Site-Quality Relationships for Shortleaf Pine in the Boston Mountains of Arkansas

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Abstract. In the Boston Mountains, site index of shortleaf pine at age 50 was correlated with elevation, slope type, aspect, subsoil stone content, and loss-on-ignition of the A_1 and Ap_1 horizons. These factors are interpreted as reflections of soil moisture, stand composition, and climatic properties of the sites. Regression equations developed for all soils, residual soils, and colluvial soils predicted site indexes within an average of 2 ft on confirmatory plots. ***Forest Sci. 17:16–22.***

Additional key words. *Pinus echinata*, site factors, soil moisture, air temperature, stand composition.

DESPITE problems well summarized by Broadfoot (1969), the soil-site approach appears to be the most promising for estimating site potential for abused stands in areas like the Boston Mountain Province of Arkansas and Oklahoma. Most Boston Mountain stands have long records of high-grading, indiscriminate grazing, and wildfires that make existing trees poor indicators of site quality. An indirect method is needed for estimating productivity if landowners are to justify the large investments that will be required to clear abused stands and establish desirable ones. This paper reports a comprehensive study of the relations of soil and topography to the site index of shortleaf pine (*Pinus echinata* Mill.) on major soils in the area.

Reviews of previous research into soil-site relations for the southern pines (Coile 1952, Ralston 1964, Zahner 1958) suggested that soil and topographic features which influence soil moisture and soil aeration were likely to be most closely correlated with shortleaf pine growth. The independent variables for the multiple-regression analysis were chosen with these findings in mind. Hodgkins (1956) and Della-Bianca and Olson (1961) stressed the importance of limiting site quality estimates to small geographic areas with distinctive climatic and soil conditions. Efforts were made to limit variation to both in our analyses.

The Boston Mountains form a band that stretches from central Arkansas westward to east-central Oklahoma. Annual precipitation averages 44 to 48 inches in the portion within Arkansas, an area of about 2,200,000 acres (Fig. 1). Westward from the Arkansas-Oklahoma border, rainfall declines sharply and the portion of the province in Oklahoma was not included in the analysis.

March, April, and May are the wettest months in the area. Extended summer droughts are common, and autumn is usually dry. The frost-free period is normally from 180 to 200 days long.

The mountains are the remnants of an old plateau and are capped by massive sandstones of the Atoka formation. Elevations range from about 500 to 2,400 ft above sea level.

Soils are derived from essentially horizontally bedded sedimentary rocks that are

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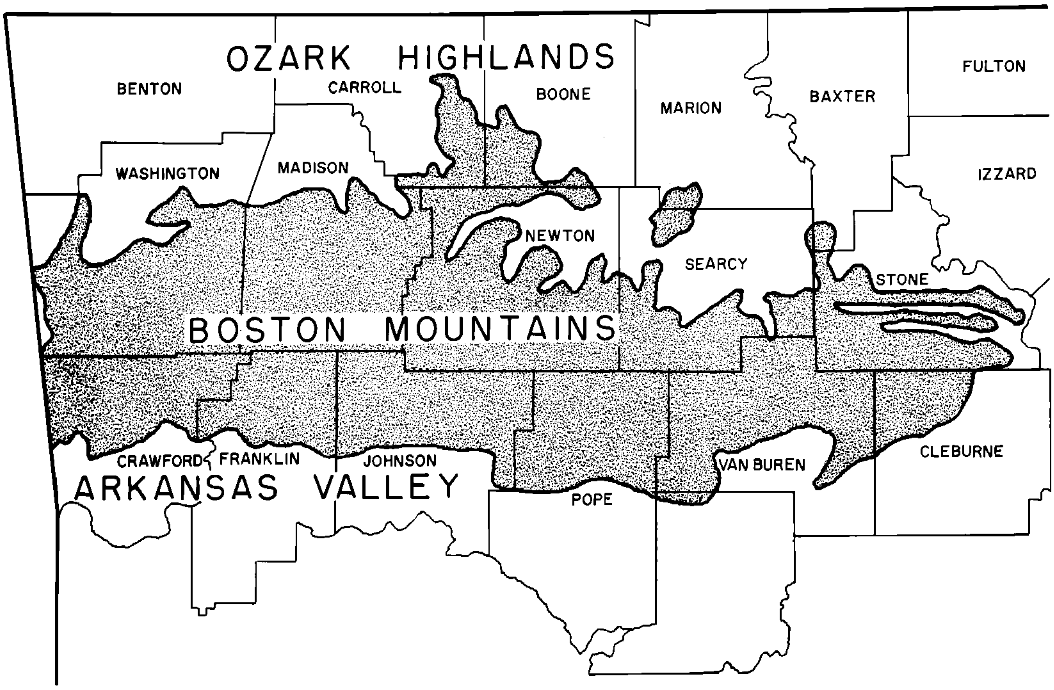

