Management of YOUNG AND INTERMEDIATE STANDS of Upland Hardwoods

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U.S.D.A. FOREST SERVICE RESEARCH PAPER NE-195
1971
NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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MANUSCRIPT RECEIVED FOR PUBLICATION 2 OCTOBER 1970

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This paper is based on a talk presented at the Symposium on Southern Appalachian Hardwoods, held at Asheville, North Carolina, on 22 September 1970.

AFTER MORE than 20 years of USDA Forest Service research on the growth and yield of hardwoods in the Central States, we can now confidently make recommendations for the management and culture of upland hardwood stands that are predominantly oak. In this paper I will deal with the first 50 years of stand development under one logical thinning policy.

Our Experiment Station is conducting 11 stand-density studies in upland hardwoods, in 4 states and with more than 200 plots. The oldest studies were established in 1949. We have growth records for more than 800 measurement periods involving nearly 35,000 trees. Many of our plots have been thinned twice. The stand age of our plots ranges from 9 to 90 years. We have one major study with a single-tree design that consists of 3,500 trees, in which single-tree growth factors, such as localized density and other factors affecting tree growth, are being studied.

Our volume tables have been constructed from measurements of felled trees or from measurements of standing trees with a Barr and Stroud dendrometer. Our measurements, which total in the hundreds of thousands, can be analyzed by the latest data-processing systems. We have developed growth models and are now in the process of analyzing and publishing our results. This paper is the first report.

Growth rates and yields given in this paper are compatible with the silvicultural prescriptions and residual densities given in the *Timber Management Guide for Upland Central Hardwoods* (*4*), published in 1962, and in *Even-Aged Silviculture for Upland Central Hardwoods* (*5*), published in 1968 (USDA Agriculture

Handbook 355). With data in this paper, future yields can be predicted for stands that are thinned according to the stand characteristics and prescriptions outlined in the two guides.

GROWTH AND DEVELOPMENT OF UNTHINNED UPLAND HARDWOOD STANDS

One way of evaluating the effects of thinning is to compare the growth and yield of a thinned stand with the growth and yield of an unthinned or normal stand. The first 10 to 15 years of stand development in upland hardwoods are a dynamic period. During this "brushy" stage there are as many as 10,000 woody stems per acre, in a wide variety of commercial species and brush. This is the period of stand development when skeptics doubt whether a new forest will ever become a reality.

When the new stand is between 15 and 20 years old, certain predictable patterns can be identified. Most of the brushy species have died or are relegated to a subdominant position in the stand. The new forest has clearly emerged, and the stand has some measurable characteristics, although it is still variable in terms of species composition and spacing.

At 20 years of age the basal area per acre will range from 55 to 70 square feet, depending on the quality of the site. The total number of trees will range from about 1,400 to 2,500, most of which are commercial or at least timber trees. The larger trees on the better sites will be about 7 inches in diameter.

The normal development of these stands during the next 60 years is shown in table 1. On all sites, without thinning — that is, simply following the development of normal stands — about 90 percent of the trees present at age 20 will die during the next 60 years (table 14, in appendix). Mean annual growth culminates between age 50 and 70 years for all units of measurement. Individual tree growth is slow; and the dominant trees on site 55, at age 80, will average about 12 inches in diameter, whereas dominant trees on site 75 at age 80 will average about 18 inches in diameter.

Table 1.—*Yields per acre for upland oak; no thinning*

Age (years)	Basal area	Trees	Average tree diameter[1]	Yields		
	Square feet	*No.*	*Inches*	*Cubic feet*	*Cords*	*Board feet*
			SITE INDEX 55			
20	55	2,500	2.0	60	0.6	—
30	75	1,260	3.3	583	5.3	—
40	87	790	4.5	1,320	12.1	—
50	97	480	6.1	2,150	19.7	400
60	104	357	7.3	2,520	22.9	900
70	108	295	8.2	2,730	24.4	2,800
80	112	242	9.2	2,880	25.6	5,400
			SITE INDEX 65			
20	59	1,880	2.4	178	1.6	—
30	81	930	4.0	1,200	10.6	—
40	96	505	5.9	1,840	18.2	440
50	105	342	7.5	2,800	26.9	2,150
60	111	262	8.8	3,300	30.8	5,160
70	115	215	9.9	3,700	33.3	7,200
80	117	187	10.7	3,950	35.6	8,200
			SITE INDEX 75			
20	70	1,425	3.0	694	6.4	—
30	89	680	4.9	1,670	16.7	—
40	101	400	6.8	2,440	23.7	1,380
50	110	279	8.5	3,315	30.1	4,100
60	114	222	9.7	4,140	37.7	9,288
70	117	187	10.7	4,760	43.0	11,200
80	120	166	11.5	5,160	46.5	12,500

[1]The diameter of the tree of average basal area.

THINNING UPLAND HARDWOODS

When stands of this make-up are thinned, several things occur. Thinnings made from below result in an increase in the average tree diameter of the residual stand. This happened in all our plots, and also in other stands that we have examined. Also, the range of diameters is reduced, which means that both large and small trees are removed in the thinning.

However, generally speaking, the first and second thinnings in hardwood stands would have to be characterized as thinning from below. And there are some good reasons for this. In even-

aged stands the larger trees, being the same age as the smaller trees, have grown at a faster rate and therefore have a higher vigor rating. Except for an occasional wolf tree, the larger trees are the best quality trees in the stand and are usually the preferred species for the site.

