Growth and Yield of Thinned Upland Oak Stands in the Boston Mountains of Arkansas

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ABSTRACT. *Eighty-seven permanent plots were installed in natural even-aged upland oak* (Quercus *sp.) stands in the Boston Mountains of Arkansas on an array of sites and representing a range of ages. These plots were subsequently thinned to stocking levels of 40, 60, 80, and 100%. Measurements were taken at plot establishment and 5 and 10 yr after thinning. We developed a system of equations from these data to predict projected total basal area per ac and current and projected values for the following stand variables: quadratic mean dbh, total ft^3 volume per ac, merchantable ft^3 volume per ac, sawtimber ft^3 volume per ac, and bd-ft volumes per ac for the three principal log rules—Doyle, Scribner, and International 1/4 in. Forest managers can use these equations to predict the growth and yield potential of upland oak stands in the Boston Mountains. South. J. Appl. For. 18 (1): 10–14.*

The oak-hickory forest type includes about 4.3 million ac or 74% of the timberland in the Ozark Region of Arkansas (Hines 1988). Although a part of the larger oak-hickory forest type that occupies a part of the Central and Southern regions of the United States, it is a unique subregion of the oak-hickory type. Mixed-oak types occupy most of the commercial forestland in northern Arkansas, and oaks are the dominant timber species throughout this region. Valuable, fast-growing species such as yellow-poplar (*Liriodendron tulipfera* L.) do not occur in the Ozark region, and desirable species such as black walnut (*Juglans nigra* L.), black cherry (*Prunus serotina* Ehrh.), and white ash (*Fraxinus americana* L.) occur only sporadically, primarily on the better sites. Most associated species in these upland stands are either slower growing or lower in value than the oaks. Oak sites in the Ozarks range from poor on the ridges and south- and west-facing slopes to excellent on some north- and east-facing slopes and mountain benches. However, stand growth and yield on all oak sites are strongly influenced by the hot, dry summers that typify the Ozark region.

Information about the growth of oak-hickory stands in this area is lacking. However, there is some information about the growth and development of the oak-hickory type in other geographic areas (Dale 1972, Hilt 1985, Shifley 1987), but apparent differences exist between the growth and yield equations developed for the Central States and those developed for the Boston Mountains (Graney and Murphy 1991). This limited comparison was confined to basal area and total ft^3 volume development and did not consider the economically important measure of sawtimber volume. The equations we present here for upland oaks in the Boston Mountains are not only basal area and total ft^3 volume development but also sawtimber volumes for the three principal log rules.

Study Region

The Boston Mountains are the highest and southernmost member of the Ozark Plateau physiographic province (Figure 1). They form a band 30 to 40 mi wide and 200 mi long from north-central Arkansas westward into eastern Oklahoma. Elevations range from about 900 ft in the valley bottoms to 2,500 ft at the highest point. The plateau is sharply dissected, and most ridges and spurs are flat to gently rolling and generally less than one-half mile wide. Mountain slopes consist of an alternating series of steep simple slopes and gently sloping benches.

Soils common to mountain tops and slopes are shallow to medium in depth; medium-textured members of the Hartsells, Linker, and Enders series (Typic Hapludults); derived from sandstone or shale residuum; and rated medium to low in productivity. Soils common to mountain benches are deep, well-drained, medium-textured members of the Nella and Leesburg series (Typic Paleudults); derived from sandstone

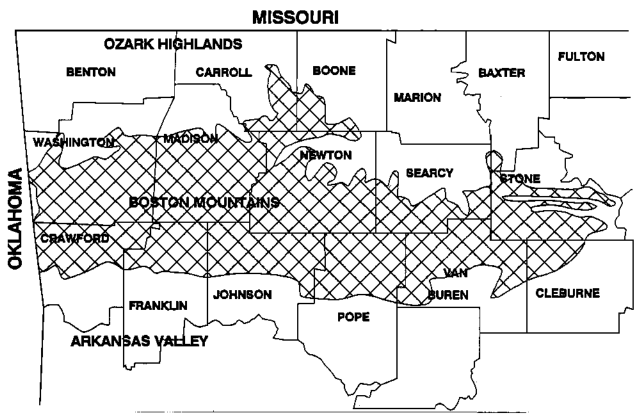

Figure 1. The Boston Mountains of Arkansas.

and shale colluvium; and rated medium to high in productivity.

