GROWTH AND YIELD COMPARISONS FOR UPLAND OAK STANDS IN THE BOSTON MOUNTAINS OF ARKANSAS [1]

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Abstract. Equations for basal area growth and total cubic-foot stand volume of even-aged upland oak stands in the Boston Mountains were compared with equations published for stands in the Central States. The basal area growth and stand volume equations for the Boston Mountains were developed using data from 87 stocking plots installed between 1976 and 1981. The same merchantability limits and volume computation procedures used in the Central States were followed in compiling the basal area growth and stand volumes for the Boston Mountains data. Differences were found in the equations for both basal area growth and stand volumes. Divergences in stand volumes were more pronounced when regional taper curves were used to compute tree volumes for the Boston Mountains data. Differences in the data sets with respect to stand age, site quality, and ingrowth and mortality rates may account for the differences. Use of the Boston Mountains equations with stand volumes derived from regional tree-taper curves is recommended when growth and yield estimates are desired for that region.

Introduction

Upland hardwoods (oak-hickory and oak-pine forest types) constitute more than 50 percent of the commercial forest land in the midsouth region. Yet despite this sizable upland hardwood resource, there is no published information on stocking, growth, and yield for midsouth hardwood stands. Schnur's (1937) yield tables, developed from unthinned stands throughout the Eastern United States, have been the main source of information for yield of upland oak stands. Published growth and yield relationships for managed oak stands in the Central States (Dale 1972, Hilt 1985, Shifley 1987) could be valuable to land managers in the midsouth, but it has not been established that growth and yield response to thinning in the Central States is the same for upland hardwood stands in the midsouth. Between 1976 and 1981, the Southern Forest Experiment Station Research Project at Fayetteville, Arkansas, installed a stocking study (Graney 1980) on Ozark National Forest lands in the Boston Mountains of northern Arkansas (Fig. 1). The objective of the study is to evaluate growth and yield response of upland oak stands to thinning.

The objectives of this paper are to: (1) compare basal area growth and stand volume equations developed for upland oak stands in the Boston Mountains of Arkansas with upland oak stand models published for the

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Central States (Dale 1972); and (2) evaluate the use of regional tree-taper equations for determining upland oak stand volumes for the Boston Mountains.

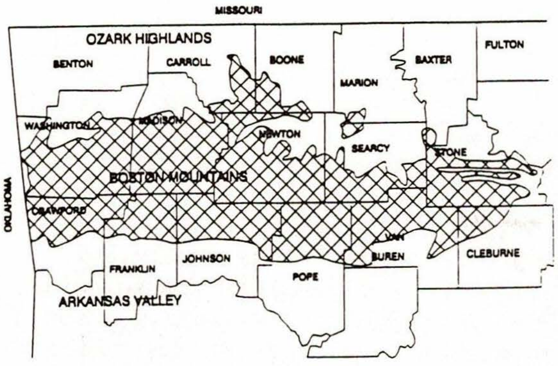

Figure 1. The Boston Mountains of Arkansas.

Study Description

Boston Mountains Study

This study is based on 87 permanent 0.25- to 0.5-ac plots distributed across the Boston Mountains. Stand age at the time of initial thinning varied from 11 to 75 years. Site indexes (Schnur 1937, Farrar 1985) for northern red or black oaks (*Quercus rubra* L. or *Q. velutina* Lam.) ranged from 46 to 82 ft (base age 50). All plots were established in fully stocked, even-aged upland hardwood stands that showed no evidence of recent fire or cutting.

Measurements consisted of a complete inventory of trees larger than 0.5 inches dbh measured to the nearest 0.1 inch. Total height of sample trees, which were selected at random in proportion to the number of stems in each 1-inch dbh class before and after thinning, was obtained for each plot. Four levels of stocking were created by thinning. Residual stands were left with 40, 60, 80, or 100+ percent of full stocking based on Gingrich's (1967) tree-area equation for upland oak stands. Thinning was mostly from below. Culls and poor-quality stems were removed first, then intermediate and suppressed trees of low quality and vigor. High-quality, desirable species were cut only to attain the residual stocking goal and a uniform spatial distribution.

Although 43 tree species are represented on one or more plots, black, northern red, and white (*Q. alba* L.) oaks account for 86 percent of the total basal area over all plots after thinning (Table 1). Plots on site index 50 and 60 are predominantly white oak; those on site index 70 are mixed red and white oak; and those on site index 80 are predominantly red oak (Table 1). Other desirable species such as black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), and black walnut (*Juglans nigra* L.) are present only as scattered individual trees on most plots and account for only about 3 percent of the total basal area. Hickories (*Carya* spp.) and blackgum (*Nyssa sylvatica* March.) plus other species represent 8.5 percent of the total basal area after thinning, but these species are more common in the midstory and understory positions on most plots (Table 1).