THE THINNING SCHEDULE

For simplicity, only one thinning schedule will be considered. I have used a uniform thinning interval of 10 years on each of three site classes. Residual stocking after each thinning is near the minimum for full utilization of the site with minor adjustments that depend on the stand age at the time of the first thinning (table 2). Species composition will not be considered as a separate variable in this paper.

The site classes used are oak site indexes 55 (range 50 to 60), 65 (60 to 70), and 75 (70 to 80). Yields will be expressed in three units — total cubic-foot volume, cord volume, and board-foot volume. Volume tables and their merchantability standards are listed in table 15, in the appendix. Cubic-foot and cord volumes include all trees 4.6 inches in diameter and larger, and board-foot volumes include trees 10.6 inches in diameter and larger.

I have calculated yields based generally on thinning to a residual stocking of 60 percent or approximately B-level (*2*),

Table 2.—*Thinning policy for upland hardwood stands, showing stocking percent after each thinning. Thinning interval: 10 years.*

Stand age at first thinning (years)	Residual stocking percent after —					
	First thinning	Second thinning	Third thinning	Fourth thinning	Fifth thinning	Sixth thinning
10	50	60	60	60	60	60
20	60	60	60	60	60	60
30	70	60	60	60	60	60
40	70	60	60	60	60	60
50	70	60	60	60	60	60
60	70	65	60	60	60	60

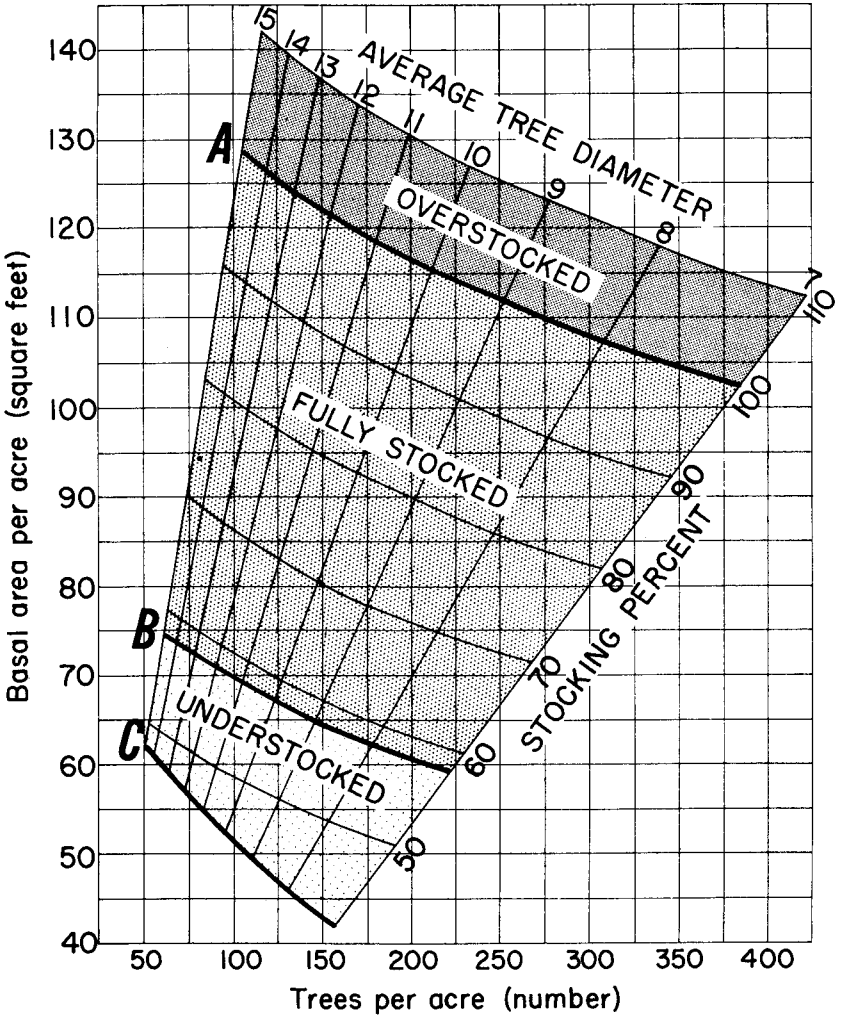
but there are several exceptions (fig. 1). For stands at age 10, I used a residual stocking of 50 percent. This was found to be the best at this age in terms of stand development (*1*). Stands of this age increase rapidly in stocking after thinning, and by age 20 they are near maximum stocking. For first thinnings in previously unthinned stands of 30 years and older, I used a residual stocking of 70 percent after the first thinning and 60 percent stocking after subsequent thinnings. Stands 60 years and older are gradually reduced to 60 percent stocking by the third thinning to reduce the possibility of epicormic branching.

Our research and practical field experience in using the *Timber Management Guide* has shown that most unmanaged hardwood stands do not have the recommended minimum stocking in desirable trees. This, of course, depends on the definition of a desirable tree; but even when tree-class standards are permissive, the minimum stocking in desirable trees is generally below the recommended residual level.

