THINNING OF YOUNG NATURAL HARDWOOD REGENERATION IN SOUTHEASTERN WEST VIRGINIA[1]

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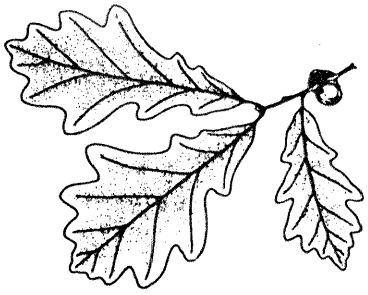

ABSTRACT.--A thinning study in young natural hardwood regeneration established following clearcutting has been done in southeastern West Virginia. Three five-to-seven-year-old mixed hardwood stands were studied, with species present representative of the Appalachian type and northern hardwood type. The average density ranged from 7000 to 12,000 stems per acre (SPA) taller than 4.5 feet. Manual thinning on a stand area basis brought the density down to 3000 and 1000 SPA. After four growing seasons, significant (0.05 level) positive growth responses were observed, which varied with sites, treatments, and species. Significant growth responses were achieved on Appalachian sites but little responses occurred on northern hardwood sites. To gain maximum responses, thinning down to 1000 SPA was necessary. For individual trees, there were growth responses in diameter and crown length but not in height, ranging from 18 to 56 percent over the control trees for diameter and 3 to 133 percent for crown length. On a stand area basis, the thinned plots could produce from as much as 114 percent to as low as 44 percent of the production of the unthinned plots in biomass. Mortality of crop-trees in the control treatment and the combined thinning treatments was 9.3 and 3.2 percent, respectively, over a four-year period. Differential responses between sites and treatments were related to environmental conditions, species composition and to self-thinning occurring at a site.

INTRODUCTION

West Virginia contains four major forest types, namely oak-hickory at lower elevations, northern Applachian hardwoods at higher elevations, northern boreal forest at very high elevations, and the yellow pine forests of the south. More than 136 hardwood tree species and 12 conifers occur within the state (Core 1966, Bones 1978).

Most of Westvaco's natural hardwoods in West Virginia are located in the southeastern part of the state. Westvaco's hardwood practice is to use clearcutting, removing all culls and residual trees, and allowing the stand to naturally regenerate by seedling and sprouting.

Following clearcutting, the total number of regeneration stems per acre increases to a maximum in about two to four years and then declines by self-thinning with minor fluctuations following a curvilinear function (Bridgen 1980[3]).

A maximum of 60,000 stems per acre (counting all visible woody stems), and of 40 species has been observed by the author in the area. Thinning may offer an opportunity for controlling species composition and increasing growth rates of crop trees of these stands at early ages.

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[3]Bridgen, M. R. 1980. Natural regeneration of hardwood species in West Virginia Woodlands. Westvaco, West Virginia Research Center, Rupert, West Virginia Research Report No. 26.

With the shortening of rotation age, perhaps below age 50, for fiber production, thinning at younger ages needs to be examined in terms of volume and weight not only of crop trees but the stand *in toto*.

LITERATURE REVIEW

Generally, crop-tree release in precommercial stands is applied more often as an individual tree treatment, and less often on a stand area basis. Results from crop-tree release techniques in young natural hardwoods have been variable (appendix 2). The positive response is almost exclusively with diameter growth. The possible reasons for this variation in research results can be attributed to:

1. Stand age.

2. Species with different life histories: For example, the pioneering characheristics of pin cherry[1] in colonizing clearcuts of northern timber type (Marks and Bormann 1972). Its death at a stand age of 10 to 20 years often resembles a natural crop-tree release (Smith 1977).

3. Species composition of the stand, i.e., other crop trees and non-crop trees: There is some evidence of allelopathic effects of some tree species on others (Fisher 1980). Tubbs (1973) has shown that phenolic compounds from the roots of sugar maple inhibit the growth of yellow birch. Moderately dense stands of pin cherry stimulate height growth and self-pruning of other species (Safford and Filip 1974).

4. Site quality: It may be too early to select for black cherry or yellow-poplar at age seven on good sites (Oak Site Index 80) to permanently improve their crown position (Smith 1977). Oaks are more competitive on fair sites with other more intolerant species like black cherry and yellow-poplar (Smith 1983).

5. Stage of development: Trees of the same age may represent different stages of development and respond to release differently. Smith and Lamson (1983) found that sweet birch and black cherry on fair sites (Oak Site Index 63) in the 25 to 33-foot height range responded while they did not in the 33 to 40-foot range.

