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Site index curves and yield predictors for three species in the vicinity of Norris Lake

Cassandra Lee Hohanshelt

To the Graduate Council:

I am submitting herewith a thesis written by Cassandra Lee Hohanshelt entitled "Site index curves and yield predictors for three species in the vicinity of Norris Lake." 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.

John C. Rennie, Major Professor

We have read this thesis and recommend its acceptance:

Robert McLean, Glendon W. Smalley

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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Date August 1985

SITE INDEX CURVES AND YIELD PREDICTORS FOR THREE SPECIES IN THE VICINITY OF NORRIS LAKE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Cassandra Lee Hohanshelt

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ABSTRACT

In the late 1930's, L. S. Minckler established eight planting experiments on abandoned fields in the vicinity of Norris Lake. These plantings included 700 plots with 11 hardwoods and 3 conifers on 167 acres. In 1968 G. W. Smalley evaluated the condition of the 30-year-old plantations and initiated a growth and yield study of shortleaf pine (Pinus echinata Mill.), eastern white pine (P. strobus L.), and yellow-poplar (Liriodendron tulipifera L.). This study included 66 plots on three soil parent materials (limestone, dolomite and shale) and two aspects (north and south). In the early 1970's, all of the shortleaf pine and six of the white pine plots were destroyed by southern pine bark beetles (Dendroctonus frontalis Z.). The remaining white pine plots and the yellow-poplar plots were remeasured at plantation age 46.

The diameter at breast height (dbh) and total height were measured on each of the plots to estimate per acre number of stems, basal area, total cubic-foot volume, merchantable cubic-foot volume, mean dbh and average height of dominants and codominants at each measurement age. These estimates were analyzed by parent material and aspect for each of the three species.

At plantation age 30, shortleaf pine height growth was less on shale soils than on dolomite and limestone, though stand volume was not affected by parent material. Mortality of white pine at plantation age 30 was highest on shale soils and northern slopes, though stand volume was not affected by either variable. At

plantation age 46 white pine yield was best on dolomitic northern slopes and poorest on dolomitic southern slopes. Growth of yellow-poplar was best on shale soils and poorest on dolomitic sites; aspect did not significantly effect any stand attributes. White pine had the greatest mean volumes of the three species and yellow-poplar had the least.

Total cubic-foot yield and yield to a 4-inch top (outside bark) were predicted for white pine and yellow-poplar from site index, basal area, and age in years from seed. Additionally, a prediction equation for cubic-foot yield to a 3-inch top (outside bark) for white pine was developed and compared to a published equation. The published equation for white pine overpredicted yield at 32 years from seed and underpredicted yield at 48 years from seed. The equation for yellow-poplar total yield was also compared to a published equation. The published equation for yellow-poplar overpredicted yield at 31 years from seed and underestimated yield at 47 years from seed.

. Stem analysis was conducted on one white pine per plot at 32 years from seed and the height to each whorl was measured on two white pine per plot at 48 years from seed. These data were used to construct site index curves with base age 25 (years from seed) for white pine. Stem analysis was also conducted on one yellow-poplar per plot at 31 years from seed and total height at 47 years from seed was measured on ten trees per plot. These data were used to construct site index curves with base age 25 (years from seed) for yellow-poplar. The curves for white pine and yellow-poplar were compared to published curves which underpredicted heights at ages less than 25 years and overpredicted heights at older ages.

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CHAPTER I

INTRODUCTION

Decisions for timber management are based on expected yields. Yield of a forest stand is the total amount of wood available for harvest at a given time, and is closely related to stand age, stand density and site quality.

Forest site quality is the sum total of all of the factors affecting the capacity of a site to produce forests, including climatic, soil and biological. Site quality is often quantified as site index - the average height of dominant and codominant trees in a stand at a reference age.

Shortleaf pine (*Pinus echinata* Mill.), eastern white pine (*P. strobus* L.) (called white pine hereafter) and yellow-poplar (*Liriodendron tulipifera* L.) occur naturally throughout the eastern United States. White pine grows from Canada to northern Georgia, while shortleaf pine and yellow-poplar occur from southern New England to Florida. Because of their wide occurrence, they grow under a variety of site factors which affect the yield of these species in different physiographic regions. Site index curves and yield prediction equations for white pine and yellow-poplar have been developed for neighboring regions, but none exist for the Ridge and Valley Province. Existing curves and equations need to be tested for their applicability in East Tennessee. Site index curves and yield predictors have previously been developed for shortleaf pine plantations on abandoned fields in the Ridge and Valley, Cumberland

Plateau, and Highland Rim Provinces (Smalley and Bower 1971, Smalley and Bailey 1974). These site index curves and yield predictors were developed using some of the plots from the current study. Therefore, no site index curves or yield predictors were developed for shortleaf pine in this study.

There are three objectives of this study: (1) to analyze the differences in productivity of shortleaf pine, white pine and yellow-poplar plantations by aspect and soil parent material, (2) to develop total and merchantable cubic-foot yield equations for white pine and yellow-poplar, and (3) to test the applicability of published site index curves for white pine and yellow-poplar in this area and develop new curves if the existing curves are not suitable.

CHAPTER II

LITERATURE REVIEW

Site and Growth Relationships

Yellow-poplar

Yellow-poplar grows well on soils derived from a variety of parent materials. The species grows best on moderately moist, well-drained and loamy soils. Yellow-poplar has been found to grow exceptionally well on north and east aspects, on lower slope positions, in sheltered coves, and on gentle concave slopes (McCarthy 1933).

White Pine

White pine can be grown on nearly every soil within its range, though it grows best on soils with a high proportion of sand (Lancaster 1984). Ike and Huppuch (1968) found that white pine grows better on lower slopes and that site index decreased as steepness of slope and elevation increased.

Shortleaf Pine

Shortleaf pine is generally less site sensitive than white pine. In the Boston Mountains of Arkansas, Graney and Ferguson (1971) found that shortleaf pine height growth did not vary by soil parent material, but higher site indices were found on north and northeastern exposures than on warmer exposures due to less evaporative stress.

Site Index

Site index, a measure of forest productivity, gives a numerical expression to site quality rather than a subjective description. Site index is defined as the average height of dominant and codominant trees in an even-aged stand at a specified reference age. A reference age of 50 years is generally used in the eastern U.S. with 25 years being used for fast-growing species or those grown for short rotations. Site index curves are graphed by height and age to allow site classification of a stand at any age.

Site index curves can be prepared by several methods, but the majority of curves now in use were prepared by the guide curve method developed by Bruce (1926). This method produces anamorphic curves based on a single guiding curve and harmonized with the same form and trend.

Constuction of Anamorphic Curves

A large number of temporary plots representing a range of sites and ages are required to construct anamorphic site index curves. Total height and age of dominant and codominant trees with no apparent damage or disease are measured on these plots.

A mathematical model is then chosen to describe the height growth of the stand. Schumacher's (1939) equation

$$\log H = a + b\,(1/A) \qquad (1)$$

where H = height in feet

A = age in years

a, b = regression coefficients

is often used (e.g. Beck 1962, Vimmerstedt 1959). The coefficients in the model are determined by simple linear regression and the resulting equation represents the "average" site index, or the guide curve (Husch, Miller and Beers 1982).

If the y-axis is moved to the reference age by mathematical translation, the y-intercept becomes the logarithm of site index, then the equation can be solved for site index.

$$\log S = \log H + b\,(1/R - 1/A) \qquad (2)$$

where S = site index in feet

R = reference age in years

This equation is generally graphed by height and age to produce site index curves.

There are numerous examples of anamorphic curves developed by this method, including Vimmestedt's (1959) curves for white pine plantations in the Southern Appalachians, Doolittle and Vimmerstedt's (1960) curves for natural stands of white pine in the Southern Appalachians, Beck's (1962) curves for natural yellow-poplar stands in the Southern Appalachian Mountains and in the Piedmont, and Schlaegel et al. (1969) curves for natural yellow-poplar stands in West Virginia.

Weaknesses of Anamorphic Curves

When site index curves are developed by the anamorphic method, two assumptions are often violated. First, the guide curve is accurate only if the average site quality is the same for each age class sampled. However, harvesting patterns often result in younger stands being found more often on better sites while older stands are concentrated on poorer sites. This pattern distorts the guide curve and growth of young stands is overpredicted and growth of older stands is underpredicted (Curtis 1964, Beck 1971, Beck and Trousdell 1973). This problem can be eliminated by the use of stem analysis (Beck and Trousdell 1973). Rather than sampling the total heights and ages of many different stands, successive measurements of height and age are taken on individual trees.

The second assumption is that the shape of the height-growth curve is the same for all sites. This assumption has been found to be invalid for several species. Bull (1931) showed that the shape of the height-growth curve varies with site quality in red pine (*Pinus resinosa* Ait.) plantations. On poorer sites, rates of height growth were found to increase slowly but were maintained longer, while on better sites growth rates increased rapidly and then became relatively slow (Beck and Trousdell 1973). Therefore, site index curves developed by the guide curve method often resulted in biased estimates.

Polymorphic Site Index Curves

Polymorphic site index curves assume that curve shape varies with site quality. Bull (1931) constructed the first polymorphic site index curves in the U. S. by grouping the sample data into seven site classes and hand-fitting the curves by standard anamorphic methods within each class. Later Curtis (1964) constructed polymorphic curves by stratifying the sample data into site classes and performing regression analysis on each class.

Beck (1971) constructed polymorphic curves for natural stands of white pine in the Southern Appalachians using Richards' (1959) modification of the von Bertalanffy equation. The coefficients of the growth equation were expressed as functions of site index and polymorphic curves were developed from a single regression (Beck 1971).

Growth and Yield

Normal Yield Tables

The first yield tables in the southern U.S. were normal yield tables such as those found in Miscellaneous Publication No.50 (USDA Forest Service 1929). These tables were developed using graphical procedures which limited them to two independent variables- age and site index. Stand density was held constant at "full-stocking." However, a stand that is fully-stocked now has probably been overstocked or understocked at some point in time. Since normal yield tables are a compilation of fully-stocked stands at different ages, they represent the development of a theoretical stand that is fully-stocked over its entire life. Therefore, the implied stand development is not likely to occur in existing stands (Avery and Burkhart 1983).

Empirical Yield Tables

Empirical yield tables are also limited to two independent variables, but stand density is held constant at "average stocking" rather than "full stocking," thus eliminating the problem of reconciling "fully-stocked" stands to existing stands.

Variable Density Yield Tables

MacKinney and Chaiken (1939) developed the first variable density yield tables by introducing stand density as an independent variable. Since then, many others have utilized multiple regression techniques to predict yield by age, site index and some form of stand density. Vimmerstedt (1962) developed a yield model for white pine plantations in the Southern Appalachians based on age, site index and number of trees planted per acre. Beck and Della-Bianca (1970) developed varible density yield tables for natural unthinned yellow-poplar stands in the Southern Appalachians using a diameter distribution method. Numbers of surviving trees were estimated by diameter class from measurements of age, site index and number of trees per acre. Next, the heights of trees of given diameters were estimated from the same independent variables. Then, the volume of a tree of a given height and diameter was determined from tree volume equations (Beck 1963). Finally, these individual tree volumes were applied to the diameter distributions to obtain per-acre yields for a combination of stand age, site index and number of surviving trees (Beck and Della-Bianca 1970). These data were later used to develop yield tables based on age, site index and basal area (Beck and Della-Bianca 1981).

Compatible Growth and Yield Models

Variable density yield models are significantly more useful than normal and empirical yield tables, but do not relate growth to yield (Avery and Burkhart 1983). Buckman (1962) developed a compatible growth and yield model for red pine plantations using age, site index and initial basal area as independent variables. Rate of stand growth was expressed as the first derivative of the current yield equation. Future yield predictions were derived by summation of the of net annual increments obtained from the integration of the growth rate equation (Buckman 1962).

