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Board-Foot and Diameter Growth of Yellow-Poplar After Thinning

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Cover Photo: A thinned second-growth stand of even-aged yellow-poplar on the Bent Creek Experimental Forest in the Southern Appalachian Mountains. This 60-year-old stand growing on site index 110 land, with a density of 150 square feet of basal area per acre, contains about 32,000 board feet per acre.

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Because the primary commercial value of yellow-poplar (Liriodendron tulipifera L.) is for lumber and veneer, tree size and quality are important considerations in its management (figs. 1 and 2). Most stands of yellow-poplar can produce substantial numbers of lumber- and veneer-size trees without thinning (Beck and Della-Bianca 1970), but in unthinned stands as old as 70 years more than half the trees may be less than ll inches d.b.h., the minimum size for sawtimber. Thinnings designed to concentrate growth on the best and largest stems would therefore seem logical for management of yellow-poplar.

This paper provides data needed to determine optimum thinning regimes for yellow-poplar stands. It contains equations and tables for estimating board-foot growth and yield, and redidual quadratic mean stand diameter growth for a wide range in site index, age, residual basal area, and residual quadratic mean stand diameter after thinning. Response of individual trees to thinning is also discussed.

The equations and tables presented here were developed from measurements taken on 141 permanent plots 5 years after the first thinning. At the beginning of the 5-year measurement period plots varied widely in site index, age, and residual stand basal area (table 1). Data and methods for calculating various stand parameters are described in detail elsewhere (McGee and Della-Bianca 1967; Beck and Della-Bianca 1970, 1972).

BOARD-FOOT GROWTH AND YIELD

In analyzing the plot data, an equation was derived for estimating board-foot stand volume from mean stand diameter, height, and basal area. Changes in the independent variable were estimated with auxiliary equations. This technique permits projection of stand volume to a future age. Volume growth was computed as the difference between successive stand volume estimates.

Figure 1. --An old-growth yellow-poplar in Spivy Basin, Union County, Georgia, in 1931. The tree was 69 inches d.b.h. and contained 10,930 board feet log scale, as much board-foot volume as is found in a second-growth managed yellow-poplar stand on site index 110 land at age 40, and at a density of 80 square feet per acre of basal area.

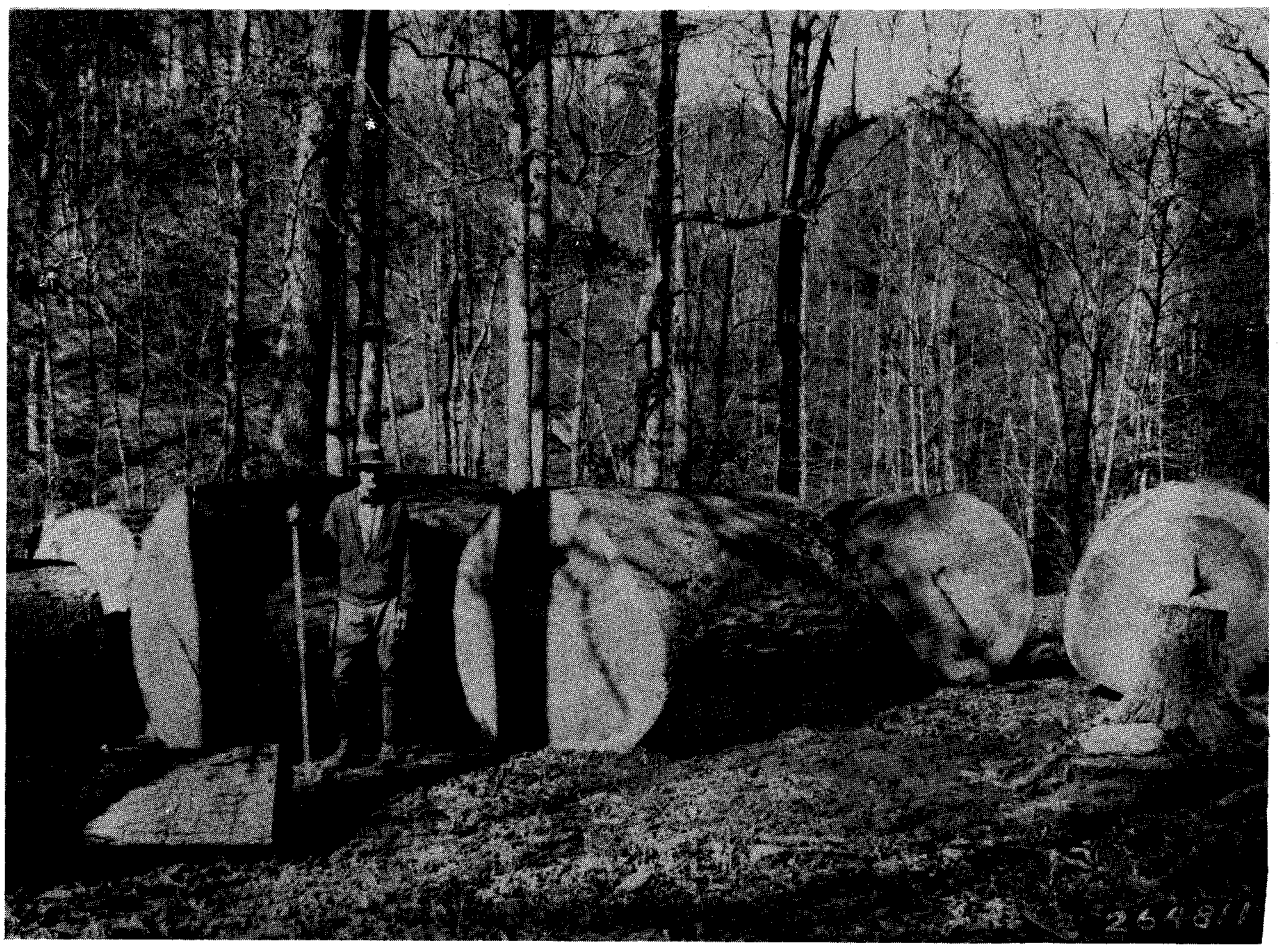

Figure 2. --Curly yellow-poplar veneer logs cut from a tree in Spivy Basin, Union County, Georgia, in 1932. Although yellow-poplar stands will not be kept to the great age necessary to produce logs of the size shown here, their potential under management for more efficient production of lumber and veneer is great.

