PRODUCTION OF UNMANAGED BOTTOMLAND HARDWOODS IN ARKANSAS[1]

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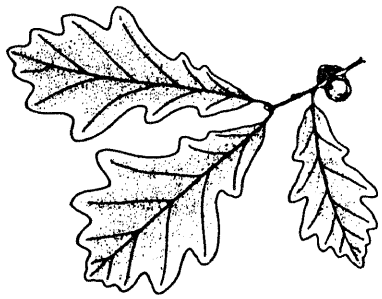

ABSTRACT.--Growth and yield of unmanaged bottomland hardwood stands of southeastern Arkansas were estimated from measurements of 49 square 0.15-acre plots. Due to the uniformity of environmental conditions, the investigated stands were roughly equally productive. Because no age trend was discovered for the majority of stand variables, it was assumed that the stands are balanced. The average total volume was 4206 cu. ft./acre. The merchantable volumes were 3909 cu. ft./acre (above 4" outside bark) and 2330 cu. ft./acre (above 10" inside bark). The average annual increment was 84 cu. ft./acre. A program was written for HP-41-series calculators to compute growth and yield variables of individual stands. Using tree number by diameter classes (stand table) as input, the program produces values of 26 variables for each diameter class and of 12 variables for the entire stand, including merchantable variables for any utilization limit.

Information on the growth and yield of Arkansas hardwoods required for proper forest management is limited. Smith et al.(1975) indicated that prior to their work there had been no published estimates on the yield of naturally occurring, mixed hardwood stands. Their study developed yield predictions utilizing data from 641 plots of 1/5-acre size, on nine forest site types. The data were collected from North Carolina to eastern Texas and thus provided broad regional estimates. However, the applicability of their prediction equations to the Arkansas bottomland hardwoods is not obvious because Smith et al. (1975) established only nine plots in Mississippi and Arkansas bottomland stands.

The purpose of this study is to provide information on the growth and yield of bottomland hardwood stands of southeastern Arkansas which were high-graded 40-50 years ago and left unmanaged since. The main species found in these stands are oaks (Quercus spp.) and sweetgum (Liquidambar styraciflua L.). This group of stands was selected for two reasons. First, it occupies a major part of the stream bottoms in our area. Second, this group can provide a standard with which to judge the effects of management activities.

MATERIALS AND FIELD METHODS

The stands selected for this study were situated far from improved roads in areas where there are plenty of more accessible and yet largely unmanaged hardwoods of similar quality. Historical records, testimony of old-timers, and careful inspection of the stands were used to ascertain the lack of disturbance, at least during the last 40-50 years.

Stands were sampled with clusters of square 0.15-acre plots. Although time consuming, the square configuration is recommended for research studies as the most useful and accurate (Curtis 1983). The total number of plots in eight clusters (locations) was 49. Each cluster was located in one stream bottom. Other information about locations, plot area, and size of various subsamples is presented in Table 1. Each plot was divided into five 16.4 x 82.0 foot strips. For each tree larger than 1.57 inches in diameter

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TABLE 1.--Sampling of unmanaged stands

Location	Number of plots	Area of plots, acres	Number of measured trees	check strips	cored trees	upper-stem measured trees	height measurements
1	12	1.85	625	6	74	43	98
2	5	0.77	303	3	46	34	52
3	4	0.62	336	3	46	16	49
4	4	0.62	230	2	17	14	23
5	8	1.24	440	2	35	26	38
6	8	1.24	372	4	58	30	60
7	4	0.62	191	2	16	12	18
8	4	0.62	147	2	15	13	16
TOTAL	49	7.57	2644	24	307	188	354

at breast height the following variables were recorded: species, crown class, dbh, and spatial coordinates. Total number of measured trees was 2644. Several strips (Table 1) were chosen at random on each plot to check all of the measurements. No significant errors were discovered in this check.

Total height was measured on 354 trees. 307 of these trees were cored to determine age (at breast height) and radial increments for 3, 6, and 10 years. These trees were sampled from all diameter classes in proportion to basal area of each class. 188 of the cored trees were used to measure crown dimensions (height of the first living branch, crown length and width), and upper stem diameters (at crown base and midcrown) using a pentaprism and a Suunto clinometer mounted on a tripod.