Clutter (1963) used site index, age and basal area to develop a compatible growth and yield model for loblolly pine (*Pinus taeda* L.). Yield models were differentiated with respect to age to obtain growth models. These were fit to data from permanent plots and then integrated to produce the yield equations.

Sullivan and Clutter (1972) extended Clutter's (1963) model by estimating yield and cumulative growth of loblolly pine simultaneously. This model uses initial age, initial basal area, site index and future age to project future yields of loblolly pine. When the projection period is zero, the future age is equal to the current age, and the projection model simplifies to a conventional yield model.

Schlaegel and Kulow (1969) followed Clutter's (1963) procedure to develop compatible growth and yield equations for yellow-poplar in natural stands in West Virginia. Beck and Della-Bianca (1972) also developed compatible growth and yield equations for thinned natural yellow-poplar stands in the Southern Appalachians following Clutter's (1963) methodology.

CHAPTER III

STUDY AREA DESCRIPTION

In 1937 the Appalachian (now Southeastern) Forest Experiment Station and the Tennessee Valley Authority (TVA) cooperated in the establishment of a series of eight long-term planting experiments on abandoned fields in four counties in eastern Tennessee (Anderson, Campbell, Claiborne and Union). The study included 167 acres scattered over an area measuring approximately 12 by 35 miles.

Geology, Topography and Soils

The study area lies in the Appalachian Ridge and Valley physiographic province and is drained by the Tennessee River. The region is underlain by folded sedimentary rocks and consists of long, narrow, steep-sided ridges and intervening valleys. Elevation ranges from about 1000 feet at Norris Lake to about 1700 feet at White Hollow on the Central Peninsula.

Limestone, dolomite and shale are the dominant parent rocks in the study area. Dewey and Talbott silt loam soils were developed from limestone, Fullerton and Clarksville cherty silt loam soils were developed from dolomite, and Montevallo and Armuchee silt loam soils were developed from shale (Minckler 1941b).

Climate

The climate of the study area is characterized by short, mild winters and long, warm summers. The mean winter temperature is 36.2 degrees F and the mean summer temperature is 73.0 degrees F. This area receives an average of 50.21 inches of precipitation each year, which is evenly distributed from December through August and somewhat drier in the fall. The area receives an average of 13.4 inches of snow each year. The average frost-free period of 173 days extends from April 25 to October 16 (Soil Conservation Service 1953).

Vegetation

The plantations were established on abandoned fields representing various stages of soil exhaustion and erosion. The most common vegetation types on these old fields were: (1) weeds and annual grasses, (2) broomsedge (*Andropogon* spp.), and (3) briers and brush (*Rubus* spp., *Sassafras albidum* (Nutt.) Nees, and *Smilax glauca* Walt.). Some areas were covered with pure stands of sassafras and other areas contained understocked stands of shortleaf pine and Virginia pine (*Pinus virginiana* Mill.) (Burton 1964).

Description of Experiments

The study, one of the most extensive planting projects up to that time, consisted of eight separate experiments in which 14 hardwood and conifer species were planted on 700 plots (Minckler 1941a).

Experiment One compared the growth and survival of six oak species planted on dolomitic soils on three topographic positions (north slopes, south slopes and ridge tops). The six species were white, black, chestnut, bur, northern red, and southern red oak (*Quercus alba* L., *Q. velutina* Lam., *Q. prinus* L., *Q. macrocarpa*

Michx., *Q. rubra* L., and *Q. falcata* Michx.). Each of the 1/10-acre plots contained 120 trees of a single species.

Experiment Two tested the growth of two conifers and four hardwoods on three soil parent materials (limestone, dolomite and shale) on north and south slopes. The species tested were shortleaf pine, white pine, yellow-poplar, black walnut (*Juglans nigra* L.), white ash (*Fraxinus americana* L.), and northern red oak. Each of the 1/4-acre plots contained 297 trees of a single species. This was the largest experiment with 216 plots.

Experiment Three tested the effect of black locust (*Robinia pseudoacacia* L.) on the growth of black walnut, yellow-poplar, shortleaf pine, and white ash planted on limestone and dolomitic soils. This was a split-plot design; each plot contained a mixed subplot and a pure subplot of the main species. Each of the mixed subplots contained three rows of the main species alternated with two rows of locust.

Experiment Four compared the growth of two conifers and five hardwoods underplanted in young, poorly-stocked natural shortleaf pine stands on dolomitic soils. The species were shortleaf pine, white pine, white oak, black oak, northern red oak, yellow-poplar, and black locust.

Experiments Five and Six tested the compatibility of nine species planted in checkerboard mixtures on north and south slopes over limestone and dolomitic soils. Each plot contained 48 squares each containing nine trees of one species. Experiment Five tested mixtures of (1) shortleaf pine and yellow-poplar, (2) white pine, yellow-poplar and northern red oak, (3) shortleaf pine and white oak, (4) white pine and northern red oak, and (5) sweetgum (Liquidambar styraciflua L.) and yellow-poplar. Experiment Six tested mixtures of (1) black walnut, yellow-poplar and northern red oak, (2) northern red oak and white ash, (3) baldcypress (Taxodium distichum [L.] Rich.), sweetgum and white ash, (4) black walnut and yellow-poplar, and (5) black walnut and northern red oak.

Experiment Seven tested the growth of white ash, yellow-poplar and northern red oak underplanted in dense stands of sassafras on dolomitic soils. Various release cutting treatments were applied to these stands during the first four growing seasons.

Experiment Eight tested the growth of shortleaf pine, yellow-poplar, white pine, black walnut, white ash, northern red oak, white oak, chestnut oak, sweetgum and black locust underplanted in a sassafras stand without release cutting.

All of the experiments used 6-by 6-foot spacing. Black walnut on all plots and oaks on all plots except chestnut oak and bur oak in Experiment One were direct seeded. All other species were planted. White pine seedlings were 1-1 transplants and all other species were 1-0 seedlings (Minckler 1941a).

Related Studies

The soils in the experimental area were studied extensively in 1937 by T. S. Coile. Horizons were identified and thickness measured in 118 soil pits. Samples were taken from each horizon for laboratory analyses to determine moisture equivalent; wilting percentage; and percentages of gravel, sand, "total colloidal material," clay, silt, fine clay, carbon and organic matter. These soil analyses were done to characterize the planting areas and not to determine soil properties on each plot. Some of the soil pits were located within the study plots, while others were not.

In 1938, L. S. Minckler examined the soils on each plot with an auger and constructed three-dimensional soil maps of each block in the study (Minckler 1941a, Minckler and Chapman 1948). Soil data and maps are filed at the USDA Forest Service Silviculture Laboratory, Sewanee, Tennessee.

Minckler also mapped the herbaceous and shrubby vegetation on the plots and W. E. McQuilkin described the plant communities in relation to soil parent material and degree of erosion. This information is also filed at Sewanee.

Survival and growth of the experimental plantations were measured after the first, third and fifth growing seasons. Several reports of early results were published (Minckler 1941a, 1941b, 1941c, 1943, and Minckler and Chapman 1948). Emphasis was on plantation success as related to aspect, vegetative cover, soil depth, soil type and soil consistency.

The Southern Forest Experiment Station (SFES) of the USDA Forest Service and TVA remeasured Experiments 2, 3, 5 and 6 at plantation age 11. These data were summarized but never reported. A 20-year inventory was made by SFES and TVA in accordance with a sampling plan devised by J. C. Allen with some modification by L. R. Grosenbaugh. Results of this inventory were reported by Burton (1964).

CHAPTER IV

METHODS

Field Procedures

Plot Establishment

In 1968, G. W. Smalley of the SFES assessed the condition of the experimental plots. He found enough adequately stocked plots in Experiments Two and Three to establish a growth and yield study for shortleaf pine, white pine and yellow-poplar. This study consisted of 66 plots representing three soil parent materals (limestone, dolomite and shale) and two aspects (north and south slopes) (Table 1).

Smalley established a 1/20-acre rectangular measurement plot within a well-stocked portion of each original plot; the length and width was measured and recorded. Each plot was given a six digit identification number designating the original experiment number, block, species, parent material and aspect.

Of the 66 plots in the study, 37 were planted in 1938 and 29 were planted in 1939. Plots planted in 1938 were measured early in 1968 before the beginning of the growing season. Plots planted in 1939 were measured in the fall of 1968, after the growing season. Thus all plots were measured at plantation age 30.

Data Collection at Plantation Age 30

Diameter at breast height (dbh) of every living planted tree within the measurement plot was measured to the nearest 1/10-inch

TABLE 1

DISTRIBUTION OF PLOTS AT PLANTATION AGE 30 BY PARENT MATERIAL, ASPECT AND SPECIES

Parent Material	Aspect	Shortleaf Pine	White Pine	Yellow-Poplar
Shale	North	3	3	4
	South	4	2	2
Dolomite	North	6	7	3
	South	5	3	4
Limestone	North	3	3	2
	South	6	4	2
Totals		27	22	17

with a diameter tape. Total height to the nearest foot was measured on every fourth tree in each dbh class with a minimum of ten sample trees per plot. Crown class was recorded for each sample tree using the four standard classes (dominant, codominant, intermediate and overtopped).

A dominant or codominant tree of average height was selected and felled on each plot for stem analysis. Disks were cut at breast height (4.5 feet), 10 feet and approximately every 5 foot interval above that. The interval was varied on the pines so that the disks were cut from the internodes. The annual rings on each disk were counted in the laboratory.

Mortality of Pine Plots

In the early 1970's all of the shortleaf pine and six of the white pine plots were destroyed by an infestation of southern pine bark beetles (*Dendroctonus frontalis* Z.). Because data were only available for the shortleaf pine plots at one measurement age, no site index curves or yield prediction equations were developed for this species. The remaining 33 plots are shown by species, parent material and aspect in Table 2. Of the remaining plots, 20 were planted in 1938 and 13 in 1939. Plots planted in 1938 were remeasured in the fall of 1983 and those planted in 1939 were remeasured in the fall of 1984 at plantation age 46.

Data Collection at Plantation Age 46

The dbh of every living planted tree was remeasured to the nearest 1/10-inch. Total height was measured and crown class was

TABLE 2

DISTRIBUTION OF SURVIVING PLOTS AT PLANTATION AGE 46
BY PARENT MATERIAL, ASPECT AND SPECIES

Parent Material	Aspect	White Pine	Yellow-Poplar
Shale	North	3	4
	South	2	2
Dolomite	North	3	3
	South	2	4
Limestone	North	3	2
	South	3	2
Totals		16	17

recorded on a sample of ten trees per plot which were selected from each dbh class.

Two dominant or codominant trees of average height were selected on each of the white pine plots and the height to each whorl was measured as far up the stem as visible.

<u>Data Summarization</u>

The mean dbh of all trees and the average height of dominants and codominants (average height) were calculated for each plot.

The computer program, REPS, was used to summarize plot yields. This Fortran program was developed by the Biometric Section of the Southern Forest Experiment Station to process standard plot data. REPS provided per acre estimates of number of stems, basal area and total stem cubic-foot volume (outside bark) for all trees larger than 3-inch dbh for each plot. Per acre merchantable cubic-foot volume (outside bark) to a 4-inch top (o.b.) for all trees larger than 5-inch dbh was also estimated. Smalley and Bower's (1968) tree volume equations were used to determine the total stem volume (outside bark) and volume (o.b.) to a 4-inch top (o.b.) for shortleaf pine. Smalley and Beck's (1971) tree volume equation was used to determine total stem volume (outside bark) and Vimmerstedt's (1961) equation was used to determine volume (o.b.) to a 4-inch top (o.b.) for white pine. Beck's (1963) equations were used to determine total stem volume (outside bark) and volume (o.b.) to a 4-inch top (o.b.) for yellow-poplar.