Table 1. --Distribution of yellow-poplar plots by site index, age, and basal area after thinning

Site index (feet at 50 years)	Age class	Residual basal area (square feet per acre)							Total
		40	60	80	100	120	140	160	
	Years	Number of plots							
80	50	--	2	--	--	--	--	--	3
	60	--	--	--	--	--	--	--	
	70+	--	--	1	--	--	--	--	
90	20	--	--	--	--	--	--	--	16
	30	3	1	--	--	--	--	--	
	40	1	1	1	--	--	--	--	
	50	--	--	1	--	--	--	--	
	60	--	1	3	--	--	--	--	
	70+	--	--	--	1	3	--	--	
100	20	2	--	--	1	--	--	--	32
	30	2	--	1	--	--	--	--	
	40	1	--	1	1	--	--	--	
	50	--	3	3	1	1	--	--	
	60	1	2	1	1	3	--	1	
	70+	--	1	2	3	--	--	--	
110	20	--	--	--	1	--	--	--	52
	30	1	2	1	1	--	--	--	
	40	2	2	3	2	2	--	--	
	50	1	1	3	1	3	2	1	
	60	--	3	5	2	3	3	--	
	70+	--	1	2	2	1	1	--	
120	20	--	1	--	--	--	--	--	26
	30	3	1	3	2	2	--	1	
	40	1	2	1	2	--	--	--	
	50	--	--	--	1	2	--	--	
	60	--	--	--	--	1	1	1	
	70+	--	--	--	1	--	--	--	
130	20	1	--	--	--	--	--	--	10
	30	--	1	--	1	3	--	--	
	40	1	--	--	1	2	--	--	
	50	--	--	--	--	--	--	--	
	60	--	--	--	--	--	--	--	
	70+	--	--	--	--	--	--	--	
140	20	--	--	--	--	--	--	--	2
	30	--	--	--	1	--	--	--	
	40	--	--	--	--	--	--	--	
	50	--	--	--	--	--	--	--	
	60	--	--	--	--	--	--	--	
	70+	--	--	1	--	--	--	--	
Total		20	25	33	26	26	7	4	141

Present Stand Volume

A preliminary analysis indicated that the model for cubic-foot yield, which contained only the independent variables, age, site index, and residual stand basal area, would be inadequate for board-foot yield estimates (Beck and Della-Bianca 1972). Some measure of stand structure was needed. The model eventually derived expresses board-foot stand volume as a function of dominant stand height, residual quadratic mean stand diameter, and residual stand basal area. Coefficients for the equation were computed using the ratio of International $\frac{1}{4}$-inch board-foot stand volume to residual stand basal area as the dependent variable. The equation is:

$$BFV/B_1 = -545.33701 + 222.63551(D^{\frac{1}{2}}) - 18.18270(D) + 0.35306(H*D^{\frac{1}{2}}) \quad (1)$$

where

BFV = International $\frac{1}{4}$-inch board-foot stand volume per acre of all trees 11.0 inches d.b.h. and over.

B_1 = Residual stand basal area in square feet per acre of all trees 4.6 inches d.b.h. and over.

H = Height of the dominant stand in feet; measured on a sample of 15 to 20 dominant and codominant trees per acre. This is equivalent to the height used in determining site index.

D = Residual quadratic mean stand diameter in inches computed as

$$\sqrt{\frac{B_1}{\text{Residual number trees per acre}}} \Big/ 0.005454$$

The equation accounts for 96 percent of the variation in the board-foot/residual basal area ratio, and has a coefficient of variation of 10.8 percent. Appendix table II shows the board-foot/residual basal area ratio for selected values of residual quadratic mean stand diameter and dominant stand height.

Future Stand Volume and Growth

To estimate board-foot growth and future volume with Equation 1, stand height, basal area, and residual quadratic mean stand diameter must first be projected. Suitable equations for projecting height and basal area were derived earlier (Beck 1962; Beck and Della-Bianca 1972). These are shown as Equations 2 and 3, respectively, in Appen-

dix table I. Dominant stand heights in relation to age and site index, obtained from Equation 2, are shown in Appendix figure 1. Appendix table III shows expected basal area 5 years after thinning to a specified residual basal area for various age and site classes.

An equation expressing 5-year change in quadratic mean stand diameter as a function of site index, age, and residual stand basal area was developed by regression (Equation 4 in Appendix table 1; table IV). Quadratic mean stand diameter 5 years after the first thinning is computed by adding the expected 5-year change in quadratic mean stand diameter (Equation 4 or Appendix table IV) to residual quadratic mean stand diameter as computed from individual stand data taken immediately after thinning.

Present and future board-foot volume and board-foot growth can be computed with Equations 1 through 4 (Appendix table I) for all combinations of site index, age, and residual stand basal area for a range of residual quadratic mean stand diameters.

For simpler but less precise board-foot estimates we developed tables 2, 3, and 4, which show current and future board-foot stand volume per acre and 5-year board-foot growth per acre. These estimates were made using an average residual quadratic mean stand diameter for each age, site, and residual stand basal area class as computed with Equation 5 in Appendix table I. Residual quadratic mean stand diameters by age, site, and residual stand basal area class are shown in Appendix table V; for more precise estimates of residual quadratic mean stand diameter for individual yellow-poplar stands use Equation 5.

DIAMETER GROWTH RESPONSE TO THINNING

The foregoing equations and graphs relate board-foot growth of stands to residual stand basal area for given sites and ages. They do not, however, te11 us specifically about the response to thinning. How much does thinning increase growth of individual trees? And, how do trees of different sizes and ages respond?

Because we had no growth data prior to thinning, we extracted increment cores from 133 trees in nine stands. These stands were all in the site 110 class; three stands were in each of the 30-, 50-, and 70-year age classes. For each tree we computed the ratio of radial growth for the 5 years after thinning to the 5-year radial growth before thinning. A ratio less than one indicates a slower rate of growth after thinning. A ratio greater than one indicates an acceleration of growth after thinning.