Central States Study

Dale's (1972) upland oak equation system was developed from data on 154 permanent-growth plots established as part of eight growth studies representing upland oak stands in Iowa, Kentucky, Missouri, and Ohio. Individual studies were installed between 1949 and 1962 and represented 5 to 12

Table 1. Percentages of numbers of trees and basal areas by site class and species group[1] for Boston Mountain study after first thinning.

Site index	Group 1		Group 2		Group 3		Group 4		Group 5	
	No. trees	Basal area	No. trees	Basal area	No. trees	Basal area	No. trees	Basal area	No. trees	Basal area
(ft)	(percent)									
>56	47.3	58.6	19.8	24.4	1.0	0.6	24.3	13.8	7.6	2.6
56-65	41.4	54.0	17.5	30.6	4.7	3.8	18.8	7.0	17.6	4.6
66-75	39.6	45.9	27.0	41.9	3.4	3.2	20.0	7.3	10.0	1.7
75+	28.3	30.3	34.1	58.3	2.6	1.4	15.7	6.9	19.3	3.1
All sites	41.1	47.6	22.2	38.3	3.1	2.5	20.3	8.5	13.3	3.1

[1] Group 1: White oak.
Group 2: Black oak, northern red oak, southern red oak.
Group 3: Ash, basswood, black cherry, black walnut, cucumber tree, shortleaf pine.
Group 4: Beech, blackgum, blackjack oak, black locust, chinkapin oak, elm, hackberry, hickory, post oak, red cedar, sugar maple.
Group 5: Blackhaw, buckeye, devil's walkingstick, dogwood, Indian cherry, hophornbeam, mulberry, Ozark chinkapin, papaw, persimmon, redbud, red haw, sassafras, serviceberry, spice bush, tree huckleberry, umbrella magnolia, wild plum, witch hazel, miscellaneous understory.

years of growth. Initial stand age varied from 22 to 90 years. Site indexes--based on Schnur's (1937) curves for upland oaks--ranged from 55 to 89 ft (base age 50). All plots represented fully stocked, even-aged upland oak stands that showed little evidence of recent fire or logging. Four or more density levels were created by thinning. Cutting varied from very light or none to removing 70 or 80 percent of the original basal area. Stands were thinned to leave a suitable number of the best stems as evenly spaced as possible over the plot. Species composition varies widely among studies, from white oak in the Kentucky studies to almost pure black oak in the two Missouri studies. Over all plots, upland oaks represent at least 90 percent of the total basal area after thinning.

Analysis

For this analysis, some 87 plots were available; 68 plots had two 5-year growth periods, and 19 had one 5-year growth period for a total of 155 growth observations. Plot basal area per acre was calculated for all live trees 2.6 inches dbh or larger for each plot measurement. Net annual basal area growth for each period was calculated by subtracting the initial basal area from the ending basal area and dividing by the growth period. The average basal area for the growth interval was calculated by averaging the beginning and ending basal areas. Average age was also calculated as the mean for the growth period.

Plot Summary

Several conventions were observed to make the results comparable: (1) the same threshold diameter of 2.6 inches was used; (2) the same definition of tree total ft^3 volume was observed; (3) plot height-diameter curves were constructed for the same species groups; and (4) the same total ft^3 volume equation was used to calculate tree volumes for plot volume summarization.

Individual tree volumes-- ft^3, outside bark, from ground level to tip, excluding branches--were calculated by two different procedures. In one procedure, they were computed from the total ft^3 volume equation developed by Dale (1973) to ensure that the results of the Boston Mountain study would be comparable to those for the Central States (Dale 1972). In the second procedure, tree volumes were calculated using individual species tree-taper curves developed by Clark et al. (in press). If a taper equation was not available for a particular species, one for the genus or appropriate species group (for example, the red oak group) was used instead. Lacking this option, volume was calculated using equations developed for soft hardwoods or hard hardwoods as appropriate.

Both techniques required total tree height and diameter. Separate height-diameter curves were constructed for red oaks and white oaks at each plot measurement. Non-oak species were combined with the red oak group.

Plot volumes/ac were determined for each measurement by summing the volumes of all live trees 2.6 inches dbh or larger. Average plot volumes/ac for each growth period were calculated by averaging the beginning and ending volumes. Note that these average volumes include ingrowth and mortality for the period. Plot volumes were summarized for both tree-volume computation procedures.