Data Analysis

Comparison Among Species and Ages

Mean total volume and merchantable volume for each species and age were compared, though no statistical tests were performed.

Analysis of Variance

Analyses of variance were performed on each species at each measurement age using the SAS procedure General Linear Models (GLM). Independent variables in the analyses were parent material and aspect. Six dependent variables were analyzed: number of stems, basal area, total cubic-foot volume, merchantable volume, mean diameter at breast height and average height of dominants and codominants. A significance level of .05 was chosen for each of these analyses of variance.

Means of the dependent variables grouped by the independent variables were calculated. Orthogonal contrasts were performed on the effect of parent material and the parent material*aspect interaction.

Analysis of Site Index

Site index curves were constructed for the white pine and yellow-poplar plantations. These were anamorphic site index curves because of the limited data.

The stem analysis and height-to-whorl data were adjusted from plantation age to age from seed to facilitate comparisons with published curves. Two years were added to each age for the white pine and one year for the yellow-poplar.

In the stem analysis data, the height at the point of sectioning underestimates the actual height at the determined age because the section will generally occur at some point along the annual leader rather than at the terminal bud. This bias was removed by increasing each section height by one-half of the estimated length of the annual leader (Carmean 1972).

White pine. The stem analysis data (at 32 years from seed) and the height-to-whorl data (at 48 years from seed) were fitted to the regression model

$$\log H = a + b(1/A) \qquad (1)$$

where H = total height in feet

A = stand age in years from seed

a, b = regression coefficients

The resulting b values were used to graph site index curves with base age 25 years from seed for each data set. These curves were developed using the equation

$$\log S = \log H + b(1/25 - 1/A) \qquad (2)$$

where S = site index in feet

The curves developed from the two data sets were tested for parallel slopes using the test statistic described by Kleinbaum and Kupper (1978)

$$Z = \frac{Bs - Bh}{\sqrt{S^2s + S^2h}} \qquad (3)$$

where Bs = the estimated b value from the stem analysis

Bh = the estimated b value from the height-to-whorls

S^2s = the estimated variance of the estimated slope for the stem analysis

S^2h = the estimated variance of the estimated slope for the height-to-whorls

The distribution of Z will be approximately normal with zero mean and unit variance for moderately large sample sizes (Kleinbaum and Kupper 1978). A critical value of 1.96 was chosen which is associated with the 95 percent confidence level.

Next, the height-to-whorl data were fitted to the model again, but this time only the first 32 heights were analyzed. The b value from this analysis was compared to the b value from the complete height-to-whorl data set and to the b value from the stem analysis using equation 3.

Since the variance of the slope of the published curves was not known, the slopes were compared using another test statistic described by Kleinbaum and Kupper (1978)

$$T = \frac{Bd - Bp}{ESE} \qquad (4)$$

where Bd = the estimated b value from this study

Bp = the estimated b value from the published study

ESE = an estimate of the standard error of the estimated slope from this study

This test statistic has the T distribution with n-2 degrees of freedom (Kleinbaum and Kupper 1978). A critical value of 1.96 was chosen, which is associated with the 95 percent confidence level.

The b value from Vimmerstedt's (1959) site index curves for white pine plantations was compared to the b values from the stem analysis and height-to-whorls data using equation 4.

Height of dominants and codominants at 15 years from seed, determined from the stem analysis data, and the average height of dominants and codominants at 32 and 48 years from seed were used to calculate the site index for each plot at three separate ages using Vimmerstedt's equation. These estimates of site index were compared by graphing.

Yellow-poplar. The yellow-poplar stem analysis data (at 31 years from seed) were also fitted to the model (equation 1) and the resulting b value was used to graph site index curves with base age

25 years from seed. Next, the average height of dominants and codominants at age 47 were added to the stem analysis data set and the coefficient was recalculated. This b value was compared to the initial b value using equation 3. The slope of these curves was then compared to the slopes of Beck's (1962) curves for the Piedmont and for the Southern Appalachian mountains, and Schlaegel et al. (1969) West Virginia curves using equation 4. Curves were also developed from the regionwide data in McCarthy's (1933) Table 17 using SAS procedure GLM. The slope of the curves constructed with McCarthy's data was compared to the slope of the curves developed with the study data using equation 4.

Yield Prediction

Total and merchantable cubic-foot yields per acre were graphed by site index and basal area for each species and measurement age to determine if the yields could be predicted from these variables. These graphs indicated relationships between yield, site index and basal area. A modification of Schumacher's (1939) model that was first applied to variable density yield prediction by MacKinney and Chaiken (1939), was selected to predict cubic-foot yield.

$$\ln V = a + b_1 S + b_2 (\ln B) + b_3 (1/A) \quad (5)$$

where ln V = the natural logarithm of cubic-foot volume per acre

S = site index in feet

B = basal area per acre in square feet

A = stand age in years from seed

b_1, b_2, b_3 = regression coefficients

Equation 5 has two advantages in describing current yield. First, the mathematical form of the equation agrees with biological concepts of even-aged stand development (Schumacher 1939). And second, the use of the natural logarithm of volume, rather than volume itself, is generally more compatible with the statistical assumptions of regression analysis, such as linearity, normality, additivity, and homogeneity of variance (Clutter 1963).

The model, including the three possible two-variable interactions,

$$\ln V = a + b_1S + b_2(\ln B) + b_3(1/A) + b_4S(\ln B) + b_5S(1/A) + b_6(\ln B)(1/A) \qquad (6)$$

was fitted for both total and merchantable cubic-foot yields. For these regressions, site index was defined as the height at 25 years from seed which was determined from stem analysis. The white pine yield predictor was developed using only the data from the 16 plots which survived the bark beetle attack.

The resulting analyses of variance indicate that the three independent variables are highly significant and none of the interactions are significant; therefore, the model was fitted again without the interactions.

Predicted cubic-foot yields were compared to observed plot yields for both species. Differences between the observed and predicted yields were graphed by site index for each species to locate trends which may suggest the need for additional terms in the model.

The volume to a 3-inch top (outside bark) was predicted for the white pine plots using Vimmerstedt's (1962) equation and the newly developed equation. The predicted yields were graphed by basal area and site index for each measurement age to establish possible trends of differences.

The total yield (inside bark) was predicted for the yellow-poplar plots using Schlaegel and Kulow's (1969) equation. However, Beck (1963) did not publish a tree volume equation for total stem volume (inside bark), so the yields predicted from this study could not be directly compared to yields predicted from Schlaegel and Kulow's equation. Therefore, total inside bark volume predicted from Schlaegel and Kulow's equation was divided by total outside bark volume predicted from the newly developed equation. This ratio of total inside bark volume to the total outside bark volume was compared to the ratio of Beck's (1963) volumes to a 4-inch top (o.b.).

CHAPTER V

RESULTS

Comparison Among Species and Ages

White pine yields were much greater than yellow-poplar or shortleaf pine yields on all parent materials and aspects. At plantation age 30, white pine had about 2.5 times more total volume than yellow-poplar and nearly 50% more total volume than shortleaf pine (Table 3). At plantation age 46, white pine still had over two times more total volume than yellow-poplar. Similarly, white pine had more merchantable volume than yellow-poplar and shortleaf pine (Table 4).

White pine total volume increased by 58% from age 30 to age 46. Periodic growth was largest (120%) on southern shale sites and least (3%) on southern dolomitic soils. Yellow-poplar total volume increased by 77% from age 30 to 46. Periodic growth was greatest (190%) on northern dolomitic soils and least (39%) on southern limestone soils.

Effect of Parent Material and Aspect on Yield

Shortleaf Pine

In the analysis of the shortleaf pine plots at plantation age 30, the contrast of dolomite and limestone versus shale was significant for the average height of dominants and codominants (Table 10, Appendix). The mean average height for dolomite and

TABLE 3

TOTAL CUBIC-FOOT YIELDS[1] PER ACRE BY SPECIES, AGE AND TREATMENT

Treatment	Age 30			Age 46	
	Shortleaf Pine	White Pine	Yellow-poplar	White Pine	Yellow-poplar
Overall Mean	4478	6574	2611	10,413	4618
Dolomite	4263	6714	1588	10,037	3482
Limestone	4842	6858	3189	10,063	4612
Shale	4350	5897	3419	11,209	5949
North	4293	6679	2583	10,747	4895
South	4627	6422	2642	9,983	4307
Dolomite/North	4367	6762	1299	12,176	3822
Dolomite/South	4138	6600	1804	6,829	3227
Limestone/North	4784	7109	2989	9,528	4515
Limestone/South	4871	6669	3389	10,599	4709
Shale/North	3653	6055	3342	10,539	5890
Shale/South	4872	5661	3572	12,214	6067

[1]Total stem cubic-foot volume (outside bark) for all trees > 3.0 inch dbh.

TABLE 4

MERCHANTABLE CUBIC-FOOT YIELDS[1] PER ACRE
BY SPECIES, AGE AND TREATMENT

Treatment	Age 30			Age 46	
	Shortleaf Pine	White Pine	Yellow-poplar	White Pine	Yellow-poplar
Overall Mean	3996	6084	2158	10,091	4161
Dolomite	3789	6199	1219	9,742	3046
Limestone	4310	6355	2670	9,750	4151
Shale	3917	5476	2912	10,849	5469
North	3834	6216	2097	10,438	4411
South	4125	5893	2227	9,645	3880
Dolomite/North	3895	6283	912	11,847	3340
Dolomite/South	3661	6002	1450	6,585	2825
Limestone/North	4308	6648	2515	9,277	4048
Limestone/South	4311	6135	2824	10,222	4253
Shale/North	3238	5629	2777	10,190	5396
Shale/South	4426	5247	3181	11,838	5617

[1]Cubic-foot volume (outside bark) to a 4-inch top (o.b.) for all trees > 5.0 inch dbh.

limestone was greater than the mean for shale (Table 5). The mean average height for dolomite was not significantly different from the mean for limestone.

There were no significant independent variables in the analyses of number of stems, basal area, total volume, merchantable volume, or mean dbh for the shortleaf pine plots. Therefore, while the average height was less on the shale plots, the volumes on these plots were not affected.

Yellow-poplar

In the analysis of the yellow-poplar plots at plantation age 30, the effect of parent material was significant for basal area, total volume, merchantable volume, average height, and mean dbh. The contrast of dolomite and limestone versus shale was significant for merchantable volume and mean dbh. The contrast of dolomite versus limestone was significant for basal area, total volume, merchantable volume, and average height (Table 11, Appendix).

The means of the basal area, total volume, average height, and merchantable volume for limestone were greater than the means for dolomite. The means of the merchantable volume and mean diameter for shale were greater than the combined means for dolomite and limestone (Table 6).

There were no significant variables in the analysis of number of stems indicating that the yellow-poplar mortality was not related to either parent material or aspect. Aspect was not significant for any of the stand attributes.