Rocks in the area are sedimentary and predominantly of Pennsylvanian age, consisting of alternating horizontal beds of shales and resistant sandstones. Annual precipitation averages 46 to 48 in., with March, April, and May being the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

Study Description

This study was based on 87 permanent 0.25 to 0.5 ac plots distributed across the Boston Mountains (Graney 1980). Stand age at the time of initial thinning ranged from 11 to 75 yr. Site indexes (Farrar 1985, Schnur 1937) for northern red or black oaks (*Quercus rubra* L. or *Q. velutina* Lam.) ranged from 46 to 82 ft (base age 50 yr). All plots were established in fully stocked, even-aged upland hardwood stands that showed no evidence of recent fire or cutting. Of the plots studied, 68 plots were installed over a 3 yr period from 1975 to 1977, and 19 were installed later in 1980 and 1981.

Preharvest measurements consisted of a complete inventory of trees larger than 0.5 in. dbh measured to the nearest 0.1 in. Total heights of sample trees, which were selected at random in proportion to the number of stems in each 1 in. dbh class (before and after thinning), were obtained for each plot. Four levels of stocking were created by thinning. Residual stands were left with 40, 60, 80, or 100+% of full stocking in trees 2.6 in. dbh and larger 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 stems of desirable species were cut only to attain the residual stocking goal and uniform spatial distribution.

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

Analysis

Of the 87 plots used in this analysis, 68 had two 5-yr growth periods, and 19 had one 5-yr growth period for a total of 155 observations. Only live trees 2.6 in. dbh and larger after the initial thinning were used in the analysis. Thus, the basal area of plots at each measurement is for trees that were at least 2.6 in. dbh after the initial treatment and surviving at that measurement. Ingrowth past the 2.6-in. threshold was not included. This ingrowth would be composed of more tolerant, slower growing species that remain as understory trees for the remaining life of the stand. Moreover, they will never comprise any significant volume. Therefore, this portion of the stand was excluded from the analysis.

Plot volumes were calculated by first constructing height-dbh curves for each plot and each measurement to obtain heights for nonsample trees. All species were grouped because some species were not present in sufficient numbers for a separate group and examination of scatterplots and preliminary regression analyses showed no gain by separating the height-dbh measurements into species groups. Tree volumes were calculated from individual-species taper curves by Clark et al. (1991) for stems 5.0 in. dbh and larger. Volumes for smaller stems were calculated using equations from Clark et al. (1986). Examination of scatterplots of tree volumes versus dbh and total height showed a smooth transition at 5 in. dbh, which indicates that volumes from the two methods merge well and show no discontinuities. The following volumes were calculated: total ft^3 volume (inside bark) of stem from 0.2 ft stump to tip for all live trees; merchantable ft^3 volume (inside bark) from a 0.5 ft stump to a 5 in. top (inside bark) for trees 6.0 in. dbh and larger; and sawtimber ft^3 volume (inside bark) and bd-ft volumes (Doyle, Scribner, and International 1/4-in. rule) from a 1-ft stump to a 10-in. top (inside bark) for trees 12.0 in. dbh and larger. Per-ac plot

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

	Group 1		Group 2		Group 3		Group 4		Group 5	
Site index (ft)	No. trees	Basal area	No. trees	Basal area	No. trees	Basal area	No. trees	Basal area	No. trees	Basal area
<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, red maple, sassafras, serviceberry, spice bush, tree huckleberry, umbrella magnolia, wild plum, witch hazel, miscellaneous understory.

volumes were calculated for each plot measurement by summing individual tree volumes and applying the appropriate plot expansion factor.