6. Direct competition from weed species and non-crop trees: Grapevines can cause serious problems in the development of young even-aged stands on better sites (Trimble and Tryon 1976). Della-Bianca (1975) found that the growth on non-crop trees had to be taken into account in explaining the response of crop trees. In this case, the attainment of near basal area equality between cleaned and uncleaned treatments was perhaps the major reason that the original impact of the intensive cleaning on increasing crop tree d.b.h. growth had dissipated during the last part of the 10-year experimental period. Striped maple as an understory competitor can crowd out desirable species (Shipman 1984).

7. Lack of an objective measure of the degree of release around the crop tree: In reviewing the variation of the research results on crop tree release, Smith and Lamson (1983) rightly pointed out that many studies lack an objective measure of the degree of release which must be applied uniformly over all crop trees. Treatments described such as "5-foot bole", "free-to-grow", or "stand area" based on residual basal area may be too subjective and may leave crop trees actually unreleased in terms of crown competition. On the other hand, treatments described such as "5-foot crown" or "crown touching" are more objective and easy to apply uniformly in practice.

The objectives of the present study were to thin young mixed natural hardwood regeneration based mainly on number of stems per acre on different timber types and to observe responses in terms of both crop tree dimensions and production per acre.

PROCEDURE

The thinning study involved three different stands established naturally following clearcutting in southeastern West Virginia in western Greenbrier County. The characteristics of the sites/stands before application of thinning treatments are presented in table 1. The three sample stands have developed from different original timber types and consequently have different species composition for the regeneration. The Henry, Bingham, and Browns Creek sites support a red oak-black cherry stand, a red maple-black cherry stand, and a black cherry-sugar maple stand, respectively (table 2). Due mainly to the altitude and the exposure, the growing conditions at Henry are the most favorable, followed by Bingham and Browns Creek, as evidenced by the respective number of species and number of stems per acre on a site (table 1).

In the fall of 1980, the sample stands were selected to test three thinning levels: control, 3000, and 1000 stems per acre (SPA). Treatment plots are 0.1 acre with the center 0.02 acre used for measurement, giving 60 and 20 trees per measurement plot for the thinned condition. For control plots, 60 crop trees were selected in an unthinned condition. The total number of crop trees monitored is 420 per site or 1260 for the study. The experimental design for each site is a randomized block design with three treatments and three replications.

A pre-thinning inventory was carried out using mil-acre plots systematically located throughout the study sites. Then the crop trees from the overstory (> 4.5 ft.) were selected and tagged. The basis of

[1]Common names and scientific names of all species mentioned are found in Appendix 1.

Table 1.--Characteristics of the three experimental sites/stands of young natural hardwood regeneration used for thinning in southeastern West Virginia.

Site	Age at Establishment in 1980	Timber Type of Original Stand	Number of Species	Number Stems per Acre		Elevation Above Sea Level	Aspect	Expected Annual Precipitation[1]
	Years			< 4.5 ft.	≥ 4.5 ft.	Feet		Inches
Henry	5	Appalachian	24	19000	12000	2680	South	52.2
Bingham	6	Mixed Appalachian-Northern	21	4000	11000	2680	Flat Ridge	52.2
Browns Creek	7	Northern	13	4000	7000	3300	Northwest	57.0

[1]Estimated with equations by Grafton and Dickerson (1969).

Table 2.--Species composition and distribution of crop trees of young natural regeneration at three experimental sites in southeastern West Virginia.

Species	Henry Site	Bingham Site	Browns Creek Site	Total
	- - - - - - -Number- - - - - - -			
White ash	5	5		10
American beech			17	17
Yellow birch	4		34	38
Black cherry	65	93	111	269
Pin cherry		9	67	76
Cucumbertree	18	56	30	104
Fraser magnolia	11		19	30
Red maple	54	125	39	218
Sugar maple	2	16	85	103
Hickories	15	5		20
Black oak	22	1		23
Chestnut oak		4		4
Red oak	150	27	11	188
Scarlet oak	10	3		13
White oak	1	43		44
Yellow-poplar	22	7		29
Blackgum	22	1		23
American chestnut		1		1
Ironwood			1	1
Serviceberry	5	23	6	34
Sourwood	14	1		15
Total	420	420	420	1260

selection was a combination of size, spacing, and species to get the desired number of stems per plot. After thinning, crop trees in the 1000 SPA treatment were fully released while those in the 3000 SPA treatment were partially to fully released. Thinning was done by hand. All trees ≥ 4.5 feet other than leave-trees were cut and left on site. All vegetation < 4.5 feet was untouched. The leave-trees usually were the dominants or codominants of desirable species. However, species such as blackgum, chestnut, ironwood, serviceberry, pin cherry, and sourwood were occasionally retained only to get the desired number of stems per acre.