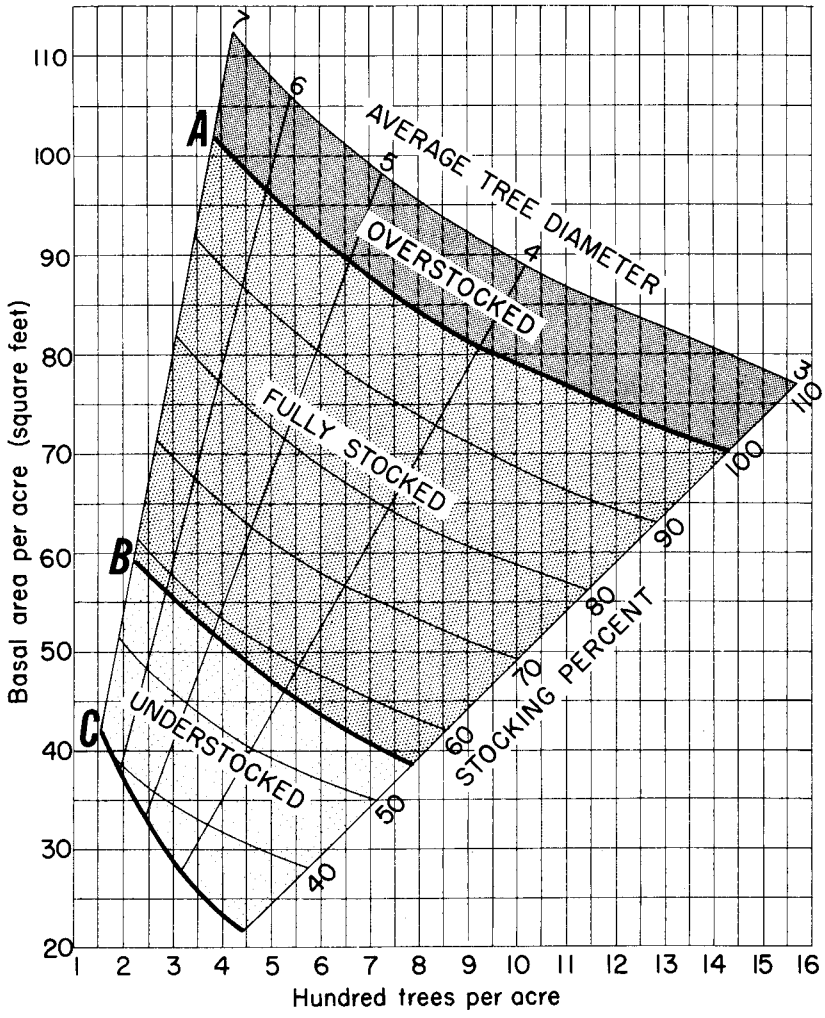
This usually means that one thinning will not put the stand in the best condition for growth. Some of the residual trees will be of low quality or of unwanted species, and spacing problems cannot always be adjusted.

There is some doubt about the value of a single thinning if subsequent thinnings are not planned. Though the intermediate yields from a single thinning may be beneficial from a management standpoint, the stand will eventually grow back to a highly stocked condition and will develop much like a normal unthinned stand, with slightly larger tree diameters.

Figure 1.—Relation of basal area, number of trees, and average tree diameter to stocking percent for upland central hardwoods. For average tree diameters 7 to 15, use the chart at left; for diameters 3 to 7, use the chart at right. (Average tree diameter is the diameter of the tree of average basal area.)



On both charts the area between curves A and B indicates the range of stocking where trees can fully utilize the site. Curve C shows the lower limit of stocking necessary to reach the B level in 10 years on average sites.



YIELDS FROM THINNING

One of our studies involves a planned series of thinnings at 10-year intervals, starting at different points in the life of an even-aged upland hardwood stand.

The general stand characteristics and cumulative yields for three sites and six different stand ages for a 50-year management period and a 10-year thinning interval are shown in tables 3 to 8. The implications and utility of these types of data are very broad and cannot be discussed fully here. A few cases will serve as examples.

The possibilities for growing different amounts of timber within the range of conditions given are great. At one extreme, a recently regenerated area on site 55, if left alone for 50 years, will produce a stand of about 480 trees, averaging 6 inches in diameter. The physical yields would be 2,150 cubic feet, or 19.7 standard cords or 400 board feet per acre (table 7). At the other extreme is a 10-year-old stand on site 75 that is thinned every 10 years until age 60. This stand will have an average diameter over 15 inches and will produce 6,360 cubic feet, or 56.7 standard cords or 18,840 board feet per acre (table 3) — about three times as much cubic and cord volume as the unmanaged site 55 stand would produce.

The younger the stand age when thinning is begun, the greater the yield increase for the same management period of 50 years, except in terms of board-foot yields (table 9). For example, on site 75, stands that are first thinned at age 10 will produce more cubic-foot volume during the next 50 years than will stands that are thinned at any other age. The same is true in terms of cord yields. However, in terms of board-foot yields on sites 65 and 75, stands first thinned at age 30 or 40 will produce more yield in the next 50 years than stands that are first thinned before age 30 or after age 40. On the other hand, stands that are thinned at age 10 on site 75 will have a cumulative yield of 18,840 board feet at age 60 or a mean annual growth of 314 board feet, whereas stands first thinned at age 30 on site 75 will have a cumulative yield of 23,040 board feet at age 80 but a mean annual growth of 288 board feet.

