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Evaluation of site quality of an upland hardwood forest at Scott County, Tennessee

Luis E. Rodriguez

To the Graduate Council:

I am submitting herewith a thesis written by Luis E. Rodriguez entitled "Evaluation of site quality of an upland hardwood forest at Scott County, Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Garland R. Wells, Major Professor

We have read this thesis and recommend its acceptance:

Frank W. Woods, John W. Barret

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Vice Provost and Dean of the Graduate School

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

August 24, 1973

To the Graduate Council:

I am submitting herewith a thesis written by Luis E. Rodriguez entitled "Evaluation of Site Quality of an Upland Hardwood Forest at Scott County, Tennessee." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

G. R. Wells

Major Professor

We have read this thesis and recommend its acceptance:

Frank W. Woods

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Accepted for the Council:

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EVALUATION OF SITE QUALITY OF AN UPLAND HARDWOOD FOREST AT SCOTT COUNTY, TENNESSEE

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Luis E. Rodriguez

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To my wife Nora, who provided understanding and encouragement.

To my father, Luis Jorge.

To the memory of my mother, Maria Trinidad.

ABSTRACT

Management of upland hardwood forests involves many problems and is still at an early stage of development. A better understanding of the inherent complexity of these forests will be required before better schemes of forest management can be planned. Site evaluation is a management problem of high priority. Large numbers of species forming many-aged stands which are frequently abnormally stocked characterize upland hardwood forests. Under such conditions neither growth nor site index methodology can be directly applied to assess forest productivity.

This study was conducted to determine the feasibility of the site index methodology for evaluating site productivity of a tract of the Cumberland Forest Station of the University of Tennessee in Scott County.

By stepwise multiple regression analysis it was found that:

- Site index of chestnut oak can be estimated ($r^2 = 0.50$) using logarithm of langleys/basal area ratio, total basal area growth (10-year periodic growth) and slope position as independent variables.
- Site index of white oak can be estimated ($r^2 = 0.45$) using azimuth, slope position, white oak basal area growth (10-year periodic growth) and total basal area growth (10-year periodic growth) of the study plot as independent variables.

- Yellow poplar site index can be estimated ($r^2 = 0.35$) using azimuth and effect of surrounding landmasses, arctangent exposure, as independent variables.
- Total basal area growth (ten-year periodic growth) of the study plots can be estimated ($r^2 = 0.58$) using chestnut oak basal area growth (10-year periodic growth) and chestnut oak site index as independent variables.
- Basal area growth of yellow poplar (10-year periodic growth) can be estimated ($r^2 = 0.35$) using altitude, exposure percent, and logarithm of langleys/basal area ratio as independent variables.

The most useful variables for estimating site productivity were azimuth, slope position, logarithm of langleys/basal area ratio, basal area of the plot, and total basal area growth (10-year periodic growth).

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CHAPTER I

INTRODUCTION

In 1953 the University of Tennessee stated its policy for developing and using its forest lands in Morgan and Scott Counties. The University policy encourages research work that develops methods for solving problems related to forest management comparable to similar woodland on the Cumberland Mountains and Plateau. In 1962 a study was initiated to (1) relate soil and other site factors, such as aspect, topographic position and slope to species composition and growth rate, and (2) to obtain a modern timber inventory system for all its forest tracts (The University of Tennessee Agricultural Experiment Station, 1962).

This research includes determination of site requirements and species best adapted for underplanting as well as the question as to whether forests of the Cumberland Plateau can be managed as a long-term investment at a reasonable profit. In 1962 a Continuous Forest Inventory System (CFI) was established on the named Cumberland Forestry Field Station over some 8,200 acres. Analysis of CFI results must be related to characteristics of the various sites throughout the tract. This study was carried out to determine the best available methods for extending the inventory results to other forest lands in the region.

Management of upland hardwood forests involves many challenging problems and is still at an early stage of development. A better understanding of the inherent complexity of these forests will be required before better schemes of forest management can be planned. Reconsideration of silvicultural methods and practices, mainly involving regeneration procedures, seems to be the tendency in forestry today. Silviculture for these forests must be based on a more complete understanding of their ecology.

For developing methods of forest management, proper evaluation of productive capacity of the various forest sites and forest types of a tract of land is a fundamental requirement. Therefore, the analysis of permanent CFI results should identify site characteristics that affect growth. The present study attempted to evaluate quantitatively the behavior of the selected forest tree species in relation to site and those physical factors which seem to explain the variation of site indices of these species. In this respect environmental variation within the tract was considered. Another important objective was to identify those characteristics that would provide reliable predictors of environment-tree relationships.

CHAPTER II

REVIEW OF SELECTED LITERATURE

Continuous Forest Inventory and Site Evaluation

Management of upland hardwood forests may be considered to be at an early stage of development in the United States and requires much research. Sound management of these forests demands the solution of ecological problems that did not exist at the same phase of forest management for simpler forest types. Forest management naturally leads to methods of obtaining more information for management at a higher level of productivity.

The devising and application of permanent forest sampling systems is usually related to the great expansion and intensification of forestry in the United States and Canada in the 1950's. Among the contributing factors, according to Davis (1966), may be stressed the natural human yearning for a "system" that would wrap up all forest data needs for continuing forest management in a neat package. There was need to be "businesslike" — to be able to present up-to-date information of known accuracy and consistency acceptable to executive management. The not well defined assumption regarding their application to uneven-aged timber management which these systems hint was also an important factor.

CFI is essentially a frequently repeated, directly comparable measurement of forest stands using permanently placed sample plots (Diller, 1960; Stott, 1959; Stott and Semmens, 1960). Plots in this method of inventory are regarded by Stott (1962) as bounded samples, embracing the whole biological and ecological make-up of a forest and one used to improve forest management practices by giving an accurate measure of growth so that cut and growth can be brought into closer balance. In Stott's opinion, CFI provides the basis for intensified silvicultural practices by introducing the concept of a system of unit accounting where the individual tree is the ultimate unit. Changes in volume, growth (including ingrowth), mortality and stand structure may be directly measured.

CFI permits application of new managerial tools which are being developed in computer science to forest operations. These include simulation, game theory, dynamic programming, mathematical models, and other operations research techniques (Martin, 1970).

CFI provides a dynamic picture of forest growth through recurring mensuration of the changing conditions of it. Analysis of data from CFI allows the formulation of general management policy and constitutes the basis for determination of correlations between soil-site factors and establishment, survival, growth, and reproduction of different forest tree species. Measures of site, stand, and species reactions under many management practices can be evaluated (Haselrud, 1965; Becker, 1965).

Davis (1966) suggested that with proper analysis of CFI, the relative economic yield of different investments in silviculture can be compared and evaluated.

These goals have to be achieved through a systematic analysis of the results obtained from the individual plots. Direct data from the inventory are useful only for decisions that involve the forest under study as a whole. Most of the information needed in the decision-making processes of forest management is related to units that reflect the various environmental conditions within the tract; however, these units must express the biological variation upon which silvicultural treatments are based.

It is in this context that site evaluation procedures will facilitate research by supplying a means of identifying and stratifying initial productivity levels of prospective experimental areas (Ralston, 1960; Gaiser, 1951).

As stated by Carmean (1970a) intensive management requires that site quality be carefully identified so that each parcel of land may be managed to grow species and products and benefits it is best adapted to produce. Furthermore, a knowledge of site quality is necessary so that heavy investments are restricted to excellent sites capable of producing large volumes of high-grade timber that can command the best possible price. Site quality is one of the most important determinants of growth and yield.

The relationship of tree growth to environment is difficult to measure since the site factors and the plants themselves are interacting and interdependent (Husch, 1963) and a multitude of factors are involved. As stated by Basset (1963), forest crops mature slowly, and many cuttings remove only part of the standing timber from any area. During the time required for a stand of trees to reach the time of the final harvest, much cumulative growth may be lost by fire, insects, disease and competition. This loss of growth is not measured unless stands are visited often.

As pointed out by Davis (1966), remeasurement of permanent plots and repeated forest surveys are old practices. However, their combination with modern sampling techniques and integration into a permanent system of wide application is relatively new. The inclusion of site interpretation into the system would provide an excellent tool for the kind of management that new needs and social stresses are placing on forests.

This idea appears behind the philosophy of Continuous Forest Inventory for it requires a wide range of tree data as well as information concerning the physical and ecological characteristics of the plots which are used to assess growth (Bourdo, 1963; Collins, 1962; Diller, 1960, Tennessee Valley Authority, 1960). This type of inventory provides the necessary framework for programs of applied research in forest management (Rock, 1961).

According to Mader (1963), in studies of environmental effects on tree growth, identification of dependent and independent variables is simple, for growth is dependently related to the environment. Unfortunately, neither growth nor the environment can be measured with precision. Improved methods of growth evaluation provide insight for better site evaluation which, in turn, helps in understanding growth patterns and enables better selection of factors for measurements. Mader concluded that continued study of the relationships between height and volume growth and of their feasibility for site evaluation seems desirable. In site research it is necessary to obtain the most precise measure of growth response if site classifications based on soil, topographic and climatic factors are to be better achieved.

Site and Site Quality

The forest production is a complex of interdependent processes operating within an assemblage of living organisms and their non-living environment. Such assemblages of forest organisms and of soil and atmospheric features, occupying specific portions of the earth's surface and unified by the processes of forest production are termed forest productivity systems (Hills, 1960). According to the Society of American Foresters, forest productivity system may be simply called site. Hills paraphrased the society's definition as "the combination of the biotic, climatic and soil conditions of an area considered with reference to its capacity to produce forests or other vegetation."

Scientific forestry, no less than scientific farming, must be based on a knowledge of the productive potential of the land (Trimble and Weitzman, 1956). Site quality is therefore analogous to "productivity rating." It connotes the capacity of a particular area to produce timber, as that capacity is influenced by the combined effect of the various biotic, climatic, and soil conditions unique to the area (Basset, 1963).

Direct and Indirect Methods for Establishing Site Quality

Methods of assessing forest site quality can be grouped in several ways, but perhaps the simplest initial division is between methods that measure just the forest growth and methods that measure forest growth together with related attributes of the habitat. In the first case the forest growth itself serves as the criterion of site quality. In the second group of methods the attribute constitutes the criterion. Here, therefore, it is indirect and depends for its reliability upon the validity of the relationship between the attribute and forest growth (Rennie, 1962).

For forest management purposes areas having similar forest quality or forest attributes must be recognized and mapped. One of the procedures for obtaining the criteria by which a decision is made in the grouping process in adult plantations or adult forest, is to establish sample plots typical of the site. There is no limit to the amount of growth detail that it is possible to record — ranging from basal areas and timber volumes to the total weights of all organs (Ovington, 1957). Climate, ground vegetation, soil properties, foliar characteristics, and site mapping (strictly an integration of attributes) are the most commonly recognized indirect methods of site assessment which are used.

Standards for Assessing Site Quality

The importance of site evaluation lies in the fact that site quality relates selected economic characteristics to the ecological characteristics on which forest production is based. Measurement of growth for site evaluation includes two aspects: (1) scrutiny of the factors of the environment to learn how they relate to growth rates of forest trees as well as to the distribution and succession of forest communities; and (2) the use of site ratings for actual management purposes.

There are different bodies of opinion as to the proper methods to be considered as standards of site evaluation for forest management. Discussions include height growth, volume growth and site types as the most appropriate criteria. Mader (1963) pointed out that it is generally recognized that in the use of site-types with either volume or height measures are not basically in conflict but serve complementary purposes. In the same way it may be recognized that these two aspects of site evaluation can be regarded as comprising the whole problem of the ecological interpretation of site.

Bates (1918) proposed the current annual cubic foot increment of a "fully-stocked" stand of the species under consideration as the only final criterion of site quality.

A committee set up by the Society of American Foresters in 1923 considered and reported on methods for classifying forest sites. It expressed a favorable opinion toward height growth (in spite of the fact that the committee did not make any recommendation as to which method of evaluation was best). Research has been inclined to develop methods based on this criterion. Simplicity, accuracy, relative freedom from effects of tree density, and the assumption that height growth was a reliable indicator of volume yields have been the principal characteristics attributed to this criterion. Lack of information on volume yields and difficulties involved in developing methods on site types favored this decision at that time.

The report reaffirmed the point of view of Bates (1918), in stating that

> "The only valid basis for classification is the potential volume production of wood, of the species growing or to be grown on given sites. In order that this potential production may be expressed on a standard basis, it is necessary to assume a definite period in the life of the stand, preferably approximately the period of culmination of mean annual growth, and a definite method of treatment, preferably well-stocked unthinned natural stands of approximately even age."

Marty (1965) considered that the best way to define forest site is in terms of its potential for producing some product, say in terms of maximum mean annual cubic-foot increment per acre.

<u>Site Index as a Criterion of Site Quality</u>

The most widely used standard for assessing forest land productivity in North America is "site index," an expression of forest site quality based on the height of dominant and codominant trees in even-aged stands at an arbitrarily chosen age (Society of American Foresters, 1958). Height and age measurements are used with published site index curves to estimate how tall trees will be at an index age, usually 50 years. Site index is then usually related to yield tables to estimate growth and yield of forest stands at various stand ages (Carmean, 1970b). Trimble and Weitzman (1956) considered site index as a standard measure of timber-land productivity stating that for each site index, mensurationists have spelled out the expected production per acre.

Site index as an expression of potential site productivity is based on the assumption of the relative independence of height growth of dominant trees on the factors that affect growth of trees.

Trees measured for site index must have been free from suppression and damage throughout their lives; such trees generally occur in well-stocked, even-aged forest stands that have not suffered from past cutting, heavy grazing, repeated burning or stagnation caused by overstocking. These precautions are extremely important if dependable site index estimates are to be obtained because much evidence is available showing that tree height growth can be affected by stand origin and early competition, and by stagnation in certain overstocked conifers stands (Alexander et. al., 1967). Basset (1963) considered that very old stands are inadequate for applying the site index method. Gaiser (1951) and Basset (1963) considered that poorly stocked stands cannot be used to measure the productivity of the sites they occupy.

Advantages and disadvantages of the site index method have been described by Vincent (1961), Mader (1963), and Cool (1965). The meaning and the role this method plays in forestry as well as the trends of its historical evolution have been presented in the reviews of forest site evaluation done by Coile (1952, 1959), Ralston (1964), Rowe (1962), Rennie (1962), Doolittle (1958) and Foster (1959).