The crop trees were measured for height, d.b.h., and crown length. Crown length was measured from the top of tree to the lowest live branch, as an indication of tree vigor.

The crop trees were remeasured annually from 1981 to 1984. To monitor the development of the unthinned stands or self-thinning, two circular plots of 0.002 acre size randomly located within a control plot were marked and remeasured in 1981, 1982, and 1984 for number of stems > 1 foot in height, and d.b.h. or above-buttswell diameter.

For the 1980-1984 period, mean trees are compared in terms of growth in diameter (D), height (H), and crown length. Production per acre is compared in terms of basal area, volume (using D^2H as an index), and dry weight. Biomass equations for small hardwood trees developed for the study area were used to calculate dry weight (Bridgen 1982[1]). Treatment differences at each site were tested by analysis of variance and Duncan's New Multiple Range Test. Analysis of covariance was also carried out for appropriate parameters. Data on mortality for different species and treatments are presented. Relationships between mean tree weight and biomass per acre with density (stems per acre) were examined in relation to the -3/2 power rule of self-thinning.

RESULTS AND DISCUSSION

Individual Trees

To examine the effects of thinning on individual trees' dimensions, the best 1000 crop trees per acre in each treatment were used to calculate average growth in diameter, height, and crown length (table 3). This procedure was chosen because it is unreasonable to compare the average growth of 3000 stems of the control and the 3000 SPA treatments with that

[1]Bridgen, M. R. 1982. Biomass equations for small hardwood trees. Westvaco, West Virginia Research Center, Rupert, West Virginia Research Report No. 34.

Table 3.--Four-year responses of young natural hardwood regeneration to three thinning levels at three experimental sites in southeastern West Virginia. Data are for the best 1000 trees per acre for each treatment.

		Henry Site			Bingham Site			Browns Creek Site		
Treatment (Stems/Acre)	Parameter	Initial	Four-Year Growth	Percent of Control Growth (%)	Initial	Four-Year Growth	Percent of Control Growth (%)	Initial	Four-Year Growth	Percent of Control Growth (%)
Control[1]	D.b.h.	0.93	0.63 a[2]	100	1.27	0.76 a	100	1.69	0.62 a	100
3000	(in.)	0.82	0.87 b	138	1.21	0.91 b	120	1.41	0.73 a	118
1000		0.75	0.98 c	156	0.92	0.92 b	121	1.04	0.73 a	118
Control	Height	13.0	7.4 a	100	14.1	9.3 a	100	16.4	8.8 a	100
3000	(ft.)	11.1	7.2 a	97	13.2	7.8 a	84	15.9	6.9 a	78
1000		10.1	7.2 a	97	11.5	6.4 a	69	15.9	6.9 a	78
Control	Crown Length	7.7	2.4 a	100	10.1	3.6 a	100	11.4	3.3 a	100
3000	(ft.)	7.2	4.1 b	171	9.5	4.4 a	122	10.4	4.3 a	130
1000		5.7	5.6 c	233	8.1	3.7 a	103	8.1	3.4 a	103

[1]Using 3000 stems per acre in unthinned condition.

[2]Values in columns with same letter(s) are not significantly different at 0.05 level (Duncan's New Multiple Range Test).

Table 4.--Four-year responses of young natural hardwood regeneration to three thinning levels at three experimental sites in southeastern West Virginia. Data are per acre basis, using all crop trees per plot.

		Henry Site			Bingham Site			Browns Creek Site		
Treatment (Stems/Acre	Parameter	Initial	Four-Year Growth	Percent of Control Growth (%)	Initial	Four-Year Growth	Percent of Control Growth (%)	Initial	Four Year Growth	Percent of Control Growth (%)
Control[1]	Basal Area	8.18	13.38 a[3]	100	15.78	27.75 a	100	27.78	24.47 a	100
3000	(sq. ft./ac.)	6.76	21.90 a	163	13.68	29.43 a	106	22.25	27.94 a	114
1000		3.47	14.04 a	105	5.51	15.94 a	57	7.19	12.49 a	51
Control	D^2H	18,130	62,227 a	100	40,569	124,506 a	100	87,366	175,779 a	100
3000	(in.^{2} ft./ac.)	13,748	80,343 a	129	32,530	138,133 a	111	72,741	165,832 a	94
1000	Volume Index	7,225	52,563 a	84	13,425	66,133 a	54	20,100	60,797 a	35
Control	Dry Weight[2]	2.40	3.95 ab	100	3.79	6.01 a	100	5.92	5.62 a	100
3000	(tons/ac.)	1.85	4.12 b	104	3.33	6.77 a	113	5.15	6.41 a	114
1000		0.92	3.13 a	79	1.28	3.35 a	56	1.54	2.49 a	44

[1]Using 3000 SPA of crop trees in unthinned condition.

