(4.2-5.0)	14±3.8
Beech	8	25	1± 1.2	18± 5.5	6.40±1.12	19.84±10.62	203.7±15	4.9(4.2-5.4)	16±1.7
Red maple-northern red oak	7	0	9± 4.0	11± 4.0	7.34±1.50	8.21± 1.29	233.3±48	4.8(4.3-5.4)	13±2.4
Spruce-yellow birch	19	58	14± 6.5	48± 8.8	2.72±0.81	7.57± 2.25	108.5±26	4.7(4.0-5.2)	13±1.1

Table 3 (continued)

Forest Types	N	% with Soil Depth <50 cm	Surface Rock Cover (%)	Stone Volume (%)	Water-Holding Capacity[a]	Total Available Phosphorus[b]	Total Available Potassium[b]	pH_w[c]	Clay in B Horizon (%)
Chestnut oak	46	28	7± 2.0	14± 1.7	7.24±0.36	7.39±0.28	308.3±23	5.1(4.3-5.7)	22±1.2
Northern red oak	19	10	13± 5.2	15± 2.2	7.70±0.64	12.24±2.58	247.9±12	5.1(4.5-5.4)	16±1.3
Oak-pine	5	40	1± 1.1	9± 4.1	6.32±0.73	7.06±3.92	274.7±38	4.9(4.7-5.3)	30±4.2
Table-mountain pine	7	57	14± 8.1	24± 6.1	5.03±0.99	5.33±0.72	217.8±43	4.7(4.3-5.1)	22±1.8
Table-mountain pine-pitch pine	8	50	6± 2.6	23± 6.9	4.32±1.37	7.15±1.33	280.7±50	5.1(4.8-5.4)	17±2.5

[a] Centimeters of water in solum or top 50 cm.

[b] Total in solum or top 50 cm, in kg/ha.

[c] Median and (range), water pH of top mineral horizon.

Colluvial material is extremely important in the Smokies as soil forming material and as a rooting substrate. Though quite variable, most of the small coves and narrow valleys at middle to higher elevations are dominated by colluvium. Additionally, steep slopes at higher elevations often have soils consisting largely of a shallow layer of colluvial rubble over bedrock. These observations are reflected in the positive correlation between rock cover and microtopographic position; between stone volume and elevation; and the negative correlations of soil depth with elevation, rock cover and stone volume (Tables 4 and 5).

Many of the soils sampled which were deeper than 50 cm were from locations between large colluvial boulders in coves and valleys. Soil depth was not correlated with topographic position. Soil depths greater than 50 cm were found in 70-80% of samples of the three forest types located primarily in coves and valleys (Buckeye, Hemlock-Buckeye, and Basswood), although surface rock cover was generally high (Table 3, page 64).

In contrast, most of the surface rocks in the pine types were rock outcroppings on ridges or upper slopes, and consequently, a higher percentage of the samples had shallow soils.

Most of the surface and subsurface mineral soil layers had Munsell color hues of 2.5Y or 10YR. Hues were typically 2.5Y when dry and 10YR when moist. Very few reddish soils

Table 4. Correlations[a] Between Soil and Site Characteristics of the Central Great Smoky Mountains

	Site							
Soil	Elevation	Total Annual Irradiation[b]	Macrotopographic Position[c]	Microtopographic Position[c]	Mean AM Shading[d]	Mean PM Shading[d]	Mean Total Shading[d]	Aspect[e]
Rock cover (%)				.32	.24			
Litter thickness			-.28	-.25				
Stone volume (%)	.35					.24	.24	
Thickness of A horizon	-.22							
pH_W of A horizon		.22						-.27
Available P in top 50 cm[f]								
Available K in top 50 cm[f]	-.28							
Total available H_2O[g]	-.24						-.20	
Clay (%) in A horizon	-.34	.21		-.21			-.24	
Clay (%) in B horizon	-.25	.23	-.22	-.34	-.21		-.30	

Table 4 (continued)

[a] Only correlations ≥.20 are reported (significant at .001 probability level.

[b] Total annual potential solar irradiation in Langleys, from Frank and Lee (1966).

[c] Percent vertical distance from ridge (0) to draw or valley (100).

[d] Daily average for growing season, in hours.

[e] Cosine transformation of Beers, _et al._, (1966).

[f] Or to bedrock, if shallower, in kg/ha.

[g] In top 50 cm (if not shallower), in centimeters, corrected for stone content.

Table 5. Correlations[a] Among Soil Characteristics of the Central Great Smoky Mountains

Soil Characteristics	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Soil depth[b]	1.00										
2. Total available H_2O[c]	.66	1.00									
3. Rock cover (%)	-.39		1.00								
4. Stone volume (%)	-.55	-.63	.33	1.00							
5. Clay (%) in B horizon		.30			1.00						
6. Available P in top 50 cm[d]	.30					1.00					
7. Available P in top 30 cm[d]						.96	1.00				
8. Available K in top 50 cm[d]	.42	.39		-.28	.23	.21		1.00			
9. Available K in top 30 cm[d]	.37	.32		-.27				.69	1.00		
10. Thickness of the A horizon	.32							.34	-.26	1.00	
11. pH_w of the A horizon		.22			.31			.26		.30	1.00

[a] Only correlations ≥.20 are reported (significant at .001 probability level).

[b] Only to 50 cm. If deeper than 50 cm, coded as 62.5 cm (25 inches).

[c] In top 50 cm (if not shallower) in centimeters, corrected for stone content.

[d] Or to bedrock, if shallower, in kg/ha.

were sampled. No noticeable trends in hue were detected with change in elevation or vegetation type.

Definite trends were evident in mineral soil darkness and color saturation as measured by Munsell value and chroma. Soils of mesic forest types had lower values and chromas than those of xeric types. Moist values of less than 4.0 were found in 98% of the top mineral soil samples from Buckeye, Hemlock-Buckeye, Basswood, Yellow-Poplar, Sugar Maple and Silverbell-Hemlock types. In contrast, among the Oak-Pine, Table-Mountain Pine and Table-Mountain Pine-Pitch Pine type samples, only 46% had moist values less than 4.0. In subsurface horizon samples, 59% of those from the mesic types listed above had values less than 4.0, while only 6% of those from the xeric types had values less than 4.0. Chromas of moist samples showed a similar trend, with the surface layer comparison of mesic vs xeric types being 100% vs 47% of chromas less than 4.0. The subsurface layer comparison was 70% vs 12%.

No deep litter accumulation was observed on the samples of this study. None exceeded 7.5 cm in depth, and most were near 3 cm. The pine stands had litter depths consistently 3.5 cm to 5 cm. High elevation (above 1800 m) spruce-fir stands commonly have thicker litter layers, but they were not included in this analysis. O horizons were typically 2 cm to 5 cm thick. Almost all the samples with O horizons thicker than 8 cm were from higher elevation (above 1150 m) stands of the Hemlock, Yellow Birch-Hemlock or Spruce-Yellow Birch types which had a heavy *Rhododendron maximum* or *R. catawbiense* shrub layer. Several of these high elevation stands with heavy *Rhododendron* understories had humus layers exceeding 20 cm, usually located directly over decomposing rock. An extreme example was a Spruce-Yellow Birch stand on a small ridge with an 0 horizon 43 cm thick, directly over decomposing phyllite.

Relationships between the top mineral horizon (usually A_1) thickness and topographic position were quite inconsistent, as evidenced by the lack of correlation (Table 4, page 67). Inspection of the raw data, however, indicated that a tendency for thinner horizons to occur on upper slopes and narrow ridges did exist. Thicknesses varied from 0.5 cm to 30 cm, but values from 12 - 18 cm were most common.

The great majority of soil textures of both surface and subsurface horizons were loams, silt loams, or sandy loams. Only one sample subsurface horizon had a clay texture--an upper-slope Oak-Pine stand at 850 m elevation.

A positive correlation between stone volume and elevation (Table 4) was due to both the greater abundance of colluvial rock in the narrow upper-elevation coves and the occurrence of abundant loose phyllite rubble on many of the steep upper slopes.

Water pH of the top mineral horizon varied from 3.8 to 5.9 (Table 3, page 64). The lowest pH values occurred in higher elevation stands with Tsuga canadensis or Picea rubens as dominants, and pH was weakly negatively correlated with elevation. Rainfall increases with elevation and higher rainfall increases the leaching of bases, resulting in lower soil pH. Additionally, T. canadensis and P. rubens produce acid litter (Fowells, 1965).

Available phosphorus levels were generally quite low (Table 3). Sugar Maple, Northern Red Oak and particularly the Beech types had phosphorus levels conspicuously higher than the others. This suggests that these species concentrate phosphorus in their litter more readily than the other abundant species.

Noticeably higher available soil potassium levels occurred in the Chestnut Oak, Yellow-Poplar and Red Maple-Sweet Birch types, while levels in Spruce-Yellow Birch and Yellow Birch-Hemlock types were conspicuously low (Table 3). Although P. rubens and T. canadensis probably have litter with low potassium levels, other factors appear to contribute to the low levels in these types. Both the Spruce-Yellow Birch and the Hemlock-Yellow Birch types typically occurred at higher elevations (Table 1, page 55) and had frequent shallow and rocky soils (Table 3). Total available potassium was positively correlated with soil depth and negatively correlated with both stone volume (Table 5, page 69) and elevation (Table 4, page 67). Obviously, shallower soils have less total available nutrients than deeper soils, and rocky soils have less than non-rocky soils. Additionally, the higher rainfall of higher elevation sites should result in greater leaching of bases such as potassium. The reverse holds true in the case of the higher potassium-level forest types. These types were generally at lower elevations with deeper and less stony soils.

Vegetation

The 283 samples involved the measurement of 19,509 stems >2.5 cm dbh, 8492 of these >12.7 cm dbh. Seventy-one woody taxa occurred in the samples, 54 of these occurred as stems >2.5 cm dbh and 45 of these occurred as stems >12.7 cm dbh. Shrub and vine species occurrence in the 17 forest types are shown in Table 6. Three to nineteen taxa occurred in each sample as stems >2.5 cm dbh.

In the canopy (stems 12.7 cm dbh), the highest number of taxa occurred in the Red Maple - Sweet Birch and the Red Maple-Northern Red Oak types. Stands of these types characteristically showed signs of disturbance due to fire and death of *Castanea dentata*. Certain early successional species were typically found, such as *Betula lenta*, *Robinia pseudoacacia* and *Sassafras albidum*. The lowest number of canopy taxa was found in the Table-Mountain Pine type. Some of these plots had

Table 6. Frequency (%) of Shrubs and Woody Vine Taxa and Average Shrub Cover (%) of Forest Types

Taxa	Buck[a]	Hem-Buck	Bass	Yellow-Poplar	Sugar Maple	SB-Hem	Hem	YB-Hem	RM-SwB	Beech	RM-NRO	Sp-YB	CO	NRO	Oak-Pine	TMP	PP-TMP
Aristolochia macrophylla	13	20	100	40	9	17	28	7			14		2	11			
Calycanthus floridanum							2		40		29		33	5	20		
Clethra acuminata							2	7	40		29		14			14	
Cornus alternifolia	13	20	33		9	6	5			12		11		5			
Euonymous americana						6	2	3									
E. obovatus				20													
Gaylussacia baccata													2		20	43	75
G. ursina									20		29		78		60	43	37
Hydranga arborescens	33	20	33	60	18		5	3		12		16					
Ilex montana			33				2	17	40	12	29	16	4	63	20	29	12
Kalmia latifolia							5	11	60		43	16	83	21	100	100	100
Lindera benzoin		20				6	4				14						
Leucothoe axillaris var. editorum	7	40				6	9	38				5		5			
Lyonia ligustrina													4			14	38
Pieris floribunda											43			5	20	29	12
Pyrularia pubera							2						20				12
Rhododendron calendulaceum											14		43	11	40		

Table 6 (continued)

Taxa	Buck[a]	Hem-Buck	Bass	Yellow-Poplar	Sugar Maple	SB-Hem	Hem	YB-Hem	RM-SwB	Beech	RM-NRO	Sp-YB	CO	NRO	Oak-Pine	TMP	PP-TMP
R. catawbiense								7				21				14	
R. maximum	13	20	33	60		28	42	83	60		71	47	67	26	40	43	12
R. minus												5				14	
Ribes spp.			33		9									11			
Sambucus pubens					9		2			12							
Smilax glauca				20			4	20			14		55		80	71	88
Smilax rotundifolia	7				9	50	61	10	80		71		94	53	100	43	50
Vaccinium spp.								3	20	12	29		49	16	100	71	100
Viburnum acerfolium						6	5				14		8	26			
V. alnifolium	13		67		9	22	16	7		12		47				14	
Vitis spp.				40	9		9		20		29		12	5			
No. samples in type	15	5	3	5	11	18	56	29	5	8	7	19	46	19	5	7	8
Mean shrub cover	19	12	10	20	1	9	20	61	28	4	27	49	50	24	72	65	84

[a] Abbreviations are as follows: Buck=buckeye, Hem=hemlock, Bass=basswood, SB=silverbell, YB=yellow birch, RM=red maple, SwB=sweet birch, NRO=northern red oak, Sp=Spruce, CO=chestnut oak, TMP=table-mountain pine, PP=pitch pine.

no other canopy taxon present. When understory (2.5-12.7 cm dbh) trees were included, the lowest diversity, however, was in the higher elevation type, Spruce-Yellow Birch.

Stem densities ranged from 346 to 5584 stems/ha (140 to 2260 stems/acre) > 2.5 cm dbh and 161 to 1173 stems/ha (65 to 475 stems/acre) >12.7 cm dbh. The highest canopy densities and total (all above 2.5 cm dbh) stem densities occurred in the pine types. These stands were characterized by thickets of small canopy stems, predominantly less than 30.6 cm (12 inches) dbh. Types characterized by large trees and mesic sites usually had the lowest canopy stem densities. Hemlock-Buckeye, Yellow Birch-Hemlock and Buckeye types had mean canopy densities less than 300 stems/ha (121 stems/acre). Canopy basal areas (stems >12.7 cm dbh) per sample varied from 7.6 to 116 m^2/ha (33 to 507 ft^2/acre). The highest basal areas occurred in mesic middle elevation stands with Tsuga canadensis as a canopy dominant. Mesic site T. canadensis stems greater than 91 cm (36 inches) dbh were abundant in the Hemlock-Buckeye and many of the Hemlock type plots. These two types had mean basal areas greater than 65 m^2/ha (283 ft^2/acre).

Definite evidence of fire, such as charred tree trunks or stumps, occurred in 41 sample plots. Disturbance by fire was most common in the Chestnut Oak, Northern Red Oak and pine types. Fires occur most frequently on exposed slopes and ridges facing south or west, probably caused by lightning. Fire has apparently occurred only rarely in sheltered cove sites. Stumps or logs from past cutting were found in only seven samples. Several stands, primarily in the Yellow-Poplar and Red Maple-Sweet Birch types, probably were cultivated before establishment of the stands. Forty years had elapsed since cutting occurred in this area of the park, and quite possibly many stumps had completely disintegrated.

Some evidence of *Castanea dentata* occurrence (stumps, logs, sprouts) were found in 91 plots and were most common in the Chestnut Oak, Northern Red Oak, Red Maple-Sweet Birch, and Red Maple-Northern Red Oak types. Living *C. dentata* sprouts were found in samples of 22 stands. The largest living individual *C. dentata* sampled was 15 cm dbh.

Simple correlations between vegetation and site characteristics (Table 7) indicated that the diversity (number of taxa present) of woody taxa decreased with increased elevation. There was a weak tendency for the total stem density (>2.5 cm dbh) to decline at higher elevations.

The xeric conditions of sites receiving high solar insolation was reflected in correlations of potential solar insolation with vegetation. The high solar insolation sites (xeric) tended to have high total stem densities (>2.5 cm dbh), high shrub and understory (2.5-12.7 cm dbh) densities, and low canopy coverage and basal area.

Table 7. Correlations[a] Between Vegetation and Site Characteristics

	Site					
Vegetation	Elevation	Annual Potential Insolation[b]	Microtopographic Position[c]	Macrotopographic Position[c]	Aspect[d]	Total Daily Topographic Shading[e]
Total no. woody taxa[f]	-.45	.30			-.22	
Total stem density		.36	-.54	-.38	-.30	-.20
Density, stems 12.7 cm dbh			-.41	-.34		-.28
Density, stems 2.5-12.7 cm dbh	-.21	.36	-.49	-.34	-.30	
Basal area, stems 12.7 cm dbh		-.23	.32	.31	.21	
Percent tree cover		-.30	.48	.33	.25	
Percent shrub cover			-.27			
Percent herb cover			.25			
Acer rubrum[g]	-.24					
A. saccharum			.26			
Aesculus octandra		-.21	.41			
Betula alleghaniensis	.33	-.34			.21	
Halesia carolina		-.21			.24	
Oxydendrum arboreum	-.46					
Picea rubens	.42					
Pinus pungens			-.38	-.28		
P. rigida			-.33	-.27		
Quercus coccinea	-.25	.24	-.21			
Q. prinus	-.35	.26	-.25		.30	
Q. rubra		.30				
Tilia heterophylla			.42	.23		.27
Tsuga canadensis		-.21	.24	.30		

Table 7 (continued)

[a] Only correlations ≥.20 reported (significant at .001 probability level).

[b] Total annual potential irradiation in Langleys, from tables of Frank and Lee (1966).

[c] Percent elevational distance from ridge (0) to draw or valley (100.

[d] Cosine transformation of Beers, *et al.*, (1966).

[e] Mean daily total during growing season in hours.

[f] Occurring as stems >2.5 cm dbh.

[g] Basal area.

Microtopographic position was significantly correlated (both positively and negatively) with a larger number of vegetation attributes (including basal areas of individual tree taxa) than any of the other site or soil characteristics. Understory, canopy and total stem densities, and shrub coverage tended to decrease, while canopy basal areas, tree and herb coverage tended to increase with proximity to a cove or valley position. Basal areas of mesic taxa increased, basal areas of xeric taxa decreased. Similar but weaker relationships occurred between macrotopographic position and vegetation.

A horizon pH, and clay content of both the A and B horizons were soil characteristics most highly and most frequently correlated with vegetation characteristics (Table 8). Cain (1931) related soil pH to plant communities in the Smokies, but did not include correlations or other relationships of pH with specific taxa or specific vegetation characteristics.

Correlations indicated that total number of taxa (>2.5 cm dbh), understory density, total stem density, and the basal areas of *Quercus prinus* and *Q. rubra* increased with increasing pH (decreased acidity), while canopy basal areas and the basal areas of *Tsuga canadensis*, *Betula alleghaniensis*, *Magnolia fraseri* and *Picea rubens* exhibited the opposite trend. These correlations appear to generally reflect increased

Table 8. Correlations[a] Between Vegetation and Soil Characteristics

Vegetation	Soil						
	Surface Rock Cover[b]	Stone Content[c]	pH_w	% Clay A Horizon	% Clay B Horizon	Total Available Phosphorus[d]	Total Available Potassium[d]
Total no. woody taxa[e]		-.21	.31	.23			.26
Total stem density[e]		.22	.32		.39		
Density, stems >12.7 cm dbh							
Density, stems >2.5-12.7 cm dbh			.24	.30	.40		
Basal area, stems >12.7 cm dbh			-.37	-.35	-.42		
Percent tree cover				-.22	-.36		
Percent shrub cover					.24		
Percent herb cover						.21	
Acer rubrum[f]		-.21					
Aesculus octandra	.29	.21			-.21		
Betula allagheniensis		.32	-.29	-.34	-.23		-.30
Magnolia acuminata	.21						
M. fraseri			-.26				
Oxydendrum arboreum				.33	.31		
Picea rubens		.23	-.21				-.22
Quercus coccinea				.30	.30		.20
Q. prinus			.25	.32	.40		.24
Q. rubra			.24				
Tilia heterophylla	.32				-.21		
Tsuga canadensis			-.38		-.28		

Table 8 (continued)

[a] Only correlations ≥.20 reported (significant at .001 probability level).

[b] In percent of plot area.

[c] In percent of soil pit volume.

[d] Total in solum or top 50 cm, kg/ha.

[e] Occurring as stems 2.5 cm dbh.

[f] Basal area. Taxa absent here which were in Table 7, page 78, had no r ≥.20.

acidity with increased elevation and with the increased abundance of taxa which produce acid litter (such as *Tsuga canadensis*).

Correlations of clay content of the A and of the B horizons were similar, with clay in the B more frequently and generally more strongly correlated with vegetation characteristics. Understory density and total density, and basal areas of *Oxydendron arboreum*, *Quercus prinus* and *Q. coccinea* increased with increased clay content of either the A or B horizons, while canopy basal area and the basal area of *Betula alleghaniensis* exhibited the opposite trend. Additionally, shrub cover increased and basal areas of *Tsuga canadensis*, *Tilia heterophylla* and *Aesculus octandra* decreased with increased clay in the B horizon. These correlations tend to parallel the findings of Losche (1967), *viz.*, that clay content of the B horizon increases toward more xeric sites.

Classification of Forest Types by Agglomerative Clustering

The agglomerative hierarchical classification procedure suggested by Orloci (1967) was used to obtain a grouping of the sample plots into types. In agglomerative clustering, n individual samples are initially n clusters, which are then joined in n-1 steps into a single cluster. At each step the clusters joined are those which have the smallest "distance" (D) between them. Agglomerative classifications are polythetic.

That is, they are based on a measure of similarity or dissimilarity (ecological "distance") applied over all attributes, so that a sample is grouped with those samples which it most resembles based on all characteristics (Williams, 1971).

The procedure can be presented conceptually as beginning with all the plots (samples) as individuals within a multidimensional universe. Each individual plot is characterized by a set of variates. In this study, variates for each plot were the set of importance values (relative stem density + relative basal area) in that plot of 26 tree taxa. The taxa selected for stand comparisons were those occurring in the canopy in more than 5% of the total sample. The same 26 taxa were used in all stands.

Individual plots can be conceived as distributed in a multidimensional space whose coordinate axes are the variates. Thus the position of any individual in the space is determined by the values of the set of variates derived for that individual sample.

The Euclidean distance between the two plots in the multidimensional space is termed "standard distance." The standard distance between two plots j and k is defined as d_{jk}, where

$$d^2{}_{jk} = \sum_{i=1}^{p} [(X_{ij}/V_j) - (X_{ik}/V_k)]^2$$

where X_{ij} is the variate (importance value) of the i^{th} taxon in plot j and X_{ik} is the variate of the i^{th} taxon in plot k, p is the number of variates (26 in this study) and

$$V^2{}_j = \sum_{i=1}^{p} X^2{}_{ij} \text{ and } V^2{}_k = \sum_{i=1}^{p} X^2{}_{ik}.$$

A measure of the spread or dispersion of a group of plots in multidimensional space is "within-group dispersion" (Orloci, 1967). The average within-group dispersion, Q, of a set of plots A, is defined as

$$Q_A = 1/n_A \sum_{j=1}^{n_{A-1}} \sum_{k=j+1}^{n_A} d^2{}_{jk}$$

where n_A is the number of plots in group A, and d_{jk} is the standard distance between the plots j and k of the set A.

At the beginning of the procedure, each plot is considered to be a separate "group." During each clustering cycle, the procedure joins two existing groups, provided that the increase in within-group dispersion is less than it would be if either of the two groups clustered with another existing group. To determine this, all possible fusions in twos of the entities (individuals or groups) must be formed and tested at each cycle.

The clustered pairs become new groups used in the next cycle. No more than two entities are united per group per clustering cycle. During each cycle, the average within-group dispersion is calculated for each newly formed group. The procedure continues to join groups, resulting in the minimum dispersion at each cycle, until all of the individuals are contained within a single group (Goldstein and Grigal, 1972).

Only 248 of the stands sampled were used in the computer clustering procedure, due to computer storage limitations. The stands omitted were those of elevations below 759 m (2490 ft) or above 1585 m (5200 ft) and plots which were easily classified as being strongly dominated by pines. The pine stands were classified by inspection of the data and were treated as types throughout the further analyses. The names given the three pine-dominated types were Oak-Pine, Table-Mountain Pine (*Pinus pungens*), and Table-Mountain Pine-Pitch Pine (*Pinus rigida*).

Graphical representation of the resulting hierarchy is made in a dendrogram (Figure 2). The vertical axis represents the average within-group dispersion of a group expressed as a percentage of the total dispersion among all samples. Thus the dispersion level resulting from the joining of stems (groups) can be seen on the vertical axis. The number at the base of each stem is the number of stands included in the group at the 20% average dispersion level. The horizontal arrangement of stems has no significance.

The 40% dispersion level was subjectively chosen for the naming of types in this study. This level was considered

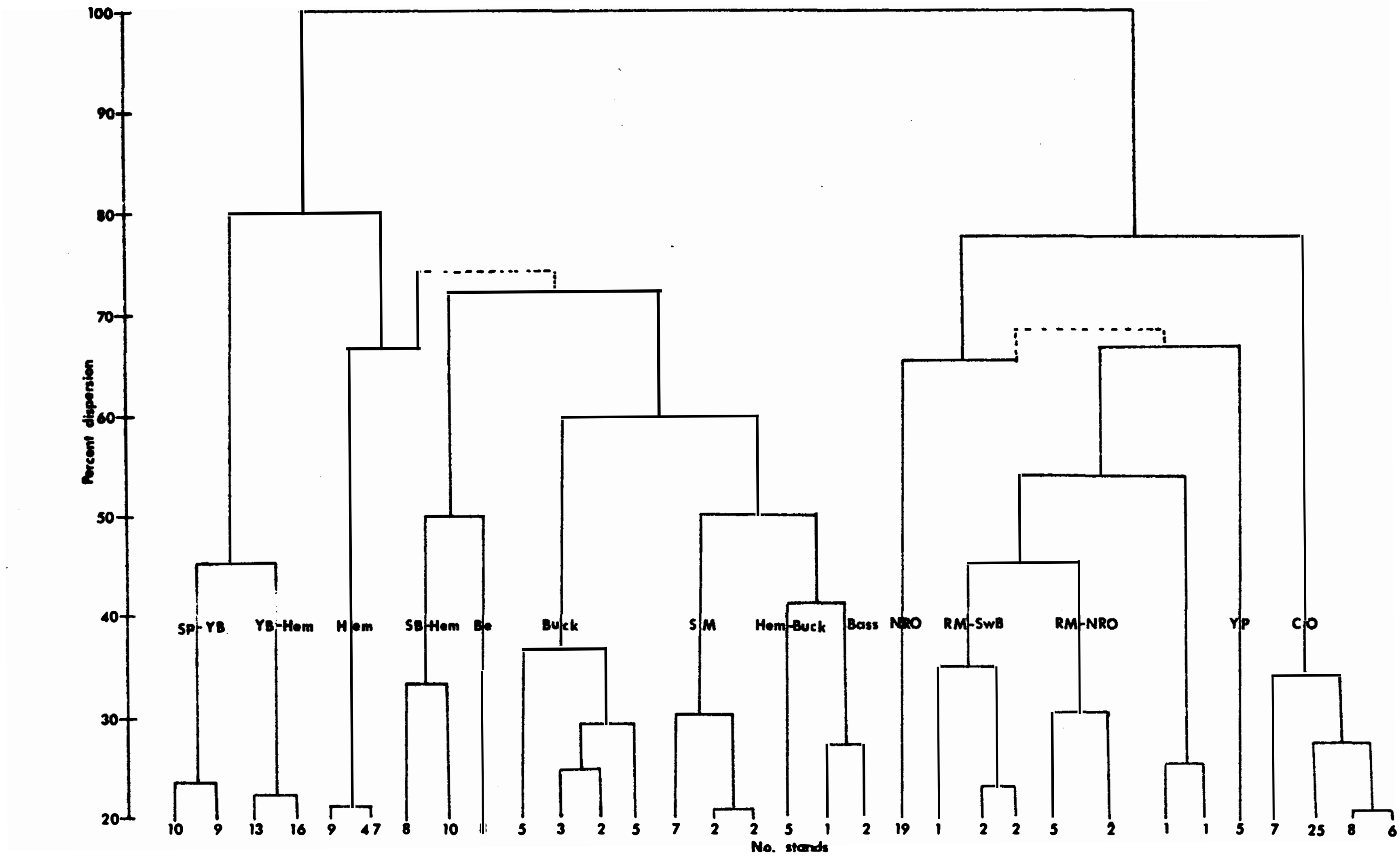

Figure 2. Classification dendrogram, Central Great Smoky Mountains. Vertical axis is within-group dispersion (Orloci, 1967) expressed as percent of total dispersion. Abbreviations: Sp=spruce, YB=yellow birch, Hem=hemlock, SB=silverbell, Be=beech, Buck=buckeye, SM=sugar maple, Bass=basswood, NRO=northern red oak, RM=red maple, SwB=sweet birch, YP=yellow-poplar, and CO=chestnut oak.

most logical and consistent with experience. A higher level would obscure some distinctions felt by this investigator to be important. A lower level would result in separating out several types felt to be of little importance. Thirteen groups of five or more stands and one group with three resulted. For each group at the 40% level, the mean importance value of each taxon was calculated. The type name was determined by the one or two taxa which had a mean importance value considerably larger than any of the other taxa in the group.

The 14 groups of samples which were named from the dendrogram as types were (left to right across the dendrogram in Figure 2, page 86) Spruce (*Picea rubens*)-Yellow Birch (*Betula alleghaniensis*) Yellow Birch-Hemlock (*Tsuga canadensis*), Hemlock, Silverbell (*Halesia carolina*)-Hemlock, Beech (*Fagus grandifolia*), Buckeye (*Aesculus octandra*), Sugar Maple (*Acer saccharum*), Hemlock-Buckeye, Basswood (*Tilia heterophylla*), Northern Red Oak (*Quercus rubra*), Red Maple (*Acer rubrum*)-Sweet Birch (*Betula lenta*), Red Maple-Northern Red Oak, Yellow-Poplar (*Liriodendron tulipifera*) and Chestnut Oak (*Quercus prinus*).

This classification of sample plots into types is that which has been followed in the previous discussion and each type is described below.

The term "type" was not used here in any rigid sense.

No implication was intended that the vegetation described was composed of discrete and definable units *sensu* Braun-Blanquet (1951). The procedure of classification and the use of the term "type" were for the sake of convenience and communication. Even those investigators which have strongly argued the continuum approach to vegetation study have usually at some point used groupings or classification units analogous to "types" (cf. Whittaker, 1956; Curtis, 1959).

Canonical Analysis

The discreteness of the plot groups (types) derived through the clustering procedure was tested by "canonical analysis" (Seal, 1964), also termed "canonical variate analysis" (Blackith and Reyment, 1971). A computer program developed by Goldstein and Grigal (1972) was used to perform the procedure.

Canonical analysis makes a geometric representation of the arrangement of the various groups by calculating the generalized distances between each of the groups in multidimensional space, termed "canonical space."

The procedure first calculates the underlying dimensions of variation then uses these as the axes on which the mean positions of the groups are plotted. The first axis is inclined in the direction of greatest variability among the means of the samples. The second axis is perpendicular to the first and is inclined along the second greatest variability, and this continues for subsequent axes (Blackith and Reyment, 1971). A maximum of G-1 axes may be extracted, where G is the number of groups. Usually only the first two or three axes are capable of biologically meaningful interpretation.

The fourteen groups obtained in the agglomerative classification and the three pine-dominated groups were included in the canonical analysis. Positions of the plot groups along the first two axes are shown in Figure 3, where the circles represent 90% confidence intervals around each group mean (Seal, 1964).

A definite grouping and overlapping of types occurs in the upper left-hand quadrant. The types Hemlock, Silverbell-Hemlock, Hemlock-Buckeye, Buckeye, Beech, Basswood, Sugar-Maple, and Yellow-Poplar form an overlapping group of types. This group of types is recognizable as the rather broad type commonly referred to as cove hardwoods (Cain, 1943; Whittaker, 1956). Although these groups were segregated at lower levels in the clustering technique, their close relationship is recognized in the canonical analysis.

Also overlapping are the Red Maple-Northern Red Oak and Red Maple-Sweet Birch types and the Table-Mountain Pine and Table-Mountain-Pitch Pine types. The remaining five types, Spruce-Yellow Birch, Yellow Birch-Hemlock, Northern Red Oak, Chestnut Oak and Oak-Pine are distinct.

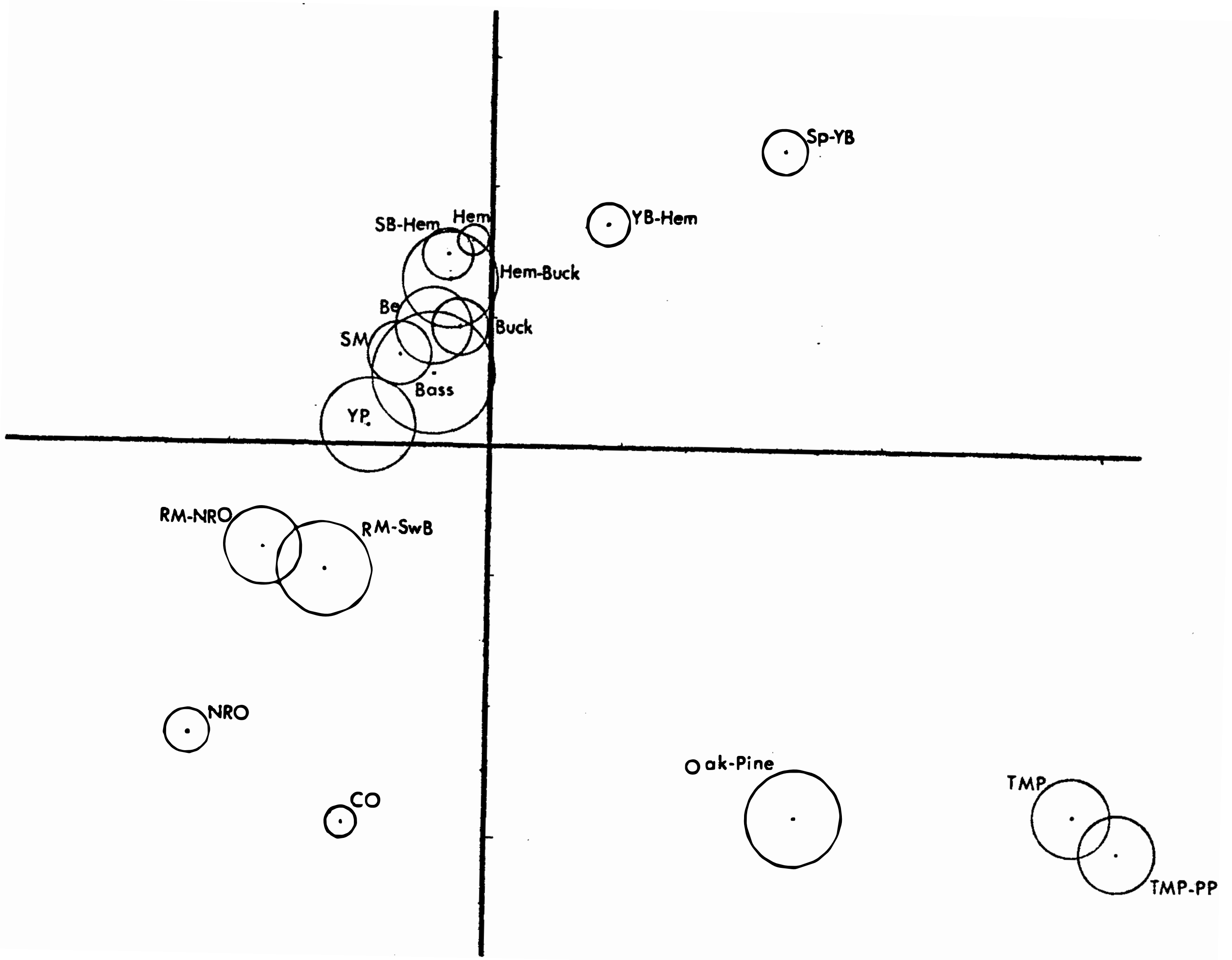

Figure 3. Position along first two canonical axes of 17 stand types from the central Great Smoky Mountains. Circles represent 90% confidence intervals around group means.

