THINNING

in Young Northern Hardwoods: 5-Year Results

by David A. Marquis

U. S. D. A. FOREST SERVICE RESEARCH PAPER NE-139
1969

NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
RICHARD D. LANE, DIRECTOR

The Author

DAVID A. MARQUIS received his bachelor of science degree in forestry from The Pennsylvania State University in 1955 and his master of forestry degree from Yale University in 1963. He joined the Northeastern Forest Experiment Station as a research forester, and was assigned first to the northern hardwood silviculture project in New Hampshire, where he studied problems of regeneration and thinning. Since 1965 he has been assigned to the timber management research staff at the Station's headquarters in Upper Darby, Pa.

THINNING

in Young Northern Hardwoods: 5-Year Results

WHAT EFFECTS FROM THINNING

THE YIELD of even-aged hardwoods can be increased by a program of regular thinnings. The questions are: How much increase can be expected? And what are the effects on quality?

The 5-year results from a long-term study of thinning in young northern hardwoods on the Bartlett Experimental Forest in New Hampshire show that heavy thinning increased crop-tree basal-area growth by 53 percent and crop-tree diameter growth by 64 percent. There were no adverse effects on tree quality, and overall stand quality has been improved.

THE STUDY

The Stand

The thinnings were made in a 25-year-old even-aged northern hardwood stand that originated after complete clearcutting of an old-growth stand in 1933-35. The stand covers about 22 acres, located on a lower north-facing slope, at about 1,100 feet elevation. The stony, sandy loam soil is a well-drained podzol derived mainly from granite and granitic gneiss glacial till. Paper birch site index on this area is estimated to be 70 feet at 50 years (based on curves prepared by *Curtis and Post 1962*).

The 25-year-old stand contained large numbers of sugar maple, beech, yellow birch, paper birch, and pin cherry; and moderate numbers of white ash, red maple, striped maple, aspen, and red spruce (fig. 1). There were over 4,000 stems 0.5 inches d.b.h. or larger per acre, representing 99 square feet of basal area. Average stand diameter was only 1.8 inches, but individual trees measured more than 8 inches in diameter. There were 130 stems per acre 4.5 inches d.b.h. or larger, representing

Figure 1.—The 25-year-old northern hardwood stand before thinning.

Table 1.—Twenty-five-year-old stand before thinning

Species	Entire stand[1]			Crop trees only		
	Stems per acre	Basal area per acre	Mean diameter	Stems per acre	Basal area per acre	Mean diameter
	No.	*Square feet*	*Inches*	*No.*	*Square feet*	*Inches*
			TOLERANTS			
Beech	1,029	11	1.3	24	1	2.7
Sugar maple	1,041	11	1.3	73	3	2.8
Striped maple	126	2	1.4	—	—	—
Conifers	58	1	1.8	—	—	—
			INTERMEDIATES			
Yellow birch	474	10	1.7	67	4	3.2
White ash	93	3	2.3	31	3	3.9
Red maple	176	5	2.0	21	2	3.5
			INTOLERANTS			
Paper birch	401	24	2.7	169	20	4.4
Aspen	54	9	5.1	—	—	—
Pin cherry	636	23	2.4	—	—	—
All species	4,088	99	1.8	385	33	3.7

[1] Includes all trees 0.5 inches d.b.h. and larger.

24 square feet of basal area. Although the tolerant species such as sugar maple and beech were the most numerous, (about 55 percent of the total number of trees), they were not the dominant species. The intolerant and intermediate species dominated the stand. They were the larger trees; they occupied much of the main crown canopy; and they represented 74 percent of the total basal area (table 1). For a more complete description of the stand before thinning, see Marquis (*1967*).

The Thinning

Twenty 1/4-acre plots were laid out in the study area, with 1-chain isolation strips between them. Plots were then assigned to blocks on the basis of total plot basal area, proportion of

weed species, and proportion of crop-tree species. Of numerous block arrangements tested by analysis of variance, the arrangement with maximum between-block variation in the above attributes was selected. This provided minimum variation among the plots within each block, and helped to reduce problems due to differences in original stand condition from place to place. There were 5 blocks of 4 plots each.

