SITE INDEX RELATIONSHIPS FOR SHORTLEAF PINE AND UPLAND OAKS IN THE OZARK-OUACHITA HIGHLANDS OF MISSOURI, ARKANSAS AND OKLAHOMA

David L. Graney

Southern Forest Experiment Station
Forest Service - USDA
Fayetteville, Arkansas

ABSTRACT

Site index for shortleaf pine or upland oak in various areas of the Ozark-Ouachita Highlands can be predicted with equations employing a few simple soil and topographic variables. The predictions are most reliable for shortleaf pine in the Ozark Plateau or Boston Mountains, where variability in site index is relatively small. Localized site index curves developed for pine and oak generally present more accurate indications of height growth patterns than the old regional curves.

INTRODUCTION

The Ozark-Ouachita Highlands encompass more than 40 million acres of southern Missouri, central and northern Arkansas, and eastern Oklahoma. Of this total, more than 23 million acres are commercial forest land. To properly and profitably manage these lands, foresters need reliable estimates of site productivity for a variety of tree species.

This paper summarizes research on soil and site characteristics affecting productivity of shortleaf pine (*Pinus echinata* Mill.) and several oak species (*Quercus* spp.) in various physiographic areas of the region. It also presents localized site index curves for some areas and compares them with the regional curves now in use.

STUDY AREA AND PROCEDURES

The Ozark-Ouachita Highlands consist of two major physiographic provinces, each of which has two distinct subdivisions (Fig 1):

(1) Ozark Plateaus Province

(a) Ozark Plateau (including Salem and Springfield Plateaus)

(b) Boston Mountains

(2) Ouachita Province

(a) Arkansas Valley

(b) Ouachita Mountains

Upland forests of the Ozark Plateaus Province are composed primarily of oak and hickory (Carya spp.). Shortleaf pine is limited mainly to

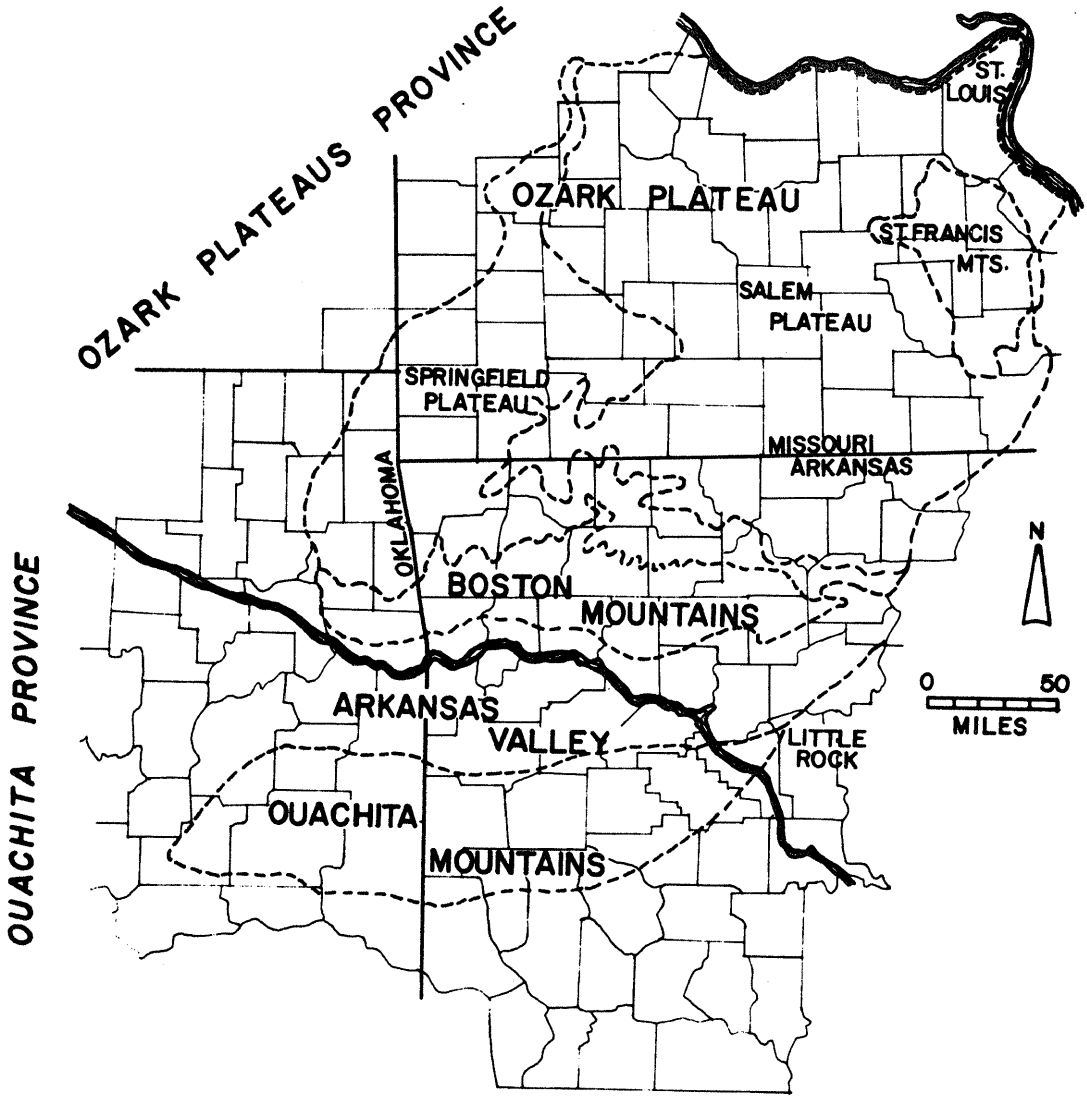

Figure 1. The Ozark-Ouachita Highlands of Missouri, Arkansas and Oklahoma.

the southern and eastern portions of the province, where it is found occasionally in pure stands but more commonly in mixture with hardwoods on ridges and south and west slopes.

In the Ouachita Province, shortleaf pine is a major component of most upland forest stands. Scattered oak and hickory occur, but pure hardwood stands are rare and are confined mainly to bottomlands and north mountain slopes.

Average annual precipitation in the region increases southward from about 40 inches in the northern part of the Ozark Plateau to about 52-54 inches in the Ouachita Mountains. April, May and June are the wettest months. Extended summer dry periods are common, and the autumn is usually dry. The average frost-free period ranges from about 170 days in the north to about 220-230 days in the south.

Data on shortleaf pine site index, soil and topography were collected on a series of 1/10- to 1/5-acre plots established to represent the range of soil and site conditions in each of three physiographic areas (the Arkansas Valley was excluded). Since the primary objective was to develop practical techniques for predicting site productivity, emphasis was placed on those soil and topographic variables that could be easily recognized and measured in the field.