Descriptions of Forest Types and Their Habitats

Introduction. To aid in description, the samples of each type were plotted onto topographic maps in contrasting colors. This was to facilitate the determination of patterns which might not be readily detectable from tabular data, or even from having observed them in the field. Personal experience has indicated that significant variation exists across localities, even in an area the size of the Smokies. For example, the prominence of *Picea rubens* and *Betula alleghaniensis* which is evident at elevations 1472-1676 m on the slopes of Mt. LeConte and Mt. Mingus, does not occur at the same elevations on Thomas Ridge, although the areas are less than 7 km apart. Some of the types herein recognized appeared to be more common in certain localities than in others. These patterns are discussed below.

Buckeye type. The Buckeye forest type was restricted to coves and lower slopes, primarily in the elevation range 1130 to 1400 m, although stands sampled ranged from 939 to 1524 m (Table 1, page 55). They were mostly on WNW to NE aspects, although they occurred also in well-protected south-facing coves (two plots). All of the Buckeye plots were located around Mt. LeConte and ridges radiating from it, or in coves adjoining Sugarland Valley. Few cove sites were sampled in the Thomas Ridge area, which may account for the Buckeye type not having been sampled there.

Stands typically consisted of tall, large overstory trees with closed canopies, a well-developed understory, and a thin, mainly deciduous shrub layer. A luxuriant herb layer was common except where large boulders covered most of the ground surface. Overstory (>12.7 cm dbh) basal areas ranged from 34.6 to 73.2 m^2/ha, averaging 52.9 m^2/ha. Overstory stem densities ranged from 173 to 494 stems/ha, averaging 288 stems/ha. A total of 18 taxa occurred in sample plot overstories (Table 9), averaging 5.8 per sample, and an average of 7.2 tree taxa occurred among all stems 2.5 cm or larger. Seventy-eight vascular taxa occurred in all the samples, averaging 21 taxa/sample. The taxa listed in Table 9 and in other similar tables following are those which reached a dbh of 12.7 cm in any of the samples of this study. As a result, Rhododendron maximum and Kalmia latifolia were included and certain small tree taxa such as Cornus alternifolia and Ilex montana were not (these taxa were included with the shrub taxa in Table 6, page 74). The largest individual tree measured in the Buckeye type was a Prunus serotina of 123 cm (48 inches) dbh, and the largest Aesculus octandra was 112 cm (44 inches) dbh.

The canopy was typically dominated (in terms of importance values) by Aesculus octandra, with Betula alleghaniensis, Tilia heterophylla, Halesis carolina, Acer

Table 9. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Buckeye Type[a]. N=15.

	All Stems >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Importance Value Max.=200	I.V. Range
Abies fraseri	7	1	7	2	1	3	0-38
Acer pennsylvanicum	27	1	7	+[b]	+	+	0-6
A. rubrum	7	1	7	1	1	2	0-33
A. saccharum	73	20	73	7	5	12	0-28
A. spicatum	54	17	40	2	+	3	0-23
Aesculus octandra	100	17	100	36	51	87 (1)	33-154
Amelanchier spp.	7	+	7	1	+	1	0-12
Betula alleghaniensis	73	10	73	16	13	30 (2)	0-102
Carya cordiformis	20	1	20	2	3	5	0-46
Cladrastis lutea	7	1	7	1	1	2	0-24
Fagus grandifolia	40	5	27	2	1	3	0-18
Fraxinus spp.	27	1	27	1	1	2	0-17
Halesia carolina	54	5	47	7	5	12 (4)	0-59
Liriodendron tulipifera	7	+	7	+	1	1	0-13
Picea rubens	13	+	13	1	1	2	0-17
Prunus serotina	27	1	13	1	3	4	0-30
Rhododendron maximum	13	2	0	0	0	0	0
Tilia heterophylla	60	6	60	11	12	23 (3)	0-54
Tsuga canadensis	73	10	67	8	2	10 6	0-39
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha	Mean m^2/ha	
	7.2	810	5.8		288	52.9	

[a] All taxa which reached a size of 12.7 cm dbh in any sample of this study.

[b] Present, but less than 1%.

saccharum and *Tsuga canadensis* occurring as conspicuous components (Table 9). *Acer spicatum* (mountain maple) was a very common understory species and frequently reached overstory (12.7 cm) size. Shrubs and woody vines were not abundant, only seven taxa occurred in the 15 samples. These were *Aristolochia macrophylla*, *Cornus alternifolia*, *Hydrangea arborescens*, *Rhododendron maximum*, *Smilax rotundifolia*, and *Viburnum alnifolium* (Table 6, page 74). Fifty-three herb and fern taxa occurred among the samples. Taxa with 50% or higher frequency were *Cimicifuga racemosa*, *Euonymus obovatus*, *Laportea canadensis*, *Solidago curtisii*, *Tiarella cordifolia*, *Dryopteris intermedia* and *Caulophyllum thalictroides*.

To gain insight into type stability, frequencies and relative densities among three strata were compared for this and all following types. The data in Table 10 and other similar tables were derived by computing relative density for established individuals less than 2.5 cm dbh (seedlings) and for those 2.5 to 12.7 cm dbh (saplings) among only the tree taxa frequently reaching canopy size. Shrub and understory taxa such as *Cornus florida* (flowering dogwood) and *Hamamelis virginiana* (witch-hazel) were omitted from these relative calculations. Such a limitation was critical to meaningful comparisons, for in several types shrub species such as *Rhododendron maximum* or *Kalmia latifolia* overwhelmingly dominated the seedling or shrub strata or both. These species

Table 10. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Buckeye Type. N=15.

	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
Taxa	% Frequency	Mean Relative Density	% Frequency	Mean Relative Density	% Frequency	Mean Relative Density
Abies fraseri	0	0	7	2	7	2
Acer rubrum	0	0	7	1	7	1
A. saccharum	54	40	60	33	73	7
Aesculus octandra	34	11	60	16	100	38
Betula alleghaniensis	20	9	47	13	73	16
Carya cordiformis	7	+[c]	7	+	20	2
Cladrastis lutea	0	0	0	0	7	1
Fagus grandifolia	13	8	40	9	27	2
Fraxinus spp.	0	0	7	1	27	1
Halesia carolina	13	1	47	4	47	7
Liriodendron tulipifera	0	0	0	0	7	+
Picea *rubens*	13	7	0	0	13	1
Prunus serotina	13	8	14	1	13	1
Tilia heterophylla	20	5	33	3	60	11
Tsuga canadensis	13	3	60	16	67	8

[a] Mean density = 9/sample = 2295/ha.

[b] Mean density = 14/sample = 350/ha.

[c] Present, but less than 1%.

will not become part of the canopy, and so have no direct significance in such comparisons; although they may have some effects on succession.

Although the major dominants of the Buckeye type were represented in all three size classes (Table 10), some shifting of relative density in the canopy appears likely with time. Although fairly low in canopy relative abundance, *Acer saccharum* was strongly dominant in the lower strata. *Fagus grandifolia* was also significantly higher in relative density in the lower strata, while *Halesia carolina* trended in the opposite direction.

In broad size-class comparisons, the seedling relative densities probably should not be regarded as significant as those of the 2.5 to 12.7 cm (sapling) class. At each site, only a single 0.004 ha sample was taken of the seedling stratum, a sample too limited to be considered an adequate representation of seeding densities. While the sapling sample suffers from a similar criticism, it was ten times larger than the seedling sample, and hopefully gave a more reliable estimate. Additionally, since mortality rates generally decline with increasing size, a much higher percentage of saplings than seedlings will ultimately reach the canopy, and are thus better estimates of future canopy composition.

Other factors also complicate interpretation of seedling relative densities. Acer saccharum is a prolific seeder, particularly on mesic sites (Fowells, 1965). In the seven most mesic types (see discussion of the site gradient below), A. saccharum was highest in relative density in the seedling size class. As another example, Fagus grandifolia produces root sprouts prolifically, very few of which become trees (Fowells, 1965). Even disregarding the seedling values, however, sapling data indicated that Acer saccharum and Fagus grandifolia are increasing in importance in the Buckeye type.

Another possibility which makes such broad comparisons as presented here more difficult is the likelihood of periodic reproduction by some or all of the tree taxa. Such periodic reproduction may be caused by catastrophes or sudden canopy opening, by wet and dry cycles, variations in seed production, or by changes in microhabitat factors (Hough and Forbes, 1943). Stratal comparisons of Tsuga canadensis and Halesia carolina suggest such periodic reproduction.

Of the Buckeye type soils sampled, 40% were Typic Haplumbrepts, 20% were Typic Dystrochrepts and 13% were Umbric Dystrochrepts. Soil depths varied, but usually were greater than 50 cm (Table 3, page 64). Boulders of varied sizes were common on the surface, but typically were covered by organic mats supporting abundant herbs in depressions or where surfaces were level. Stone content of the solum was highly variable, but colluvial rock material was commonly abundant, composing over 50% of the soil volume in five of the Buckeye plots. The pH of two-thirds of the top mineral soil horizon samples were 5.0 or greater, and the modal pH was 5.4. This is substantially higher than the pH of 4.2 reported by Cain (1931) for a cove forest within the study area. However, Cain's description of that cove forest included abundant *Rhododendron maximum* in the shrub layer, a species which forms a highly acid litter. *Rhododendron* was not important in the Buckeye type.

A horizon thicknesses were usually 20 to 30 cm, sometimes less. There was practically no differentiation between moist colors of the A and B horizons, as hues of 10YR, values of 2 or 3, and chromas of 2 were predominant for both horizons. A horizon textures included silt loams, loams, and loamy sands, but 47% of the samples were sandy loams. Loams and silt loams each constituted 38% of the B horizon textures. Soil water-holding capacity in the top 50 cm (or to bedrock) varied from 0.97 to 7.92 cm, averaging 3.61 cm (Table 3, page 64), which is among the lower one-third of type means. Total available soil phosphorus in the top 50 cm ranged from 3.63 to 20.17 kg/ha, averaging 8.05 kg/ha (among lower one-third of types). Total available potassium ranged from 114.9 to 636.5 kg/ha, averaging 252.1 kg/ha (among middle one-third of types). Average clay content of the B horizon was the lowest of any type, only 8%.

Topographic shading of direct solar beam irradiation added to the mesic nature of the Buckeye sites. A growing season average of 2.2 hours shading per day (among upper one-third of types) was determined for Buckeye sample plots, ranging from 1.2 to 3.5 hours per day. Typically, shading was longer in the morning than in the afternoon, and the minimum average morning shading was 0.8 hours.

The Buckeye type falls into the general category Cove Hardwoods as used by Cain (1931, 1937, 1943, 1945), Shanks (1954b) and Whittaker (1956). Cain (1943) included the Buckeye-Basswood segregate in the Aesculion alliance of the cove hardwood complex. He found _Aesculus octandra_ dominant or codominant in 10 of 18 samples of the Aesculion alliance in the Greenbrier Cove area. Whittaker (1956) did not separate the Cove Hardwoods Forest into types or segregates, stating that "various combinations of dominants appear locally." He found a rise in the importance of _A. octandra_, _Tilia heterophylla_ and _Betula alleghaniensis_ in coves at higher elevations. Braun (1950) considered the cove hardwoods, except for the addition of _Halesia carolina_, "typical mixed mesophytic communities," distinguishable into a number of segregates, and she adopted as segregates those earlier named by Cain (1943). Whittaker (1956) disagreed, considering the cove forests of the Smokies more mesic in nature than Braun's mixed mesophytic forests, which she described chiefly from the Cumberland Mountains.

Hemlock-buckeye type. Hemlock-Buckeye sample plots occurred in coves and on lower slopes with high surface rock cover, primarily on the north side of Mt. LeConte and ridges radiating from it. Sixty percent of the sample plots occurred between 1119 and 1125 m elevation. Usually having NW to E aspects, plots also occurred on southerly aspects in well-protected coves (Table 1, page 55).

Hemlock-Buckeye plots were characterized by large canopy trees, low sapling densities, low density, mainly deciduous shrub cover, and a well-developed herb stratum. Overstory basal areas ranged from 35.1 to 116.4 m^2/ha, averaging 68.9 m^2/ha. Overstory stem densities ranged from 198 to 334 stems/ha, averaging 264 stems/ha. Only 12 taxa occurred in sample overstories, averaging 7.2 taxa per sample plot. Sixteen tree taxa occurred among stems >2.5 cm, averaging 8.6 per sample plot (Table 11). Fifty-seven vascular taxa occurred in all the samples, averaging 23 taxa/sample. A Tsuga canadensis of 152 cm (60 inches) dbh was the largest individual tree encountered in this type. Tsuga canadensis and Aesculus octandra stems larger than 75 cm dbh were quite common.

Canopies were typically dominated by large Tsuga canadensis, Aesculus octandra and Acer saccharum, with

Table 11. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Hemlock-Buckeye Type.[a] N=5.

	All Stems >2.5 cm dbh		Stems ≥12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Abies fraseri	20	+[b]	20	1	+	1	0-6
Acer pennsylvanicum	20	+	0	0	0	0	0
A. rubrum	40	2	40	3	6	9	0-37
A. saccharum	100	14	100	18	14	32	5-65
A. spicatum	20	8	0	0	0	0	0
Aesculus octandra	100	14	100	19	23	42	29-59
Amelanchier spp.	20	+	0	0	0	0	0
Betula alleghaniensis	60	4	60	3	3	7	0-17
Fagus grandifolia	100	13	80	9	2	10	0-22
Fraxinus spp.	60	4	40	2	3	5	0-16
Halesia carolina	100	8	80	8	+	12	0-26
Magnolia acuminata	20	+	20	1	+	1	0-7
Picea rubens	20	2	0	0	0	0	0
Prunus serotina	20	+	20	1	+	1	0-5
Tilia heterophylla	60	2	60	4	6	10	0-19
Tsuga canadensis	100	27	100	31	39	70	58-85
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha	Mean m^2/ha	
	8.6	531	7.2		264	68.94	

[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Present, but less than 1%.

scattered Fagus grandifolia, Halesia carolina, Tilia heterophylla, Betula alleghaniensis and Acer rubrum individuals (Table 11). Understory trees were scattered, and primarily mixtures of the same taxa found in the canopy, although Acer spicatum was sometimes common. Shrubs and woody vines were scattered and even less abundant than in the Buckeye type. Aristolochia macrophylla, Cornus alternifolia, Hydrangea arborescens, Lindera benzoin, Leucothoe axillaris var. editorum, and Rhododendron maximum were the only taxa sampled and each (except Leucothoe) occurred in only one of the five samples (Table 6, page 74). The low shrub density may be partially explained by the typically high rock cover, which restricts shrub rooting ability.

The herb stratum was fairly rich, although considerably less so than in the Buckeye type, probably due to the higher rock cover. Thirty-five herb and fern taxa occurred in the five 0.004 ha sample plots. The most common were Laportea canadensis (in all five samples), Solidago curtisii, Tiarella cordifolia, Dryopteris intermedia and Cimicifuga racemosa, all of which were also common in the Buckeye type.

A comparison of frequencies and relative densities by strata (Table 12) indicated that the type is relatively stable, although Tsuga canadensis may be less prominent in future canopy composition. Sample seedling densities of T. canadensis were quite low, but its high relative density in

Table 12. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Hemlock-Buckeye Type. N=5.

Taxa	Seedlings[a] (<2.5 cm) Percent Frequency	Seedlings[a] (<2.5 cm) Mean Relative Density	Saplings[b] (2.5-12.7 cm) Percent Frequency	Saplings[b] (2.5-12.7 cm) Mean Relative Density	Canopy (>12.7 cm) Percent Frequency	Canopy (>12.7 cm) Mean Relative Density
Abies fraseri	0	0	0	0	20	1
Acer rubrum	20	7	20	2	40	3
A. saccharum	60	34	40	9	100	18
Aesculus octandra	40	7	60	15	100	19
Betula alleghaniensis	40	17	20	5	60	3
Fagus grandifolia	20	4	60	18	80	9
Fraxinus spp.	40	23	40	11	40	2
Halesia carolina	40	3	60	11	80	8
Magnolia acuminata	0	0	0	0	20	1
Picea rubens	0	0	20	5	0	0
Prunus serotina	0	0	0	0	20	1
Tilia heterophylla	40	3	0	0	60	4
Tsuga canadensis	20	2	80	24	100	31

[a] Mean density = 8/sample = 2000/ha.

[b] Mean density = 8/sample = 190/ha.

the sapling size class indicates that either periodic reproduction (cf. Hough and Forbes, 1943) or a sampling anomaly may have been responsible. A similar observation can be made for *Tilia heterophylla*, *Halesia carolina* and *Fagus grandifolia*. *Acer saccharum* seedlings were extremely abundant in many samples, thus depressing the relative densities of all other taxa. *Fraxinus* spp. exhibited significantly increased relative densities in the lower strata, true also for *Betula alleghaniensis* in the seedling stratum.

Soils were Typic and Umbric Dystrochrepts, although one Typic Haplumbrept occurred. Three of the five soils sampled were of the loamy-skeletal particle-size class, reflecting the abundant colluvial material present.

Soil depths between boulders were predominantly greater than 50 cm (Table 3, page 64). Colluvial rocks and boulders were very abundant in the solum and on the surface. Top mineral horizon pH's were generally lower than those of the Buckeye type, possibly due to the greater abundance of *Tsuga canadensis*, which produces an acid litter (Fowells, 1965). A horizon thicknesses were usually 15 to 20 cm, averaging 19 cm. No clear color changes occurred between the A and B horizons. Moist colors of all samples had hues of 10YR, values of 2 to 4, and chromas of 1 to 3. A horizon textures were sandy loams, loams or silt loams, whereas all of the B horizon textures were silt loams. Total water-holding capacity of the upper 50 cm varied from 1.1 to 8.4 cm, averaging 3.7 cm (among lower one-third of the range of type means). Total available soil phosphorus ranged from 4.48 to 17.92 kg/ha, averaging 8.21 (among lower one-third of types). Available potassium varied from 156.8 to 612.8 kg/ha, averaging 278.5 kg/ha (among upper one-third of types).

Each Hemlock-Buckeye site received some topographic shading during the growing season, but somewhat less than the case of the Buckeye type. No plot averaged a mean daily total of more than 2.2 hours shading.

Hemlock-Buckeye plots occurred on sites topographically similar to those of Buckeye, but differed primarily in that they had higher amounts of colluvial rock. Compositionally, the Hemlock-Buckeye type differed from the Buckeye type in the much greater importance of *Tsuga canadensis*, *Acer saccharum* and *Fagus grandifolia*, and lesser importance of *Betula alleghaniensis*. Its understory stratum was somewhat less dense.

This type fits into the general cove hardwoods type of Cain (1937, 1943), Shanks (1954), and Whittaker (1956), although none of them distinguished a segregate dominated by *Tsuga canadensis* and *Aesculus octandra*. Braun (1950) described Hemlock-Mixed Mesophytic forests in the Cumberland Mountains, but stated that *Aesculus octandra*, *Acer saccharum* and *Tilia heterophylla* were poorly represented, which was not the case in the Hemlock-Buckeye samples of this study. Though not distinguishing it as a segregate, she described a north-facing cove slope in the Smokies in which *Tsuga canadensis*, *Tilia heterophylla* and *Aesculus octandra* together comprised 54% of the canopy.

Basswood type. The plots grouped together as Basswood type occurred in steep, rocky coves or on lower slopes on the sides of Mt. LeConte and of Pinnacle Lead.

A close scrutiny of the data from these three plots indicated that two of the three may properly be considered variants of the Hemlock-Buckeye type. Site, soil and vegetation characteristics of these two stands fell within easily tolerable limits of variation for that type (Table 13).

The third plot was at a lower elevation (820 m) than the Buckeye or Hemlock-Buckeye types, and had a considerably more diverse list of taxa (15 taxa - 2.5 cm dbh). *Quercus rubra* was a strong second dominant, contrasted with its absence in the Buckeye and Hemlock-Buckeye types.

Yellow-poplar type. Yellow-Poplar sample plots occurred on the lower slopes of larger valleys at elevations below 1000 m (Table 1, page 55). Lower slope position, low elevation and past disturbances appeared to be factors favoring the occurrence of this type. Definite evidence of past disturbance in the form of stumps, fire scars, or dead

Table 13. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Basswood Type.[a] N=3.

	All Stems[b] >2.5 cm dbh		Stems ≥12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer rubrum	33	2	33	3	2	5	0-16
A. saccharum	100	19	67	17	12	29	0-49
A. spicatum	33	3	33	1	+[c]	2	0-5
Aesculus octandra	100	5	100	7	7	15	8-27
Betula alleghaniensis	100	6	100	6	3	9	5-13
Carya cordiformis	33	+	33	1	1	2	0-6
Fagus grandifolia	67	11	67	8	5	13	0-35
Fraxinus spp.	67	2	67	2	3	6	0-12
Halesia carolina	33	3	33	4	2	6	0-19
Hamamelis virginiana	33	4	0	0	0	0	0
Liriodendron tulipifera	33	2	33	2	+	3	0-7
Magnolia acuminata	33	1	33	2	7	9	0-28
Picea rubens	67	4	33	1	2	4	0-11
Quercus rubra	33	2	33	2	9	11	0-32
Tilia heterophylla	100	25	100	30	30	60	55-68
Tsuga canadensis	100	6	100	10	16	27	14-44
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha	Mean m^2/ha	
	10.3	829	8.6		350	53.61	

[a]All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b]*Prunus serotina* occurred only as seedlings.

[c]Present, but less than 1%.

Castanea dentata occurred in 80% of the sample plots. Greatly disturbed sites were not sampled.

Plots were usually dominated by tall (>21m), straight, medium-sized (25-45 cm dbh) Liriodendron tulipifera individuals, with a well-developed understory and a low density shrub layer. The summer herb stratum was generally less developed than that of the cove types. Overstory basal areas ranged from 41.3 to 85.0 m^2/ha, averaging 54.5 m^2/ha. Overstory stem densities ranged from 297 to 581 stems/ha, averaging 447 stems/ha. A total of 15 taxa occurred in sample overstories (Table 14), averaging 6.6 per sample plot. An average of 11 tree taxa occurred among stems 2.5 cm dbh or larger. Fifty-nine vascular taxa occurred in all samples, averaging 25 taxa/sample.

The largest individual trees encountered were a Liriodendron tulipifera and a Tsuga canadensis, both 135 cm (54 inches) dbh, occurring in the same plot. This plot was dominated by very large trees. It was located on a gentle lower valley slope at 970 m (3180 ft) elevation and except for scattered down trees, appeared to have been undisturbed for at least a century. Besides a number of very large (>100 cm dbh) L. tulipifera individuals, a mixture of large Tilia heterophylla, Tsuga canadensis, Halesia carolina, Betula alleghaniensis and Fraxinus spp. occurred in the canopy.

Commonly associated trees were mostly cove hardwood

Table 14. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Yellow-Poplar Type.[a] N=5.

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer rubrum	80	11	80	10	5	15	0-35
A. saccharum	80	7	40	2	1	2	0-7
Aesculus octandra	40	5	20	2	2	4	0-22
Betula alleghaniensis	40	5	20	3	1	4	0-21
B. lenta	100	6	100	10	3	12	3-26
Carya cordiformis	20	1	0	0	0	0	0
Cornus florida	40	3	0	0	0	0	0
Fraxinus spp.	60	1	40	2	2	4	0-11
Halesia carolina	100	7	100	13	3	16	3-30
Liriodendron tulipifera	100	19	100	39	60	98	55-126
Magnolia acuminata	20	+[c]	20	1	1	2	0-9
M. fraseri	40	1	20	1	+	1	0-4
M. tripetala	20	1	20	1	1	2	0-8
Ostrya virginiana	20	1	0	0	0	0	0
Prunus serotina	40	+	40	1	3	4	0-10
Quercus rubra	40	1	40	2	2	3	0-12
Rhododendron maximum	40	14	0	0	0	0	0
Robinia pseudoacacia	40	2	40	3	4	7	0-28
Tilia heterophylla	60	2	60	6	8	14	0-37
Tsuga canadensis	80	7	80	6	6	12	0-30
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha		Mean m^2/ha
	11	1168	6.6		447		54.53

Table 14 (continued)

[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Tree taxa which occurred only as seedlings were: *Amelanchier* spp., *Castanea dentata*, *Prunus pennsylvanicum*, and *Sassafras albidum*.

[c] Present, but less than 1%.

taxa such as *Halesia carolina*, *Tsuga canadensis*, *Tilia heterophylla*, *Acer rubrum*, *A. saccharum* and *Prunus serotina*. Also commonly present were intermediate tolerance taxa common on disturbed sites, *Betula lenta* and *Robinia pseudoacacia*. The shrub stratum was generally not well-developed. Only six shrub and woody vine taxa occurred in the type (Table 6, page 74). Thirty herb and fern taxa occurred in the 0.004 ha samples. Taxa occurring in over half the samples were: *Parthenocissus quinquefolia* (a vine), *Polygonatum biflorum*, *Stellaria pubera*, *Viola rotundifolia* and *Polystichum acrostichoides*.

The successional nature of this type was confirmed by comparison of frequencies and relative densities by strata (Table 15). The importance of *L. tulipifera* was very low in the seedling and sapling strata, compared to high densities of more shade tolerant taxa, primarily *Acer rubrum*, *A. saccharum*, *Aesculus octandra*, *Betula alleghaniensis* and *Tsuga canadensis*. *Liriodendron tulipifera* smaller than 60 cm (24 inches) dbh were not present in the old growth plot, suggesting that it will not remain indefinitely as a part of the stand. The samples of this type appeared to be successional to the cove hardwood types, primarily Sugar Maple, Hemlock-Buckeye, or Hemlock.

Soils were Typic Dystrochrepts, Typic Haplumbrepts and Umbric Dystrochrepts. None had lithic contacts within 50

Table 15. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Yellow-Poplar Type. N=5.

Taxa	Seedlings[a] (<2.5cm) Percent Frequency	Seedlings[a] (<2.5cm) Mean Relative Density	Saplings[b] (2.5-12.7cm) Percent Frequency	Saplings[b] (2.5-12.7cm) Mean Relative Density	Canopy (>12.7cm) Percent Frequency	Canopy (>12.7cm) Mean Relative Density
Acer rubrum	60	10	80	80	80	10
A. saccharum	80	34	60	19	40	2
Aesculus octandra	40	8	40	13	20	2
Betula alleghaniensis	0	0	40	10	20	3
B. lenta	20	+[c]	20	4	100	10
Carya cordiformis	60	7	20	1	0	0
Castanea dentata	20	+	0	0	0	0
Fraxinus spp.	80	22	20	3	40	2
Halesia carolina	60	5	20	5	100	13
Liriodendron tulipifera	20	1	20	5	100	39
Magnolia acuminata	20	4	0	0	20	1
M. fraseri	0	0	40	3	0	1
Prunus pennsylvanica	20	1	0	0	40	1
P. serotina	20	1	0	0	40	1
Quercus rubra	60	4	0	0	40	2
Robinia pseudoacacia	0	0	0	0	40	3
Tilia heterophylla	20	2	20	2	60	6
Tsuga canadensis	20	1	80	15	80	6

[a] Mean density = 33/sample = 8250/ha.

[b] Mean density = 16/sample = 400/ha.

[c] Present, but less than 1%.

cm of the soil surface. Stone volume was low, although colluvial surface rock cover averaged 20% (Table 3, page 64). Top mineral horizon pH's were generally higher than any of the other types, having a median of 5.4. A horizon thicknesses were highly variable, ranging from 2 - 30 cm. No definite color change was evident between mineral horizons. Moist hues were 10YR, values 2 or 3, and chromas 1 or 2 in both the top and subsurface horizons of all samples. Soil textures were loams, sandy loams or silt loams. Total available potassium was high, averaging 339 kg/ha, while average phosphorus was among the lower one-third of all types.

All the Yellow-Poplar sample plots received 0.8 or more hours of topographic shading each day during the growing season, averaging 1.6. The low elevation and lower slope position of these stands resulted in the shading effect from nearby ridges, contributing to their mesic nature.

Stands dominated by Liriodendron tulipifera are widespread in the central and southern U.S., primarily as a successional type (Society of American Foresters, 1964; Fowells, 1965). Cain (1937) referred to such stands in the Smokies as Yellow-Poplar-Old Field type. In describing the Cove Hardwoods, Cain (1937, 1943), Whittaker (1956) and Braun (1950) indicated that L. tulipifera was sometimes the dominant canopy taxon. The single old-growth plot classified here in the Yellow-Poplar type appears to have been such a case.

Sugar maple. Sample plots of the Sugar Maple type occurred in coves and on lower slopes in the Mt. LeConte and Ramsey Prong areas, and on steep north and northeast-facing slopes at high elevations in the Thomas Ridge area. Elevations ranged from 942 m to 1442 m, averaging 1191 m (Table 1, page 55). Plots occurred above 1250 m only in the Thomas Ridge area.

Sample plots typically had medium to large-sized trees with closed canopies, a well-developed understory, very few shrubs, and a luxuriant herb stratum. Overstory basal areas ranged from 29 to 83 m^2/ha, averaging 44 m^2/ha. Overstory stem densities ranged from 198 to 432 stems/ha, averaging 341 stems/ha. A total of 14 taxa occurred in sample overstories, averaging 6.6, and an average of 7.7 tree taxa occurred as stems 2.5 cm or larger dbh. Seventy-nine vascular taxa occurred in all plots, averaging 25 taxa/sample. The largest individual tree found in these plots was a Quercus rubra of 97 cm (38 inches) dbh, the largest Acer saccharum measured was 91 cm (36 inches) dbh.

Canopies were typically dominated by a mixture of Acer saccharum, Halesia carolina, Aesculus octandra, Fagus grandifolia and Tilia heterophylla (Table 16). Other taxa occurring commonly (>20% of the samples) were: Tsuga canadensis, Betula alleghaniensis, Quercus rubra and Fraxinus spp. Sapling densities averaged 687 stems/ha. Shrubs were

Table 16. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Sugar Maple Type.[a] N=11.

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer pennsylvanicum	18	1	0	0	0	0	0
A. rubrum	18	+[c]	9	+	+	1	0-6
A. saccharum	100	25	100	32	40	72	26-107
A. spicatum	9	+	0	0	0	0	0
Aesculus octandra	82	6	82	11	16	26	0-65
Amelanchier spp.	9	+	0	0	0	0	0
Betula alleghaniensis	46	2	36	2	3	5	0-24
B. lenta	18	1	9	+	+	1	0-5
Castanea dentata	9	+	0	0	0	0	0
Fagus grandifolia	73	26	73	15	10	25	0-72
Fraxinus spp.	27	+	27	2	2	4	0-27
Halesia carolina	91	16	91	18	10	28	0-55
Magnolia acuminata	9	+	9	+	+	1	0-8
Ostrya virginiana	9	+	0	0	0	0	0
Picea rubens	9	+	9	+	+	1	0-6
Prunus serotina	9	+	0	0	0	0	0
Quercus rubra	36	1	27	2	4	6	0-44
Robinia pseudoacacia	9	+	9	1	1	1	0-15
Tilia heterophylla	91	8	82	10	11	21	0-51
Tsuga canadensis	82	10	64	6	3	9	0-24
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha		Mean m^2/ha
	7.7	1028	6.3		341		43.97

Table 16 (continued)

[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] *Castanea dentata* occurred only as seedlings.

[c] Present, but less than 1%.

rare (mean cover ca. 1%), resulting in a typical openness near the ground surface. This is one of only two types (Beech was the other) which had neither *Rhododendron* spp. nor *Kalmia latifolia* occurring in any samples. *Hydrangea arborescens* occurred in two sample plots; it was more frequent than any other shrub or vine taxon. Samples of the mesic, rich herb stratum included 51 taxa. Herb taxa in more than 50% of the samples (with decreasing frequency) were: *Stellaria pubera*, *Disporum lanuginosum*, *Dryopteris intermedia*, *Laportea canadensis*, *Solidago curtisii*, *Tiarella cordifolia*, *Caulophyllum thalictroides*, *Cimicifuga racemosa*, *Aster divericatus*, *Trillium* spp., *Viola* spp., *Polygonatum biflorum* and *Polystichum acrostichoides*.

When strata were compared (Table 17), the Sugar Maple type appeared to be relatively stable. Three (36%) of the 11 sample plots had evidence of *Castanea dentata* occurrence, either past (stumps, logs, snags) or present (as sprouts), and these were in the Thomas Ridge area. *Fagus grandifolia* was more common in the four samples in the Thomas Ridge area, particularly in the sapling and seedling classes.

Soils were divided among Typic Dystrochrepts (3), Umbric Dystrochrepts (3), and Typic Haplumbrepts (3), but with one Lithic Umbrept and one Lithic Dystrochrept. Two soils were of a loamy-skeletal particle-size class. Soil depths were typically greater than 50 cm (Table 3, page 64).

Table 17. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Sugar Maple Type. N=11.

	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
Taxa	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density
Acer rubrum	9	+[c]	9	+	9	+
A. saccharum	82	37	64	25	100	32
Aesculus octandra	46	18	9	3	82	11
Betula alleghaniensis	9	+	36	3	36	2
B. lenta	0	0	18	2	9	+
Castanea dentata	9	1	9	+	0	0
Fagus grandifolia	73	24	64	31	73	15
Fraxinus spp.	37	4	0	0	27	2
Halesia carolina	55	15	64	17	91	18
Magnolia acuminata	0	0	0	0	9	+
Picea rubens	0	0	0	0	9	+
Prunus serotina	9	+	9	+	0	0
Quercus rubra	9	+	19	+	27	2
Robinia pseudoacacia	0	0	0	0	9	1
Tilia heterophylla	19	1	73	7	82	10
Tsuga canadensis	0	0	64	12	64	6

[a] Mean density = 25/sample = 6250/ha.