Errors in site-index estimation occur when regional harmonized site-index curves do not accurately portray the variable patterns of tree height that are found within many large forest regions (Carmean, 1970b). Tree height-growth patterns may vary either in different parts of the range of a forest species or in local areas that have contrasting site conditions. Hence, required site index curves are needed that better describe these polymorphic patterns of tree height growth. For this purpose Carmean (1970a) proposed that site-index curves based on stem-analysis techniques are most satisfactory.

Soil Site Studies

The site index method is simple and easy to apply when suitable forest trees are available for the required height and age measurements. However, in many hardwood forest areas suitable trees are lacking because stands may be uneven-aged, poorly stocked, too young, damaged by fire or heavy grazing or may have been subjected to various intensities of cutting. In such events, soil-site evaluation must be used to establish necessary correlations continues to be site index.

As stated by Watt and Newhouse (1973), soils and topography, separately or combined, are often used to estimate site quality, because they are stable factors of the landscape that are relatively undisturbed by man's activities.

A number of additional studies (Graney and Ferguson, 1971; Hannah, 1968; Hartung and Lloyd, 1969; Ike and Huppuch, 1968; Smalley, 1967; VanLear and Hosner, 1967; and Yawney and Trimble, 1968) have shown topography to be more important than soil classification in the indirect determination of site quality for hardwoods and conifers. For these reasons it seems that emphasis on topographic factors should have high priority in the initial phase of site evaluation research.

The importance of causal factors in site evaluation predictions is explained by Yawney and Trimble (1968). They stated, based on the studies on oak site quality in West Virginia (Trimble and Weitzman, 1956; Trimble, 1964), that soil depth can be eliminated from a prediction equation without appreciably affecting its accuracy because of the soil depth relationship to both slope position and slope percent (the two other "independent" variables in the equation).

Results of soil site studies have been published for white oak in Southern Ohio (Gaiser, 1951) and in Northern Mississippi and Western Tennessee (McClurkin, 1963), in which no soil factors were significantly related to tree height after the effects of age and topography were taken into account. Smalley (1967) found that topographic factors were associated with white oak tree heights for upland oaks in Northern Alabama. Significant factors were slope position and total slope length plus distance from plot center to ridge.

Many other studies have reported the contributions of topographic position and/or aspect to oak site quality: Carmean (1965), Della Bianca and Olson (1961), Doolittle (1957), Einspahr and McComb (1951), Gysel and Arend (1953), Hebb (1962).

Effect of topographic variables on tree growth is indirect, however. Smalley (1967) considers topography as an integrator of the primary causes of site variation — soil moisture and structure, nutrients and microclimate.

Topographic variables affect site quality also through their effect on productivity by modifying climatic action. Whatever may be the cause-effect relationships among climate, topography, and soil as factors in forest productivity, for site evaluation studies, it appears that climatic-topographic variables can be studied in a first step as general factors and subsequently more detailed consideration can be given to soil factors.

Topographic factors more frequently used in relation to site quality have been azimuth, steepness and slope position. There were differences in the way these factors were expressed by the authors. Gaiser (1951) pointed out that there are difficulties for expressing topographic differences. He advocated methods describing topography in numerically continuous units. This need is only partially satisfied by present practices.

The most important method developed by Coile (1952) which consists of examining by multiple regression analysis, the relationship between site index and soil characteristics.

Soil characteristics are major determinants of site quality, and they are always related to other determinants reflecting climate and the biotic environment. For example, the ability to supply moisture is a key soil characteristic influencing site quality (Marty, 1965). Site quality is controlled largely by the amount of soil water available to tree roots, and the rate at which it can be absorbed (Basset, 1963).

Carmean (1961) found that site index was related to several physical properties of soil but varied greatly within soil taxonomic units. He pointed out that taxonomic units do not reflect all the site factors important to tree growth. He concluded that relationships between taxonomic units and site quality could be improved to provide more precise estimates of forest site quality, provided the following conditions were met: if existing soil descriptions were modified, if soil types and phases were better described, and if important site factors could be used in conjunction with taxonomic units.

There are also limitations to the use of soil-site measurements. Hodgkins (1960) stated that soil-site index measurements can replace site index only when the studies involved are for relatively uniform conditions of topography and soil formation. The methodology of soil-site evaluation consists primarily of the development of an evaluation system which includes the collection and compilation of field data for specific uses or applications.

Coile (1959) considered that results from most soil-site investigations are applicable only within the study area, and the precision of site quality estimates generally decreases as the size of the study is increased.

Ike and Huppuch (1968) considered that complicated and time-consuming methods of soil analysis and tree growth measurements are often a deterrent; therefore, a simplified and reliable guide is highly desirable.

Gaines (1949) felt that soil factors may be of considerable value in evaluating forest site quality in many, if not all, forest regions and types. However, the exact factors to be used will vary from one region or type to another.

Once the basic relationships are established, fewer samples will suffice to determine differences in the basic relationships for other parts of the region. Although much work has been done on the influence of soil-site conditions on the growth of Southern pines little work has been published which deals with the effect of these relationships on Southern hardwoods (Ike and Huppuch, 1968).

Site Index Comparisons

Doolittle (1958) stated that the ideal method of predicting or estimating site index is by the use of soil and topographic features. This will require as many studies of soil-site relationships as there are species; and since each study requires considerable time and effort, such studies have been completed for a relatively few species. One method of providing information more quickly and conveniently is to relate the site indices of several species.

Species comparisons are very useful means for extending the application of direct site index estimations. These comparisons are particularly helpful in judging which species are most productive on particular sites. However, such comparisons must be based on tree-height growth alone. Therefore the choice of species should be based on additional comparisons, especially of volume and value of the yield, where possible (Carmean, 1970a).

Reviews of literature about site index comparisons are given by Doolittle (1958) and Foster (1959). Species-comparison graphs have been published for hardwoods in the Southern Appalachians (Doolittle, 1958), for the Piedmont (Nelson and Beaufait, 1956; Olson, 1959), for Vermont (Curtis and Post, 1962) and for white pine and red maple in Connecticut and Massachusetts (Foster, 1959). Site-index comparisons among various species of oak have been listed by Trimble and Weitzman (1956).

Site Evaluation Research in the Upland Hardwood Forests

Research in site evaluation for management of upland hardwood forests may be focused on two principal objectives: (1) gathering of information concerning growth and (2) establishment of standards for rating site quality. Solution of these points is more difficult for upland hardwood forests than for simpler forest types. The principal reason for this situation is the large number of species present and the variable types of exploitation to which they have been exposed. Upland hardwood forests are mostly many-aged and conditions of understocking and stagnation can be found throughout their range. All of these factors contribute to the perplexing variables which complicate site evaluation studies. Under these circumstances, growth cannot easily be used as a direct method for assessing forest productivity. Even then, the problem still remains as to the establishment of standards for rating site quality.

Because of the relatively high development of techniques for determining site index this seems to be the best initial course of action to be taken to establish standards for rating site quality. Site indices have been determined for many species of upland hardwood forests and much information is available. Furthermore, yield information is available as it relates directly or indirectly to site index.

Site index would be affected by some of the characteristics of forest tracts studied elsewhere which are similar to the one under study. Too, the philosophical basis of site index methodology does not lend itself for application to uneven-aged, abnormally stocked stands.

It should be recognized that forest management has been quite successful in forest types that better fit the requirements of this criterion, namely, natural even-aged stands having one or a few species. The best application has been found in regulated forests managed according to even-aged systems.

The Problem

Following the reasoning set forth in the preceeding section, several questions arise with respect to evaluating site quality in upland hardwoods:

1. To what extent is site index related to growth measurements obtained in permanent plots?
2. Which factors affecting growth are also manifested in the site index values and which of them are masked?
3. What are the conditions, if any, under which site index constitutes a reliable standard of site quality?
4. Under what conditions can site quality be expressed and for what species or group of species?
5. Are site-types necessary in any phase of the development of the criteria for assessing standards of site quality?
6. Are CFI useful for assessing site types?
7. To what extent are site types, height and volume growth, or combinations of them, needed for assessing standards of site quality?

Response to these questions can be expected only from a long-term research program on site evaluation; the first step of which would be as attempted by the study reported here, understanding the possibilities and limitations of the site index method, and the exploration of sources of variation of growth in the conditions of the forest under consideration.

Results could eventually indicate paths of action dealing with the analysis of CFI results as well as reveal what site variables may be added for repeated mensuration. All these points that are related to the accuracy and usefulness of CFI may be the basis for completing the systems as required by modern forest management. The nature of CFI permits revision and feedback for obtaining the best and most precise measurement of forest growth, which is the basis for sound management.

Finally, it may be pointed out that as awareness of the need for this type of research increases the importance of meaningful standards for setting site quality increases.

CHAPTER III

THE STUDY AREA

Location

The 4,289-acre Scott County tract lies astride the Morgan-Scott County line about 50 miles northwest of Knoxville and about 10 miles north of Wartburg. The towns of Sunbright and Robbins are about 10 miles north and northeast, respectively.

History

The Cumberland Forestry Field Station, containing 8,200 acres which includes the Scott County tract was deeded to the University in 1937. Timber has been sold both before and after this time, but lumbering on a large scale was halted in 1949. The last fire in the study area occurred in 1953.

Strip mining has disturbed or completely removed soil on 2.3 percent of the land area of the Scott County tract. Soils lying immediately below these mines have been altered or modified by deposition of eroded material.

Geology

The study lies in the Wartburg Basin of the Cumberland Mountain physiographic division of the Cumberland Plateau, just east of the Northern Cumberland Plateau (Wilson et. al., 1956). This plateau is a highland which extends across the state from Kentucky and Virginia in the north to Georgia and Alabama in the south. It is not a simple plateau but is dissected by prominent valleys with mountains protruding above the plateau surface (Fenneman, 1938).

According to MacDonald (1964), six of the nine groups in which Wilson et. al. (1956) divided the Pennsylvanian strata are found on the area. They are, in order from oldest to youngest: Crooked Fork, Slatestone, Indian Bluff, Graves Gap, Redoak Mountain, and Vowell Mountain. All six groups are composed of interstratified sandstone, shale, and coal.

Topography

Topography is complex: 65 percent of the plots have a slope of more than 30 percent and 71 percent of the plots lie between middle slopes to ridge crests. The surfaces of the plots are mostly straight (58 percent) with equal amounts of concave and convex slopes (21 percent each) (MacDonald, 1964).

The tract has numerous ridges and draws. Ridge lines tend to be broad or rounded rather than narrow and sharp. Sixty percent of the plots are well drained with the remainder excessively drained (MacDonald, 1964). Coves vary in shape from narrow to wide and open. In most coves the drainageways carry running water only during rains and shortly thereafter. Large sandstone outcrops are common. The minimum elevation is 1,400 feet; the maximum is 2,850 feet.

Soils

The soils, all derived from sandstone and shale, are in the Muskingum Series which here have a grayish-brown silt loam A horizon and yellowish-brown silty clay loam B horizon (Thor et. al., 1969). According to MacDonald (1964), Upland soils occupy 89.0 percent of the total land area of the Scott County tract, and Muskingum silt loam is found under 83.5 percent of the forest.

MacDonald (1964) found that pH of the soil of the plots ranged from 3.6 to 6.5 (very acid to moderately acid) with a median value of 4.8. Some 35 percent of the plots had values in the range from 4.6 to 5.0.

Four great soil groups and nine soil series are represented. They are: Hapludults (Hartsells, Jefferson, and Wellston Soil Series), Fragiaguults (Tyler Soil Series), Dystrochrepts (Pope, Muskingum, and Philo Soil Series) and Fragiudults (Johnsburg Soil Series).

The soil depth is greater than three feet to rock on 76 percent of the plots. Stone percentages of from zero to twenty percent were recorded on 62 percent of the plots and thus is relatively low.

Humus is typically very shallow. This is probably due to the past history of severe logging and frequent burning. Ninety-five percent of the plots have humus layers of less than one-half inch. Well developed A horizons are evident over most of the forest but 86 percent of the plots have A horizon depths less than six inches.

Climate

According to MacDonald (1964) the mean annual temperature is approximately 56 degrees Fahrenheit, with monthly mean temperatures ranging from 37 degrees for January to 74 degrees for July. Precipitation is fairly constant throughout the year with an annual mean of around 54 inches. Monthly values range from about 3 inches for October, to about 6 inches for January. On the average, one or more prolonged dry spells occur during the spring and fall.

Average annual snowfall is over 10 inches, while damaging ice and glazestones occur somewhat irregularly.

Vegetation

Both Morgan and Scott Counties, where the University of Tennessee has two forest tracts, have over 85 percent of their total acreage covered by forests (Tennessee Forest Industries Commission, 1964). These tracts are representative of the forest types and conditions prevalent on thousands of acres in the Cumberland Mountains and on the Cumberland Plateau.

The mixed mesophytic forest to which these tracts belong is a mosaic of association-segregates. They range from cove hardwood stands with hemlock, white oak, yellow poplar, and beech on northerly slopes at low elevations, to open oak and pine stands on the more exposed south-facing slopes and ridges (Braun, 1942).

At the time the CFI was established, 50 percent of the forest was found to be in stands of very light sawtimber (less than 1,500 board feet per acre) in combination with pulpwood stands of varying stocking. Fifty-eight percent of the forest had heavy or medium pulpwood stands. Total volumes for the tract were some 6.8 million board feet for sawtimber and almost 800,000 cubic feet for pulpwood. Results of volume analysis revealed that the forest was understocked due to a previous history of fires and logging and that most of the timber was of low quality.

The greatest merchantable sawtimber volume is contained in hickory, the red oak group, and the white oak group (mainly chestnut oak) in trees less than 20" dbh.* The species composition of the pulpwood volume is somewhat more desirable. More volume is contained in yellow poplar of pulpwood size than any other species. The quality of the sawtimber volume leaves much to be desired. Pulpwood data however indicated a trend toward merchantable volumes of higher quality.

Results of the first five-year period revealed that net growth for sawtimber was 64.9 board feet per acre per year or 4.5 percent annually. Pulpwood was growing at a rate of 3.9 cubic feet per acre per year or 5 percent.