FIGURE 1. *The Boston Mountains in Arkansas.*

predominantly Pennsylvanian and Upper Mississippian. The soils are classed as Ultisols according to the 7th Approximation (USDA Soil Conserv. Serv. 1960, 1967). Soils were classified as to series and then, for convenience, soils were grouped physiographically into colluvial, residual from sandstone, or residual from shale.

Soils on ridges and upper slopes were generally residual and occupied by low-quality hardwoods and by shortleaf pine. Lower slopes and benches had colluvial soil and usually supported good-quality hardwoods on north and east exposures, and shortleaf pine and medium-quality hardwoods on south and west aspects.

Soil profiles varied greatly in depth and subsoil characteristics. Depth to bedrock ranged from less than 2 ft to more than 6 ft, and subsoil textures varied from light sandy clay loams to heavy clays.

Since the purpose of the study was to find useful prediction equations, one series of plots (102) was used to develop equations and another (48) to test their accuracy.

Procedures

Field. A total of 150 plots were selected Colluvial soils (Allen and Holston series) were represented by 50 plots, residual soils of sandstone origin (Hartsells, Linker, and Mountainburg series) by 59 plots, and residual soils of shale origin (Enders series) by 41 plots. The range in site index for each of the three soil groups is shown in Figure 2

Study plots were confined to even-aged 30- to 75-year-old stands of shortleaf pine and pine-hardwood mixtures located on uniform profiles with no evidence of erosion or recent burning. The plots selected ranged from approximately 1/10 to 1/5 acre in size with dominant or codominant sample trees grouped as closely as possible to insure uniform soil conditions. No more than one plot was located in an individual stand unless the stand extended over more than one set of soil or topographic conditions.

Tree age was determined by adding 4 to the number of rings at breast height. Height of each tree was measured with a Haga

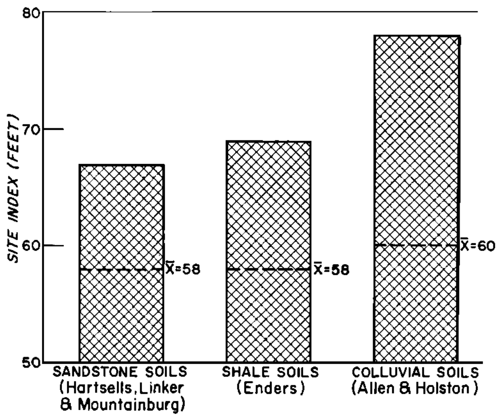

FIGURE 2. *Ranges and means for shortleaf pine site index, by major soil groups.*

hypsometer. Site index curves from USDA Miscellaneous Publication 50 (USDA Forest Service 1929) and from Coile and Schumacher (1953) were compared with data from 20 felled and sectioned sample trees representing the full range of soil series. Both published curves proved erratic for ages under 30 years, but those from Miscellaneous Publication 50 best represented the observed growth pattern of older shortleaf pine.

On each plot, three soil pits were dug with a backhoe to bedrock or to a minimum depth of 50 inches. One pit was at the approximate center of the plot; the other pits were near the limits of occupancy of the sample trees.