[b] Mean density = 27/sample = 668/ha.

[c] Present, but less than 1%.

Most sites had no surface rock, but one cove site was covered with colluvial boulders. The non-cove sites were all on very steep slopes ranging from 38% to 85% and facing north to east. The top mineral soil pH's were unusually consistent, ranging only from 5.0 to 5.4. Horizon differentiation by color was generally poor. Moist hues were usually 10YR in both A and B horizons, A values were all 2 or 3, but B horizon values were generally 4 or 5. Chromas commonly changed from 2 or 3 to 4 or 5 at horizon boundaries. Textural changes were slight or non-existent, loams or silt loams were best represented, surface 50 cm water-holding capacity was among the highest for any type, averaging 7.70 cm. Total available phosphorus was higher than that of most of the other types, averaging 15.19 kg/ha while potassium levels were among the middle one-third of all types (Table 3, page 64).

Every Sugar Maple sample received some topographic shading, averaging 1.5 hours each day during the growing season. For most plots, shading was greater in the morning than in the afternoon. One plot received an average of three hours shading in the morning, but none in the afternoon.

The Sugar Maple type was less restricted to coves than the Buckeye or Hemlock-Buckeye types, and had significantly less colluvial rock. Compositionally, besides type species differences, _Halesia carolina_ and _Fagus grandifolia_ were significantly more important than in the Buckeye or Hemlock-Buckeye types.

This type is apparently the same as that described by the Society of American Foresters (1964) as Type 27. Except for the common occurrence of _Halesia carolina_, it is quite similar to the "Sugar Maple-Basswood-Buckeye" type described by Braun (1950) for the Cumberland Mountains. Cain's (1943) "Sugar Maple-Silverbell" type was likely essentially the same as described here. Whittaker (1956) did not distinguish this type, including it in the cove hardwood forest.

Silverbell-hemlock type. Samples of the Silverbell-Hemlock type occurred scattered throughout the study area, but were most abundant in the Roaring Fork and Porter's Creek areas, on the north side of Mt. LeConte. They occurred on well-protected north-facing middle and lower slope positions and in small coves at various aspects. Most were in the elevation range 860 to 1156 m, although they occurred to 1433 m (Table 1, page 55).

Characteristically, plots consisted of closed canopies of medium to large trees, moderately-developed sapling strata, variable but usually very thin shrub strata and abundant herb cover. Overstory basal areas ranged from 27 to 58 m^2/ha, averaging 46 m^2/ha. Overstory densities ranged from 284 to 519 stems/ha. averaging 392 stems/ha. A total of 19 taxa occurred in sample overstories, averaging 6.2 taxa per 0.08 ha sample (Table 18). Eighty-two vascular taxa occurred in the total sample, averaging 20 taxa/sample. Large individual trees encountered in this type included a *Prunus serotina* and a *Tilia heterophylla*, each 127 cm (50 inches) dbh.

Halesia carolina and *Tsuga canadensis* were most abundant in typical overstories, mixed with numerous other mesic taxa, principally *Fagus grandifolia*, *Betula alleghaniensis*, *Tilia heterophylla*, *Acer saccharum*, and *Aesculus octandra*. Understory trees were usually scattered, and *Acer pennsylvanicum*, *Cornus florida*, and *Ostrya virginiana* were small-tree taxa which occurred occasionally. Shrubs were absent from most, but 17% of the plots had moderately heavy shrub strata dominated by *Rhododendron maximum*. Other shrubs and vines occurring in more than one sample included *Smilax rotundifolia*, *Viburnum alnifolium*, and *Aristolochia macrophylla* (Table 6, page 74). Fifty-three fern and herb taxa occurred in the 18 0.004 ha samples. Those with more than 50% frequency were *Dryopteris intermedia*, *Laportea canadensis*, *Mitchella repens*, *Stellaria pubera*, *Tiarella cordifolia*, and *Aster divericatus*.

Seedling relative densities were dominated by *Acer saccharum* (Table 19), and this depressed the values for all other taxa. A sharp drop in the frequency and relative density of *Halesia carolina* in the sapling and seedling

Table 18. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Silverbell-Hemlock Type.[a] N=18.

	All Stems >2.5 cm dbh[b]		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer pennsylvanicum	28	2	6	+[c]	+	+	0-5
A. rubrum	39	3	28	3	3	6	0-51
A. saccharum	67	7	44	5	5	10	0-54
Aesculus octandra	50	3	44	3	7	10	0-43
Betula alleghaniensis	67	2	61	4	6	9	0-33
B. lenta	28	1	22	1	+	1	0-5
Cornus florida	6	+	0	0	0	0	0
Fagus grandifolia	72	13	72	15	14	28	0-73
Fraxinus spp.	28	1	22	1	2	2	0-21
Halesia carolina	100	2	100	33	32	65	13-116
Liriodendron tulipifera	6	+	6	+	+	1	0-10
Magnolia acuminata	11	+	11	+	+	+	0-4
M. fraseri	22	+	22	1	1	2	0-12
Ostrya virginiana	11	1	6	+	+	+	0-4
Picea rubens	11	1	11	1	1	1	0-18
Prunus pennsylvanicum	6	+	6	+	+	+	0-7
P. serotina	11	1	6	+	+	1	0-9
Rhododendron maximum	28	5	0	0	0	0	0
Robinia pseudoacacia	6	+	5	+	+	1	0-9
Tilia heterophylla	44	2	44	3	6	9	0-38
Tsuga canadensis	94	37	94	31	23	54	0-87
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha		Mean m^2/ha
	7.4	864	6.2		392		46.03

Table 18 (continued)

[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Taxa occurring only as seedlings were: *Castanea dentata*, *Nyssa sylvatica*, and *Quercus rubra*.

[c] Present, but less than 1%.

Table 19. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Silverbell-Hemlock Type. N=18.

Taxa	Seedlings[a] (<2.5 cm) Percent Frequency	Seedlings[a] (<2.5 cm) Mean Relative Density	Saplings[b] (2.5-12.7 cm) Percent Frequency	Saplings[b] (2.5-12.7 cm) Mean Relative Density	Canopy (>12.7 cm) Percent Frequency	Canopy (>12.7 cm) Mean Relative Density
Acer rubrum	28	3	28	4	28	3
A. saccharum	83	41	50	11	44	5
Aesculus octandra	56	9	28	4	44	3
Betula alleghaniensis	11	21	12	2	61	4
B. lenta	6	+[c]	12	2	61	4
Castanea dentata	6	+	0	0	0	0
Fagus grandifolia	62	2	34	12	72	15
Fraxinus spp.	11	1	6	1	22	1
Halesia carolina	45	4	61	7	100	33
Liriodendron tulipifera	0	0	0	0	6	+
Magnolia acuminata	11	2	0	0	11	+
M. fraseri	11	1	0	0	22	1
Nyssa sylvatica	6	2	0	0	22	1
Picea rubens	0	0	11	1	0	0
Prunus pennsylvanica	0	0	0	0	6	+
P. serotina	23	4	11	1	6	+
Quercus rubra	23	+	0	0	1	0
Robinia pseudoacacia	0	0	0	0	1	+
Tilia heterophylla	28	3	17	2	54	3
Tsuga canadensis	39	2	94	53	94	31

[a] Mean density = 34/sample = 8500/ha.

[b] Mean density = 16/sample = 397/ha.

[c] Present, but less than 1%.

classes indicated that this species was decreasing in importance with time, and was in contrast with the increasing importance of *Acer saccharum*.

Evidence of minor *Castanea dentata* occurrence was observed in three plots (17%), indicating that it was once an occasional tree in the Silverbell-Hemlock type.

Half (9) of the soil samples were classified as Typic Dystrochrepts, but Typic Haplumbrepts (5) and Umbric Dystrochrepts (3) were common. One fragmental soil occurred, and one in the loamy-skeletal particle-size class. Surface and subsurface rock was typically very low or absent (Table 3, page 64). Only one soil was less than 50 cm deep. A Horizon pH's were scattered between 4.0 and 5.4. Most moist color hues were 10YR in the two upper horizons. Moist values commonly changed from 3 to 4 in comparing A with B horizons, but in several samples, chromas changed from 2 to 4. Soil textures were quite variable, ranging from loamy sand to clay loam. Average water-holding capacity was among the upper one-third of the range among types, total available phosphorus in the lower one-third, and potassium in the upper one-third (Table 3, page 64).

The Silverbell-Hemlock type differed from the previously described mesic types in that it rarely occurred in cove or valley bottoms, but usually was on lower slopes or on steep, north-facing slopes. Many convex slopes on the north side of Mt. LeConte at elevations 950 to 1200 m support this type.

Compositionally it was characterized by more abundant *Halesia carolina*, *Tsuga canadensis*, and *Fagus grandifolia*, but less *Aesculus octandra* and *Tilia heterophylla* than in the Buckeye type. *H. carolina* and *F. grandifolia* were more abundant than in the Hemlock-Buckeye type and surface rock much less common. It differed from the Sugar Maple type in the greater abundance of *H. carolina* and *Tsuga canadensis*, lesser abundance of *Acer saccharum* and *Aesculus octandra*.

Since neither distinguished a type or segregate where *H. carolina* was a co-dominant with *T. canadensis*, it would appear that both Cain (1943) and Whittaker (1956) included such stands under the type "Hemlock" or "Eastern Hemlock." Cain's (1943) data showed *H. carolina* a dominant or co-dominant in 23% of stands of the Tsugion alliance. Whittaker (1956) listed *H. monticola* (*carolina*) first among the most important associates of *T. canadensis* in the Eastern Hemlock type.

Hemlock type. Hemlock stands are very abundant and widespread in the central Smokies. Sample plots occurred at a wide range of sites and elevations. At elevations below 900 m, sample plots were usually restricted to coves and near streams. At elevation 1000 to 1200 m, Hemlock stands dominated most of the protected and north-facing slopes, but seldom occurred in coves. None occurred higher than 1465 m in this study, 95% of the sample plots occurring below 1260 m. Although *Tsuga canadensis* was not uncommon in the Thomas Ridge area, no plots sampled there were classified as Hemlock. No samples were taken below 1305 m elevation in the Thomas Ridge area and high-elevation Hemlock slope stands were rare or absent there.

Though samples of this type were relatively diverse in site and vegetation characteristics, plots commonly were dominated by a few very large *T. canadensis* trees, with abundant stems of the same species in small to medium size classes. As indication of this, 45 of the 56 samples (80%) had *T. canadensis* basal areas exceeding 23 m^2/ha (100 ft^2/acre), and nine samples exceeded 46 m^2/ha (200 ft^2/acre). One sample plot contained a *T. canadensis* basal area of 112.2 m^2/ha (490 ft^2/acre).

Twenty-five tree taxa occurred as stems larger than 12.7 cm dbh, averaging 6.4 taxa per sample plot. Taxa other than *T. canadensis* found in more than 40% of the sample canopies were: *Halesia carolina*, *Fagus grandifolia*, *Acer rubrum*, *Betula alleghaniensis*, *Acer saccharum*, and *Magnolia fraseri* (Table 20). A total of 118 vascular taxa occurred in Hemlock samples, averaging 17 taxa/sample.

Halesia carolina was canopy second-dominant in 18 plots, *Acer rubrum* in nine, *Fagus grandifolia* in eight, and *Betula*

Table 20. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Hemlock Type.[a] N=56.

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer pennsylvanicum	33	2	9	+[c]	+	+	0-14
A. rubrum	62	3	62	5	9	14	0-63
A. saccharum	55	4	45	3	4	7	0-33
A. spicatum	2	+	0	0	0	0	0
Aesculus octandra	24	1	16	1	1	2	0-26
Amelanchier spp.	2	+	2	+	+	+	0-12
Betula alleghaniensis	58	4	55	6	6	12	0-53
B. lenta	17	+	14	1	+	1	0-23
Fagus grandifolia	66	6	66	7	5	12	0-49
Fraxinus spp.	9	+	9	+	1	1	0-25
Halesia carolina	84	12	82	14	10	24	0-81
Hamamelis virginiana	2	+	0	0	0	0	0
Ilex opaca	11	+	2	+	+	+	0-9
Juglans cinerea	2	+	2	+	+	+	0-9
Kalmia latifolia	5	1	7	+	+	+	0-10
Liriodendron tulipifera	27	1	27	1	4	6	0-74
Magnolia acuminata	11	+	11	+	1	1	0-15
M. fraseri	47	2	43	3	2	5	0-68
Nyssa sylvatica	2	+	2	+	+	+	0-6
Ostrya virginiana	4	+	2	+	+	+	0-4
Oxydendrum arboreum	8	+	5	1	+	1	0-26
Picea rubens	18	1	14	1	+	2	0-24
Prunus pennsylvanicum	4	+	2	+	+	+	0-9

Table 20 (continued)

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Importance Value Max.=200	I.V. Range
P. serotina	16	+	16	1	1	2	0-25
Quercus prinus	2	+	2	+	+	+	0-10
Q. rubra	11	+	11	1	1	2	0-44
Rhododendron maximum	40	12	0	0	0	0	0
Tilia heterophylla	27	3	27	3	3	6	0-56
Tsuga canadensis	100	45	100	52	50	102	55-194
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha	Mean m^2/ha	
	7.6	872	6.4		409	66.46	

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[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Carya cordiformis occurred only as seedlings.

[c] Present, but less than 1%.

alleghaniensis in seven. Six other taxa occurred as second-dominants: *Acer saccharum*, *Tilia heterophylla*, *Liriodendron tulipifera*, *Magnolia fraseri*, *Picea rubrum*, and *Quercus rubra*. Elevation of the 18 plots in which *H. carolina* was second-dominant occurred in the elevation range 1050 to 1170 m (3440 to 3840 ft). *H. carolina* was second-dominant in most of the Hemlock plots in this elevation range. *Betula alleghaniensis* was the most frequent second-dominant above 1220 m (4000 ft) elevation.

Understory shrub and herb densities were quite variable, depending somewhat upon whether a heavy shrub stratum of *Rhododendron maximum* was present. Of small-tree taxa, *Acer pennsylvanicum* was most common, yet it occurred in only one-third of the samples (Table 20, page 129). Seventeen shrub and vine taxa occurred in Hemlock plots (Table 6, page 74). *Smilax rotundifolia* occurred most frequently (61%) but *Rhododendron maximum* and *Aristolochia macrophylla* occurred in more than 25% of the sample plots (*R. maximum* in 42%). The significance of *R. maximum* is discussed below.

At least 71 herb and fern taxa were recorded from herb sample plots. *Mitchella repens* was the most characteristic, occurring with a frequency of 71%. Other herb taxa occurring in more than 20% of the samples were (in order of decreasing frequency): *Dryopteris intermedia*, *Medeola virginiana*, *Oxalis montana*, *Laportea canadensis*, *Viola rotundifolia*, *Tiarella cordifolia*, *Aster divericatus*, *Goodyera pubescens*, and *Solidago curtisii*.

When strata were compared (Table 21), the Hemlock type appeared stable. *Acer saccharum*, as in most of the mesic types, produced large numbers of seedlings, thus depressing the seedling relative densities of several other taxa including *Tsuga canadensis*.

Soil depths were typically greater than 50 cm. Surface rock cover was typically low, although several of the lower slope and cove sites had greater than 40% rock cover. Soil pH's varied widely (Table 3, page 64), but only 14% were 5.0 or higher. *Tsuga canadensis* litter tends to produce highly acid conditions (Fowells, 1965).

Most (68%) of the Hemlock soils were Typic Dystrochrepts; 20% were Typic Haplumbrepts, and only 7% were Lithic Dystrochrepts. Significant color variation between the first two horizons was rare. Most had moist hues of 10YR. Values were dark and changes between horizons rarely exceeded one unit. The A horizon values were usually 3 or less, the B, 4 or less. Changes in chromas occurred more frequently, but were rarely large. Textural changes were rarely great. Most were loams, silt loams or sandy loams. Available phosphorus was in the lower one-third of the range of type means, potassium in the middle one-third, and available water-holding capacity in the upper one-third.

Topographic shading varied widely (Table 1, page 55),

Table 21. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Saplings, and Canopy Size Classes of the Hemlock Type. N=56.

Taxa	Seedlings[a] (<2.5 cm) Percent Frequency	Seedlings[a] (<2.5 cm) Mean Relative Density	Saplings[b] (2.5-12.7 cm) Percent Frequency	Saplings[b] (2.5-12.7 cm) Mean Relative Density	Canopy (>12.7 cm) Percent Frequency	Canopy (>12.7 cm) Mean Relative Density
Acer rubrum	36	11	18	4	62	5
A. saccharum	58	29	23	5	45	3
Aesculus octandra	18	3	13	2	16	1
Betula alleghaniensis	15	2	16	3	55	6
Betula lenta	4	+[c]	4	+	14	1
Fagus grandifolia	42	14	38	7	66	7
Fraxinus spp.	17	2	0	0	9	+
Halesia carolina	38	6	51	12	82	14
Liriodendron tulipifera	0	0	0	0	27	1
Magnolia acuminata	9	2	0	0	11	+
M. fraseri	24	2	21	2	43	3
Nyssa sylvatica	0	0	0	0	2	+
Picea rubens	9	1	11	1	14	1
Prunus pennsylvanica	0	0	2	+	2	+
P. serotina	24	3	0	0	16	+
Quercus prinus	0	0	0	0	2	+
Quercus rubra	9	1	0	0	11	1
Robinia pseudoacacia	2	+	0	0	0	0
Tilia heterophylla	15	2	11	3	27	3
Tsuga canadensis	52	12	91	57	100	52

[a] Mean density = 24/sample = 6000/ha.

[b] Mean density = 11/sample = 275/ha.

[c] Present, but less than 1%.

averaging 1.5 hours per day during the growing season. Most of the middle to upper slope Hemlock plots averaged an hour or more daily shading.

In virgin stands in the North Carolina mountains, Oosting and Billings (1939) and Oosting and Bourdeau (1955) distinguished two segregates among hemlock stands based on the shrub and herb strata. These were the Hemlock-Rhododendron and the Hemlock-Herb types. Such a general distinction can be made among these Hemlock sample plots in the central Smokies, but no strong site relationships which distinguish these segregates were found in this study. The Polycodium (Vaccinium) stamineum dominance of the shrub strata of the non-Rhododendron stands which were found by Oosting and Billings (1939) was not the case in any of the stands found in this study. This condition was absent in Whittaker's (1956) data also.

Generally, at lower elevations Hemlock plots in coves and stream valleys frequently had a moderate to heavy Rhododendron maximum shrub layer. These closely resembled the Hemlock-Rhododendron segregate described by Oosting and Billings (1939) and Oosting and Bourdeau (1955). At elevations above 900 m (2950 ft), plots of the Hemlock type rarely occurred in large coves or stream valley bottoms, but were common on lower slopes, middle and upper north-facing slopes, and even on small well-protected ridges. As was reported by

Whittaker (1956), many of the upper elevation (1050 to 1300 m) Hemlock plots on steep slopes had high shrub coverages of *Rhododendron maximum*.

Among the stands (27%) with a *R. maximum* shrub coverage greater than 25%, *Halesia carolina* was the most common canopy second-dominant (46%), with *Acer rubrum* and *Betula alleghaniensis* the only other taxa occurring as second-dominants in these plots. *Tilia heterophylla* was rarer in the canopy and *Aesculus octandra* did not occur at all. Canopy and understory trees were generally more scattered than in plots without heavy *R. maximum* shrub layer. However, canopy trees were generally quite large, as 82% of such plots had basal areas exceeding 53 m^2/ha (233 ft^2/acre). The herb stratum in such plots was poorly developed, 67% having none at all.

Rhododendron maximum frequently formed dense thickets which were 3 to 4 m tall. Ground surface and soil conditions were strongly affected. Most of the light which penetrated the tree canopy was intercepted by the broad, thick shrub leaves, making light levels at the ground surface very low. The thick leaves decompose slowly, thus forming a thick litter layer which makes seedling and herb establishment difficult. The litter tends to be strongly acid. Soil pH's in Hemlock stands with *Rhododendron* understories ranged from 3.9 to 4.9 with a median of only 4.3.

Most of the Hemlock sample plots (70%) did not have heavy *R. maximum* understories. No consistent site differences could be determined between the plots with and without heavy *R. maximum* understories. Both occurred infrequently in coves but commonly on sheltered slopes. The Hemlock type had *R. maximum* understories more frequently than the Silverbell-Hemlock type, but less frequently than the Yellow Birch-Hemlock type.

Tsuga canadensis occurs as an important tree from northern Georgia northward throughout the northeastern U.S. and southeastern Canada (Little, 1953; Fowells, 1964). A Hemlock type (Type 23) was recognized by the Society of American Foresters (1964). Braun (1950) considered this type in the Cumberland Mountains to be an association-segregate of the Mixed Mesophytic Association. Cain (1937) reported that the only stands dominated by *T. canadensis* alone were those he termed Hemlock-Ridge type. He described these as occurring between about 1200 and 1500 m elevation on upper slopes and ridges on thin soils. He included all other stands dominated by *T. canadensis* as part of the Tsugion alliance of the Cove Hardwood forest complex (Cain, 1943). Whittaker's (1956) Eastern Hemlock type was not as restricted, it included most stands in which *T. canadensis* comprised 70% to 80% or more of the canopy stems.

Yellow birch-hemlock type. Yellow Birch-Hemlock sample plots occurred at higher elevations in all of the study area except Thomas Ridge. The type was predominant over much of the north slopes and steep protected slopes at elevations 1220 to 1400 m (4000 to 4596 ft), overlapping considerably and intergrading with upper elevation Hemlock stands. They usually occurred on slopes and occasionally on small protected ridges. None were sampled in cove or valley bottoms, although they were not uncommon as low as the 90% slope position, particularly in the lower part of the elevation range.

Large trees greater than 76 cm (30 inches) dbh, principally *Betula alleghaniensis* and *Tsuga canadensis*, were common in many of the plots. Overstory basal areas ranged from 27.7 to 71.7 m^2/ha, averaging 47.6 m^2/ha. Overstory stem densities ranged from 148 to 582 stems/ha, averaging 276. A total of 19 taxa occurred in canopy samples, but averaged only 4.2 taxa in each. A total of 71 vascular taxa occurred in the 29 samples, averaging only 9 taxa/sample.

Sapling density was inconsistent, but commonly low. Most plots (83%) had a moderate to very heavy shrub cover, typically composed mainly of *Rhododendron maximum*. This heavy shrub layer resulted in low occurrence of herbs.

Betula alleghaniensis typically had the highest importance value of stems greater than 12.7 cm dbh, and *Tsuga* *canadensis* was typically second-dominant. Only three other taxa had a frequency of more than 20% in the canopy (Table 22). *Picea rubens* had a frequency of more than 40%. *Fagus grandifolia* and *Aesculus octandra* were important primarily on lower slopes. Stems in the sapling size class (2.5 to 12.7 cm dbh) averaged 682/ha, but most of these were usually larger stems of *Rhododendron maximum*, which had a sapling-size density ranging up to 1186 stems/ha (480 stems/acre). Twelve other shrub taxa occurred, but none with a frequency of more than 20% (Table 6, page 74). Herbs and ferns were scarce or absent in most of the stands with heavy *R. maximum* shrub cover, but 36 taxa occurred in the 29 0.004 ha samples. *Dryopteris intermedia* was the only taxon with a frequency greater than 24% and it was only 34%.

The Yellow Birch-Hemlock type appears to be fairly stable (Table 23). The relative density of *Tsuga canadensis* was similar in all strata, but *Betula alleghaniensis* declined somewhat in the sapling and seedling classes while *Fagus grandifolia* increased. All taxa had low frequencies in the seedling samples, perhaps a result of the inadequacy of the single sample plot in each stand.

Typic Dystrochrepts were the most common (55%) soils, but 17% were classified as Lithic and 10% as Fragmental. Ten percent of the soils were Histosols, composed of humus layers directly over bedrock. One of these Histosols was slightly more than 50 cm thick.

Table 22. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Yellow Birch-Hemlock Type.[a] N=29.

	All Stems >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Abies fraseri	14	2	7	2	1	2	0-61
Acer pennsylvanicum	24	2	10	1	+[b]	1	0-11
A. rubrum	17	1	10	1	+	1	0-12
A. saccharum	7	+	7	+	+	1	0-15
A. spicatum	37	9	7	1	+	1	0-19
Aesculus octandra	24	+	24	2	3	5	0-38
Amelanchier spp.	10	+	7	1	+	1	0-18
Betula alleghaniensis	100	20	100	52	56	108	57-195
B. lenta	3	+	3	+	+	+	0-9
Fagus grandifolia	31	9	30	6	2	9	0-67
Halesia carolina	14	1	10	2	+	2	0-32
Hamamelis virginiana	7	+	0	0	0	0	0
Kalmia latifolia	10	2	0	0	0	0	0
Liriodendron tulipifera	7	+	7	+	+	+	0-8
Magnolia acuminata	3	+	3	+	1	1	0-38
M. fraseri	17	1	17	2	1	2	0-33
Picea rubens	52	3	42	5	4	9	0-33
Prunus pennsylvanicum	7	+	3	1	+	+	0-6
P. serotina	10	+	7	+	+	1	0-20
Quercus rubra	7	+	7	1	+	+	0-5
Rhododendron maximum	83	35	3	+	+	+	0-7
Tilia heterophylla	7	+	7	+	1	1	0-21
Tsuga canadensis	93	14	90	25	28	53	0-118

Table 22 (continued)

Taxa	All Stems >2.5 cm dbh Percent Frequency	All Stems >2.5 cm dbh Mean Relative Density Max.=100	Stems >12.7 cm dbh Percent Frequency	Stems >12.7 cm dbh Mean Relative Density Max.=100	Stems >12.7 cm dbh Mean Relative Basal Area Max.=100	Stems >12.7 cm dbh Mean Importance Value Max.=200	Stems >12.7 cm dbh I.V. Range
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha		Mean m^2/ha
	6.2	958	4.2		276		47.64

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[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Present, but less than 1%.

Table 23. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Yellow Birch-Hemlock Type. N=29.

	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
Taxa	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density
Abies fraseri	5	1	10	4	7	2
Acer rubrum	7	6	14	2	10	1
A. saccharum	3	1	3	+[c]	7	+
Aesculus octandra	0	0	7	4	24	2
Betula alleghaniensis	35	39	59	26	100	52
B. lenta	4	2	0	0	3	+
Fagus grandifolia	18	16	21	14	30	6
Halesia carolina	4	4	10	3	10	2
Liriodendron tulipifera	0	0	4	+	7	+
Magnolia acuminata	0	0	0	0	3	+
M. fraseri	0	0	7	4	17	2
Picea rubens	11	7	10	2	42	5
Prunus pennsylvanica	0	0	4	+	3	+
P. serotina	0	0	4	3	7	+
Quercus rubra	7	1	4	+	7	+
Tilia heterophylla	0	0	4	+	7	+
Tsuga canadensis	28	22	62	29	90	25

[a] Mean density = 3/sample = 750 ha.

[b] Mean density = 8/sample = 188/ha.

[c] Present, but less than 1%.

Slightly more than one-third of the sites had soil depths less than 50 cm (Table 3, page 64). These shallow soils were typically found on steep, upper slopes, on convex slopes or small ridges. High surface rock cover and solum stone volume occurred on some slopes and on lower slopes. Soil pH's were low, only four were higher than 4.7, and none were higher than 5.0. The higher rainfall of the upper elevations and the acid litter of _Tsuga canadensis_ and _Rhododendron maximum_ contributed to the high soil acidity. Total available potassium was low, possibly as a consequence of the high acidity and factors related to it. Profile color and texture changes from the A to B horizon were generally slight, although chroma changes of 1 or 2 units occurred in about half the samples. Colors were dark and subdued, and textures were mostly loams, sandy loams or silt loams. Average water-holding capacity was low due to the shallow and rocky soils. Total available phosphorus was in the lower one-third of the range of type means and potassium was markedly lower than most of the other types, only the Spruce-Yellow Birch type had a lower mean.

In spite of their elevation, 28 of the 29 plots received some topographic shading and averaged 1.5 hours shading each day. Most were on north-facing or protected slopes or both.

The Yellow Birch-Hemlock type differed from the Hemlock type primarily in its occurrence at predominantly higher elevations and in being absent in coves. Shrub cover was higher more consistently. The two types appeared to be part of a continuum varying with elevation on mesic slopes. *Betula alleghaniensis* became more important with elevation increase and *Halesia carolina* less so. At higher elevations, the continuum continued into the Spruce-Yellow Birch type.

The Hemlock-Yellow Birch type of the Society of American Foresters (1964) was described as occurring at higher elevations in the southern Appalachians as well as in the north-central U.S. No satisfactory equivalent to this type was described by Cain (1937, 1943), Whittaker (1956), or Braun (1950). Stands with *Betula alleghaniensis* as a dominant or co-dominant were classed either with the cove hardwoods (Whittaker, 1956; Cain, 1943) or the northern hardwoods (Shanks, 1954b; Braun, 1950).

Red maple-sweet birch type. Sample plots classified as Red Maple-Sweet Birch occurred on the sides of Mt. LeConte on sheltered slopes and small north-facing protected ridges at elevations 792 to 1070 m (2600 to 3510 ft). It is basically a successional *Castanea dentata* replacement type on sub-mesic middle elevation sites.

Plots were predominantly of stems less than 40 cm in diameter, with occasional larger stems and occasional large, bleached *Castanea dentata* snags still standing. In the five sample plots, 17 tree taxa occurred in the canopy. Besides the dominants, *Halesia carolina*, *Liriodendron tulipifera*, *Magnolia fraseri*, *Oxydendrum arboreum*, and *Robinia pseudoacacia* occurred with frequencies of at least 80% (Table 24). A total of 48 vascular taxa occurred, averaging 21 taxa/sample. Mean canopy stem density (588/ha) was higher than in any of the other non-pine types. Sapling densities were also high and the shrub strata varied from 10 to 40% in area coverage. Sixty percent of the plots had moderate heath-dominated shrub strata, principally of *Rhododendron maximum*, but with some *Kalmia latifolia*. In addition to these two shrubs, only *Smilax rotundifolia* had a frequency greater than 40% (Table 6, page 74). The herb stratum was poorly developed. Seventeen herb and fern taxa occurred, but no taxon occurred in more than 40% of the samples.

Every stand of this type had conspicuous evidence of past occurrence of *Castanea dentata*. This evidence, plus the predominant small tree size and abundance of successional taxa lead to the conclusion that the type is successional following the death of *Castanea dentata*, a previous dominant on the site. *Betula lenta* is intolerant (Tryon, 1943) or intermediate in tolerance (Baker, 1949), which was supported by its total absence in the seedling samples. *Acer rubrum* has a very wide ecological amplitude in the Smokies. Although it was found occasionally in mesic climax stands in this study,

Table 24. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Red Maple-Sweet Birch Type.[a] N=5.

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer pennsylvanicum	20	+[c]	20	+	+	1	0-3
A. rubrum	100	14	100	23	27	50	21-70
A. saccharum	40	+	20	+	1	1	0-7
Aesculus octandra	20	+	20	1	+	1	0-5
Amelanchier spp.	40	+	40	1	1	2	0-6
Betula alleghaniensis	20	1	20	1	1	3	0-14
B. lenta	100	13	100	26	16	42	21-93
Carya cordiformis	20	+	0	0	0	0	0
Cornus florida	20	+	0	0	0	0	0
Halesia carolina	80	4	80	7	3	9	0-21
Hamamelis virginiana	20	+	0	0	0	0	0
Kalmia latifolia	20	2	0	0	0	0	0
Liriodendron tulipifera	80	2	80	7	15	16	0-40
Magnolia acuminata	20	+	20	1	+	1	0-5
M. fraseri	100	4	100	4	2	6	0-15
Nyssa sylvatica	40	1	40	2	7	8	0-42
Oxydendrum arboreum	100	13	100	11	6	13	0-32
Prunus serotina	20	13	20	+	2	3	0-13
Quercus rubra	60	1	60	2	4	5	0-19
Rhododendron maximum	60	21	0	0	0	0	0
Robinia pseudoacacia	80	2	80	6	4	9	0-27
Sassafras albidum	60	1	60	3	2	5	0-12
Tsuga canadensis	80	20	60	3	7	10	0-25

Table 24 (continued)

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
	Mean No. Taxa 12.6	Mean Stems/ha 2292	Mean No. Taxa 10.2		Mean Stems/ha 588		Mean m^2/ha 37.3

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[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Tree taxa which occurred only as seedlings were: Castanea dentata, Fagus grandifolia, and Tilia heterophylla.

[c] Present, but less than 1%.

it is usually considered a pioneer or subclimax species (Fowells, 1965). It was typically a common or abundant species on disturbed sites at middle and lower elevations. Stratal comparisons (Table 25) and examination of individual plot data indicated that most of these stands will probably develop into the Hemlock type.

Soils were Typic Dystrochrepts and all were deeper than 50 cm. Surface rock was very rare, pH ranged from 4.4 to 5.0, average total water holding capacity was in the middle one-third of the range of type means, total available phosphorus and clay content of the B horizon were both in the lower one-third of types, and potassium was in the upper one-third.

These stands were the most mesic of the *Castanea dentata* "replacement" types. The other replacement types, discussed below, were characterized by the prominence of species of *Quercus*.

This type was not found described elsewhere. It appeared to be quite local in occurrence and was observed only in the immediate vicinity of Mt. LeConte. Probably these stands developed on somewhat mesic, mid-elevation sites formerly dominated by *Castanea dentata* which had available seed sources of *Acer rubrum* and *Betula lenta* and thus were largely a result of chance coincidence of vegetation conditions. As stated earlier, these stands appeared to be

Table 25. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Red Maple-Sweet Birch Type. N=5.

Taxa	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density
Acer rubrum	20	2	80	22	100	26
A. saccharum	0	0	20	1	20	1
Aesculus octandra	0	0	0	0	20	1
Betula alleghaniensis	0	0	20	1	20	2
B. lenta	0	0	80	13	100	29
Castanea dentata	40	7	0	0	0	0
Carya cordiformis	20	2	20	+[c]	0	0
C. glabra	20	+	0	0	0	0
Fagus grandifolia	20	+	0	0	0	0
Halesia carolina	40	11	40	6	80	8
Liriodendron tulipifera	0	0	20	1	80	8
Magnolia acuminata	20	1	0	0	20	1
M. fraseri	0	0	80	9	100	5
Nyssa sylvatica	20	1	20	2	40	3
Picea rubens	20	3	0	0	0	0
Prunus serotina	0	0	0	0	20	+
Quercus prinus	20	1	0	0	0	0
Quercus rubra	60	19	20	1	60	3
Robinia pseudoacacia	20	4	20	1	80	8
Tilia heterophylla	20	7	0	0	0	0
Tsuga canadensis	60	42	80	44	60	4

[a] Mean density = 11/sample = 2750/ha.