OZARK PLATEAU

Topography within the Ozark Plateau is gently rolling to steep, and elevations range from about 500 to 1,500 feet above sea level. The area is underlain by essentially horizontally bedded sandstones, dolomites and cherty limestones dating from the Cambrian to Mississippian periods. Upland soils are light-colored and medium-textured, and most are relatively shallow. Fragipans are common on ridgetop positions.

Productivity by Soil Group

Shortleaf pine site index data for similar soils were combined into three major groups: soils of limestone and dolomite origin (Noark, Clarksville, Poynor, Doniphan, Macedonia series), soils of sandstone origin (Coulstone, Pineville, Hartsells, Linker series), and soils containing a fragipan (Lebanon, Captina, Wilderness, Nixa series) (Graney and Ferguson 1972). Average site index was quite similar for the three soil groups, and overall range in site index was about the same for Arkansas and Missouri (Fig 2). Similarly, Watt and Newhouse (1973) found no practical difference in the average site quality for either black oak (Q. *velutina* Lam.) or white oak (Q. *alba* L.) on the major upland soils of the Salem Plateau.

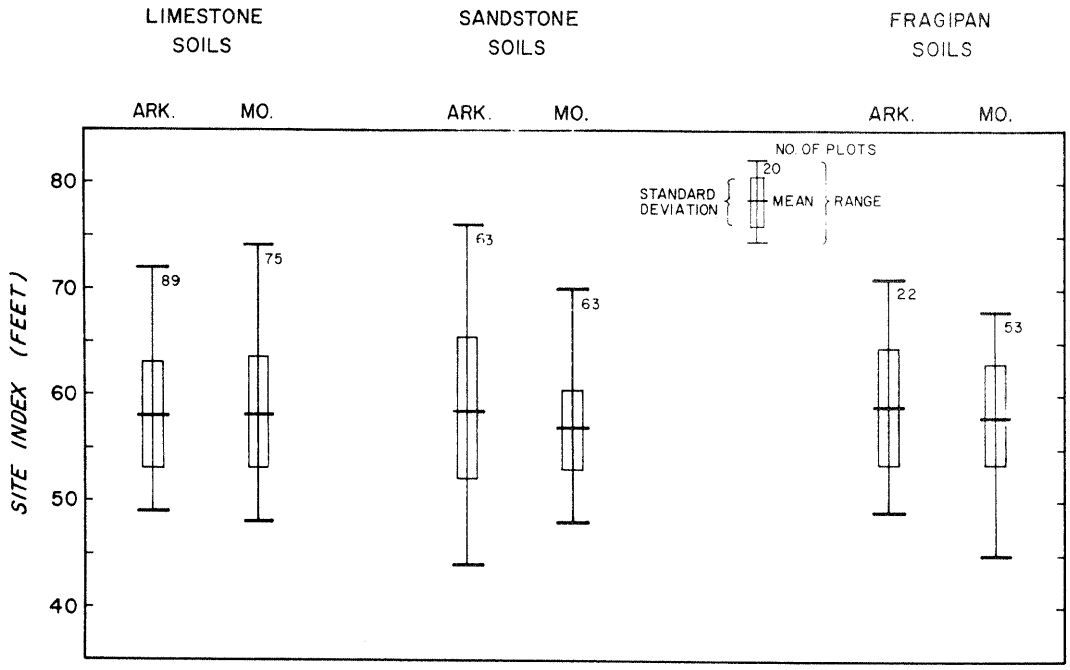

Figure 2. Site index mean, range and standard deviation for shortleaf pine on major soil groups of the Ozark Plateau of Missouri and Arkansas.

When pan and nonpan soils are compared (Fig 3), black oak has the highest average site index for each soil group. Shortleaf pine averages 4 to 5 feet less than black oak, and white oak averages about 7 feet less than black oak.

Indirect Estimation of Site Index

Shortleaf Pine: Equations for predicting shortleaf pine site index (Table 1) in the Ozark Plateau were derived from data taken on 221 plots and were tested for accuracy on an independent sample of 75 plots (Graney and Ferguson 1972). Predictions for all but three plots fell within ± 3 feet of the measured site index. The mean absolute deviation was less than 1.5 feet for limestone soils and only slightly higher for the other two groups.

Correlations between site index and the various soil and topographic factors included in the three equations apparently reflect differences in soil moisture, microclimate, hardwood competition, growing season, and rainfall within the Ozark Plateau.

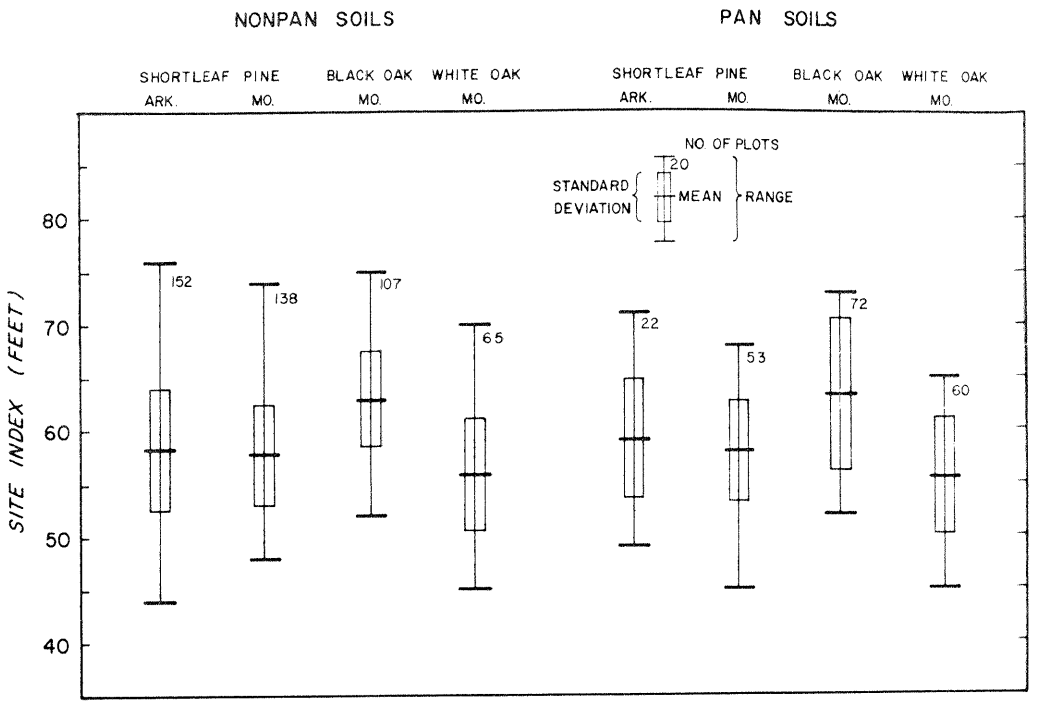

Figure 3. Site index mean, range and standard deviation for shortleaf pine, black oak and white oak on pan and nonpan soils of the Ozark Plateau of Missouri and Arkansas.