All soil profiles were described and classified by soil scientists of the Soil Conservation Service. Soil samples were collected from each major horizon of each soil pit. Percentage of coarse fragments exceeding 2 mm in the subsoil was estimated; occasional samples were screened to insure accuracy. Elevation, aspect, and slope position, type, steepness, and length were measured or estimated.

Laboratory. The bulk soil samples were air-dried, rolled, and sieved through a 2-mm mesh screen, and corresponding horizon samples for the three soil pits in each plot were composited for analysis. Portions of the samples were used to determine particle-size distribution, percent loss-on-ignition, pH, and moisture contents at ⅓ and 15 atm of tension. Sand, silt, and clay contents were determined by hydrometer, after dispersion in 5-percent sodium metaphosphate (Bouyoucos 1962). Organic matter content was estimated from loss-on-ignition (650°C) following the techniques of the Forest Soils Committee of the Douglas Fir Region (1953). pH of a 1 : 1 soil-water mixture was determined by glass electrode. Moisture contents at 0.33 and 15 atm were determined by pressure plate and pressure membrane. The difference between the two values was taken as an index of available moisture storage capacity.

Data Analysis. Of the 150 selected plots, 48 were excluded from initial analyses to provide a second population on which to test the effectiveness of the derived equations. Of the 48, 13 plots represented colluvial soils and 35 were typical of residual soils.

All field and laboratory data were summarized, and a series of regression screening analyses were computed for each soil series and for soil groups. Twenty-eight variables representing prominent terrain features plus textures and soil moisture properties of individual and combined soil horizons were tested.

In studies of site index correlations, total height is sometimes taken as the dependent variable and tree age is included as an independent variable. However, in this study, sectioned trees exhibited growth patterns similar to those in published curves. Since the possibility of age bias was small, age of sample trees was not included as an independent variable.

The data were processed using Program BMD 02R, which computes a sequence of multiple linear regression equations in a stepwise manner.

The statistical model used in screening was:

$$Y = b_0 + b_1X_1 + \ldots + b_nX_n$$

where Y = shortleaf pine site index

$X_0, X_1, \ldots X_n$ = independent variables

b_0, b_1, ... b_n = coefficients associated with the independent variables.

Curvilinear trends and interactions were also investigated by scatter diagrams and subsequent regression analyses, but were found to produce little or no correlation with site index.

Of the 28 independent variables screened, some were consistently correlated with site index at significant levels; others were correlated only for specific soils or soil groups. Some of the independent variables were highly intercorrelated, and in such cases, only one of the two variables was retained. The 11 independent variables that appeared most promising were:

- Asp = aspect Cos (Azimuth – 30°)
- S = percent slope
- TS = type of slope (1 = convex, 2 = linear, 3 = concave)
- E = elevation (thousands of feet)
- T_A = thickness of $A_1 + A_2$ horizons (inches)[1]
- LI = loss-on-ignition A_1 horizon (percent)
- CF_{B+C} = coarse fragments in B_1, B_2, B_3, and C horizons as combined (percent by volume)
- H_2O_A = available water $A_1 + A_2$ horizons (percent)
- $S + C_A$ = silt + clay $A_1 + A_2$ horizons (percent)
- CF_A = coarse fragments in $A_1 + A_2$ horizons (percent by volume)
- PS = position on slope

When the study began, it seemed likely that soil series would be directly correlated with site index. Accordingly, soils were initially stratified by series. The site index ranges for individual series overlapped considerably, however, and series proved to have little value for estimation of site index. Plot data for individual series were subjected to regression analyses. The resultant coefficients of multiple determination (R^2) produced were generally lower than those of analyses of combined soil series, i.e., soils from common parent materials. For example, R^2 values for individual series of residual origin ranged from 0.49 to 0.59 while all series of residual origin produced an R^2 of 0.66. Topographic variables and percent loss-on-ignition accounted for the majority of the explained variation in all analyses, although soil-related factors such as silt and clay and thickness of the A horizon were significantly correlated with site index for some of the individual soil series.