Approximately 100 crop trees were selected in each plot, or 400 per acre. Selection was on the basis of:

- Species. Paper birch, yellow birch, white ash, and sugar maple were given preference; but red maple and beech were accepted where necessary.
- Origin. Seedlings were given preference over sprouts.
- Crown class and size. Large dominant and codominant trees were given preference, but some intermediates were accepted where necessary.
- Bole condition. Clean, straight boles with a minimum of defects were given preference.

Attempts were made to select crop trees so that half of them would be paper birch and half would be other species that mature later than paper birch. In this way, a double harvest—first the short-lived paper birch and later the longer-lived species—could be obtained. Crop-tree tallies showed that an average of 385 trees had actually been selected per acre, representing 33 square feet of basal area in trees averaging 3.7 inches diameter (table 1).

After the crop trees were selected and marked, one of four treatments was randomly assigned to the plots in each block. These treatments consisted of the following:

1. ***Heavy crop-tree thinning.***—All trees that competed directly with the crop trees were removed. Competition was judged as competition between crowns for growing space. An average of 615 stems per acre (mean diameter 3.2 inches), totaling 41 square feet of basal area, were removed in this treatment (table 2).

Table 2.—Twenty-five-year-old stand before and after thinning, by treatment

Treatment	Entire stand[1]			Crop trees only:
	Initial	Cut	Residual	Initial
		TREES PER ACRE *(Number)*		
Heavy	3,942	615	3,327	383
Light	3,908	326	3,582	373
Species	4,082	620	3,462	402
Control	4,253	0	4,253	392
		BASAL AREA PER ACRE *(Square feet)*		
Heavy	97.6	41.3	56.3	30.8
Light	96.9	25.1	71.8	33.5
Species	98.3	32.8	65.5	35.0
Control	99.6	0	99.6	31.2
		MEAN DIAMETER *(Inches)*		
Heavy	1.8	3.2	1.5	3.6
Light	1.8	3.4	1.6	3.8
Species	1.8	2.9	1.6	3.8
Control	1.8	—	1.8	3.6

[1] Includes all trees 0.5 inches d.b.h. and larger.

2. ***Light crop-tree thinning.***—A maximum of one of the trees competing with each crop tree was removed. In some cases (where the crop tree was a strong dominant or where a competing tree was adjacent to two crop trees) no competing tree was removed. An average of 326 stems per acre (mean diameter 3.4 inches) were removed, totaling 25 square feet of basal area (table 2).

3. ***Species thinning.***—All aspen, pin cherry, and striped maple were removed; all red maple sprout clumps were also removed except for sprouts selected as crop trees. There were only a few red maple sprout crop trees. In this treatment, trees specified were removed whether or not they were competing with the crop trees. An average of 620 stems per

acre (mean diameter 2.9 inches), totaling 33 square feet of basal area, were removed. This treatment, which was included because it would eliminate the need for marking crop trees in actual practice, resulted in the removal of about the same number of trees as the heavy crop-tree thinning. However, the trees removed were generally smaller than those removed in the other two treatments. The species thinning also tended to be more variable—very heavy in places where there were many weed species, and very light in places where there were few weed species (table 2).

4. ***Control plots***.—No trees were removed (table 2).

Actual thinning was done in late August 1959 by applying sodium arsenite in frills (fig. 2). However, for sprout clumps in which one or two crop trees were to be retained, thinning was done by cutting the unwanted trees (fig. 3).

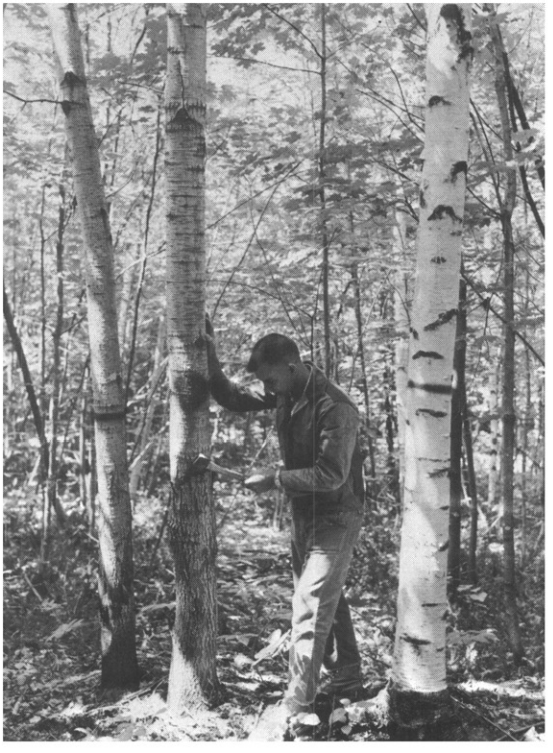

Figure 2.—Trees to be removed were killed with sodium arsenite, applied in frills. Here an aspen is being treated to release an adjacent paper birch.

