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FIFTEEN-YEAR RESULTS FROM SIX CUTTING METHODS IN SECOND-GROWTH NORTHERN HARDWOODS

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NORTH CENTRAL FOREST EXPERIMENT STATION

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FIFTEEN-YEAR RESULTS FROM SIX CUTTING METHODS IN SECOND-GROWTH NORTHERN HARDWOODS

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Presently there are over 9 million acres of northern hardwoods in the Lake States. Most of these hardwoods are in second-growth poletimber stands under 70 years of age. These second-growth stands either originated following commercial clearcutting between 1900 and 1930 or developed after years of high-grading. Consequently, they are now primarily even-aged with a scattering of older residuals, or uneven-aged. Today's uneven-aged stands usually have fewer ages and size classes than the original old-growth stands. Most stands contain a mixture of species. Sugar maple (*Acer saccharum* Marsh.) is the most abundant species on well-drained sites. Common associates are basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.), yellow birch (*Betula alleghaniensis* Britton), red maple (*Acer rubrum* L.), American elm (*Ulmus americana* L.) and eastern hemlock (*Tsuga canadensis* (L.) Carr.).

How do these stands respond to different methods of cutting and what are some of the management alternatives? During the winter of 1951-1952 a study was begun to answer these questions. This study compares the effects of different cutting methods on tree growth, species composition, and product yield in three second-growth northern hardwood stands in northeastern Wisconsin. Study objectives were: (1) to obtain information on basal-area production and volume yield in terms of cubic feet, board feet, and cords, and (2) to obtain growth and mortality data under different cutting methods. Other specific objectives dealing with tree quality and development of regeneration have been reported elsewhere (Godman and Books 1971, Metzger and Tubbs 1971).

This paper compares 15-year results of single-tree selection cuts to three stocking levels, a crop-tree release cut, and an 8-inch stump diameter limit cut in these stands. Management implications derived from a wide range of beginning basal area stocking levels are also discussed.

STUDY AREA

Three 40-acre stands located on the Argonne Experimental Forest in northeastern Wisconsin were chosen for the study. The stands are on good sites and are typical of those originating from commercial clearcutting.

Site indices at 50 years were similar for the three stands: about 65 for sugar maple and yellow birch, and about 70 for basswood and white ash. The soils are well- to moderately well-drained Iron River loams with a layer of boulders just beneath the surface.

When the study was established, two of the stands were composed primarily of 45-year-old, even-aged, pole-sized trees. The third stand contained a higher proportion of small saw-log-sized trees, but pole-sized trees were also well represented. The trees left from the original cut were mostly low-grade trees (short merchantable bole lengths or poor quality) as old as 170 years.

Before cutting, the stands averaged 237 trees 4.6 inches d.b.h. and larger per acre, of which 59 percent were sugar maple, 10 percent basswood, 7 percent yellow birch, 6 percent white ash, and 5 percent hemlock. Occasional red maple, American elm, paper birch (*Betula paperifera* Marsh.), black ash (*Fraxinus nigra* Marsh.), black cherry (*Prunus serotina* Ehrh.), aspen (*Populus* spp.), and ironwood (*Ostrya virginiana*) trees were also present.

Basal area stocking of all trees 4.6 inches d.b.h. and larger averaged 92 square feet per acre before cutting. Sugar maple was the predominant species, accounting for 57 percent of the basal area. Basswood made up 10 percent of the basal area, hemlock 9 percent, yellow birch 8 percent, white ash 6 percent, and other less common species 10 percent.

Before cutting, the stands averaged 2,199 cubic feet of peeled wood per acre.[1/] Sugar maple accounted for 56 percent of the cubic-foot volume.

1/ *Includes stump, stem, tip, and branches to 4.0 inches d.i.b. tops.*

CUTTING METHODS

A brief description of the cutting methods and subsequent treatments is given below:

Cutting method	Treatment and residual basal area[2/]
Control	Uncut stand with 94 sq. ft. basal area per acre.
Light selection	Cut to residual basal area of 90 sq. ft. per acre.
Medium selection	Cut to residual basal area of 75 sq. ft. per acre.
Heavy selection	Cut to residual basal area of 60 sq. ft. per acre.
Crop tree	Crown-released 30 to 50 crop trees per acre and cut all understory trees, except for trainers, within a 10-foot radius of a crop-tree bole. Residual basal area averaged 60 sq. ft. per acre.
Diameter limit	Cut all trees with stump diameters of 8 inches or more. Residual basal area averaged 21 sq. ft. per acre.