The screening analyses revealed similar relationships within each of the three groupings of soil series, and differences between the residual soils of sandstone and shale origin were minor. Consequently, final analyses were completed for residual soils, colluvial soils, and all soils combined.

Results and Discussion

Predictions with empirical equations were surprisingly accurate on confirmatory plots (Table 1). The equation for all soils, based on 102 plots, was:

$$SI = 65.6 - 0.80(LI) + 2.42(TS) + 2.12(Asp) - 4.09(E)$$

$$R^2 = 0.58. \text{ Standard error of estimate } S_{y \cdot x} = 3.31 \quad (1)$$

When data from the 48 confirmatory plots were entered in the equation, the mean of the deviations from actual field measurement was less than 2 ft and only three deviations exceeded 3 ft. The purpose of the confirmatory plots was to test the derived models and to determine the potential usefulness of the equation.

The equation derived for 65 residual soil plots was:

$$SI = 67.5 - 0.80(LI) + 2.08(Asp) - 0.10(CF_{B+C}) - 3.18(E) + 1.63(TS)$$

$$R^2 = 0.66. \text{ Standard error of estimate } S_{y \cdot x} = 2.62 \quad (2)$$

[1] A_1 and A_2 horizon designations correspond to those defined by the USDA Soil Conservation Service (1962). The A horizons where some past plowing was in evidence were described as Ap_1 and Ap_2. For convenience, in the text of this paper A_1 or A_2 horizon designations also include Ap_1 or Ap_2 horizons.

TABLE 1. Deviations between measured site index and predicted site index.

Deviation (ft)	No. of plots Residual soils	Colluvial soils	All soils
–4	1	0	1
–3	4	2	5
–2	4	0	6
–1	6	0	10
0	4	1	4
+1	6	4	6
+2	3	3	12
+3	7	3	2
+4	0	0	2
Total plots	35	13	48
Avg deviation (ft)	1.80	1.92	1.77

Predictions with this equation on 35 confirmatory plots deviated an average of 1.8 ft from measured values; only one deviation exceeded 3 ft. The site index range for these confirmatory plots (50 to 69 ft) was similar to that on the plots included in the analysis (49 to 67).

The equation for the 37 colluvial plots was:

$$SI = 71.9 - 1.25(LI) - 7.41(E) + 2.82(TS)$$

$$R^2 = 0.49. \text{ Standard error of estimate } S_{y \cdot x} = 4.31 \quad (3)$$

All predicted values fell within ±3 ft of the measured site indexes on confirmatory plots, and the average deviation was approximately 2 ft. The range of site index values was only 50 to 68 ft, as compared with 51 to 78 ft on the analysis plots.

To illustrate the relative effect of each variable, appropriate values were inserted in equation 2 for a single variable while all other variables significantly related to site index were held constant at their mean values.

Of the five independent variables included in the regression equations, percent loss-on-ignition of the A_1 or Ap_1 horizons produced the highest correlations with site index. Figure 3 illustrates the negative relationship for residual soils. A similar figure

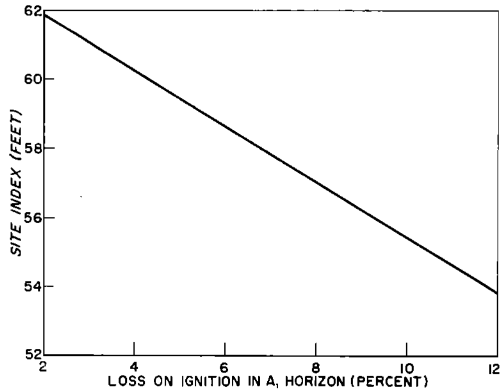

FIGURE 3. *Effect of loss-on-ignition of the A_1 horizon on site index of shortleaf pine on residual soils.*

could have been prepared for colluvial soils or all soils combined.