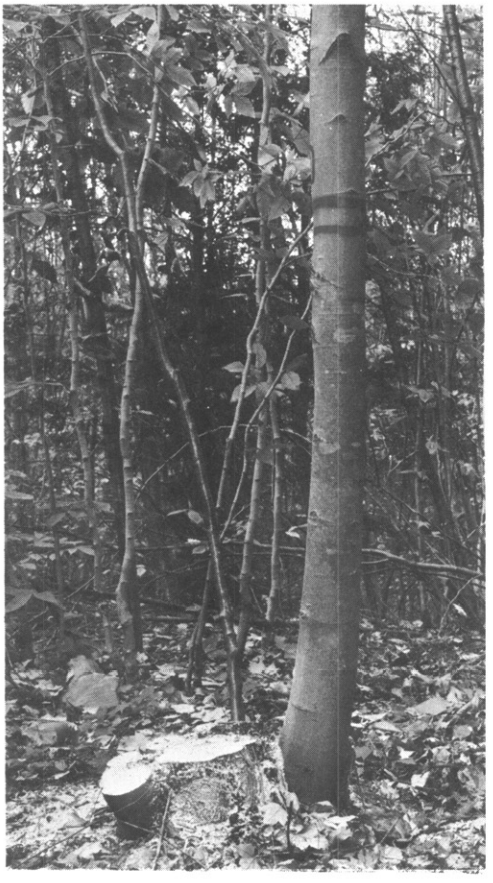

Figure 3.—This red maple crop tree was a member of a large sprout clump. The other stems of the clump have been cut to release it.

Measurements and Analysis

One hundred percent tallies were made of the crop trees and of the entire stand 0.5 inch d.b.h. and larger, both before thinning in 1959 and 5 years later in 1964. Similar tallies were made of all trees removed in the thinning. In addition, four trees of each crop-tree species present on each plot were selected at random for detailed measurements. These measurements included: diameter at breast height and at the top of the first 16-foot log (diameter at top of first 16-foot log measured only in 1964); merchantable height; total height; live crown length, crown area (basal area of crown projection), crown volume (crown area times crown length), crown class, and

crown vigor; clear length of bole (height to first live or dead branch, excluding epicormics); number and location of branches, epicormic branches, and bole defects; and bole quality class. These measurements permitted detailed evaluation of individual tree development.

Differences among the four treatments in net basal-area growth of the entire stand were tested for significance, using the analysis of variance. Differences among the four treatments in crop-tree diameter growth and crop-tree basal-area growth were also tested for significance, using the analysis of variance. Information from the sample crop trees was used in a variety of separate analyses. A series of sequential multiple-comparison tests (*Snedecor 1956*) was used to detect differences among treatments, among species, and among crown classes in such attributes as diameter growth, basal-area growth, height growth, cubic-foot volume, change in length of clear bole, change in number of branches and epicormic branches in the first log, changes in numbers of trees with forks, and changes in crown length, crown area, crown volume, and crown ratio.

Differences in diameter, basal area, crown area, and crown volume increment among treatments were tested further for significance, using the analysis of covariance and adjusting for small differences in initial tree size among the sample trees. Differences among treatments in the distribution of trees among the various crown classes, crown-quality classes, and bole-quality classes were tested with chi-square analyses. And finally, multiple regressions were computed, relating sample crop-tree diameter growth, basal-area growth, and crown-volume growth to various stem and crown variables.

RESULTS

RESPONSE OF THE ENTIRE STAND

Between 1,000 and 1,500 stems per acre—nearly one-third of the total number of stems present in 1959—died during the 5-year study period. Mortality was highest on the control plots where there was no thinning—400 to 500 more stems per acre

Table 3.—Response of the entire stand to thinning

Treatment	5-Year mortality per acre		Annual net basal-area increment per acre
	Number trees	*Percent*	*Square feet*
Heavy	1,019	31	4.0
Light	1,129	32	3.3
Species	977	28	4.9
Control	1,502	35	2.2

died on this treatment than on the three thinning treatments. Mortality was lowest on the species-thinning plots (table 3).