Mathematical Models

The models (Dale 1972) for basal area growth and average total ft^3 volume are, respectively:

$$B_g = -BA^{b_1}\ln(B) + b_2BA^{b_3} + b_4BSA^{b_5} \quad [1]$$

$$\ln(V) = c_1 + c_2S + c_3\ln(B) + c_4A^{-1}, \quad [2]$$

where, B_g = net annual basal area growth (ft^2/ac) for trees 2.6 inches dbh or larger,

B = average basal area (ft^2/ac) in trees 2.6 inches dbh or larger,

A = average stand age in years,
S = site index (ft, base age 50),
V = average total ft^3 volume/ac in trees 2.5 inches dbh or larger,
b_i = coefficients to be estimated for basal area growth equation, and
c_i = coefficients to be estimated for volume equation.

Equations [1] and [2] were solved as a system of equations using nonlinear seemingly unrelated regressions (SAS Institute 1984). This technique does not account for possible serial correlation between growth observations on the same plot; no procedure to account for this potential error structure was available for the analysis. The first fitting used data in which the tree volumes were calculated by Dale's (1973) tree-volume equation. This data set will be called "Boston Mountains-combined species." The second fitting used data in which the tree volumes were calculated using tree-taper equations developed by Clark et al. (in press). This data set will be called "Boston Mountains-individual species."

Results

Table 2 shows the goodness-of-fit statistics for equations [1] and [2]. Note that the coefficients of determination for basal area growth are higher for the regressions of the two Boston Mountains data sets than for the Central States data sets. However, the average annual basal area growth rates for the Boston Mountains and the Central States are virtually identical at about 1.8 ft^2/ac. The coefficients of determination are not markedly different for total stand volume, equation [2], for the three data sets.

Coefficients of determination were also computed for the Boston Mountains-combined species data set using the Central States coefficients. The coefficients of determination are 0.494 for basal area growth and 0.793 for total ft^3 stand volume. These are much poorer than the coefficients of determination for the fitted equations for the Boston Mountains data (Table 2).

The coefficient estimates for the Boston Mountains data sets agree in sign with those for the Central States for both basal area growth and stand volume (Table 3), but there are some divergences in magnitude. Note that the coefficient values for equation (2) differ significantly for the two Boston Mountains' data sets.

Figure 2 compares basal area development of upland oak stands in the Central States with that in the Boston Mountains using regression results from the combined-species data set, which conforms more closely to the Central States data. Note that for the three initial basal areas and the two different site index classes shown, basal area development in the Boston Mountains apparently outpaces that in the Central States for ages 50-60 years. Although the difference in growth for any single year is not great, it increases over time.

Table 2. Goodness-of-fit statistics for basal area growth and total volume equations for Central States and Boston Mountains of Arkansas.

Equation number	Mean of dependent variable	Coefficient of determination	Root mean square error
		Central States*	
(1)	1.80	0.518	0.733
(2)	7.463	.984	.064
		Boston Mountains-combined species	
(1)	1.81	.772	.571
(2)	7.727	.969	.089
		Boston Mountains-individual species	
(1)	1.81	.772	.571
(2)	7.666	.984	.075

* Source: Dale 1972, table 11.

Table 3. Coefficients for basal area growth and total volume equations for Central States and Boston Mountains of Arkansas.

Coefficients	Central States*	Boston Mountains Species: combined	Boston Mountains Species: individual
	--------------- Basal area growth	---------------	
b_1	-0.8	-0.79510	-0.79521
b_2	3.6852	2.4632	2.4999
b_3	-0.75	-0.64447	-0.64812
b_4	0.011383	0.27849	0.26740
b_5	-1.05	-1.7474	-1.7384
	------------- Total ft^3 volume	-------------	
c_1	3.0909	2.8207	3.0749
c_2	0.0093018	0.012765	0.013435
c_3	1.03909	0.97803	0.93645
c_4	-20.110	-5.8054	-14.581

* Source: Dale 1972, table 11.