TABLE 5

MEANS OF THE SIX DEPENDENT VARIABLES BY PARENT MATERIAL AND ASPECT FOR SHORTLEAF PINE AT PLANTATION AGE 30

Contrast	Number of Stems (per acre)	Basal Area (ft^2/ac)	Total Volume[1] (ft^3/ac)	Merchantable Volume[2] (ft^3/ac)	Average Height[3] (feet)	Mean Dbh (inches)
Dolomite and Limestone	763.1[a]	166.30[a]	4524[a]	4023[a]	56.2[a]	6.26[a]
Shale	668.5[a]	166.46[a]	4350[a]	3917[a]	52.6[b]	6.58[a]
Dolomite	723.4[a]	156.67[a]	4263[a]	3789[a]	56.6[a]	6.21[a]
Limestone	811.7[a]	178.07[a]	4842[a]	4310[a]	55.7[a]	6.31[a]
North	702.9[a]	158.17[a]	4293[a]	3834[a]	55.3[a]	6.37[a]
South	767.2[a]	172.87[a]	4627[a]	4125[a]	55.3[a]	6.32[a]

[a,b]Means superscripted with different letters within a contrast and column are significantly different at the 95 percent confidence level.

[1]Total stem volume (outside bark) for all trees > 3.0 inch dbh.

[2]Volume (outside bark) to a 4-inch top (o.b.) for all trees > 5.0 inch dbh.

[3]Average height of dominants and codominants.

TABLE 6

MEANS OF THE SIX DEPENDENT VARIABLES BY PARENT MATERIAL AND ASPECT FOR YELLOW-POPLAR AT PLANTATION AGE 30

Contrast	Number of Stems (per acre)	Basal Area (ft^2/ac)	Total Volume[1] (ft^3/ac)	Merchantable Volume[2] (ft^3/ac)	Average Height[3] (feet)	Mean Dbh (inches)
Dolomite and Limestone	637.5[a]	89.35[a]	2170[a]	1747[a]	53.9[a]	4.21[a]
Shale	641.3[a]	124.88[a]	3419[a]	2912[b]	61.3[a]	5.24[b]
Dolomite	599.0[a]	71.94[a]	1588[a]	1219[a]	49.7[a]	3.89[a]
Limestone	705.0[a]	119.82[b]	3189[b]	2670[b]	61.4[b]	4.78[a]
North	663.6[a]	100.91[a]	2583[a]	2097[a]	56.4[a]	4.48[a]
South	611.1[a]	103.00[a]	2642[a]	2227[a]	56.7[a]	4.68[a]

[a,b]Means superscripted with different letters within a contrast and column are significantly different at the 95 percent confidence level.

[1]Total stem volume (outside bark) for all trees > 3.0 inch dbh.

[2]Volume (outside bark) to a 4-inch top (o.b.) for all trees > 5.0 inch dbh.

[3]Average height of dominants and codominants.

In the analysis of the yellow-poplar plots at plantation age 46, the effect of parent material was significant for merchantable volume, average height, and mean dbh. The contrast of dolomite and limestone versus shale was significant for total volume, merchantable volume, average height, and mean dbh (Table 12, Appendix). The means of these variables were greater on shale than on dolomite and limestone (Table 7). The contrast between dolomite and limestone was not significant for any stand characteristic (Table 12, Appendix). Overall, the volume of the yellow-poplar plots was related to the soil parent material, but not to the aspect.

White Pine

In the analysis of the white pine plots at plantation age 30, the number of stems was the only dependent variable for which there were any significant independent variables. The significant dependent variables were : 1) parent material, 2) the contrast of dolomite and limestone versus shale, and 3) aspect (Table 13, Appendix). The shale plots had fewer stems on the average than the dolomite and limestone plots. Plots on northern aspects had fewer stems than did plots on southern aspects (Table 8). Since the number of stems is a measure of mortality, it can be concluded that mortality was greater on shale soils and northern slopes. However, plots on shale soils and northern slopes did not have significantly less volume.

The only independent variable which was significant in the white pine analyses at plantation age 46 was the second contrast of the

TABLE 7

MEANS OF THE SIX DIFFERENT VARIABLES BY PARENT MATERIAL AND ASPECT FOR YELLOW-POPLAR AT PLANTATION AGE 46

Contrast	Number of Stems (per acre)	Basal Area (ft^2/ac)	Total Volume[1] (ft^3/ac)	Merchantable Volume[2] (ft^3/ac)	Average Height[3] (feet)	Mean Dbh (inches)
Dolomite and Limestone	441.9^a	117.81^a	3893^a	3448^a	75.7^a	6.47^a
Shale	377.9^a	153.98^a	5949^b	5469^b	85.6^b	8.15^b
Dolomite	464.3^a	111.40^a	3482^a	3046^a	72.9^a	6.13^a
Limestone	402.9^a	129.02^a	4612^a	4151^a	80.5^a	7.05^a
North	437.5^a	137.18^a	4895^a	4411^a	78.3^a	7.16^a
South	398.9^a	123.15^a	4307^a	3880^a	80.1^a	6.95^a

[a,b]Means superscripted with different letters within a contrast and column are significantly different at the 95 percent confidence level.

[1]Total stem volume (outside bark) for all trees > 3.0 inch dbh.

[2]Volume (outside bark) to a 4-inch top (o.b.) for all trees > 5.0 inch dbh.

[3]Average height of dominants and codominants.

TABLE 8

MEANS OF THE SIX DEPENDENT VARIABLES BY PARENT MATERIAL AND ASPECT FOR WHITE PINE AT PLANTATION AGE 30

Contrast	Number of Stems (per acre)	Basal Area (ft^2/ac)	Total Volume[1] (ft^3/ac)	Merchantable Volume[2] (ft^3/ac)	Average Height[3] (feet)	Mean Dbh (inches)
Dolomite and Limestone	653.8^a	215.70^a	6773^a	6263^a	66.6^a	7.50^a
Shale	536.8^b	195.84^a	5897^a	5476^a	63.2^a	7.87^a
Dolomite	661.4^a	211.66^a	6714^a	6199^a	67.7^a	7.33^a
Limestone	642.9^a	221.47^a	6858^a	6355^a	65.1^a	7.73^a
North	587.3^a	208.94^a	6679^a	6216^a	67.8^a	7.77^a
South	684.8^b	214.43^a	6422^a	5893^a	63.0^a	7.31^a

[a,b] Means superscripted with different letters within a contrast and column are significantly different at the 95 percent confidence level.

[1] Total stem volume (outside bark) for all trees > 3.0 inch dbh.

[2] Volume (outside bark) to a 4-inch top (o.b.) for all trees > 5.0 inch dbh.

[3] Average height of dominants and codominants.

parent material and aspect interaction. It compares the response on dolomitic northern slopes with dolomitic southern slopes, and limestone northern slopes with limestone southern slopes. This contrast was significant for the number of stems, basal area, merchantable volume, and total volume (Table 14, Appendix).

Figure 1 shows the mean total cubic-foot volume by parent material and aspect. There is no significant difference between the overall means for dolomite and limestone. But when the means are separated by aspect, there is a significant difference. The means for basal area, merchantable volume and number of stems follow a similar pattern and are shown in Table 9.

Site Index Equations

As stated in the Methods Chapter, the data were converted from plantation age to age from seed in this section to facilitate comparisons with published site index curves.

White Pine

The stem analysis data (at 32 years from seed) were used to develop the site index equation

$$\log S = \log H - 7.253\ (1/25 - 1/A) \qquad (7)$$

where S = site index in feet

H = height in feet

A = age in years from seed

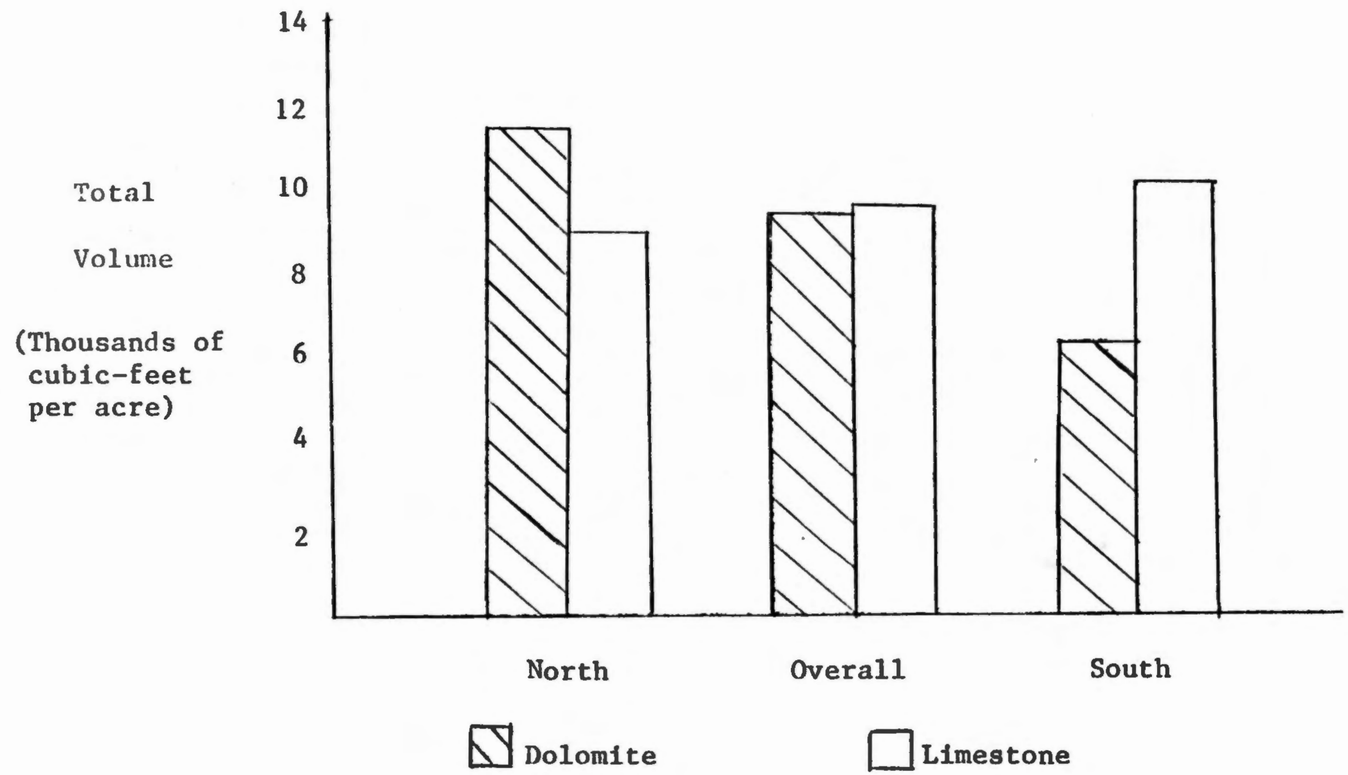

Figure 1. Mean Total Cubic-foot Volume by Parent Material and Aspect for White Pine at Plantation Age 46

TABLE 9

MEANS OF THE SIX DEPENDENT VARIABLES BY PARENT MATERIAL AND ASPECT FOR WHITE PINE AT PLANTATION AGE 46

Contrast[1]	Means of Treatments[1]	No. of Stems (per acre)	Basal Area (ft^2/ac)	Total Volume[2] (ft^3/ac)	Merchantable Volume[3] (ft^3/ac)	Average Height[4] (feet)	Mean Dbh (inches)
D and L vs Sh	D and L	323.0[a]	231.56[a]	10,051[a]	9,746[a]	89.9[a]	11.16[a]
	Sh	388.1[a]	269.12[a]	11,209[a]	10,849[a]	87.8[a]	11.06[a]
D vs L	D	308.1[a]	224.26[a]	10,037[a]	9,742[a]	91.8[a]	11.07[a]
	L	335.5[a]	237.65[a]	10,063[a]	9,750[a]	88.4[a]	11.23[a]
N vs S	N	321.4[a]	243.30[a]	10,747[a]	10,438[a]	92.1[a]	11.56[a]
	S	371.6[a]	243.30[a]	9,983[a]	9,645[a]	85.7[a]	10.57[a]
(D and L vs Sh) vs (N vs S)	D and L on N	291.8[a]	238.77[a]	10,852[a]	10,562[a]	94.2[a]	11.88[a]
	D and L on S	360.5[a]	222.92[a]	9,091[a]	8,768[a]	84.8[a]	10.28[a]
	Sh on N	380.6[a]	252.37[a]	10,539[a]	10,190[a]	87.8[a]	10.91[a]
	Sh on S	399.3[a]	294.25[a]	12,214[a]	11,838[a]	87.8[a]	11.27[a]
(D vs L) vs (N vs S)	D on N	332.5[a]	258.47[a]	12,176[a]	11,847[a]	97.8[a]	11.62[a]
	D on S	271.5[a]	172.95[b]	6,829[b]	6,585[b]	82.7[a]	10.24[a]
	L on N	251.1[a]	219.07[a]	9,528[a]	9,277[a]	90.6[a]	12.15[a]
	L on S	419.9[b]	256.23[a]	10,599[a]	10,222[a]	86.2[a]	10.31[a]

TABLE 9 (continued)

[a,b]Means superscripted with different letters within a contrast and column are significantly different at the 95 percent confidence level.