Desirable species according to Thor et. al. (1969) were observed on most sites of the Cumberland Field Station, but several species had very uneven distribution. Most white pine and yellow poplar reproduction

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*Yellow poplar, white oak, Virginia pine, and shortleaf pine occur in relatively small volume but are of consistently higher quality.

was on north ridges. White oak was common in the south draws, but almost absent in north draws. The density of white pine, white oak, red maple, yellow poplar, blackgum and pignut hickory was significantly different (at 5 percent level) among aspects. Topographic effects were not as pronounced. Density of only white pine and pignut hickory was significantly different between ridges and draws.

When the initial CFI inventory was made it was found that most of the understory was made up of commercially undesirable timber species. More than half was accounted for by three relatively undesirable species: chestnut oak, red maple, and blackgum. In comparison the most desirable reproduction consisting of shortleaf pine, white pine, northern red oak, white oak, black oak, yellow poplar, sweetgum and white ash accounted for only 30 percent of all potential timber trees. Two of the most common less desirable species, chestnut oak and red maple, were relatively evenly distributed on both exposures and in draws and on ridges. Thickness of the A horizon, slope direction, percent slope, slope position and the pH of the soil were significantly correlated with species density in the understory (Thor et. al., 1969).

Results of the first reinventory (Martin, 1970) showed that the white oak group was the second most important element in total volume and contributed the most to forest growth (28 percent). The largest contribution was made by chestnut oak. Although chestnut oak volume was much greater than that of white oak, there was little difference in volume growth between the two species. Yellow poplar was growing at a rate of 7.9 board feet per acre per year and accounted for 10 percent of the total volume.

CHAPTER IV

METHODS AND PROCEDURES

MacDonald (1964) established 99 continuous forest inventory plots on the Scott County tract. To insure mechanical systematic sampling, they were located using aerial photographs and topographic maps. The plot layout consisted of three concentric circular plots with a common plot center. Plot sizes were: one-fifth acre for sawtimber-sized trees, one-tenth acre for pulpwood-size trees, and one-hundredth acre for reproduction and ground cover measurements. There was a 0.4626 percent sample of the area for sawtimber-size trees and a 0.2313 percent sample for pulpwood-size trees.

In addition to standard mensurational data on the trees inside the plots, site data were taken and coded. The information obtained included three groups of factors: soil properties, physical features of the site and vegetation.

All information on soil properties, with the exception of pH and soil series, was obtained in the field. Representative soil samples were obtained for pH determinations. Soil series were entered later in the office from a soils map of the tract prepared by Cox (1963). The remaining soils data were obtained using soil pits and augers.

Martin (1970) expanded the analytical system with respect to timber growth calculations. Computer programs were written to calculate growth components for each species. Martin recommended the use of post stratification and the increase of the total number of plots by 85 to reduce the standard error of growth to an acceptable 10 percent.

Review of the data available from CFI inventory proved insufficient for site evaluation studies involving site index, mainly because of the criteria used for choosing individual trees and the small number of trees sampled. Then, it was decided to obtain new data concerning both site and vegetation characteristics.

Field Methods

Field work was carried out when the CFI periodic remeasurements were made from July 10 to September 6, 1972. The information obtained for the site-index study was as follows:

Topographic Variables

1. Altitude. Altitude was measured in feet at the plot center. These measurements were related to distinguishable points with known altitudes whenever possible. Values of altitude assigned to each plot are presented in Appendix Table 9.
2. Slope direction. Slope direction was measured with a compass and expressed in degrees. The slope-facing direction at right angles to the contour was measured clockwise from true North and was used for computing radiation values as explained below. As suggested by Beers et. al. (1966), azimuth values were then

transformed according to the formula $A^{1} = Cos\ (A_{max.} - A) + 1$, taking 45 degrees as $A_{max.}$ Since forest growth is frequently greater on the northern and eastern slopes (in the Northern Hemisphere) these values of azimuth should logically have greater weight in the numerical value assigned. The transformation used in the present study was derived from the original proposed by Gaiser (1951). Azimuth assigned to the plots are contained in Appendix Table 10.

3. Exposure. By using the data related to slope direction, elevation and position of the plots on the slope and topographic maps some measurements were selected for quantifying this physiographic feature. An attempt was made to give a quantitative value that expresses the action of surrounding masses on the plot.

According to Davis and Ward (1966) the angle to the highest point of nearby land masses shading the plot at the bearing of nearby maximum insolation (S85E and S85W) has proved to be closely related to the height-growth of black cherry, when interrelated with the position of the plot on the slope. Following this idea, measurements for expressing exposure that were chosen for the present study were: (1) altitude of the highest ridge to the south of the plot and (2) the horizontal distance from the plot to the above-mentioned ridge. With these values the following variables were established: (1) difference between the altitude of the highest ridge to the south and altitude of the plot divided by the distance; this figure was maintained directly as percent, and (2) a transformation of this percent to angle. Basic data used in obtaining those variables are presented in Appendix Table 9.

4. Slope percent. Measurements below and above plot center were taken following slope direction with an Abney hand level. The mean of the values obtained in the field was recorded as slope percent. Values assigned to each plot are presented in Appendix Table 10.

5. Position of the plot on the slope. With the field observations and the use of topographic maps, position on the slope was taken as percent of total distance from ridge to the stream line, with the ridge as one. Data concerning this characteristic are presented in Appendix Table 11.

Radiation. The expressions of topography mentioned above have in common the modification of the action of climatic elements as radiation and wind. From them slope percent and azimuth, in the way they are usually measured, have been included by Fribourg (1972) in a computer program for obtaining potential radiation values.

Fribourg's program is based on Lee's (1963) approach for evaluating the solar radiation striking a point on the surface of the earth, taking into account solar declination, radius vector, latitude and day length, azimuth from north and slope. He developed a computer program which computes the total potential incoming solar radiation per day for any place on the earth's surface between 60 degrees of north latitude and 60 degrees of south latitude for sites which are flat (i.e., tangential to the curvature of the earth) or which have any slope and exposure.

The output of this program consists of the relative insolation striking a sloping site expressed as a percentage of that striking a flat exposure at the same geographical location, elevation and time. The program permits obtainment of daily, seasonal or yearly options.

Two categories of input data are required for the execution of the program. First, tables of times of sunrise and sunset at different latitudes, and of solar declination and radius vector for each day are entered in storage. The second category of input needed consists of the latitude of the location, the azimuth from north and the percent slope of the place(s) to be studied.

Fribourg considers the output of the program as a quantified value of the "aspect" parameter. This parameter has been used for describing a number of unmeasured environmental factors that depend on the exposure of the site relative to the position of the sun throughout the year. This method avoids the use of coded values and dummy variables that complicate the analysis.

Inclusion of radiation in the present study follows the assumption that if "aspect" as measured by Fribourg's program provides a reasonable explanation of site index variation it may be considered as the basis for a quantitative measurement of exposure. Latitude, orographic and other physiographic characteristics that cause differences in site could be brought into consideration for obtaining an integrated value that is considered necessary in site evaluation studies.

It is obvious that the values obtained with Fribourg's program may be affected by the nearby presence of mountains, valleys and in some cases this effect could supersede or mask effects due to simple exposure.

As Fribourg's program has not been completely tested, it is impossible to foresee the kind of relationship between the potential radiation and the other topographic characteristics not included in it. For this reason radiation, its transformations, and the topographic variables included or not in Fribourg's program were included simultaneously in the statistical analysis.

Values of potential radiation were obtained both in yearly and seasonal basis. However, only yearly values were analyzed statistically against the other factors. Figures used in the analysis, and Fribourg's program output are presented in Appendix Table 10.

Tree Height and Age. Three species were selected for relating site characteristics and growth to site index: white oak (*Quercus alba* L.), chestnut oak (*Quercus prinus* L.), and yellow poplar (*Liriodendrum tulipifera* L.). Criteria for this selection were economic value and distribution of the species in the tract. From these species yellow poplar and white oak growth-site relationships are rather well known throughout their area of distribution; and chestnut oak, though less studied, and of relatively low economic value, is quite evenly distributed through the tract. Only dominant individual trees of the three selected species were considered for site index measurements. Trees with forked stems, broken tops or serious visible damage caused by fire or diseases were avoided. The tallest, best formed individual tree of each species present at the plot were used.

1. Age. Increment borers of variable size were used to extract cores that included all the wood from the pith to the bark. Cores were labeled and placed in tubes until age determinations were made at the office. Trees were bored at 4-1/2 feet above average ground level and perpendicular to the aspect orientation.

2. Total height. Total height in feet was determined with a Haga altimeter.

Site Index. Site index (height in feet of dominant tree at age 50 years) was assigned to each plot. As site index curves available are based on total age, 5 years were added to d. b. h. age obtained from field work, in order to insure approximately comparable values. Site index estimates for each sample tree species were made using standard harmonized site-index curves.

Site index values for yellow poplar were obtained by using the site index formula* presented by Beck (1962) and obtained in the Southern Appalachian Mountains.

Harmonized site indices for chestnut oak were calculated by using the formula** based on Schnur (1937) presented by McClurkin (1963).

Basal Area Growth. From the computer program system of the Continuous Forest Inventory, data for computing basal area growth were obtained for the period 1962-1972. Appendix Tables 12 and 13 contain these data.

Summarizing, climatic, topographic and vegetation variables constitute the data for the statistical analysis of site evaluation attempted by the present study. In Appendix Table 14 are included the factors considered.

Statistical Procedures

The objective of the analysis is to study how some of the most permanent site characteristics are related to growth in the upland hardwood forest under consideration.

Essentially the method chosen for this study can be categorized into the site approach developed by Coile (1952) and consists of examining statistically, by multiple regression analysis, the relationships between

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*(Yellow Poplar) Log Site Index = Log height - 9.158 $\left(\frac{1}{50} - \frac{1}{Age}\right)$

**(Oaks) Log Site Index = Log height + $\frac{11.641}{Age}$ - 0.233

site and growth. The growth characteristics considered are basal area growth measurements obtained in a ten-year period on a Continuous Forest Inventory system established in the forest tract. Site index values that generally are the characteristic against which site values are tested have not been proved to be useful in the conditions prevalent in the tract. Consequently for the purpose of the present study site index and basal area growth were considered both as dependent and independent variables. This approach is considered to be acceptable because of the fact that one of the characteristics that prevent the use of site index under the conditions prevalent in the forest tract is the effect of abnormal density. Basal area is considered as one measurement of density.

Plots basically considered in the analysis were those for which site index values were obtained. A few plots were excluded because site index values were considered too high according to previous studies. These trees were all the time among the youngest trees for the species under consideration. No attempts were made for elimination of elder trees because of lack of appropriate criteria. It is considered that results may be affected for this reason. Although any improvement in screening of data would result in a better fit in the regression analysis it was considered that for the purposes of the present study excessive care in this sense could mask the problem of site evaluation in the conditions of the forest under consideration.

Selection of Variables and Possible Interactions

The first step of the statistical analysis was to screen out the most promising variables. Matrix analysis by Pearson correlation method was used as provided by SPSS statistical system (Norman et. al., 1970). Those variables remaining were then entered in computer programs and analyzed with the air of the computer facilities provided by the University of Tennessee.

The following variables were used in the computer programs for the purpose of site evaluation analysis:

Dependent variables:

Y_1 - Chestnut oak site index

Y_2 - White oak site index

Y_3 - Yellow poplar site index

Y_4 - Basal area growth (10-year periodic growth) on plots where data of chestnut oak basal area growth and site index are available

Y_5 - Basal area growth (10-year periodic growth) on plots where data of white oak basal area growth and site index are available

Y_6 - Basal area growth (10-year periodic growth) on plots where data of yellow poplar basal area growth are available

Y_7 - Chestnut oak basal area growth (10-year period)

Y_8 - White oak basal area growth (10-year period)

Y_9 - Yellow poplar basal area growth (10-year period)

Independent variables:

X_1 - Langleys on sloping ground logarithm/basal area 1972

X_2 - Langleys on sloping ground

X_3 - Langleys on sloping ground logarithm

X_4 - Potential radiation percent: slope/flat

X_5 - Langleys on sloping ground squared

X_6 - Position on slope

X_7 - Position on slope squared

X_8 - Slope percent (steepness)

X_9 - Azimuth

X_{10} - Altitude

X_{11} - Altitude squared

X_{12} - Exposure tangent

X_{13} - Arctangent exposure squared

X_{14} - Basal area growth (10-year periodic growth)

X_{15} - Basal area 1972

X_{16} - Basal area 1972 squared

X_{17} - Chestnut oak basal area growth (10-year periodic growth)

X_{18} - White oak basal area growth (10-year periodic growth)

X_{19} - Yellow poplar basal area growth (10-year periodic growth)

X_{20} - Chestnut oak basal area growth squared (10-year periodic growth)

X_{21} - White oak basal area growth squared (10-year periodic growth)

X_{22} - Yellow poplar basal area growth squared (10-year periodic growth)

X_{23} - Chestnut oak site index (harmonized)

X_{24} - White oak site index (harmonized)

X_{25} - Yellow poplar site index

X_{26} - Exposure percent

The basic equation for the data was

$$Y = C + B_1X_1 + B_2X_2 + \ldots B_nX_n$$

Y_1 = dependent variable

C = regression constant

B_1 = regression coefficient

X_1 = independent variables

When basal area growth was considered as dependent variable in the regression analysis a second phase of screening was introduced. Besides the climatic-topographic variables related to the plots there were included only those stand factors referred to each one of the species under consideration. Site index was considered as stand factor in this phase. In this way basal area growth for the 10-year period obtained from CFI was related sequentially to the independent variables of the plots with chestnut oak, white oak and yellow poplar.

Multiple Regression Analysis

Stepwise multiple regression was selected for the final analysis. This method allows the study of the linear relationship between a set of independent variables and a number of dependent variables while taking into account the interrelationships among the independent variables.

The SPSS multiple regression program combines standard multiple regression and stepwise regression in a manner that provides considerable control over the inclusion of independent variables in the regression equation.

This variation of multiple regression provides a means of choosing independent variables which will provide the best prediction possible with the fewest independent variables.

The method recursively constructs a prediction equation one independent variable at a time. At each step the optimum variable is selected, given the other variables in the equation.

Statistical analysis was next conducted according to the following scheme:

1. Testing for the level of significance of each one of the regressions by analysis of variance.
2. Each one of the retained variables was then tested for significance according to the F ratio of the individual regression coefficients.
3. Analysis for obtaining the best prediction equation by using those variables that matched the two previously mentioned ones.