Table 3.—*Yields per acre for upland oak. First thinning at age 10.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
						SITE INDEX 55						
10	20	1.9	—	—	—	—	—	—	—	—	—	—
20	48	4.1	515	5.0	—	7	25	—	—	540	5.0	—
30	58	5.9	1,190	9.9	240	20	345	4.2	—	1,560	14.1	240
40	64	8.0	1,640	15.0	1,560	19	350	3.6	160	2,360	22.8	1,720
50	71	10.6	1,990	18.3	3,800	16	415	4.4	590	3,125	30.5	4,550
60	75	13.0	2,280	20.7	6,540	16	485	4.9	1,050	3,900	37.8	8,340
						SITE INDEX 65						
10	23	2.1	—	—	—	—	—	—	—	—	—	—
20	51	4.5	775	6.8	—	8	125	1.2	—	900	8.0	—
30	59	6.4	1,445	13.1	540	25	370	3.8	—	1,940	18.1	540
40	66	8.6	1,920	18.0	2,280	21	465	3.8	280	2,880	26.8	2,560
50	72	11.0	2,340	21.8	5,250	19	575	5.2	970	3,875	35.8	6,500
60	76	13.7	2,655	24.3	8,940	18	670	5.8	1,810	4,860	44.1	12,000
						SITE INDEX 75						
10	25	2.5	—	—	—	—	—	—	—	—	—	—
20	55	5.4	1,060	9.6	—	12	200	1.6	—	1,260	11.2	—
30	62	7.4	1,920	17.5	1,380	30	520	5.2	60	2,640	24.3	1,440
40	71	10.5	2,550	23.0	4,840	22	610	5.6	500	3,880	35.4	5,400
50	75	13.2	3,025	26.8	10,300	22	745	6.8	1,540	5,100	46.0	12,400
60	78	15.5	3,360	29.7	13,200	21	925	7.8	3,540	6,360	56.7	18,840

Table 4.—*Yields per acre for upland oak. First thinning at age 20.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
						SITE INDEX 55						
20	34	2.3	60	0.6	—	—	—	—	—	60	0.6	—
30	49	4.2	600	5.1	—	15	—	0.9	—	600	6.0	—
40	58	6.1	1,220	12.2	880	16	300	2.9	—	1,520	16.0	880
50	66	8.6	1,750	16.0	2,350	15	300	3.2	150	2,350	23.0	2,500
60	71	10.6	1,980	18.6	3,960	15	360	3.2	570	2,940	28.8	4,680
70	74	12.1	2,170	20.0	5,810	14	370	3.8	820	3,500	34.0	7,350
						SITE INDEX 65						
20	37	2.8	160	1.6	—	—	18	—	—	178	1.6	—
30	50	4.6	750	7.4	—	20	132	1.2	—	900	8.6	—
40	63	7.7	1,760	16.0	1,320	15	290	3.2	—	2,200	20.4	1,320
50	69	9.8	2,150	19.7	3,500	19	625	4.1	400	3,215	28.2	3,900
60	73	12.0	2,460	22.5	6,120	18	515	4.4	1,160	4,040	35.4	7,680
70	77	14.6	2,730	24.2	9,030	16	520	4.9	2,010	4,830	42.0	12,600
						SITE INDEX 75						
20	46	3.6	476	4.4	—	—	218	2.0	—	694	6.4	—
30	57	5.6	1,275	13.0	—	26	307	3.6	—	1,800	18.6	—
40	66	8.4	2,140	19.8	2,160	21	535	4.8	240	3,200	30.2	2,400
50	71	10.8	2,600	24.7	6,450	21	665	5.4	1,160	4,325	40.5	7,850
60	76	13.4	3,060	28.5	10,680	19	615	4.9	2,020	5,400	49.2	14,100
70	79	16.3	3,465	31.5	13,720	19	635	5.2	2,740	6,440	57.4	19,880

Table 5.—*Yields per acre for upland oak. First thinning at age 30.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
					SITE INDEX 55							
30	58	4.3	528	4.8	—	17	55	0.5	—	583	5.3	—
40	55	5.7	1,120	9.4	200	27	265	3.1	—	1,440	13.0	200
50	62	7.8	1,600	14.2	1,500	15	330	3.4	—	2,250	21.2	1,500
60	67	10.2	1,950	17.4	3,000	15	310	3.2	360	2,910	27.6	3,360
70	72	11.7	2,135	19.6	5,040	12	335	3.1	550	3,430	32.9	5,950
80	75	13.0	2,280	20.6	8,000	12	345	3.7	1,010	3,920	37.6	9,920
					SITE INDEX 65							
30	62	4.9	1,120	9.6	—	20	80	1.0	—	1,200	10.6	—
40	60	6.6	1,520	13.6	640	29	400	3.8	—	2,000	18.4	640
50	67	9.0	2,000	18.5	2,450	18	470	4.2	—	2,950	27.5	2,450
60	72	11.2	2,370	21.5	4,620	17	430	3.9	600	3,750	34.5	5,220
70	76	13.7	2,660	23.8	8,320	16	440	3.9	1,510	4,480	40.6	10,430
80	78	16.1	2,880	24.8	10,900	16	460	4.0	2,510	5,160	45.6	15,520
					SITE INDEX 75							
30	66	5.5	1,450	14.0	—	23	220	2.7	—	1,670	16.7	—
40	62	7.1	1,840	17.0	1,400	34	600	5.5	—	2,660	25.2	1,400
50	68	9.7	2,400	22.8	4,200	20	555	5.0	650	3,775	36.0	4,850
60	73	12.4	2,880	26.7	7,980	19	515	4.8	1,450	4,770	44.7	10,080
70	77	15.2	3,325	29.8	13,020	17	490	4.4	2,100	5,705	52.2	17,220
80	80	17.7	3,760	31.6	15,440	16	500	4.8	3,400	6,640	58.8	23,040