[1]D = Dolomite, L = Limestone, Sh = Shale, N = North, S = South.

[2]Total stem volume (outside bark) for all trees > 3.0 inch dbh.

[3]Volume (outside bark) to a 4-inch top (o.b.) for all trees > 5.0 inch dbh.

[4]Average height of dominants and codominants.

The height-to-whorls data (at 48 years from seed) produced the site index equation

$$\log S = \log H - 6.328\ (1/25 - 1/A) \qquad (8)$$

The slopes of these equations were compared and the null hypothesis of parallel slopes was rejected. The Z statistics are shown in Table 15 in the Appendix.

Next, the height-to-whorls data set was fitted to the same model, this time only analyzing the first 32 whorls. This partial data set resulted in the site index equation

$$\log S = \log H - 6.347\ (1/25 - 1/A) \qquad (9)$$

The slope of this equation was compared to the slope of equation 8 which was developed from the complete data set and the slopes were concluded to be parallel (Table 15, Appendix). The slope of equation 9 was also compared to the slope of equation 7 from the stem analysis data and the slopes were significantly different. This indicates that the differences in the slopes of equations 7 and 8 are due to differences in the two data sets. Equation 8 was chosen to describe the site index of the white pine plantation because it included heights at older ages. The site index curves developed from equation 8 are graphed in Figure 2.

The slopes of equations 7 and 8 were compared to the slope of Vimmerstedt's (1959) site index equation

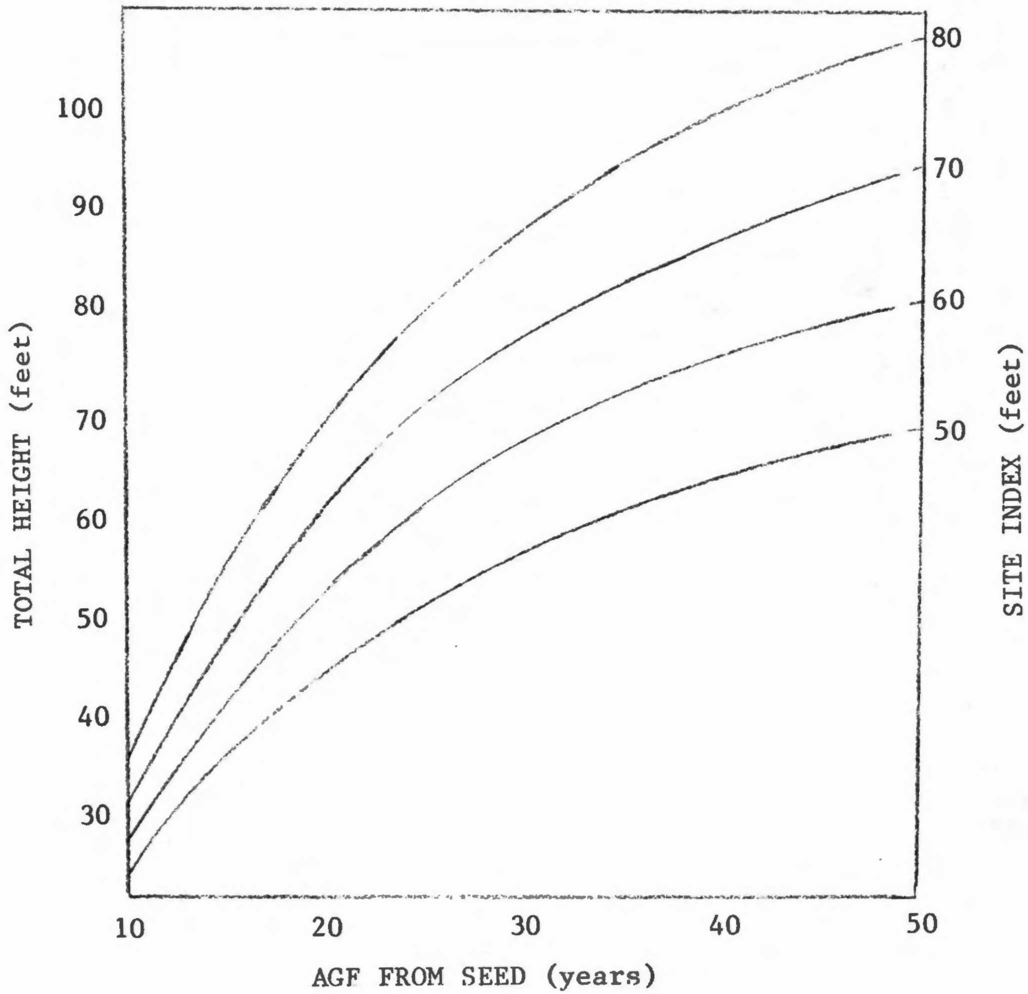

Figure 2. Site index curves (base age 25 years from seed) for white pine plantations on abandoned fields in the vicinity of Norris Lake, Tennessee.

$$\log S = \log H - 7.819\ (1/25 - 1/A) \qquad (10)$$

for white pine plantations in the Southern Appalachians. The slopes of both equations 7 and 8 were significantly different from the slope of Vimmerstedt's equation (10) (Table 15, Appendix).

Heights of dominants and codominants at 15 years from seed, as determined from the stem analysis data, and average heights of dominants and codominants at 32 and 48 years from seed were used to calculate three estimates of site index for each plot using Vimmerstedt's equation (10). These estimates were graphed by the average height at age 32 in Figure 3 which shows that the estimates of site index, using Vimmerstedt's equation, increase with age. Since site index is considered to be constant throughout the life of a stand, the increase indicates that Vimmerstedt's equation for the Southern Appalachians produces biased estimates of site index on these sites in the Ridge and Valley Province.

Yellow-poplar

The stem analysis data (at 31 years from seed) were used to develop the site index equation

$$\log S = \log H - 5.321\ (1/25 - 1/A) \qquad (11)$$

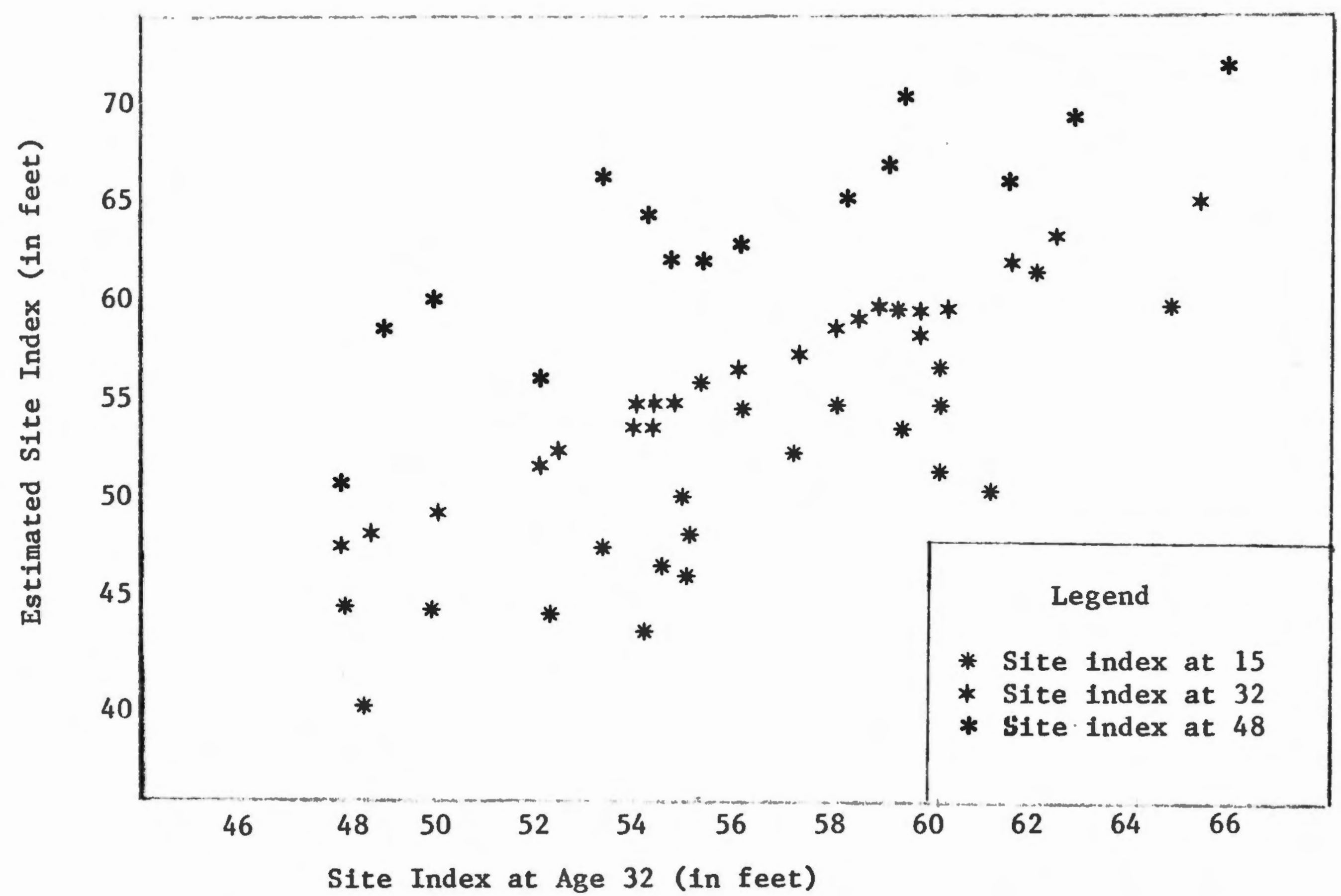

Figure 3. Estimates of site index at 15, 32 and 48 years from seed using Vimmerstedt's equation.

with base age 25. The average heights of dominants and codominants at 47 years from seed were added to the stem analysis data set to produce the site index equation

$$\log S = \log H - 5.328 \, (1/25 - 1/A) \qquad (12)$$

The slopes of these equations were compared and accepted as parallel (Table 15, Appendix). Therefore, equation 12 was chosen to predict the site index because it included data at older ages. Curves constructed from equation 12 are graphed in Figure 4.

Equation 12 was compared to several sets of published site index curves with base age 50. Slopes of equations with different base ages can be directly compared because base age affects the intercept but not the slope of the curves.