Table 2. --Board-foot volume per acre of trees over ll .O inches d.b .h. immediately after thinning to specified residual basal area, by site index and age[1]

Age (years)	Residual basal area (square feet per acre)						
	40	60	80	100	120	140	160
	Board feet per acre						
SITE INDEX 90							
30	860	700	330				
40	3,440	4,550	5,210	5,450	5,370		
50	5,140	6,960	8,350	9,230	9,550		
60	6,300	8,530	10,220	11,420	11,740		
70	6,950	9,430	11,150	12,210	12,410		
SITE INDEX 100							
30	1,830	2,190	2,350	2,200	2,030		
40	4,780	6,610	8,040	9,020	9,810	10,520	
50	6,870	9,620	11,860	13,750	15,140	16,280	17,290
60	8,330	11,640	14,520	16,810	18,700	19,990	20,970
70	9,220	12,900	16,120	18,550	20,610	21,740	22,670
SITE INDM 110							
30	2,700	3,510	4,120	4,440	4,750		
40	6,020	8,500	10,600	12,500	14,050	15,260	
50	8,380	11,950	15,060	17,840	20,390	22,540	24,290
60	10,050	14,360	18,260	21,790	24,660	27,410	29,690
70	11,210	16,090	20,410	24,270	27,540	30,390	32,630
SITE INDEX 120							
30	3,470	4,810	5,700	6,670	7,160	7,680	
40	7,230	10,350	13,110	15,490	17,690	19,840	21,740
50	9,860	14,210	18,140	21,770	24,990	28,020	30,940
60	11,740	16,960	21,810	26,200	30,270	33,890	37,270
70	13,090	19,000	24,420	29,430	33,940	38,080	41,700
SITE INDEX 130							
30	4,230	5,840	7,270	8,410	9,550	10,480	
40	8,290	11,960	15,290	18,420	21,260	23,790	26,300
50	11,200	16,240	21,010	25,420	29,450	33,300	37,060
60	13,280	19,400	25,130	30,450	35,470	40,090	44,500
70	14,850	21,690	28,110	34,170	39,630	45,060	49,890

[1]Residual quadratic mean stand diameter for each age, site, residual basal area class was computed using Equation 5 in Appendix table I.

Table 3. --Board-foot volume per acre of trees over 11.0 inches d.b.h. 5 years after thinning to specified residual basal area, by site index and age[1]

Initial age (years)	Residual basal area (square feet per acre)						
	40	60	80	100	120	140	160
	Board feet per acre						
SITE INDEX 90							
30	2,540	2,650	2,430				
40	5,270	6.680	7,470	7,720	7,620		
50	8,930	9,020	10,540	11,450	11,720		
60	7,990	10,500	12.290	13.520	13,790		
70	8,540	11,290	13.120	14.210	14,360		
SITE INDEX 100							
30	4,110	4,850	5,210	5,130	4,960		
40	7,180	9,430	11,060	12,100	12,850	13,500	
50	9,190	12,340	14,790	16,740	18,060	19,130	20,000
60	10.400	14,200	17,270	19,620	21,450	22,650	23,480
70	11,250	15,300	18,710	21,190	23,210	24,260	25,050
SITE INDEX 110							
30	5,610	6.930	7,840	8,260	8,580		
40	9,030	12,080	14,480	16,500	18,050	19,180	
50	11,260	15,380	18.780	21,700	24,220	26,310	27,920
60	12,730	17,570	21,750	25,410	28,270	30,940	33,060
70	13,700	19,070	23,670	27,650	30,920	33,690	25,770
SITE INDEX 120							
20	190						
30	7,050	9,080	10,320	11,470	11,980	12,450	
40	10.890	14,740	17.920	20,490	22,760	24,880	26,890
50	13,330	18,400	22,740	26,600	29,890	32,880	35,690
60	14,970	20,870	26,130	30,740	34,890	38.470	41,740
70	16,070	22,610	28,410	33.630	38.210	42.320	45,820
SITE INDEX 130							
20	1,050	100					
30	8,540	10,980	12,900	14.260	15,500	16,440	
40	12,620	17,210	21.100	24.560	27,550	30,080	32,520
50	15,280	21,240	26.580	31,330	35.520	39,410	43,120
60	17.070	24,040	30,320	35,960	41,160	45,810	50,170
70	18,340	25,980	32,920	39,300	44,910	50,380	55,160

[1]Residual quadratic mean stand diameter for each age, site, residual basal area class was computed using Equation 5 in Appendix table I.

Table 4.--Five-year board-foot volume growthper acre oftrees over 11.0 inches d.b.h. after thinning to specified residualbasalarea, by site index and age[1]

Initial age (years)	Residualbasalarea (square feetper acre)						
	40	60	80	100	120	140	160
	Board feetper acre						
SITE INDEX 90							
30	1,680	1,950	2,100				
40	1,830	2,130	2,260	2,270	2,250		
50	1,790	2.060	2,190	2,220	2,170		
60	1,690	1,970	2,070	2,100	2,050		
70	1,590	1,860	1,970	2,000	1,950		
SITE INDEX 100							
30	2,280	2,660	2,860	2,930	2,930		
40	2,400	2,820	3,020	3,080	3.040	2,980	
50	2,320	2,720	2,930	2,990	2.920	2.850	2,710
60	2,070	2,560	2,750	2,810	2,750	2,660	2,510
70	2,030	2,400	2,590	2,640	2,600	2.520	2,380
SITE INDEX 110							
30	2,910	3,420	3,720	3,820	3.830		
40	3,010	3,580	3,880	4,000	4,000	3,920	
50	2,880	3.430	3.720	3,860	3,830	3,770	3.630
60	2,680	3,210	3.490	3.620	3,610	3,530	3,370
70	2,490	2.980	3,260	3,380	3,380	3,300	3,140
SITE INDEX 120							
20	190						
30	3.580	4,270	4,620	4,800	4,840	4.770	
40	3,660	4,390	4,810	5,000	5.090	5,040	4,950
50	3,470	4,190	4,600	4,830	4,900	4,860	4,750
60	3,230	3,910	4.320	4,540	4,620	4,580	4,470
70	2,980	3.610	3,990	4,200	4,270	4,240	4,120
SITE INDEX 130.							
20	1.050	100					
30	4,310	5,140	5,630	5.850	5,950	5,960	
40	4,330	5,250	5,810	6.140	6,290	6,290	6,220
50	4,080	5,000	5.570	5,910	6,070	6,110	6,060
60	3,790	4,640	5,190	5,510	5,690	5,720	5,670
70	3,490	4,290	4,810	5,130	5,280	5,320	5.270

[1]Residualquadratic mean stand diameter for each age, site, residual basal area class was computed using Equation 5 in Appendix table 1.