In the selection cuttings overmature and defective growing stock were removed first. Valuable yellow birch, sugar maple, basswood, and white ash were favored, while balsam fir (*Abies balsamea* (L.) Mill.) over 6 inches d.b.h., ironwood and any hemlock except those of good form and crown development were removed. The selection cuttings in 1951 left a stand of desirable hardwood trees 4.6 inches d.b.h. and larger at the required densities. After 10 years, the selection cuttings were recut to originally assigned densities. This time fewer saw-log trees were cut in an attempt to start building an all-aged stand structure. The crop-tree and 8-inch diameter limit treatments were not recut in 1961.

MEASUREMENTS AND ANALYSIS

A randomized block design was used with six cutting treatments in each of three blocks. Treatment plots were 5x5 chains square or 2.5 acres in size. A cluster of five permanent 0.1-acre circular plots were installed as the sampling units within each treatment plot.

A 100-percent inventory was made of each 0.1-acre growth plot before and after cutting in the winter of 1951-1952. Estimates of cull- and saw-log grade recovery were made from the volume cut in 1951-1952. End-of-the-growing-season inventories were repeated in 1957, in 1961 before and after cut, and in 1966. All trees 4.6 inches d.b.h. and larger were measured to the nearest 0.1 inch and tallied by species.

In the analyses data from the five 0.1-acre plots within each treatment were combined to make a 1/2-acre measurement unit for each treatment in each block. Growth and yield data were computed for the three measurement periods and then combined for the 15-year record.

General relationships of basal-area growth, cubic-foot growth, cordwood growth, and board-foot growth to basal area stocking were also investigated using the 1/2-acre growth plots. Basal-area densities at the beginning of the measurement period and corresponding periodic annual growth from each of the 54 1/2-acre growth plots (six one-half-acre plots x three blocks x three periods) were used in developing freehand growth curves and a board-foot growth model.

Trees were felled and sectioned in 1952 and 1969 for local volume table construction. Measurements for cubic-foot volumes included diameters inside bark beginning at a 1-foot stump to the nearest 0.1 inch at 8.3 foot intervals to a 4.0-inch, top, and total tree heights to the nearest foot. In addition, measurements on saw-log trees (9.6 inches d.b.h. and larger) included those needed to compute Scribner board-foot volumes to a variable merchantable top diameter that was limited by branches, defect, or other deformity, but not less than an 8.0-inch d.i.b. top. Total cubic-foot volumes inside bark were computed for each tree over 4.6 inches d.b.h. using Smalian's formula for the stump, stem in 8.3 foot lengths to a 4.0-inch d.i.b. top, the tip, and branches to 4.0-inch d.i.b. tops. Then following Spurr's (1954) volume line method, separate local cubic-foot volume tables were constructed for sugar maple, basswood, yellow birch, and white ash. The sugar maple volume-line equations were also used for calculating cubic-foot volumes of other less commonly associated species such as red maple and American elm. Merchantable board-foot and cordwood volumes were derived from the total cubic-volume estimates by use of appropriate converting factors for different mean stand diameters (Spurr 1954). A cord was assumed to contain 79 cubic feet of solid wood in our cordwood computations.

In 1957 and 1961 complete sapling inventories by 1-inch classes were taken on each 0.1-acre growth plot.

2/ Basal area per acre in trees 4.6 inches and larger.

DEFINITION OF TERMS

Terms used in our growth analyses are defined as follows.

Survivor growth.--Growth on trees originally 4.6 inches d.b.h. and larger that were living at both the beginning and end of each of three (4- to 6-year) observation periods.

Ingrowth.--Growth on trees that attained measurable size during each observation period. Ingrowth is used in the following ways: a tree that grew into the 4.6 inch d.b.h. class during an observation period was considered new growing stock; a tree that grew into the 9.6 inch d.b.h. class was considered a new saw-log tree.

Mortality.--The number, initial volume, or basal area of all trees that died during each observation period. Such trees were assumed to have made no growth during the period.

Gross growth.--Volume or basal area for each observation period = survivor growth + ingrowth.

Net growth.--Volume or basal area for each observation period = gross growth - mortality, or survivor growth + ingrowth - mortality.

RESULTS

Basal Area Growth

Net basal area growth of all trees 4.6 inches d.b.h. or larger ranged from 2.32 to 3.22 square feet of basal area per acre per year for the six cutting treatments (table 1). Net basal area growth was least on the uncut control and tended to increase with decreasing basal area, but differences in average net and gross basal area growth among the various cutting treatments were not statistically significant.

Net basal area growth was surprisingly good in the 8-inch diameter limit treatment, which had been cut back to 21 square feet of basal area per acre. The high ingrowth volume more than offset the low survivor growth rate. Although there were enough small trees to fully utilize the site in the diameter limit cut by 1961, stocking was insufficient in trees 8 inches and larger for a second cut.