The slope of equation 12 was compared to the slope of Beck's (1962) Piedmont site index equation

$$\log S = \log H - 6.503 \, (1/50 - 1/A) \qquad (13)$$

and the slopes were found to be not parallel. Then equation 12 was compared to Beck's (1962) Southern Appalachian site index equation

$$\log S = \log H - 9.158 \, (1/50 - 1/A) \qquad (14)$$

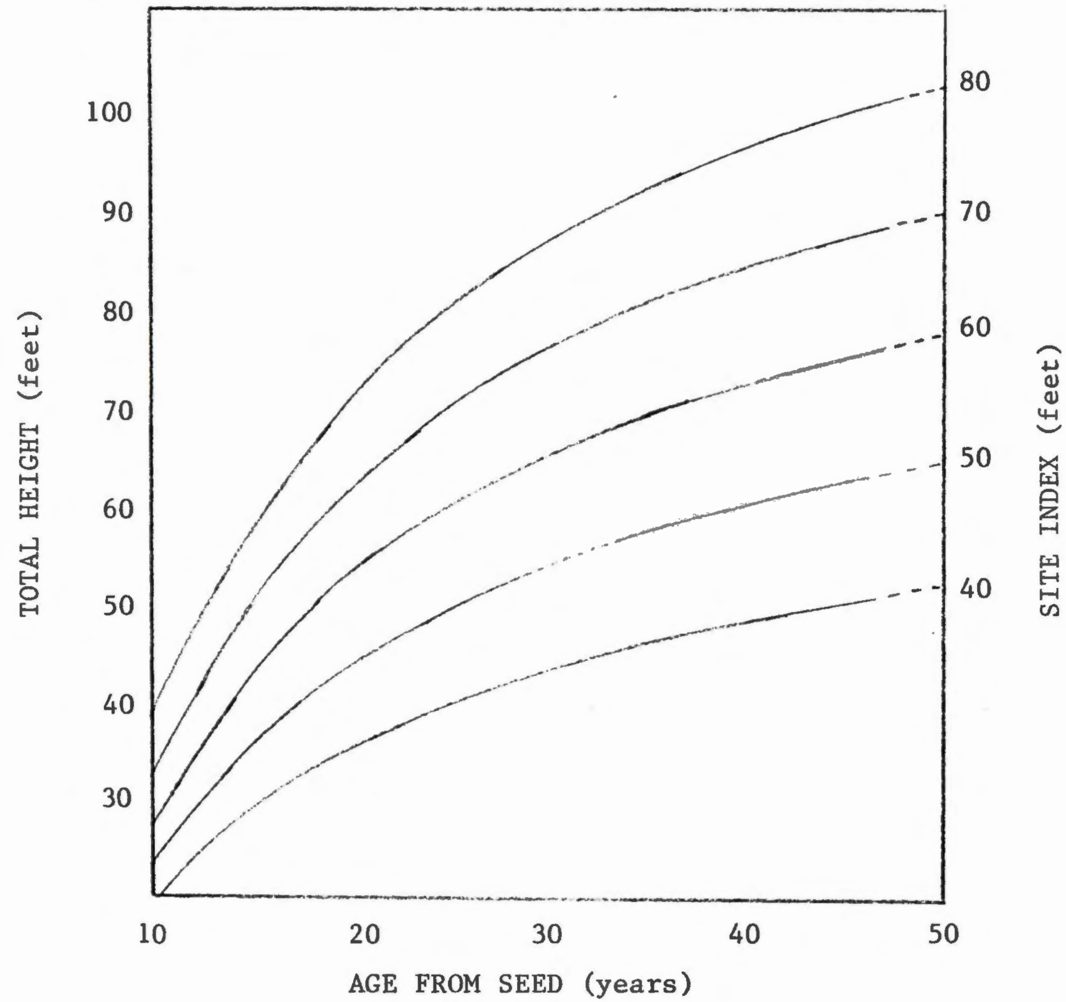

Figure 4. Site index curves (base age 25 years from seed) for yellow-poplar plantations on abandoned fields in the vicinity of Norris Lake, Tennessee.

and the null hypothesis of parallel slopes was rejected. Equation 12 was then compared to Schlaegel et al. (1969) West Virginia site index equation

$$\log S \doteq \log H - 7.716\ (1/50 - 1/A) \qquad (15)$$

and the slopes were found to be significantly different. Finally, equation 12 was compared to the equation developed from McCarthy's (1933) regionwide data

$$\log S = \log H - 4.969\ (1/25 - 1/A) \qquad (16)$$

and the slopes were concluded to be not parallel. The T statistics for each of these comparisons are shown in Table 15 in the Appendix.

Yield Prediction

White Pine

Total volume. The model

$$\ln V = a + b\ S + b\ (\ln B) + b\ (1/A) + b\ S(\ln B) + b\ S(1/A)$$
$$+ b\ (\ln B)(1/A) \qquad (6)$$

was fitted to the white pine total volume data. The resulting analysis of variance indicates that the interaction terms are not significant (Table 16, Appendix). The model was fitted again without the interactions to produce the total cubic-foot volume yield equation

$$\ln TV = 3.0538 + .0146*S + 1.0976*\ln B -30.0021/A \quad (17)$$

where TV = total cubic-foot volume (outside bark) per acre for all trees > 3.0 inch dbh

The equation explained 98.44 percent of the variation about the mean ln TV and results in a mean square error of .001652 (on the logarithmic scale).

Merchantable volume. The model (equation 6) was also fitted to the white pine merchantable volume data and the interactions were not significant (Table 16, Appendix). The model was fitted again without the interactions and the merchantable volume yield equation was calculated as

$$\ln V4 = 3.0513 + .0163*S + 1.0929*\ln B - 34.4823/A \quad (18)$$

where V4 = per acre cubic-foot volume (outside bark) to a 4" top (o.b.) for all trees > 5" dbh

This equation accounts for 98.10 percent of the variation about the mean ln V4 and results in a mean square error of .002291 (on the logarithmic scale).

In addition, the model was fitted to the white pine volume to a 3-inch top data to produce the yield equation

$$\ln V3 = 3.3948 + .0161*S + 1.0317*\ln B - 33.7351/A \quad (19)$$

where V3 = per acre cubic-foot volume (outside bark) to a 3" top (o.b.) for all trees > 4" dbh

This equation accounts for 97.81 percent of the variation about the mean ln V3 and results in a mean square error of .002449 (on the logarithmic scale).

<u>Yellow-poplar</u>

<u>Total volume.</u> The yield model was fitted to the yellow-poplar total cubic-foot volume data and the interactions were found to be not significant (Table 16, Appendix). The model was fitted without the interactions and the total volume yield equation was calculated as

$$\ln TV = 2.7342 + .0075*S + 1.2006*\ln B -26.5095/A \quad (20)$$

This equation accounts for 98.91 percent of the variation about the mean ln TV and results in a mean square error of .003313 (on the logarithmic scale).

<u>Merchantable volume.</u> The yield model was also fitted to the yellow-poplar merchantable volume data and the resulting analysis of

variance shows that the interactions were not significant (Table 16, Appendix). The model without the interactions was fitted again and produced the following merchantable volume yield equation

$$\ln V4 = 2.1237 + .0084*S + 1.3222*\ln B - 32.8582/A \quad (21)$$

This equation accounts for 97.87 percent of the variation about the mean ln V4 and results in a mean square error of .008238 (on the logarithmic scale).

Predicted versus Actual Yields

Yields predicted from equations 17, 18, 19, 20 and 21, using the plot basal areas, site indexes and ages, were subtracted from the observed yields and graphed by site index for each species and measurement age. These graphs showed no trends with site index indicating that the model accurately describes the yields.

CHAPTER VI

DISCUSSION

Comparison Among Species and Ages

White pine yields were greater than yellow-poplar and shortleaf pine yields on all parent materials and aspects. Shortleaf pine had higher yields than yellow-poplar on all sites. Shortleaf pine yields came closest to white pine yields on southern shale sites where white pine had only 16 more total volume than shortleaf pine.

While yellow-poplar had the least yield of the three species, it had a larger relative increase in volume from age 30 to age 46. Yellow-poplar increased its total volume by 77 in 16 years, while white pine increased 58. White pine total volume per acre increased by only 3 on southern dolomitic sites. This poor growth is related to the loss of four plots to bark beetles and heavy mortality on surviving plots on these sites.

Effect of Parent Material and Aspect on Yield

Shortleaf Pine

The analysis of variance of the shortleaf pine plots indicated that the average height of dominants and codominants was less on shale sites than on dolomite and limestone. These results are similar to Minckler's (1941b) findings based on the survival and growth of the plantations after three years. Minckler found that the shortleaf pine did best on dolomite soils with limestone soils second and shale soils third. He found no difference by aspect. Burton (1964) studied the plantations 20 years after establishment and found that the height and diameter did not vary with parent material or aspect, but the number of stems and volume were greater on south slopes than on north. Burton (1964) attributed the poor survival on the north slopes to severe competition from dense vegetation. These results do not agree with Graney and Ferguson (1971) who concluded that the site index of shortleaf pine in Arkansas was greater on north and northeastern aspects and that the site index did not vary by the soil parent material. Graney and Ferguson attributed the lower average site index on southern exposures to increased evaporative stress.

Yellow-poplar

The analysis of variance of yellow-poplar at plantation age 30 indicated that yields were best on shale sites and least on dolomite sites. At plantation age 46, yields were still best on shale sites, though yields on limestone were not different from those on dolomite. In addition, the analyses showed that aspect was not significant. Minckler's (1941b) evaluation of the third year growth and survival of the plantations indicated that the yellow-poplar grew best on northern shale slopes. Burton's (1964) study showed that the yellow-poplar grew much better on limestone and shale sites than on dolomite, and somewhat better on north slopes than on south. Burton (1964) attributed the low volumes on the dolomite plots to low average diameters and stems of less than five inches dbh not contributing to the volume estimate. Past studies have found yellow-poplar yields significantly greater on northern slopes (Auten 1945, Hebb 1962, McCarthy 1933). Auten (1945) studied natural yellow-poplar stands in the central states and found that the average site index on north and east slopes was 17 feet higher than on south and west slopes. He found no difference in growth by parent material.

White Pine

In the analysis of variance of the white pine plots at plantation age 30, there were fewer stems per acre on shale sites than on dolomite and limestone sites, and fewer stems on northern slopes than on southern slopes. Therefore, it seems that either the diameters and heights or the volumes should also vary on shale sites and northern slopes, but the number of stems was the only significant independent variable at the .05 level. However, at the .10 level the effect of aspect was significant for the mean diameter and average height. Thus there were fewer stems but larger trees on the northern slopes, resulting in volumes similar to those on southern slopes. There were also fewer stems on the shale sites, where the diameters and heights did not vary with parent material. On the shale sites the basal area and total volume were less though not significantly at the .05 level.

In the analysis at plantation age 46, yields on limestone and shale plots were similar and varied little by aspect. However, the plots on dolomitic soils on northern exposures had the greatest yield and the plots on dolomitic soils on southern exposures had the least yield. This difference in growth on dolomite plots by aspect may be due to greater moisture stress on the southern slopes.

In Minckler's (1941b) evaluation of plantation growth and survival after the third year, he concluded that the white pine grew best on dolomite plots and attained the least growth on shale sites. He also found no difference in growth by aspect. In Burton's (1964) inventory 20 years after establishment of the plantations, he concluded that the white pine attained better height growth on north slopes than on south, but that the number of stems, diameter growth and volume were not associated with aspect. Parent material was not significant for any of the variables (Burton 1964).

Site Index Curves

The white pine site index curves were developed from the height to each whorl of two trees per plot on 16 plots. The yellow-poplar curves were developed from the stem analysis of one tree per plot on 17 plots. Both sets of curves were developed using successive height and age measurements on individual trees. The published curves which were used for comparison were developed using total height and age measurements on numerous plots, ranging from 111 plots for Vimmerstedt's (1959) curves to 267 plots for Beck's (1962) Southern Appalachian curves. The use of successive measurements on a tree eliminates the distortion due to the violation of the assumption that the average site quality is the same for each age class sampled (Beck and Trousdell 1973).