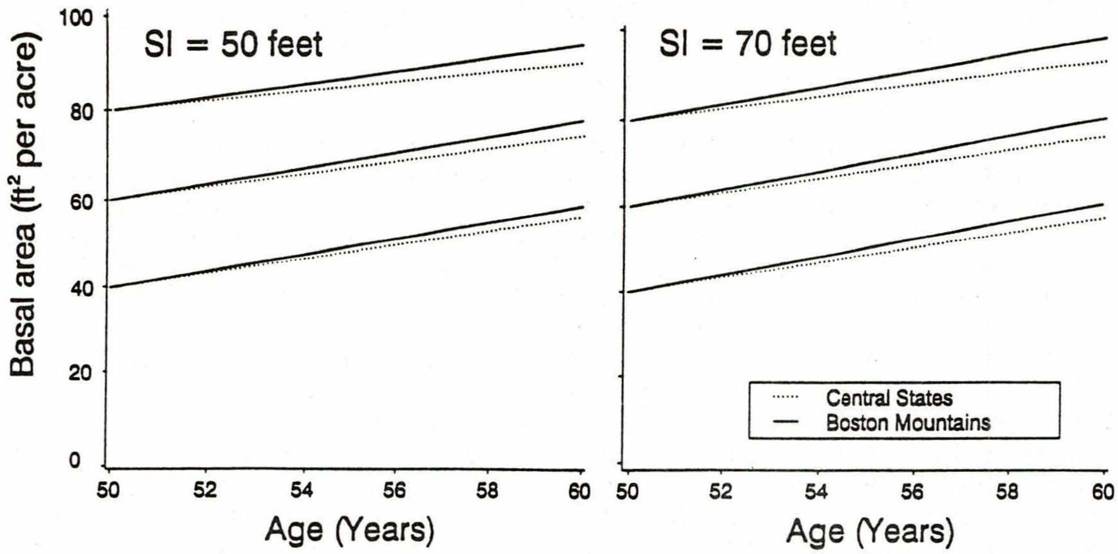

Figure 2. Computed basal area development for even-aged upland oak stands from ages 50-60 years in the Boston Mountains and Central States, given different initial stand basal areas and site indexes.

Possible Explanations for Differences

There are several possible reasons for the differences in predicted basal area development, one of which is mortality and growth characteristics. Dale (1973) recorded an average annual ingrowth rate--that is, the ratio of the number growing past the 2.6-inch dbh threshold to the average number of trees/ac--of 0.0063. The ingrowth rate for the Boston Mountains data was 0.0136, twice as high as that for the Central States. The average annual mortality rate--the ratio of the number of trees dying to the average number of trees--for the Central States data sets was 0.0092, whereas the average for the Boston Mountains was 0.0109. The net annual change in trees--ingrowth rate minus the mortality rate--is negative for the Central States, whereas the net change for the Boston Mountains is positive. This small overall increase in stems might boost basal area growth, albeit very slightly.

Initial stand characteristics also differ. The average initial ages for the Central States data sets ranged from 22-90 years, with a good representation within this range. Ages in the Boston Mountains data set ranged from 11-75 years, but nine plots were 11 years old, and the rest varied from 33-75 years. Site indexes for the Central States ranged from 55-89 ft and averaged 69 ft (calculated by weighting the midpoint of the ranges of each data set by the number of plots); site indexes for the Boston Mountains ranged from 47-82 ft and averaged 64 ft. Overall, site indexes were poorer for the Boston Mountains. Site indexes for the Boston Mountains' plots were based on height and age measurements taken from northern red and black oaks; no white oaks were used. Because the site index for the northern red and black oak is 3-5 ft higher than for white oak on the same location, the Boston Mountains site indexes may be somewhat higher than equivalent Central States plots if the Boston Mountains site indexes had been based on white oak. This difference might be especially significant, because the b_4 coefficient in equation [1], which showed the greatest difference, acts on a site variable.

Another explanation might be different species mixtures. The Boston Mountains data set has a more tolerant understory--as evidenced by greater percentages of species in groups four and five--than the Central States data sets. The Central States studies were installed in stands that had a short history of fire protection, about 20 to 30 years, and a tolerant understory had not yet developed fully (Dale 1990).

Figure 3 depicts stand development in total cubic volume by site index and stand age over a 10-year period. For site index 50 ft, the three volume estimates diverge appreciably, and this divergence increases with increased initial basal area. The relative ranks of the estimates do not change. When site index is 70 ft, however, Central States volumes are close to those for Boston Mountains-individual species. As initial basal area increases, Central States volumes coincide with those for Boston Mountains-combined species for initial densities of 60 ft^2, and then surpasses both when initial basal area is 80 ft^2. The relative positions of the Boston Mountains estimates do not change, but they do diverge with increasing initial basal area.

Note that the basal area growth equations were used to obtain ft^3 volume development, and that the differences in basal area projections are imbedded in the volume estimates. However, there also seem to be intrinsic differences in the volume estimates. Some of the reasons for differences in basal area estimates can be advanced for volume projections as well. As with basal area, the coefficient for site index in the stand volume equation [2] has more impact for the Boston Mountain data sets than for the Central States (Table 3).