[b] Mean density = 43/sample = 1075/ha.

[c] Present, but less than 1%.

transitional to the Hemlock type. Both *Acer rubrum* and *Betula lenta* are associate taxa in the Hemlock type (Type 23) of the Society of American Foresters (1964).

Beech type. Beech sample plots occurred as two general types, (1) beech gaps or high elevation beech "orchards," (2) medium to high elevation beech "flats."

The beech gaps have been described by Cain (1937), Russell (1953) and Whittaker (1956) as stands dominated by *Fagus grandifolia* found above 1372 m (4500 ft) elevation, which occur in gaps or depressions in large ridges and are characterized by an orchard-like appearance due to stunted canopy trees and open understory. Cain (1931) briefly described stands occurring in the southern Appalachians with stunted *Fagus grandifolia* which occurred over a range of high-elevation sites, including gaps. These he termed "beech orchards."

Two of the eight samples taken in this study were from Trillium Gap, a beech gap in a ridge connecting Mt. LeConte and Brushy Mountain. Sample plots on upper slopes in the Thomas Ridge area and one plot on an upper concave slope exposed to the west on the side of Balsam Point had the orchard-like appearance of a beech gap, although topographically they were not located in gaps. Both Cain (1937) and Russell (1953) attributed the existence of beech gaps to wind and winter accumulation of ice. Although not in gaps, the orchard-like plots in the Thomas Ridge area and the similar plot on the slope of Balsam Point were highly exposed to conditions similar to the true gaps. The stand on Balsam Point was bounded on the ridges and above by Spruce-Yellow-Birch forest in which there were many down trees. The stands on Thomas Ridge were below the ridgetop, but were nonetheless at the upper end of large valleys where the wind would be funnelled. They were bounded above by Northern Red Oak orchards, which dominated the more xeric sites in that area.

The beech orchards (including true beech gaps) were characterized by a canopy dominated by abundant stunted and poorly formed Fagus grandifolia of diameters mostly less than 46 cm (18 inches). Shrubs were rare or absent (Table 6, page 74), understories were open and park-like. Herb cover was typically very high. Carex aestivalis covered over 80% of the ground surface of the single west-facing gap sample, but was not present in the other samples. Solidago curtisii and Aster divericatus were the most frequent and abundant herbs in the other orchard plots.

The beech flats were stands in stream valleys, typically where the valley broadened out above the stream and below steep surrounding slopes. One sample was from a valley below the Chimneys designated on maps as Beech Flats. It was the lowest in elevation at 1122 m (3680 ft). Another large valley with extensive beech flats (located on Beech Flats Pring of the Oconoluftee River) was not sampled because it had been logged before the Park's establishment. These beech flats were primarily mesic cove-type stands, but with a heavy dominance of beech in the canopy. They occurred only in valleys with very low rock cover (Table 1, page 55). These stands had tall well-formed canopy trees. *Fagus grandifolia* stems were commonly larger than 46 cm (18 inches) dbh in the flats and did not have the stunted spreading form of the orchards. The understories were open with practically no shrubs. Mesic herbs were abundant. *Tiarella cordifolia* and *Euonymous obovatus*, absent in the orchard plots, were typically present.

The major canopy associates in both sub-types were *Halesia carolina*, *Betula alleghaniensis*, and *Aesculus octandra* (Table 26). *Tilia heterophylla* was an important canopy taxon in the flats, but was absent in the orchards. *Picea rubens* occurred occasionally in stands in the Mt. LeConte area, but were absent on Thomas Ridge. A total of 73 vascular taxa occurred in the eight samples, averaging 21 taxa/sample.

The Beech stands appeared to be climax (Table 27). The abundant root suckering of *Fagus grandifolia* resulted in a strong dominance of the seedling layer by this species. Seedlings of other species were rare or absent in most of

Table 26. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Beech Type.[a] N=8.

Taxa	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Abies fraseri	13	+[c]	0	0	0	0	0
Acer pennsylvanicum	38	6	38	2	1	3	0-16
A. rubrum	38	1	38	2	7	9	0-42
A. saccharum	25	1	12	1	2	2	0-20
Aesculus octandra	62	4	50	4	10	14	0-46
Amelanchier spp.	25	1	25	2	2	4	0-26
Betula alleghaniensis	62	4	62	5	11	16	0-65
Betula lenta	12	+	12	+	+	1	0-5
Fagus grandifolia	100	67	100	63	53	116	93-172
Fraxinus spp.	12	+	12	+	+	1	0-5
Halesia carolina	88	10	88	16	10	26	0-45
Picea rubens	50	1	48	2	1	2	0-9
Prunus pennsylvanicum	12	+	0	0	0	0	0
Tilia heterophylla	25	1	12	2	3	5	0-38
Tsuga canadensis	62	3	25	1	+	1	0-4
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha	Mean m^2/ha	
	6.5	1205	5		414	33.4	

[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Tree taxa occurring only as seedlings were *Castanea dentata* and *Quercus rubra*.

[c] Present, but less than 1%.

Table 27. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Beech Type. N=8.

	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
Taxa	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density
Abies fraseri	0	0	13	1	0	0
Acer rubrum	13	1	13	+[c]	48	2
A. saccharum	38	11	13	1	12	1
Aesculus octandra	13	1	38	5	50	4
Betula alleghaniensis	13	1	38	4	62	5
B. lenta	0	0	0	0	12	+
Castanea dentata	13	+	0	0	0	0
Fagus grandifolia	75	81	100	74	100	65
Fraxinus spp.	0	0	0	0	12	+
Halesia carolina	38	2	88	9	88	17
Picea rubens	0	0	13	1	48	2
Prunus pennsylvanica	0	0	13	1	0	0
Quercus rubra	25	1	0	0	0	0
Tilia heterophylla	0	0	13	1	12	2
Tsuga canadensis	25	1	5	5	25	1

[a] Mean density = 21/sample = 5250/ha.

[b] Mean density = 28/sample = 700/ha.

[c] Present, but less than 1%.

the orchard plots. However, seedlings of _Acer saccharum_ were common in all of the flats sampled.

Soils were typically Typic Dystrochepts or Umbric Dystrochrepts. Most were deeper than 50 cm and surface rock was present very sparingly in only one beech flats sample. The pH range was 4.2 to 5.2, which is similar to the ranges reported by Cain (1931) and Russell (1953), 4.3 to 4.8 and 4.5 to 6.0, respectively. Available soil phosphorus averaged higher in the Beech type than in any other type (Table 3, page 64). The two subtypes showed no difference in this respect.

Red maple-northern red oak type. Red Maple-Northern Red Oak is another successional type with a history of past disturbance. Like Red Maple-Sweet Birch, it is primarily a "chestnut replacement" type. It usually occupied slightly more xeric sites than did Red Maple-Sweet Birch, but less xeric sites than the Chestnut Oak type. Apparently, most of the stands were formerly dominated by _Castanea dentata_, but typically with scattered _Quercus rubra_ or _Acer rubrum_ individuals in the canopy. The picture was further complicated by the past occurrence of fires in several of the sample plots. Vegetation characteristics were highly variable, perhaps because of stand history.

All of the seven sample plots occurred in the Mt. LeConte area, on its slopes or on slopes of valleys adjacent.

There were two elevation groups, 70% of the samples occurred at 832 to 1043 m (2730 to 3420 ft) and two plots at 1345 and 1413 m (4410 and 4600 ft). At the lower elevations they occurred on middle slopes with west, east or southeast aspects. The higher elevation plots were on the western side of Mt. LeConte at upper slope positions.

Plots were generally characterized by abundant small canopy trees in the dbh range 15 to 40 cm (6 to 16 inches), but frequently with scattered larger stems 60 to 100 cm (24 to 40 inches). Canopies were generally open and saplings abundant. Seventy percent of the plots had moderate to heavy heath understories composed mostly of *Rhododendron maximum* but *Kalmia latifolia* was also present in two plots. Twenty-seven herb and fern taxa occurred. Three taxa had a frequency of 43%. These were *Dioscorea villosa*, *Medeola virginiana*, and *Thelypteris noveboracensis*. A total of 67 vascular taxa occurred in the seven samples, averaging 20 taxa/sample.

Twenty-one taxa occurred in canopy samples and 27 occurred larger than 2.5 cm dbh (Table 28). *Acer rubrum* was the most characteristic tree, with *Quercus rubra* usually, but not always, the second dominant. *Oxydendrum arboreum* was in all of the lower elevation plots, usually as a small tree but reaching 75 cm (30 inches) dbh in one plot. *Tsuga canadensis* and *Halesia carolina* were the only other taxa

Table 28. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Red Maple-Northern Red Oak Type.[a] N=7.

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer pennsylvanicum	14	+[c]	0	0	0	0	0
A. rubrum	100	16	100	41	37	78	46-137
A. saccharum	14	8	14	2	1	3	0-21
Amelanchier spp.	29	1	29	2	1	3	0-9
Betula alleghaniensis	43	1	29	1	+	1	0-7
B. lenta	43	3	29	3	2	5	0-22
Carya cordiformis	14	+	14	+	+	1	0-4
C. glabra	14	+	14	+	2	2	0-16
Cornus florida	29	1	0	0	0	0	0
Fagus grandifolia	29	2	14	1	2	4	0-25
Fraxinus spp.	14	+	14	+	1	1	0-9
Halesia carolina	72	5	57	8	4	13	0-35
Hamamelis virginiana	29	2	0	0	0	0	0
Ilex opaca	14	2	0	0	0	0	0
Kalmia latifolia	29	5	0	0	0	0	0
Liriodendron tulipifera	43	1	43	3	2	4	0-11
Magnolia acuminata	29	+	14	+	+	+	0-3
M. fraseri	57	2	43	6	4	10	0-49
Nyssa sylvatica	43	3	43	2	4	6	0-21
Oxydendrum arboreum	71	2	71	5	5	10	0-30
Picea rubens	14	+	0	0	0	0	0
Prunus serotina	14	+	14	+	+	1	0-4
Quercus prinus	29	+	29	1	3	3	0-19
Q. rubra	86	4	86	13	23	36	0-65

Table 28 (continued)

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Rhododendron maximum	71	19	0	0	0	0	0
Robinia pseudoacacia	29	1	29	2	1	3	0-14
Sassafras albidum	14	1	14	1	1	2	0-13
Tilia heterophylla	14	+	14	1	+	1	0-7
Tsuga canadensis	86	10	71	6	7	12	0-48
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha	Mean m^2/ha	
	11.9	2141	7.9		491	36.16	

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[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] *Carya ovalis* occurred only as seedlings.

[c] Present, but less than 1%.

occurring in more than 50% of the canopy samples. *Betula lenta* was present in only three samples and only as a single individual in one of those. None of the pines occurred in these stands, and *Q. prinus* was present only as single individuals in two canopy samples.

Acer rubrum exhibited marked decline in the sapling and seedling strata, suggesting that it is primarily successional (Table 29). However, its consistent high frequency suggests it will remain as part of the composition of this type over a long period of time, if not indefinitely. *Quercus rubra* declined in both frequency and relative density in the sapling classes, then had the highest relative density and a high frequency in the seedling class. This was likely because of periodic reproduction (cf. Hough and Forbes, 1943). Its high frequency and relative density in the seedling samples suggests that it may become more abundant in future composition in many of these stands. The marked increase in average relative density in the sapling and seedling classes of *Tsuga canadensis* was a result of its high density in the lower strata of the more mesic of these samples.

Six of the seven sites had Typic Dystrochrept soils, the other was a Typic Haplumbrept. All were deeper than 50 cm, all had low rock cover and low soil rock content (Table 3, page 64). Soil horizon differentiation was typically weak, and textures ranged only from sandy to silt loams.

Table 29. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Red Maple-Northern Red Oak Type. N=7.

	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
Taxa	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density
Acer rubrum	72	8	72	29	100	43
A. saccharum	29	5	14	12	14	3
Betula alleghaniensis	0	0	43	4	29	1
B. lenta	43	2	29	4	29	4
Carya cordiformis	14	+[c]	0	0	14	+
C. glabra	14	1	0	0	14	+
Castanea dentata	14	3	0	0	0	0
Fagus grandifolia	15	5	29	4	14	1
Fraxinus spp.	15	+	0	0	14	+
Halesia carolina	43	14	71	7	57	9
Liriodendron tulipifera	0	0	0	0	43	3
Magnolia acuminata	14	+	14	1	14	+
M. fraseri	0	0	43	6	43	7
Nyssa sylvatica	14	+	29	7	43	2
Picea rubens	15	+	14	2	0	0
Prunus serotina	0	0	0	0	14	+
Quercus prinus	14	+	14	1	29	1
Q. rubra	72	38	14	2	86	14
Robinia pseudoacacia	29	+	14	2	29	2
Tilia heterophylla	0	0	0	0	14	1
Tsuga canadensis	58	17	71	22	71	7

[a] Mean density = 33/sample = 8250/ha.

[b] Mean density = 23/sample = 568/ha.

[c] Present, but less than 1%.

Plots of the Red Maple-Northern Red Oak type differed from the Red Maple-Sweet Birch type in the following attributes: (1) most occurred on slightly less mesic sites; (2) *Quercus rubra* was much more important and *B. lenta* was much less important; (3) climax composition will be more varied, but generally should include more *Q. rubra* than in the other type; and (4) some plots occurred at much higher elevations.

Whittaker (1956) described the Red Oak-Chestnut forest type as occurring primarily above 1067 m (3500 ft) elevation. *Quercus borealis* (*rubra*) and *Castanea dentata* were the only frequent canopy dominants, but *Acer rubrum* was the most important understory tree. In 1947, when this field work was done, the *Castanea dentata* trees were mostly already dead. Many stands of this type in which *C. dentata* was the predominant canopy tree probably developed into the Red Maple-Northern Red Oak type. Elevations of five of the seven plots herein described were lower than 1067 m, but four follow the descriptions of the Red Oak-Chestnut type.

One sample had one large *Carya glabra* and also seedlings present. This plot resembled the description of the Red Oak-Pignut Hickory type of Whittaker (1956). It did not, however, contain *Quercus alba* or *Carya tomentosa*, which were common associates in the Red Oak-Pignut Hickory type.

Spruce-yellow birch type. Sample plots of the Spruce-Yellow Birch type occurred at higher elevations on slopes and protected ridges. Ninety percent of the plots were at elevations 1413 to 1561 m (4630 to 5120 ft). The exposed, south-facing ridges at these elevations typically were covered by treeless heath. The sample plots occurred around Mt. LeConte and in the False Gap-Wooly Tops area. None occurred in the Thomas Ridge Area, since *Picea rubens* was absent there.

Generally, plots of this type had greater *P. rubens* importance on more open slopes, on higher slope position, and at higher elevations. *Abies fraseri*, which in the Smokies forms almost pure stands on many sites above 1800 m elevation, occurred in small numbers in the canopies of 42% of the plots. Its abundance increased with increased elevation and exposure.

Only 13 taxa occurred in the canopy samples (Table 30). Only *P. rubens*, *Betula alleghaniensis*, *Abies fraseri*, *Tsuga canadensis*, *Acer pennsylvanicum*, and *Amelanchier* spp. occurred with frequencies greater than 11% as stems larger than 12.7 cm. *Amelanchier* spp. and *Acer pennsylvanicum* were small tree taxa which reached 12.7 cm dbh commonly in these plots. The rich mixture of taxa occurring over broad site ranges at lower elevations was absent (or practically so) in most of these plots, probably as a result of the more rigorous climate of the higher elevations. A total of 58 vascular taxa occurred in the 19 samples, averaging only 10 taxa/sample.

One characteristic of this type was the frequent large

Table 30. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Spruce-Yellow Birch Type.[a] N=19.

	All Stems >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Abies fraseri	58	13	42	8	4	12	0-51
Acer pennsylvanicum	32	2	20	1	+[b]	1	0-16
A. rubrum	5	+	5	+	+	+	0-9
A. saccharum	5	+	5	1	1	2	0-30
A. spicatum	37	6	11	1	+	1	0-6
Aesculus octandra	5	+	5	+	1	1	0-24
Amelanchier spp.	48	2	42	3	1	5	0-27
Betula alleghaniensis	95	18	95	33	32	65	0-142
Fagus grandifolia	11	2	11	1	+	2	0-17
Kalmia latifolia	16	1	5	+	+	+	0-4
Picea rubens	100	25	100	45	53	99	55-192
Prunus pennsylvanicum	11	+	11	1	+	2	0-25
Rhododendron maximum	43	17	0	0	0	0	0
Sorbus americana	11	+	5	+	+	+	0-4
Tsuga canadensis	64	4	63	5	6	10	0-77
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha	Mean m^2/ha	
	6	985	4.1		382	48.1	

[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Present, but less than 1%.

amount of blow-down of canopy trees. The high winds (resulting from increased exposure with elevation) and the common shallowness of the solum were the major contributing factors. This type had the highest percentage (53%) of soils less than 50 cm deep (Table 3, page 64).

Over half the sample plots had shrub layers of *Rhododendron maximum* or *R. catawbiense*, with *R. maximum* the most common and abundant. *Viburnum alnifolium* was the only other common shrub, occurring with a frequency of 47% (Table 6, page 74) and mostly in plots where *Rhododendron* was not abundant. Due largely to the overwhelming layer of *Rhododendron*, herbs were not present in 53% of the plots. However, several of the plots lacking well-developed shrub layers had rich herb layers. A total of 35 herb and fern taxa occurred, *Dryopteris campyloptera*, *D. intermedia*, *Oxalis montana*, *Senecio rugelia* and *Solidago glomerata* were the most abundant.

Stratal comparisons were somewhat inconclusive (Table 31). All taxa declined in frequency in successively lower strata. This appears to be due to the common heavy heath layer which severely restricted seedling establishment and survival. The thick evergreen shrub layer cuts off most of the light which is transmitted through the canopy, resulting in very low light intensities at the ground surface. Additionally, the heath litter is of large, thick, slowly decomposing leaves which offer serious impedence to both seedling

Table 31. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Spruce-Yellow Birch Type. N=19.

	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
Taxa	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density
Abies fraseri	27	24	42	22	53	9
Acer rubrum	0	0	0	0	5	+[c]
A. saccharum	5	8	0	0	5	1
Aesculus octandra	0	0	0	0	5	+
Betula alleghaniensis	37	17	58	28	95	35
Fagus grandifolia	0	0	5	4	11	1
Fraxinus spp.	16	2	0	0	0	0
Picea rubens	43	39	68	37	100	48
Prunus pennsylvanica	0	0	0	0	10	1
Sorbus americana	10	+	5	+	5	+
Tsuga canadensis	5	+	37	8	42	5

[a] Mean density = 4/sample = 1000/ha.

[b] Mean density = 11 sample = 275/ha.

[c] Present, but less than 1%.

root and shoot penetration. Most of the seedlings were found in openings in the shrub layer. The relative density of *Betula alleghaniensis* was considerably less in the lower strata than in the canopy, and only 17% in the seedling samples. The seedling roots of this species have very poor ability to penetrate litter and seedling establishment on undisturbed forest floor is usually restricted to cracks in boulders or on the rotted wood of stumps or logs (Cain, 1940; Fowells, 1965). A large percentage of the *B. alleghaniensis* seedlings observed in the study were on logs and stumps. Abundant blowdown created frequent canopy openings in which both *Picea rubens* and *Abies fraseri* would be able to survive better than *B. alleghaniensis*, which survives poorly in the open (Fowells, 1965). The considerable increase in *A. fraseri* relative densities in the sapling and seedling strata is difficult to explain, but was perhaps due to dense seedling establishment in openings. This explanation is supported by the reduced frequency of *A. fraseri* in the seedling sample coupled with its high relative density--indicating that seedling density was high in a few samples, though absent in 73% of the total number of samples.

Thirty-two percent of the soils were Histosols, composed of only litter and humus on rock. The rock was commonly decomposing phyllite or sandstone on ridges or steep slopes and with a heavy heath-type shrub layer which contributed slowly decomposing litter and humus. Twenty-six percent were Lithic Dystrochrepts and 26% were Typic Dystrochrepts.

Stone volume in the solum was typically very high (Table 3, page 64). This was primarily from the colluvial rubble in which many of the steep, high elevation soils were formed. Consequently, the available water-holding capacity was quite low. However, since precipitation was higher and temperatures lower than at lower elevations, most of these stands did not exhibit evidence of moisture stress. Total available soil potassium was quite low--the lowest of any type, and phosphorous was among the lower one-third of the range of type means. This was largely because of the typically shallow soils, although low pH combined with high rainfall may have resulted in increased leaching of bases when compared to other types. Soil pH was quite low, only three of the soil samples had pH's above 4.8, and the highest of these was 5.2.

The high mean total topographic shading (2.2 hours/day) was largely a result of sample plot occurrence on northerly aspects and steep slopes. Steep slopes without a southerly aspect usually received some topographic shading either in the morning or afternoon.

Above the upper elevation limit of this study, Picea rubens becomes dominant over much of the mountain slopes and ridges. The Spruce-Yellow Birch type represents a transitional type between the Yellow Birch-Hemlock type, occurring at slightly lower elevations on slopes and sheltered ridges, and the Red Spruce type described by Cain (1937) and Whittaker (1956), occurring on more exposed slopes and ridges at higher elevation. *Tsuga canadensis* occurred in 42% of the canopy samples of the Spruce-Yellow Birch type and *P. rubens* occurred in 42% of the canopy samples of the Yellow Birch-Hemlock type.

The Red Spruce-Yellow Birch type was recognized by the Society of American Foresters (1964) as occurring in the southern Appalachians at elevations of 3500 to 5000 ft (1067 to 1524 m). *Abies fraseri*, *Aesculus octandra*, *Fagus grandifolia* and *Acer saccharum* were listed as common associates, indicating that the type is the same as that described in this study.

Chestnut oak type. Chestnut Oak was the predominant forest type on open slopes with azimuths of 125° to 280° at elevations of 750 to 900 m. They occurred on upper slopes and small ridges with northern slope aspects at these elevations. They were more restricted to middle and upper slopes at higher elevations up to 1356 m (4450 ft). They occurred in all of the sampling areas which included these elevations, however, Chestnut Oak plots occurred above 1165 m (3820 ft) elevation only in the Thomas Ridge area.

Almost all of the plots had evidence of past disturbances by the death of *Castanea dentata* or by fire or both.

As a result, small stems were common in the canopy samples and saplings were typically abundant in the understory. Ninety-eight percent of the sample plots had evidence of former *Castanea dentata* occurrence, and living sprouts were present with a frequency of 19%.

Partly because of varying degrees of past disturbance, Chestnut Oak plots were quite variable in nature. Canopies varied from scattered and open on most of the xeric south-facing middle and upper slopes to fairly closed on north-facing or lower slopes. Characteristic canopy taxa (those occurring in more than 40% of the samples) were *Quercus prinus*, *Q. rubra*, *Q. coccinea*, *Acer rubrum*, *Magnolia fraseri*, *Oxydendrum arboreum* and *Robinia pseudoacacia* (Table 32). *Pinus rigida* commonly occurred in the more xeric plots--those on south and west-facing middle slopes and on upper slopes. *Quercus coccinea* and *Q. rubra* infrequently occurred in the same plots and in such cases *Q. rubra* was very low in importance. *Quercus coccinea* occurred on the more xeric sites, as evidenced by the occurrence of *P. rigida* in 13 of the 22 plots containing *Q. coccinea*. Ninety-eight vascular taxa occurred in the 46 samples, averaging 24 taxa/sample.

The shrub stratum was typically moderately thick to very thick. Sixty-seven percent of the plots had a shrub coverage greater than 35%, and coverage averaged 50%. Sixteen shrub and vine taxa occurred, with *Smilax rotundifolia*,

Table 32. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Chestnut Oak Type.[a] N=46.

	All Stems >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer pennsylvanicum	15	+[b]	10	+	+	+	0-4
A. rubrum	100	30	90	15	9	23	0-63
A. saccharum	7	1	0	0	0	0	0
Aesculus octandra	3	+	2	+	+	+	0-10
Amelanchier spp.	21	+	0	6	0	0	0
Betula alleghaniensis	5	+	2	+	+	+	0-4
B. lenta	29	1	18	2	1	2	0-24
Carya glabra	5	+	0	0	0	0	0
C. ovalis	7	+	2	+	+	+	0-7
Castanea dentata	19	+	2	+	+	+	0-4
Cornus florida	13	1	4	+	+	+	0-4
Fagus grandifolia	5	1	4	+	+	1	0-19
Fraxinus spp.	3	+	2	+	+	+	0-3
Halesia carolina	49	2	27	1	+	2	0-12
Hamamelis virginiana	43	+	2	+	+	+	0-4
Kalmia latifolia	78	13	0	0	0	0	0
Liriodendron tulipifera	19	1	16	1	2	3	0-46
Magnolia acuminata	11	+	11	+	1	1	0-19
M. fraseri	47	1	41	1	+	2	0-15
Nyssa sylvatica	84	4	39	2	3	6	0-38
Ostrya virginiana	5	+	0	0	0	0	0
Oxydendrum arboreum	100	14	84	9	3	12	0-33
Pinus pungens	11	+	10	1	1	2	0-45
P. rigida	35	1	31	3	3	6	0-84

Table 32 (continued)

	All Stems >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
P. *virginiana*	2	+	2	+	+	+	0-14
Prunus serotina	7	+	4	+	+	+	0-7
Quercus coccinea	47	2	46	12	10	22	0-104
Q. prinus	100	11	100	39	55	94	25-200
Q. rubra	67	3	67	7	7	15	0-70
Q. velutina	9	+	8	1	1	1	0-25
Rhododendron maximum	66	4	0	0	0	0	0
Robinia pseudoacacia	49	1	43	3	2	5	0-46
Sassafras albidum	45	1	11	+	+	1	0-11
Tsuga canadensis	41	2	11	1	+	1	0-17
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha		Mean m^2/ha
	11.7	2302	6.6		394		27.32

[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Present, but less than 1%.

S. glauca, *Kalmia latifolia*, *Gaylussacia ursina*, *Rhododendron maximum*, *R. calendulaceum*, and *Vaccinium* spp. occurring in more than 40% of the samples (Table 6, page 74). *Kalmia latifolia*, frequently mixed with *R. maximum*, formed dense thickets on the more xeric sites. Where the high heath cover was moderate to absent, *Gaylussacia ursina* frequently formed a dense but low shrub layer. The Kalmia thickets (which were usually 2 to 4 m tall and quite dense) were commonly intertwined with *Smilax rotundifolia* or with *S. glauca* (both woody vines with large sharp prickles). *Smilax glauca* was characteristic of the most xeric sites.

Herb cover was typically low, although the number of taxa occurring was high. Fifty herb and fern taxa occurred in the samples. *Galax aphylla* was the single most frequent species, occurring in 33 (72%) of the samples. *Chimaphila maculata*, *Goodyera pubescens*, *Gaultheria procumbens*, and *Epigea repens* were taxa occurring in more than 25% of the samples.

Stratal comparisons are shown in Table 33. The most striking aspect of this comparison is the abundance of *Acer rubrum* in the sapling class. This species was obviously very prominent in invading openings left by the dying *Castanea dentata*. In their study of 2569 chestnut openings primarily in the central Smokies (most were just to the north of Greenbrier Pinnacle), Woods and Shanks (1959) found *A. rubrum* the

Table 33. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Chestnut Oak Type. N=46.

Taxa	Seedlings[a] (<2.5 cm) Percent Frequency	Seedlings[a] (<2.5 cm) Mean Relative Density	Saplings[b] (2.5-12.7 cm) Percent Frequency	Saplings[b] (2.5-12.7 cm) Mean Relative Density	Canopy (>12.7 cm) Percent Frequency	Canopy (>12.7 cm) Mean Relative Density
Acer rubrum	90	19	98	58	90	17
A. saccharum	11	2	6	1	0	0
Aesculus octandra	0	0	0	0	2	+[c]
Betula alleghaniensis	0	0	4	+	2	+
B. lenta	9	1	27	2	18	2
Carya glabra	0	0	5	+	0	0
C. ovalis	5	+	5	+	2	+
Castanea dentata	64	11	13	+	2	+
Fagus grandifolia	2	1	4	1	4	+
Fraxinus spp.	5	+	0	0	2	+
Halesia carolina	37	3	4	4	27	1
Liriodendron tulipifera	9	1	8	1	16	1
Magnolia acuminata	13	1	8	+	11	+
M. fraseri	29	2	41	2	41	1
Nyssa sylvatica	45	10	71	9	39	2
Pinus pungens	0	0	0	0	10	1
P. rigida	0	0	13	1	31	3
Prunus serotina	11	1	4	+	4	+
Quercus coccinea	31	4	17	1	47	13
Q. prinus	80	28	79	11	100	43
Q. rubra	47	13	39	3	67	8
Q. velutina	7	+	2	+	79	1

Table 33 (continued)

Taxa	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density
Robinia pseudoacacia	4	+	15	1	43	3
Tilia heterophylla	2	+	0	0	0	0
Tsuga canadensis	35	4	43	4	11	1

[a] Mean density = 20/sample = 5000/ha.

[b] Mean density = 51/sample = 1275/ha.

[c] Present, but less than 1%.

third most abundant replacement species, following *Quercus prinus* and *Q. rubra*. It was the most abundant replacement species in the Chestnut Oak plots of this study, having a much higher frequency (98%) and relative density (58%) in the sapling sizes (2.5 to 12.7 cm dbh) than either *Q. prinus* or *Q. rubra*. Its frequency and relative densities were reduced in the seedling sample, approaching the same values as in the canopy. *Acer rubrum* should then become more prominent in the Chestnut Oak type canopies due to its ability to invade *Castanea dentata* openings. However, from the seedling evidence, the long-term status of *A. rubrum* in these canopies would appear to be similar to that of the present.

Several mesic taxa (*Acer saccharum*, *Halesia carolina* and *Tsuga canadensis*) should increase in importance on the more mesic sites. *Nyssa sylvatica* is another species which is increasing in importance. On the other hand, the pines (*Pinus rigida* and *P. pungens*) are not reproducing in these stands and probably owe their occurrence to disturbance by fire or chestnut death.

Typic Dystrochrepts comprised 61% of the Chestnut Oak soils. Another 24% were Lithic Dystrochrepts. The remaining 15% were Umbric Dystrochrepts, Lithic Umbric Dystrochrepts and Typic Haplumbrepts. The Lithic soils (28%) were most commonly on steep slopes or small ridges. Soils were typically residual, and surface rock (Table 3, page 64) was low or absent on most sites. Total available soil potassium was higher than in most of the other types. Low elevation and a large number of deep non-rocky soils were perhaps major factors affecting this. Total potassium was negatively correlated with elevation (Table 4, page 67). Soil pH was variable, but usually higher than many of the other types. Only 26% of the A horizons had pH's less than 5.0. Textural differentiation between the A and B horizons was better in many of the soils than was the case for the previously described types. Finer-textured B horizons were more common, 22 of the subsoils were silt loams, clay loams or silty clay loams. Average clay content of the B horizon was higher (22%) than in most of the other types; only the Oak-Pine type had a higher mean.

The Society of American Foresters (1964) recognized two types with *Quercus prinus* as the predominant taxon. These were the Chestnut Oak (Type 44) and White Pine-Chestnut Oak (Type 51) types. *Pinus strobus* did not occur in any of the sample plots in this study, although it is common at lower elevations and in other areas of the Park. The type named here is most similar to the Chestnut Oak type, except that white oak (*Q. alba*), post oak (*Q. stellata*) and sweetgum (*Liquidambar styraciflua*) were not found in the stands sampled here.

Whittaker (1956) described two types with *Quercus prinus* as a dominant, Chestnut Oak-Chestnut and Chestnut Oak-Chestnut Heath. At the time of Whittaker's field sampling (1947), many of the large *Castanea dentata* were still alive. These types were not separated by the method used here. Whittaker distinguished between the two types primarily by the spacing of canopy trees and the thickness of the shrub layer. Cain (1937, 1943) referred to a Chestnut Oak and a Chestnut Oak-Yellow-Poplar type. *Liriodendron tulipifera* was the second dominant in three of the 46 Chestnut Oak stands of this study, but never had an importance value greater than 46 (of a possible 200). Braun (1950) described a Chestnut Oak-Chestnut Community occurring in the Smokies and other southern Appalachian Mountains.

Northern red oak type. Northern Red Oak forests predominated on most of the large ridges and the middle to upper southeast to west-facing slopes in the Thomas Ridge area at elevations above 1280 m (4200 ft). Twelve of the 19 sample plots of this study occurred in that area, six of the other seven plots were on the southwest slopes of Rocky Spur (a large ridge adjacent to Mt. LeConte) at elevations 1257 to 1430 m (4120 to 4690 ft). A single plot was located on a small northwest-facing ridge at 988 m (3240 ft) elevation in the Roaring Fork Valley.

Castanea dentata stumps and logs were common. All of the plots had some evidence of past or present *C. dentata* occurrence. Consequently, the plots characteristically had scattered large trees (usually *Quercus rubra*) with many smaller ones of several species, principally *Q. rubra* and *Acer rubrum*. Twenty-four taxa occurred in the canopy samples (Table 34). *Acer rubrum* was the second dominant in 47% of the plots, and occurred in 95%. Although never having a high importance value, *Halesia carolina*, *Tsuga canadensis* and *Fagus grandifolia* were present in more than half of the canopy samples. The shrub stratum was variable. Thirty-seven percent of the samples had shrub cover of 45% or more, yet 42% had less than 5% shrub cover. Fourteen taxa occurred as shrubs or vines, but only *Ilex montana* and *Smilax rotundifolia* were present in more than half of the samples (Table 6, page 74). The herb samples included 50 taxa, but only *Solidago curtisii*, *Aster divericatus*, *Dioscorea villosa*, and *Prenanthes* spp. had frequencies greater than 50%. A total of 90 vascular taxa occurred in the 19 samples, averaging 22 taxa/sample.

When strata were compared (Table 35), *Acer rubrum* was present in greatest abundance in the sapling class, as was true in the Chestnut Oak type. Its role in replacing *Castanea dentata*, as discussed earlier, would appear to be the most plausible explanation, since it decreased sharply in frequency and density in the seedling sample.

Quercus rubra exhibited a pattern of periodic

Table 34. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Northern Red Oak Type.[a] N=19.