[2]Leaf, branch, and stem.

[3]Values in columns with same letter(s) are not significantly different at 0.05 level (Duncan's New Multiple Range Test).

of 1000 stems of the 1000 SPA treatment.

Dispite their younger ages, the Henry and Bingham trees responded to thinning by increasing diameter growth significantly (0.05 level) over the control treatment while the Browns Creek trees did not. No height responses were observed at any site, while only the Henry trees showed a significant increase in crown length. For example, the thinned trees at Henry increased diameter growth by 38 to 56 percent, and crown length by 71 to 133 percent over the control trees. This indicated that the thinned trees at Henry were able to expand their crown to take advantage of the space made available.

In terms of diameter growth response, the three sites rank in the decreasing order of Henry > Bingham > Browns Creek with the best treatment (1000 SPA) giving 56, 21, and 18 percent over the control treatment, respectively (table 3).

It seems that for regeneration stands with age < 10 years, thinning down to at least 1000 SPA is necessary to get the trees fully released to gain

maximum responses.

Production Per Acre

Production per acre was examined for basal area, volume, and dry weight using all crop trees per plot (table 4). Thinning removes some growing stock, thereby reducing absolute growth, but the test in thinning is whether a thinned stand with a reduced but improved growing stock can produce as much or more than the unthinned stand.

At Henry, thinning to 1000 SPA reduced 58 percent of basal area but the thinned stand produces as much as the unthinned stand (105 percent). However, at Bingham and Browns Creek the thinned stands only produced 57 and 51 percent of the control stands, respectively (table 4).

The responses in volume and dry weight follow closely that in basal area. For example, at Henry the thinned stand with 1000 SPA produced 3.13 tons/acre in four years i.e. almost as much as did the 3000 stems in the unthinned stand with 3.95 tons. Again, the Bingham and Browns Creek Sites produced only 56 and 44 percent of the control treatment, respectively. These dry weight responses will be discussed more in the section on self-thinning.

Tables 3 and 4 indicate that positive responses to thinning of mixed young hardwood regeneration can be obtained but only at certain sites with, among other factors, favorable growing conditions. The density at ages < 10 years should be brought down to 1000 SPA or less.

Species' Differences

Besides environmental conditions, the differential responses can be related in part to differences in species composition. Table 5 shows the diameter responses of a number of species present in sufficient quanity for meaningful comparison. The presented values have been adjusted for differences in initial diameters by covariance analysis.

Black cherry, cucumbertree, red maple, red oak, sugar maple, white oak, and yellow birch all responded positively to thinning in some degree while the intolerant pin cherry did not.

However, the responses were not uniform over the three sites. Black cherry responded significantly (0.05 level) at Henry and Browns Creek but did not at Bingham. Red maple did respond at Henry and Bingham but probably did not at Browns Creek.

The reasons for these differential responses of the same species are not clear but the stand species may play a part.

In terms of species composition of the crop trees (table 2), Bingham contained 22 percent in black cherry and Browns Creek contained 25 percent in pin cherry and red maple, which did not respond to thinning.

Table 5.--Four-year diameter responses of different species of young natural hardwoods to three levels of thinning (control, 3000, and 1000 stems per acre) at three experimental sites (HR-Henry Site, BH-Bingham Site, and BC-Browns Creek Site).