Figure 3 shows the radial growth response ratio by age class, d.b.h. at time of thinning, and severity of thinning expressed as percent of basal area cut. The lines showing the trend of the ratio with d.b.h. were derived by regression analysis. In all but two stands, there was a highly significant inverse relationship between the response ratio and tree d.b.h. In general, the heavier the thinning the greater the radial growth response of individual trees, smaller trees responding more than larger trees in a given stand. It should be remembered in this context that the thinnings from below removed practically all suppressed trees. Therefore, even the smallest trees in a given stand were in the intermediate crown class and had sufficient vigor to respond to thinning. In the two oldest age classes, the lightest thinnings failed to check a declining growth rate for all tree sizes. However, heavier thinnings did increase diameter growth in even the oldest stands.

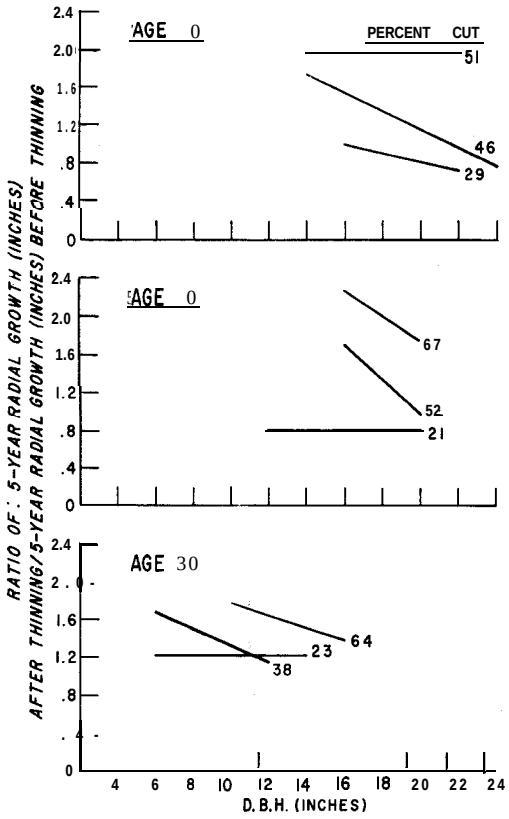

Figure 3. --Ratio of 5-year radial growth after thinning to 5-year radial growth before thinning in relation to d.b.h. at time of thinning for different cutting intensifies.

It is sometimes argued that some portion of the largest trees in a stand either is not, or is only slightly, affected by stand density. To determine the effect of density, we derived regression equations for estimating average diameter growth from residual stand basal area for the 12 largest, the 20 largest, and all trees 4.6 inches d.b.h. and over per acre. Equations for the 12 and 20 largest trees per acre were almost identical. Figure 4 shows the relationships of 5-year diameter growth to residual stand basal area for the 20 largest trees per acre and for all trees 4.6 inches d.b.h. and over. At lower densities, where the 20 largest trees comprise a large share of the residual stand, the rates of growth are no different for the two groupings. At higher densities, the 20 largest trees grow faster in d.b.h. than the stand average. However, the overall effect of increasing stand density on diameter growth of the 20 largest trees per acre compares closely with the effect of increasing density on the average stand diameter growth of the total stand. Thus, even the largest trees in the stands responded to thinning.

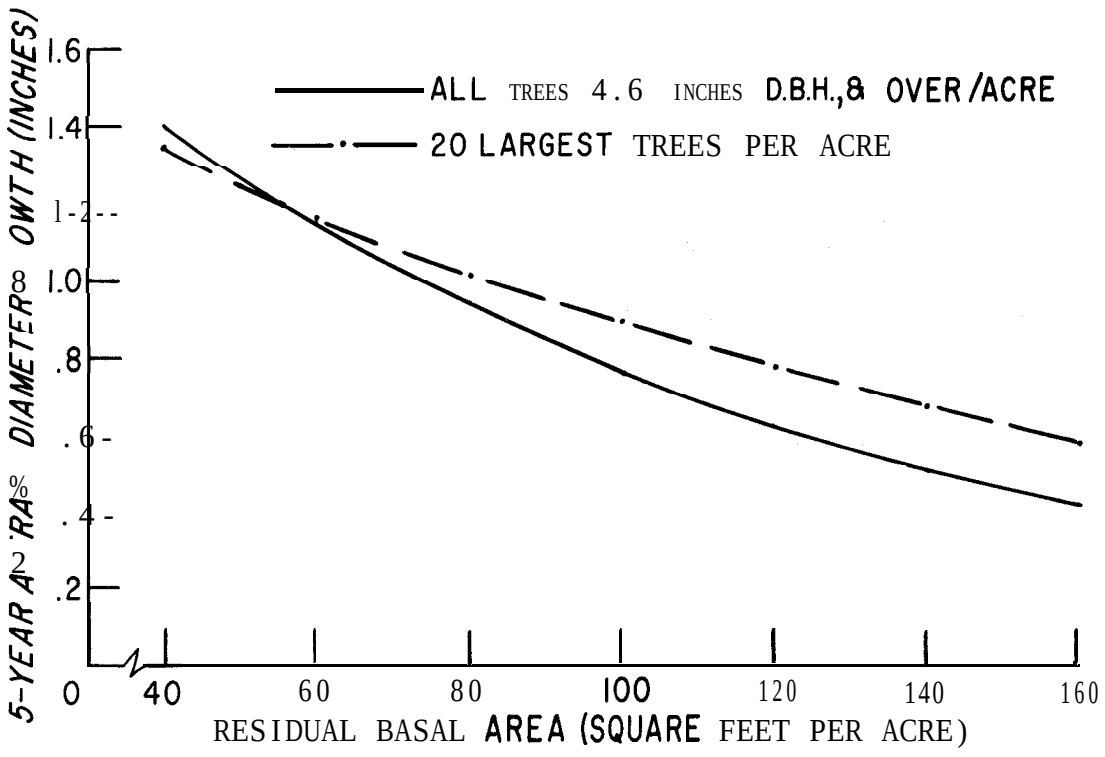

Figure 4. --Five-year average diameter growth in relation to residual basal area for all trees 4.6 inches d.b. h. and over per acre, and for the 20 largest trees per acre. Site index is 110; age is 40 years.