	All Stems >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Abies fraseri	5	+[b]	0	0	0	0	0
Acer pennsylvanicum	48	3	21	1	+	1	0-12
A. rubrum	100	17	95	16	8	24	0-59
A. saccharum	37	1	21	1	1	2	0-14
Amelanchier spp.	58	3	21	1	+	1	0-7
Betula alleghaniensis	43	2	26	2	1	2	0-14
B. lenta	53	1	37	2	1	3	0-24
Carya cordiformis	5	+	5	+	+	+	0-3
C. glabra	5	+	5	+	+	+	0-6
C. ovalis	5	1	5	+	+	1	0-15
Castanea dentata	32	1	0	0	0	0	0
Cornus florida	5	1	5	+	+	+	0-3
Fagus grandifolia	69	7	53	3	1	4	0-15
Fraxinus spp.	11	1	5	+	1	1	0-14
Halesia carolina	90	12	79	12	3	16	0-35
Hamamelis virginiana	27	3	0	0	0	0	0
Kalmia latifolia	22	4	0	0	0	0	0
Magnolia acuminata	5	+	5	+	+	1	0-10
M. fraseri	32	2	26	1	+	2	0-12
Oxydendron arboreum	11	+	11	1	+	1	0-7
Picea rubens	27	+	11	+	+	+	0-4
Prunus serotina	43	1	37	2	2	4	0-21
Quercus prinus	11	+	11	1	2	4	0-36
Q. rubra	100	19	100	46	74	120	52-171

Table 34 (continued)

	All Stems >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Rhododendron maximum	27	8	0	0	0	0	0
Robinia pseudoacacia	43	+	32	1	1	3	0-20
Tilia heterophylla	16	1	16	2	2	3	0-32
Tsuga canadensis	74	4	58	5	2	8	0-28
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha		Mean m^2/ha
	10.8	1796	6.8		380		35.35

[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Present, but less than 1%.

Table 35. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Northern Red Oak Type. N=19.

	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
Taxa	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density
Abies fraseri	0	0	5	+[c]	0	0
Acer rubrum	69	12	100	27	95	16
A. saccharum	43	7	27	2	21	1
Betula alleghaniensis	6	+	27	3	26	2
B. lenta	6	+	32	2	37	3
Carya cordiformis	0	0	0	0	5	+
C. glabra	0	0	0	0	5	+
C. ovalis	0	0	5	1	5	+
Castanea dentata	58	7	32	3	0	0
Fagus grandifolia	43	5	63	13	53	3
Fraxinus spp.	32	2	5	+	5	+
Halesia carolina	64	6	79	16	79	12
Magnolia acuminata	27	2	0	0	5	+
M. fraseri	11	2	32	7	26	1
Picea rubens	11	3	21	1	11	+
Prunus serotina	37	3	16	2	37	2
Q. prinus	11	1	0	0	11	1
Q. rubra	89	46	79	14	100	46
Robinia pseudoacacia	0	0	22	3	32	1
Tilia heterophylla	0	0	16	1	16	2
Tsuga canadensis	16	4	68	7	58	5

[a] Mean density = 26/sample = 6500/ha.

[b] Mean density = 31/sample = 775/ha.

[c] Present, but less than 1%.

reproduction--it was low in relative density in the sapling classes, while high in the canopy and seedling strata. *Fagus grandifolia* had a periodic pattern similar to that of *A. rubrum*, although of lesser magnitude. It would appear likely that *A. rubrum* may temporarily increase in canopy abundance because of its ability to replace *Castanea dentata*, but over a longer period of time, *Q. rubra* should remain the canopy dominant.

Typic Dystrochrepts and Umbric Dystrochrepts each made up 37% (7) of the soils, with Typic Haplumbrepts and Lithic Dystrochrepts comprising 16% (3) and 10% (2), respectively. Soils were typically deeper than 50 cm with low surface rock and solum stone content. In most of the soil profiles, horizon differentiation was not strong and most of the textures were loams, silt loams or sandy loams. A horizon pH's were generally higher than in most of the other types, although they ranged as low as 4.3 (Table 3, page 64). Although among the middle one-third of the range of type means, average total available phosphorus was higher than 14 of the other types. Soil potassium was also in the middle one-third of type means.

The Society of American Foresters (1964) recognized a Northern Red Oak type in the southern Appalachians (at 915 to 1524 m elevation in North Carolina), described as occurring on ridge crests and north slopes. It differs from the forests sampled in this study, however in that the associated taxa are *Quercus velutina*, *Q. coccinea*, *Q. prinus* and *Liriodendron tulipifera*. Of these taxa, only *Q. prinus* occurred in the samples of this study.

Braun (1950) discussed Oak-Chestnut communities at moderate elevations in the southern Appalachians, but did not specify *Q. rubra* as an important dominant. She described a Northern Hardwoods forest type as one of two predominant forest types at high elevations in the Smokies (Spruce-Fir was the other), but did not list *Q. rubra* as present.

Cain (1937) mentioned an Oak Ridge type, but without description or data. He also mentioned a Chestnut Orchard type as composed primarily of *Castanea dentata*. *Quercus prinus*, *Q. rubra*, and *Aesculus octandra*, but gave no other details (Cain, 1931).

Whittaker (1956) described two forest types in the Smokies with *Q. rubra* as a dominant. These were Red Oak-Pignut Hickory and Red Oak-Chestnut. His Red Oak-Pignut Hickory forest type occurred usually below 915 m (3000 ft) elevation, and his statement that "in many places they are poorly developed or absent as a type . . .," seemed to be the case in the present study area. The only Northern Red Oak sample plot below 1257 m (4120 ft) elevation seemed to fit into Whittaker's Red Oak-Pignut Hickory type description, except that *Quercus alba* and *Carya tomentosa* were absent, and *C. glabra* was present only in small numbers. It was located on a small ridge deep in the Roaring Fork Valley at 988 m elevation and contained both *Carya glabra* and *C. ovalis*. The remaining 18 plots fit satisfactorily into his description of the Red Oak-Chestnut forest type, although *Rhododendron calendulaceum* was less important than in the stands he described.

Oak-pine type. Samples of the Oak-Pine type occurred on steep upper slopes and ridges with southeast to west aspects. One was on the south slope of Greenbrier Pinnacle, the other four were on slopes or ridges adjoining Mt. Le-Conte. Although in these samples the type occurred in a fairly narrow elevation range, 847 to 981 m (2780 to 3220 ft), it occurs at lower elevations as well, and may occur at higher elevations in other areas of the Park.

The type is basically ecotonal between the Chestnut Oak type and the Table-Mountain Pine or Table-Mountain Pine-Pitch Pine types. Generally it occurred between Chestnut Oak stands lower on a slope or at a less exposed aspect and pine-dominated stands on a ridge or on a more exposed aspect. The two plots on ridges were below stands with shallower soils and more rock outcrops which had greater predominance of *Pinus* taxa.

Canopy trees were typically scattered, small and short, often being no taller than 10 - 15 m. Only nine taxa occurred in the canopy samples, with an average of 5.2 taxa per sample. Some mixture of four taxa, *Quercus coccinea*, *Q. prinus*, *Pinus rigida* and *P. pungens*, strongly predominated (Table 36). Tree saplings were dense, composed usually of a mixture of the common canopy species, but with *Acer rubrum* commonly abundant. Ericaceous shrubs, dominated by *Kalmia latifolia*, formed dense, almost impenetrable thickets. A total of only 34 vascular taxa occurred in the five samples, averaging 18 taxa/sample. Eleven shrub and woody vine taxa occurred, of these, *Kalmia latifolia*, *Smilax rotundifolia*, *S. glauca*, *Gaylussacia ursina*, and *Vaccinium* spp. occurred in more than half the samples (Table 6, page 74). Partly due to the dense heath layer, herbs and ferns were typically sparse. Only nine taxa occurred, *Galax aphylla* (100%), *Epigea repens* (80%), *Gaultheria procumbens* (80%) and *Pteridium aquilinum* (60%) were most frequent.

Stratal comparisons (Table 37) indicated that *Pinus* seedling establishment was poor. *Acer rubrum* and *Nyssa sylvatica* showed importance in the sapling and seedling classes. Definite evidence of disturbance was present in 80% of the samples, primarily in the form of *Castanea dentata* logs, sprouts or standing snags. No fire charred stumps were observed in any of the plots. The ability of *A. rubrum* to replace *C. dentata* perhaps explains its increasing importance. Scrutiny of individual plot diameter distributions indicated

Table 36. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Oak-Pine Type.[a] N=5.

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer rubrum	100	9	20	1	+[c]	1	0-5
A. saccharum	20	+	20	1	+	1	0-3
Amelanchier spp.	20	+	0	0	0	0	0
Castanea dentata	60	1	0	0	0	0	0
Hamamelis virginiana	20	+	0	0	0	0	0
Kalmia latifolia	100	21	0	0	0	0	0
Nyssa sylvatica	100	6	60	5	6	11	0-38
Oxydendrum arboreum	80	8	40	3	1	3	0-10
Pinus pungens	80	13	80	19	23	42	0-149
P. rigida	100	25	100	34	33	67	21-168
Quercus coccinea	100	8	100	24	19	43	7-102
Q. prinus	100	4	80	13	18	31	0-68
Rhododendron maximum	40	1	0	0	0	0	0
Robinia pseudoacacia	40	+	20	1	+	1	0-5
Sassafras albidum	60	2	0	0	0	0	0
Tsuga canadensis	40	1	0	0	0	0	0
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha		Mean m^2/ha
	10.6	2606	5.2		487		24.34

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[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] *Magnolia fraseri* occurred only as seedlings.

[c] Present, but less than 1%.

Table 37. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Oak-Pine Type. N=5.

Taxa	Seedlings[a] (<2.5 cm) Percent Frequency	Seedlings[a] (<2.5 cm) Mean Relative Density	Saplings[b] (2.5-12.7 cm) Percent Frequency	Saplings[b] (2.5-12.7 cm) Mean Relative Density	Canopy (>12.7 cm) Percent Frequency	Canopy (>12.7 cm) Mean Relative Density
Acer rubrum	80	28	100	24	20	1
A. saccharum	0	0	0	0	20	1
Castanea dentata	40	8	60	1	0	0
Magnolia fraseri	20	1	0	0	0	0
Nyssa sylvatica	80	25	80	13	60	5
Pinus pungens	20	1	60	15	80	19
Pinus rigida	20	10	80	32	100	35
Quercus coccinea	80	11	60	7	100	25
Q. prinus	80	13	80	6	80	13
Robinia pseudoacacia	0	0	40	1	20	1
Tsuga canadensis	40	2	40	1	0	0

[a] Mean density = 20/sample = 5000/ha.

[b] Mean density = 60/sample = 1500/ha.

that the pines were usually (in four of the five plots) well-represented in the smaller sapling sizes, although sparse or absent as seedlings. It may be that most of the sapling and small-canopy pines were established in openings created by the death of *C. dentata*, since most of them died 25 to 35 years ago. Although no evidence was obtained to support the hypothesis, the heath layer may have increased in coverage and density after the increased canopy openings were created by *C. dentata* loss. Since they do not have wind-blown propagules, the oaks (*Quercus prinus* and *Q. coccinea*) would have invaded canopy openings less rapidly than *A. rubrum* and the pines, thus accounting for their decreased importance in the sapling classes. Their slight renewal of importance in the seedling stratum reflects their ultimate re-establishment over a longer period of time. It is further hypothesized that with no further disturbance, most of these stands will ultimately become somewhat like some of the more xeric stands of the Chestnut Oak type.

Sixty percent of the soils were Typic Dystrochrepts, one was a Lithic Dystrochrept, and one soil was tentatively classed as a Lithic Hapludult. This Lithic Hapludult was the only Ultisol observed in this study. It was on an upper 36% slope with a southeast aspect at 848 m (2780 ft) elevation. The surface mineral horizon was only 7 cm (2.5 inches) thick, with a distinct change to a clay subsoil

(45% clay) with a moist Munsell color of 5YR 4/6. The depth to decomposing phyllite was 30 cm (12 inches). The canopy was a scattered mixture of Pinus rigida, Quercus coccinea, and Q. prinus, and the shrub layer was a Kalmia latifolia thicket.

Surface rock cover was practically absent in all plots, and solum stone content was very low (Table 3, page 64). Color change from the A to B horizons was more pronounced than in the types previously described. Chroma changes of two or more units were noted between the A and B horizons of three of the five soils. Soil textures also showed more pronounced changes from the A to B horizons. Although all the A horizons were silt loams or sandy loams, the B horizons were loam, clay loam, silty clay or clay. Soils had the highest average B horizon clay content of any type (30%). Total available soil phosphorus was in the lower one-third of the range of type means, but potassium was among the upper one-third. Soil water-holding capacity was also in the upper one-third of types, partly because of the typically low rock content as well as the higher (but not excessive) amounts of clay.

Neither the Society of American Foresters (1964), Braun (1950) nor Whittaker (1956) recognized an ecotonal or transitional Oak-Pine forest type with the species involved here. Cain (1937) listed an Oak-Pine forest type occurring in the Smokies, but he published no description or data. In escarpment gorges in southern North Carolina, Racine (1966) reported Pitch Pine-Scarlet Oak stands which resemble somewhat the Oak-Pine stands in the Smokies. However, *Pinus pungens* was absent, and *P. echinata* and *P. virginiana* were common in the Pitch Pine-Scarlet Oak type.

Table-mountain pine type. *Pinus pungens* is one of five pines native to the Smokies. Two of these native pines, *P. strobus* and *P. echinata* did not occur in any of the samples of this study. Both occur in the area, but chiefly at lower elevations. A single *P. virginiana* occurred in one sample, a Chestnut Oak plot at 857 m (2810 ft) elevation. Only *P. pungens* and *P. rigida* occurred in abundance in any plot.

Samples of the Table Mountain Pine forest type occurred on upper slopes and ridges at elevations from 853 to 1475 m (2800 to 4840 ft). Most of these ridges and slopes had southeast to west aspects. All were in the Mt. LeConte area.

This type was characterized by the overwhelming abundance of *P. pungens*. Its average canopy (>12.7 cm dbh) relative density in the seven samples was 87%, and it was the sole taxon occurring in three canopy samples. Canopies were typically discontinuous, composed of short, small-crowned trees of poor form. Canopy height was typically only 8 to 12 m (25 to 40 ft). The majority of the canopy stems were less than 25 cm dbh, only rarely being greater than 35 cm. The maximum stem size measured was 65 cm (26 inches) dbh. Of five other taxa occurring, only *P. rigida* was present with a frequency exceeding 14% (Table 38). Only 38 vascular taxa occurred in the seven samples, averaging 18 taxa/sample.

Saplings were very abundant and more diverse than in the canopy (14 taxa occurred). The shrub stratum was typically a dense heath tangle (average cover of 65%) dominated by *Kalmia latifolia*, frequently mixed with some *Rhododendron maximum* and usually intertwined somewhat with *Smilax glauca* or *S. rotundifolia* or both. Smaller heaths, *Gaylussacia baccata*, *G. ursina*, or *Vaccinium* spp. were the other shrubs with frequencies higher than 40% (Table 6, page 74). *Pieris floribunda*, an uncommon southern Appalachian endemic, occurred in two plots. Nine herb and fern taxa were sampled. *Gaultheria procumbens* was not frequent or abundant, but other taxa with a frequency greater than 40% were *Galax aphylla*, *Epigea repens*, *Melampyrum lineare* and *Pteridium aquilinum*.

Stratal comparisons (Table 39) reflected the sporadic reproduction of all taxa. The influence of the typical heavy heath layer has resulted in low seedling densities and a lack of high frequencies for any taxon. In the 0.004 ha seedling samples, an average of three tree taxa were present and an

Table 38. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa in the Table-Mountain Pine Type.[a] N=7.

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer rubrum	72	3	14	1	+[c]	1	0-4
Amelanchier spp.	14	+	0	0	0	0	0
Betula lenta	14	+	0	0	0	0	0
Castanea dentata	29	+	0	0	0	0	0
Hamamelis virginiana	29	+	0	0	0	0	0
Kalmia latifolia	58	7	0	0	0	0	0
Magnolia fraseri	14	+	0	0	0	0	0
Nyssa sylvatica	100	5	14	2	1	4	0-25
Oxydendron arboreum	43	2	14	+	+	1	0-4
Pinus pungens	100	63	100	87	91	78	103-200
P. rigida	72	12	43	8	6	13	0-36
Quercus coccinea	29	+	0	0	0	0	0
Q. prinus	43	1	14	2	+	4	0-29
Rhododendron maximum	43	2	0	0	0	0	0
Robinia pseudoacacia	29	1	0	0	0	0	0
Sassafras albidum	29	1	0	0	0	0	0
Tsuga canadensis	14	+	0	0	0	0	0
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha	Mean m^2/ha	
	7.9	3068	2		607	21.58	

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[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] *Picea rubens* occurred only as seedlings.

[c] Present, but less than 1%.

Table 39. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Table-Mountain Pine Type. N=7.

	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
Taxa	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density
Acer rubrum	58	17	71	5	14	+[c]
Betula lenta	0	0	14	+	0	0
Castanea dentata	29	13	29	2	0	0
Magnolia fraseri	0	0	14	+	0	0
Nyssa sylvatica	43	23	100	7	14	2
Picea rubens	15	1	0	0	0	0
Pinus pungens	43	18	100	66	100	87
P. rigida	29	16	71	16	43	8
Quercus coccinea	15	3	28	1	0	0
Q. prinus	29	3	28	1	14	2
Robinia pseudoacacia	0	0	28	1	0	0
Tsuga canadensis	29	5	14	+	0	0

[a] Mean density = 8/sample = 2000/ha.

[b] Mean density = 81/sample = 2025/ha.

[c] Present, but less than 1%.

average of eight seedlings were counted. The abundance of *Pinus pungens* dropped sharply, whereas two taxa, *Acer rubrum* and *Nyssa sylvatica*, showed marked increases in the seedling samples.

It is very difficult to interpret composite stratal data for this type, for individual diameter distributions varied widely. Study of the distributions of individual plots indicated a general pattern (in 88% of the samples) of *P. pungens* increasing in density from the largest size classes down to the sapling size classes, then decreasing markedly in density at sizes less than 4 cm dbh. One plot exhibited a periodic reproduction history as indicated by gaps in diameter classes (cf. Whittaker, 1956). Cain (1937) ascribed the maintenance of these stands primarily to periodic fire, but indicated that they may be an edaphic climax on very dry sites. Whittaker (1956) stressed the importance of fire in their maintenance, yet concluded that they were self-maintaining and not seral under present conditions. No definite evidence of recent fires (charred stumps or logs) was observed at any of the eight sites. Of course, fire may have been responsible for the original establishment of the stands, but no evidence of this was obtained. Fire aids the reproduction of *Pinus pungens* by destroying competing vegetation and litter cover, while releasing seed from the pine's serotinous cones (Zobel, 1969). *Castanea dentata* evidence was observed in 38% of the plots, but it did not appear to have been abundant.

The stands sampled appeared to be basically self-maintaining. Seedling establishment was in patches and the single sample taken at the center of each plot may have resulted in unrealistically low densities. The stands were generally open enough to permit abundant light through the canopy (cover was usually 25 - 45%). The shrub stratum presented the greatest competition for seedlings. Without fire, apparently _Acer rubrum_ and _Nyssa sylvatica_ begin to increase in the understory and can be expected to increase in future canopy composition.

Zobel (1969) reported that Table-Mountain Pine stands appearing to be permanent were associated with shallower litter, more rock outcrop and had less basal area than stands more obviously successional. Plots in this study did not exhibit such differences consistently.

Fifty-seven percent of the soils were Lithic Dystrochrepts, the remainder were Typic Dystrochrepts. Soils were typically shallow on the narrower ridges, but deeper where the ridges were wider. Surface rock varied, but was less than 15% cover on five sites. Two sites on narrow ridges had considerable (35 - 55% cover) rock outcropping. Total available phosphorus was lowest of any of the types and total available potassium was in the middle one-third of the range of type means (Table 3, page 64). This was partly because of the frequent shallow soils and moderately high stone content (averaging 24%) of the solum. Distinct color changes from the A to B horizons were observed in most of the soils. Munsell (1954) chroma color changes of 2 to 3 units were noted. Hue and value changed little. Texture changes were conspicuous in several soils because of increased clay in the B horizon. Still, most of the B textures were loams and silt loams, with one silty clay loam.

A type predominated by *Pinus pungens* was not recognized by the Society of American Foresters (1964), although it was listed as a minor associate in three types. Braun (1950) mentioned a Table-Mountain Pine type, but presented no data or discussion of it. Cain (1931, 1937) discussed Pine Heaths, but stated that stand predominance by *P. pungens* or *P. rigida* was a result of whichever species was able to seed the area first after a fire. Whittaker (1956) described the Table-Mountain Pine Heath of the Smokies as becoming more predominant than the Pitch Pine Heath at higher elevations. This was true in the present study, for Table-Mountain Pine plots occurred at elevations more than 150 m higher than those in which *P. rigida* was a co-dominant (Table-Mountain Pine-Pitch Pine type). Table-Mountain Pine stands on the southern Blue Ridge escarpment of southern North Carolina (at elevation about 730 m) differ primarily in having an abundance of *Pinus virginiana* (Racine, 1966).

Table-mountain pine-pitch pine type. Samples of the Table-Mountain Pine-Pitch Pine type occurred on ridges and upper slopes with south to southwestern (180° to 250°) aspects on the western side of Mt. LeConte. Seven of the eight plots were in the elevation range 771 to 1162 m (2530 to 3810 ft). The remaining plot was at 1317 m (4320 ft) elevation (Table 1, page 55).

These plots were characterized by the strong dominance of a mixture of *Pinus pungens* and *P. rigida*. The combined importance values of these two taxa totaled at least 173 (of a total 200) in the canopies of every sample. Canopies were similar to those of the Table-Mountain Pine type: low (typically only 8 to 12 m tall), discontinuous (but usually a high density of small stems) canopies with small, poorly formed crowns. Most of the canopy trees were 30 cm or less dbh and largest stems were no more than 45 cm (18 inches) dbh. Only eight taxa occurred in canopy samples (>12.7 cm dbh). *Quercus coccinea* and *Q. prinus* were the only hardwoods occurring in more than one canopy sample (Table 40). *Quercus coccinea* did not occur above 823 m (2700 ft) elevation. The only live *Castanea dentata* sampled which was larger than 12.7 cm dbh (15 cm) occurred in a sample on the Bull Head (a large ridge extending westward from Mt. LeConte) at 1231 m (3710 ft) elevation. Sapling densities were quite high, averaging more than 1900 stems/ha. Only 34 vascular taxa occurred in the

Table 40. Frequency, Mean Relative Density, Mean Relative Basal Area, and Mean Importance Values of Tree Taxa of the Table-Mountain Pine-Pitch Pine Type.[a] N=8.

	All Stems[b] >2.5 cm dbh		Stems >12.7 cm dbh				
Taxa	Percent Frequency	Mean Relative Density Max.=100	Percent Frequency	Mean Relative Density Max.=100	Mean Relative Basal Area Max.=100	Mean Importance Value Max.=200	I.V. Range
Acer rubrum	75	5	12	+[c]	+	+	0-3
Castanea dentata	38	1	12	+	+	+	0-3
Kalmia latifolia	88	10	0	0	0	0	0
Nyssa sylvatica	100	8	12	+	+	+	0-3
Oxydendrum arboreum	75	5	12	1	+	1	0-7
Picea rubens	12	+	0	0	0	0	0
Pinus pungens	100	30	100	49	50	99	30-150
P. rigida	100	35	100	43	45	88	47-162
Quercus coccinea	38	2	38	3	2	6	0-17
Q. prinus	63	2	38	3	2	5	0-20
Q. rubra	50	1	0	0	0	0	0
Q. velutina	12	+	0	0	0	0	0
Rhododendron maximum	12	+	0	0	0	0	0
Robinia pseudoacacia	25	+	12	+	+	+	0-3
Sassafras albidum	38	1	0	0	0	0	0
Tsuga canadensis	12	+	0	0	0	0	0
	Mean No. Taxa	Mean Stems/ha	Mean No. Taxa		Mean Stems/ha		Mean m^2/ha
	8.4	2717	3.4		747		25.26

[a] All taxa which reached a size of 12.7 cm dbh in any sample of the study.

[b] Tree taxa which occurred only as seedlings were: *Quercus alba*, *Q. marilandica*, *Diospyrus virginiana*, *Halesia carolina*, and *Magnolia fraseri*.

[c] Present, but less than 1%.

eight samples, averaging 19 taxa/sample.

The shrub stratum was similar to that of the Table-Mountain Pine type: a dense tangle of *Kalmia latifolia* with *Smilax* spp. intertwined and with a lower layer of low heaths in openings between the high heaths. The shrub coverage was typically even denser (averaging 84%) and *Vaccinium* spp., *Smilax glauca*, and *Gaylussacia baccata* were more frequent and abundant (Table 6, page 74). *Lyonia ligustrina* occurred in two plots. Nine herb and fern taxa occurred, four taxa with frequencies of 75%. Of these, *Gaultheria procumbens* was most abundant, followed by *Galax aphylla*, *Epigea repens*, and *Pteridium aquilinum*.

Thirty-eight percent of the plots did have evidence of past fires. Eighty-eight percent had evidence of minor *Castanea dentata* occurrence. Evidence of past cutting was observed in several plots and blowdown was common in most.

Stratal comparisons (Table 41) reflected the spotty seedling establishment of the pines. As was the case in the Table-Mountain Pine type, *Acer rubrum* and *Nyssa sylvatica* were taxa showing the strongest increases in abundance in the lower strata. However *A. rubrum* was most abundant (mean relative density of 41) in the seedling stratum of the Table-Mountain Pine-Pitch Pine type. *Quercus rubra* showed increased occurrence in the lower strata, whereas it was totally absent from all strata of the Table-Mountain Pine type.

Table 41. Frequency and Mean Relative Density of Overstory Taxa in Seedling, Sapling, and Canopy Size Classes of the Table-Mountain Pine-Pitch Pine Type. N=8.

Taxa	Seedlings[a] (<2.5 cm)		Saplings[b] (2.5-12.7 cm)		Canopy (>12.7 cm)	
	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density	Percent Frequency	Mean Relative Density
Acer rubrum	75	41	75	11	12	+[c]
Castanea dentata	63	11	25	1	12	+
Halesia carolina	13	+	0	0	0	0
Magnolia fraseri	13	+	0	0	0	0
Nyssa sylvatica	75	14	100	15	12	+
Picea rubens	13	1	12	+	0	0
Pinus pungens	38	7	88	29	100	49
P. rigida	50	9	75	37	100	43
Quercus coccinea	25	4	37	3	38	3
Q. prinus	25	6	50	2	38	3
Q. rubra	50	7	50	1	0	0
Q. velutina	0	0	12	+	0	0
Robinia pseudoacacia	0	0	12	1	12	+
Tsuga canadensis	0	0	12	+	0	0

[a] Mean density = 12/sample = 3000/ha.

[b] Mean density = 70/sample = 1750/ha.

[c] Present, but less than 1%.

Study of diameter distributions of individual plots showed considerable variation. Half appeared to have had periodic pine reproduction as described by Whittaker (1956). He ascribed this to past fires which had opened the forest floor at intervals, allowing greater pine establishment. Three of these four plots had definite evidence of past fires. Half of all the plots had very few *Pinus pungens* smaller than 12.7 cm dbh, although having abundant *P. rigida* in these sizes. Thirty-eight percent had the opposite trend, *i.e.*, very few *P. rigida* smaller than 12.7 cm dbh, but abundant *P. pungens*. Typically, the samples with low abundance of *P. pungens* and high abundance of *P. rigida* in the sapling sizes had canopies dominated by *P. rigida*, and vice versa. This supports Cain's (1937) assertion that the dominant pine species is dependent upon the most abundant seed source at the time of disturbance. Both *Pinus pungens* and *P. rigida* are resistant to fire (as canopy trees), and *P. rigida* is the more fire-resistant of the two (Zobel, 1969).

Considered separately, successional trends appeared to be strong in 25% and significant in 38% of the plots. The trends were to increases of *Acer rubrum*, *Nyssa sylvatica*, and less strongly to *Quercus prinus* and *Q. rubra*. These successional trends were strongest at lower elevations and weaker or absent at the higher elevations.

Most of the soils were either Lithic Dystrochrepts or

Typic Dystrochrepts. Bedrock occurred at less than 50 cm in half the plots, although surface rock was generally low. Total available soil phosphorus, potassium and soil pH were all higher than in the Table-Mountain Pine type and were quite similar to those of the Oak-Pine type (Table 3, page 64). The average clay content of the B horizon was lower (17%) than in the other two pine types, but still higher than in most of the other types. These differences among the two pine-dominated types might have been due to the considerably higher occurrence and abundance of hardwood taxa in the Table-Mountain Pine-Pitch Pine type. The deciduous litter breaks down more rapidly and would tie up less of the bases than would be the case with pine litter.

Of types described by the Society of American Foresters (1964), this type most resembles the Pitch Pine type (Type 45), although _Pinus pungens_ was described as a minor associate. Braun (1950) mentioned a Pine-Heath community occurring in the Smokies on ridges and south slopes. Cain's (1937) Pine-Heath type included stands dominated by either _P. pungens_ or _P. rigida_, or both. Whittaker (1956) segregated the pine types into either Table-Mountain Heath or Pitch Pine Heath, but with no combination type. His discussion and diagrams indicated that the two types were segregated by elevation, the Table-Mountain Pine type dominant at higher elevations (above about 976 m or 3200 ft) and the Pitch Pine type dominant at lower elevations down to about 660 m (2200 ft).

Such an elevational segregation was not definite in this study. *Pinus pungens* was dominant (using importance value) in a sample as low as 771 m (2530 ft) and *P. rigida* was dominant as high as 1162 m (3810 ft). In all of the pine-dominated plots above 1162 m, *P. pungens* was the dominant *Pinus* species. Whittaker's elevation distinctions were apparently generalizations which de-emphasized species overlaps. His "composite elevation transect in xeric sites" (Whittaker, 1956, p. 17) showed *P. pungens* had a higher relative density than *P. rigida* at elevations 754 to 915 m (2800 to 3000 ft) and *P. rigida* had a higher relative density than *P. pungens* at elevations 1128 to 1189 m (3700 to 3900 ft).

Topographic Site Gradient

Derivation of the gradient. An attempt was made to graphically relate the individual sample plots and forest types to gradients of site conditions. Whittaker (1956) approached this problem by constructing a "mosaic chart" which used elevation as the ordinate and the "moisture gradient" as the abscissa. The moisture gradient was termed by Whittaker a "complex-gradient" (cf. Whittaker, 1967), which is a complex of factor gradients reflecting varying conditions of temperature, atmospheric humidity, exposure to wind, soil moisture, and other site conditions. His moisture gradient was presented as having five steps defined by topographic position as follows: "(1) deep coves and valley flats, deep canyons; (2) open shallow valleys and flats, smaller ravines and draws; (3) lower sheltered slopes or valleys; (4) open slopes; and (5) ridges, summits and peaks" (Whittaker, 1956, page 58). He further subdivided the open slopes category by aspect, arranged northeast (most mesic) to southwest (most xeric). No further descriptions of these five steps were given, but apparently they were not defined by site characteristics which had been quantified.

A moisture gradient definable in quantitative terms was sought for application in this investigation. Although topographic position was considered to be the primary influence, aspect and slope angle were considered to be important as well. These factors interact greatly, particularly in an area as topographically complex as the Smokies. An approach was sought which would reflect these interactions.

Since the occurrence of most taxa varied noticeably with elevation, sample plots were first grouped into three elevation classes to reduce possible elevational influence. These were: (1) 760 to 915 m (2490 to 3000 ft); (2) 915 to 1220 m (3000 to 4000 ft); and (3) 1220 to 1585 m (4000 to 5200 ft). This resulted in three groups in which site differences within each group would be less directly related to elevation and more directly related to topography and aspect than was the case within the total sample.

In mountainous areas the effects of aspect are strongly affected by slope steepness. A 5% north-facing slope and a 60% north-facing slope differ greatly in incoming irradiation, temperature, and soil moisture. The potential solar beam irradiation figure as determined from the tables of Frank and Lee (1966) provided a convenient integration of the effect of slope angle and aspect, since its value is dependent upon these factors.

After studying the distribution of values determined for samples of this study, the plots of each elevation group were divided into four categories on the basis of potential insolation. These categories, with descriptions of the slope angles and aspects falling into each one, are shown in Table 42. The plots in each solar irradiation category (within each elevation group) were then sorted into slope positions, expressed as percent vertical distance from ridge (0%) to cove or valley bottom (100%).

The mean canopy importance values of several important tree taxa were computed for each elevation--solar irradiation--topographic position category. For example, the mean importance value of Tsuga canadensis was 74 on 70% slope positions receiving 240,000 to 280,000 Langleys per year potential irradiation at elevations 915 to 1220 m. Taxa representing the entire range of site conditions were chosen.

Table 42. Four Potential Solar Irradiation Categories and the Slope Aspect-Angle Combinations which Constitute Each Category.[a]

Solar Irradiation Categories (Langleys Per Year)	Slope Aspects	Slope Angles (%)
<240,000	NW-NE	<15
	ENE, WNW	>35
240,000-280,000	All	<5
	NW-NE, SE, SW	<15
	ENE, WNW, ESE, WSW	5-35
	E, W	All
	ESE, WSW	>80
280,000-300,000	SSE-SSW	5-25
	SE, SW	15-45, >85
	ESE,WSW	35-80
>300,000	SSE-SSW	>25
	SE, SW	45-85

[a] From the tables of Frank and Lee (1966) for 36° N latitude.

These were *Aesculus octandra*, *Tilia heterophylla*, *Tsuga canadensis*, *Quercus prinus*, *Pinus pungens* and *P. rigida*. *Betula alleghaniensis* was added in the elevation range 1220 to 1585 m because of its importance at these elevations.

For each solar irradiation category in each elevation band, each taxon's mean importance value was plotted by topographic position (Figures 4-6). The values of *Aesculus octandra* and *Tilia heterophylla* were combined, as were those for *Pinus pungens* and *P. rigida*. This was done to reduce the effects of low or absent values for any single taxon which may have occurred due to chance. The paired taxa were assumed to be very similar in moisture requirements.