Species /Site Treatment	Sample Size	Diameter at Breast Height: Initial	Diameter at Breast Height: Four-Year Growth	Percent of Control Growth
Stems/Acre	No.	- - Inches - -		%
Black cherry/ HR				
Control	21	0.65	0.25 a[1]	100
3000	21	0.41	0.63 b	252
Black cherry/ BH				
Control	14	1.50	1.02 a	
3000	14	1.16	1.17 a	
1000	14	0.85	0.96 a	
Black cherry/ BC				
Control	28	1.77	0.47 a	100
3000	28	1.35	0.74 b	157
1000	28	0.96	0.77 b	164
Pin cherry / BC				
Control	11	1.64	0.91 a	
3000	11	1.61	0.64 a	
1000	11	1.33	0.73 a	
Cucumbertree/ BH				
Control	10	1.04	0.42 a	100
3000	10	0.84	0.78 b	186
1000	10	0.79	1.18 c	280
Red maple / HR				
Control	9	1.15	0.53 a	100
3000	9	1.19	0.99 b	186
1000	9	0.91	1.26 c	238
Red maple / BH				
Control	17	1.39	0.60 a	100
3000	17	1.20	0.90 ab	150
1000	17	1.07	0.97 b	161
Red maple / BC				
Control	15	0.70	0.29 a	100
3000	15	1.09	0.39 a	134
Red oak / HR				
Control	28	0.77	0.42 a	100
3000	28	0.73	0.73 b	174
1000	28	0.63	0.88 c	210
Sugar maple / BC				
Control	16	0.69	0.27 a	100
3000	16	0.74	0.37 b	137
White oak / BH				
Control	7	0.68	0.71 a	100
3000	7	1.19	0.71 a	100
1000	7	0.90	1.06 b	149
Yellow birch/ BC				
Control	6	1.00	0.46 a	100
3000	6	1.28	0.80 b	174
1000	6	1.21	1.21 c	263

[1]Values in columns with same letter(s) are not significantly different at 0.05 level. Values presented have been adjusted for initial diameters by covariance analysis.

Mortality of Crop Trees

The three experimental stands were in a vigorous stage of self-thinning. Therefore, there is a concern that crop trees selected at these younger ages may not survive.

As expected, thinning reduced the mortality rate of crop trees in all three sites (table 6). Out of the total of 73 dead in the four-year period, there were 50, 20, and three dead in the control, 3000 SPA, and 1000 SPA treatments, respectively. While the mortality in the control or 3000 SPA treatment was due mainly to self-thinning, that in the 1000 SPA treatment was due to other causes such as diseases and species' intolerance. In fact, the three dead in this treatment consisted of one diseased black cherry and two intolerant pin cherry. Percent dead in the control, the 3000 SPA, and the 1000 SPA thinning treatments was 9.3, 3.7, and 1.6, respectively, over the four-year period.

Out of the 21 species present at the three sites, 14 species showed some mortality. The seven species with no mortality included white ash, beech, Fraser magnolia, blackgum, ironwood, serviceberry, and sourwood.

In an unthinned condition, pin cherry, cucumbertree, sugar maple, hickories, black oak, chestnut oak, scarlet oak, white oak, and yellow-poplar all had more than 10 percent mortality rate, while yellow birch, black cherry, red maple, and red oak had less. Thus by observing the mortality rate of different species, crop trees can be selected with some confidence that they will not die prematurely. Red oak was one of the best candidates to continue to survive with only five percent mortality in an unthinned condition and one percent in the thinned condition. Fraser magnolia showed no mortality while cucumbertree suffered considerable mortality. On the other hand, both black cherry and pin cherry showed similar mortality rates in both unthinned and thinned conditions, indicating their intolerance.

Perhaps table 6 suggests that the experimental stands are too young to select for crop trees. However, using only 1000 SPA or less and avoiding intolerant species like pin cherry, the mortality rate should be minimal.

Table 6.--Mortality of crop trees[1] during the four-year period of young natural regeneration under three thinning levels in southeastern West Virginia.

	Thin Treatment			No. of Crop Trees		% Dead	
Species	C[2]	3000 SPA	1000 SPA	C	T[3]	C	T
Yellow birch	1			16	22	6.2	–
Black cherry	6	8	1[4]	123	146	4.9	6.2
Pin cherry	6	1	2	40	36	15	8.3
American chestnut		1		–	1	–	100
Cucumber-tree	10	2		56	48	18	4.2
Red maple	7	2		106	112	6.6	1.8
Sugar maple	3	2		25	78	12	2.6
Hickories	3			12	8	25	–
Black oak	1	2		5	18	20	11
Chestnut oak	1			3	1	33	–
Red oak	4	1		76	112	5.3	0.9
Scarlet oak	2	1		7	6	29	17
White oak	3			12	32	25	–
Yellow-poplar	2	1		13	16	15	6.3
Total	50	20	3	494	536		

[1]Excluding seven species with no mortality (white ash, beech, Fraser magnolia, black gum, ironwood, serviceberry, and sourwood).

[2]Control.

[3]Thinned.

[4]Diseased.

Thinning Responses and the -3/2 Power Rule of Self-Thinning

The relationship between average plant size ($\bar{s}$) and stand density (ρ) in monospecific single-aged plant populations undergoing self-thinning is bounded asymptotically by the -3/2 power rule line (Yoda et al 1963) i.e. $\bar{s}_m = b_0\rho^{-b_1}$ or $\log \bar{s}_m = \log b_0 - b_1 \log \rho$ where $\bar{s}_m$ is the maximum attainable average plant size (volume or weight), ρ is the actual stand density or number of plants, b_0 is the intercept parameter, and b_1 is the slope parameter.