Aspect was important in all soil group equations: northeast slopes were the best sites, and southwest slopes were the poorest. Hartung and Lloyd (1969) reported a similar relationship between aspect and shortleaf pine site quality in Dent County, Missouri.

On limestone and sandstone soils, site index increased as slope shape changed from convex to linear to concave. Concave slopes generally receive subsurface water from convex upper slopes; they also tend to retain soil water longer than convex slopes and have deeper soils, thicker surface soils, and probably higher nutrient levels.

Percent loss-on-ignition, an approximation of organic matter content, was negatively correlated with site index. This relationship seems to reflect the effects of hardwood competition on pine height growth since loss-on-ignition values were generally lowest in pure pine stands and increased with hardwood occupancy of the stand. Other site factors being equal, site indexes averaged 5 to 8 feet higher for pines in pure stands than for those in mixed pine-hardwood stands.

Table 1. Equations for predicting shortleaf pine site index on the major soils of the Ozark Plateau.

Independent variables	Soil Group Equations		
	Limestone-Dolomite (97 plots)	Sandstone (91 plots)	Pan (33 plots)
Intercept (b_o)	56.80	57.20	33.90
Aspect	2.31	3.37	2.46
Slope shape	2.29	2.14	-
Loss-on-ignition	-0.91	-0.79	-
Township (latitude)	0.31	-	-
Depth of pan	-	-	1.08
R^2	0.63	0.49	0.74
Standard error of estimate (± feet)	2.93	4.26	2.52
	Accuracy of Predictions		
Number of plots	35	20	20
Predictions: within ± 3 feet	35	18	19
within ± 4 feet	35	20	20
Mean deviation (feet)	1.5	1.8	1.8

Site index on limestone soils also increased slightly with decreasing latitude (north to south), probably because of increases in rainfall and length of growing season.

Site index increased linearly with depth to fragipan (from 14 to 28 inches), a factor which controls potential moisture storage. The comparable site indexes for pan and nonpan soils (Fig 3) probably result because pan soils have moisture holding capacities similar to those of nonpan soils to a depth of 36 inches (Watt and Newhouse 1973).

Oak: McQuilkin (1972, 1974a) derived separate equations for predicting black oak site index for ridges and slopes in the Salem Plateau of Missouri. The ridgetop equation was based on 54 plots, included eight variables (A_2 clay, A_1 thickness, A thickness x A_2 silt, A thickness x A_2 sand, elevation, B_2 sand, A_2 sand, A_2 silt), and produced an R^2 of 0.66. However, when it was tested on an independent sample of 27 plots, only 44 percent of the predictions were within ± 5 feet of measured values. The slope equations included seven variables (Sin SE x

slope gradient, Sin N x distance to ridge x percent distance to ridge, distance to ridge x elevation, distance to ridge, elevation, A_1 thickness, and B_2 depth x B_2 sand) and accounted for 31 percent of the site index variation on the 151 plots used to derive the equation but only 17 percent of the variation in 75 other plots used to test the equation.

Direct Measurement of Site Index

Direct measurement of site index is the easiest, most widely used, and--when reliable site index curves and tables are available--the most accurate method of estimating site quality. Until recently only regional site index curves were available for pine and oak. However, recent studies have shown that a species' height growth patterns can vary widely within regions (Graney and Bower 1971, Carmean 1971, 1972, McQuilkin 1974b).

Shortleaf Pine: Since the summer of 1975, I have been investigating height growth patterns for natural stands and plantations in the Ozark Plateau of Missouri. Stem analysis (according to the procedures of Curtis 1964 and Carmean 1972) of 350 sectioned trees supplied data for plotting preliminary site class curves. These curves for Missouri pine are not fitted curves but represent only average heights for trees within each site index class.

When the average 50-year base site class curves for natural stands of Missouri pine are compared with those for Ouachita Mountain shortleaf pine (Graney and Burkhart 1973) and with the regional curves in Miscellaneous Publication 50 (U.S. Forest Service 1929), the three are quite similar on poor quality sites (Fig 4). On medium sites, the Missouri and Ouachita curves remain almost identical, but through age 40 the Misc. Publ. 50 curves would overestimate Missouri pine site index. On the best sites, both published curves generally overestimate site index for young Missouri pine, and after age 35 the growth rate seems to decline more rapidly for Missouri pine than for the others.

Site index curves (25-year base) for Missouri pine plantations were compared with curves for plantations in Tennessee, Alabama and Georgia (Smalley and Bower 1971) and with curves for natural stands in the Ouachita Mountains (Graney and Burkhart 1973) (Fig 5). Except for the poor sites, either set of published curves would produce accurate estimates of site index in Missouri shortleaf pine plantations between the ages 15 and 30 years. However, for younger and older plantations, errors of 3 to 5 feet could occur. On medium and good sites, the growth rate declined more rapidly after age 20 for Missouri plantations than for the other pines. This decline must be carefully considered in projecting long-term plantation yields. For example, the mean site index (25-year base) for 99 plantations sampled in 1975 was 5.5 feet higher than that for 76 natural stands (Fig 6); but when plantation heights were projected

to age 50, the average site index for plantations was nearly 10 feet higher than the measured site index for 50-year-old natural stands, and some plantations were assigned the unlikely site index of 80 to 85 feet.