The reduced mortality noted on the thinned plots may be partially artificial because some stems that would have died anyway were cut. This is especially true on the species-thinning plots, where many small pin cherry and striped maple weed trees were removed even though they were not competing with the crop trees. However, the thinning almost certainly reduced mortality among the smaller trees in the stand. This reduction in mortality may not be important at this time because these trees are too small to be merchantable. However, if this trend continues after the trees reach merchantable size, salvage of this mortality by thinning will provide important increases in total stand yield.

Net basal-area growth of the entire stand was nearly twice as high on the three thinning treatments as it was on the control plots (table 3). The differences among treatments reflect the high mortality on the control plots and the lower mortality on the thinned plots. If an allowance is made for the extra mortality on the control plots, basal-area growth on the thinned plots is more nearly equal to that on the control plots.

RESPONSE OF THE CROP TREES

Little mortality occurred among the crop trees during the 5 years after thinning. An average of only one crop tree per acre died on each of the three thinning treatments, and an average of five crop trees per acre died on the control plots.

Growth Response of All Crop Trees

Diameter growth and basal-area growth were about one-third greater on the thinned plots than on the unthinned plots. These differences were highly significant (0.01 level). Growth was also significantly greater (0.05 level) on the heavy crop-tree thinning plots than on the other thinned plots (table 4).

All species responded well to thinning. The tolerant sugar maple and beech more than doubled their growth after heavy crop-tree thinning. Although the percentage increase on the other species was less, the actual increases were important for all species. Thinning also increased growth of trees in all diameter classes. The larger trees showed the largest absolute increase, although the percentage increase was greater for the smaller trees.

It is interesting to note that the basal-area growth on the heavy crop-tree thinning amounted to 3.2 square feet of basal area per acre per year on the crop trees alone. This does not include any growth made by the other 2,000 trees in the stand.

Table 4.—Growth response of all crop trees to thinning

Treatment	Basal-area growth per acre per year[1]	Diameter growth per year
	Square feet	*Inches*
Heavy	3.2	0.18
Light	2.7	.15
Species	2.7	.15
Control	2.1	.11

[1] Because of minor differences in original crop-tree basal area among the four treatments (table 2), crop-tree basal-area growth was adjusted to a common original basal area.

Growth Response of the Sample Crop Trees

The sample crop trees provide a means of comparing differences in growth among treatments, for not only d.b.h. and basal area, but also for height, volume, crown volume (crown

Table 5.—Growth response of the sample crop trees to thinning

Treatment	D.b.h. increment	Basal-area increment	Height increment	Volume, 1964	Crown-length increment	Crown-ratio change	Crown-volume increment
	Inches per year	*Square feet per tree per year*	*Feet per year*	*Cubic feet per tree*	*Feet per year*	*Ratio change per year*	*Cubic feet per year*
Heavy	0.18	0.0087	1.5	1.5	1.2	+0.008	514
Light	.15	.0075	1.6	1.6	1.1	+ .005	548
Species	.15	.0073	1.4	1.4	.8	+ .002	378
Control	.10	.0045	1.7	1.1	.9	– .001	306

basal area X crown length), crown ratio, and crown length (table 5).

Diameter increment at b.h. and basal area increment of the sample trees corresponded almost exactly with the results obtained from all crop trees, indicating that the samples accurately represented the entire crop tree stand.

Cubic-foot volume was computed as the mean of the basal area at b.h. and the basal area at 17 feet X a log length of 16 feet. No diameter measurements were taken at 17 feet in 1959, so volume increment cannot be determined at this time. However, differences in 1964 volume indicate that butt-log volumes are greater on the thinned plots than on the control plots. Differences among the three thinning treatments were not significant.

Differences in height increment were not significant. However, the general trend suggests that heavy thinnings may have reduced height increment slightly.

Crown-length increment did not vary significantly among treatments, but the general trend suggests that crown length is increasing faster on the more heavily thinned plots.

Although neither height increment nor crown-length increment varied significantly, the small differences that appeared in these two parameters combined to yield a significant difference in crown-ratio change between the heavy crop-tree thinning and the control stands. Differences among the other treatments

were not statistically significant. Relative crown size is decreasing on the unthinned plots while it is increasing on the thinned plots. If this change continues at the present rate for another 5 years, crown ratio will average 0.62 on the heavily thinned trees versus 0.53 on the unthinned trees.

