SRS-4101 CCT-APP

# SITE INDEX EVALUATIONS IN A 100-YEAR-OLD EASTERN WHITE PINE PLANTATION AT THE BILTMORE ESTATE, NC[1]

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Abstract-The precision of three equations for estimating site index and the effects of four topographic variables on total height were evaluated in a 1.6-acre planted stand of 100-year-old eastern white pines (*Pinus strobus* L.) on the Biltmore Estate. near Asheville, NC. A polymorphic site index equation developed for the Southern Appalachian Mountains was only slightly more precise than a polymorphic equation developed for New Hampshire and an anamorphic equation developed for Wisconsin. A regression model that included age alone explained 72 percent of variation associated with stand total height. The inclusion of four significant topographic variables increased the explained variation to 91 percent.

## INTRODUCTION

Eastern white pine is one of the most productive coniferous timber species in the Eastern U.S., and a considerable body of knowledge is available on its biology and management (Wilson and Hough 1966). White pine is widespread in the Southern Appalachians (Cope 1932) and, aside from published studies of site. index (Beck 1971) and soil-site relationships (Ike and Huppuch 1968), little has been reported on its regional silviculture. However, considerable information on stand development in the Southern Appalachians is available from a small planting on the Biltmore Estate, near Asheville, NC. Since 1930, diameter growth and volume yields resulting from a thinning study have been periodically reported, most recently by Della-Bianca (1961). Little information has been reported on site quality relationships in this stand, such as evaluation of site index equations and site variables affecting height growth. This report presents a preliminary evaluation of site index equations for the Biltmore Estate's Old Orchard stand and the effects of topographic variables on the periodically measured average total stand height.

## METHODS

### Study Area

The study was conducted in the 7-acre Old Orchard plantation, several miles south of Asheville, NC. A plantation of 4-year-old eastern white pine seedlings was established in March 1699 on an eroded, abandoned pasture. In the fall of 1916, when the trees were 22 years old (from seed), researchers with the Appalachian Forest Experiment Station began a study to investigate the effect of stand density on growth and yield. They established three small plots (0.125 to 0.25 acre) that have been the basis of periodic reports on diameter and volume (Della-Bianca 1961). individual trees on each plot were identified by number in 1916 and have been inventoried at ages 34, 41, 47, 52, 57, 75, and 100. The 100-year measurement was made in the spring of 1995. Subsequent references to tree ages are implied to be age from seed: references to time of measurement and tree age imply documentation in the spring of each year. For this investigation the three established plots form a single 0.5-acre measured stand. A 33-ft buffer zone around each plot results in a total delineated stand area of 1.6 acre.

### Site Index Equations

We evaluated three white pine site index equations (table 1). Beck (1971) sampled 42 natural stands aged 44 to 70 years in the Southern Appalachian Mountains using stem analysis techniques to develop a polymorphic equation for site index ranging from 60 to 130 ft at 50 years. Gevorkiantz (1957) established 92 plots in natural stands in northern Wisconsin and developed anamotphic site index equations for stands up to 120 years of age with site indexes between 40 to 60 ft. Carmean and others (1969) reparameterlzed Gevorkiantz's (1957) original formulation for electronic solution and we used it in this study. Parresol and Vissage (1996) used data collected earlier from 196 natural stands in New Hampshire to develop polymorphic curves for stands up to 100 years and site index between 50 and 90. These three site index equations are based on total tree age. Models for planted stands were not available for ages greater than 50 years and, therefore, were not evaluated. Also not tested were several other equations for stands based on stand age measured at breast height.

### Total Height Model

A total height regression model was developed to determine variation in height associated with site variables. Lohrey (1967) proposed the following model:

$$\log(H) = b0 + b1*(1/A) + b2(1/(A*A)) \qquad (1)$$

where

log = logarithm to base 10,
H = average total height of dominant trees (ft),
A = stand age from seed (years), and
b(I) = regression coefficients.

This model was also used to predict site index, which is equivalent to total height at age 50.

### Data

In periodic inventories beginning at stand-age 34, the total height of five dominant trees was measured on each of the three plots. On these plots we selected the tree nearest plot center and midway along each of the four plot boundaries. This sampling design accounted for site quality variation in two directions: parallel and perpendicular to the direction of

[1]Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport. LA, February 16-18, 1999.