Within each elevation band different vertical alignments of topographic positions across solar irradiation categories were tried, each time calculating the mean importance of each taxon in each combination of topographic positions. These mean importance values were plotted on a gradient representing the trial alignment of topographic positions across solar irradiation categories. A number of these trial alignments were tried in each elevation band, the objective being to find the alignment that resulted in the smoothest curves for all taxa in all three elevation bands. The resulting combinations are shown in Figures 7-9. No sites

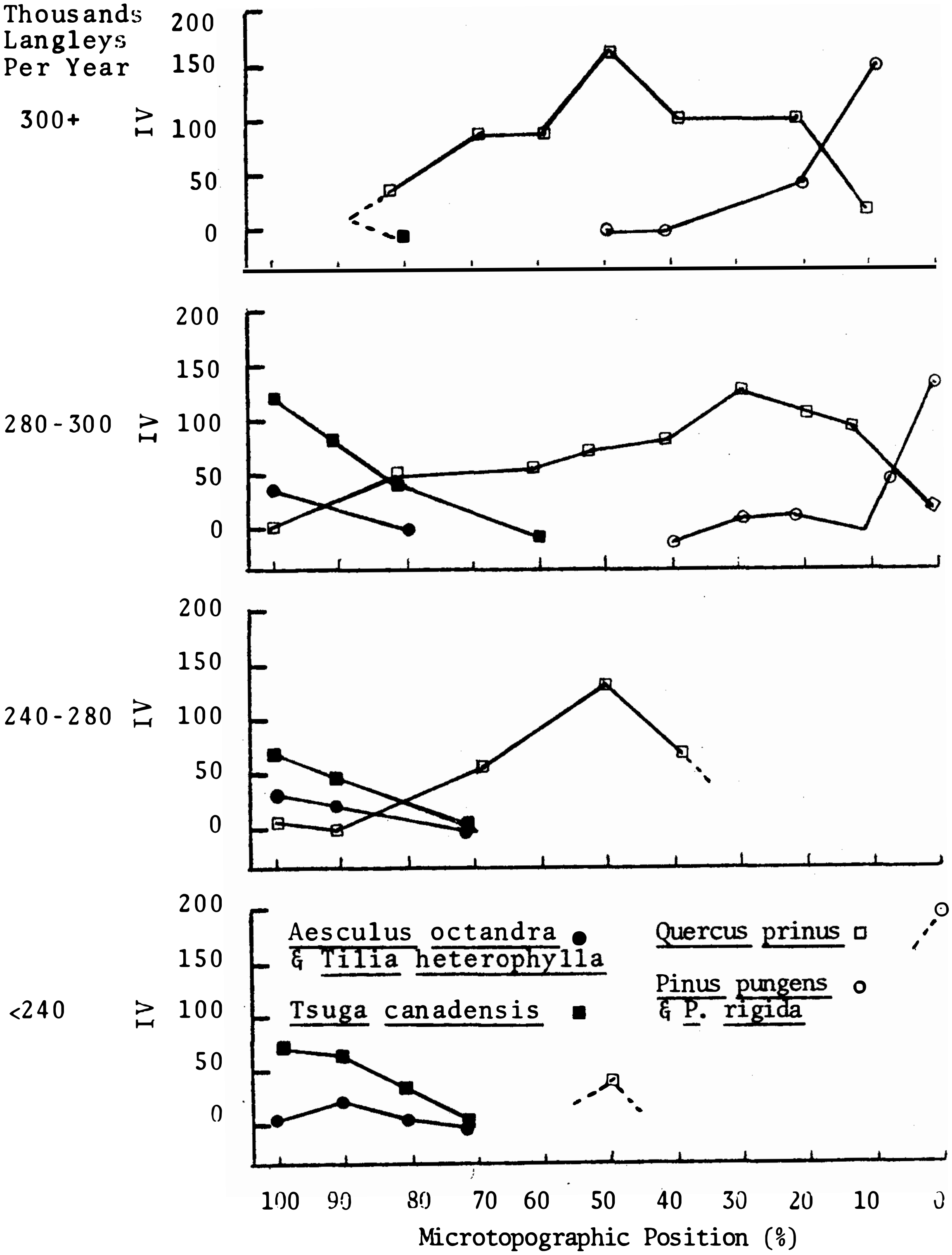


Figure 4. Average importance values (IV) of selected taxa on each slope position within four potential solar irradiation classes; plots at 760 to 915 m (2490 to 3000 ft) elevation.

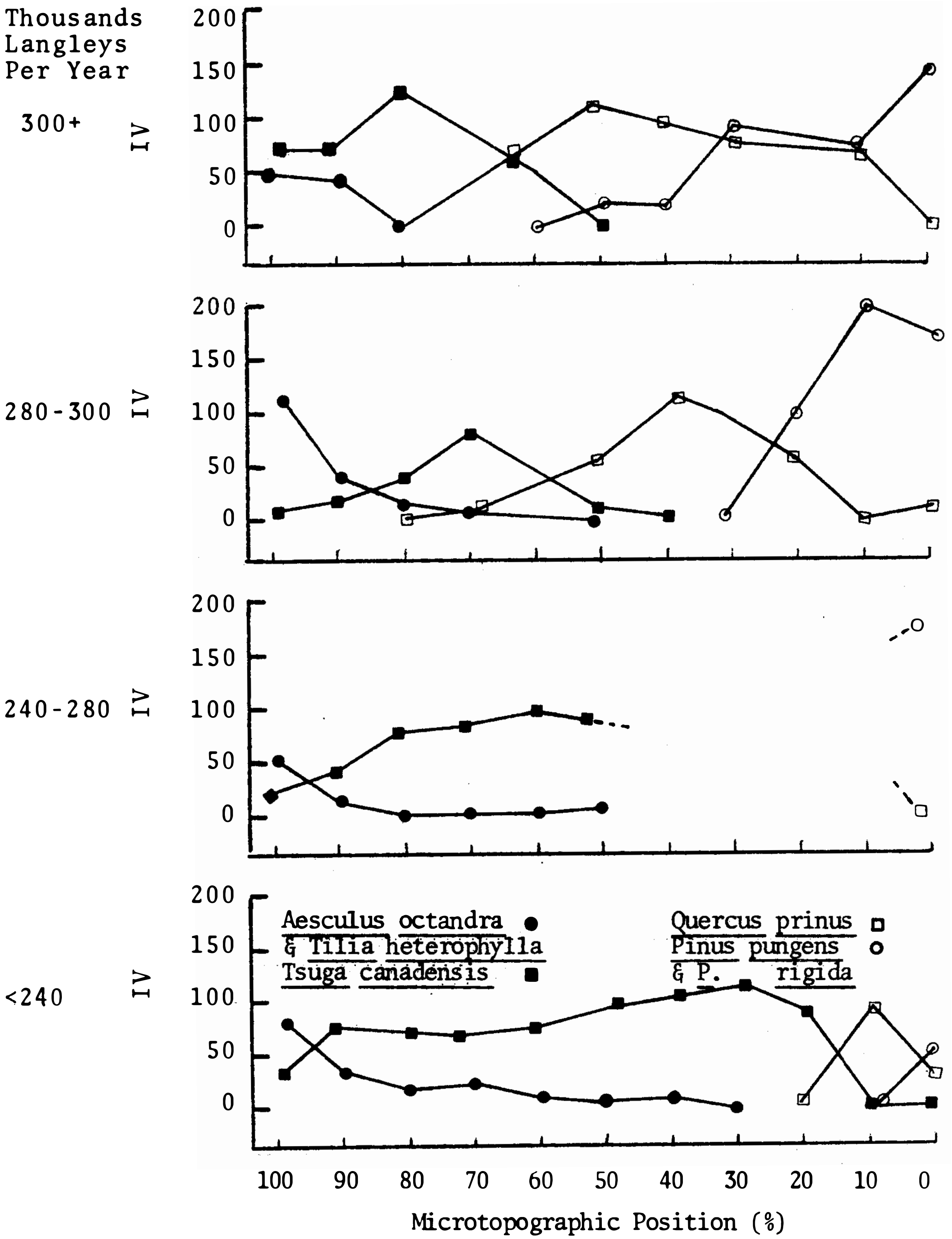


Figure 5. Average importance values (IV) of selected taxa on each slope position within four potential solar irradiation classes; plots at 915 to 1220 m (3000 to 4000 ft).

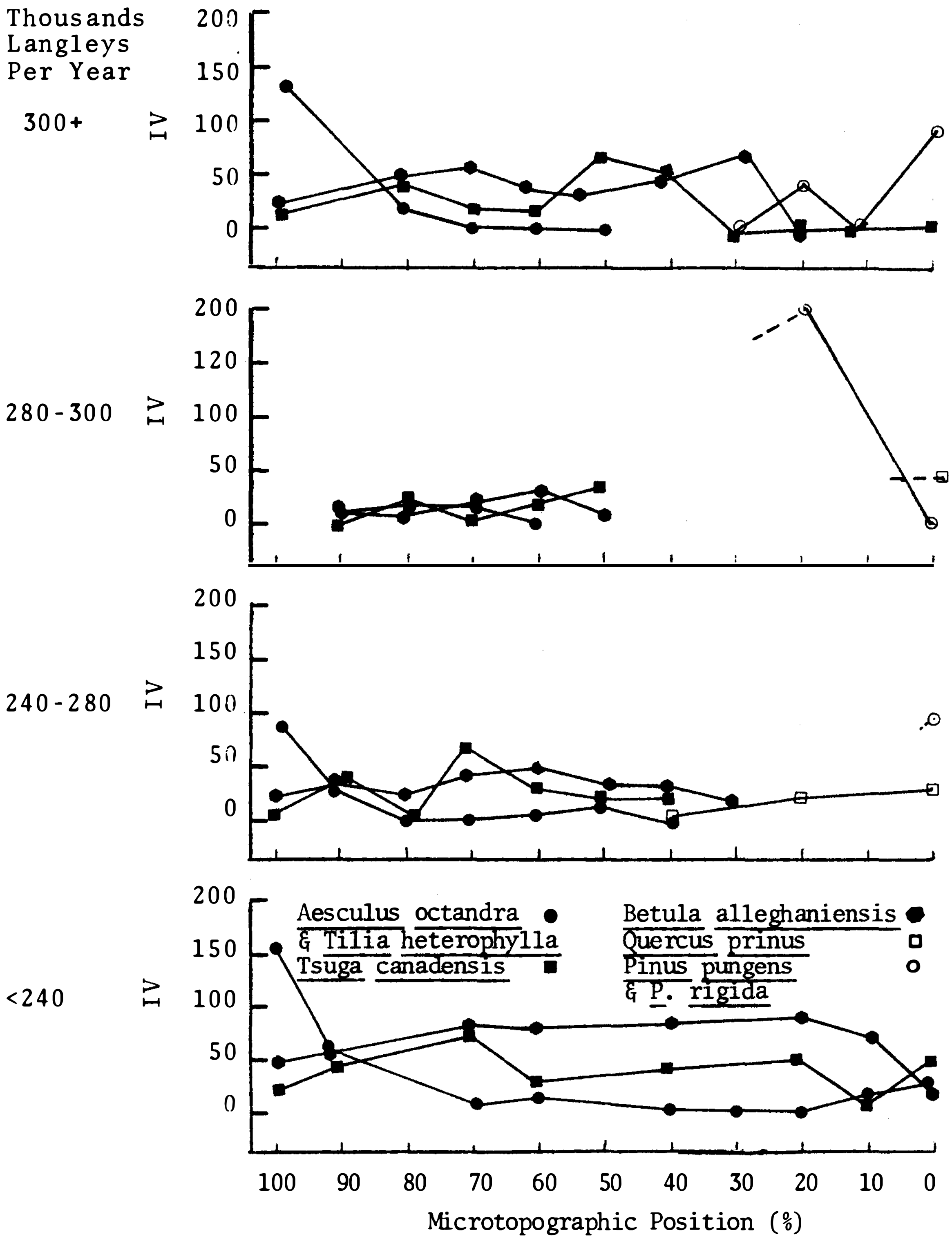


Figure 6. Average importance values (IV) of selected taxa on each slope position within four potential solar irradiation classes; plots at 1220 to 1585 m (4000 to 5200 ft).

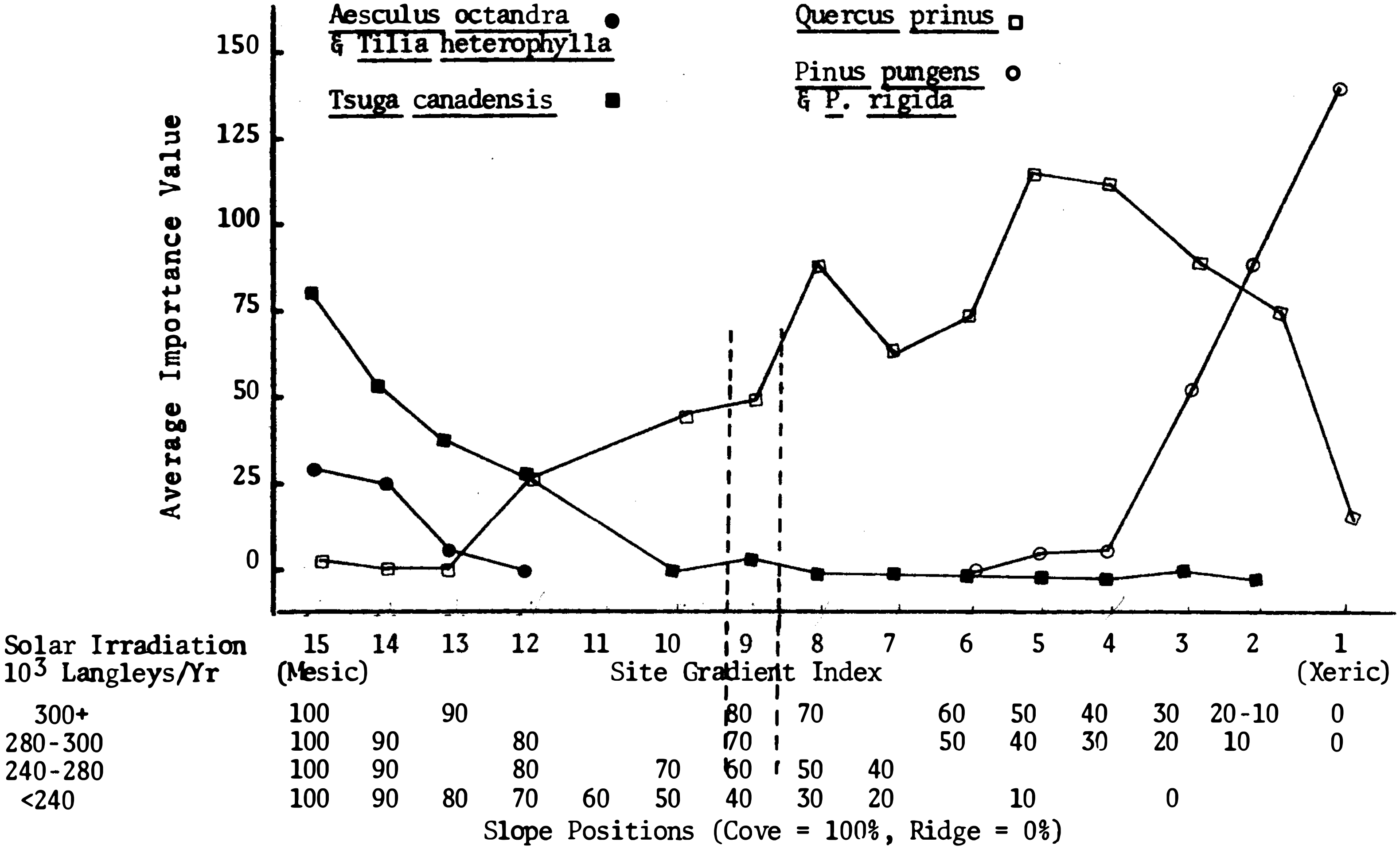
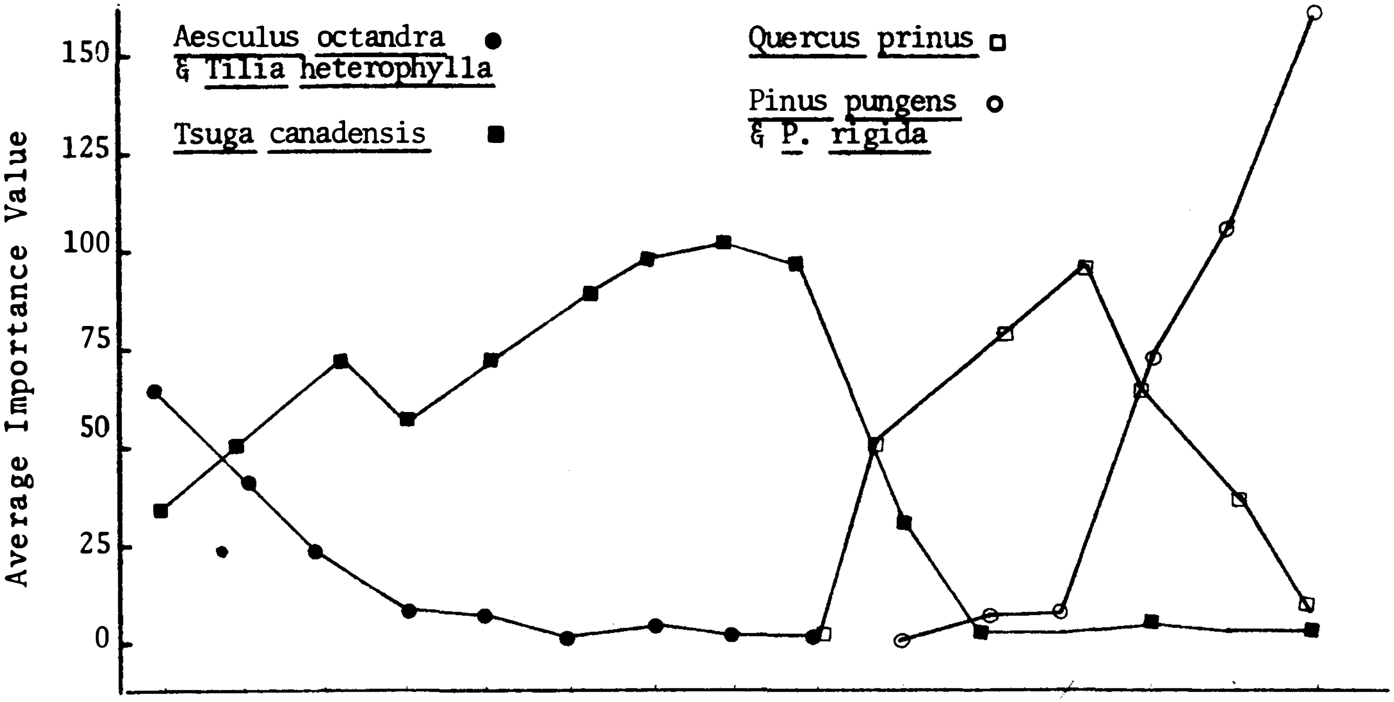


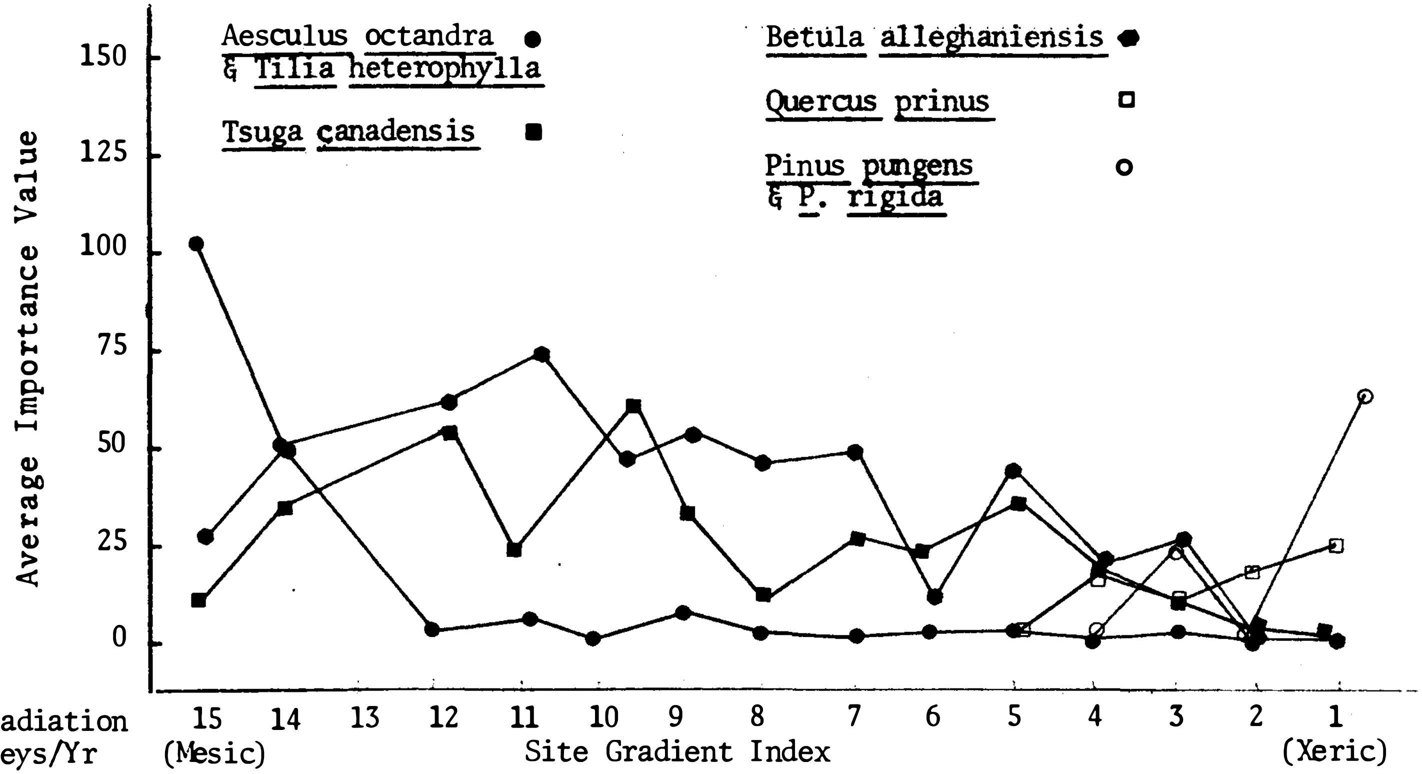
Figure 7. Average importance value of selected taxa along a topographic site gradient of plots at 760 to 915 m (2490 to 3000 ft) elevation. Vertically aligned slope positions are equivalent on the topographic site gradient and have the same site gradient index.



Solar Irradiation 10^3 Langleys/Yr	15 (Mesic)	14	13	12	11	10	9	8	7	6	5	4	3	2	1 (Xeric)
	Site Gradient Index														
300+	100		90				80	70		60	50	40	30	20-10	0
280-300	100	90		80			70			50	40	30	20	10	0
240-280	100	90		80		70	60	50	40						
<240	100	90	80	70	60	50	40	30	20		10		0		

Slope Positions (Cove = 100%, Ridge = 0%)

Figure 8. Average importance value of selected taxa along a topographic site gradient of plots at 915 to 1220 m (3000 to 4000 ft) elevation. Vertically aligned slope positions are equivalent on the topographic site gradient and have the same site gradient index.



Solar Irradiation 10^3 Langleys/Yr	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
300+	100		90				80	70		60	50	40	30	20-10	0
280-300	100	90		80			70			50	40	30	20	10	0
240-280	100	90		80		70	60	50	40						
<240	100	90	80	70	60	50	40	30	20		10		0		

Slope Positions (Cove = 100%, Ridge = 0%)

Figure 9. Average importance value of selected taxa along a topographic site gradient of plots at 1220 to 1585 m (4000 to 5200 ft) elevation. Vertically aligned slope positions are equivalent on the topographic site gradient and have the same site gradient index.

were sampled which occurred on 0 to 30% slope positions in the solar irradiation range 240,000 to 280,000 Langleys per year.

The interpretation of the horizontal axis of the diagrams can be illustrated by an example using Figure 7, page 210, showing the elevation band 760 to 915 m. By reading within the column between dashed lines, it can be seen that a site at a slope position 80% of the vertical distance from the ridge to draw and receiving more than 300,000 Langleys per year potential direct solar irradiation is equivalent to sites at 70% positions receiving 280,000 to 300,000 Langleys per year, sites at 60% slope positions receiving 240,000 to 280,000 Langleys per year, and sites at 40% position receiving less than 240,000 Langleys per year. The species curves show that all samples on these sites in the elevation range 760 to 915 m had a mean importance value of 48 for *Quercus prinus* and 2 for *Tsuga canadensis*.

The resulting gradient from left to right represents a continuum of topographic site conditions from mesic to xeric as reflected in varying importance values of the taxa selected. Breaking the samples into fairly narrow elevation groups minimized the effect of elevation change on taxa importance values.

To facilitate further use, the gradient was arbitrarily assigned 15 equally-spaced values ranging from 15 (most mesic) to 1 (most xeric). Each number along the gradient was termed the "site gradient index" (SGI) of that position on the gradient.

Correlations with site, soil, and vegetation characteristics. The final site gradient was an attempt to quantify a "complex-gradient" (Whittaker, 1956, 1967) of topography-related moisture conditions. SGI was significantly correlated to most of the measured site characteristics (Table 43). It was most strongly correlated with those factors which were used in its derivation, microtopographic position (.93) and annual potential irradiation (-.42). The strong correlation with macrotopographic position (.60) was due largely to the correlation between it and microtopographic position (Table 2, page 61). Slope angle and aspect were the factors determining the irradiation value, hence their correlation with SGI. Topographic shading values were related to topographic position (Table 2), and were also correlated with SGI. The negative correlation of elevation with SGI was probably due to the smaller number of valleys and coves occurring at higher elevations, which was also reflected in the negative correlation between elevation and microtopographic position (Table 2).

The negative correlation of SGI with clay content of the B horizon would appear to be parallel to the situation found by Losche (1967) and Mowbray and Oosting (1968) in a gorge in southern North Carolina. They found clay content

Table 43. Correlation[a] of Site Gradient Index (SGI) with Site, Soil and Vegetation Characteristics, and with Basal Areas of Selected Tree Taxa

Characteristic	r
Elevation	-.20
Macrotopographic position	.60
Microtopographic position	.93
Aspect[b]	.36
Slope angle (percent)	-.26
Total annual irradiation[c]	-.42
Mean AM shading[d]	.30
Mean PM Shading[d]	.20
Total mean shading[d]	.40
Rock cover (percent)	.29
Litter thickness	-.22
Clay in B horizon	-.37
Canopy coverage (percent)	.53
Shrub coverage (percent)	-.28
Herb coverage (percent)	.29
Canopy stem density[e]	-.39
Basal area (canopy)	.38
Acer saccharum	.29
Aesculus octandra	.43
Betula alleghaniensis	.20
Halesia carolina	.28
Pinus pungens	-.37
P. rigida	-.33
Quercus coccinea	-.28
Q. prinus	-.34
Q. rubra	-.21
Tilia heterophylla	.41
Tsuga canadensis	.29

[a] Only correlations ≥.20 are reported (significant at .001 probability level).

[b] Cosine transformation of Beers, *et al.*, (1966).

[c] Total annual potential solar irradiation in Langleys, from Frank and Lee (1966).

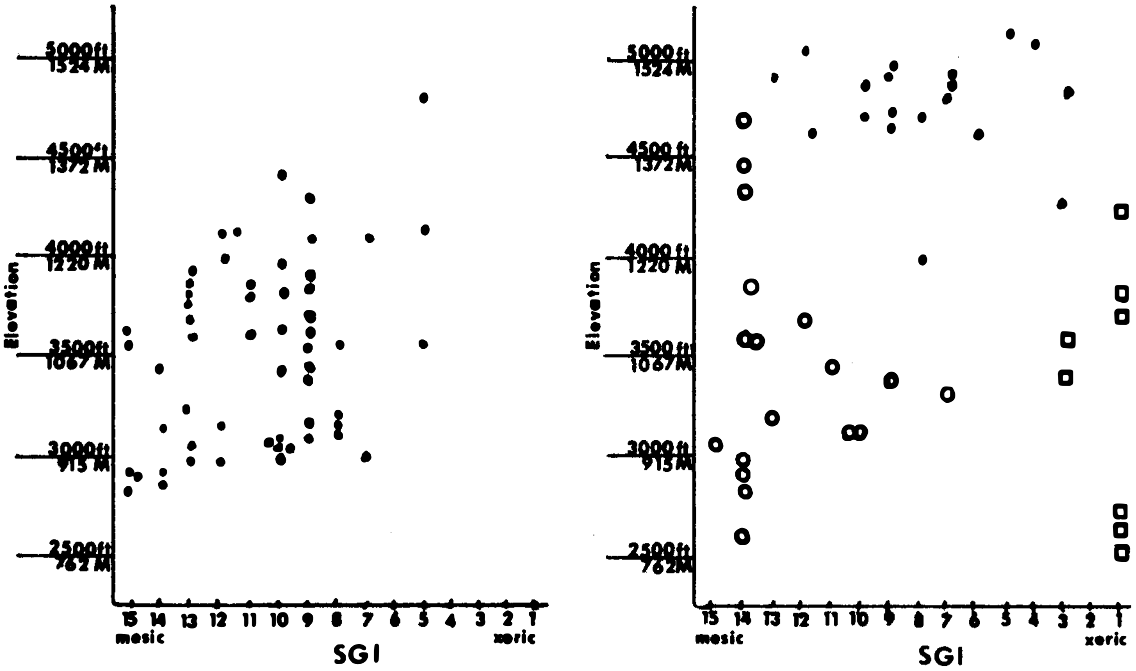
[d] Daily average for growing season, in hours.

[e] Stems/ha ≥12.7 cm dbh.

of the B horizon ranged from a low in the gorge bottom to progressively higher values up the north slope to still higher values at the bottom of the south slope to the highest values at the top of the south-facing slope. Losche (1967) found soil temperature and water infiltrating into the soil to be closely related to this clay gradient. He attributed the increase in clay to increased mineralization of the soil due to higher soil temperature and increased water percolation (resulting from the relatively more open forest canopy).

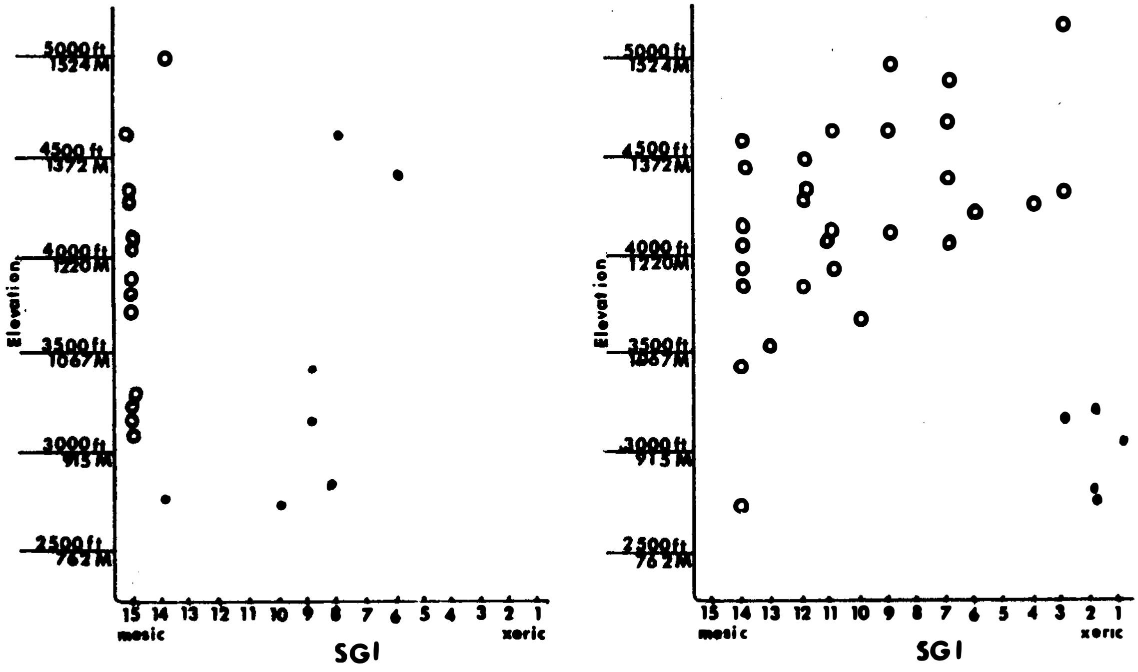
The correlations with vegetation characteristics and basal areas of tree taxa followed the trends one would expect for a figure which increases toward mesic sites and decreases toward xeric sites. Generally higher canopy cover, herb cover and canopy basal areas of mesic sites resulted in positive correlations, while the generally higher shrub cover and stem densities (many smaller trees) of xeric sites led to negative correlations. The more mesic taxa had positive and the more xeric taxa had negative correlations.

The composite site diagram. After the site gradient index (SGI) was derived, the sample plots of each type were plotted on axes of elevation and SGI (Figure 10). After studying the distribution of individual types, a composite diagram was made portraying the site-elevation pattern of



(a) Hemlock •

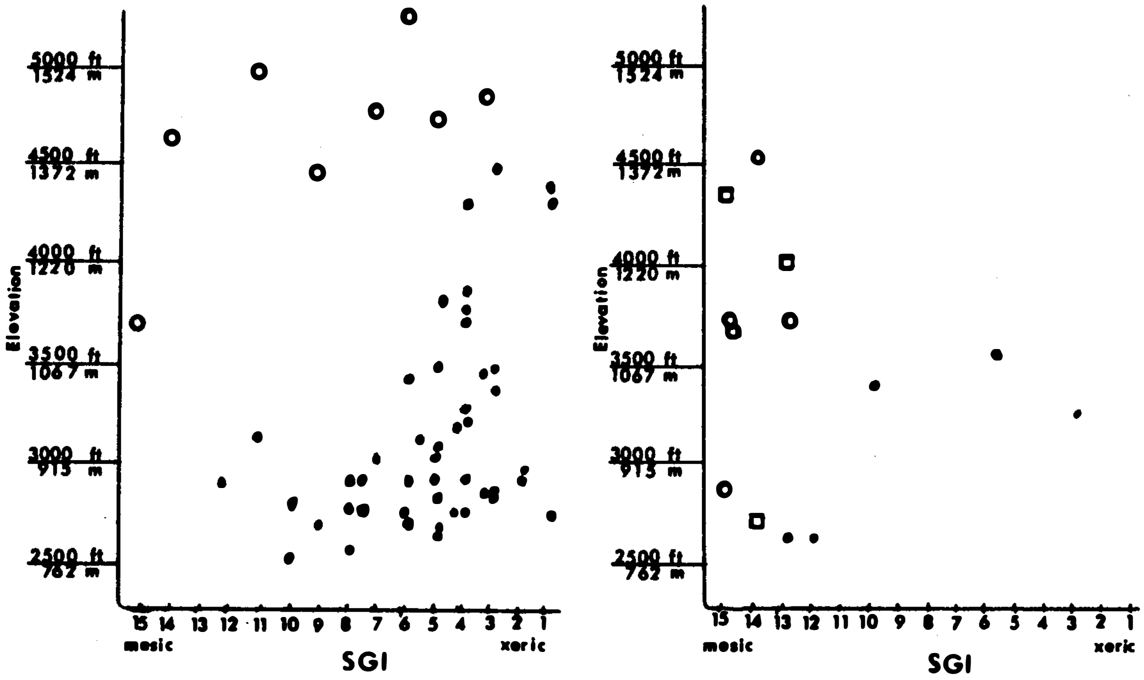
(b) Table-Mountain Pine-
Pitch Pine □
Spruce-Yellow Birch •
Silverbell-Hemlock o



(c) Buckeye o
Red Maple-Northern Red Oak •

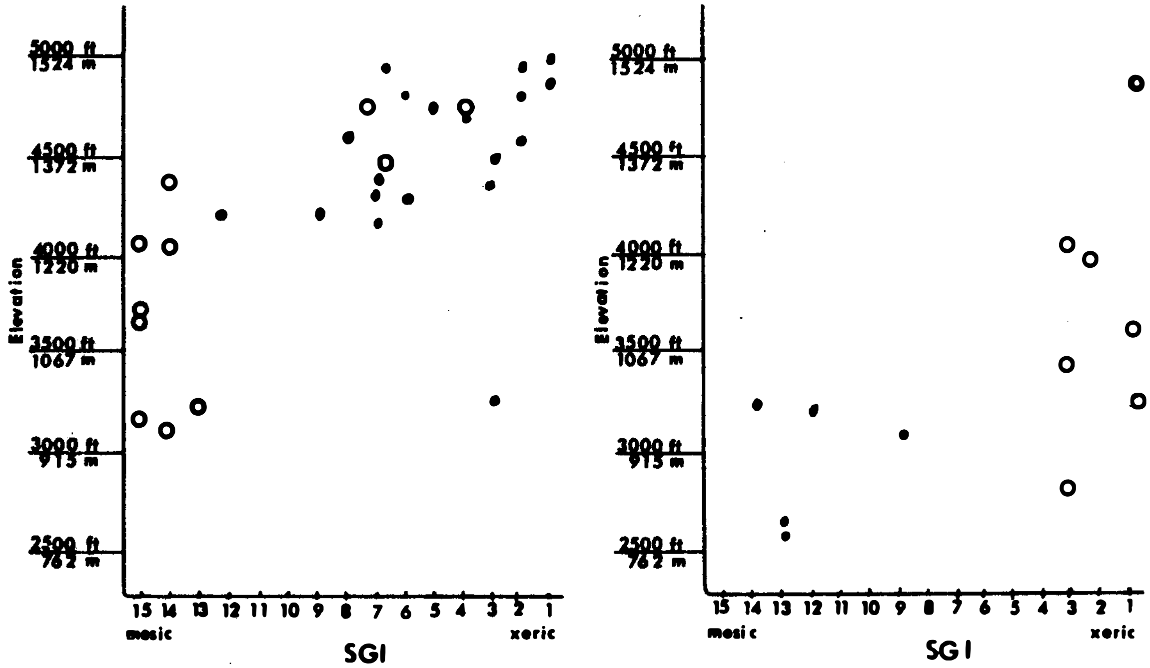
(d) Yellow Birch-Hemlock o
Oak-Pine •

Figure 10. Locations of individual plots of forest types on axes of elevation and site gradient index (SGI).