Our general conclusions based on the core analysis are:

1. Diameter growth is increased by thinning; the heavier the thinning, the more diameter growth increases.

2. Even older yellow-poplar stands respond with increased diameter growth after thinning, provided the thinning is heavy.

3. Within a stand, all trees increase diameter growth after heavy thinning, but the smallest trees show the greatest response relative to growth before thinning.

These conclusions agree with observations on other tree specie's (Spurr 1952; Lundgren and Wambach 1963; and Assmann 1970).

DISCUSSION

Thinning practices can be evaluated and growth and yield for specific situations can be predicted with the equations and tables presented here. Figure 5 illustrates 5-year board-foot growth in relation to residual stand basal area by site class in 40-year-old yellow-poplar stands. On all sites, board-foot growth increases with increasing basal

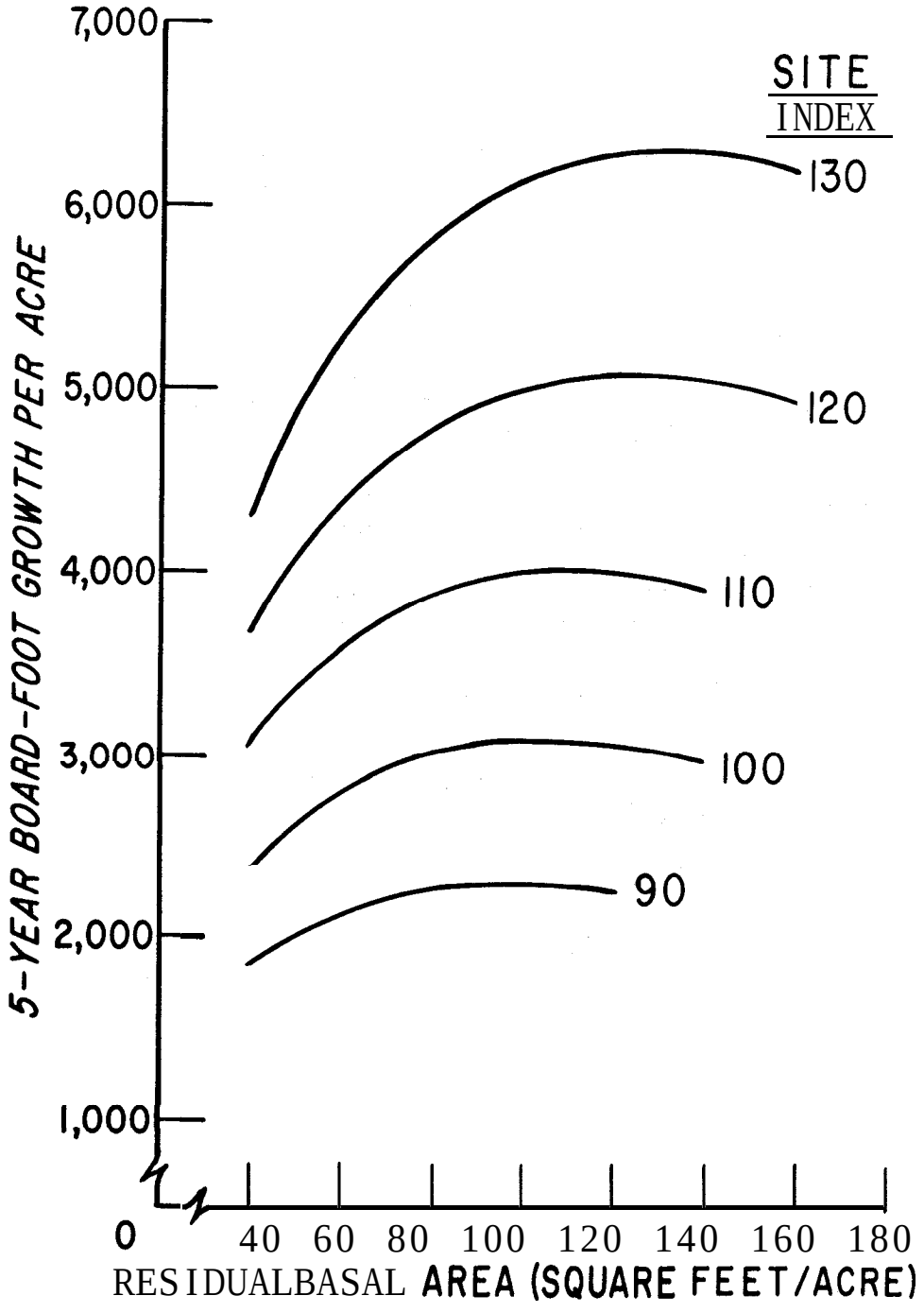

Figure 5. --Five-year board-foot growth in relation to residual stand basal area by site-index classes for stands 40 years of age.

area up to a maximum and thereafter declines. The leve1 of residual basal area at which board-foot growth is maximized increases with site quality. As a rule of thumb, between the ages of 30 and 70 years maximum rates of board-foot growth are reached at basal areas approximately equal to site index, i.e., maximum board-foot growth is reached at 90 square feet of basal area per acre on site 90, 100 square feet on site 100, etc.

The 'curve of board-foot growth on residual stand basal area is relatively fiat. For example, on site index 110 land, 95 percent of maximum board-foot growth can be obtained with a residual stand basal area as low as 75 square feet per acre. Therefore, it is possible to encourage faster growth of individual trees by heavy thinning without markedly decreasing board-foot growth.