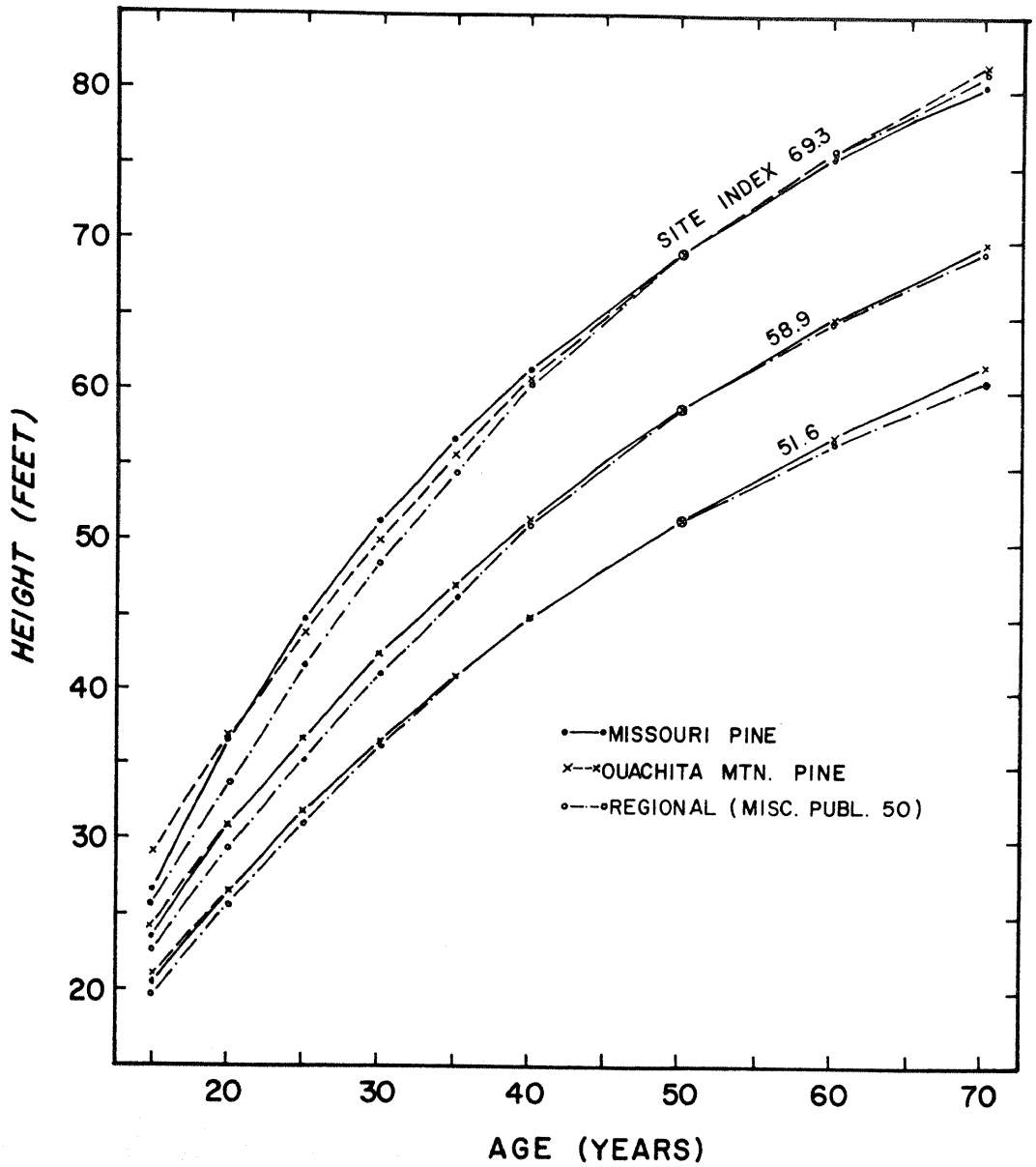

Figure 4. Site index curves for natural stands of shortleaf pine in the Ozark Plateau of Missouri, in the Ouachita Mountains (Graney and Burkhart 1973), and throughout the Southern region (Misc. Publ. 50, U.S. Forest Service 1929).

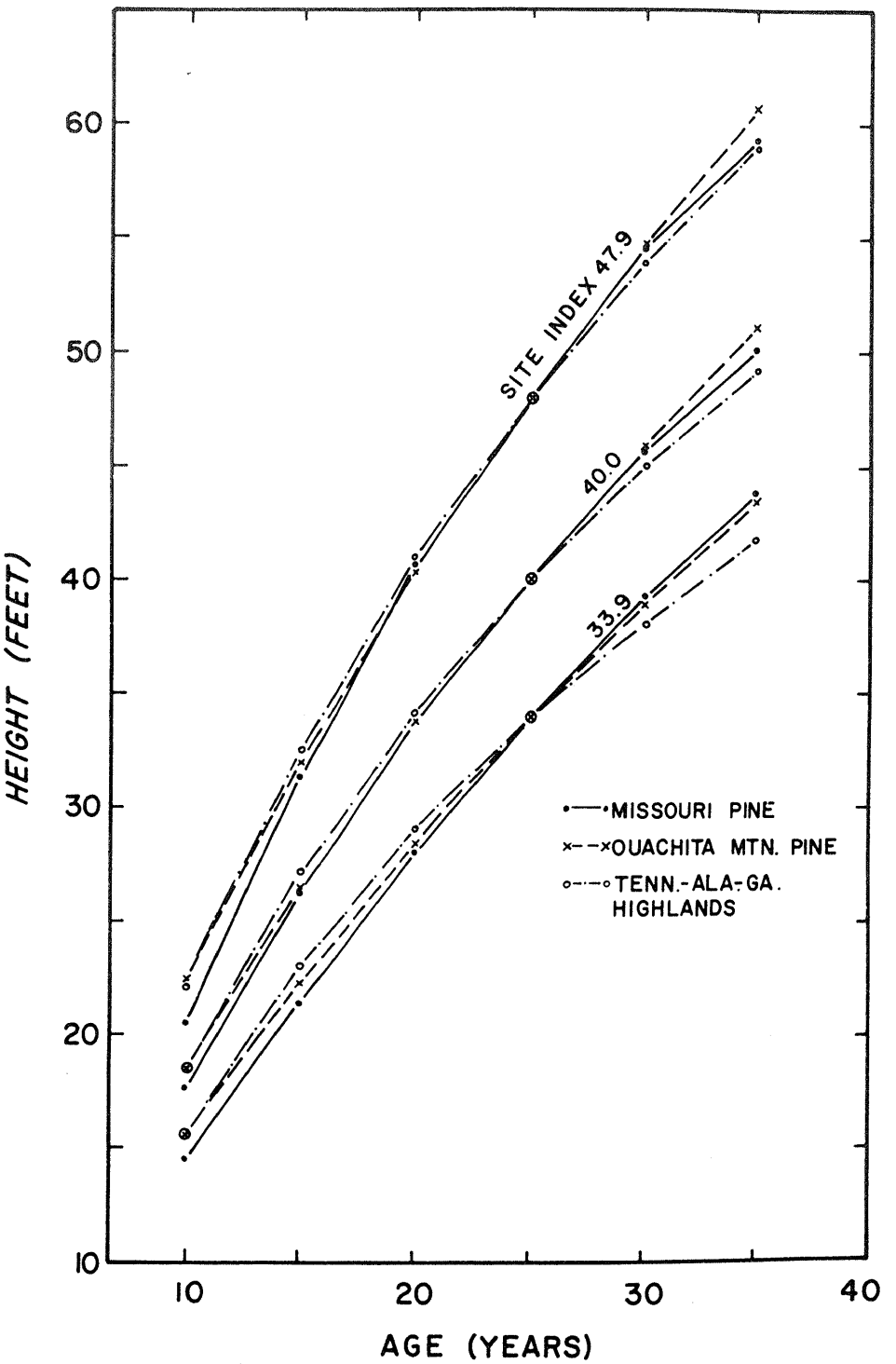

Figure 5. Site index curves (base age 25 years) for shortleaf pine plantations in the Ozark Plateau of Missouri and in the highlands of Tennessee, Alabama and Georgia (Smalley and Bower 1971) and for natural stands in the Ouachita Mountains (Graney and Burkhart 1973).