CHAPTER V

RESULTS AND DISCUSSION

The following dependent variables were subjected to regression analyses in attempts to obtain prediction equations.

1. Chestnut oak site index
2. White oak site index
3. Yellow poplar site index
4. Basal area growth (10-year period) on plots with chestnut oak
5. Basal area growth (10-year period) on plots with white oak
6. Basal area growth (10-year period) on plots with yellow poplar
7. Chestnut oak basal area growth (10-year period)
8. White oak basal area growth (10-year period)
9. Yellow poplar basal area growth (10-year period)

Chestnut Oak Site Index

Characteristics of the regression equation for chestnut oak site index are contained in Appendix Table 15. The overall equation which included 15 independent variables was significant at the 1% level. It explained 63% of the variation in site index and had a standard error of the estimate of ±11.78 feet at 1% level. From this regression equation, taking into consideration the level of significance of the regression coefficients, only three of the variables were found valuable for predicting site index —

logarithm of langleys/basal area ratio (X_1), basal area growth (X_{14}), and slope position (X_6).

Chestnut oak site index can be estimated using logarithm of langleys over basal area of the plot (X_1), basal area growth during a ten-year periodic growth (in square feet) (X_{14}) and slope position (X_6) ($\alpha = 0.01$). Characteristics of the prediction equation are presented in Table 1, which explains 50% of the variation. The standard error of the estimate is ±11.8 feet. All regression coefficients are significant ($\alpha = 0.05$).

According to these results the quality of site for chestnut oak increases when logarithm of langleys/basal area ratio decreases; increases when basal area growth becomes greater, and increases when distance from the ridge top increases. Furthermore, as the logarithm of langleys/basal area ratio increases on southeastern slopes and decreases in northeastern slopes, lowest site indices are in southeastern slopes and highest in northeastern.

These results fundamentally agree with those obtained by Ike and Huppuch (1968) in the Georgia mountains. They found site index of chestnut oak to be closely related to slope position and slope steepness. Most studies dealing with upland hardwoods have found aspect to be an important factor in site quality.

Basal area and basal area growth, the two stand variables included in the analysis, are strongly related to the site index prediction and their inclusion appears to be justified.

TABLE 1

PREDICTION EQUATION FOR CHESTNUT OAK SITE INDEX

Variable(s)	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression Correlation
<u>Step Number 1</u>						
X_1	-32.08129	-0.56561	6.75143	22.579**	0.31991	-0.56561
(Constant)	241.77384					
<u>Step Number 2</u>						
X_1	-28.36716	-0.50013	6.39571	19.672**		
X_{14}	53.83513	0.33175	18.29728	8.656**	0.42569	0.43047
(Constant)	217.06082					
<u>Step Number 3</u>						
X_1	-27.16704	-0.47897	6.06686	20.052**		
X_{14}	49.34553	0.30409	17.39392	8.068**		
X_6	0.15451	0.27019	0.06038	6.547**	0.49725	0.35322
(Constant)	204.06807					

Standard error of the estimate = 11.80 feet.

* Significant at 5% level
** Significant at 1% level

White Oak Site Index

Characteristics of the regression equation of white oak site index are contained in Appendix Table 16. The overall equation includes seven independent variables ($\alpha = 0.05$). This equation explains 51% of the variation in site index values and has a standard error of the estimate of ±8.7 feet at 5% level. From this equation, based on "t"-tests of the regression coefficients, a prediction equation was developed. The variables included in the equation are azimuth (X_9), slope position, white oak basal area growth (X_{21}), and basal area growth for all of the species on the plot (X_{14}).

White oak site index can be estimated using azimuth (X_9), slope position (X_6), white oak basal area growth (X_{21}), and basal area growth for all species (X_{14}) ($\alpha = 0.05$). Characteristics of the prediction equation are in Table 2. The variation explained by the equation is 45% and the standard error of the estimate is ±8.71 feet at 1% level. All of the regression coefficients are significant ($\alpha = 0.05$) except for basal area growth, which was nevertheless used because it contributes heavily to the empirical equation.

According to these results the quality of site for white oak growth is highest on northeastern exposures with poorest ones on southwest slopes. Superior sites occur on lower slopes and become poorer as ridge tops are approached. Similar results were found by Ike and Huppuch (1968), and Trimble (1964). Differences in results, as in the case of chestnut

TABLE 2

PREDICTION EQUATION FOR WHITE OAK SITE INDEX

Variable(s)	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression Correlation
Step Number 1						
X_9	5.62937	0.41126	2.66007	4.479*	0.16914	0.41126
(Constant)	56.10623					
Step Number 2						
X_9	7.43898	0.54347	2.80037	7.057*		
X_6	0.10715	0.33102	0.06622	2.618*	0.26124	0.11397
(Constant)	48.92562					
Step Number 3						
X_9	6.71969	0.49092	2.63390	6.509*		
X_6	0.12903	0.39862	0.06265	4.242*		
X_{21}	0.00000	0.37100	0.00000	4.171*	0.38871	0.38108
(Constant)	46.30491					
Step Number 4						
X_9	6.37258	0.46556	2.58519	6.079*		
X_6	0.12895	0.39838	0.06121	4.439*		

TABLE 2 (Continued)

Variable(s)	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression Correlation
Step Number 4 (continued)						
X_{21}	0.00000	0.45848	0.00000	5.935*		
X_{14}	-26.35128	-0.25369	18.85074	1.954	0.44572	-0.13452
(Constant)	47.90666					

Standard error of the estimate = 8.71 feet.

* Significant at 5% level
** Significant at 1% level

oak site index, are due to stand variables such as white oak basal area and basal area growth. The influence of white oak basal area can be interpreted as follows. Sites naturally stocked, that include white oak in their composition, and with intermediate ages of trees are better indicators of site index. Too much or too little growth is usually due to other factors such as cutting and fire.

Basal area growth (X_{14}) in the prediction equation of white oak site index is inversely correlated with site quality. Although this variable was not statistically significant it was included for the purpose of reinforcing the previous variable (white oak basal area growth, X_{21}). Its meaning in the prediction model would be that white oak site index is lower when basal area growth is greater. This result is contrary to what would be expected.

Site index values and sites with northerly and easterly aspects were found to be higher than on southerly and westerly aspects for upland oaks by Nash (1959).

The larger quantities of radiation received by south-facing slopes are considered by Geiger (1965) responsible for differences of growth due to aspect. South-facing slopes, as a consequence, have greater evapo-transpiration which creates more severe moisture stresses within trees than occurs on less exposed north-facing slopes. Of the topographic characteristics that influence site quality of white oak in North Mississippi and West Tennessee, McClurkin (1963) found the best correlation with slope position.

Hannah (1968) found that site quality of white oak improves with increasing distance from the ridge top (slope position). This better growth is particularly due to additions of gravitational water, and to surface water flow from upper slope positions (Hewlett, 1961) and to more favorable microclimatic conditions found on lower slopes.

Ike and Huppuch (1968) found that the influence of slope position on site index for white oak was stronger at higher elevations than at low elevations.

Yellow Poplar Site Index

Characteristics of the regression equation of yellow poplar site index are contained in Appendix Table 17. This equation includes 13 independent variables ($\alpha = 0.05$), and it explains 55% of the variation in site index with a standard error of ±12.5 feet in the estimate. The prediction equation derived from the analysis of the regression coefficients of the variables included azimuth (X_9) and arctangent exposure (X_{13}) ($\alpha = 0.01$). Statistical characteristics of this prediction equation are presented in Table 3. The variation on site index explained by the equation is only 35%. The standard error of the estimate is ±12.6 feet at 1% level. The individual regression coefficients are significant ($\alpha = 0.01$) for azimuth and ($\alpha = 0.05$) for arctangent squared.

Yellow poplar site quality is highest on northeastern exposures while lowest values are found on south-facing slopes. Best sites are on lower slopes or where there are higher ridges to the south (greater angles from

TABLE 3

PREDICTION EQUATION FOR YELLOW POPLAR SITE INDEX

Variable(s)	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression Correlation
Step Number 1						
X_9	12.10716	0.49934	3.45352	12.290**	0.24934	0.49934
(Constant)	75.34914					
Step Number 2						
X_9	13.09921	0.54026	3.28660	15.885**		
X_{13}	-127.37196	-0.31897	54.12884	5.537*	0.34931	-0.24967
(Constant)	78.49201					

Standard error of the estimate = 12.58 feet.

* Significant at 5% level
** Significant at 1% level

the plot to the ridge to south) and decrease with decreasing distance to the ridge top.

Aspect and position on slope were found to be important factors influencing yellow poplar site quality by Auten (1935) and Minckler (1941). As explained by Olson (1958) these factors as well as elevation are important because they indirectly influence the moisture and nutrient-supply of the soil as well as the microclimate. Della-Bianca and Olson (1961), studying productivity of soils in near-climax piedmont forests of South Carolina, North Carolina and Southern Virginia, found that site index of yellow poplar was highest on lower slopes.

Auten (1945), working in the Southern Appalachians, studied the influence of soil and topography of yellow poplar. According to his results, yellow poplar is seldom found on hot upper south slopes with a southern aspect. He found that site index is influenced with changes in elevation more than 50 feet. Ike and Huppuch (1968) working in Georgia found that site index for this species was related primarily to topographic position. Smalley (1964) indicated that height growth rate was less on southerly slopes than northerly slopes. Similar results related to the effect of topographic position on growth of yellow poplar were found by Schomaker (1958).

Basal Area Growth of Plots with Chestnut Oak

Characteristics of the regression equation on basal area growth of plots with chestnut oak are given in Appendix Table 18. This equation includes 15 independent variables ($\alpha = 0.01$). It explains 65% of the variation on growth over a 10-year period. The standard error of the estimate is ±0.07099 square feet.

Taking into consideration the level of significance of the individual regression coefficients only two of the variables, chestnut oak basal area growth (X_{17}) and chestnut oak site index (X_{23}) were found valuable for the prediction of basal area growth. Statistical information about this prediction equation is presented in Table 4. The two variables in the prediction equation account for 58% of the variation in basal area growth with a standard error of the estimate of ±0.06581 square feet ($\alpha = 0.01$).

Total basal area growth of each plot is positively correlated with chestnut oak basal area growth, their correlation coefficient being 0.72. In the prediction equation it drops to 0.53. Nevertheless chestnut oak basal area growth accounted for almost 90% of the explanation of the variance in basal area growth.

The contribution of the site-index variable to the prediction of basal area growth was less than would be expected. Chestnut oak site index contributes only near 10% of the variance in basal area growth when functioning as indicator species. As well as that of the accompanying variable, the correlation is positive as expected.

TABLE 4

PREDICTION EQUATION FOR BASAL AREA GROWTH (10-YEAR PERIODIC GROWTH) BASED ON CHESTNUT OAK BEHAVIOR

Variable(s)	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression Correlation
Step Number 1						
X_{17}	1.12520	0.72718	0.15331	53.867**	0.52880	0.72718
(Constant)	0.05337					
Step Number 2						
X_{17}	1.03668	0.66997	0.15110	47.071**		
X_{23}(1)	0.20545	0.23159	0.08663	5.624*	0.57916	0.39709
(Constant)	-0.31480					

Standard error of the estimate = 0.07099 square feet.

* Significant at 5% level
** Significant at 1% level

(1) Site index = log. site index

Basal Area Growth on Plots With White Oak

The regression equation obtained considering basal area growth as dependent variable and data concerning plots with white oak as independent variables was not statistically significant. Consequently a prediction equation could not be obtained.

Basal Area Growth of Plots With Yellow Poplar

A regression equation on basal area growth based on the variables related to yellow poplar with four variables was found significant (α = 0.05). Statistical information of the equation is presented in Appendix Table 19. These four variables all together accounted for only 24% of the variation on basal area growth. A prediction equation could not be obtained using these results.

Chestnut Oak Basal Area Growth

The regression analysis using chestnut oak basal area growth as the dependent variable and the plot data with this species as independent variables did not produce statistically significant results. Consequently a prediction equation could not be obtained.

White Oak Basal Area Growth

The analysis using white oak basal area as the dependent variable and the plot data with this species as independent variables did not produce statistically significant results. Consequently, no prediction equation could be obtained.

Basal Area Growth of Yellow Poplar (10-Year Period)

The regression equation (Appendix Table 20) for this dependent variable includes 14 independent variables. The standard error of the estimate is ±0.03344 square feet ($\alpha = 0.05$). These variables explain 60% of the variance on yellow poplar basal area in a growth period of 10 years. From these data a prediction equation (Table 5) including three variables was developed ($\alpha = 0.01$).

Yellow poplar growth can be predicted using altitude (X_{11}), exposure (X_{26}), and logarithm of langleys/basal area of the plot (X_1). The level of significance of the prediction equation is 1% with a standard error of ±0.03552 square feet. The variation explained is 35% and all the regression coefficients are significant ($\alpha = 0.05$).

The three variables (X_{11}, X_{26}, and X_1) that were significant in prediction of basal area growth for yellow poplar are climatic-topographic in nature. The only stand variable that appears is basal area of the plot which is performing as denominator of the logarithm of potential radiation. All independent variables are positively correlated with basal area growth of yellow poplar.

The Independent Variables

Logarithm of Langleys/Basal Area. This is a compound variable that represents the ratio between the logarithm of potential radiation and the basal area of the plot. The numerator is the logarithm of the

TABLE 5

PREDICTION EQUATION FOR BASAL AREA GROWTH OF YELLOW POPLAR (10-YEAR PERIODIC GROWTH) PLOTS WITH THE SPECIES

Variable(s)	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression Correlation
Step Number 1						
X_{11}	0.00000	0.44822	0.00000	9.302**	0.20090	0.44822
(Constant)	-0.01405					
Step Number 2						
X_{11}	0.00000	0.39160	0.00000	7.231**		
X_{26}	0.11754	0.26937	0.06354	3.421*	0.27025	0.35168
(Constant)	-0.02624					
Step Number 3						
X_{11}	0.00000	0.29871	0.00000	4.160*		
X_{26}	0.15039	0.34465	0.06287	5.722*		
X_1	0.04903	0.30152	0.02369	4.283*	0.34981	0.31413
(Constant)	-0.28229					

Standard error of the estimate = 0.03552 square feet.