The slope parameter, b_1, is apparently fixed at about 1.5, for weight and volume, irrespective of species, age, and site conditions. The intercept parameter varies with species (White and Harper 1970) but only within narrow limits (Gorham 1979, White 1980, 1981).

For forest species, Smith and Hann (1984) found a slope of -1.46 for red alder seedling weight and -1.6 for red pine volume for 20-50-year-old trees. Zeide (1984), using yield tables for southern pines, obtained slope values of -1.38 to -2.37 and showed that the slope parameter systematically changes with species and site (it increased with site index and decreases with tolerance) rather than merely fluctuating about a constant value.

For natural hardwood regeneration, to the best of my knowledge, no published information on the self-thinning rule is available. Therefore, I will attempt to use the -1.5 power rule line to interpret

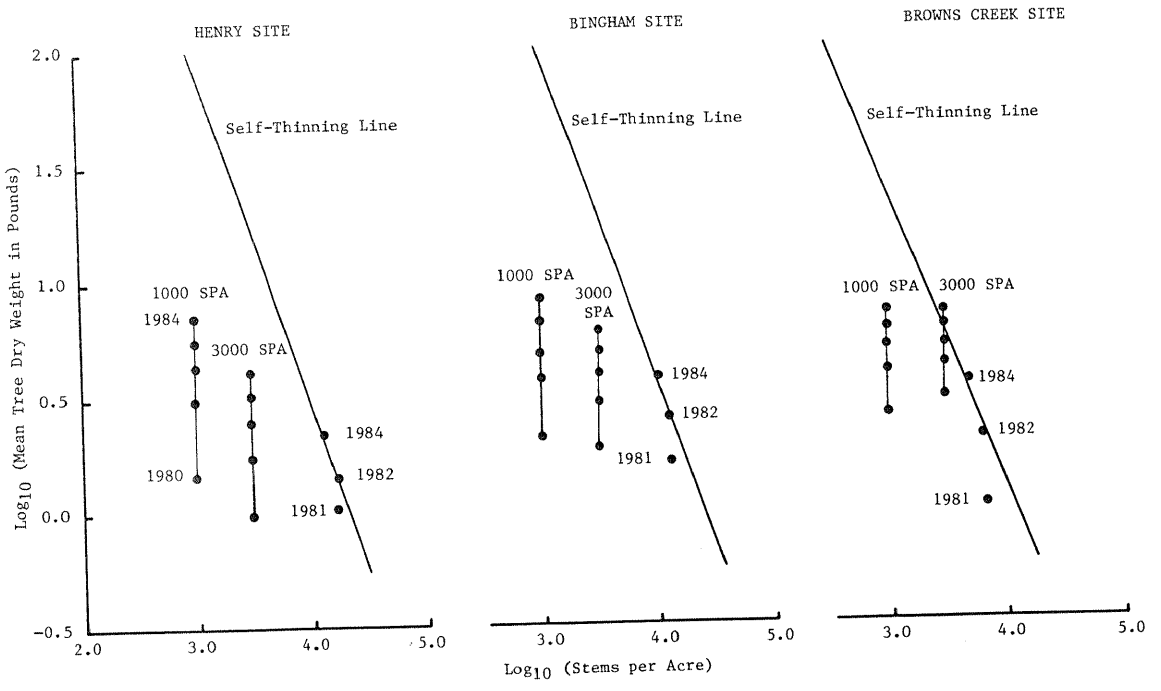

Figure 1.--The relationships between mean tree dry weight (branch plus stem) and stand density of the thinned plots (3000 and 1000 SPA) and the unthinned plots (all stems > 1 foot) at the three experimental sites. The self-thinning lines were drawn using the slope of -1.5 and data collected in 1981, 1982, 1984.