In figure 4, the curve for al1 trees 4.6 inches and larger shows the relationship of expected 5-year average diameter growth by residual basal area for site 110, and stand age 40. If we maintain an average stand at 110 square feet of basal area in order to maximize board-foot growth, we can expect the average 5-year stand diameter growth to be 0.7 inch. On the other hand, if we 'thin the stand to 75 square feet of basal area, we will get 95 percent of maximum board-foot growth but increase the 5-year average stand diameter growth by 0.3 inch.

From our observations, the majority of unthinned natural yellow-poplar stands are overstocked for maximum board-foot growth as well as for maximum diameter growth. By using the equations or tables presented here,thinning regimes for specific management objectives can be planned for individual natural yellow-poplar stands.

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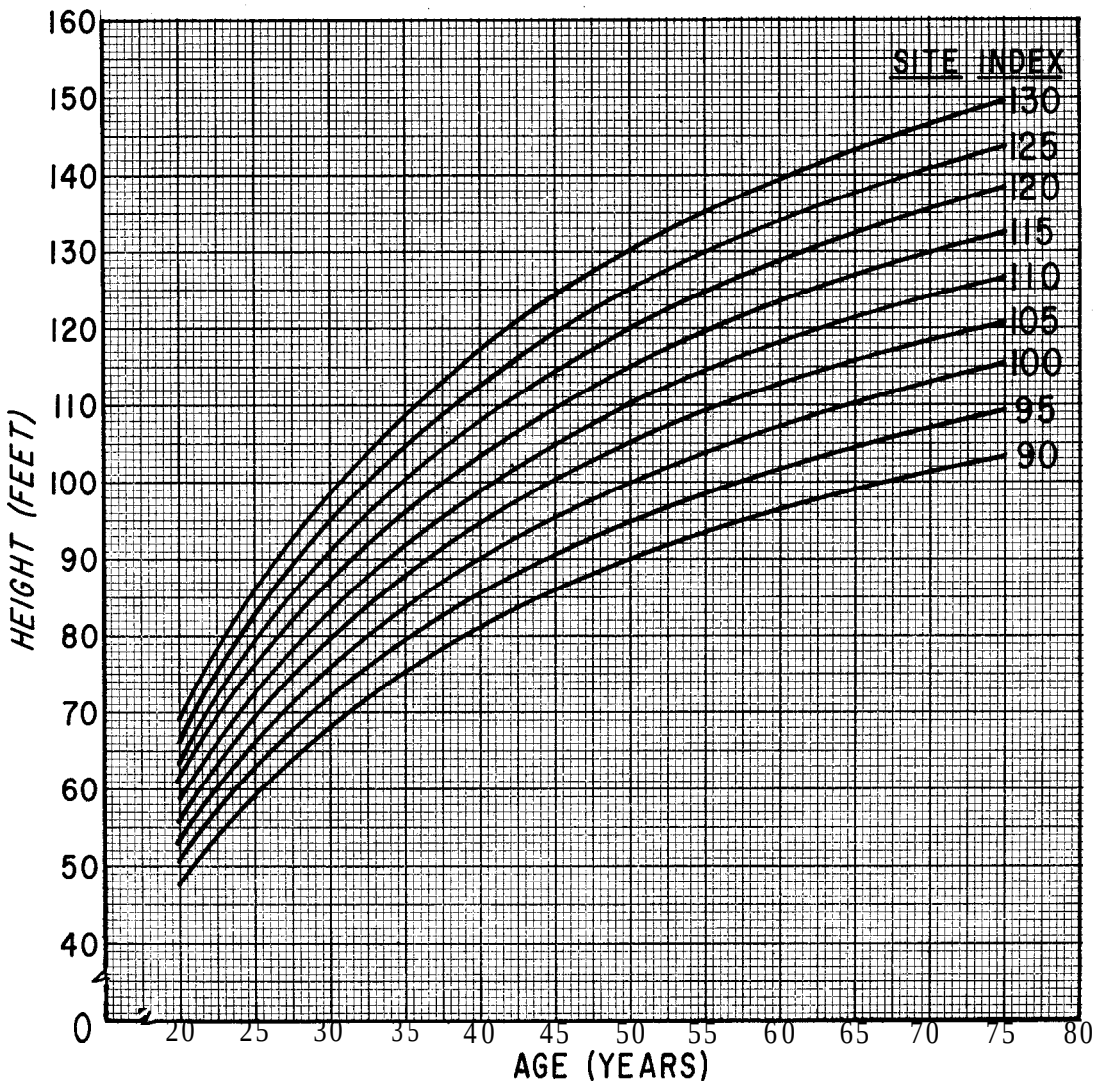
APPENDIX



Appendix figure I. --Dominant stand height, by site index and age.

Table 1. --Regression equations used for growth and yield estimates

Equation number	Equation [1]
1	$BFV/B_1 = -545.33701 + 222.63551(D^{\frac{1}{2}}) - 18.18270(D) + 0.35306(H*D^{\frac{1}{2}})$
2	$\ln H = \ln S + 21.08707(1/50 - 1/A)$
3	$\ln B_2 = (\ln B_1)A_1/A_2 + 3.82837(1 - A_1/A_2) + 0.01667(S)(1 - A_1/A_2)$
4	$\ln \Delta D = 2.50044 - 0.00852(B_1) - 195.13700(S^{-1}) - 0.05810(B_1 A_1^{-1})$
5	$D = 1.69866 + 5.11396(A_1 S/1000) - 0.28209(A_1^2/100)$
	$= - 0.43439(S^2/1000) - 0.80745(A_1 B_1/1000) + 0.05724(B_1^2/1000)$

BFV = Board-foot stand volume per acre of trees 11 .O inches d.b.h. and over; International $\frac{1}{4}$-inch rule.
B_1 = Residual stand basal area in square feet per acre; all trees 4.6 inches d.b .h. and over are included.
B_2 = Future stand basal area in square feet per acre; all trees 4.6 inches d.b.h. and over are included.
AD = Five-year residual quadratic mean stand diameter growth (inches); all trees 4.6 inches d.b.h. and over are included.
H = Dominant stand height (feet).
D = Residual quadratic mean stand diameter (inches); all trees 4.6 inches d.b.h. and over are included.
S = Site index in feet at age 50 years.
A_1 = Initial age (years).
A_2 = Future age (years).
ln = Natural logarithm.