(e) Chestnut Oak •
Beech ○

(f) Red Maple-Sweet Birch •
Hemlock-Buckeye ○
Basswood □



(g) Sugar Maple ○
Northern Red Oak •

(h) Yellow-Poplar •
Table-Mountain Pine ○

Figure 10 (continued)

the types (Figure 11). Due to their scattered occurrence, the Yellow-Poplar, Red Maple-Sweet Birch, and Red Maple-Northern Red Oak types were omitted. The Yellow-Poplar, Red Maple-Sweet Birch and Red Maple-Northern Red Oak types are basically disturbance-related, and are less stable than most of the other types.

The delineation of a type in the diagram was intended to show the position of the bulk of the type samples. No attempt was made to portray types as occurring exclusively in any portion of the site-elevation continuum, so type delineations were overlapped wherever a significant number of samples overlapped. This is in recognition that for most of the sites as defined in this diagram, there are alternative forest types which may occur. The strongest overlaps appeared among the types having _Tsuga canadensis_ as a dominant or co-dominant. In the study area, _T. canadensis_ appears to be a species of very wide ecological amplitude, but it varies in its topographic site affinities with elevation.

Sixty-three percent of the Northern Red Oak plots occurred in the Thomas Ridge area. Although elevations in that area rise to slightly more than 1524 m (5000 ft), stands of _Picea rubens_ do not occur. The probable reason for this anomally is that advanced by Whittaker (1956), _viz._, during the xerothermic period (cf. altithermal, Flint, 1947)

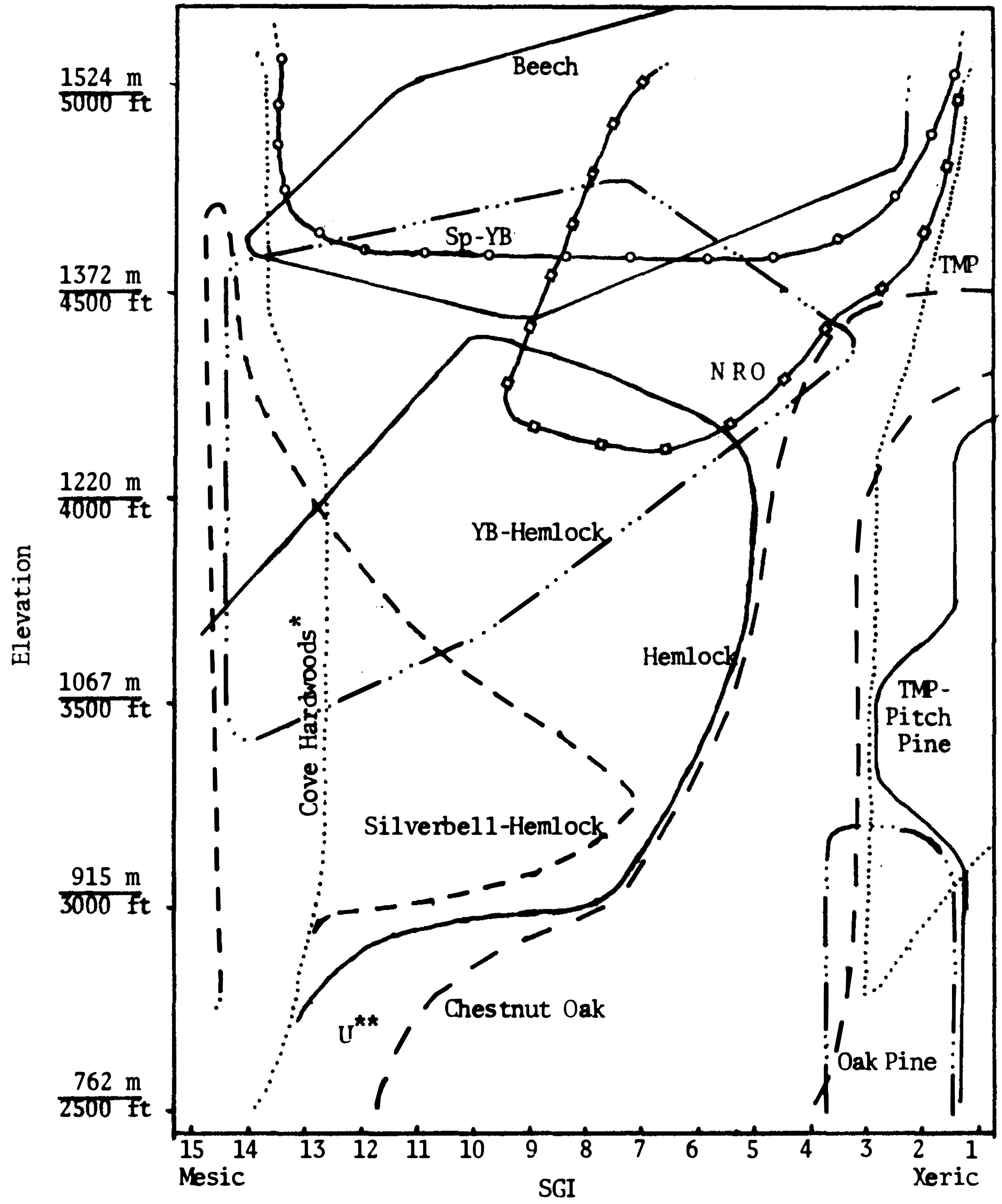


Figure 11. Composite diagram of major forest types in relation to elevation and site gradient index (SGI). Abbreviations: Sp=Spruce; YB=Yellow Birch; NRO=Northern Red Oak; TMP=Table-Mountain Pine.

*Buckeye, Basswood, Hemlock-Basswood and Sugar Maple types.

**U is lightly sampled area, with Yellow-Poplar and Red Maple-Sweet Birch types.

Picea rubens and other high elevation taxa were displaced upward to elevations exceeding 1700 m, thus disappearing from peaks not reaching that elevation. *Quercus rubra* and other taxa adaptable to the high elevations displaced *Picea rubens* and reinvasion by that species has not occurred (cf. Billings and Mark, 1957; Mark, 1958). Five of the seven Northern Red Oak plots in the Mt. LeConte-Greenbrier area were at elevations below 1310 m (4300 ft). Basically then, the Northern Red Oak type location higher than 1310 m applies primarily to the Thomas Ridge area. The Spruce-Yellow Birch type typically dominates these sites in the Mt. LeConte-Greenbrier area.

The Buckeye, Hemlock-Buckeye, Basswood, and Sugar Maple types overlapped so thoroughly (see Figure 10, page 217) that no attempt was made to separate them. They were designated "cove hardwoods." Three Sugar Maple type samples found in the Thomas Ridge area were disjunct in position from the other eight plots, occurring in the SGI range 4 to 7 and at elevations 1350 to 1450 m. This suggests that *Acer saccharum* may occur as a replacement or alternative for *Picea rubens* on some high elevation north-facing slopes where *A. saccharum* seed are available and those of *P. rubens* are not.

Because of the absence of *Picea rubens* and *Abies fraseri*, the vegetation pattern at higher elevations of the Thomas Ridge area is quite different from the area on the north side of the central Smokies. A separate thorough study of the Thomas Ridge area (and perhaps a large area contiguous with it) would be necessary to adequately describe it. When data from both areas are combined, some important differences between the vegetation of the two areas may be obscured.

The Buckeye type also overlapped with the other cove hardwood types at elevations 915 m to about 1300 m. It is generally more restricted to cove bottoms at these elevations than were the other cove types. At higher elevations, the Buckeye type was predominant in north-facing coves but less restricted to them.

The pine types segregated only above elevations of about 1060 m. Above that, the Table-Mountain Pine-Pitch Pine type was more restricted to south-facing ridges, and the importance of *Pinus rigida* decreased, culminating in the dominance of *P. pungens* at elevations above 1300 m. Oak-pine stands were common on upper slopes below pine-dominated ridges at elevations below 1000 m. They were primarily ecotonal between the pine forests of the ridges and xeric upper slopes and the Chestnut Oak forests of the slopes.

Several soil and vegetation characteristics were plotted on the composite site diagram to see if patterns of occurrence were discernible.

Umbrept and Umbric Dystrochrept soils showed an interesting pattern (Figure 12). These are soils with thicker dark epipedons than those of the Typic Dystrochrepts (Soil Survey Staff, 1970). They were rare or absent at more xeric, lower elevation sites of the diagram, but somewhat common at mesic sites and at higher elevation. Wolfe (1967) reported that Umbric Dystrochrepts comprised the majority of soils he sampled at higher elevations.

Lithic Dystrochrepts have thinner or lighter epipedons than Umbrepts or Umbric Dystrochrepts, and are shallower (less than 50 cm) than Typic Dystrochrepts (Soil Survey Staff, 1970). Although somewhat scattered over the diagram (Figure 13), Lithic Dystrochrepts were common at upper slope positions and on ridges. There was a general tendency for steep soils to be shallow because of instability and less infiltration of surface water. Many of the Lithic soils were on very steep slopes, which were scattered, but more common at higher elevations and less common at lower slope positions.

Other sample characteristics were plotted as forest type means. This was to simplify the mass of numbers and somewhat obscured pattern which resulted when each individual value was plotted. Because of the small number and unclear status of the three Basswood plots, their mean was omitted. Three of the Sugar Maple plots which were in the Thomas Ridge area and disjunct from the Sugar Maple plots located elsewhere (see Figure 10, page 217) were omitted from the means of that

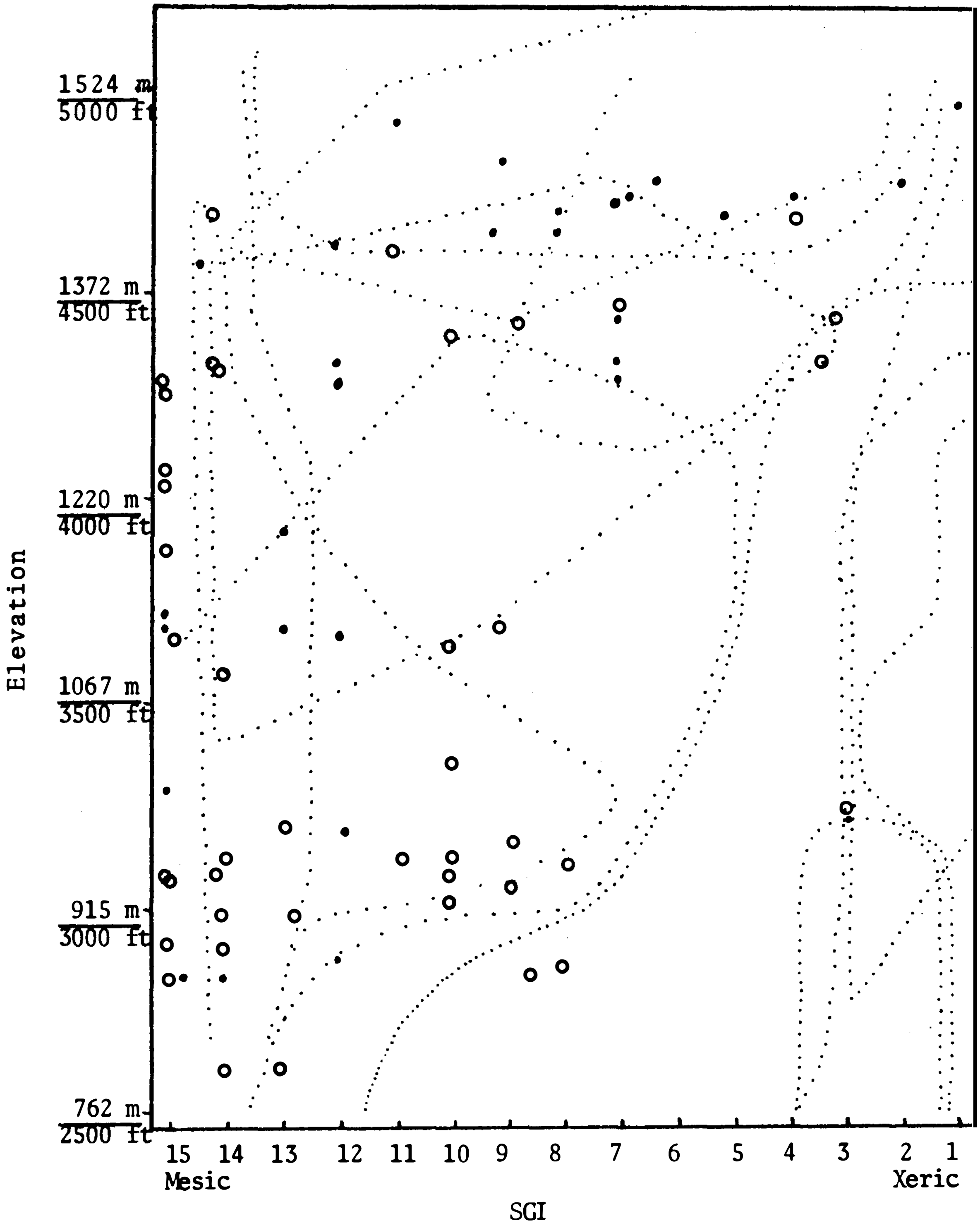


Figure 12. Umbrept (o) and Umbric Dystrochrept (•) soils plotted on axes of elevation and SGI (site gradient index).

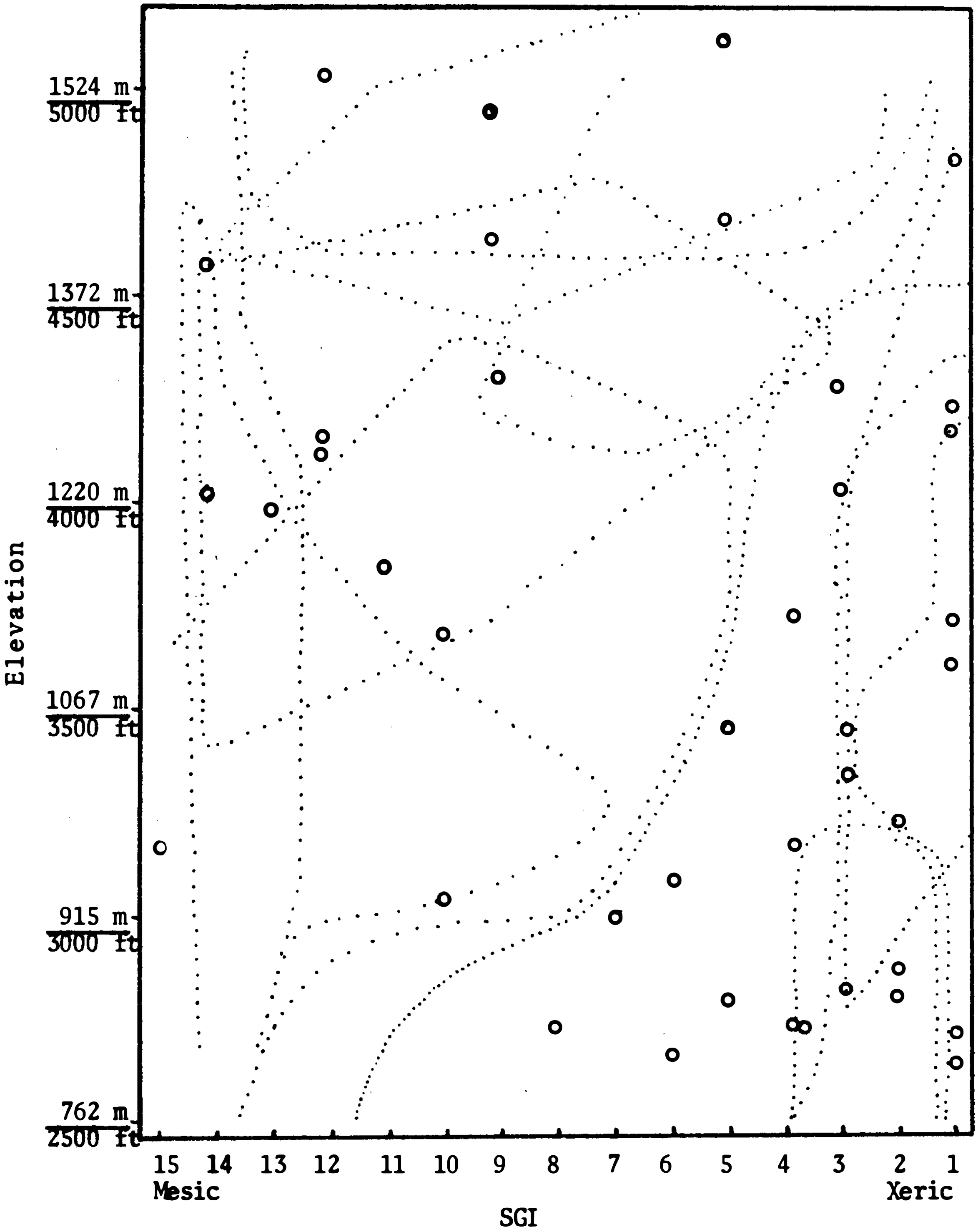


Figure 13. Lithic Dystrochrept soils plotted on axes of elevation and SGI (site gradient index).

type. Each type mean was positioned at the intersection of the elevation-SGI means for that type.

Percent clay content of the B horizon (Figure 14) showed a general decrease at the mesic side of the diagram, a marked increase at the xeric side. This is a reflection of the earlier discussed relationship between clay in the B horizon and the SGI, and similar to results from studies at the southern Blue Ridge escarpment (Losche, 1967; Mowbray and Oosting, 1968).

Some patterns were discernible when vegetation characteristics were plotted, but were frequently somewhat modified by other factors. For example, the Spruce-Yellow Birch and Yellow Birch-Hemlock types commonly differed markedly in means of vegetation characteristics from the Beech and Northern Red Oak types, although all four type means were positioned in the same area of the diagram. This was probably because of the prominence of coniferous trees and heavy heath shrub layer of the two former types, contrasting with the deciduous trees and thin shrub cover of the latter two. Such differences appeared when mean total vascular taxa (Figure 15), mean shrub cover (Figure 16) and mean tree sapling densities (Figure 17) were plotted. On mesic sites, heavy shrub cover depressed sapling densities, whereas the open canopies of stands on xeric sites allowed sufficient light for dense sapling survival in spite of

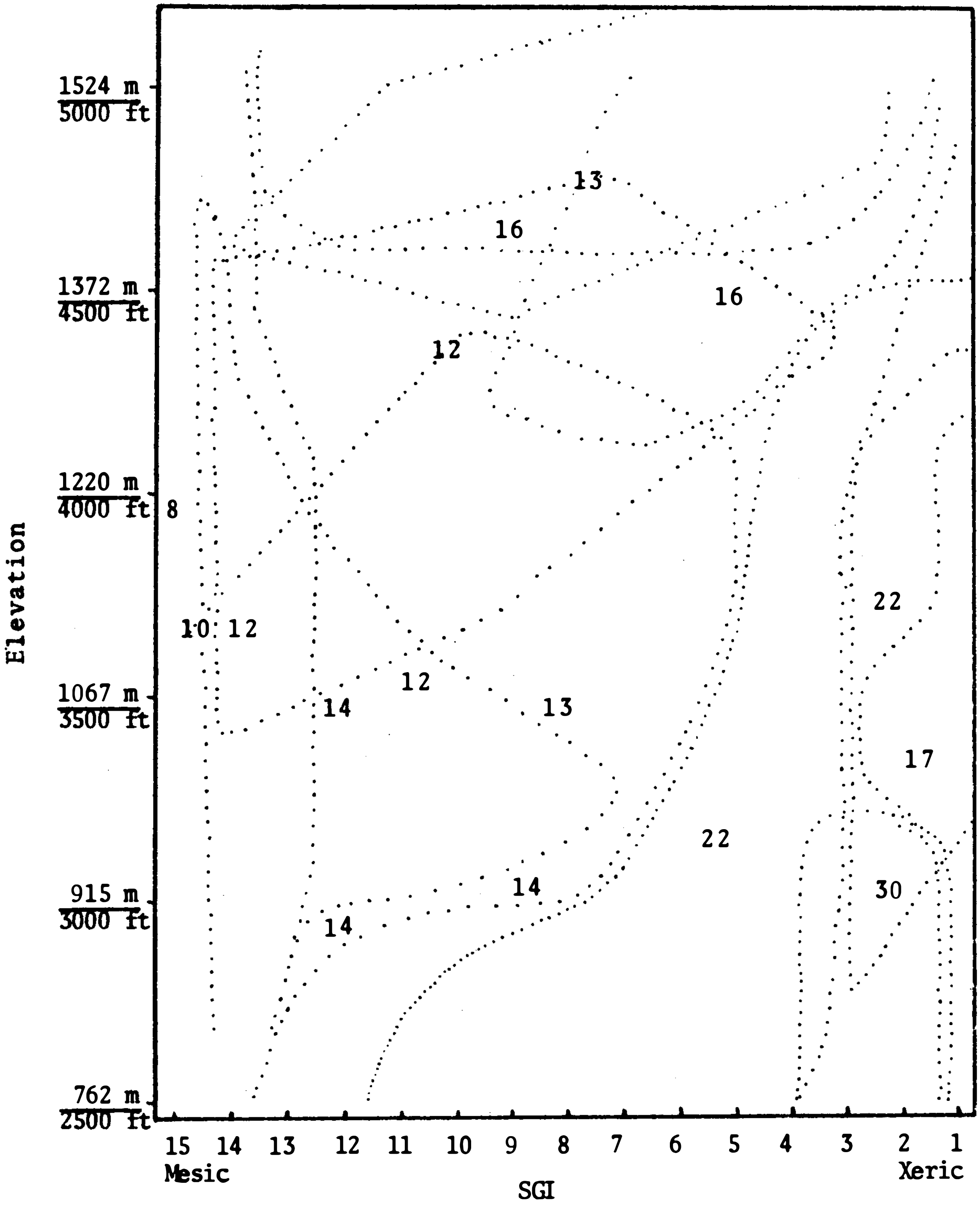


Figure 14. Mean percent clay in the B horizon of soils of 16 forest types plotted on axes of elevation and SGI (site gradient index).

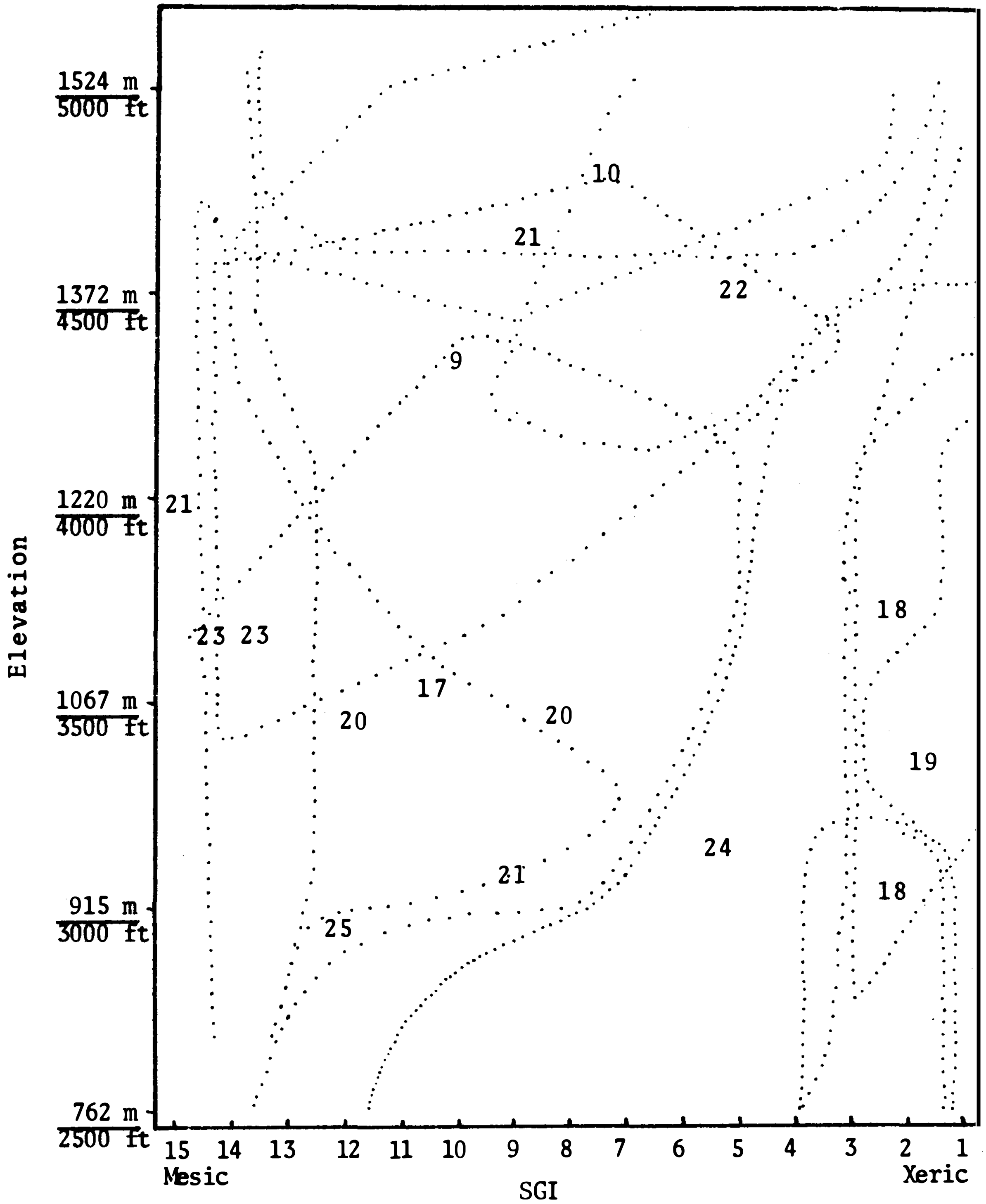


Figure 15. Mean total vascular taxa of 16 forest types plotted on axes of elevation and SGI (site gradient index).

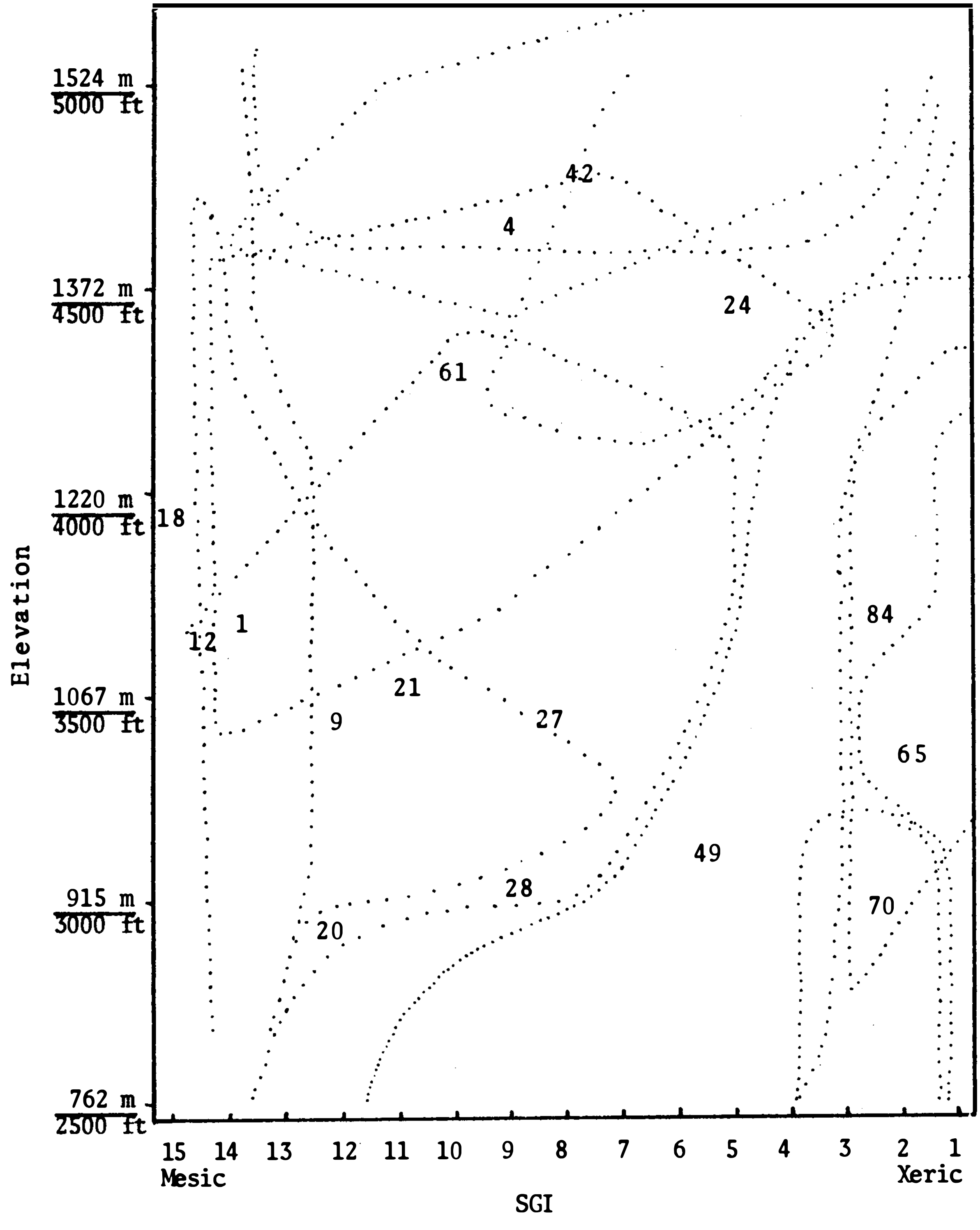


Figure 16. Mean percent shrub cover of 16 forest types plotted on axes of elevation and SGI (site gradient index).

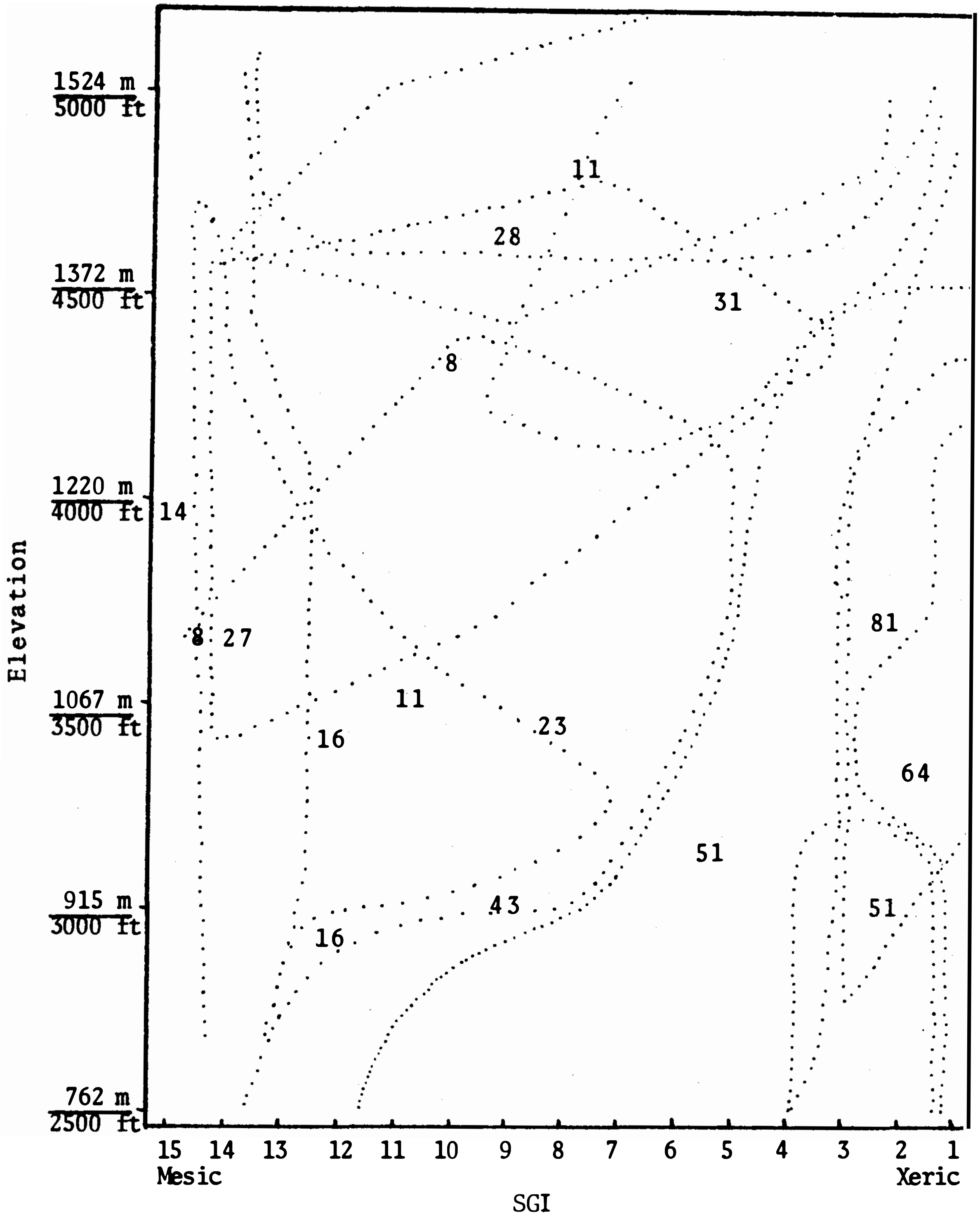


Figure 17. Mean tree sapling (2.5 - 12.7 cm dbh) densities (stems/0.04 ha sample) of 16 forest types plotted on axes of elevation and SGI (site gradient index).

typical heavy shrub cover.