To find out the number of years required to reach breast height, 90 saplings of the main species were cut at the base (2 inches from ground) and at breast height level, and the number of annual rings was counted. The average difference between the base and the breast height ages was 3.31 years for the white oak group, 3.22 years for red oak group, and 3.56 years for sweetgum. The average for all species was 3.36 years.

For precise measurement of form factor, 20 trees representing all crown classes were felled. The following variables were determined for each of these trees: 20-30 diameter measurements along the stem; age and bark width at 10-15 different heights; branch diameter, length, and weight; and specific gravity of the stem.

ANALYSIS AND TREATMENT OF DATA

The treatment of the data consisted of the calculation of basic stand variables by location and species (tree number per unit area, average diameter, height, age, basal area, and increment), preparation of a stand table (diameter distribution of trees), and a stock table (distribution of volume by diameter classes). In addition, diameter and volume increments were found by diameter classes.

Classification of stands according to productivity

Besides providing descriptive information on the measured stands, the basic stand variables (Table 2) allow one to draw conclusions about the uniformity of the stands with respect to their productivity. At present there is no established consensus on how to estimate productivity of uneven-aged stands. In even-aged stands the estimation of productivity is based on measuring dominant trees and the application of site index curves. This approach is not suitable for uneven-aged stands because in two deciding aspects they are a direct opposite to even-aged stands. First, dominant trees, usually spared by both natural and artificial thinning in even-aged stands, are subject to considerable natural mortality and harvest cutting in uneven-aged stands. Second, site index curves, intended to reflect the change of dominant height with age, do not exist for balanced uneven-aged stands, where height and other variables do not change with time.

Volume or its increment--the most direct indicator of productivity in an ideal, undisturbed situation--cannot be employed in actual situations because, in addition to site productivity, volume is affected by disturbances and as a result may greatly vary on equally productive sites.

Tree height, being less affected by stand density, is a more reliable indicator of site quality. In uneven-aged stands it probably is better to rely on the average rather than the dominant height. The average height in our study was calculated as the arithmetic mean of sample heights distributed by diameter classes in proportion to their basal area. The average height, however, is affected by stand age (Table 3). To eliminate the age influence it was decided to use mean height increment (tree height divided by its age) as the indicator of site quality.

To decide whether there is a statistically significant difference among the locations with respect to the mean height increment (Table 2), the general linear models procedure from the SAS

TABLE 2.--Stand variables by location

Variables	Location 1	2	3	4	5	6	7	8
Number of trees per acre	337.25	392.40	543.92	372.32	356.14	301.10	309.19	237.96
Arithmetic mean diameter, inches	5.57	5.59	4.98	5.67	6.10	7.54	5.59	7.90
Standard deviation, inches	5.96	4.56	3.99	5.31	4.89	5.49	5.94	8.29
Coefficient of variation	1.07	0.82	0.80	0.94	0.80	0.73	1.06	1.05
Quadratic mean diameter, inches	8.15	7.21	6.38	7.77	7.81	9.32	8.15	11.45
Basal area, sq. ft./acre	122	111	121	122	119	143	112	169
Age, years	65.59	39.04	47.82	57.29	51.16	50.07	72.84	67.53
Mean height, ft.	83.23	70.60	67.75	80.58	77.59	90.91	94.65	108.14

statistical package was employed. The null hypothesis that there is no significant difference among the locations was rejected based upon the results of an F-test. Application of Tukey's studentized range test revealed two statistically different site groups (Table 4). Group A includes all locations except location 1 while group B comprises five locations with lower increments. Considerable overlap of the groups makes the clear-cut separation needed for practical management impossible. These statistical results must be considered together with managerial considerations. Given the present relatively low intensity of bottomland hardwood management, it would be inappropriate to distinguish more than one site class in this situation. Therefore, it was decided to treat all of the data as one whole.