* Significant at 5% level
** Significant at 1% level

number obtained from Fribourg's (1972) program. It is the result of several elements including latitude, azimuth and slope percent calculated for a specific situation. The ratio as a whole is correlated negatively with chestnut oak site index. This compound variable accounts for 32% of the observed variation for the chestnut oak site index. It represents 64% of the amount of variation explained by the prediction equation.

The compound variable (X_1) compounds two of the factors that more commonly appear in soil site studies, namely azimuth and slope percent.

1. Azimuth. Many research publications have indicated that azimuth is an important factor in tree growth. Yawney (1964) found lowest site indices of oaks on slopes with southwest aspects and highest on northeast aspects of the Belmont soils in West Virginia. Trimble (1964) and Trimble and Weitzman (1956), for the mountainous areas of West Virginia and Maryland, reported higher site indices of upland oaks on the north and east slopes than on the south and west slopes. Carmean (1965) reported a similar relationship on medium-textured well-drained soils of Southeastern Ohio.

   Azimuth as an independent variable proved to be an important factor in the prediction of yellow poplar site index. This factor and arctangent of exposure squared were the only two variables significant for this purpose. As in the case of chestnut oak site index, azimuth was positively correlated with yellow poplar site index. The high correlation found between the compound variable (logarithm of langleys/basal area, X_1) that includes azimuth, and azimuth made it impossible for both of them to be included in the same prediction equation. In this case the effect of azimuth is considered to be masked by the other variables included in the compound variable.

2. Slope percent. As with azimuth, slope percent showed to be highly correlated (-0.40) to the compound variable (X_1) and was not significant in any of the steps of the regression analysis. If these assumptions are valid, it follows that the variable obtained from Fribourg's program integrates topographic and climatic factors in a sensible way.

3. Basal area. Basal area is correlated (0.45 with chestnut oak site index and much more so with the compound variable (-0.85). Basal area was also included as a single independent variable and through several transformations in the regression analysis, none of them were significant after the compound variable was included. The correlation coefficient between the potential radiation alone and chestnut oak site index is -0.39. When divided by basal area this correlation coefficient increases to -0.56. According to the prediction equation as basal area increases chestnut oak site index increases. This may be expected from "fully stocked" stands. In addition to slope position and the per-

cent of clay in the surface horizon, McClurkin (1963) found it necessary to include basal area and stand age to arrive at workable prediction equation for white oak in Northern Mississippi and Western Tennessee.

Gevorkiantz and Scholz (1944) studying forest productivity in oak forests of the Upper Mississippi Valley found that in "partially stocked" stands height growth was retarded and diameter growth accelerated, while in very dense forests, growth trends were reversed. They assumed that at a given age, the greater the average volume of trees comprising the main overstory, the better the site. They stated that this concept is universally accepted and is fundamental to the use of height as an index of site as an approximation of volume in "fully stocked" stands.

As the forest under study has been considered "understocked" (Martin, 1970) it appears a contradiction with the results of the present study. It is true that because of past exploitation the Scott forest has not yet reached its "normal" density. However, because of the site characteristics some stands will probably never reach the standards of density normally desired. Furthermore as chestnut oak was not a merchantable species at the time cuttings were made, it is possible that stands with chestnut oak have been relatively undisturbed. Consequently their basal area may be considered an expression of site potentiality.

Basal area is often regarded as the standard unit for measuring stand density (Bruce and Schumacher, 1935; Spurr, 1952; Stahelin, 1949). Eyre and Zillgitt (1953) considered that even with unbalanced structure, basal area may be an acceptable measure of density in many-sized stands. Bickford et. al. (1957) stated that there can be no doubt that basal area will be used as a measure of density in many-aged stands for some time to come.

Beck (1971) exploring the effect of stand density on site index for white pine in the Southern Appalachians found no significant association between height growth and stand density. On the same topic Holmes and Stackle (1962) pointed out that within a narrow range of stand density, height growth of dominant and codominant trees probably expresses land quality as well as does stand basal area because it too is reasonably well correlated with several land qualities.

In view of the wide range of densities occurring in natural stands, regardless of site quality, stand basal area appears the more logical measure of productivity unless dominant height can be adjusted for density. Consequently they considered that the evaluation of land for growth of future stands requires a criterion that is at least partially independent of existing stand conditions. Stand basal area, although closely correlated with stand age, is not closely correlated with number of stems. Therefore within an age group, or in older stands where the annual percentage in basal area is small, basal area appears sufficiently independent of age and density to be a reliable reflection of site quality.

Basal area growth. This variable was the second significant variable in the prediction equation on chestnut oak site index ($\alpha = 0.01$). The correlation is positive. It implies that site index for this species increases as the basal area growth increases. The inverse appears to be true, which constitutes one of the postulates of site evaluation, under the standard of site index. The importance of this result can be remarked since as pointed out by Bickford (1957) the correlation of net or gross growth with growing stock, intuitively expected, has not been established in many cases where plots have been remeasured. Trimble (1969) found that growth was positively correlated with site quality.

Furthermore as stated by Carmean (1970a) the yield of wood products is the final criterion of site quality; hence, we should strengthen our knowledge of the relation between yield and site index. Growth in basal area can be obtained from measurements on permanent plots, like in the present case, or directly estimated from increment cores taken in the stand if this is deemed an applicable source.

Position of the plot on the slope. This variable appears both in the prediction equations on site index of chestnut oak and white oak. Site index of chestnut oak is positively correlated to slope position and constitutes the third and last variable in the prediction equation. In this pattern position on slope is affecting chestnut oak site index in addition to the logarithm of potential radiation to basal area ratio, basal area growth and slope position. Position of the plot on the slope is significant at 1% level in the prediction equation on site index of chestnut oak and the correlation is positive. Azimuth and slope percent are included in the first of the variables of the regression equation. Then it is not surprising that position on slope resulted significant in predicting chestnut oak site index as these three variables have consistently been found significant in site evaluation of oaks.

Position on slope is also included in the white oak site index prediction equation with azimuth, white oak basal area growth squared and basal area growth for all the species. Its significance in this case is only at the 5% level, however.

For both species, the correlation of slope position with site index in the context of the prediction equations means that site quality improves with increasing the distance from the ridge. The other conditions being equal for both species, this relationship is stronger for white oak than for chestnut oak.

These better conditions for growth as explained by Hewlett (1961) are no doubt partially due to additions of gravitational water flow from upper slope positions; and to more favorable microclimatic conditions found on lower slopes (Hannah, 1968). Smalley (1967) found that slope position and total slope length plus distance from the plot center to the ridge were the topographic factors associated with white oak tree height in upland oaks in North Alabama.

White oak basal area growth. This stand variable, when squared, was significant in white oak site index prediction ($\alpha = 0.05$). The regression coefficient is positive which indicates that as white oak basal area growth increases site index increases. The regression coefficient is zero; however the Beta coefficient is 0.46, almost as high as that of azimuth, the variable which explains most of the variance of site index for this species.

Arctangent of exposure. This variable, squared, was introduced in the analysis in an effort to supply an element that obviously Fribourg's program does not take into account, the effect of the surrounding land masses. In view of the numerous elements plugged into the program, the way this variable could be considered for this purpose was not clear; variables X_{11} and X_{12} were included for the same objective. In spite of the fact that the prediction equation on site index of yellow poplar explains but a relatively low percentage of its variance (35%), the fact that it is reached with only climatic-topographic factors may be considered satisfactory.

Site Indices From Harmonized Curves

Site index estimations obtained from harmonized curves ranged from

37 to 105 for chestnut oak; from 36 to 104 for white oak; and from 59 to 124 for yellow poplar. These estimations are shown in Appendix Tables 21, 22, and 23.

Table 6 presents average of site index estimations for the three species, and their standard deviations. Average site index ranged from 61.5 feet for white oak to 89.5 feet for yellow poplar. Standard deviations ranged from 10.7 feet (white oak) to 16.1 feet (chestnut oak).

Comparison of the site index results of the present studies to those obtained in previous reports are presented in Table 7. Site index of the species considered in the present study are similar to those obtained elsewhere in the region. The differences are greater in the upper parts of the ranges for chestnut oak and white oak. This suggests that there is an overestimation on site index when applying harmonized curves to upland oaks.

Site Indices Using Polymorphic Curves

Site index estimations from polymorphic curves are included in Appendix Tables 24 and 25. Values were consistently lower than those obtained from harmonized curves for both chestnut oak and white oak.

For chestnut oak site index differences between the two methods ranged from 0 to -8 feet. It was impossible to obtain polymorphic site index values for seven of the trees because they were outside the range for which the curves were prepared. These trees were over 100 years in age.

TABLE 6

CHARACTERISTICS OF THE SAMPLE ACCORDING TO HARMONIZED SITE INDEX (TOTAL NUMBER OF PLOTS STUDIED - 99)

Species	Plots	Age Range	Height Range	Harmonized Site Index	
					Standard Deviation
	No.	(years)	(feet)		
Chestnut Oak	50	29-145	46-105	37 (65) 92	16.1
White Oak	25	38-135	37-92	36 (62) 104	10.7
Yellow Poplar	41	21-145	52-110	59 (90) 124	15.4

TABLE 7

COMPARISON OF SITE INDEX VALUES OBTAINED IN THE PRESENT STUDY WITH THOSE OF PREVIOUS REPORTS

		Site Index							
		Mean				Range			
Species	Number of Plots	Present Study	Georgia Mountains[1]	Virginia Carolina Piedmont[2]	Southern Appalachians[3]	Present Study	Georgia Mountains[1]	Virginia Carolina Piedmont[2]	Southern Appalachians[3]
Chestnut oak (Q. prinus L.)	50	65	65	--	59	37-105	39-83	---	35-80
White oak (Q. alba L.)	25	62	65	69	59	36-104	32-90	49-90	42-81
Yellow poplar (Liriodendron tulipifera L.)	41	90	92	83	88	59-124	65-123	55-122	55-121

(1) Ike and Huppuch, 1968

(2) Olson and Della-Bianca, 1959

(3) Doolittle, 1958

Differences between white oak site index values obtained from the two methods ranged from +3 to -24. Values obtained from polymorphic curves were usually lower than values obtained by using the harmonized curves. Site index values from polymorphic curves were obtained for all the trees except one which was outside the range for which the curves were prepared. This tree was over 100 years.

From the 99 plots of the tract, characterization of site index values was possible for 87 of them; 50 plots with chestnut oak, 25 with white oak, and 41 with yellow poplar. Only two plots have site index values for all three species, and twenty-four for two of them. Table 8 presents plots with site index values for more than one species.

Site Index Comparisons

Chestnut oak basal area growth was studied in 62 of the 99 plots on the tract. Of the 62 plots, 50 were used to develop a chestnut oak site index. In 33 of the plots, chestnut oak accounted for more than 30% of the basal area stocking. On the other hand, there is white oak data on basal area for only 35 plots and to 25 of them were assigned site index values. Only 7 of the plots presented more than 1/3 of the basal area of the plot. From 60 plots with basal area growth information on yellow poplar 41 have site index values and only 10 plots presented more than 30 percent of the total basal area of the plot.

TABLE 8

SITE INDEX VALUES FOR PLOTS WITH MORE THAN ONE CHARACTERISTIC SPECIES

Plot Number	Chestnut Oak	White Oak	Yellow Poplar
6	44	45	
8	89	60	
12	47		82
27		58	86
28	58	50	
32	38		68
35	72		66
37	53	44	
39	56		
42	63		75
49	93		104
50	68	64	88
54		73	98
60		57	61
61	66	53	
63		68	83
72	85	56	
81	92		90
83		66	94
86	85		78
88	67		124
93	92		79
94	69		59
95	76	36	
98	91	72	98
99	80		88

CHAPTER VI

CONCLUSIONS

The following conclusions were drawn relative to the studies carried out at Scott County Forest reported here:

1. Site index of chestnut oak can be estimated ($r^2 = 0.50$) using logarithm of langleys/basal area ratio (X_1), total basal area growth ten-year periodic growth (X_{14}) and slope position (X_6) as independent variables.

2. Site index of white oak can be estimated ($r^2 = 0.45$) using azimuth (X_9), slope position (X_6), white oak basal area growth squared (ten-year periodic growth) (X_{21}), and total basal area growth (ten-year periodic growth) of the study plot (X_{14}) as independent variables.

3. Yellow poplar site index can be estimated ($r^2 = 0.35$) using azimuth (X_9) and effect of surrounding land masses, arctangent exposure (X_{13}) as independent variables.

4. Total basal area growth (ten-year periodic growth) of the study plots with chestnut oak can be estimated ($r^2 = 0.58$) using chestnut oak basal area growth (ten-year periodic growth) (X_{17}) and chestnut oak site index (X_{23}) as independent variables.

5. Basal area growth on plots with white oak cannot be predicted with independent variables used in the present study.

6. Basal area growth on plots with yellow poplar cannot be predicted with the independent variables used in the present study.

7. Chestnut oak basal area growth (ten-year periodic growth) cannot be predicted with the independent variables analyzed in the present study.

8. White oak basal area growth (ten-year periodic growth) cannot be predicted with the independent variables used in the present study.

9. Basal area growth of yellow poplar (ten-year periodic growth) can be estimated ($r^2 = 0.35$) using altitude (X_{11}), exposure percent (X_{26}), and logarithm of langleys/basal area ratio (X_1) as independent variables.

10. Among the variables included in the prediction models azimuth (X_9), the most useful for estimating site productivity, was included in the prediction equation for both white oak and yellow poplar. Also, azimuth forms part of the logarithm of langleys/basal area ratio (X_1), which was the most important variable in the chestnut oak site index prediction and was included in the prediction equation for basal area growth of yellow poplar.

11. Slope position (X_6), the second most important factor, was included in the prediction equations for chestnut oak and white oak site indices.

12. Stand variables also proved to be important for site evaluation in the Scott County Forest. Basal area of the plot (X_{15}), total basal area growth (ten-year periodic growth) (X_{14}) were important factors in the prediction models of site index for chestnut oak and white oak.