The rigorous environment of the xeric sites resulted in smaller trees, thus low canopy basal areas (Figure 18). However, recent stand perturbation also could result in a predominance of smaller trees, and doubtless affected the basal areas of those types with past chestnut death, fire, or windthrow.

Discussion

The forest types were originally named by considering only the vegetation, without regard to soil and site conditions. This approach assumes that the best measurement of soil-site conditions affecting vegetation is found in using the vegetation itself as an indicator of those conditions (Hodgkins, 1961; Goodall, 1970; Spurr and Barnes, 1973). An important limitation to this approach lies in the reality that plant species have widely differing ecological amplitudes or tolerances, thus having variable value as indicators. Ideally, when criterion species are those with narrow ecological amplitudes, the correlation between species groupings and critical environmental factors may be high. The greatest problem lies in selecting the indicator species or group of species. This is greatly complicated by the fact that certain species vary somewhat in their environmental relationships in different parts of their range, or may change in indicator value when in competition with particular species

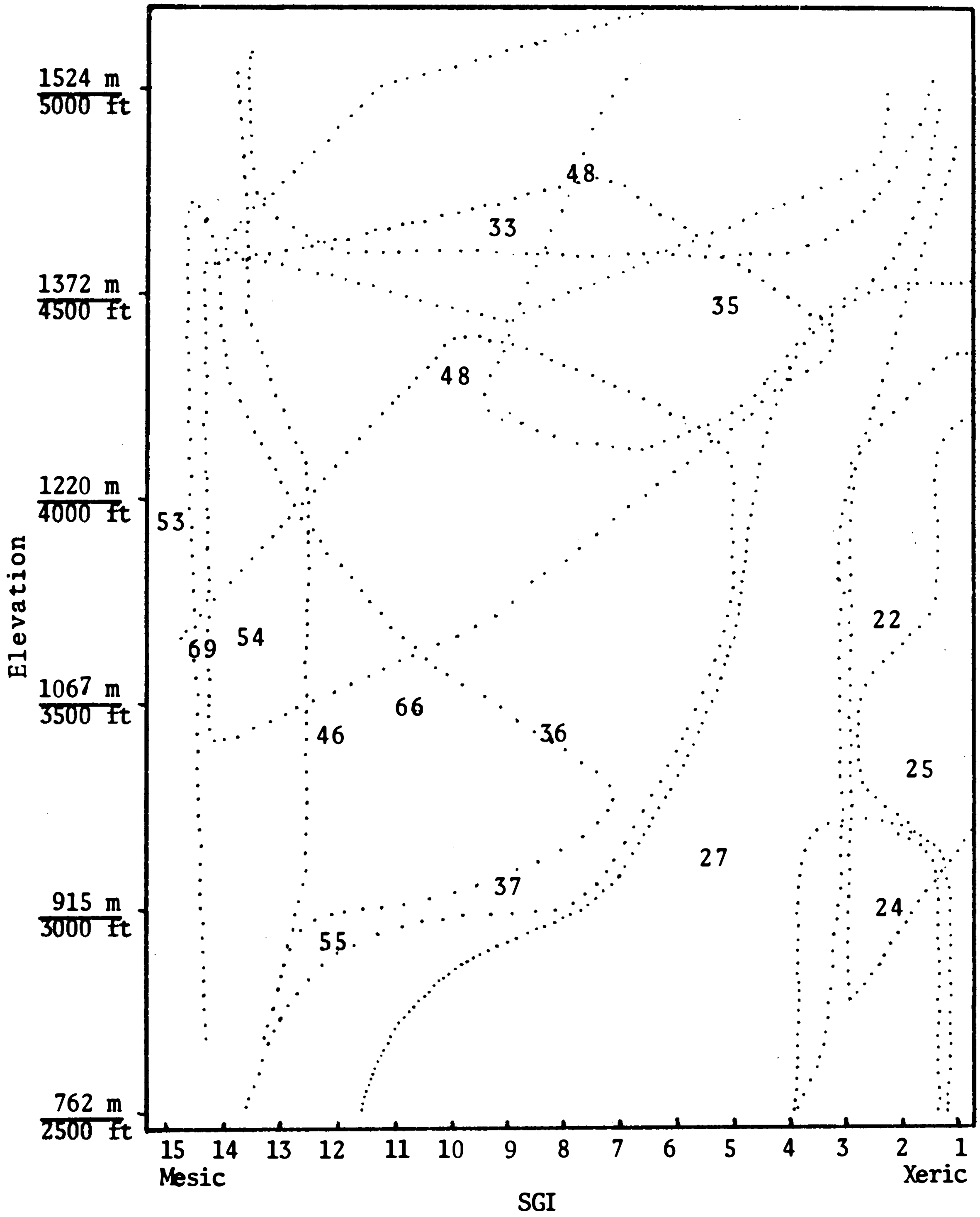


Figure 18. Mean canopy basal area (m^2/ha) of 16 forest types plotted on axes of elevation and SGI (site gradient index).

(Goodall, 1970). Genetic variation within a population also can result in diminishing the value of a species as an indicator (Whittaker, 1956).

In this study, the use of all overstory taxa occurring in 5% of the samples as attributes for comparison involved no assumptions regarding differences in species indicator value. The samples were grouped based on overall similarity in overstory importance values. Admittedly, this resulted in species with low indicator value being given the same weight as those with high indicator value, and probably resulted in poorer type--environment correlations than would be the case if only the "good" indicator species were used. Uncertainty about which were the good indicator species precluded the preferable method.

It should be recognized that the agglomerative clustering procedure used in this study resulted in some differences in groupings of samples from those which would be made if only the predominant one or two species were used as criteria for grouping (cf. Society of American Foresters, 1964). In most cases, plots of the same type had the same leading dominants, but exceptions occurred.

One major purpose for using this approach to grouping samples as representative of types was to base these groups on similarity of the total canopy composition, rather than only on the one or two most predominant taxa, with disregard for the others. This recognized the possibility of two samples which have the same leading dominants, but are very different as regards the importance of associated taxa. As an example, several of the Silverbell-Hemlock and Yellow Birch-Hemlock samples would probably have been included in Hemlock type if the leading dominant only was used as the criterion. However, the total canopy composition of these samples was most similar to other stands which had either *Halesia carolina* or *Betula alleghaniensis* as a strong co-dominant.

The agglomerative procedure used in this study theoretically treats vegetation samples as part of a universe which is definable in multidimensional space or hyperspace. Whether the clusters which are defined are part of multidimensional continue or are discrete and separate does not have to be presumed. The procedure simply begins with those samples that are closest in multidimensional space (and thus most similar based on the values of specific variates--in this case, the importance values of 26 tree taxa), then adds the next closest samples to these, each time calculating the average dispersion (variation within) of the resulting groups. The decision as to which groups of samples are to be called representatives of types lies with those who interpret the information supplied in the procedure.

The resulting classification is hierarchical, thus permitting groupings of samples at any level, or on more than one level. For the types to be (theoretically) at the same level in the hierarchy, they are all at the same dispersion level, which was subjectively chosen as 40%. Other levels could be chosen, alternatively or in addition. If a lower level had been chosen, more types would have resulted, and fewer at a higher level.

It was noted earlier that two of the three plots typed as Basswood were thought best included with the Hemlock-Buckeye type. An examination of the dendrogram (Figure 2, page 87) showed that these two types combine at a dispersion level of 41%, barely above the criterion level used.

This example serves to point out the place that chance can play in this particular method. If the third sample of the Basswood group (discussed earlier, page107) had not been included in the analysis, the other two probably would have been combined with the Hemlock-Buckeye group at a lower dispersion level. The "odd" sample was more similar to the other two Basswood samples than to any other and when combined with them resulted in a dispersion at 26%. Without the odd sample clustered with them, the other two plots would likely have been combined with the Hemlock-Buckeye group sooner and at a lower level of dispersion, thus resulting in their being part of the Hemlock-Buckeye type.

The question of whether or which groups might be split or combined to be most ecologically meaningful is one subject to varied opinions. The most obvious example in the types described here is in the Beech type. The gap or orchard plots clearly could be split from those occurring on broad, protected flats. Both were characterized by very strong dominance of *Fagus grandifolia* and even some of the same associated taxa, but the different habitats and the different appearance of the two sub-group or sub-types make a strong case for ecologically meaningful distinction. Other examples are certainly possible among the other types.

In the other direction, several of the types distinguished here have by others been considered simply as part of the cove hardwood forest, without any segregation of less inclusive classes (Shanks, 1954; Whittaker, 1956). The dendrogram (Figure 2, page 87) shows a combination of the Silverbell-Hemlock, Beech, Buckeye, Sugar Maple, Hemlock-Buckeye and Basswood types at a dispersion of 72%. The canonical analysis (Figure 3, page 91) showed these same types to occupy some of the same canonical space. This seems to be roughly equivalent to the broader interpretation of the cove hardwoods. Braun (1950) probably would have included these in mixed mesophytic communities or as association segregates of the Mixed Mesophytic Association. Cain (1943) termed types similar to these as segregates of the cove hardwood forest complex, in which he also included stands dominated strongly by Tsuga canadensis.

Table 44 presents a summary comparison of the types of this study with those of Cain (1937, 1943) and Whittaker (1956). Types that appeared to be very similar or equivalent were placed on the same line. The types recognized by Shanks (1954b) were quite general, and to some degree derived from those of Cain and Whittaker, so they were omitted. Cain (1937) included data and detailed descriptions for only seven of the types listed in Table 44: Yellow Poplar-Old Field, Buckeye-Basswood, Mixed Cove Hardwoods, Hemlock Ridge, Red Spruce, Beech and Pine-Heath. He included data (1943) for the cove hardwood forest complex combined into two alliances, making interpretation of individual types difficult.

Seven types of this study (those above the dashed line in Table 44) fell into the general category cove hardwoods as described by the earlier investigators. The Silverbell-Hemlock type was not recognized by Cain (1937, 1943), and no Hemlock-Yellow-Poplar or Hemlock-Beech types were distinguished using the data and methods of this study. The Mixed Cove Hardwoods of Cain (1937), with Tsuga

Table 44. Comparison of Forest Types with Those of Two Earlier Studies, Great Smoky Mountains National Park

This Study	Cain (1937, 1943)	Whittaker (1956)
Yellow-Poplar	Yellow-Pop[a] Old Field	
Sugar Maple	SM-Silverbell	
Buckeye	Buckeye-Basswood	
Basswood		
Hemlock-Buckeye	Mixed Cove Hardwoods	Cove Hardwoods
	Hem-Yellow-Poplar	
Silverbell-Hemlock		
	Hemlock-Beech	
- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -[b]
Hemlock	Hemlock Ridge	Hemlock
Yellow Birch-Hem	Yellow Birch-Rhod	
Spruce-Yellow Birch	Red Spruce	Red Spruce
Beech	Beech	Gray Beech
Northern Red Oak	Oak Ridge	Red Oak-Chestnut
Red Maple-NRO	Oak-Chestnut	
RM-Sweet Birch		
	CO-Yellow-Poplar	
Chestnut Oak	Chestnut Oak	CO-Chestnut
		CO-Chestnut Heath
Oak-Pine	Oak-Pine	
TMP-Pitch Pine	Pine Heath	Pitch Pine Heath
Table-Mountain Pine		TMP Heath

[a] Abbreviated type names: Yellow-Pop=Yellow-Poplar; SM=Sugar Maple; Hem=Hemlock; Rhod=Rhododendron; NRO=Northern Red Oak; CO=Chestnut Oak; TMP=Table-Mountain Pine.

[b] The types above the dashed line are part of the cove hardwoods.

canadensis, Aesculus octandra and Acer saccharum the most prominent canopy taxa, is the most similar to the Hemlock-Buckeye type of this study.

The pattern of types described in canonical space by the canonical analysis (Figure 3, page 91) and the hierarchical classification pattern displayed in the dendrogram of the agglomerative procedure (Figure 2, page 87) are quite similar, the clustering of the cove hardwood types in the canonical analysis (CA) corresponds somewhat to the same types (excepting Yellow-Poplar) fusing in the central part of the dendrogram. The CA, however, better portrays the relationship of the Yellow-Poplar type to the other cove hardwoods, while at the same time describing a proximity to the other disturbance types, Red Maple-Sweet Birch and Red Maple-Northern Red Oak. The dendrogram emphasized the relationship of the Yellow-Poplar type to the other disturbance types, but obscured its similarity to the cove hardwood types.

The Yellow Birch-Hemlock and Spruce-Yellow Birch types of this study and the Yellow Birch-Rhododendron and Red Spruce types of Cain appear to be slightly differing interpretations of very similar species gradiants. Above the upper elevation limit of this study (1646 m), Picea rubens becomes dominant over much of the mountain slopes and ridges. The Spruce-Yellow Birch type represents a somewhat transitional type between the Yellow Birch-Hemlock type, occurring at slightly lower elevations on slopes and sheltered ridges, and the Spruce type of Cain and Whittaker, occurring on more exposed ridges and on slopes of higher elevations.

The Yellow Birch-Hemlock type of this study and the Yellow Birch-Rhododendron type are probably very similar, but no data are available from Cain's study for direct comparison. The Yellow Birch-Hemlock type was characterized by a heavy shrub layer averaging more than 60% coverage, dominated by *Rhododendron maximum* and/or *R. catawbiense*.

It is not clear how the Oak Ridge and Oak-Chestnut types of Cain (1937) are related to the oak types of this study or those of Whittaker (1956). Cain did not specify which oak species were dominant. *Castanea dentata* occurred with both *Quercus rubra* and *Q. prinus*, as was indicated in the type names and descriptions of Whittaker.

The differences between the types of this study and those of Cain (1937, 1943) and Whittaker (1956) may be partly because of differences in the nature of the investigations. Cain's were apparently limited to a part of the Greenbrier Cove--Brushy Mountain area and his analyses were based on simple frequency and basal area. Whittaker (1956) on the other hand, stated that his "composite transects were designed to form a grid covering the whole of the vegetation pattern of the Great Smoky Mountains." He explained that the "bulk of the site samples were obtained from the mountains surrounding Greenbrier, Sugarland, and Cades Cove on the Tennessee side." Thus his study encompassed a much larger area of the Smokies, including samples as much as 48 km (30 miles) away from the area of this study. Also, his analyses were based on relative stem densities of all stems greater than 2.5 cm (1 inch) dbh (but excluding *Rhododendron maximum*). Importance values (relative density plus relative basal area) of only stems greater than 12.7 cm dbh were used in the clustering procedure of this study.

The removal of *Castanea dentata* by the chestnut blight had a very strong influence on a number of the types described here and may have contributed to some of the type differences between this and previous studies. Evidence of former chestnut occurrence (stumps, logs, sprouts) was found in 12 types, and in 100%, 100%, 86% and 98% of the Northern Red Oak, Red Maple-Sweet Birch, Red Maple-Northern Red Oak and Chestnut Oak sample plots, respectively. Woods and Shanks (1959) found *Quercus prinus*, *Q. rubra* and *Acer rubrum* to be the three most abundant taxa replacing chestnut in the Smokies. This apparently was true among the plots of this study also.

Picea rubens, which is a major dominant on slopes and ridges in the Mt. LeConte and stateline ridge areas (northeast of Double Springs Gap) does not occur in the Thomas Divide area, although Thomas Ridge actually connects with the stateline ridge near Indian Gap and reaches elevations above 1500 m. The major replacing species for *Picea rubens* in the Thomas Ridge area is *Quercus rubra*. Although Whittaker (1956) found that *Q. alba* was also an important replacement species south of Double Springs Gap, *Q. alba* was not encountered anywhere in the present study above 640 m (2100 ft) elevation, except as seedlings in one Chestnut Oak plot.

The vegetation pattern in the Central Smokies seems to be most easily and directly related to elevation and topography (including aspect). This was demonstrated by Whittaker (1956) and was reinforced in this study by the effective use of axes quite similar to the mosaic chart of Whittaker. The abscissas of the two diagrams were both based on topography, but were quite different in derivation and description. It is somewhat difficult to relate Whittaker's moisture gradient to quantitative site data (slope position, slope angle, slope aspect) since it was defined only by descriptive terms. Forty percent of Whittaker's gradient (on the mesic side) was categorized as "coves, canyons, flats, ravines, draws" in that order. The remaining 60% of the gradient was composed of three equal categories, "sheltered slopes, open slopes (divided by aspect), ridges and peaks." No definition of these categories was given.

The topographic site gradient derived and used in this study was the result of an attempt to quantitatively define a vegetation-related gradient of topographic conditions. Slope position, slope aspect and slope angle were integrated and related to the importance values of specific (arbitrarily-chosen) tree taxa having high to low importance along the moisture gradient. A specific stand or sample plot can be fairly definitely placed on the resulting axis using three measurements: slope position (as percent distance from the ridgetop to the valley bottom), slope azimuth and slope angle (percent). The slope azimuth and angle determine the amount of potential solar irradiation, then the appropriate point along the gradient (SGI) can be determined from the detailed axis description (Figure 7, page 210).

Perhaps the most striking difference between the vegetation pattern shown by Whittaker (1956) and that of this study is the much greater prominence of Tsuga canadensis in this study. Whittaker showed only a narrow band termed "Hemlock Forest" occurring in flats at lower elevations and moving onto some of the sheltered slopes at higher elevation. Types with Tsuga canadensis as a dominant or co-dominant occupy a very large part of the pattern diagram presented here (Figure 11, page 220).

Probably the xeric half of the site gradient is somewhat compressed. Most of the sample plots were from the northwest side of the Smokies. Area-wise, a much larger portion of the slopes in the area are northerly than southerly in aspect.

VI. SUMMARY AND CONCLUSIONS

This study involved the analysis of data from 266 sample locations at elevations ranging from 759 to 1585 m in the central Great Smoky Mountains National Park. At each location, vegetation of canopy (>12.7 cm dbh), sapling (2.5 - 12.7 cm dbh) and seedling-shrub-herb strata (less than 2.5 cm dbh) were inventoried in concentric circular plots of 0.08, 0.04 and 0.004 ha, respectively. Other vegetation data included were estimates of areal coverage of the canopy, shrub, and herb strata and evidence of American chestnut (*Castanea dentata*) occurrence. Basal areas, stem densities, relative basal areas, relative densities, importance values and diameter distributions were calculated for each taxon in each sample by computer. Site and soil data taken included elevation, slope angle, surface rock coverage, slope shape, soil depth (only to 50 cm), a soil profile description, stone volume (of soil pit), litter thickness and coverage. Soil samples were analyzed for color, pH, available phosphorus and potassium, and texture. Macrotopographic and microtopographic position and estimated direct topographic shading by surrounding ridges were determined using topographic maps. Potential annual direct solar beam irradiation was determined for each plot (based on latitude, slope angle and slope azimuth) from the tables of Frank and Lee (1966).

Slope angles of sample locations varied from 5% to 85%, with an overall mean of 36%. Potential annual solar irradiation varied from 124,000 to 332,000 Langleys. Average daily topographic shading (sum of mean morning and afternoon shading) during the growing season ranged as high as 4.3 hours. Significant correlations among site characteristics included elevation with slope angle; mean morning, afternoon and total topographic shading with microtopographic position; and elevation with both macro- and microtopographic position (negative, because the position value increases toward lower slope positions).

The 266 sample soils were tentatively classified as: Typic Dystrochrepts, 51%; Lithic Dystrochrepts, 14%; Typic Haplumbrepts, 15%; Umbric Dystrochrepts, 10%; Lithic Histosols, 4%; Lithic Umbric Dystrochrepts, 3%; Fragmental, 2%; and Lithic Umbrepts, 1%. Only one sample soil was classified as an Ultisol, a Lithic Hapludult profile at 850 m elevation. Twenty-one percent of the sample soils had total solum depths less than 50 cm. These occurred primarily on ridges, upper slopes, or in small coves or valleys filled with colluvial boulders. Most of the small coves and valleys at middle to higher elevations had soils formed in colluvium, and frequently had abundant surface rock. Mineral soil colors tended to be darker and of lower color saturation on mesic than on xeric sites. Most of the mineral soil horizons (both A and B) had Munsell color hues (moist) of 2.5Y or 10YR. No noticeable trends in hue were detected with change in elevation or vegetation type. O horizons were typically 2 - 5 cm thick, and the few sites with organic horizons thicker than 8 cm were at higher elevations and under forest stands dominated by *Tsuga canadensis*, *Betula alleghaniensis* or *Picea rubens* which had thick shrub strata of *Rhododendron maximum* or *R. catawbiense*. The large majority of soil textures of both A and B horizons were loams, silt loams or sandy loams. Water pH of the A horizon ranged from 3.8 to 5.9, and was weakly negatively correlated with elevation.

Significant correlations among soil characteristics indicated that available phosphorus and potassium, total available water, and thickness of the A horizon increased with increased soil depth, while rock cover and stone volume decreased. Total available water also increased with increasing clay content of the B horizon and decreased with increasing rock cover. Total available potassium (top 50 cm) increased with increasing clay in the B, thickness of the A, and pH of the A.

Site with soil correlations indicated that clay in the A and B horizons, thickness of the A horizon, available potassium (top 50 cm), and available water-holding capacity decreased with increasing elevation, while stone volume increased. Clay in the B horizon increased with increasing potential annual solar irradiation and decreased with increasing proximity to cove bottoms and with increasing topographic shading. Rock cover increased and litter thickness decreased with increasing proximity to cove bottoms.

The relationships of clay content of the B horizon seemed to somewhat parallel the results of a previous study in the Southern Appalachians by Losche (1967). It was generally higher on warmer and more open sites. The highest average B horizon clay contents were in the lower elevation pine and Chestnut Oak plots and was lowest in the cove types.

Seventy-one woody taxa occurred in sample plots, 45 of these as stems >12.7 cm dbh. The canopy stem densities ranged from 161 to 1173 stems/ha (65 to 475 stems/acre). They were highest in pine types and lowest in the Hemlock-Buckeye, Yellow Birch-Hemlock and Buckeye types. Canopy basal areas ranged from 7.6 to 116 m^2/ha (33 to 507 ft^2/acre) and were highest in mesic stands with _Tsuga canadensis_ as a dominant.

Evidence of past fire occurrence was observed in 15% of the plots and were most common in the Chestnut Oak, Northern Red Oak and pine types. Evidence of past cutting was observed in 2% of the plots, although several of the Yellow-Poplar and Red Maple-Sweet Birch plots appeared to have been cultivated in the past. Evidence of the occurrence of *Castanea dentata* was noted in 34% of the samples and was most common in the Chestnut Oak, Northern Red Oak, Red Maple-Northern Red Oak and Red Maple-Sweet Birch types. Living *C. dentata* sprouts occurred in 9% of the plots.

The highest number of significant vegetation - soil correlations occurred with clay content of the A and B horizons and with pH_w. All three of these were negatively correlated with canopy basal areas and positively correlated with understory (2.5 - 12.7 cm dbh) density and with total stem density (>2.5 cm dbh). Percent tree coverage was negatively correlated with clay content of both the A and B horizons. The total number of woody taxa (>2.5 cm dbh) was negatively correlated with stone content and positively correlated with pH_w, total available potassium (top 50 cm), and clay in the A horizon. Basal areas of individual tree taxa were most frequently correlated with clay in the B horizon and with pH.

Most of the general vegetation characteristics were significantly correlated with microtopographic position. Correlations indicated that stem densities (canopy, understory and total) and shrub cover decreased with lower slope positions, while tree cover, canopy basal area and herb cover increased. Understory and total stem densities and total woody taxa (>2.5 cm dbh) increased with increased potential solar irradiation, while tree cover and canopy basal areas decreased. Canopy and total densities decreased with increased topographic shading. Basal areas of several mesic taxa increased with lower slope position and aspects approaching NE. They tended to decrease with increasing potential irradiation. Xeric taxa showed the opposite trends.

Canopy sample plots were grouped into forest types (based on taxa importance values) with the aid of the agglomerative minimum dispersion clustering procedure suggested by Orloci (1967). Fourteen types resulted from separating groups at the 40% dispersion level. The fourteen types were named according to the one or two taxa with the highest average importance values. The types were: Spruce-Yellow Birch, Yellow Birch-Hemlock, Hemlock, Silverbell-Hemlock, Beech, Buckeye, Sugar Maple, Hemlock-Buckeye, Basswood, Northern Red Oak, Red Maple-Sweet Birch, Red Maple-Northern Red Oak, Yellow-Poplar and Chestnut Oak. Twenty pine-dominated plots omitted from the clustering procedure because of computer storage limitations were grouped into three types: Oak-Pine, Table-Mountain Pine-Pitch Pine and Table-Mountain Pine.

The computer-based clustering procedure used here provided a rapid, easily-useable method to group a large number of forest sample plots into types. Besides speed, one advantage of this and similar methods is the capability of classifying communities using comparisons of a large number of community attributes (importance values of 26 canopy taxa were used here).

The discreteness of the plot groups (types) were tested by canonical analysis. A definite grouping and overlapping of types occurred among mesic types (Hemlock, Silverbell-Hemlock, Hemlock-Buckeye, Buckeye, Beech, Basswood, Sugar Maple, and Yellow-Poplar). Vegetation, site and soil characteristics of the 17 forest types were described.

The Buckeye, Hemlock-Buckeye, Basswood and Sugar Maple types may be considered segregates of the cove hardwoods. Beech plots occurring in flats (gently sloping lower slopes or terraces of larger valleys) can also be included, as well as some of the Silverbell-Hemlock plots occurring on lower slopes and in coves. One old-growth Yellow-Poplar plot appeared to fit among the cove hardwoods. The other Yellow-Poplar plots were on mesic sites, but were successional on old fields. This interpretation of the cove hardwoods was supported by the canonical analysis and by the relationships among types in the clustering dendrogram.

The cove hardwood types had certain differences among their site and soil characteristics. The Buckeye type occurred almost exclusively in cove bottoms with medium to low surface rock cover. It was the most common segregate in the cove bottoms above 1200 m elevation. The Hemlock-Buckeye type was uncommon above 1200 m elevation and did not occur higher than 1380 m. It occupied sites topographically similar to Buckeye, but differed primarily in that sites had higher amounts of colluvial rock. Two of the three Basswood sample sites were very similar to the Hemlock-Buckeye sites and perhaps should be included with them. The third sample did not fit compositionally with any one of the cove hardwood segregates, but was on a cove site and had a mixture of cove hardwood taxa. The Sugar Maple type was less restricted to coves than the Buckeye, Hemlock-Buckeye or Basswood types, and had significantly less colluvial rock. Some plots of this type occurred at upper north slope positions at high elevations in the Thomas Ridge area. Plots of the Silverbell-Hemlock type rarely occurred in cove bottoms, although they were quite common at lower slope positions. Stands of this type were common on north-facing convex slopes on the north side of Mt. LeConte at elevations 920-1060 m. Frequent canopy associates on these sites were *Magnolia fraseri*, *Acer saccharum* and *A. rubrum*.

Tsuga canadensis was a very important and widespread canopy dominant in this area on most mesic slopes at middle elevations. It was a co-dominant in some of the cove hardwood stands (chiefly Hemlock-Buckeye and Silverbell-Hemlock) but reached its greatest importance on protected and north-facing slopes at elevations 915 - 1300 m. At higher elevations it was an important dominant on more xeric and exposed sites and was less common in coves. It was co-dominant more frequently with *Betula alleghaniensis* with increased elevation, and samples of the Yellow Birch-Hemlock type occurred even on protected ridges. Although the Hemlock plots could be separated into those with and without a heavy *Rhododendron maximum* shrub stratum, no consistent site differences occurred between these subtypes except that soil pH's were generally lower in the Hemlock-*Rhododendron* plots. The Hemlock type had *R. maximum* understories more frequently than did the Silverbell-Hemlock type, but less frequently than the Yellow Birch-Hemlock type.

The Yellow Birch-Hemlock type differed from the Hemlock type primarily in its occurrence at predominantly higher elevations and in being absent in coves. Shrub cover was high more consistently. The stands with abundant *Tsuga canadensis* formed a continuum on mesic slopes which varied with elevation. *Betula alleghaniensis* became more important with increased elevation and *Halesia carolina* became less so. At higher elevations the continuum continued into the Spruce-Yellow Birch type.

In most cases the Oak-Pine type appeared to be ecotonal between Chestnut Oak and pine stands. *Pinus* seedling establishment was poor, indicating that they may become Chestnut Oak stands with successional change, provided no disturbance occurs. The Table-Mountain Pine and Table-Mountain Pine-Pitch Pine types did not segregate by sites at lower elevations. *Pinus pungens* generally became more important at the higher elevations and the combination type did not occur above 1320 m.

Relative densities of tree taxa in the canopy, sapling and seedling strata were compared to judge the successional stability of the types. Types which had no evidence of past disturbance appeared to be relatively stable, although periodic reproduction apparently had occurred in some plots. These relatively stable types were: Buckeye, Hemlock-Buckeye, Sugar Maple, Silverbell-Hemlock, Hemlock, Yellow Birch-Hemlock, Beech, and Spruce-Yellow Birch. Since cut-over stands were generally avoided, most of the disturbance effects in sampled stands were due to the death of *Castanea dentata* or to occasional ground fires.

The virtual elimination of *Castanea dentata* (except for reoccurring sprouts which die before reaching canopy size) had very pronounced effects on forests of the Smokies. Evidence of former *Castanea dentata* occurrence was found in 12 types, and in 100%, 100%, 86% and 98% of the Northern Red Oak, Red Maple-Sweet Birch, Red Maple-Northern Red Oak, and Chestnut Oak sample plots, respectively. *Acer rubrum*, *Quercus prinus*, *Q. rubra* and *Oxydendrum arboreum* were the most common tree taxa which had replaced chestnut.

The Red Maple-Sweet Birch, Red Maple-Northern Red Oak and Yellow-Poplar types were primarily successional, strongly influenced by past disturbance. Red Maple-Sweet Birch and Red Maple-Northern Red Oak types were generally chestnut-replacement in nature, occurring on sites where *Castanea dentata* was once abundant. Plots of the Red Maple-Northern Red Oak type differed from the Red Maple-Sweet Birch type plots in the following ways: (1) most occurred on slightly less mesic sites; (2) *Q. rubra* was much more important and *B. lenta* was much less important; (3) climax composition was more varied but generally should include more *Q. rubra* than in the Red Maple-Sweet Birch type; and (4) some plots occurred at much higher elevations. The Yellow-Poplar type was primarily on lower elevation, lower slope sites which had a history of heavy cutting or past cultivation. The Yellow-Poplar type appeared to be successional to various cove hardwood types.

In the oak types, Chestnut Oak and Northern Red Oak, *Castanea dentata* was replaced primarily by *Acer rubrum* and by *Quercus* species. The Chestnut Oak type predominated on open slopes with south to west exposures at lower and middle elevations. The Northern Red Oak samples were primarily at elevations above 1250 m and most were in the Thomas Ridge area, where this type predominated on most slopes and large ridges above 1200 m. Although some continued changes in canopy composition appear likely in many stands, the dominants of these two types will maintain their dominance.

Pinus seedling establishment was poor in the Oak-Pine type, and it was hypothesized that with no further disturbance, most of these stands will ultimately resemble the more xeric stands of the Chestnut Oak type. Samples of the two pine dominated types (Table-Mountain Pine and Table-Mountain Pine-Pitch Pine) were inconsistent in their successional status. Most of the Table-Mountain Pine samples appeared to be basically self-maintaining, although pine reproduction was periodic and often in scattered patches. Some of the Table-Mountain Pine-Pitch Pine samples exhibited successional trends toward increases in *Acer rubrum*, *Nyssa sylvatica* and some of the oaks. Evidence of successional change was strongest at lower elevations and weaker with increased elevation.

A "topographic site gradient" was constructed based on combinations of potential solar irradiation classes (which were determined by aspect and slope angle) and microtopographic slope positions. Each position along this gradient was assigned a number, termed the "site gradient index" (SGI), which increased toward mesic sites. SGI was significantly correlated with a number of site, soil and vegetation characteristics. Correlations indicated that SGI increased toward coves, as aspect approached NE, with increased topographic shading, with increased canopy cover, with increased herb cover, with increased canopy basal area, and with increased basal area of *Aesculus octandra*, *Tilia heterophylla*, *Acer saccharum*, *Tsuga canadensis*, and *Halesia carolina*. It decreased with increased potential solar irradiation, clay in the B horizon, canopy stem density, shrub cover, and increased basal areas of *Pinus pungens*, *P. rigida*, *Quercus prinus* and *Q. coccinea*.

The samples of each forest type were plotted on axes of elevation and SGI. A composite diagram was made portraying the site-elevation pattern of most of the types on the SGI-elevation axes. Observable patterns were noted when the occurrences of Umbrepts, Umbric Dystrochrepts and Lithic Dystrochrepts were plotted on the site diagram. Other characteristics showing patterns on the diagram were: percent clay in the B horizon, total vascular taxa, percent shrub cover, tree sapling density, and canopy basal area.

The combined vegetation-site summary contained in the composite site diagram suggests that the Mt. LeConte area departs significantly in detail (if not in broad outline) from the mosaic chart of Whittaker. This suggests that further local studies are needed in the Park to further verify or redefine its outline and/or details.

The vegetation pattern in the Central Smokies seems to be most easily and directly related to elevation and topography (including aspect). Significant differences in soil characteristics occurred between some vegetation types, but appeared to be less consistent and to have less utility for direct relation to vegetation pattern than topographic differences.

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