Most foresters tend to associate higher organic matter content with higher productivity, and positive correlations have been reported; but negative correlations between organic matter content and site index or productivity have also been reported by several researchers (Della-Bianca and Olson 1961, Mader and Owen 1961, Pawluk and Arneman 1961, Walker and Reed 1960). Explanations for these relationships have varied with the soils or site conditions studied.

In the Boston Mountain Province, lowest loss-on-ignition values were associated with relatively pure pine stands. Conversely, highest loss-on-ignition values were obtained from even-aged mixed pine-hardwood stands. Mean site index for 64 plots classified as pure pine was 63.6 ft as compared with 56.1 ft for 86 plots classed as mixed pine-hardwood. There was no evidence to indicate that the pure pine stands were on inherently better sites; soils and topography were about the same on many pure pine and mixed pine-hardwood plots.

Shortleaf pine site index decreased as elevation increased. Ike and Huppuch (1968) observed a similar relationship for shortleaf pine in the mountains of northern Georgia In the Boston Mountains, temperature differences are the probable cause. Observations indicate that the growing season is at

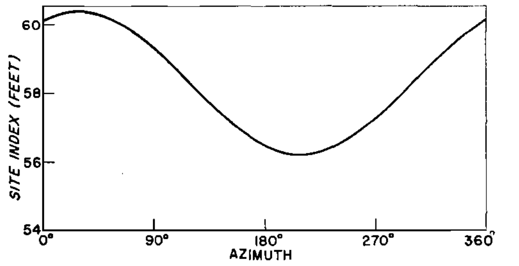

FIGURE 4. *Influence of aspect on site index of shortleaf pine on residual soils.*

least 2 weeks longer on the lower one-third of the mountains than on the upper slopes. At the higher elevations, spring flowering is often 2 weeks later and fall leaf coloration is 1 to 2 weeks earlier than at low elevations.

Site quality increased as slopes changed from convex through linear to concave. Carmean (1967) also reported a significant relationship between slope shape and black oak height growth in Ohio. The contribution of slope shape to pine site quality may be explained by surface and subsurface water movement. Concave slopes receive more water and retain it for longer periods. Concave slopes might also benefit from the thicker A horizons that are commonly associated with this slope shape. Severe summer droughts are common in most of northern Arkansas and small improvements in moisture retaining capacity would be a big advantage during such periods.

Aspect entered the equation for residual soils and that for all soils combined. It was also correlated with site index on colluvial soils, but did not significantly improve the regression. Figure 4 illustrates the effect of aspect on pine site quality. In general, north to northeast exposures have higher site indexes than south and southwest exposures. Ike and Huppuch (1968) reported a somewhat similar response of shortleaf pine height growth to aspect in the mountains of northern Georgia. Both there and in the Boston Mountains, north and east exposures are subjected to less evaporative stress.

Volume of coarse material in the B_1, B_2, B_3, or C horizons was negatively correlated with site index on residual soils. This factor was significant only in the equation for the residual soils, which are relatively shallow. Coarse fragments for these soil profiles ranged up to 60 percent. Increasing rock content, which reduces an already limited root space, influences the total amount of water which can be held.

Conclusions

Most of the soil and topographic factors represented in the equations were thought to reflect soil moisture or climatic properties of the site. Aspect influences evapotranspiration, slope shape affects degree of surface and subsurface water movement, and amount of coarse fragments in the subsoil control moisture storage capacity. Elevation, through seasonal temperature gradients, reflects length of growing season Concentrations of organic matter in the horizons, defined and taken as they were, indicated a negative relationship with site index. Lowest loss-on-ignition values were associated with pure pine stands, highest with mixed pine-hardwood stands.

The empirical equations predicted, within reasonable limits, expected height at age 50 for existing stands and will be used to derive site estimation tables for field use. Although developed from and tested on data obtained from existing stands, the equations presented should provide an index of potential shortleaf pine site quality for most sites in the Boston Mountains that have not been overly abused by fire or severe erosion in recent years.

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