Crown-volume increment was significantly greater on the two crop-tree thinning treatments than on the species-thinning treatment or the control plots.

Although every effort was made to minimize differences among plots at the beginning of the study, there were significant differences among treatments in original crown volume of the sample crop trees. This presented the possibility that the differences in growth reported above might be due, at least in part, to these initial differences in crown size. A series of covariance analyses was made, using initial crown volume and other variables as covariates. These analyses, in effect, provide a test for treatment after adjusting for initial differences in the covariate. The results of these covariance analyses indicate that the growth differences due to treatment were still highly significant.

Factors Affecting Growth of the Sample Crop Trees

To provide a better understanding of the factors that affect growth of the crop trees, a series of multiple regressions was computed for diameter, basal area, crown area, and crown volume increment. Independent variables included original d.b.h., basal area, crown area, crown volume, height, crown class, species, and treatment (the latter three entered as dummy or classification variables), and some of their cross products. Regressions incorporating these variables were computed by using a full screening technique.

In all cases, the single factor accounting for the largest proportion of the observed variance was either original d.b.h. (for diameter growth) or original basal area (for the other three dependent variables).

Although original crown volume (or original crown area) had

a significant effect by itself, the addition of crown volume to regressions that already contained d.b.h. (or basal area) did not produce a significant increase in the coefficient of determination (R^2). Original d.b.h. (or basal area) and original crown volume were apparently related closely.

Crown class, as evaluated with six classes in this study (see appendix for definitions), accounted for more of the variation than did the measured crown volume. And the addition of crown class to equations containing basal area (or d.b.h.), resulted in significant increases in the coefficient of determination. Although these results were somewhat unexpected, there may be reasons for them. First, crown class, as used in this study, provides a measure of competition as well as a measure of crown position, so it may be more sensitive than measures of crown position alone. Second, crown volume may not provide a very realistic measure of the effective crown size. In crowns of irregular shape—particularly on tolerant hardwoods that may have one or two very long branches at a point low on the bole—crown volume measured as it was here may not be too useful.

Although the addition of crown class to equations containing basal area (or d.b.h.) resulted in a significant increase in R^2, the increase was not as great as the addition of species or treatment dummy variables. Sequential addition of variables produced final equations containing these variables: basal area (or d.b.h.), species, and treatment. The addition of crown class or other variables to these equations did not produce further significant increases in the R^2 at the 0.05 level.

The best equation developed in this screening relates basal area increment to original basal area, species, and treatment. This equation accounts for 80 percent of the observed variation in basal-area increment. The regression of d.b.h. increment on similar independent variables accounts for 63 percent of the observed variation. The higher R^2 obtained with basal-area growth is probably due to the fact that basal area is a better measure of total wood production than is d.b.h. For example, diameter growth of 0.10 inch on a 6-inch tree represents considerably more wood than 0.10 inch on a 2-inch tree. In

contrast, 0.008 square feet of basal-area growth represents the same amount of wood area no matter what the tree diameter.

From this information above, separate regressions were computed for each of the six crop-tree species, relating basal area and d.b.h. increment to original basal area (or original d.b.h.), treatment, and the interaction between original basal area (or original d.b.h.) and treatment. Of the 12 regressions thus computed, all were found to be statistically significant. Coefficients of determination (R^2) for d.b.h. increment varied from 0.42 (beech and yellow birch) to 0.64 (paper birch), and

Table 6.—Predicted annual basal-area increment of 25-year-old crop trees on site index 70
(Square feet per tree per year)

Species	Treatment	Original d.b.h.				
		2	3	4	5	6
Paper birch	Heavy	—	0.005	0.010	0.014	0.019
	Light	—	.005	.009	.013	.017
	Species	—	.003	.009	.014	.020
	Control	—	.002	.007	.013	.018
White ash	Heavy	—	.008	.012	.016	—
	Light	—	.006	.011	.015	—
	Species	—	.007	.012	.016	—
	Control	—	.006	.011	.015	—
Red maple	Heavy	—	.006	.013	.020	—
	Light	—	.006	.011	.017	—
	Species	—	.007	.013	.018	—
	Control	—	.004	.006	.008	—
Yellow birch	Heavy	0.002	.006	.010	.013	—
	Light	.002	.004	.007	.009	—
	Species	.001	.004	.006	.008	—
	Control	.000	.003	.006	.008	—
Sugar maple	Heavy	.002	.007	.012	—	—
	Light	.001	.005	.009	—	—
	Species	.002	.005	.009	—	—
	Control	.001	.003	.006	—	—
Beech	Heavy	.004	.005	—	—	—
	Light	.001	.004	—	—	—
	Species	.001	.004	—	—	—
	Control	.000	.003	—	—	—