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**Table I-Site index equations evaluated for eastern white pine in the Old Orchard Plantation, Biltmore Estate, near Asheville, NC**

| Site index equation | Formulation[a] |
|---|---|
| Beck (1971)[b] | H = (63.06+0.67*S)*(1-exp(-(0.00985+0.00033*S)*A))^2 |
| Gevorkiantz (1957) | S = (0.5086*(H^1))*(1-exp(-0.024*A))^(-1.8942*(H^0)) |
| Parresol and Vissage (1998) | S = exp(1.1881*(exp(-8.6188/A))*(ln(H)+(74.7099/A)-2.0862)+(0.592)) |

[a] H = dominant stand height (feet), S = site index (base age 50 years), A = total stand age (years), ln(x) = base e logarithm of x, exp = base of natural logarithm.
[b] Equation can not be inverted to directly solve for site index.

predominant slope gradient, which had been identified as a primary source of the variation. Average total height of the 1 .&acre stand was determined from the 15 sample trees for each of seven measurement periods, i.e., 1929, 1936, 1942, 1947, 1953, 1967. and 1995. This resulted in 105 pairs of total height and age records. We used linear interpolation to estimate height of 10 trees for which 1929 and 1967 data were missing, and also for height at 50 years of age which had been measured at age 47 and 52. Topographic data collected at each of the 15 sample trees included aspect (nearest degree), slope gradient (nearest percent), landform index (a measure of slope position of the site), and terrain shape index (a measure of convexity or concavity of the site itself). We excluded elevation as a stand site variable because it varied by less than 25 ft.

**Analysis**

We evaluated the precision of each site index equation by calculating the difference between estimated and actual values (estimated - actual) determined at each of the seven periodic inventories. A regression model of total height and age was developed from periodic measurements of the same subset of 15 sample trees at various ages. We used stepwise multiple regression analysis implemented in SAS (1985) to develop models of total height as a function of age, aspect, slope gradient, landform index, and terrain shape index. A backward solution of the stepwise multiple regression model was used to reduce possibility of spurious results when multicollinearity could have been present (Zar 1996). Variables were excluded from the model at the 0.10 level of probability. Total height was transformed to log base 10 because the variance increased with age.

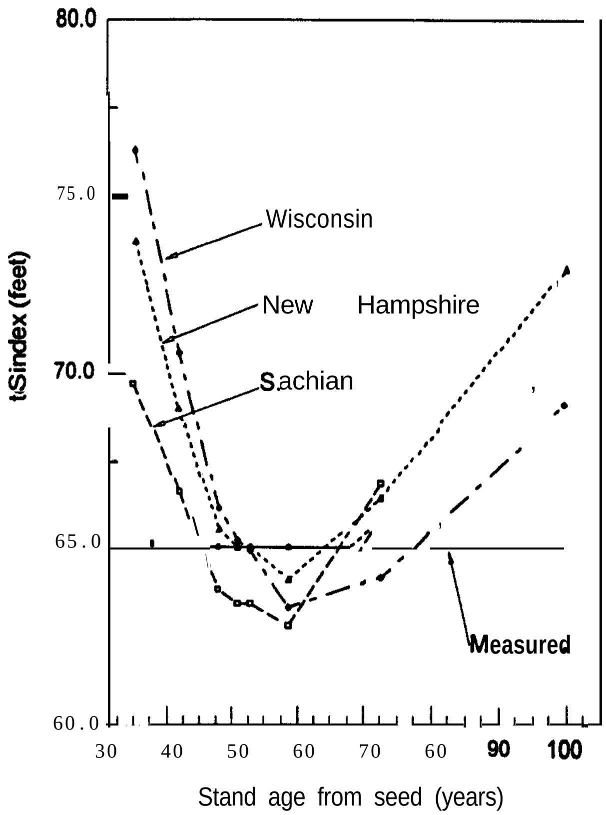


Figure I-Actual and estimated site index using three equations at seven periodic inventories (excluding 50 years) for the Old Orchard planting at the Biltmore Estate, North Carolina.

**RESULTS AND DISCUSSION**

**Evaluation of Site index Equations**

Total height of the 15 sample trees averaged 62.0 (sd = 10.8) ft at 47 years and 67.2 (sd = 11.3) ft at 52 years. The interpolated height of 65.1 ft at age 50 was used as the best estimate of site index for the Old Orchard stand. Site index of 65 is at the lower limit of applicability for Beck (1971) and is about midway for the other two equations. The three equations provide similar estimates of site indexes at various ages (fig. I). Minimum deviations occurred near the reference age (50 years), and greatest errors occurred in the youngest and oldest trees. Errors of estimated site index were of about the same magnitude for all equations (table 2). Overall, the equation developed by Beck (1971) is slightly more precise (mean absolute deviation = 2.8 ft), although there are few practical differences among the three equations. For all equations, most of the deviations were within 5 ft of the actual site index. Mean absolute deviation was 3.7 ft for the Gevorkiantz (1957) equation and 3.8 ft for Parresol and Vissage (1998).