The published curves for both white pine and yellow-poplar underpredicted site index at ages less than the reference age. At ages beyond 25 years the published curves overpredicted site index. The errors were largest at older ages and increased as site index increased. Beck and Trousdell (1973) compared conventional site index curves for white pine developed from total heights and ages to curves developed from stem analysis data. The conventional curves were found to underestimate site index in young stands. This bias was attributed to differences in the average site quality of age classes sampled.

The yellow-poplar site index curves presented here were developed for plantations but they were compared to curves for natural stands because there were no curves for plantations available. The height growth is assumed to be similar in plantations and natural stands because stand density is assumed to have little effect on height growth.

Yield Predictions

The correlation coefficients of the yield prediction equations indicated an excellent explanation of variation. Scatter diagrams showed that the equations accurately describe yield.

White Pine

The white pine cubic-foot yield equation to a 3-inch top (outside bark) was compared to Vimmerstedt's (1962) yield equation. Vimmerstedt's equation overpredicted yield for every observation at age 32 and underpredicted yield for all but one plot at age 48. At age 48 the difference increased as basal area increased, and at age 32 the difference increased as site index increased. Vimmerstedt's equation uses the original number of trees planted per acre as the stand density variable, but because all the white pine plots in this study had the same initial spacing, this variable became a constant in the equation. Therefore, the equation relied heavily on site index to predict yield.

Yellow-poplar

Beck and Della-Bianca (1970) constructed yield tables for unthinned natural stands which were not compared to the yield equations developed for the study plantation because the tables were based on fewer stems per acre than occurred on the study plots. Beck and Della-Bianca estimated from 48 to 332 trees per acre at 31 to 50 years of age, while the stems on the plantation measured for this work ranged from 473 to 936 with a mean of 639 at 31 years from seed and ranged from 226 to 549 with a mean of 419 at 47 years.

The predicted total cubic-foot yield (outside bark) for yellow-poplar was compared to the total yield (inside bark) predicted from Schlaegel and Kulow's (1969) equation. The average ratio of predicted inside bark volume using Schlaegel and Kulow's equation to the predicted outside bark volume using the newly developed yield equation is .91 at 31 years from seed and .62 at 47 years. This ratio decreased as basal area and site index increased. The average ratio of inside bark to outside bark cubic-foot yields to a 4-inch top (Beck 1963) is about .83. This indicates that Schlaegel and Kulow's equation overpredicted the yield on plots with less than 100 square feet of basal area at age 31, while it underpredicted yield on plots with higher basal areas at age 31 and on all plots at age 47.

Regional Differences

The published site index curves and yield prediction equations may vary from those developed in this work due to physiographic regional differences.

Ridge and Valley Province

The site index curves presented here were developed for the Ridge and Valley Province, which consists of steep parallel ridges and narrow intervening valleys. The elevation ranges from about 1000 to 4500 feet. The soils in the area are sedimentary, primarily sandstone, limestone, shale and dolomite. The soils are generally well-drained, strongly acidic and low to medium in fertility (Smith and Linnartz 1980).

Blue Ridge Province

Both the white pine and yellow-poplar site index curves and the white pine yield equations were compared to published curves and equations developed for the Southern Appalachians (also known as the Blue Ridge Province). The mountains of this area have steep slopes and sharp crests, and are dissected by steep narrow valleys. The elevations are considerably higher than the Ridge and Valley ranging from 2000 to 6000 feet. The Province is underlain by crystalline rocks with granite, gneiss and schist as compared to the sedimentary rocks of the Ridge and Valley Province. The climate, drainage and soil fertility of this area are similar to that found in the soils of the Ridge and Valley (Smith and Linnartz 1980).

Piedmont Province

The yellow-poplar site index curves were also compared to published curves developed for the Piedmont Province. The Piedmont consists of very old metamorphic rocks, including gneiss, schist, marble and quartzite. The soils in this area are less acidic than soils in the Ridge and Valley region. The topography is gently rolling as compared to the steep ridges of the Ridge and Valley and elevations only range from 300 to 1200 feet (Smith and Linnartz 1980).

Appalachian Plateau

The yellow-poplar site index curves and yield equations were compared to published curves and equations from West Virginia which is part of the Appalachian Plateau. This is a maturely dissected plateau with narrow ridges, steep-sided slopes and narrow valleys. The elevations are somewhat higher than in the Ridge and Valley region ranging from 3000 to 5000 feet. This area consists of mostly sandstone and shale and the soils are strongly acidic and well-drained similar to those of the Ridge and Valley Province (Smith and Linnartz 1980).

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

White pine produced the highest yields and yellow-poplar produced the lowest yields on all parent materials and aspects. White pine mortality was greater on northern slopes than on southern, and greater on shale soils than on dolomite or limestone at plantation age 30. At plantation age 46, white pine yield was best on northern dolomitic sites and poorest on southern dolomitic sites.

Height growth of shortleaf pine was less on shale soils than on dolomite and limestone, though stand volume was not affected by parent material.

Yellow-poplar growth was best on shale soils and poorest on dolomitic soils; aspect did not effect any stand attribute.

The published white pine and yellow-poplar site index curves underpredictd heights at ages less than 25 years and overpredicted heights at ages older than 25.

The published white pine yield prediction equation overpredicted yields at 32 years from seed and underpredicted yields at 48 years from seed. Similarly, the published yellow-poplar yield prediction equation overpredicted yields at 31 years from seed and underpredicted yields at 47 years from seed.

These results indicate that the local site index curves and yield prediction equations developed in this work are more appropriate for similar sites in East Tennessee and should be favored over the published curves and equations.

Recommendations

It is recommended that white pine be planted on eroded old-fields in the vicinity of Norris Lake.

The use of the site index curves and yield prediction equations developed in this study should be limited to eroded old fields in the vicinity of Norris Lake, Tennessee.

Growth prediction equations could not be developed for this study because the data only included measurements at two ages. Therefore, remeasurement of the study plots at plantation age 60 and construction of compatible growth and yield equations is recommended.

In addition, it is recommended that the soils on each plot be studied and an attempt be made to correlate soil morphology and chemical and physical properties with vrious growth parameters for white pine and yellow-poplar.

REFERENCES CITED

LITERATURE CITED

Auten, J. T. 1945. Prediction of site index for yellow-poplar from soil and topography. J. Forestry 43:662-668.

Avery, T. E. and H. E. Burkhart. 1983. Forest measurements. Third edition. New York: McGraw-Hill Book Co. 331 pp.

Beck, D. E. 1962. Yellow-poplar site index curves. U.S. Forest Service Res. Note SE-180, 2 pp.

Beck, D. E. 1963. Cubic-foot volume tables for yellow-poplar in the Southern Appalachians. U.S. Forest Service Res. Note SE-16, 4 pp.

Beck, D. E. 1971. Polymorphic site index curves for white pine in the Southern Appalachians. U.S. Forest Service Res. Paper SE-80, 8 pp.

Beck, D. E. and L. Della-Bianca. 1970. Yield of unthinned yellow-poplar. U.S. Forest Service Res. Paper SE-58, 20 pp.

Beck, D. E. and L. Della-Bianca. 1972. Growth and yield of thinned yellow-poplar. U.S. Forest Service Res. Pap. SE-101, 20 pp.

Beck, D. E. and L. Della-Bianca. 1981. Yellow-poplar: characteristics and management. U.S. Forest Service Ag. Handbook 583, 91 pp.

Beck, D. E. and K. B. Trousdell. 1973. Site index: Accuracy of prediction. U.S. Forest Service Res. Paper SE-108, 7 pp.

Bruce, D. 1926. A method of preparing timber yield tables. J. Agr. Res. 32:543-557.

Buckman, R. E. 1962. Growth and yield of red pine in Minnesota. U.S. Forest Service Tech. Bul. 1272, 50 pp.

Bull, H. 1931. The use of polymorphic curves in determining site quality in young red pine plantations. J. Agr. Res. 34:1-28.

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

Carmean, W. H. 1972. Site index curves for upland oaks in the Central States. Forest Science 18:109-120.

Clutter, J. L. 1963. Compatible growth and yield models for loblolly pine. Forest Science 9:354-371.

Curtis, R. O. 1964. A stem analysis approach to site index curves. Forest Science 10:241-256.

Doolittle, W. T. and J. P. Vimmerstedt. 1960. Site index curves for natural stands of white pine in the Southern Appalachians. U.S. Forest Service Res. Note SE-141, 2 pp.

Graney, D. L. and E. R. Ferguson. 1971. Site-quality relationships for shortleaf pine in the Boston Mountains in Arkansas. Forest Science 17:16-22.

Griswold, H. C. 1976. Polymorphic site index curves for two hardwood species in West Tennessee. Unpublished M.S. thesis, University of Tennessee, Knoxville, TN. 68 pp.

Hebb, E. A. 1962. Relation of tree growth to site factors. Tennessee Ag. Exp. Stn. Bul. 349, 18 pp.

Husch, B., C. I. Miller, and T. W. Beers. 1982. Forest mensuration. Third edition. New York: John Wiley and Sons. 402 pp.

Ike, A. F., Jr., and C. D. Huppuch. 1968. Predicting tree height growth from soil and topographic site factors in the Georgia Blue Ridge Mountains. Ga. For. Res. Counc. Res. Pap. 54, 11 pp.

Kleinbaum, D. G. and L. L. Kupper. 1978. Applied regression analysis and other multivariable methods. Duxbury Press, Mass. 556 pp.

Lancaster, K. F. 1984. White pine management: a quick review. U.S. Forest Service NA-FR-27, 4 pp.

MacKinney, A. L. and L. E. Chaiken. 1939. Volume, yield and growth of loblolly pine in the Mid-Atlantic Coastal Plain region. U.S. Forest Service Tech. Note 33, 30 pp.

McCarthy, E. F. 1933. Yellow-poplar characteristics, growth, and management. U.S.D.A. Tech. Bul. 356, 58 pp.

Minckler, L. S. 1941a. Plantation survival as related to soil type, aspect, and growing season. J. Forestry 39:26-29.

Minckler, L. S. 1941b. The right tree in the right place. J. Forestry 39:685-688.

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

Minckler, L. S. 1943. Effect of rainfall and site factors on the growth and survival of young forest plantations. J. Forestry 41:829-833.

Minckler, L. S. and A. G. Chapman. 1948. Tree planting in the Central, Piedmont, and Southern Appalachian regions. U.S.D.A. Farmers Bul. 1994, 39 pp.

Richards, F. J. 1959. A flexible growth function for empirical use. J. Exp. Bot. 10:290-300.

Schlaegel, B. E. and D. L. Kulow. 1969. Compatible growth and yield equations for West Virginia yellow-poplar. W. Va. Univ. Agric. Exp. Stn. Bul. 573-T, 20 pp.

Schlaegel, B. E., D. L. Kulow, and R. N. Baughman. 1969. Empirical yield tables for West Virginia yellow-poplar. W. Va. Univ. Agric. Exp. Stn. Bul. 574-T, 24 pp.

Schumacher, F. X. 1939. A new growth curve and its application to timber-yield studies. J. Forestry 37:819-820.

Smalley, G. W. and R. L. Bailey. 1974. Yield tables and stand structure for shortleaf pine plantations in Tennessee, Alabama, and Georgia highlands. U.S. Forest Service Res. Pap. SO-97, 57 pp.

Smalley, G. W. and D. E. Beck. 1971. Cubic-foot volume table and point-sampling factors for white pine plantations in the Southern Appalachians. U.S. Forest Service Res. Note SO-118, 2 pp.