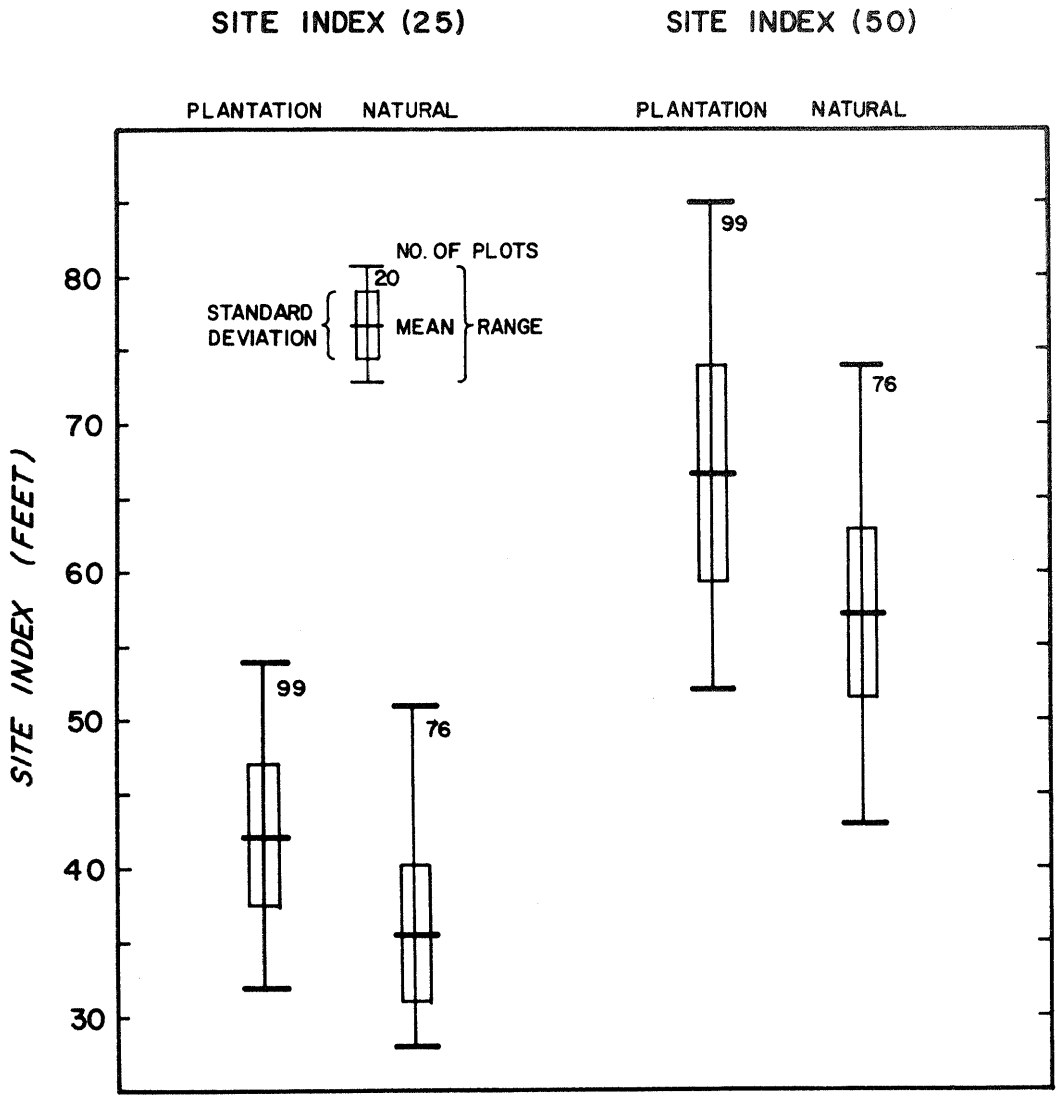

Figure 6. Measured site index mean, range and standard deviation for shortleaf pine plantations at age 25 years and for natural stands at ages 25 and 50 years in the Ozark Plateau; 50-year values for plantations are projections.

Oak: Based on stem analysis data from 741 trees, McQuilkin (1974b) derived site index tables which now permit reliable direct estimates of site index for black, scarlet (Q. coccinea Muenchh.), and white oaks in southeastern Missouri. These tables should also be evaluated in the Arkansas portion of the Ozark Plateau.

BOSTON MOUNTAINS

The Boston Mountains consist of narrow, flat to gently rolling mountain tops whose sides are an alternating series of steep simple slopes and gently sloping benches. Elevations range from about 500 to 2,500 feet above sea level.

Soils common to ridges and upper slopes are predominately shallow, medium-textured, and are derived from sandstone residuum (Mountainburg, Hartsells, Linker series) dating from the Pennsylvanian age. Soils common to steeper side slopes are fine-textured and are derived from shale residuum (Enders series). The mountain benches are typified by deep, well drained, medium-textured soils derived from sandstone and shale colluvium (Nella, Leesburg series).

Productivity by Soil Group

For shortleaf pine, mean site index was quite uniform on all three major soil groups (Fig 7) (Graney and Ferguson 1971). Site indexes for oaks were more variable. Site index for red oaks (northern red, Q. rubra L., and black oak) was highest on colluvial soils and poorest on sandstone soils (Graney 1974). Site index for white oak was comparable on colluvial and shale soils but was much lower on sandstone soils. Differences among the three species were most pronounced on sandstone soils, where site index for shortleaf pine averaged 6 feet greater than that for red oak and 11 feet greater than that for white oak.