Table 6.—*Yields per acre for upland oak. First thinning at age 40.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
						SITE INDEX 55						
40	63	5.0	1,140	10.5	—	24	180	1.6	—	1,320	12.1	—
50	62	7.4	1,538	13.0	900	23	282	3.4	—	2,000	18.0	900
60	67	9.1	1,830	15.6	2,430	15	288	3.1	270	2,580	23.7	2,700
70	72	11.0	2,065	18.6	4,445	12	300	2.7	465	3,115	29.4	5,180
80	74	12.7	2,240	21.6	6,880	12	350	2.8	865	3,640	35.2	8,480
90	76	13.8	2,430	24.8	9,180	9	355	3.0	1,100	4,185	41.4	11,880
						SITE INDEX 65						
40	69	6.5	1,600	15.9	440	27	240	2.3	—	1,840	18.2	440
50	66	8.5	1,910	17.7	1,800	28	410	4.0	200	2,560	24.0	2,000
60	70	10.4	2,200	20.7	4,200	18	400	3.6	280	3,270	30.6	4,680
70	74	12.4	2,485	23.1	7,210	16	420	3.7	710	3,955	36.7	8,400
80	77	14.5	2,720	24.8	8,960	15	410	4.0	1,050	4,600	42.4	11,200
90	79	16.5	2,925	26.6	10,710	13	460	4.0	1,630	5,265	48.2	14,580
						SITE INDEX 75						
40	73	7.4	2,130	20.2	1,380	28	300	3.0	—	2,440	23.2	1,380
50	68	9.6	2,390	21.8	3,450	31	635	6.2	300	3,325	31.0	3,750
60	73	11.6	2,730	24.9	7,680	19	625	5.2	1,020	4,290	39.3	9,000
70	76	13.8	3,115	28.0	11,200	19	610	4.8	1,620	5,285	47.2	14,140
80	79	16.5	3,480	30.8	14,080	17	590	5.2	2,340	6,240	55.2	19,360
90	81	18.7	3,735	33.7	15,840	15	660	5.3	3,000	7,155	63.4	24,120

Table 7.—*Yields per acre for upland oak. First thinning at age 50.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
					SITE INDEX 55							
50	69	6.5	1,627	14.9	400	28	523	4.8	—	2,150	19.7	400
60	66	8.4	1,710	14.7	1,350	23	317	3.9	150	2,550	23.4	1,500
70	68	9.3	1,855	15.4	3,585	15	280	3.2	165	2,975	27.3	3,900
80	71	10.5	1,960	18.0	6,160	12	280	2.1	325	3,360	32.0	6,800
90	73	11.5	2,115	20.0	8,240	10	220	2.2	620	3,735	36.2	9,500
100	74	12.7	2,250	22.8	8,900	9	230	1.5	1,240	4,100	40.5	11,400
					SITE INDEX 65							
50	75	8.0	2,130	19.6	1,850	30	670	7.3	300	2,800	26.9	2,150
60	68	9.6	2,130	19.5	4,090	29	470	4.4	210	3,270	31.2	4,600
70	70	10.4	2,240	20.6	6,160	18	400	3.7	330	3,780	36.0	7,000
80	74	12.2	2,480	22.8	8,240	14	300	2.6	520	4,320	40.8	9,600
90	77	14.8	2,745	25.2	10,305	12	275	2.7	935	4,860	45.9	12,600
100	79	17.0	3,000	28.5	10,700	10	235	1.8	1,905	5,350	51.0	14,900
					SITE INDEX 75							
50	78	9.0	2,590	24.4	3,650	32	725	5.7	450	3,315	30.1	4,100
60	72	11.3	2,700	25.2	6,300	30	655	6.8	1,050	4,080	37.7	7,800
70	75	12.8	2,965	26.8	9,200	19	475	5.2	1,100	4,820	44.5	11,800
80	77	14.1	3,180	29.0	11,500	18	425	4.8	1,500	5,460	51.5	15,600
90	79	16.5	3,620	31.4	13,000	16	420	4.6	1,900	6,320	58.5	19,000
100	81	18.4	3,880	33.0	14,450	14	500	4.9	2,750	7,080	65.0	23,200

Table 8.—*Yields per acre for upland oak. First thinning at age 60.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
						SITE INDEX 55						
60	76	8.2	1,860	17.1	780	28	660	5.8	120	2,520	22.9	900
70	73	9.3	1,960	17.5	2,345	19	285	4.0	685	2,905	27.3	3,150
80	70	10.3	2,000	18.4	4,320	16	335	3.0	555	3,280	31.2	5,680
90	72	11.3	2,115	19.3	5,850	10	250	2.5	530	3,645	34.6	7,740
100	74	12.3	2,200	20.8	7,300	8	270	1.9	510	4,000	38.0	9,700
110	75	13.2	2,310	22.6	8,580	7	235	2.0	570	4,345	41.8	11,550
						SITE INDEX 65						
60	78	9.4	2,400	22.2	3,900	33	900	8.6	1,260	3,300	30.8	5,160
70	75	10.2	2,450	22.1	4,550	23	360	3.6	770	3,710	34.3	6,580
80	73	12.0	2,520	23.0	5,920	20	400	3.6	810	4,180	38.8	8,760
90	77	14.1	2,610	23.8	7,785	13	365	3.6	895	4,635	43.2	11,520
100	78	15.5	2,650	25.5	9,850	12	325	3.1	915	5,000	48.0	14,500
110	80	17.2	2,750	26.6	11,770	9	345	3.1	960	5,445	52.2	17,380
						SITE INDEX 75						
60	82	10.2	3,060	27.0	7,848	32	1,080	10.7	1,440	4,140	37.7	9,288
70	78	11.5	3,150	27.3	8,540	21	460	4.7	870	4,690	42.7	10,850
80	76	13.5	3,320	28.4	9,760	21	420	4.2	1,290	5,280	48.0	13,360
90	78	15.6	3,510	29.9	10,935	16	425	3.6	1,665	5,895	53.1	16,200
100	80	17.2	3,725	31.5	12,200	13	415	3.3	1,835	6,525	58.0	19,300
110	82	19.1	3,795	33.0	13,530	9	445	3.2	1,920	7,040	62.7	22,550