A set of 8 equations that predict projected basal area; quadratic mean dbh; total, merchantable, and sawtimber ft^3 volumes; and bd-ft volumes for the Doyle, Scribner, and International 1/4 in. log rules were fitted using nonlinear least squares (SAS Institute 1984) using a parameter estimation technique suggested by Borders (1989).

Results and Discussion

Table 2 shows the regression results. The R^2's varied from a low of 0.81 in Table 2 for quadratic mean dbh to 0.99 for total ft^3 volume. The coefficients were logical in sign and magnitude.

The equations can be used to study the overall growth potential of these stands, or to look at a specific stand in detail. The equations can be used in a variety of other ways such as to help determine timing and intensity of thinning schedules, to select rotation length, or to provide data about operability and product mix of intermediate cuts.

For example, one use of the equations is to gain an overall understanding of the growth potential of these stands by observing graphs of basal area and volume growth. Here, we used a site index of 64 ft, which is the average for the study plots. Figure 2 shows that periodic annual basal area growth has already peaked by age 40, and growth varies from about 1.6 to 1.9 ft^2 at that age. The higher initial densities are growing more at age 40, but by age 70 the lower initial densities are putting on more basal area. There is a fairly wide range of growth for total ft^3 volume at age 40 (Figure 3). However, they converge to a fairly narrow band at age 70 to about 45 ft^3 per acre. In contrast to periodic annual growth for total cubic volume, bd ft volume growth for the Doyle rule starts out at around 45 bd ft at age 40 for all initial densities, increases, and diverges at older ages (Figure 4). Periodic annual growth has not peaked, which suggests that the upland oaks have a slow, steady growth in bd ft volume, albeit at a somewhat slow pace. At least for some oak species, a fairly long rotation can be adopted for bd ft volume production

To look at a specific stand, one might apply the equations to calculate basal area and volume changes over a growth period. For example, suppose a stand is currently 50 yr old, has a total basal area of 60 ft^2/ac, and is on land with a site index of 65 ft (base age 50). A spreadsheet can be used to determine not only what volumes the stand might now have but also what might be expected in 10 yr which can be seen in the following table:

Stand variable	Age 50	Age 60
Total basal area (ft^2/ac)	60	74.3
Total ft^3 volume/ac	1,369	1,898
Quadratic mean dbh (in.)	8.23	9.40
Merchantable ft^3 volume/ac	1,117	1,661
Sawtimber ft^3 volume /ac	221	473
Bd-ft volume/ac (Doyle rule)	785	1,734

The annual growth per ac for this 10-yr period is 1.4 ft^2 for basal area, 53 ft^3 for total volume, 54 ft^3 for merchantable volume, 25 ft^3 for sawtimber volume, and 95 bd ft for the Doyle rule. Stand conditions for other sites, ages, and densi-

Table 2. Regression equations and resultant goodness-of-fit statistics.

Equation		Mean of dependent variable	R^2	Root mean square error
$B_2=[0.02590-\{0.02590-B_1^{-0.71754}\}(A_2/A_1)^{-0.71754(2.4884)}]^{1/(0.71754)}$	(1)	81.2	0.98	3 5
$T=B^{0.94000}\exp[3.1427+0.015209S-37.920/A]$	(2)	1,932	0.99	117
$M=0.92588T[1-\exp\{0.028105(-24.422)D\}]^{1/0.028105}$	(3)	8.9	0.81	1 2
$D=2.0672+0.0024004AS-0.027340B$	(4)	1,570	0.99	61
$V=0.91634M[1-\exp\{0.12375(-0.026524)SD\}]^{1/0.12375}$	(5)	546	0.85	220
$F_D=3.4528V+0.00044738V^2$	(6)	2,192	0.99	171
$F_S=5.1686V+0.00026988V^2$	(7)	3,008	0.99	103
$F_I=6.0194V+0.00032819V^2$	(8)	3,509	0.99	135

where:

A_1 = current stand age,
A_2 = projected or future stand age,
B_1 = current basal area (ft^2) per ac at age A_1,
B_2 = projected basal area (ft^2) per ac at age A_2,
S = site index (ft),
A = stand age,
T = total ft^3/ac,
B = stand basal area (ft^2)/ac,
D = quadratic mean dbh (in.),
M = merchantable ft^3/ac,
V = sawtimber ft^3/ac,
F_D = bd-ft volume (Doyle rule)/ac,
F_S = bd-ft volume (Scribner rule)/ac, and
F_I = bd-ft volume (International 1/4-in. rule)/ac.