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APPENDIX

TABLE 9

DATA FOR THE ANALYSIS OF THE EFFECT OF SURROUNDING LAND MASSES

Plot No.	Altitude of Highest Ridge to South (feet)	Altitude of the Plot (feet)	Distance from the Plot to the Highest Ridge to South (feet)
1	2800	1410	08900
2	2800	1430	10000
3	2800	1460	13800
4	2700	2260	02100
5	2700	2540	06000
6	2800	1530	09800
7	2800	1950	10600
8	2500	2060	08300
9	2800	1400	06700
10	2800	1520	07800
11	2600	2400	02900
12	2600	2440	04100
13	2700	2370	11300
14	2700	2420	10200
15	2600	2540	00200
16	2800	2400	03100
17	2800	2320	01500
18	2700	2070	04500
19	2800	1600	01800
20	2800	1460	15800
21	2700	1470	14900
22	2700	1800	06500
23	2800	2560	00600
24	2800	2780	00100
25	2800	2700	09100
26	2800	2700	00300
27	2500	2400	12200
28	2700	2600	10400
29	2700	2600	12600
30	2800	1500	15500
31	2700	1700	16100
32	2800	1620	14800

TABLE 9 (continued)

Plot No.	Altitude of Highest Ridge to South (feet)	Altitude of the Plot (feet)	Distance from the Plot to the Highest Ridge to South (feet)
33	2600	1780	12700
34	2800	1500	13700
35	2800	1480	11700
36	2700	1560	12600
37	2800	1700	11500
38	2800	1680	12800
39	2600	2200	10500
40	2800	2150	01800
41	2800	1920	02500
42	2800	1950	03900
43	2800	1640	04700
44	2800	1620	06100
45	2700	1570	10500
46	2800	1920	09200
47	2900	2630	10300
48	2700	2650	00700
49	2700	2200	11200
50	2600	2030	10600
51	2800	1700	07300
52	2600	2000	02500
53	2800	2000	05200
54	2800	1670	05700
55	2600	2200	02300
56	2500	1550	07600
57	2300	1410	06300
58	2100	1500	05000
59	1900	1450	08400
60	1500	1440	02400
61	2300	1500	02300
62	2700	2500	02100
63	2800	1500	07300
64	2600	1500	08500
65	2300	1800	08100
66	2500	2120	09500
67	2500	1800	05400

TABLE 9 (continued)

Plot No.	Altitude of Highest Ridge to South (feet)	Altitude of the Plot (feet)	Distance from the Plot to the Highest Ridge to South (feet)
68	2800	1910	03500
69	2500	2330	01300
70	2800	2290	10400
71	2500	2260	03300
72	2300	2110	01900
73	2600	2150	09300
74	2700	2000	10800
75	2100	1620	03000
76	2300	2040	04300
77	2600	2330	03500
78	2700	2340	04600
79	2800	2030	04900
80	2800	2700	00100
81	2600	1600	11500
82	2800	1720	11600
83	2600	1500	19600
84	2600	1550	07300
85	2700	1650	08600
86	2700	1700	06500
87	2600	1850	07100
88	2700	1820	08000
89	2400	1940	04300
90	2700	1740	06000
91	2600	1640	05200
92	2300	1640	08900
93	2200	1750	01200
94	2400	2100	01000
95	2200	2140	05700
96	2600	2100	05300
97	2300	1600	06000
98	2300	1900	06900
99	2700	1950	04500

TABLE 10

YEARLY AND SEASONAL POTENTIAL RADIATION ON SLOPING GROUND

Plot	Azimuth from North	Slope	Potential Radiation[1] Yearly Langleys	Yearly Slope/Flat Ratio [3]	Seasonal[2] Langleys	Seasonal Slope/Flat Ratio [4]
No.	(degrees)	%	No.	%	No.	%
1	275	24	236183.8	88.95	156610.3	90.25
2	28	23	195623.3	73.67	151754.7	87.45
4	82	11	257265.5	96.89	170074.2	98.01
5	2	33	126576.6	47.67	122047.7	70.85
6	238	15	282840.2	106.52	174219.6	100.40
7	225	35	293636.5	110.58	160903.9	92.73
8	260	32	240570.6	90.60	150027.2	86.46
9	68	2	263240.1	99.14	172996.2	99.69
11	71	68	105427.4	39.70	83889.1	48.34
12	198	57	288405.4	108.61	128876.9	74.27
14	14	2	259667.9	97.79	172157.1	99.21
15	290	40	176593.4	66.50	129502.5	74.63
16	236	22	286796.7	108.01	171166.3	98.64
17	330	58	95427.4	35.94	104843.4	60.42
18	60	31	211015.8	79.81	153759.5	88.61
19	18	61	108812.5	40.98	115331.4	66.46
21	22	29	167752.2	63.18	140876.3	81.18
22	70	46	183420.4	69.08	132800.8	76.53
23	20	25	180059.3	67.81	145760.9	84.00
26	55	42	187040.5	70.44	143112.4	82.47
27	218	39	299237.9	112.69	157797.1	90.93
28	290	31	199778.6	75.24	142709.6	82.24
29	200	22	308027.4	116.00	175297.4	101.02
30	15	51	86640.8	32.63	105060.4	60.54
31	322	21	194937.1	73.41	148492.9	85.57
32	270	30	230022.8	86.63	149844.8	86.35
33	0	38	100308.4	37.78	111103.8	64.03
34	302	9	246624.8	92.88	167299.1	96.41
35	190	35	309162.0	116.43	161473.2	93.05

TABLE 10 (continued)

			Potential Radiation[1]			
			Yearly		Seasonal[2]	
Plot	Azimuth from North	Slope	Langleys	Slope/Flat Ratio (3)	Langleys	Slope/Flat Ratio (4)
No.	(degrees)	%	No.	%	No.	%
37	225	4	273530.8	103.01	175082.8	100.90
38	354	42	81305.7	30.68	102135.1	58.86
39	45	13	236267.6	88.98	165482.7	95.36
40	10	32	138893.7	52.31	128560.1	74.09
42	65	28	201507.3	75.89	146111.9	84.20
43	290	46	160876.3	60.59	120033.2	69.17
44	68	55	155826.5	58.68	117256.6	67.57
45	260	28	249002.4	93.77	156235.1	90.03
46	32	52	142082.1	53.51	129240.9	74.48
47	72	30	221815.9	83.54	154137.7	88.83
48	88	10	260693.6	98.18	170935.0	98.51
49	150	32	262523.9	98.87	144078.0	83.03
50	152	55	184093.1	69.33	80619.2	46.46
51	222	52	251518.2	94.72	122557.9	70.63
52	10	47	75380.9	28.39	99634.8	57.42
53	10	45	82336.3	31.01	102946.8	59.33
54	10	36	120636.0	45.43	120558.3	69.48
56	180	45	282948.7	106.56	136959.1	78.93
57	330	16	210043.4	79.10	155182.9	89.43
58	344	36	116528.9	43.88	117637.3	67.79
60	320	30	165020.3	62.15	135543.2	78.11
61	190	32	309865.9	116.69	165024.0	95.10
62	225	52	243331.1	91.64	119709.8	68.99
63	247	25	271975.6	102.43	164865.9	95.01
64	162	26	286486.2	107.89	160243.2	92.34
65	142	57	160580.0	60.47	70596.8	40.68
66	108	55	151618.3	57.10	87380.8	50.36
67	285	47	163659.8	61.63	118145.7	68.08
68	282	34	202954.6	76.43	140281.2	80.84
69	20	2	259870.4	97.87	172212.0	99.24
70	290	19	230050.3	86.64	158472.8	91.32
71	75	27	229266.1	86.34	157033.1	90.49

TABLE 10 (continued)

Plot	Azimuth from North	Slope	Potential Radiation(1) Yearly Langleys	Yearly Slope/Flat Ratio (3)	Seasonal(2) Langleys	Seasonal Slope/Flat Ratio (4)
No.	(degrees)	%	No.	%	No.	%
72	110	18	262350.2	98.80	165164.2	95.18
73	138	41	221603.1	83.46	118281.7	68.16
74	125	56	151848.2	57.19	75899.2	43.74
75	308	34	168427.5	63.43	132932.6	77.18
76	278	41	189439.5	71.34		
77	230	41	272673.3	102.69		
79	325	29	162831.8	61.32	135460.4	78.06
80	268	18	254650.8	95.90	165300.7	95.26
81	2	38	101468.3	38.21	111690.7	64.36
82	330	34	140045.2	52.74	126395.2	72.84
83	62	20	233132.1	87.80	162800.0	93.82
84	312	21	203170.8	76.51	150587.8	86.78
85	110	36	220777.7	83.14	134061.6	77.26
86	312	64	100980.5	38.03	97496.7	56.19
87	145	42	225776.9	85.03	116982.2	67.41
88	112	30	238917.7	89.98	146105.3	84.20
89	138	35	241639.6	91.00	133955.9	77.20
90	314	62	104023.6	39.18	100833.7	58.11
91	298	45	154334.7	58.12	121540.3	69.99
92	300	37	171256.8	64.49	132055.1	76.10
93	338	45	96753.5	36.44	108198.5	62.35
94	278	28	223377.4	84.12	150319.7	86.63
95	154	16	286981.3	108.08	171092.1	98.60
96	18	45	107553.3	40.50	114803.6	66.16
98	122	30	244264.8	91.99	145004.4	83.56
99	295	51	142725.9	53.75	112373.5	64.76

(1) Potential Langleys per day. After Fribourg (1972).

(2) From 4 April through October (growth season).

(3) Level ground value = 265535.4 at 36.23 degrees.

(4) Level ground value = 173527.5.

TABLE 11

POSITION OF THE PLOTS ON SLOPES

Plot	Distance from Ridge to the Plot	Distance from Ridge to the Stream	Position
No.	(1000 feet)	(1000 feet)	%
1	11	11	100
2	12	12	71
3	04	05	80
4	02	13	15
5	03	14	21
6	24	27	89
7	10	27	37
8	12	12	100
9	21	22	95
10	07	14	50
11	04	13	31
12	04	06	67
13	04	13	31
14	02	13	15
15	02	11	18
16	01	10	10
17	02	11	18
18	03	08	38
19	05	09	56
20	03	05	60
21	01	05	20
22	06	11	55
23	02	20	10
24	00	27	1
25	05	11	46
26	04	11	36
27	08	08	100
28	00	19	1
29	04	11	36
30	01	05	20
31	02	08	25
32	07	14	50
33	06	16	38
34	11	25	44

TABLE 11 (continued)

Plot	Distance from Ridge to the Plot	Distance from Ridge to the Stream	Position
No.	(1000 feet)	(1000 feet)	%
35	08	12	67
36	03	13	23
37	01	05	20
38	08	19	42
39	00	13	1
40	18	18	100
41	25	31	81
42	08	16	50
43	03	10	30
44	13	23	57
45	08	15	53
46	09	09	100
47	02	10	20
48	00	21	1
49	13	19	68
50	18	25	72
51	12	17	71
52	07	07	100
53	06	08	75
54	10	11	91
55	00	12	1
56	03	13	23
57	25	26	96
58	05	11	46
59	21	25	84
60	04	09	44
61	14	17	82
62	08	20	40
63	16	18	89
64	05	09	56
65	08	08	100
66	03	16	19
67	07	15	47
68	23	23	100
69	14	18	78
70	00	35	1

TABLE 11 (continued)

Plot No.	Distance from Ridge to the Ridge (1000 feet)	Distance from Ridge to the Stream (1000 feet)	Position %
71	04	06	67
72	04	08	50
73	02	06	33
74	03	25	12
75	01	06	17
76	05	06	83
77	04	19	21
78	06	16	38
79	00	08	1
80	01	07	14
81	05	11	46
82	11	13	85
83	07	17	41
84	04	07	57
85	12	21	57
86	04	08	50
87	14	24	58
88	03	14	21
89	05	09	56
90	02	03	67
91	04	05	80
92	02	15	13
93	07	08	88
94	03	07	43
95	03	15	20
96	05	07	71
97	03	04	75
98	06	15	40
99	13	25	52

TABLE 12

DATA USED FOR GROWTH ANALYSIS, SCOTT COUNTY FOREST TRACT, 1962

			Chestnut Oak		White Oak		Yellow Poplar	
Plot	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area
No.	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)
1	17	0.549425			1	0.021178		
2	17	0.636471			10	0.394390		
3	13	0.530405						
4	8	0.245762					4	0.128839
5	12	0.230639					2	0.046597
6	14	0.494206	3	0.137056	3	0.108031	2	0.044438
7	11	0.438858	9	0.384691				
8	11	0.589299	1	0.049462	2	0.088726	2	0.072245
9	21	0.718589					1	0.025475
10	11	0.514984			1	0.024731		
11	15	0.532093					1	0.063075
12	8	0.495909	5	0.314823			1	0.096326
13	12	0.690054	6	0.401811	2	0.152730	1	0.049721
14	6	0.301396	4	0.205511				
15	16	0.791380					5	0.195917
16	6	0.179549	4	0.124165				
17	11	0.802856					1	0.063643
18	7	0.295094	2	0.112193				
19	15	0.587323	6	0.165979				
20	10	0.844977	1	0.303625				
21	21	0.819543			9	0.372270		

TABLE 12 (continued)

			Chestnut Oak		White Oak		Yellow Poplar	
Plot	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area
No.	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)
22	15	0.650713	1	0.145719				
23	19	1.092906	2	0.097756				
24	15	0.478105					2	0.059326
25	17	0.807616			1	0.048727		
26	22	0.777692					22	0.777692
27	17	0.688960			3	0.169762	6	0.248882
28	16	0.965023	6	0.467765	4	0.120906		
29	15	0.809858			4	0.229449		
30	24	1.160859			8	0.335595	1	0.146989
31	13	0.628408	7	0.212970				
32	2	0.073168	1	0.053991				
33	9	0.382490	4	0.247172			3	0.082864
34	14	0.598152	1	0.038355	1	0.071402		
35	23	0.857865			4	0.107458	2	0.086658
36	1	0.111289	1	0.111289				
37	15	0.641702	3	0.276801	4	0.103072		
38	14	0.580732						
39	19	0.857301	7	0.433916	3	0.083377		
40	11	0.449967					4	0.139973
41	12	0.867107	1	0.035799			1	0.014330
42	19	0.804858	7	0.258182				
43	8	0.597763	4	0.422322				
44	16	0.727002	5	0.184303			2	0.099045

TABLE 12 (continued)