Table 9.—*A comparison of yields per acre for even-aged upland hardwoods. Management period: 50 years, Cutting interval: 10 years.*

Stand age at first thinning (years)	Site 55			Site 65			Site 75		
	Volume at beginning of period	Cumulative yields 50 years later	Increase in yield	Volume at beginning of period	Cumulative yields 50 years later	Increase in yield	Volume at beginning of period	Cumulative yields 50 years later	Increase in yield
				CUBIC FEET					
10	—	3,900	3,900	—	4,860	4,860	—	6,390	6,390
20	60	3,500	3,440	178	4,830	4,652	694	6,440	5,746
30	583	3,920	3,337	1,200	5,160	3,960	1,670	6,640	4,970
40	1,320	4,185	2,865	1,840	5,265	3,425	2,440	7,155	4,715
50	2,150	4,100	1,950	2,800	5,350	2,550	3,315	7,080	3,765
60	2,520	4,345	1,825	3,300	5,445	2,145	4,140	7,040	2,900
				CORDS					
10	—	37.8	37.8	—	44.1	44.1	—	56.7	56.7
20	0.6	34.0	33.4	1.6	42.0	40.4	6.4	57.4	51.0
30	5.3	37.6	32.3	10.6	45.6	35.0	16.7	58.8	42.1
40	12.1	41.4	29.3	18.2	48.2	30.0	23.2	63.4	40.2
50	19.7	40.5	20.8	26.9	51.0	24.1	30.1	65.0	34.9
60	22.9	41.8	18.9	30.8	52.2	21.4	37.7	62.7	25.0
				BOARD FEET					
10	—	8,340	8,340	—	12,000	12,000	—	18,840	18,840
20	—	7,350	7,350	—	12,600	12,600	—	19,880	19,880
30	—	9,920	9,920	—	15,520	15,520	—	23,040	23,040
40	—	11,880	11,880	440	14,580	14,140	1,380	24,120	22,740
50	400	11,400	11,000	2,150	14,900	12,750	4,100	23,200	19,100
60	900	11,550	10,650	5,160	17,380	12,220	9,238	22,550	13,312

Therefore, though stands thinned at age 30 on site 75 produce a greater yield increase over the 50-year period, one must consider the mean annual growth difference and the compound interest for 80 years versus 60 years. For all classes of site and units of yield, stands that are first thinned at age 50 and 60 will produce substantially less yield than stands that are thinned at an earlier age.

Two examples of how the yield information might be used in making silvicultural decisions where the objective is timber production are shown in table 10. The best option can be selected by comparing the cumulative yields during the period.

In Example 1 the objective is pulpwood management. The site is 65, the stand age 30, and there have been no previous thinnings. The problem is to select one of four options that will produce the highest cord yield in a 30- and 50-year period. In the 30-year management period the best option is to start thinning, whereas for the 50-year management period the options to start thinning or to regenerate and thin will produce similar cumulative yields during the period. In the 30-year period it would be better to leave the stand alone than to regenerate, but for the 50-year period the least desirable option is to leave the stand alone. Our analyses have shown that even when first thinnings under pulpwood management are delayed until age 30, the best rotation is less than 80 years. On good sites with early thinnings, the best pulpwood rotation, when considering economic factors, may be as low as 40 years.

In Example 2 (table 10) the objective is sawtimber production. The site is 75, the stand age is 50 years, and there have been no previous thinnings. In this situation the best silvicultural option for the next 30- or 50-year period is to start thinning. The second best option for the 50-year period is to regenerate and thin, whereas for the shorter period of 30 years the second best option is to do nothing.

The best silvicultural options for a series of stand ages, two management periods, and three site classes are shown in table 11. These data show the desirability of early thinnings for all sites where maximum timber production is the objective. In the

Table 10.—*Two examples of the use of yield information in making silvicultural decisions. Figures in parenthesis refer to the table number for data source.*

EXAMPLE 1 Situation: Objective — timber production for pulpwood. Site 65, stand age 30, no previous thinnings. Management periods — 30 and 50 years. All data in standard cords.

Silvicultural options	Present volume	Volume cut during period		Residual volume at end of period		Cumulative yields[1] during period	
		30 years	50 years	30 years	50 years	30 years	50 years
Leave alone	10.6 (1,5)	—	—	30.8 (1)	35.6 (1)	30.8	35.6
Start thinning	10.6 (1,5)	12.9 (5)	20.8 (5)	21.6 (5)	24.8 (5)	34.5	45.6
Regenerate with no thinnings	10.6 (1,5)	10.6	10.6	10.6 (1)	26.9 (1)	21.2	37.5
Regenerate with thinnings	10.6 (1,5)	15.6 (3)	24.6 (3)	13.1 (3)	21.8 (3)	28.7	46.4

EXAMPLE 2 Situation: Objective — timber production for sawtimber. Site 75, stand age 50, no previous thinnings. Management periods — 30 and 50 years. All data in board feet.