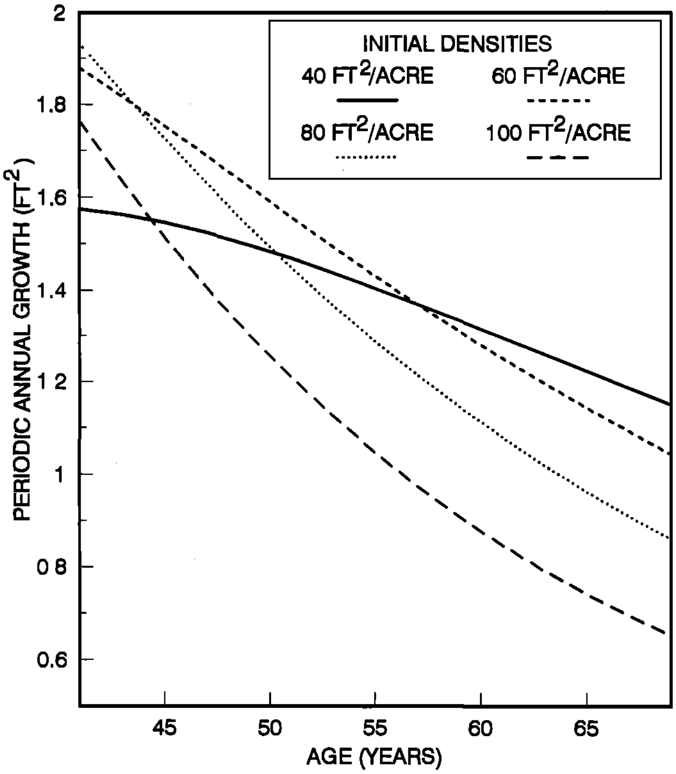

Figure 2. Periodic annual total basal area growth per ac (2-yr basis) for different initial densities.

ties can be obtained by following the same procedure.

To use the equations, the user must specify a starting basal area in trees 2.6 in. dbh and larger per acre, the stand age in years, and site index. Although the equations can be solved by using a scientific calculator, repeated calculations can be quite laborious. An alternative is to use an electronic spreadsheet, and a spreadsheet template is available on request (see the software announcement at end of this article).

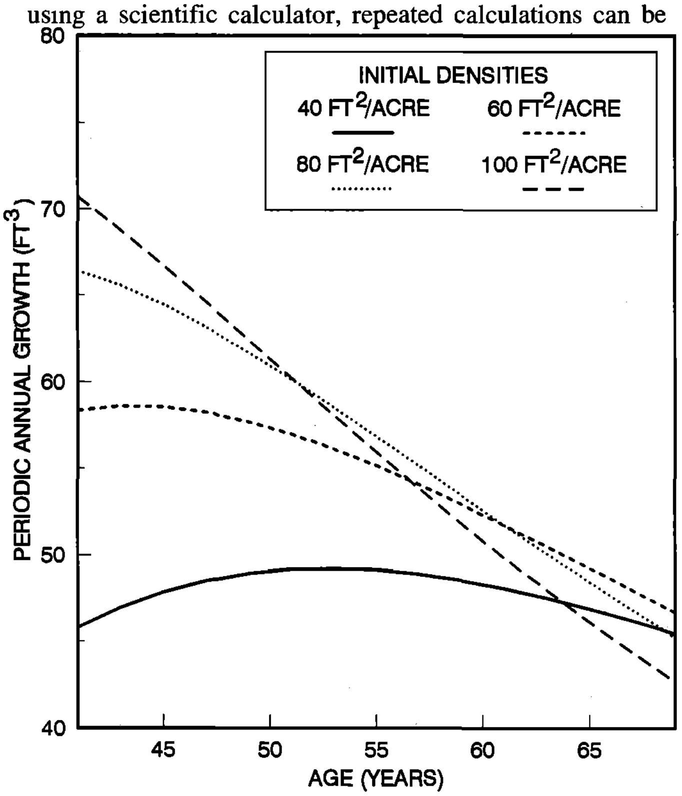

Figure 3. Periodic annual total ft^3 volume growth (2-yr basis) for different initial densities and a site index of 64 ft.