Table 7.—Predicted annual d.b.h. increment of 25-year-old crop trees on site index 70

(Inches per year)

Species	Treatment	Original d.b.h.				
		2	3	4	5	6
Paper birch	Heavy	—	0.13	0.17	0.22	0.26
	Light	—	.14	.17	.20	.23
	Species	—	.13	.17	.22	.27
	Control	—	.07	.12	.19	.25
White ash	Heavy	—	.20	.23	.25	—
	Light	—	.18	.21	.24	—
	Species	—	.18	.22	.26	—
	Control	—	.15	.20	.24	—
Red maple	Heavy	—	.17	.24	.32	—
	Light	—	.14	.23	.31	—
	Species	—	.17	.23	.29	—
	Control	—	.10	.13	.15	—
Yellow birch	Heavy	0.11	.16	.20	.24	—
	Light	.07	.10	.13	.16	—
	Species	.05	.09	.13	.18	—
	Control	.03	.07	.11	.16	—
Sugar maple	Heavy	.10	.17	.23	—	—
	Light	.07	.13	.19	—	—
	Species	.08	.14	.19	—	—
	Control	.05	.10	.15	—	—
Beech	Heavy	.12	.14	—	—	—
	Light	.07	.12	—	—	—
	Species	.06	.10	—	—	—
	Control	.03	.09	—	—	—

for basal-area increment they varied between 0.56 (beech) and 0.80 (paper birch and white ash).

Comparison of the plotted regression lines with the actual data strongly suggested that the relationships, although statistically significant, are not adequately expressed as a straight line. No attempts were made to fit curvilinear regression forms to the data because the relative importance of the various independent variables seems to have been well established in the previous regressions, and the values obtained from the linear regressions are adequate for growth-prediction purposes over the middle range of diameter classes represented by the data. Predicted

diameter and basal area increments for 25-year-old crop trees of various original d.b.h. and thinning treatments are presented in tables 6 and 7.

Quality Response of the Sample Crop Trees

Changes in some of the many attributes that affect tree quality are listed in table 8.

- *Changes in crown class.* At the end of the 5-year period there were nearly twice as many dominant and strong codominant trees (see appendix for description of classes) in the heavy crop-tree thinning as there were in the unthinned stands. And there were five times as many dominants in the heavy treatment as in the control plots (table 8). Chi-square analyses of changes in distribution of trees by crown class revealed that significantly more trees dropped in crown class in the unthinned stand than did in the thinned stands. Thus, heavy thinning has helped to retain more crop trees in the upper crown classes. Even in this treatment, however, the trend is for the number of trees in the upper crown classes to be reduced gradually as the trees get larger and approach mature size.

- *Change in bole quality class.* Changes in the distribution of trees by bole-quality class (see appendix for description of classes) did not vary significantly by treatment for all species together. Paper birch and red maple improved significantly after thinning; beech dropped significantly in bole quality after thinning; ash improved regardless of treatment; and sugar maple and yellow birch did not change significantly after thinning. However, the overall trend was for a slight improvement in bole quality for the stand as a whole. Most of these changes in bole quality were due to a general reduction in the number of branches or to changes (increase or decrease) in the number of epicormic branches.