Table II. --Ratio of board-foot stand volume per acre to residual stand basal area per acre for selected values of dominant stand height and residual quadratic mean stand diameter[1] [2]

Residual quadratic mean stand diameter (inches)	Dominant stand height (feet)										
	50	60	70	80	90	100	110	120	130	140	150
7					0.49	9.83	19.17	28.52	37.86	47.20	56.54
8				18.80	28.78	38.77	48.76	58.74	68.73	78.71	88.70
9		22.48	33.07	43.66	54.25	64.84	75.44	86.03	96.62	107.21	117.80
10	32.69	43.86	55.02	66.19	77.35	88.52	99.68	110.85	122.01	133.18	144.34
11	51.60	63.31	75.02	86.73	98.44	110.15	121.86	133.57	145.28	156.99	168.70
12	68.85	81.08	93.31	105.55	117.78	130.01	142.24	154.47	166.70	178.93	191.16
13	84.66	97.39	110.12	122.85	135.58	148.31	161.04	173.77	186.50	199.23	211.96
14	99.18	112.39	125.60	138.81	152.02	165.23	178.44	191.65	204.86	218.08	231.29
15	112.56	126.23	139.90	153.58	167.25	180.93	194.60	208.27	221.95	235.62	249.30
16	124.89	139.02	153.14	167.26	181.38	195.51	209.63	223.75	237.87	252.00	266.12
17	136.29	150.85	165.41	179.96	194.52	209.08	223.63	238.19	252.75	267.31	281.86
18	146.83	161.81	176.79	191.77	206.75	221.73	236.71	251.69	266.66	281.64	296.62
19	156.59	171.97	187.36	202.75	218.14	233.53	248.92	264.31	279.70	295.09	310.48
20	165.61	181.40	197.19	212.98	228.77	244.56	260.35	276.14	291.93	307.72	323.51
21	173.97	190.15	206.33	222.50	238.68	254.86	271.04	287.22	303.40	319.58	335.76
22	181.70	198.26	214.82	231.38	247.94	264.50	281.06	297.62	314.18	330.74	347.30
23	188.84	205.78	222.71	239.64	256.57	273.50	290.44	307.37	324.30	341.23	358.17
24	195.45	212.74	230.04	247.34	264.63	281.93	299.22	316.52	333.82	351.11	368.41
25	201.54	219.19	236.84	254.50	272.15	289.80	307.46	325.11	342.76	360.42	378.07

[1] Board-foot stand volume per acre of trees 11.0 inches d.b.h. and over using International $\frac{1}{4}$-inch rule.
[2] Residual stand basal area (square feet per acre) includes all trees 4.6 inches d.b.h. and over per acre.

Table III. --Expected basal area by site index and age 5 years after thinning to a specified residual basal area

SITE INDEX 90

Initial age (years)	Residual basal area (square feet per acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Square feet per acre												
20	56	66	77	87									
30	51	61	72	82	92	101	111						
40	48	59	69	79	89	99	108	118	127				
50	46	57	67	77	87	97	107	116	126	136			
60	45	56	66	76	86	96	106	115	125	135	144		
70	45	55	65	75	85	95	105	115	124	134	144	253	

SITE INDEX 100

20	57	69	79	90	100								
30	52	63	73	84	94	104	114	124					
40	49	60	70	80	91	101	110	120	130	139	149		
50	47	58	68	78	89	99	108	118	128	138	147	157	166
60	46	56	67	77	87	97	107	117	127	136	146	156	165
70	45	56	66	76	86	96	106	116	126	135	145	155	165

SITE INDEX 110

20	59	71	82	93	103								
30	53	64	75	86	96	106	116	126	136	146			
40	50	61	71	82	92	102	112	122	132	142	152	161	171
50	48	59	69	80	90	100	110	120	130	140	150	159	169
60	47	57	68	78	88	99	109	119	128	138	148	158	168
70	46	56	67	77	87	97	107	117	127	137	147	157	166

SITE INDEX 120

20	61	73	85	96	107	117							
30	54	66	77	88	98	109	119	129	139	149	159		
40	51	62	73	83	94	104	115	125	135	145	155	164	174
50	49	60	70	81	91	102	112	122	132	142	152	162	171
60	47	58	69	79	89	100	110	120	130	140	150	160	170
70	46	57	67	78	88	98	108	119	129	139	149	158	168

SITE INDEX 130

20	63	76	88	99	110	121	132						
30	56	67	79	90	101	111	122	132	143	153	163	172	182
40	52	63	74	85	96	106	117	127	137	147	157	167	177
50	49	60	71	82	93	103	113	124	134	144	154	164	174
60	48	59	69	80	91	101	111	122	132	142	152	162	172
70	47	57	68	79	89	99	110	120	130	140	150	160	170

Table IV. --Five-year residual quadratic mean stand diameter growth by site index, initial age, and residual basal area

SITE INDEX 90

Initial age (years)	Residual basal area (square feet per acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Inches												
20	.88	.79	.70	.63									
30	.92	.83	.74	.67	.60	.54	.49						
40	.94	.85	.77	.69	.63	.57	.51	.47	.42				
50	.95	.86	.78	.71	.64	.58	.53	.48	.44	.40			
60	.95	.87	.79	.72	.65	.59	.54	.49	.45	.41	.37		
70	.96	.87	.80	.72	.66	.60	.55	.50	.45	.41	.38	.34	

SITE INDEX 100

20	1.10	.98	.87	.78	.69								
30	1.14	1.03	.92	.83	.75	.68	.61	.55					
40	1.16	1.05	.95	.86	.78	.71	.64	.58	.52	.47	.43		
50	1.18	1.07	.97	.88	.80	.72	.66	.60	.54	.49	.45	.41	.37
60	1.18	1.08	.98	.89	.81	.74	.67	.61	.55	.50	.46	.42	.38
70	1.19	1.08	.99	.90	.82	.75	.68	.62	.56	.51	.47	.43	.39