Stand dynamics

Truly uneven-aged stands are balanced, that is, their measurable variables do not change with time. The lack of disturbances during the extended period of time for which their histories are known makes plausible the hypothesis that the studied stands are balanced. To test this hypothesis, major stand variables (Table 3) were regressed on age. It was found that neither basal area, nor diameter and tree number have a statistically significant trend (slope b was not sufficiently different from zero). Height, however, does show a marginally significant trend. (Therefore the mean height increment, not height, was used in classification of stands according to productivity.) Because the majority of the variables (Table 3) did not exhibit a significant age trend, the stands were assumed to be balanced and subsequent analysis was done without regard to age. This analysis, described below, consisted in regressing the factors of volume (number of trees per acre by diameter classes, height, and form factor) and increment information on a common variable, diameter at breast height.

TABLE 3.--Stand variables in relation to age

Variables	Statistics R^2	Mean	SEE	a	b	SEB	95% confidence intervals of b	
Diameter	.035	6.12	1.091	5.167	0.017	0.036	-0.071,	0.105
Basal area	.082	127	20.273	99.716	0.489	0.668	-1.146,	2.124
Tree number	.328	356.28	79.465	608.905	-4.480	2.616	-10.881,	1.921
Height	.553	84.18	9.613	35.617	0.860	0.315	0.0891,	1.631

TABLE 4.--Grouping of locations by Tukey's standardized range (HSD) test. Alpha = 0.05, SEE = 0.77 ft. Means with the same letter are not significantly different.

Mean annual height increment of cored trees, ft.	Sample size	Location	Grouping
2.03	15	8	A
2.03	58	6	A
1.94	46	2	A
1.68	17	4	A B
1.59	16	7	A B
1.59	35	5	A B
1.41	46	3	A B
1.24	74	1	B

Diameter distribution

Generally, the distribution of tree diameters at each location followed the J-shaped pattern, typical for uneven-aged stands. The same was true for individual species as well. Such a pattern is usually described by the negative exponential function:

$$n_i = ke^{-ad_i} \quad a>o \qquad (1)$$

where d_i is the midpoint of the ith diameter class, and k and a are constants for a given stand.

This equation is also a basis for classification (Meyer and Stevenson 1943, Meyer 1952, Meyer et al. 1961) and management (Davis 1966, Leak and Filip 1975, Trimble and Smith 1976, Alexander and Edminster 1977) of uneven-aged stands. At the same time, numerous authors (Leak and Graber 1976, Murphy and Farrar 1981, Muller 1982, Proctor et al. 1983) have reported that the actual number of smaller trees exceeds the number predicted by the exponential function.

This is also true for the studied stands. For example, the actual number of trees with diameter less than 6" was 1.8 times greater than that predicted by equation (1). The predicted values were calculated using the logarithmic transformation of the equation. Despite the excellent value of the coefficient of determination (R^2 = 0.953), which only proves how unrealiable this coefficient can be, the discrepancy between reality and equation (1) demands its modification.

One of the most efficient ways to modify equation (1) is to add the second term to the power of the equation:

$$n_i = ke^{-ad_i + bd_i^c} \qquad (2)$$

The coefficient c, however, makes linearization difficult. Therefore, using the actual diameter distribution, the value of this coefficient (-0.25), which minimized the sum of the squared residuals, was found by successive iterations. Other coefficients providing the best fit were found using the log-transformed equation (2): k = 1.4026, a = 0.1168, b = 5.4407 (assuming the diameter class equal 1"). By the criterion utilized (the sum of squared residuals), the modified equation is over 200 times more accurate than equation (1). For equation (2) R^2 = 0.969 and SEE = 0.14.

Height-diameter relationship

This relationship was investigated on 354 trees. Three regressions were tested. The best one (R^2 = 0.692, SEE = 4.97) was:

$$TH = -16.4949 + 39.3683 \ln(d) \qquad (3)$$

where TH is total height in feet and d is diameter in inches.