- *Changes in epicormic branching.* Individual species varied considerably in the development of epicormic branches

Table 8.—Quality responses of the crop trees 5 years after thinning

Response	Heavy	Light	Species	Control
Proportion of trees in dominant crown classes[1] ..... percent ..	10	9	6	2
Proportion of trees in dominant and strong codominant crown classes[1] ..... percent ..	49	40	40	27
Changes in the proportion of trees in bole class 1 and 2[1] ..... percent ..	+3	+4	+3	+1
Changes in proportion of trees with no epidermic branches ..... percent ..	-9	-27	-18	-9
Trees with increased number of epicormic branches ..... percent ..	41	59	49	57
Increases in length of clear bole .... feet per year ..	0.7	0.6	0.8	0.8
Proportion of live branches in the butt log that died during the time ..... percent ..	45	49	52	55
Changes in proportion of trees with forks in the lower 25 feet of bole ..... percent ..	-1	+4	0	+2
Taper—ratio of diameter at 17 feet to d.b.h. ..... ratio ..	0.79	0.80	0.78	0.77

[1] See appendix for description of crown classes and bole classes.

during the 5-year period after thinning. No epicormic branches were found on either paper birch or white ash crop trees. The number of trees with epicormic branches increased by nearly 30 percent among the other four species, but this increase occurred on both thinned and unthinned trees. Differences among treatments were not significant. In general, the lighter thinnings seemed to cause epicormic branch formation on more trees than the heavier thinnings; but this

trend was not significant and it is probably just a chance occurrence.

Epicormic branches were common on yellow birch, beech, and sugar maple even before thinning. About half the crop trees of these species had epicormic branches. However, these epicormic branches were generally little more than short shoots with one or two leaves; they were seldom large enough to be true branches and probably do not represent important defects in their present form. We shall need additional time to determine whether or not these little branches will persist and grow to become important sources of defect as the trees reach merchantable size.

- *Changes in length of clear bole.* Changes in length of clear bole (height to the first branch, either dead or alive) during the period did not follow any consistent pattern, and differences among treatments were not statistically significant. Overall increase in length of clear bole averaged nearly 4 feet in 5 years.

  The proportion of live branches in the first log that died during the 5-year period is another measure of natural pruning. Although no statistical tests were made of these data, there appeared to be slightly fewer live branches dying in the heavily thinned treatment than in the unthinned treatment. A longer period of time will be required to evaluate this effect.

- *Changes in numbers of forks.* Changes in the numbers of crop trees with forks below 25 feet revealed no significant differences among treatments.

- *Changes in stem taper.* Because diameter at 17 feet was not measured in 1959, changes in stem taper could not be determined. However, comparisons of taper present in 1964 revealed no significant differences among treatments, except that the light crop-tree thinning had significantly less taper than the control. This is probably just a chance occurrence.

DISCUSSION

One effect of the thinning in this 25-year-old stand is rather definite: diameter and basal-area growth of residual crop trees was stimulated at breast height. The amount of the increase varied with degree of thinning, species, and original tree size. Increases in growth were significant statistically, and these increases are economically and silviculturally highly significant as well.

For example, if we assume that repeated thinnings would maintain growth at the present rates, it should take the heavily thinned paper birch crop trees about 15 years less time to reach an average diameter of 13 inches d.b.h. than it will those in the unthinned stands. Or, heavily thinned yellow birch crop trees should reach 18 inches average diameter nearly 50 years before unthinned yellow birch. If the actual growth rate falls off as the stands get older, but relative differences between thinned and unthinned crop trees remain similar, then the reductions in rotation due to thinning will be even larger than above. Such differences suggest that thinnings begun early and repeated regularly will materially reduce the rotation age required to grow a given-size tree or increase tree size attainable at a given age.

Of the three thinning treatments used, the heavy crop-tree thinning has resulted in best growth. Heavy crop-tree-thinning increased crop-tree basal-area growth by 53 percent and diameter growth by 64 percent over those of the unthinned control plots.

The increased bole growth resulting from thinning was accompanied by—and perhaps the result of—increased crown expansion among the thinned trees. Crown ratio of thinned crop trees increased, whereas crown ratio of unthinned crop trees decreased. Heavily thinned crop trees produced 36 percent more crown-area increment and 68 percent more crown-volume increment than unthinned crop trees. And thinning helped to maintain the crop trees in the upper crown classes; 5 years after thinning there were twice as many dominant and strong

codominant crop trees on the heavily thinned plots as on the control plots.

Although 5 years is not long enough to determine how thinning will affect quality of the eventual yield, there have been no reductions in quality to date that can be attributed to thinning. Changes in bole-quality classification of the crop trees was not affected by treatment. Although the number of epicormic branches increased over the 5-year period, the increases were as large on the unthinned plots as on the thinned plots. Changes in other parameters, such as length of clear bole, numbers of forks, and stem taper, did not differ significantly among treatments. Overall stand quality should improve after thinning, since growth is now being concentrated on the best stems of the more valuable species.