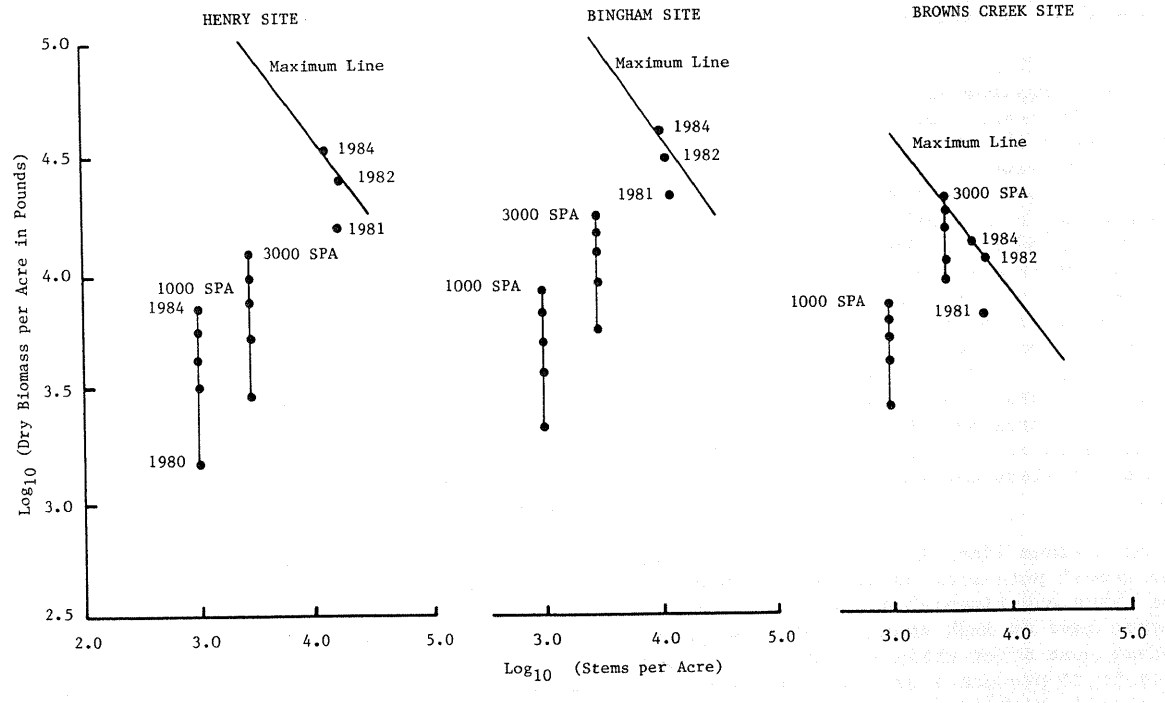

Figure 2.--The relationships between biomass (branch plus stem) and density of the thinned plots (3000 and 1000 SPA) and the unthinned plots (all stems > 1 foot) at the three experimental sites. The maximum lines were drawn in arbitrarily using the data collected in 1981, 1982, and 1984.

the thinning responses at the three experimental sites.

Figure 1 shows the log-log relationships between mean tree dry weight (woody tissue only) and density of the thinned stands (3000 and 1000 leave-trees per acre) and unthinned stands (all stems > 1 foot) at the three sites.

The self-thinning lines at the three sites were drawn arbitrarily, using the slope of -1.5 and data collected in 1981, 1982, and 1984. These lines will be better defined with future measurements.

The effects of thinning is to reduce density and to shift growth onto bigger trees (fig. 1). The relative responses of the three sites can be judged from the location of a particular size-density point in relation to the self-thinning line. The lower the point from the line, the better the growth potential of the crop trees, assuming that the species in question are able to respond. For example, in 1980 when the stands were thinned, the 1000 SPA treatment at Henry was relatively lower than the same treatment at Bingham and Browns Creek, supporting the ranking order of Henry > Bingham > Browns Creek in terms of diameter response (table 3). In 1984, the same situation still persisted suggesting the response may continue at the Henry Site, at least.

On the other hand, the 3000 SPA treatment was much closer to the self-thinning lines; in fact in 1984, the Browns Creek stand was approximately on the line, suggesting another thinning may be necessary to accelerate growth (assuming again the responsiveness of the species). Otherwise, growth would continue along the self-thinning line at a slower rate.

Using the same maximum size-density relation but applied to maximum biomass per acre, figure 2 shows the relationships at the three sites. Again the maximum lines were drawn in arbitrarily using data collected in 1981, 1982, and 1984. The biomass of the unthinned stand (all stems > 1 foot) at Browns Creek was somewhat lower than expected i.e. less than that of the thinned stands in the same year. This was due mainly to chance in locating the sample plots (0.002 acre size) within the unthinned plots, because the calculated biomass of the 3000 stems in the control treatment at this site was indeed equal to that of the 3000 SPA treatment. This would bring the maximum line upwards somewhat but probably not as high as the lines at Henry and Bingham, judging from the number of stems available at each site in 1980 (table 1).

Again, the maximum lines in figure 2 can be used to judge the growth potential of different treatments at the three experimental sites. A thinned stand can never have as much standing biomass as an unthinned stand just after thinning but the idea behind thinning is to produce a maximum biomass at some future date in a shorter time on higher quality stems. It is interesting and useful to see when the thinned stands reach the maximum lines.