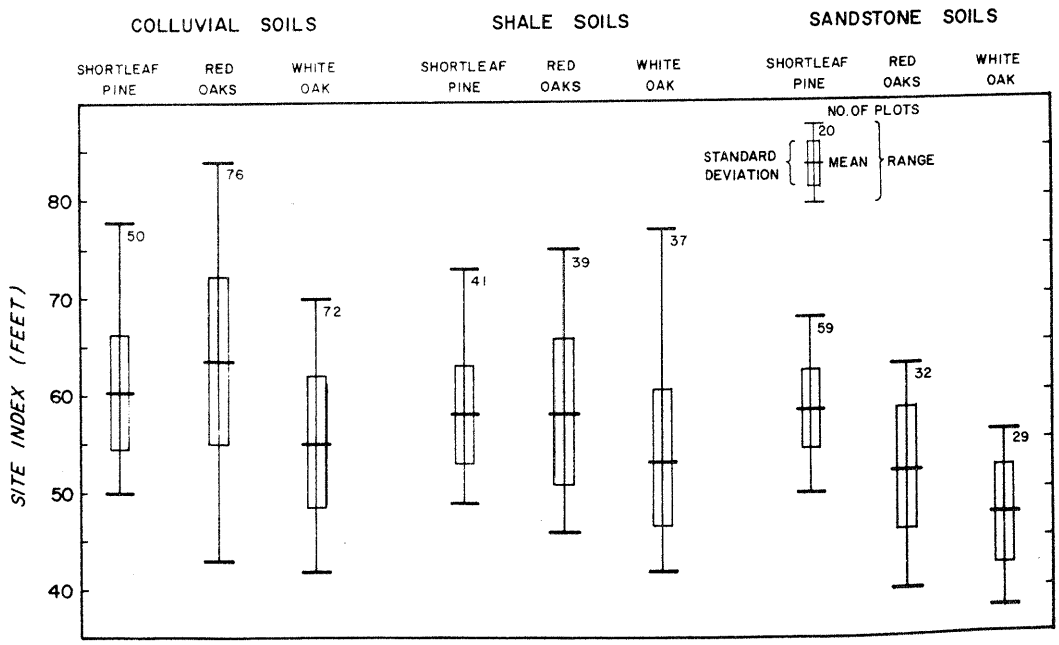

Figure 7. Site index mean, range and standard deviation for shortleaf pine, red oaks and white oak on major soil groups of the Boston Mountains in Arkansas.

Indirect Estimation fo Site Index

Shortleaf Pine: Equations for predicting site index in the Boston Mountains were derived from data from 102 plots and were tested on an independent sample of 48 plots (Graney and Ferguson 1971). Although separate equations were derived for each soil grouping, individual soil group equations differed little from and offered no improvement over the combined soil equation. The equation for all soils was:

$$\text{Shortleaf Pine Site Index} = 65.60 - 0.80\ (\text{loss-on-ignition } A_1) + 2.42\ (\text{slope shape}) + 2.12\ (\text{aspect}) - 4.09\ (\text{elevation})$$

$R^2 = 0.58$; standard error of estimate = 3.31 feet.

Eighty percent of the site index predictions for confirmatory plots were within ± 2 feet of measured values; mean absolute deviation was 1.8 feet.

Except for elevation, all site variables in the Boston Mountain equation had also been included in the prediction equations for shortleaf pine in the Ozark Plateau. Elevation probably affects pine site quality because of differences in temperature in the upper and lower portions of the mountains. The growing season is at least 2 weeks longer on the lower third of the mountains than on the upper slopes; spring flowering often begins 2 weeks earlier and fall leaf coloration, 1 to 2 weeks later at the low elevations. Highest shortleaf pine site indexes were associated with pure pine stands on concave, northeast slopes at elevations of 1,000 feet or less. Poorest pine sites were mixed pine-hardwood stands on convex, southwest slopes at elevations greater than 2,000 feet. Mean site index for pure shortleaf pine stands was 7.5 feet greater than that for pine in mixed stands.

Direct Measurement of Site Index

Oak: Stem analysis of red and white oak sample trees in the Boston Mountains has established height growth patterns for each species group (Graney and Bower 1971). For site index classes 50, 60 and 70, height growth for red and white oaks is similar up to age 50, but between age 50 and 80 white oak maintains a much more rapid growth rate than red oak (Fig 8). Thus, if red oak and white oak are the same height at age 50, white oak is likely to be about 5 feet taller at age 80 and may be as much as 10 feet taller than red oak at age 100.

The regional site index curves (Schnur 1937) show less rapid growth up to age 50 on poor sites than the Boston Mountain oak curves, comparable early growth on medium sites, and more rapid early growth on good sites (Fig 8). After age 50, growth of white oak on all sites is greater than indicated by the regional curves. Growth rate for red oak after age 50 is actually slower on poor sites, comparable on medium sites, and more rapid on good sites than the regional curves indicate.