Plot	Trees	Basal Area	Chestnut Oak Trees	Chestnut Oak Basal Area	White Oak Trees	White Oak Basal Area	Yellow Poplar Trees	Yellow Poplar Basal Area
No.	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)
45	23	0.905608	3	0.108807	4	0.148221		
46	18	0.889376	1	0.026995			3	0.115380
47	7	0.404317			4	0.240341		
48	20	1.167041			8	0.489330		
49	18	0.666626	10	0.303096			1	0.050773
50	18	1.022131	7	0.363521	1	0.034383	2	0.099174
51	9	0.388578	7	0.288197				
52	24	1.100856					12	0.442116
53	22	0.936361					1	0.064483
54	24	1.122411			2	0.080308	7	0.297050
55	2	0.043920						
56	16	0.653115			5	0.207280		
57	20	0.776907					3	0.142673
58	15	1.013405			3	0.060425	3	0.095095
59	18	0.891461			1	0.024731		
60	11	01501605			2	0.056222	1	0.074088
61	15	0.708827	1	0.021178	2	0.117655		
62	19	0.949148	12	0.746461				
63	20	0.711308			1	0.048727	3	0.067890
64	15	0.738880	1	0.060739	6	0.282357		
65	20	0.824328	1	0.085327	1	0.041675	4	0.124189
66	15	0.619753	7	0.352242				
67	2	0.056886	2	0.056886				

TABLE 12 (continued)

			Chestnut Oak		White Oak		Yellow Poplar	
Plot	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area
No.	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)
68	18	0.606798	3	0.148298			5	0.154490
69	10	0.455228	3	0.119851			6	0.227385
70	8	0.393820	3	0.153275	1	0.041699		
71	16	0.522146	2	0.063742			3	0.058007
72	8	0.313864	4	0.213899	1	0.027772		
73	4	0.387850	4	0.223851				
74	12	0.667516	6	0.406455				
75	13	0.616701	1	0.135759				
76	28	1.112565	9	0.462583				
77	13	0.428665	2	0.083498				
78	13	0.674284	1	0.064260				
79	19	0.953172	2	0.111512			4	0.105001
80	8	0.521863	3	0.241935				
81	20	1.416945	1	0.126151			1	0.154724
82	19	0.813728					8	0.315043
83	14	0.943377			6	0.198101	2	0.068777
84	25	0.915294					11	0.318908
85	21	0.836129	2	0.033606				
86	22	1.014435	2	0.081669	1	0.032664	3	0.105215
87	12	0.525006	1	0.104744			1	0.033331
88	18	0.905154	1	0.043639			3	0.128553
89	14	0.577779	4	0.153614			6	0.259727

TABLE 12 (continued)

Plot	Trees	Basal Area	Chestnut Oak Trees	Chestnut Oak Basal Area	White Oak Trees	White Oak Basal Area	Yellow Poplar Trees	Yellow Poplar Basal Area
No.	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)
90	22	0.702397	8	0.250279			3	0.150526
91	15	0.498203	1	0.040746				
92	13	0.785637	3	0.204547				
93	19	0.753724	7	0.429090			2	0.056607
94	4	0.117611	2	0.077405			1	0.024731
95	13	0.729925	4	0.389776	1	0.061902		
96	4	0.229496					2	0.120837
97	6	0.124305						
98	14	0.500079	5	0.185000	2	0.084432	1	0.045622
99	18	0.577363	5	0.224265			2	0.049859

TABLE 13

DATA USED FOR GROWTH ANALYSIS, SCOTT COUNTY FOREST TRACT, 1972

			Chestnut Oak		White Oak		Yellow Poplar	
Plot	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area
No.	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)
1	20	0.652779			2	0.040372		
2	17	0.621511			10	0.038652		
3	14	0.590004						
4	10	0.373653					5	0.187986
5	16	0.429236					4	0.172268
6	15	0.589271	3	0.154540	3	0.122184	2	0.051842
7	11	0.451019	9	0.411392				
8	15	0.725051	1	0.060337	2	0.115176	5	0.144138
9	23	0.752250					1	0.036146
10	10	0.502765			1	0.028560		
11	16	0.641958					1	0.047272
12	9	0.556607	6	0.361902			1	0.124974
13	13	0.744780	6	0.397814	2	0.176720	1	0.035174
14	6	0.323690	4	0.206618				
15	18	0.916263					6	0.270650
16	12	0.332058	10	0.262085				
17	12	0.964167					1	0.083399
18	8	0.377956	3	0.165613				
19	17	0.711598	6	0.226862				
20	10	0.916614	1	0.335516				
21	20	0.835710			10	0.457341		

TABLE 13 (continued)

			Chestnut Oak		White Oak		Yellow Poplar	
Plot	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area
No.	No.	(sq. ft)	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)
22	17	0.837041	2	0.244293				
23	20	1.249891	2	0.088481				
24	16	0.617514					2	0.109628
25	15	0.715041			1	0.053222		
26	21	0.869512					21	0.869512
27	18	0.789328			3	0.183111	7	0.300501
28	18	1.128179	6	0.498487	4	0.146425		
29	13	0.704700			4	0.252959		
30	25	1.243104			8	0.326667	1	0.150832
31	13	0.498719	8	0.253733				
32	3	0.100511	1	0.061979				
33	13	0.540384	4	0.290596			5	0.160396
34	14	0.663508	1	0.043732	1	0.075906		
35	24	0.892546			5	0.114193	2	0.097728
36	6	0.207056	1	0.113515				
37	17	0.647465	3	0.209858	4	0.124914		
38	14	0.651644						
39	20	0.923144	7	0.470574	3	0.093470		
40	14	0.605496					6	0.223121
41	14	0.979920	1	0.043732			1	0.026229
42	19	0.898719	7	0.286698				
43	8	0.303870	4	0.117854				

TABLE 13 (continued)

			Chestnut Oak		White Oak		Yellow Poplar	
Plot	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area
No.	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft)
44	23	0.950352	5	0.201748			3	0.175100
45	21	0.890012	3	0.137588	3	0.124096	3	0.132541
46	17	0.923927	1	0.034383				
47	7	0.365992			4	0.210720		
48	20	1.210016			8	0.504343		
49	23	0.885182	12	0.431767			2	0.052781
50	17	0.843183	7	0.265485	1	0.043639	2	0.117289
51	9	0.439618	7	0.329560				
52	23	1.168864					11	0.454532
53	23	1.097101					2	0.114176
54	22	1.144899			1	0.069640	7	0.311583
55	4	0.096541						
56	17	0.728740			6	0.255607		
57	20	0.797925					4	0.145675
58	18	1.096900			5	0.093194	3	0.085658
59	17	0.978942			1	0.025475		
60	13	0.599914			2	0.062877	1	0.075906
61	16	0.692035	1	0.026229	2	0.104733		
62	20	1.074447	13	0.838162			6	0.161941
63	23	0.888937			2	0.087162		
64	16	0.789953	1	0.033940	6	0.315153		
65	18	0.857408	1	0.103673	1	0.046553	4	0.123944

TABLE 13 (continued)

Plot	Trees	Basal Area	Chestnut Oak Trees	Chestnut Oak Basal Area	White Oak Trees	White Oak Basal Area	Yellow Poplar Trees	Yellow Poplar Basal Area
No.	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)
66	15	0.675375	7	0.391095				
67	7	0.155173	5	0.125947			2	0.029227
68	24	0.787989	4	0.158727			9	0.257381
69	12	0.575170	3	0.144094			8	0.310786
70	10	0.418686	4	0.129938	1	0.048680		
71	18	0.671973	2	0.083410			6	0.173761
72	12	0.442265	7	0.304250	1	0.036146		
73	7	0.463093	5	0.276032				
74	12	0.655938	6	0.387261				
75	17	0.731822	1	0.141943	3	0.046437		
76	28	1.195554	10	0.542635				
77	16	0.456983	5	0.143174				
78	15	0.749488	1	0.033331				
79	19	0.974171	2	0.096406			4	0.151769
80	8	0.531336	3	0.264427				
81	20	1.512254	1	0.140695			1	0.162657
82	19	0.910074	1	0.044429			8	0.341245
83	15	1.060074			7	0.231628	2	0.100516
84	26	1.058558					10	0.337066
85	22	0.932552	2	0.043506				
86	21	1.096093	2	0.111623	2	0.069580	3	0.127142
87	13	0.601168	1	0.112400			1	0.041000

TABLE 13 (continued)

			Chestnut Oak		White Oak		Yellow Poplar	
Plot	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area	Trees	Basal Area
No.	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)	No.	(sq. ft.)
88	17	0.968948	1	0.050773			3	0.111251
89	15	0.695293	4	0.189160			7	0.336849
90	24	0.845203	9	0.321147			3	0.138626
91	17	0.606357	1	0.050773			1	0.016665
92	13	0.829380	3	0.221215				
93	22	0.924764	8	0.467704			2	0.078650
94	14	0.356230	3	0.088905			2	0.073427
95	18	0.923053	4	0.440943	2	0.058932		
96	8	0.333794					6	0.231696
97	13	0.311591						
98	21	0.819342	5	0.238564	7	0.281059		
99	22	0.797214	7	0.330138			2	0.078848

TABLE 14

MEASURABLE FACTORS CONSIDERED IN THE SITE EVALUATION ANALYSIS

<u>Climatic variables</u>

Potential radiation
- Percent: slope/flat
- Langleys on sloping ground

<u>Topographic variables</u>

Position on slope
Steepness (slope percent)
Azimuth
Altitude of the plot
Distance from the plot to the highest ridge to south
Altitude of the highest ridge to south of the plot

<u>Vegetation variables</u>

Basal area of the plot (1962)
Basal area of the plot (1972)
Number of trees on the plot (1962)
Number of trees on the plot (1972)
Chestnut oak basal area (1962)
Chestnut oak basal area (1972)
White oak basal area (1962)
White oak basal area (1972)
Yellow poplar basal area (1962)
Yellow poplar basal area (1972)
Chestnut oak number of trees (1962)
Chestnut oak number of trees (1972)
White oak number of trees (1962)
White oak number of trees (1972)
Yellow poplar number of trees (1962)
Yellow poplar number of trees (1972)
Chestnut oak total height
White oak total height
Yellow poplar total height
Chestnut oak age
White oak age
Yellow poplar age

TABLE 14 (continued)

Chestnut oak harmonized site index
White oak harmonized site index
Yellow poplar harmonized site index
Chestnut oak polymorphic site index
White oak polymorphic site index

TRANSFORMATIONS AND INTERACTIONS CONSIDERED IN SITE EVALUATION ANALYSIS

Langleys on sloping ground squared
Langleys on sloping ground logarithm
Logarithm of langleys on sloping ground/basal area 1972

Position on the slope squared
Altitude squared

$$\text{Exposure percent} = \frac{\text{Altitude of highest ridge to south} - \text{Altitude of the plot}}{\text{Distance from plot to highest ridge to the south}}$$

Tangent of exposure
Arctangent of exposure squared (angle from the plot to the highest ridge to south squared)

Basal area growth (1972-1962)
Basal area 1972 squared
Chestnut oak basal area growth (1972-1962)
White oak basal area growth (1972-1962)
Yellow poplar basal area growth (1972-1962)

Chestnut oak basal area growth squared
White oak basal area growth squared
Yellow poplar basal area growth squared

TABLE 15

REGRESSION EQUATION OF CHESTNUT OAK SITE INDEX ON SELECTED ENVIRONMENTAL FACTORS, AS OBTAINED BY MULTIPLE REGRESSION ANALYSIS

Variable	Regression Coefficient	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression
X_1	91.62631	1.61542	180.57780	0.257	0.31991	-0.56561
X_{14}	60.51903	0.37294	27.20704	4.948*	0.42569	0.43047
X_6	0.24572	0.42970	0.25732	0.912	0.49725	0.35322
X_{16}	293.04023	3.30653	469.72612	0.389	0.50980	0.47347
X_7	-0.00115	-0.20420	0.00244	0.223	0.51455	0.33159
X_{12}	-85.41287	-0.82315	48.91226	3.049	0.51809	-0.05719
X_{13}	173.41292	0.97935	87.53960	3.924	0.54283	-0.07023
X_{20}	0.00000	0.11872	0.00000	0.677	0.55034	-0.14941
X_{11}	-0.00005	-4.20156	0.00002	5.772*	0.55834	-0.17342
X_{10}	0.20318	4.06041	0.08572	5.618*	0.61288	-0.14852
X_5	0.00000	0.45581	0.00000	1.321	0.61486	-0.35821
X_3	-174.67596	-1.46240	200.48033	0.759	0.62463	-0.42336
X_{15}	-97.52898	-1.74490	165.03199	0.349	0.62815	0.45757
X_{17}	-0.00001	-0.05661	0.00005	0.088	0.62916	0.26493
X_9	0.40503	0.01617	3.46290	0.014	0.62931	0.26453
(Constant)	99.51788					

(Standard error of the estimate = 11.78480 feet)

* Significant at 5% level.
** Significant at 1% level.

TABLE 16

REGRESSION EQUATION OF WHITE OAK SITE INDEX ON SELECTED ENVIRONMENTAL FACTORS AS OBTAINED BY STEPWISE MULTIPLE REGRESSION ANALYSIS

Variable	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression
X_9	5.75692	0.42058	2.50551	4.882*	0.16914	0.41126
X_6	0.42319	1.30737	0.24759	2.921	0.26124	0.11397
X_{21}	0.00000	0.42180	0.00000	4.858*	0.38871	0.38108
X_{14}	-24.98819	-0.24056	19.60020	1.625	0.44572	-0.13452
X_7	-0.00275	-0.93329	0.00228	1.455	0.47330	0.03373
X_{16}	17.64626	0.20223	15.80287	1.247	0.50929	0.12710
(Constant)	27.94685					

Standard error of the estimate = 8.66469 feet

* Significant at 5% level.
** Significant at 1% level.

TABLE 17

REGRESSION EQUATION OF YELLOW POPLAR SITE INDEX ON SELECTED ENVIRONMENTAL FACTORS, AS OBTAINED BY STEPWISE MULTIPLE REGRESSION ANALYSIS

Variable	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression
X_9	12.25169	0.50530	4.02379	9.271**	0.24934	0.49934
X_{13}	-362.38106	-0.90749	275.67898	1.728	0.34941	-0.24967
X_{19}	-0.00024	-0.66507	0.00014	2.976	0.38332	-0.23421
X_7	0.00457	0.98479	0.00369	1.535	0.41332	0.11801
X_6	-0.41968	-0.73026	0.47838	0.770	0.45793	0.08803
X_{22}	0.00000	0.41005	0.00000	1.336	0.47972	-0.09759
X_{16}	60.78466	0.56616	157.18666	0.150	0.49272	0.21748
X_{10}	0.04501	1.06619	0.07233	0.387	0.51040	-0.04910
X_{12}	91.95296	0.61308	105.63639	0.758	0.52122	-0.21085
X_3	78.06842	0.90919	83.01124	0.884	0.52995	-0.14179
X_2	-0.00018	-0.79665	0.00021	0.701	0.54681	-0.15258
X_{11}	-0.00001	-0.79962	0.00002	0.198	0.54994	-0.05755
X_{15}	-21.60412	-0.35141	91.40335	0.056	0.55094	0.21243
(Constant)	-385.56827					

Standard error of the estimate = 12.54517 feet.