Equation [2] for the Boston Mountains-individual species data set predicts less volume than for Boston Mountains-combined species (Fig. 3). This difference can probably be attributed to the tree-volume computation. Table 4 compares individual tree volumes after the initial thinning calculated by the tree-volume equation with those calculated by the tree-taper curves. The tree-volume equation predicts about 0.4 ft^3/tree more than does the tree-taper equation for all species, and the paired t-test indicates that the volumes are different ($p = 0.0001$). The tree-taper volume estimates are probably more precise because they were developed from a data set that included samples from the Boston Mountains and can account for species differences. Therefore, their use is recommended for the Boston Mountains area.

Conclusions

Despite painstaking efforts to minimize differences in computation procedures, the basal area growth and total stand volume models for the Central States (Dale 1972, 1973) and those for the Boston Mountains-combined species data sets still produced different estimates. Although several plausible reasons can be advanced for these differences, none can be proven

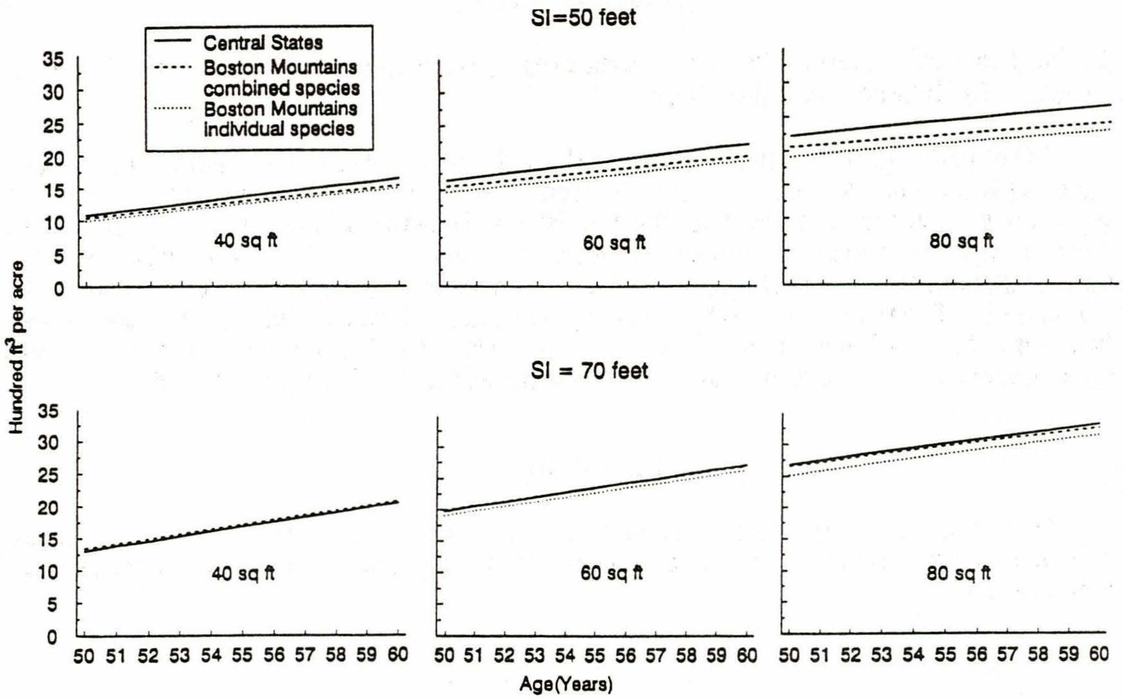

Figure 3. Total volume development for even-aged upland oak stands from ages 50-60 years in the Boston Mountains and Central States, given different initial basal areas and site indexes.

Table 4. Comparison of tree volumes calculated by combined species volume equation versus volumes calculated using individual species tree-taper equations for Boston Mountain study.

Species group [1]	Number of trees	Difference [2]	
		Mean	Standard deviation
		ft³	
1	4,112	0.38	0.21
2	2,712	.20	.54
3	262	.39	.52
4	1,833	.49	.34
5	1,197	.67	.12
All species	9,616	.40	.37

[1] Group identities are the same as those provided in Table 1.

[2] Difference = combined species volume minus tree taper volume.

to be the real cause. Perhaps comparing growth and yield between different studies is inherently hazardous.

If a user wants basal area growth and total volume estimates for even-aged upland oak stands in the Boston Mountains, we recommend using the equations developed from the Boston Mountains-individual species data set (which uses volumes computed from tree-taper curves). The simple two-equation growth and yield system described here does not provide answers to questions of yields for other merchantability limits and volume measures. However, further analysis is being done with the Boston Mountain data, and more comprehensive growth and yield information will be developed.

Acknowledgments

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