Data presented in this paper should be useful in estimating the short-term growth increases that can be expected from thinnings in young northern hardwoods. Economic evaluations of these data are now being made. These should provide forest managers with some guides on whether or not investments in thinnings are desirable for short-term product goals such as paper birch boltwood. And evaluations of the effects of thinning on long-term product goals such as sawtimber and veneer will be possible after additional years of growth and quality data are obtained.

LITERATURE CITED

Curtis, R. O. and B. W. Post.
1962. SITE INDEX CURVES FOR EVEN-AGED NORTHERN HARDWOODS IN THE GREEN MOUNTAINS OF VERMONT. Vt. Agr. Exp. Sta. Bull. 629, 16 pp.

Marquis, David A.
1967. CLEARCUTTING IN NORTHERN HARDWOODS: RESULTS AFTER 30 YEARS. U. S. Forest Service Res. Paper NE-85, 13 pp. NE. Forest Exp. Sta., Upper Darby, Pa.

Snedecor, George W.
1956. STATISTICAL METHODS. Ed. 5, 534 pp. The Iowa State College Press, Ames, Iowa.

APPENDIX

QUALITY CLASSIFICATION

The quality classification used in this study is a three-attribute classification indicating crown position and relation to surrounding trees (crown-class), crown development, and bole condition. Criteria for classification are listed below:

CROWN POSITION & RELATION TO SURROUNDING TREES

100—***Strong dominant.*** Tree taller than all its immediate neighbors. Crown extends well above the general level of the crown cover and receives full light from above and considerable light from the sides. DOMINATES ALL IMMEDIATE NEIGHBORS.

200—***Dominant.*** Tree slightly taller than its immediate neighbors. Crown extends somewhat above the general level of the crown cover and receives full light from above and considerable light from the sides. COMPETES WITH OTHER DOMINANTS OR CODOMINANTS, WHICH ARE SOMEWHAT INFERIOR.

300—***Codominant.*** Tree with crown formed at the general level of the crown cover. Receives full light from above but comparatively little from the sides. COMPETES WITH OTHER CODOMINANTS, BUT IS IN NO IMMEDIATE DANGER OF BEING CROWDED OUT.

400—***Weak codominant.*** Tree with crown formed at the general level of the crown cover. Receives full light from above but very little from the sides. COMPETES WITH OTHER CODOMINANTS OR DOMINANTS, WHICH ARE SUPERIOR IN VIGOR.

500—***Intermediate.*** Tree shorter than those above but with crown extending into the crown cover formed by the dominants and codominants. Receives a little direct light from above but none from the sides. COMPETES WITH TREES OF HIGHER CROWN CLASS AND DEVELOPMENT.

600—***Overtopped.*** Tree with crown entirely below the general crown level. Receives no direct light from above.

CROWN DEVELOPMENT

10—*Good.* Very large, well-developed, well-rounded crown, not compressed by neighboring crowns.
20—*Average.* Well-developed vigorous crown, slightly compressed by neighboring crowns, but not flattened.
30—*Fair.* Smaller than desirable crown, compressed on all sides or flattened on one side.
40—*Poor.* Very small spindly, flattened crown; very low vigor.

BOLE CONDITION

1—*Good.* No live branches, no epicormic branches in first 17 feet. Allows these defects[1]:
Slight lean.
One slight crook and/or one slight sweep.
Slight wounds.

2—*Medium.* Allows one live branch and/or fewer than 5 epicormic branches in first 17 feet. Also allows these defects:
Slight lean.
Slight crook.
Slight sweep.
Moderate crook if located so 12-foot log still obtainable.
Moderate sweep if located so 12-foot log still obtainable.
Slight wounds.

3—*Fair.* Allows any number of live branches or epicormic branches. Also allows the following defects:
Slight or moderate lean.
Slight or moderate crook.
Slight or moderate sweep.
Severe crook if located so 12-foot log still obtainable.
Fork.
Slight or moderate wounds.

4—*Poor.* Allows any number of defects of any severity.

Example: 432 would represent a weak codominant of fair crown development and medium bole condition.

[1] The various types of bole defects were carefully defined as to type and severity. Photographs of typical defects were used to aid in maintaining uniformity of classification.

THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.