Relationship between form factor and diameter

This relationship was established from 20 felled trees and 188 trees measured with the pentaprism caliper. For each felled tree the volumes of six sections were calculated using several diameter and length measurements obtained within each section. The bottom section was the shortest, about 1' long. The next two sections were 2-3' long. The upper limit of the fourth section was crown base. The fifth section was comprised of the stem portion between this base and the midcrown point, and above this was the sixth section. Form factor of each section was calculated as the ratio of the actual volume to the volume of a cylinder with the same length and diameter.

To check the overall accuracy of these calculations, the volume of the 20 trees was computed using the average form factors. A paired t-test showed no significant difference between actual and predicted volumes (t = 1.704 with 19 degrees of freedom).

The average sectional form factors allowed the estimation of stem volume for 188 standing trees, the upper diameters of which were measured with a pentaprism caliper. These stem volumes were found as sums of the sections and were used to calculate stem form factors which are the ratios between the stem volumes and the volume of cylinders with the same heights and with diameters equal to dbh.

The following equation provided the best fit (SEE = 0.10) between diameter, d, and form factor, F, of the entire stem of 188 trees measured with a pentaprism caliper:

$$\ln(F) = -0.6903 - 0.0150d \qquad (4)$$

Diameter and volume increments calculations

While obtaining increment cores of trees, the radial increment was measured at breast-high level for 3, 6, and 10 years (rings). The annual

diameter increment was calculated for each period and diameter class. Abnormalities of the weather during the last three years brought about the decision to use as the final increment the average of the annual increments derived from 6 and 10 year periods. After testing several equations, equation (5) with $R^2 = 0.999$ and SEE = 0.002 was selected for description of the relationship between diameter, d, and its increment, i:

$$i = 9.3464E-2 - 2.548E-3d + 9.71E-4d^2 - 3.6E-5d^3 + 3.51E-7d^4 \quad (5)$$

Total stem and stand volumes

Stem volume in cubic feet was determined as the product of the squared diameter, height, and form factor. Diameter inside bark was found from the measurement of cored trees. The number of trees by diameter classes in an average stand was calculated using equation (2), total height using equation (3) and form factors were found from equation (4). Diameter inside bark was used for the calculation of form factor inside bark. Stem volume inside bark was calculated using these corresponding inside bark variables. Volumes outside and inside bark per acre, given in Table 5, were obtained by multiplication of tree volumes and tree number.

The annual volume increment of one tree was determined for each diameter class as the difference between the present stem volume inside bark and the corresponding stem volume for the previous year. The previous year's diameter inside bark was found as the difference between the present diameter and the annual diameter increment calculated from equation (5). Height and form factor were calculated using equations (3) and (4) with the previous year's diameter as the independent variable. The stand volume increment is the product of the stem increment and the tree number.

Survival of trees

Because the investigated stands were assumed to be balanced, any increase in volume must be compensated for by mortality. This compensation makes it possible to calculate the survival probability of trees, s, for one year by diameter classes:

$$s = 1 - \frac{2svi}{svib + spvib} = 1 - \frac{2bvi}{bvib + bpvib} \quad (6)$$

TABLE 5.--Stand and stock table of unmanaged bottomland hardwoods.