Silvicultural options	Present volume	Volume cut during period		Residual volume at end of period		Cumulative yields[1] during period	
		30 years	50 years	30 years	50 years	30 years	50 years
Leave alone	4,100 (1,7)	—	—	12,500 (1)	13,500 (*)	12,500	13,500
Start thinning	4,100 (1,7)	4,100 (7)	8,750 (7)	11,500 (7)	14,450 (7)	15,600	23,200
Regenerate with no thinnings	4,100 (1,7)	4,100	4,100	— (1)	4,100 (1)	4,100	8,200
Regenerate with thinnings	4,100 (1,7)	4,160 (1,3)	6,200 (1,3)	1,380 (3)	10,300 (3)	5,540	16,500

[1]Volume cut during period + residual volume at end of period.
*Extrapolated.

Table 11.—*Best silvicultural options[1] for previously unthinned stands by stand age and site, based on predicted yields in cords and board feet. Options are: (1) leave stand alone, (2) start thinning, (3) regenerate without future thinnings, and (4) regenerate with thinnings.*

Stand age (years)	Site 55		Site 65		Site 75	
	Cords	Board feet	Cords	Board feet	Cords	Board feet
	PERIOD OF MANAGEMENT: 20 YEARS					
10	2	2	2	2	2	2
20	2	2	2	2	2	2
30	2	2	2,1	2,1	2	2
40	2,1	2	1,2,4	1,2	2,1	1,2
50	2	2	2,4,1	1,2	2,1,4	2,1
60	2	2,1	2,4	2,1	4,2,1	2,1
	PERIOD OF MANAGEMENT: 40 YEARS					
10	2	2	2	2	2	2
20	2	2	2	2	2	2
30	2	2	2,4	2	2,4	2
40	2,4	2	4,2	2	4,2	2
50	4	2	4	2	4	2
60	4	2	4	2	4	2

[1]Where two or more options are listed the physical yields are about equal.

40-year management period the best option for board-foot production is to start thinning on all sites. When pulpwood production is the objective the best option for stands 40 years and older is to regenerate and thin. However, for the shorter 20-year management period there are generally two or three options that will produce similar yields, particularly on sites 65 and 75 for stands 30 years and older. Factors other than physical yields may have to be considered in making a decision. However, when a 10-year management period is used in stands that are 30 years and older and never have been thinned, the best option, especially for pulpwood yields, is often to leave stand alone.

In the foregoing examples of silvicultural decisions based on physical yield data, economic factors have been ignored. However, except for this, the results are logical recommendations for upland hardwood stands where the same thinning policy and silvicultural principles are applied.

The thinning policy used here was selected for the convenience of making yield comparisons, and because many management plans are made for a 10-year period. The theoretically ideal thinning interval is one based on stand development. Thinnings should be made when there is a need for one as expressed in individual tree growth rate, mortality, and overall productivity. In table 12, the same residual densities shown in table 2 are used, but the thinning interval is determined by the time required for the thinned stand to reach 80 percent stocking. This policy produces a variable thinning interval. At 80 percent stocking, diameter growth and net volume growth are reduced and tree mortality starts to increase.

Both the uniform and variable thinning intervals offer some advantages. The uniform interval is administratively easier to use and will result in lower mortality, larger tree diameters, and shorter rotations than the variable thinning interval. The same arguments could be used for a 5-year thinning interval; but the point will be reached where the volume and competition removed is so small that the thinning is not very effective. On the other hand, the longer periods associated with the variable thinning interval will produce higher volumes per thinning. The important point to consider is that the thinning interval for a 20-year-old stand on site 75 should be shorter than the thinning interval for a 60-year-old stand on site 55. Each stand could be thinned at uniform intervals, but the intervals would not be the same.

Perhaps the most important factor to consider when managing for maximum timber production is the stand age when thinning begins. The yield increase in cubic feet and cords when thinnings are begun at age 10 is more than 50 percent greater than the yields when thinning is begun at age 60 (table 13). Board-foot comparisons cannot be made during this 50-year period because many of the trees have not reached the minimum size (11 inches) in stands that are first thinned at 30 years or later. When thinnings are begun at 40 years or later the total yields in cubic feet and cords are about equal to the normal development of unthinned stands. But the lower densities in the thinned stands cause an increase in the diameter growth of residual trees; con-

Table 12.—*Variable thinning interval, in years, under a thinning policy based on the change in stocking after thinning. All stands thinned when stocking attains 80 percent. Residual stocking is shown in table 2.*

Stand age at time of first thinning (years)	Site 55			Site 65			Site 75		
	Second thinning	Third thinning	Fourth thinning	Second thinning	Third thinning	Fourth thinning	Second thinning	Third thinning	Fourth thinning
10	10	11	12	8	10	12	7	8	10
20	10	14	16	8	12	14	7	10	12
30	12	16	18	10	13	16	8	12	15
40	12	18	22	10	14	18	8	14	17
50	13	20	—	12	15	—	10	15	—
60	15	22	—	13	17	—	10	16	—

Table 13.—*A comparison of yields per acre at age 60 when thinning is begun at different ages (Source: tables 3 to 8). Thinning interval—10 years.*

Yields at age 60	Age of stand at time of first thinning (years)					
	10	20	30	40	50	60
			SITE 55			
Cubic feet	3,900	2,940	2,910	2,580	2,550	2,520
Cords	37.8	28.8	27.6	23.7	23.4	22.9
Board feet	8,340	4,680	3,360	2,700	1,500	900
			SITE 65			
Cubic feet	4,860	4,040	3,750	3,270	3,270	3,300
Cords	44.1	35.4	34.5	30.6	31.2	30.8
Board Feet	12,000	7,680	5,220	4,680	4,600 (7,000)*	5,160 (6,580)*
			SITE 75			
Cubic feet	6,360	5,400	4,770	4,290	4,080	4,140
Cords	56.7	49.2	44.7	39.3	37.7	37.7
Board feet	18,840	14,100	10,080	9,000	7,800 (11,800)*	9,288 (10,850)*

*Board-foot yields at age 70 (see tables 7 and 8).

sequently there is an increase in board-foot yields, especially by age 70 (see footnote, table 13).