SITE INDEX 110

20	1.31	1.17	1.04	.93	.83								
30	1.36	1.23	1.10	.99	.90	.81	.73	.65	.59	.53			
40	1.39	1.26	1.14	1.03	.93	.84	.76	.69	.62	.57	.51	.46	.42
50	1.40	1.27	1.16	1.05	.95	.87	.79	.71	.65	.59	.53	.48	.44
60	1.41	1.29	1.17	1.06	.97	.88	.80	.73	.66	.60	.55	.50	.45
70	1.42	1.30	1.18	1.07	.98	.89	.81	.74	.67	.61	.55	.51	.46

SITE INDEX 120

20	1.52	1.35	1.21	1.08	.96	.86							
30	1.58	1.42	1.28	1.15	1.04	.94	.84	.76	.68	.62	.55		
40	1.61	1.46	1.32	1.19	1.08	.98	.88	.80	.72	.66	.59	.54	.49
50	1.63	1.48	1.34	1.22	1.10	1.00	.91	.83	.75	.68	.62	.56	.51
60	1.64	1.49	1.36	1.23	1.12	1.02	.93	.84	.77	.70	.64	.58	.53
70	1.65	1.50	1.37	1.25	1.13	1.03	.94	.86	.78	.71	.65	.59	.54

SITE INDEX 130

20	1.72	1.53	1.37	1.22	1.09	.97	.87						
30	1.79	1.61	1.45	1.31	1.18	1.06	.95	.86	.77	.70	.63	.57	.51
40	1.82	1.65	1.49	1.35	1.22	1.11	1.00	.91	.82	.74	.67	.61	.55
50	1.84	1.67	1.52	1.38	1.25	1.14	1.03	.94	.85	.77	.70	.64	.58
60	1.86	1.69	1.54	1.40	1.27	1.16	1.05	.96	.87	.79	.72	.65	.60
70	1.87	1.70	1.55	1.41	1.29	1.17	1.07	.97	.88	.81	.73	.67	.61

Table V. --Residual quadratic mean stand diameter, immediately after thinning, by site index, age, and residual basal area

SITE INDEX 90

Age (years)	Residual basal area (square feet per acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Inches												
20	5.7	5.6	5.5	5.4									
30	8.6	8.4	8.2	8.0	7.9	7.7	7.6						
40	10.9	10.6	10.4	10.1	9.9	9.6	9.4	9.2	9.0				
50	12.6	12.3	11.9	11.6	11.3	11.0	10.7	10.4	10.1	9.9			
60	13.8	13.4	12.9	12.5	12.1	11.7	11.4	11.0	10.6	10.3	10.0		
70	14.4	13.9	13.4	12.9	12.4	12.0	11.5	11.0	10.6	10.2	9.8	9.4	
	SITE INDEX 100												
20	5.9	5.8	5.7	5.6	5.5								
30	9.3	9.1	8.9	8.7	8.6	8.4	8.3	8.2					
40	12.1	11.8	11.6	11.3	11.1	10.8	10.6	10.4	10.2	10.1	9.9		
50	14.4	14.0	13.7	13.3	13.0	12.7	12.4	12.1	11.8	11.6	11.3	11.1	10.9
60	16.0	15.6	15.2	14.8	14.4	14.0	13.6	13.2	12.9	12.6	12.2	11.9	11.6
70	17.2	16.6	16.1	15.6	15.2	14.7	14.2	13.8	13.4	13.0	12.5	12.1	11.8
	SITE INDEX 110												
20	6.0	5.9	5.8	5.7	5.6								
30	9.9	9.7	9.5	9.4	9.2	9.1	8.9	8.8	8.7	8.6			
40	13.2	13.0	12.7	12.4	12.2	12.0	11.8	11.6	11.4	11.2	11.0	10.9	10.7
50	16.0	15.6	15.3	15.0	14.6	14.4	14.0	13.8	13.5	13.2	13.0	12.8	12.5
60	18.2	17.8	17.3	16.9	16.5	16.1	15.8	15.4	15.0	14.7	14.4	14.1	13.8
70	19.8	19.3	18.8	18.3	17.8	17.4	16.9	16.5	16.0	15.6	15.2	14.8	14.4
	SITE INDEX 120												
20	6.0	5.9	5.8	5.7	5.7	5.6							
30	10.4	10.2	10.1	9.9	9.7	9.6	9.5	9.3	9.2	9.1	9.0		
40	14.3	14.0	13.8	13.5	13.3	13.0	12.8	12.6	12.4	12.2	12.1	11.9	11.8
50	17.6	17.2	16.9	16.5	16.2	15.9	15.6	15.3	15.0	14.8	14.5	14.3	14.1
60	20.3	19.8	19.4	19.0	18.6	18.2	17.8	17.5	17.1	16.8	16.4	16.1	15.8
70	22.4	21.9	21.4	20.9	20.4	20.0	19.5	19.0	18.6	18.2	17.8	17.4	17.0
	SITE INDEX 130												
20	6.0	5.9	5.8	5.7	5.6	5.5	5.5						
30	10.9	10.7	10.5	10.4	10.2	10.0	9.9	9.8	9.7	9.6	9.5	9.4	9.4
40	15.2	15.0	14.7	14.5	14.2	14.0	13.8	13.6	13.4	13.2	13.0	12.9	12.7
50	19.0	18.7	18.3	18.0	17.7	17.4	17.1	16.8	16.5	16.3	16.0	15.8	15.6
60	22.2	21.8	21.4	21.0	20.6	20.2	19.8	19.4	19.1	18.8	18.4	18.1	17.8
70	24.9	24.4	23.9	23.4	22.9	22.4	22.0	21.6	21.1	20.7	20.3	19.9	19.5

Beck, Donald E., and Lino Deíla-Bianca
1975. Board-foot and diameter growth of yellow-poplar after thinning. USDA For. Serv. Res. Pap. SE-123, 20 p. Southeast. For. Exp. Stn., Asheville, N.C.

Board-foot growth and yield of thinned yellow-poplar stands (Liriodendron tulipifera L.) is related to age, site index, residual basal area, and residual quadratic mean stand diameter after thinning. Diame te r growth of individual trees is i n c r e a s e d considerably by thinning. Equations describing growth and yield are based on data from 141 natural yellow-poplar stands in the Appalachian Mountains of Virginia, North Carolina, and Georgia.

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