We found several surprising results in this study. First, site index equations developed for white pine in Wisconsin and New England performed almost as well as equations

**Table 2—Deviations of estimated eastern white pine site index from actual site index of three equations applied at seven ages at the Old Orchard Plantation, Biltmore Estate, near Asheville, NC**

| Site index equation | Deviations within +/- | | |
|---|---|---|---|
| | o-2 ft | 2-5 ft | 5-12 ft |
| | ------- *Percent* ------ | | |
| Beck (1971) | 33.3 | 33.4 | 33.3 |
| Gevorkiantz (1957) | 42.8 | 28.6 | 28.6 |
| Parresoi and Vissage (1998) | 42.9 | 14.2 | 42.9 |

developed relatively near the Biltmore Estate. Also, anamorphic curves developed by Gevorkiantz (1957) predicted site index about as well as polymorphic curves developed by Beck (1971) and Parresoi and Vissage (1998). However, because evaluation consisted of only a single stand of low to average site quality, this study was a poor test of anamorphic versus polymorphic curves. We have not determined how site index equations developed specifically for planted stands might account for variations in the height growth of young stands, where vegetative competition has been reduced.

**Height-Age Model**

Mean stand tree heights ranged from 47 ft at 34 years to 112 ft at 100 years (fig. 2). Within-stand variation of the dominant component ranged from 25 ft at 34 years to over 40 ft at 100 years, indicating a broad range of site quality within in the Old Orchard stand. As the plantation aged, the pattern of total stand height increased almost linearly at a rate of about 1 -ft per year. The simple model of height as a function of age fits the stand data well and accounts for 72 percent of the height variation. The regression model predicted height of 64.5 ft at age 50, which agrees closely with the interpolated height of 65.1 ft.

Much of the variation in total height, over 20 ft at each measurement, results from sample tree location on the plot. Dominant trees on lower slope positions were as much as 20 ft taller than dominant trees on the upper slope. This marked variation in height in the Old Orchard plantation has been previously observed and has fostered discussion of actual site index values and site quality effect on diameter growth and volume yield (Delia-Bianca 1981).

**Height-Age-Site Variables Model**

Slope gradient ranged between 14 and 41 percent (table 3). Total height of the 15 sample trees at age 100 was significantly correlated with only two topographic variables: landform index r = 0.67, p ~0.006) and terrain shape index r = 0.58, p <0.02). These two variables were also highly correlated with each other ® = 0.75, p <0.001). When included in a multiple regression to predict total height relative to age for the 105 height-age pairs, all topographic variables were significant, accounting for 19 percent variation in total height. Next to age, the most important variable was landform index, which accounted for an

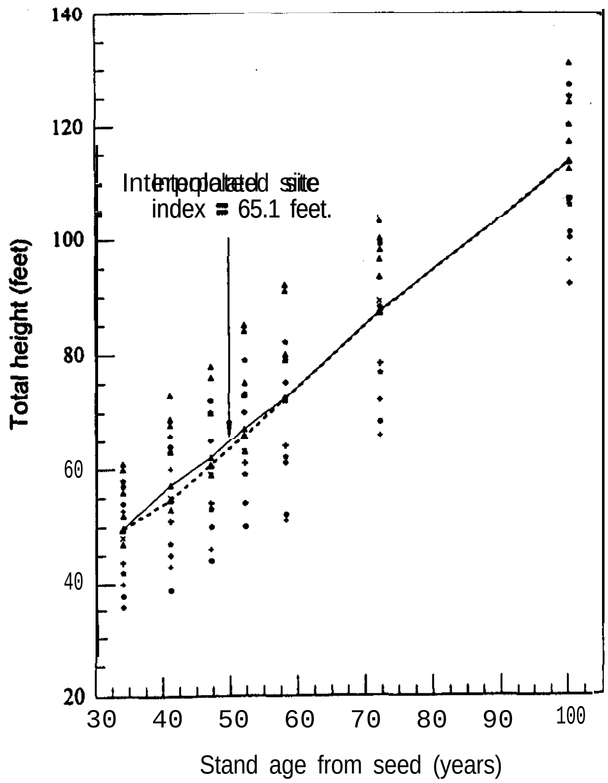


Figure P-Actual (solid line) and predicted (dashed line) total heights of the dominant stand at periodic ages of the Old Orchard planting at the Biltmore Estate, North Carolina. Points plotted vertically at each of the seven periodic inventories represent range of heights of 15 dominant sample trees.

additional 15 percent of variation, followed by gradient (2 percent), aspect (1 percent), and terrain shape index (1 percent). The effect of iandform index and gradient on predicted height (fig. 3) accounts for much of the variation in sample trees' measured heights (fig. 2).