These data clearly indicate the potential for reducing the rotation age for upland hardwood stands under a planned thinning schedule. When thinning is begun at age 10 or 20 and is followed by periodic thinnings at 10- to 15-year intervals, the time required to grow a tree of a given diameter can be reduced by nearly 50 percent. Added to this is higher tree quality from the application of good silviculture.

SUMMARY

Three major silvicultural implications for upland hardwoods are supported by both biological and quantitative factors.

First, whether by intuition or otherwise, foresters generally thin hardwoods from below. There is a good biological basis for this. Small trees in the subdominant class that have endured long periods of high competition are not good candidates for release

by thinning. The dominant stand contains the high-vigor trees, the best quality stems, and often the preferred species for the site.

Second, a single thinning has very little effect on the final yield of a forest stand. But a one-thinning policy will produce the greatest return in terms of physical yields if it is done at an early age. A single thinning produces very small yields regardless of when it is made. In young stands the material removed is too small to utilize. In older stands the first thinning will remove defective and low-quality trees, and merchantable yields will be low. Also, first thinnings in older high-density hardwood stands do not always produce the expected growth response. Because such stands contain low-vigor trees, dense clumps, and mixed species, the first thinning may actually result in a net growth deficit (*3*). On the other hand, the accrued benefits from a thinning schedule at 10- to 15-year intervals will produce high volume returns.

Third, the earlier a stand is thinned the greater the accumulated yields over a similar management period. When precommercial thinnings are not feasible, the latest effective thinning age for pulpwood production is between 30 and 40 years, and for sawtimber production between 50 and 60 years. If thinning is not started by this age, it may be better to leave the stand alone, or to regenerate the stand, especially if it is in poor condition.

■

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APPENDIX

Table 14.—*Mortality rates for upland hardwoods. Percentages indicate the proportion of trees in each diameter class that will survive the next 10-year period. For stands that are 100 ± 10% stocked.*

D.b.h. (inches)	Stand age, years					
	20	30	40	50	60	70
1	18	10	—	—	—	—
2	42	20	10	—	—	—
3	77	30	25	10	5	—
4	93	57	48	35	32	28
5	97	84	67	60	55	50
6	100	99	90	80	77	72
7	—	100	95	85	82	78
8	—	—	98	90	87	83
9	—	—	100	95	92	87
10	—	—	—	98	96	92
11	—	—	—	100	98	95
12	—	—	—	—	100	99
13	—	—	—	—	—	100

Table 15.—*Volume tables for upland hardwoods, by site classes.*

D.b.h. (inches)	Site 55				Site 65				Site 75			
	Average total height	Cubic foot volume[1]	Cord volume[2]	Board-foot volume[3]	Average total height	Cubic foot volume[1]	Cord volume[2]	Board-foot volume[3]	Average total height	Cubic foot volume[1]	Cord volume[2]	Board-foot volume[3]
5	34	2.72	0.025	—	41	3.15	0.029	—	45	3.40	0.031	—
6	41	4.28	.039	—	47	4.81	.044	—	52	5.26	.048	—
7	46	6.21	.057	—	52	6.94	.063	—	57	7.55	.069	—
8	51	8.73	.080	—	57	9.68	.088	—	63	10.6	.097	—
9	55	11.7	.107	—	62	13.1	.120	—	68	14.3	.131	—
10	50	15.3	.140	27	66	17.0	.155	36	73	18.8	.171	44
11	62	19.3	.176	46	69	21.4	.195	56	78	24.1	.220	69
12	64	22.9	.215	66	71	26.1	.238	78	82	30.0	.274	96
13	66	28.4	.259	88	73	31.3	.286	102	86	36.8	.336	128
14	67	33.3	.304	111	75	37.2	.340	130	89	44.0	.402	161
15	69	39.3	.359	139	77	43.7	.399	160	93	52.7	.481	202
16	70	45.2	.413	167	79	51.0	.465	194	95	61.2	.559	241
17	71	51.7	.472	197	81	58.9	.538	231	97	70.4	.643	284
18	72	58.7	.536	230	83	67.6	.617	271	99	80.5	.735	331
19	73	66.2	.605	265	85	77.0	.703	315	101	91.3	.835	382
20	74	74.3	.679	303	87	87.3	.797	363	102	102.2	.937	433
21	75	83.0	—	343	88	97.2	—	410	103	113.7	—	486
22	76	92.2	—	386	90	109.1	—	465	105	127.1	—	549
23	77	102.0	—	432	91	120.5	—	518	106	140.2	—	610
24	78	112.5	—	481	92	132.6	—	574	107	154.1	—	675

[1]Total cubic-foot volume of entire stem, including bark, tip, stump, but no branches. Cubic volume = $0.60 + 0.00249D^2H$

[2]Standard cords to a 4-inch top inside bark, excluding bark and branches. Cord volume = $0.00532 + 0.02275D^2H/1000$

[3]Board-foot volume, International ¼-inch rule, to an 8.5-inch top, outside bark. Board-foot volume = $-41.046 + 0.01161D^2H$