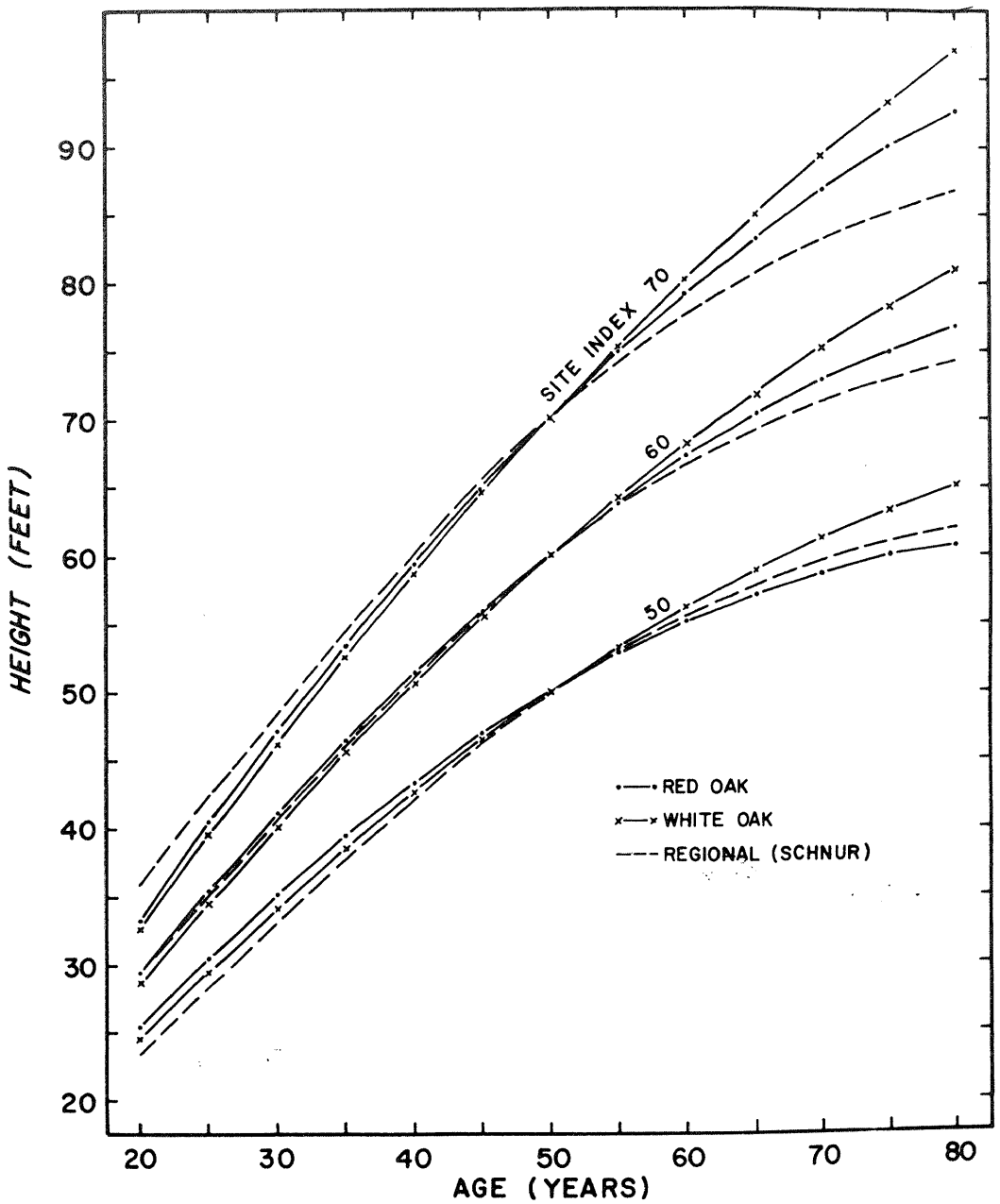

Figure 8. Site index curves for red and white oaks in the Boston Mountains and regional curves for upland oaks (Schnur 1937).

OUACHITA MOUNTAINS

The Ouachita Mountains generally consist of a series of east-west ridges and structural valleys. Narrow topped mountains with steep side slopes alternate with gently sloping valleys. Elevations range from about 500 to 2,800 feet above sea level.

Rocks in the area are primarily of sedimentary origin, range in age from Cambrian to Pennsylvanian, and consist chiefly of cherts, shales, slates, sandstones and novaculites. All geologic materials have been intricately folded and faulted, and at many places they dip at angles of 40° or more from the horizontal. Because of this inclined and fractured nature of the parent materials, tree roots can often penetrate to considerable depths even though the soils are generally shallow.

Soils on mountain ridges and upper slopes are shallow (Goldston and Pickens series); those on the lower mountain slopes and rolling valleys are deeper and are derived from shales or slates (Carnasaw and Sacul series) or from sandstone (Sherwood, Pirum, Zafra series). Still deeper soils derived from sandstone and shale colluvium (Allen and Holston series) are found on some mid- to low slopes and in smaller drains. The common terrace soils are Wickham and Sallisaw (old terrace) and Altivista and Augusta (low terrace).

Productivity by Soil Group

Average site index for shortleaf pine varied widely among soil groups (Fig 9), but the ranges in site index on the various soils overlapped considerably (Graney 1974). Site index ranges varied from about 30 feet for shallow soils to nearly 50 feet for low terrace soils. The overall range for all soils in the Ouachita Mountains was 65 feet, considerably more than the overall ranges encountered in the Ozark Plateau (33 feet) or in the Boston Mountains (30 feet).

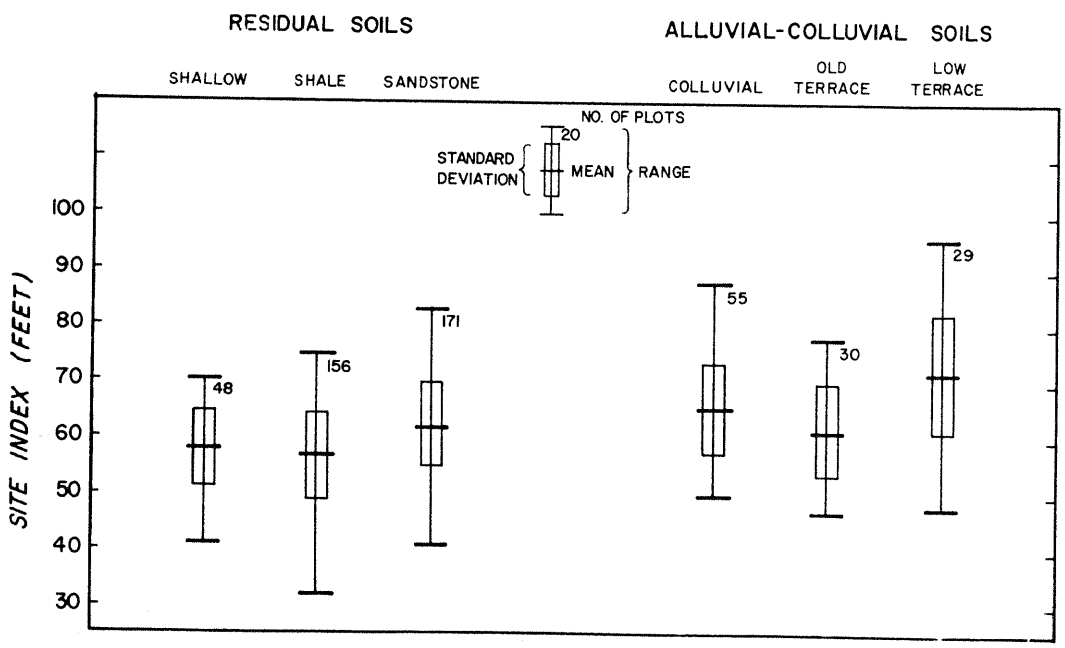

Figure 9. Site index mean, range and standard deviation for shortleaf pine on the major soil groups of the Ouachita Mountains of Arkansas and Oklahoma.

Indirect Estimation of Site Index

Shortleaf Pine: Preliminary equations for predicting site index for individual soil groups in the Ouachita Mountains and for various combinations of soil groups were derived from soil/site data from 367 plots and tested on an independent sample of 122 plots (Graney 1974). Equations for three combinations of soil groups (Table 2) each accounted for about 60 percent of the variation in site index and predicted site index within ± 5 feet of measured values for about two-thirds of the test plots. Mean absolute deviations of predicted from measured values was about 4.5 feet for these three equations. Equations for individual soil groups had higher R^2s but could predict site index no better than the combined equations.

Table 2. Equations for predicting site index for shortleaf pines on various soil group combinations in the Ouachita Mountains.