Smalley, G. W. and D. R. Bower. 1968. Volume tables and point-sampling factors for shortleaf pine in plantations on abandoned fields in Tennessee, Alabama, and Georgia highlands. U.S. Forest Service Res. Paper SO-39, 13 pp.

Smalley, G. W. and D. R. Bower. 1971. Site index curves for loblolly and shortleaf pine plantations on abandoned fields in Tennessee, Alabama, and Georgia highlands. U.S. Forest Service Res. Note SO-126, 6 pp.

Smith, D. W. and N. E. Linnartz. 1980. The southern hardwood region, p.145-230. In J. W. Barrett, Regional silviculture of the United States. Second edition. New York: John Wiley and Sons.

Soil Conservation Service. 1953. Soil survey of the Norris Area, Tennessee. Series 1939, No. 19, 173 pp.

Sullivan, A. D. and J. L. Clutter. 1972. A simultaneous growth and yield model for loblolly pine. Forest Science 18:76-86.

U.S. Department of Agriculture, Forest Service. 1929. Volume, yield, and stand tables for second-growth Southern pines. U.S. Forest Service, Misc. Pub. 50, 202 pp.

Vimmerstedt, J. P. 1959. Site index curves for Southern Appalachian white pine plantations. U.S. Forest Service Res. Note SE-131, 2 pp.

Vimmerstedt, J. P. 1961. Cubic-foot volume tables for Southern Appalachian white pine plantations. U.S. Forest Service Res. Note SE-162, 2 pp.

Vimmerstedt, J. P. 1962. Southern Appalachian white pine plantations- site, volume, and yield. U.S. Forest Service Station Paper SE-149, 13 pp.

APPENDIX

TABLE 10

MEAN SQUARES OF THE SIX DEPENDENT VARIABLES IN THE ANALYSIS OF SHORTLEAF PINE AT PLANTATION AGE 30

Source	df	No. of Stems	Basal Area	Total Volume	Merchantable Volume	Average Height	Mean Dbh
Parent Material	2	30,845.0	847.9	899,197.3	726,100.5	43.50	0.255
D and L vs S[1]	1	44,260.7	18.9	385,311.1	224,652.9	83.55*	0.328
D vs L[2]	1	22,034.4	1694.6	1,524,272.4	1,304,939.0	1.25	0.144
Aspect	1	22,625.4	1288.7	798,001.2	631,518.8	2.02	0.015
Parent Material * Aspect	2	7,218.2	627.6	1,143,183.4	1,132,831.3	26.49	0.324
Contrast 1[3]	1	28.3	842.5	2,079,098.5	2,126,541.6	8.64	0.005
Contrast 2[4]	1	14,214.0	321.4	114,488.0	65,043.9	46.21	0.648
Error	21	17,179.7	583.3	602,255.8	597,444.2	14.75	0.292

*Significant at the 95 percent confidence level.

[1]Dolomite and limestone versus shale.

[2]Dolomite versus limestone.

TABLE 10 (continued)

[3]Dolomite and limestone on northern aspects versus dolomite and limestone on southern aspects and shale on northern aspects versus shale on southern aspects.

[4]Dolomite on northern aspects versus dolomite on southern aspects and limestone on northern aspects versus limestone on southern aspects.

TABLE 11

MEAN SQUARES OF THE SIX DEPENDENT VARIABLES IN THE ANALYSIS OF YELLOW-POPLAR AT PLANTATION AGE 30

Source	df	No. of Stems	Basal Area	Total Volume	Merchantable Volume	Average Height	Mean Dbh
Parent Material	2	14,587.1	5530.1*	6,417,559.7*	5,593,220.8*	272.75*	3.477*
D and L vs S[1]	1	2,671.7	3349.4	4,124,006.9	3,877,907.5*	102.27	3.719*
D vs L[2]	1	28,504.1	6053.3*	6,769,563.6*	5,599.423.8*	370.01*	2.187
Aspect	1	12,104.4	473.8	550,840.5	672,395.7	21.71	0.707
Parent Material * Aspect	2	4,392.1	17.3	28,431.1	17,685.2	35.41	0.067
Contrast 1[3]	1	4.196.8	11.6	43,216.8	339.4	18.19	0.016
Contrast 2[4]	1	3,237.1	17.7	6,931.1	33,147.2	46.56	0.126
Error	11	15,581.3	742.8	995,821.0	755,610.3	52.65	0.684

*Significant at the 95 percent confidence level.

[1]Dolomite and limestone versus shale.

[2]Dolomite versus limestone.

TABLE 11 (continued)

[3]Dolomite and limestone on northern aspects versus dolomite and limestone on southern aspects and shale on northern aspects versus shale on southern aspects.

[4]Dolomite on northern aspects versus dolomite on southern aspects and limestone on northern aspects versus limestone on southern aspects.

TABLE 12

MEAN SQUARES OF THE SIX DEPENDENT VARIABLES IN THE ANALYSIS OF YELLOW-POPLAR AT PLANTATION AGE 46

Source	df	No. of Stems	Basal Area	Total Volume	Merchantable Volume	Average Height	Mean Dbh
Parent Material	2	17,526.5	2,628.7	9,030,859.9	8,808,358.3*	286.88*	6.422*
D and L vs S[1]	1	18,152.4	3,979.8	12,734,324.2*	12,461,603.0*	339.24*	8.980*
D vs L[2]	1	11,577.4	653.2	2,987,328.2	2,880,339.9	150.82	2.185
Aspect	1	8,128.2	66.9	21,621.0	3,378.2	76.56	0.110
Parent Material * Aspect	2	5,050.9	339.7	300,566.5	262,822.8	3.05	0.008
Contrast 1[3]	1	2,239.3	150.8	124,569.6	123,139.4	6.05	0.005
Contrast 2[4]	1	9,010.3	433.3	393,677.9	327,782.0	0.00	0.010
Error	11	8,055.5	1,097.7	2,365,502.5	2,155,630.4	64.70	1.163

*Significant at the 95 percent confidence level.

[1]Dolomite and limestone versus shale.

[2]Dolomite versus limestone.

TABLE 12 (continued)

[3]Dolomite and limestone on northern aspects versus dolomite and limestone on southern aspects and shale on northern aspects versus shale on southern aspects.

[4]Dolomite on northern aspects versus dolomite on southern aspects and limestone on northern aspects versus limestone on southern aspects.

TABLE 13

MEAN SQUARES OF THE SIX DEPENDENT VARIABLES IN THE ANALYSIS OF WHITE PINE AT PLANTATION AGE 30

Source	df	No. of Stems	Basal Area	Total Volume	Merchantable Volume	Average Height	Mean Dbh
Parent Material	2	39,252.6*	1004.7	1,616,345.0	1,334,573.6	18.67	0.918
D and L vs S[1]	1	61,481.8*	1861.8	3,132,354.1	2,504,840.2	31.65	0.464
D vs L[2]	1	13,923.6	203.9	163,429.1	233,722.2	4.42	1.290
Aspect	1	38,164.2*	20.6	524,271.9	730,365.5	84.96	1.275
Parent Material * Aspect	2	13,089.5	230.1	41,760.9	25,366.3	16.15	0.189
Contrast 1[3]	1	21,437.4	33.9	7,936.7	193.3	23.89	0.030
Contrast 2[4]	1	3,782.6	413.5	72,988.4	50,725.1	5.38	0.367
Error	10	7,910.7	509.9	1,127,170.7	1,068,455.7	23.38	0.354

*Significant at the 95 percent confidence level.

[1]Dolomite and limestone versus shale.

[2]Dolomite versus limestone.

TABLE 13 (continued)

[3]Dolomite and limestone on northern aspects versus dolomite and limestone on southern aspects and shale on northern aspects versus shale on southern aspects.

[4]Dolomite on northern aspects versus dolomite on southern aspects and limestone on northern aspects versus limestone on southern aspects.

TABLE 14

MEAN SQUARES OF THE SIX DEPENDENT VARIABLES IN THE ANALYSIS OF WHITE PINE AT PLANTATION AGE 46

Source	df	No. of Stems	Basal Area	Total Volume	Merchantable Volume	Average Height	Mean Dbh
Parent Material	2	9,486.4	4,068.1	4,476,033.5	4,125,735.6	7.94	0.119
D and L vs S[1]	1	16,783.6	7,197.6	8,406,514.8	7,761,388.8	7.51	0.001
D vs L[2]	1	2,994.2	1,283.8	840,278.6	758,921.5	9.35	0.237
Aspect	1	6,849.1	17.9	2,897,551.4	3,050,324.4	162.69	3.483
Parent Material * Aspect	2	18,569.7	6,474.9	18,693,182.8	17,821,744.4	73.80	1.721
Contrast 1[3]	1	1,023.0	3,611.3	12,026,202.8	11,991,105.0	138.95	0.347
Contrast 2[4]	1	35,230.9*	10,034.1*	27,466,901.0*	25,688,566.2*	13.43	3.213
Error	10	6,413.2	1,815.8	4,765,918.5	4,606,771.3	45.50	1.394

*Significant at the 95 percent confidence level.

[1]Dolomite and limestone versus shale.

[2]Dolomite versus limestone.

TABLE 14 (continued)

[3]Dolomite and limestone on northern aspects versus dolomite and limestone on southern aspects and shale on northern aspects versus shale on southern aspects.

[4]Dolomite on northern aspects versus dolomite on southern aspects and limestone on northern aspects versus limestone on southern aspects.

TABLE 15

TEST STATISTICS FOR SITE INDEX EQUATION COMPARISONS

Equation	Slope	Equation	Slope	Z	T	Conclusion[1]
7	-7.253	8	-6.328	- 9.188		reject
7	-7.253	9	-6.347	-20.698		reject
8	-6.328	9	-6.347	0.174		accept
7	-7.253	10	-7.819		57.743	reject
8	-6.328	10	-7.819		14.876	reject
11	-5.321	12	-5.328	0.261		accept
12	-5.328	13	-6.503		62.505	reject
12	-5.328	14	-9.158		203.739	reject
12	-5.328	15	-7.716		127.031	reject
12	-5.328	16	-4.969		-19.097	reject

[1] H_o: $b_1 = b_2$ accepted if $|Z| < 1.96$ or $|T| < 1.96$. These critical values are associated with the 95 percent confidence level.

TABLE 16

MEAN SQUARES OF CUBIC-FOOT PER ACRE YIELDS BY SITE INDEX, BASAL AREA AND AGE

Source	White Pine		Yellow-poplar	
	Total Volume	Merchantable Volume	Total Volume	Merchantable Volume
S[1]	0.525816**	0.590921**	3.314154**	4.033776**
lnB[2]	1.689694**	1.787198**	5.145402**	6.556078**
1/A[3]	0.704547**	0.930670**	0.516389**	0.793346**
SxlnB	0.002109	0.003570	0.000531	0.017386
Sx(1/A)	0.000016	0.000191	0.003589	0.000401
(lnB)x1/A	0.000052	0.000814	0.006706	0.005538
Error	0.001763	0.002383	0.003280	0.008290
Degrees of freedom of error	25	25	27	27

**Significant at the 99 percent confidence level.

[1]Site index in feet (base age 25).

[2]Basal area in square feet per acre.

[3]Stand age in years from seed.

VITA

Cassandra Lee Hohanshelt was born in Pomona, California on February 1, 1960. She attended elementary school in San Diego, California and graduated from Scottsdale High School in Scottsdale, Arizona in June 1978. The following fall she entered Arizona State University, then transferred to Northern Arizona University in the fall of 1979. She received a Bachelor of Science degree in Forestry in December 1982.

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The author is a member of Society of American Foresters and Xi Sigma Pi.