The influence of topographic variables on height growth has not been made clear in other studies. Ike and Huppuch (1968) found that growth increased with elevation, but decreased with slope gradient and was least on ridges. Foster (1959) reported that site index was lowest on upper slopes, but was decreased when elevation increased. Beck (1971) found little effect of site variables on white pine height growth. Slope position appears to be one of the most important variables affecting the species' height growth, as we found with the landform index variable. Compared to our single site in the Old Orchard planting, growth reported in other studies may have been affected by other, unmeasured environmental variables.

Overall, residuals-the differences between the calculated and actual values of heights-exhibited little discemabie pattern when graphed on a stand basis, although a pattern was evident when they were examined on a plot basis. Tree heights on one unthinned plot were ail underestimated and heights on the other unthinned plot were overestimated, indicating an unexplained source of variation in site quality. Residuals from the thinned portion of the stand were

Table 3—Statistics of topographic variables associated with 15 dominant eastern white pines sampled in the Old Orchard Plantation, Biltmore Estate, near Asheville, NC

| Variable | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Aspect (degrees) | 75.0 | 103.5 | 31.0 | 338.0 |
| Gradient (percent) | 28.3 | 7.0 | 14.0 | 41.0 |
| Landform index | .092 | .022 | .050 | .122 |
| Terrain shape index | -.023 | .030 | -.090 | .013 |

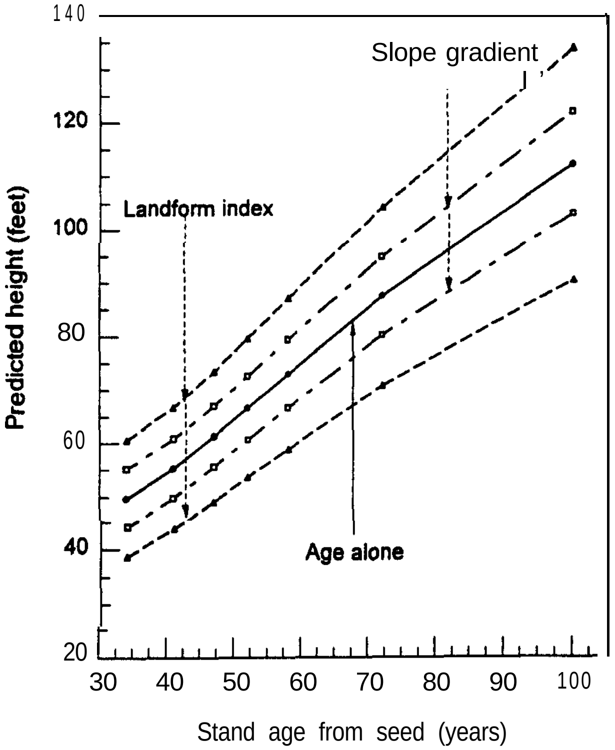


Figure 3—Predicted total height based on age compared with an equation based on age, landform index, and slope gradient for the Old Orchard planting at the Biltmore Estate, North Carolina. The two pairs of regressions show the effects of varying landform index or gradient individually between its minimum and maximum values while the other variable is held constant at the average value for the stand.

uniformly distributed, suggesting that tree heights are not correlated with stand basal area, a finding also reported by Beck (1971) in natural stands. In New Hampshire Adams (1935) reported that height increased as basal area was reduced. Ike and Huppuch (1968), however, reported a small increase in height as basal area increased. Variables accounting for effects of stand density on tree height were not explored in our regression analysis, but as reported by Lloyd and Jones (1982) for two species of southern pines, and might account for additional variation.

## CONCLUSIONS

When evaluated in a small, planted stand of white pines on the Biltmore Estate, site index equations developed for the Southern Appalachian Mountains were only slightly more precise than equations developed in Wisconsin and New Hampshire. Topographic variables had a significant influence on height variation in the stand's IOO-year-old dominant trees. Nevertheless, these site index and height growth relationships were based on data gathered from a single site and should not be extended to other locations without additional testing. These relationships, however, were not confounded by differing temperature and precipitation regimes, soils, or other unexplained sources of variation usually present in broader geographic regions. Results of this study should be useful in formulating hypotheses about site quality relationships of eastern white pine for use in the design and testing growth relationships.

## ACKNOWLEDGMENTS

We gratefully acknowledge suggestions for data analysis and summarization of comparisons provided by F. Thomas Lloyd. T. Lloyd and B. Parresol reviewed an early draft of this manuscript.

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