*Significant at 5% level.
**Significant at 1% level.

TABLE 18

REGRESSION EQUATION ON BASAL AREA GROWTH
(10 YEARS) PLOTS WITH CHESTNUT OAK

Variable	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression
X_{17}	0.98495	0.63654	0.23417	17.692**	0.52880	0.72718
X_{23}(1)	0.24494	0.27610	0.13639	3.225	0.57916	0.39709
X_9	0.01306	0.08460	0.02074	0.396	0.58528	0.17583
X_{12}	0.63082	0.98653	0.28432	4.923*	0.58891	-0.03960
X_{13}	-1.09999	-1.00808	0.51707	4.526*	0.61576	-0.05789
X_{11}	0.00000	0.70194	0.00000	0.144	0.63092	0.16113
X_{20}	-0.47823	-0.06447	1.04498	0.209	0.63746	-0.45274
X_3	-0.22259	-0.30241	1.21879	0.033	0.63915	-0.04761
X_{10}	-0.00017	-0.55679	0.00056	0.095	0.64063	0.17455
X_5	-0.00000	-0.01976	0.00000	0.003	0.64125	-0.01819
X_6	-0.00076	-0.21452	0.00157	0.232	0.64160	0.11785
X_7	0.00001	0.18640	0.00001	0.193	0.64330	0.10685
X_1	0.29289	0.83794	1.09077	0.072	0.64346	-0.19738
X_{16}	0.60749	1.11233	2.84576	0.046	0.64546	0.23681
X_{15}	-0.16537	-0.48011	0.99988	0.027	0.64575	0.23631
(Constant)	-1.10988					

Standard error of the estimate = 0.07099 square feet.

* Significant at 5% level.
** Significant at 1% level.

(1) Site index = log. site index.

TABLE 19

REGRESSION EQUATION ON BASAL AREA GROWTH OF YELLOW POPLAR (10 YEARS), PLOTS WITH THE SPECIES

Variable	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression
X_{11}	0.00000	1.78710	0.00000	0.958	0.20090	0.44822
X_{26}	0.60856	1.39467	0.25420	5.731*	0.27025	0.35168
X_1	0.28635	1.76112	0.19829	2.085	0.34981	0.31413
X_6	0.00157	0.98296	0.00125	1.587	0.39899	0.07275
X_{13}	-1.38451	-1.24531	0.66120	4.385*	0.46277	0.33064
X_7	-0.00001	-0.50399	0.00001	0.415	0.49066	0.09752
X_5	0.00000	1.82736	0.00000	0.231	0.51008	0.05807
X_{15}	0.15201	0.88808	0.12126	1.571	0.53714	-0.40574
X_{25}(1)	-0.12873	-0.23221	0.10002	1.656	0.55624	-0.20416
X_9	0.01103	0.16347	0.01290	0.732	0.57074	0.08306
X_{14}	0.08011	0.15501	0.07639	1.100	0.58221	0.19661
X_{10}	-0.00014	-1.15132	0.00021	0.402	0.59424	0.44063
X_2	-0.00000	-4.76584	0.00000	0.450	0.59999	0.08346
X_3	0.47333	1.97993	0.86163	0.302	0.60496	0.10982
(Constant)	-3.50086					

Standard error of the estimate = 0.03344 square feet.

*Significant at 5% level.
**Significant at 1% level.

(1)Site index = log. site index.

TABLE 20

REGRESSION EQUATION ON BASAL AREA GROWTH (10 YEARS), AS OBTAINED BY STEPWISE MULTIPLE REGRESSION ANALYSIS (PLOTS WITH YELLOW POPLAR)

Variable	Regression Coefficient B	Beta	Standard Error of B	F	Coefficient of Multiple Determination R^2	Simple Regression
X_{22}	14.00024	0.74365	6.90330	4.113*	0.09677	0.31109
X_7	-0.00001	-0.20224	0.00000	1.737	0.15631	-0.24491
X_{13}	0.59550	0.27680	0.34454	2.987	0.19812	0.25966
X_{19}	-1.06295	-0.54930	0.73367	2.099	0.24475	0.19661
(Constant)	0.11540					

Standard error of the estimate = 0.07516 square feet.

* Significant at 5% level.
** Significant at 1% level.

TABLE 21

HARMONIZED SITE INDEX FOR CHESTNUT OAK

Plot No.	Tree No.	Height (feet)	Age (Yrs.)	Site Index*
6	2	62.0	145.0	43.61870
7	2	60.0	62.0	54.06384
8	5	99.0	63.0	88.59535
12	2	63.0	110.0	47.00729
14	3	51.0	63.0	45.64005
16	3	52.0	117.0	38.23810
18	8	51.0	64.0	45.33768
19	10	73.0	44.0	78.50340
22	5	72.0	35.0	90.55873
23	15	57.0	61.0	51.72603
28	9	63.0	60.0	57.59113
31	2	78.0	81.0	63.50516
32	1	46.0	78.0	37.93141
33	2	96.0	70.0	82.33217
34	3	54.0	94.0	41.99837
37	8	61.0	69.0	52.60637
39	4	64.0	67.0	55.83734
42	5	76.0	78.0	62.66942
43	5	51.0	74.0	42.84293
45	17	63.0	41.0	70.83775
49	15	80.0	39.0	93.01968
50	16	66.0	47.0	68.26898
51	3	47.0	70.0	40.30840
61	13	57.0	39.0	66.27655
62	3	75.0	54.0	72.04984
64	13	78.0	63.0	69.80240
65	7	105.0	88.0	83.26653
66	1	80.0	114.0	59.18367
67	1	75.0	64.0	66.67303
68	18	63.0	34.0	81.04390
70	4	72.0	67.0	62.81699
72	5	58.0	29.0	85.47501
73	2	78.0	113.0	57.82425
74	4	88.0	95.0	68.23669
75	4	63.0	173.0	43.01575
76	23	64.0	63.0	57.27379

TABLE 21 (continued)

Plot No.	Tree No.	Height (feet)	Age (Yrs.)	Site Index*
77	7	52.0	43.0	56.71811
79	19	84.0	95.0	65.13501
80	1	78.0	140.0	55.23868
81	7	96.0	54.0	92.22383
85	16	54.0	38.0	63.93417
86	6	72.0	38.0	85.24561
88	19	74.0	61.0	67.15309
91	9	63.0	38.0	74.48989
92	5	93.0	81.0	75.71771
93	8	68.0	32.0	91.89417
94	2	52.0	33.0	68.51076
95	4	59.0	34.0	75.89830
98	5	69.0	33.0	90.90866
99	8	61.0	33.0	80.36852

*Logarith site index = Logarithm height + $\frac{11.641}{Age}$ - 0.233 (McClurkin, 1963).

TABLE 22

HARMONIZED SITE INDEX FOR WHITE OAK

Plot No.	Tree No.	Height (feet)	Age (Yrs.)	Site Index*
1	12	49.0	43.0	53.44601
2	3	87.0	69.0	75.02866
6	1	56.0	82.0	45.40981
8	7	69.0	69.0	59.50558
21	2	92.0	99.0	70.52950
27	3	79.0	122.0	57.54979
28	6	53.0	56.0	50.02058
29	2	78.0	120.0	57.02971
30	13	69.0	67.0	60.19966
35	11	69.0	46.0	72.26247
37	10	51.0	71.0	43.50371
39	11	75.0	74.0	63.00429
47	6	72.0	59.0	66.31866
48	6	84.0	68.0	72.85646
50	15	67.0	55.0	63.78624
54	4	84.0	68.0	72.85646
56	5	87.0	86.0	69.48280
60	11	48.0	38.0	56.83040
61	3	75.0	135.0	53.49200
63	2	84.0	82.0	68.11472
64	3	91.0	73.0	76.82527
72	4	51.0	43.0	55.62744
83	4	84.0	89.0	66.38580
95	5	37.0	53.0	35.87901
98	21	66.0	43.0	71.98851

*Logarithm site index = Logarithm height + $\frac{11.641}{\text{Age}}$ - 0.233 (McClurkin, 1963).

TABLE 23

HARMONIZED SITE INDEX FOR YELLOW POPLAR

Plot No.	Tree No.	Height (feet)	Age (Yrs.)	Site Index*
4	11	55.0	21.0	98.46825
5	14	60.0	24.0	94.74855
9	21	66.0	28.0	91.92940
11	6	71.0	35.0	108.24744
12	4	81.0	48.0	82.43564
15	10	63.0	41.0	69.11061
17	7	78.0	63.0	71.49883
26	2	90.0	45.0	94.31735
27	2	85.0	49.0	85.73447
32	5	72.0	59.0	67.51372
35	5	69.0	55.0	66.40448
40	8	84.0	34.0	102.44029
41	12	55.0	29.0	74.64383
44	6	81.0	39.0	91.23123
46	7	102.0	37.0	118.29099
49	6	90.0	37.0	104.37440
50	9	65.0	29.0	88.21545
52	8	90.0	41.0	98.72937
53	23	78.0	31.0	101.00735
54	1	90.0	42.0	97.52779
57	11	85.0	29.0	115.35864
58	16	90.0	37.0	104.37440
60	2	80.0	145.0	60.68482
63	18	76.0	41.0	83.37158
68	10	69.0	51.0	68.43167
69	4	63.0	36.0	74.22800
71	14	67.0	26.0	98.88815
81	3	110.0	97.0	89.66927
82	4	93.0	54.0	90.13937
83	9	81.0	37.0	93.93701
84	9	90.0	39.0	101.36798
86	1	69.0	39.0	77.71559
87	8	72.0	46.0	74.68927
88	15	96.0	31.0	124.31667
89	2	80.0	36.0	94.25774

TABLE 23 (continued)

Plot No.	Tree No.	Height (feet)	Age (Yrs.)	Site Index*
90	3	93.0	42.0	100.77893
93	18	58.0	29.0	78.71535
94	5	52.0	38.0	59.40749
96	1	78.0	36.0	91.90135
98	4	72.0	29.0	97.71556
99	6	58.0	25.0	88.42746

*Logarithm site index = Logarithm height - 9.158 $(\frac{1}{50} - \frac{1}{Age})$ (Beck, 1962).

TABLE 24

POLYMORPHIC SITE INDEX FOR CHESTNUT OAK

Plot No.	Tree No.	Height (feet)	Age (Yrs.)	Site Index*
7	2	60.0	62.0	52
8	5	99.0	63.0	87
14	3	51.0	63.0	44
18	8	51.0	64.0	43
19	10	73.0	44.0	79
22	5	72.0	35.0	90
23	15	57.0	61.0	50
28	9	63.0	60.0	56
31	2	78.0	81.0	58
32	1	46.0	78.0	35
33	2	96.0	70.0	80
34	3	54.0	94.0	36
37	8	61.0	69.0	49
39	4	64.0	67.0	53
42	5	76.0	78.0	57
43	5	51.0	74.0	40
45	17	63.0	41.0	72
49	15	80.0	39.0	92
50	16	66.0	47.0	68
51	3	47.0	70.0	38
61	13	57.0	39.0	66
62	3	75.0	54.0	70
64	13	78.0	63.0	68
65	7	105.0	88.0	78
67	1	75.0	64.0	65
68	18	63.0	34.0	80
70	4	72.0	67.0	60
72	5	58.0	29.0	84
74	4	88.0	95.0	62
76	23	64.0	63.0	55
77	7	52.0	43.0	57
79	19	84.0	95.0	57
81	7	96.0	54.0	90
85	16	54.0	38.0	65
86	6	72.0	38.0	84

TABLE 24 (continued)

Plot No.	Tree No.	Height (feet)	Age (Yrs.)	Site Index*
88	19	74.0	61.0	65
91	9	63.0	38.0	74
92	5	93.0	81.0	73
93	8	68.0	32.0	92
94	2	52.0	33.0	68
95	4	59.0	34.0	65
98	5	69.0	33.0	88
99	8	61.0	33.0	80

*From Carmean (1971).

TABLE 25

POLYMORPHIC SITE INDEX FOR WHITE OAK

Plot No.	Tree No.	Height (feet)	Age (Yrs.)	Site Index*
1	12	49.0	43.0	56
2	3	87.0	69.0	69
6	1	56.0	82.0	38
8	7	69.0	69.0	54
21	2	92.0	99.0	57
27	3	79.0	122.0	47
28	6	53.0	56.0	48
29	2	78.0	120.0	46
30	13	69.0	67.0	57
35	11	69.0	46.0	74
37	10	51.0	71.0	39
39	11	75.0	74.0	56
47	6	72.0	59.0	62
48	6	84.0	68.0	67
50	15	67.0	55.0	62
54	4	84.0	68.0	67
56	5	87.0	86.0	59
60	11	48.0	38.0	60
63	2	84.0	82.0	59
64	3	91.0	73.0	71
72	4	51.0	43.0	56
83	4	84.0	89.0	56
95	5	37.0	53.0	36
98	21	66.0	43.0	73

*From Carmean (1971)

VITA

Luis Enrique Rodriguez Poveda was born in Chía, Colombia, South America, April 9, 1936. He was graduated from high school in 1953. He received his Bachelor degree in Forestry from the Universidad de Los Andes, Mérida, Venezuela in 1958. After graduation he worked for the Instituto Agrario Nacional de Venezuela and taught in the Universidad del Tolima, Colombia. In 1965 he joined the Instituto de Silvicultura de la Universidad de Los Andes, Venezuela, where he worked until 1971. At that time he accepted a grant from the Universidad de Los Andes and in January 1972 he began study toward a Master of Science degree at the Forestry Department of the University of Tennessee.

He is married to the former Nora Contreras of Mérida, Venezuela and has four children.