	Soil Group Equations		
	All combined (367 plots)	Residual (282 plots)	Alluvial-colluvial (85 plots)
Intercept (b_o)	31.68	51.76	57.00
Aspect	1.78	1.40	2.66
Slope shape	3.33	3.18	-
Position on slope	-	-	0.06
Elevation	-0.0049	-0.0041	-0.0098
Township (latitude)	0.74	0.88	-
Depth restricting horizon	-	-	0.10
Thickness A + B_1 horizon	-	0.44	-
Hardwood competition	-2.81	-2.13	-3.72
(3 x township) + range	-	-	0.26
Soil group	25.71	-	-
R^2	0.59	0.56	0.63
Standard error of estimate (± feet)	5.7	5.4	6.2

	Accuracy of Predictions		
Number of plots	122	93	29
Predictions: within ± 5 feet (%)	66	69	66
within ± 6 feet (%)	76	74	79
within ± 8 feet (%)	86	82	100
Maximum deviation (feet)	18	18	10
Average deviation (feet)	4.6	4.7	4.3

Most of the topographic variables included in the Ouachita Mountain equations appeared in pine equations for the other physiographic areas. In the Ouachitas, elevation probably reflects differences in soil moisture and soil groups. Higher elevations and ridgetop positions tend to have convex upper slopes and are generally dominated by shallow and shale soils (residual soil group) or by the old terrace and colluvial soils (alluvial-colluvial soil group); the more productive sandstone and low terrace soils are found at lower elevations. Hardwood competition, expressed as the percentage of the overstory occupied by hardwoods, was negatively correlated with site index in the Ouachitas; this finding supports the explanation of the site index/loss-on-ignition relationship proposed for the other areas. The only soil variables included in the combined soil group equations were thickness of the A + B_1 horizon and depth to a restricting horizon. Most shale soils have fine-textured subsoil horizons that reduce root penetration; thus, thick surface soil horizons would provide a greater volume of soil favorable for root development. Other layers that restrict root development, such as rock lines (old river beds) or gray mottled horizons, were also correlated with low site index.

Direct Measurement of Site Index

Shortleaf Pine: Stem analysis of sectioned pines in natural stands indicated that height growth patterns in the Ouachita Mountains differed from those indicated by the regional curves of Coile and Schumacher (1953) and of Misc. Publ. 50 (U.S. Forest Service 1929) and that the pattern of growth varied by site index class (Graney and Burkhart 1973). For site index classes 40, 60 and 80, the local curves and the regional curves agreed fairly well for all sites and ages above 50 years (Fig 10). For younger ages, the Ouachita Mountain and Misc. Publ. 50 curves are very close for poor sites, but Misc. Publ. 50 curves tend to overestimate site index on medium and good sites. The curves of Coile and Schumacher badly underestimate site index at ages of 35 years or less.

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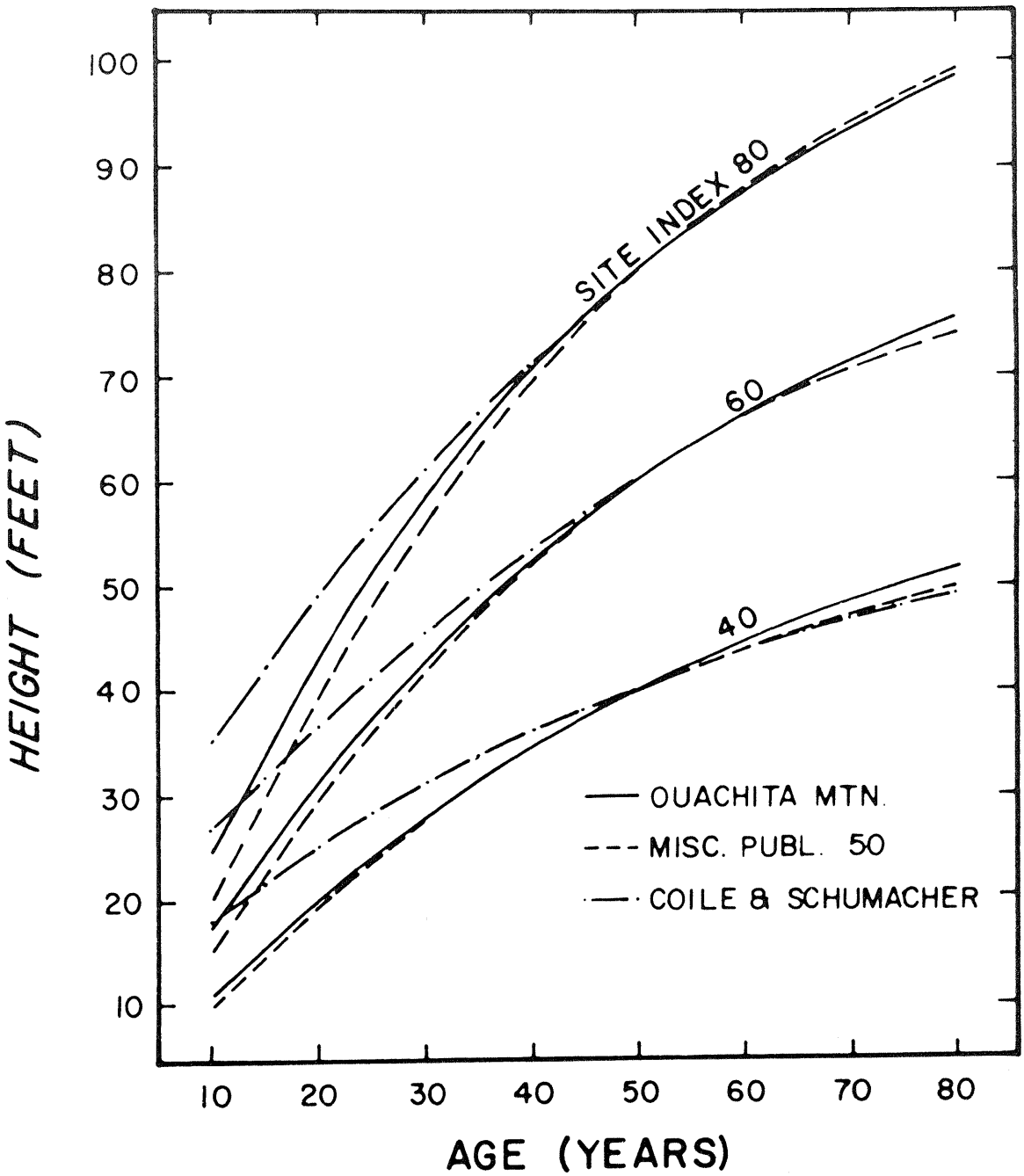

Figure 10. Ouachita Mountain shortleaf pine curves compared to the regional site index curves of Miscellaneous Publication 50 (U.S. Forest Service 1929) and Coile and Schumacher (1953).

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ABOUT THE AUTHOR

David Graney received a B.S. in forestry from Southern Illinois University in 1961, a M.S. in agronomy from Virginia Polytechnic Institute in 1964, and a Ph.D. in forest ecology from Virginia Polytechnic Institute in 1974. Since 1964, he has been a research forester with the Southern Forest Experiment Station's Silviculture and Hydrology Laboratory at Harrison and Fayetteville, Arkansas. He is the author or coauthor of ten publications in the field of silviculture.

For reprints write: Dr. David L. Graney
Southern Forest Experiment Station
830 Fairview Street
Fayetteville, Arkansas 72701