Diameter class	Tree number	Total height	Basal area	Outside bark			Inside bark			
				Form Factor	Volume stem	Volume stand	Diameter	Form Factor	Volume stem	Volume stand
inches	1/acre	feet	sq.ft./acre		cu.ft.	cu.ft.	inches		cu.ft.	cu.ft.
6	45.01	54.0	8.8	0.458	5	219	5.35	0.463	4	176
8	28.00	65.4	9.8	0.445	10	284	7.25	0.450	8	236
10	18.60	74.2	10.1	0.432	17	325	9.15	0.437	15	276
12	12.85	81.3	10.1	0.419	27	344	11.05	0.425	23	296
14	9.11	87.4	9.7	0.406	38	346	12.96	0.413	33	301
16	6.57	92.7	9.2	0.394	51	335	14.86	0.401	45	294
18	4.81	97.3	8.5	0.383	66	316	16.76	0.390	58	279
20	3.55	101.4	7.8	0.371	82	292	18.66	0.379	73	259
22	2.65	105.2	7.0	0.360	100	265	20.56	0.368	89	237
24	1.99	108.6	6.2	0.350	119	237	22.46	0.358	107	212
26	1.50	111.8	5.5	0.339	140	210	24.36	0.348	126	189
28	1.13	114.7	4.9	0.329	162	183	26.26	0.338	146	165
30	0.86	117.4	4.2	0.320	184	159	28.16	0.329	167	144
32	0.66	119.9	3.7	0.310	208	137	30.06	0.319	189	124
34	0.50	122.3	3.2	0.301	232	117	31.96	0.310	212	106
36	0.39	124.6	2.7	0.292	257	99	33.86	0.302	235	91
38	0.30	126.7	2.3	0.284	283	84	35.76	0.293	259	77
40	0.23	128.7	2.0	0.275	309	71	37.66	0.285	284	65
42	0.18	130.7	1.7	0.267	336	59	39.56	0.277	309	54
44	0.14	132.5	1.4	0.259	363	49	41.46	0.269	334	45
46	0.11	134.2	1.2	0.252	390	41	43.36	0.262	360	38
48	0.08	135.9	1.0	0.244	417	34	45.26	0.254	386	31
12.63	139.20	95.14	121			4,206				3,697

where svi = annual stand volume increment;
svib = stand volume inside bark;
spvib = stand volume inside bark in previous year;
bvi, bvib, and bpvib are the corresponding variables for average stem by diameter classes.

RESULTS

The preceding analyses resulted in the preparation of the combined stand and stock table shown in Table 5. An average bottomland stand in southeastern Arkansas has a quadratic mean diameter of 12.6 inches and has 139 trees (with dbh greater than 5.0 inches) per acre. Oaks make up half of the total basal area with the red oak group accounting for 36% and the white oak group for 14%. The remaining half is split equally between sweetgum and 36 other species. Stem volume outside bark is 4206 cu. ft./acre and inside bark 3697 cu. ft./acre. Annual increment is 84 cu. ft./acre (2.3% of the total volume). Merchantable stand volume above 4" outside bark is 3909 cu. ft./acre, and 2330 cu. ft./acre above 10" inside bark.

Given a stand table, the presented equations can also provide information on growth and yield for any particular bottomland stand in the studied area. To facilitate these calculations a program was written for HP-41-series calculators to compute growth and yield variables of individual stands. Using tree number by diameter classes as input, the program produces values of 26 variables for each diameter class and of 12 variables for the entire stand, including merchantable variables for any utilization limit. The variables are listed in the Appendix.

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APPENDIX.

Variables calculated for each diameter class

Yield

1. Total height from the stump (1 foot) level to the tree top, in feet.
2. Basal area, in sq. ft.
3. Form factor outside bark.
4. Bole volume outside bark, in cu. ft.
5. Stand volume outside bark, in cu. ft.
6. Diameter inside bark at breast height, in inches.

7-9. Form factor, bole and stand volume inside bark.

10. Annual diameter increment, in inches.

Growth

11-16. Variables for previous year: diameter outside bark, diameter inside bark, total height, form factor inside bark, bole volume inside bark, stand volume inside bark.

17. Bole volume increment, in cu. ft.
18. Stand volume increment, in cu. ft.

19. Survival.

Merchantable variables

20. Merchantable height, in feet.

21-22. Merchantable bole and stand volumes outside bark, in cu. ft./acre.

23-24. Merchantable bole and stand volumes inside bark, in cu. ft./acre.

25. Merchantable annual stand volume increment, in cu. ft./acre.

26. Volume of bole tops outside bark, in cu. ft./acre.

Variables calculated for total stand

1. Quadratic mean diameter, in inches.

2. Total number of trees per acre.

3. Mean (Lorey's) total height, in feet.

4. Basal area, in sq. ft./acre.

5-6. Stand volume outside and inside bark, in cu. ft./acre.

7. Annual stand volume increment, in cu. ft./acre.

8. Mean merchantable height, in feet.

9-10. Merchantable stand volume outside and inside bar, in cu. ft./acre.

11. Merchantable annual stand volume increment, in cu. ft./acre.

12. Volume of bole tops outside bark, in cu. ft./acre.