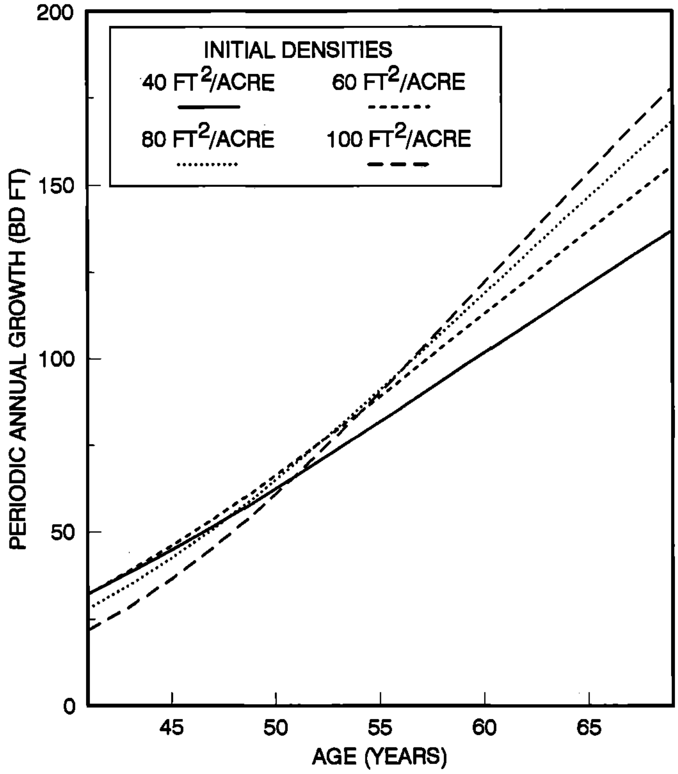

Figure 4. Periodic annual bd-ft volume growth ((2-yr basis), Doyle rule, for different initial densities and a site index of 64 ft.

If you want to construct your own spreadsheet or software, be sure that you observe the following sequence in equation solution. Site index, current age, and total basal area per ac are known, and present total ft^3 volume is predicted from these variables, but for current merchantable volumes, quadratic mean dbh must first be estimated. Merchantable volumes are then estimated in the following progression: merchantable ft^3 volume, sawtimber ft^3 volume, and bd ft volumes. These volumes are solved in a sequential manner because some are functions of others. For the future stand, total basal area must be estimated from current and projected stand ages and the current basal area. Once projected basal area is obtained, future quadratic mean dbh and total ft^3 volume can be estimated. Finally, projected merchantable volumes are estimated in a manner similar to current volumes.

The user should be aware of certain details when using the equations. The data are essentially a 10-yr growth response of previously unthinned stands that were cut back to different density levels by thinning from below. Therefore, the basal area and volume estimates are indicative of that sort of treatment, and radically different treatments will probably give different results. The merchantable volume predictions are dependent on quadratic mean dbh, and if the actual quadratic mean dbh is substantially different, then the estimates will not be as accurate. Finally, as with any growth and yield predictions, the estimates are for the average condition, and estimates for individual stands may or may not be close to actual values.

The estimates are at a stand level and do not provide the detail nor the sensitivity of individual-tree models, but the models should be a welcome addition to the growth and yield information for upland oaks in the Boston Mountains. Development of more refined models is underway.

Software Announcement

A spreadsheet template for Borland Quattro Pro 4.0™[1] and instructions are available. To receive a copy, please send either a 3.5 in. or 5.25 in. diskette and a stamped, self-addressed diskette mailer to the authors.

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