CONCLUSIONS

The present study showed that positive growth responses to thinning of young mixed natural hardwood regeneration (< 10-years old) can be achieved with the appropriate species composition and at a density about 1000 stems per acre or less. At these young ages, stands of the Appalachian type responded much more than those of the northern timber type. However, evidence (table 5) suggested that certain species of the latter type if occurring in relatively pure stands may also respond to thinning. Also information on self-thinning in these stands can be used to interpret and guide thinning treatments.

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Appendix 1.--Common and scientific names of species mentioned in this report according to Little (1979).

Ash, white	*Fraxinus americana* L.
Basswood	*Tilia americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, Yellow	*Betula alleghaniensis* Britton
Birch, sweet	*Betula lenta* L.
Black locust	*Robinia pseudoacacia* L.
Blackgum	*Nyssa sylvatica* Marsh.
Cherry, black	*Prunus serotina* Ehrh.
Cherry, pin (fire)	*Prunus pensylvanica* L.
Chestnut, American	*Castanea dentata* (Marsh. L.) Borkh.
Elms	*Ulmus* Spp.
Grapevines	*Vitis* Spp.
Hickories	*Carya* Sp.
Cucumbertree	*Magnolia acuminata* L.
Magnolia, Fraser	*Magnolia fraseri* Walt.
Maple, red	*Acer rubrum* L.
Maple, striped	*Acer pensylvanicum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, black	*Quercus velutina* Lam.
Oak, chestnut	*Quercus prinus* L.
Oak, northern red	*Quercus rubra* L.
Oak, scarlet	*Quercus coccinea* Muenchh.
Oak, white	*Quercus alba* L.
Serviceberry downy	*Amelanchier arborea* (Michx. L.) Fern.
Sourwood	*Oxydendrum arboreum* (L) DC
Yellow-poplar	*Liriodendron tulipifera* L.

Appendix 2.--Responses of young even-aged natural hardwood stands to crop-tree release techniques.

Species	Stand Age	Treatment	Responses and Associated Conditions	Reference
Sugar maple, white oak, yellow-poplar	7-14	3-ft. crown	Diameter.	Downs 1946
Sugar maple, elm, white ash, basswood	11	5-ft. bole	Diameter.	Stoeckler and Arbogast 1947
Northern hardwoods	11	2 1/2- and 5-ft. bole	Diameter.	Conover and Ralston 1959
Red oak, yellow-poplar	7-9	Stand area	Diameter positive, height negative.	Allen and Marquis 1970
Red maple, red oak	7	5-ft. bole	Red maple with diameter positive, red oak no response on Oak Site Index 60.	Smith 1977
Sugar maple, red oak, black cherry, yellow-poplar	9	5-ft. bole	No responses on Oak Site Index 70.	Smith 1977
Black cherry, yellow-poplar	7	5-ft. bole	No responses on Oak Site Index 80.	Smith 1977
Upland hardwoods	6	Stand area	Diameter.	Boyette and Brenneman 1978
Yellow birch	7	8-ft. crown	Diameter positive, height positive.	Erdmann et al 1981
Mixed hardwoods	11	Free-to-grow	Diameter.	Della-Bianca 1975
Sweet birch, yellow-poplar, black cherry	10	Free-to-grow	Diameter.	Smith 1981
Yellow-poplar, basswood, red maple, black cherry, red oak	7-12	Free-to-grow	Diameter.	Lamson 1983
Sweet birch, yellow-poplar black cherry	10-12	Crown-touching	Diameter responses on fair to good sites with trees 25 to 40 ft. tall. Positive height response with yellow-poplar.	Smith and Lamson 1983
Sweet birch, black cherry	10-12	Crown-touching	No responses with trees 33 to 40 ft. tall.	Smith and Lamson 1983
Sugar maple, red oak, yellow-poplar, black cherry	9	5-ft. bole	No responses, presence of grapevines.	Lamson and Smith 1978
Yellow-poplar, black cherry, red oak	7	5-ft. bole	No responses, presence of grapevines.	Trimble 1978 Smith 1979
Sugar maple, yellow-poplar, black cherry	2-12	Free-to-grow	Sugar maple, black cherry no responses. Yellow-poplar some diameter response.	Smith 1983
Yellow-poplar	6	Free-to-grow	No responses.	Beck 1977
Central hardwoods	8	Stand area	Species composition, growth and quality of crop trees not improved.	Hilt and Dale 1982