Basal Area Growth and Stocking

In northern hardwood stands both periodic gross and net annual basal area growth peaked at about 45 square feet of basal area per acre (fig. 1). Net annual basal area growth exceeded 3 square feet per acre between 20 and 70 square feet of beginning basal area stocking. Below 20 square feet per acre, net growth was reduced because the site was not being fully utilized by trees pole-sized or larger. Above 115 square feet, net growth per acre dropped off sharply due to higher mortality.

Average annual basal area growth of trees surviving the measurement period was constant between 45 and 80 square feet per acre but decreased above the 80-square-foot stocking level. Average basal area ingrowth into the 4.6-inch d.b.h. class decreased from about 1 square foot per acre annually at 50 square foot stocking to less than 0.1 square foot annually above 115 square foot stocking.

Fifteen-Year Mortality

Fifteen-year mortality for all species of trees 4.6 inches d.b.h. and larger averaged only

Table 1.--Average annual gross and net basal area growth, survivor growth, ingrowth, and mortality on all trees 4.6 inches d.b.h. and larger by cutting method (15-year basis)1/ (Square feet per acre per year)

Cutting method	Survivor growth	Ingrowth2/	Gross growth	Mortality	Net growth
Control	2.87	0.23	3.10	0.78	2.32
90 sq. ft.	2.81	.27	3.08	.42	2.66
75 sq. ft.	2.82	.27	3.09	.37	2.72
60 sq. ft.	2.83	.54	3.37	.29	3.08
Crop tree	3.23	.55	3.78	.64	3.14
Diameter limit	2.29	1.33	3.62	.40	3.22
$S_{\bar{x}}$	.15	.11	.23	.13	.34

1/ Values in the same column enclosed by a bracket are not significantly different (0.05 level) using Duncan's new multiple range test.

2/ Into 4.6 inch d.b.h. class.

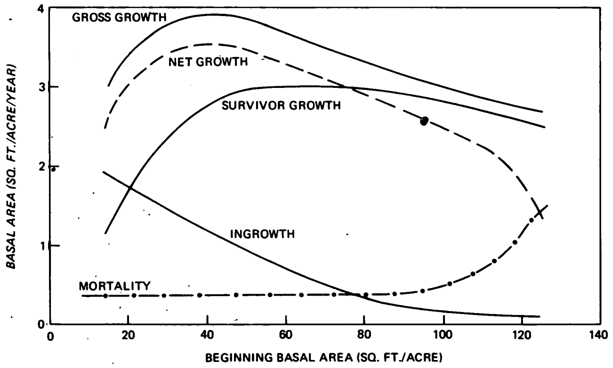

Figure 1.--Relation of periodic annual gross and net basal area growth, survivor growth, ingrowth, and mortality to beginning basal area per acre (all trees 4.6 inches d.b.h. and larger, site index 65 at age 50 for sugar maple).

9 percent for all treatments. Losses were low regardless of the cutting method used. Significantly more pole-sized trees (19 per acre) died than did saw-log sized trees (three per acre).

Sugar maple, the most abundant species, accounted for half of the total 15-year mortality; yet, only 7 percent of the sugar maple stems died. Hemlock, white ash, and red maple mortality was also low (5 to 6 percent), while mortality of yellow birch, basswood and other moderately tolerant species[3/] was between 12 and 15 percent. Short-lived and intolerant species dropped out of the stand most rapidly. The number of aspen stems decreased by 75 percent during the study.

There were no significant differences in 15-year mortality by cutting method in terms of number of trees, basal area, cubic-foot volume, cordwood volume, or Scribner board-foot volume. Eventually, however, the uncut stands would suffer considerable volume loss through natural mortality even with a tolerant species like sugar maple.

Fifteen-Year Ingrowth

Sugar maple made up significantly more of the 15-year ingrowth than any other species. It accounted for almost 87 percent of the trees growing into the 4.6 inch d.b.h. class, while basswood, yellow birch, red maple, and ironwood each contributed about 2.5 percent. Ingrowth increased with intensity of cut, especially when cutting removed large trees, as in the diameter limit treatment. This treatment had the highest ingrowth, with 139 trees growing to measurable size during the observation period; the uncut control had the least ingrowth, with only 26 trees coming into the measurable class. In all treatments except the control, gain in numbers of trees and basal area per acre from ingrowth more than offset mortality. Nearly all of the gain in ingrowth over mortality was made by sugar maple, regardless of the cutting treatment used. An average of 50 sugar maples per acre attained measurable size, while only 11 maples per acre died during the 15-year period. Ingrowth for red maple slightly exceeded mortality. For white ash and hemlock, ingrowth just balanced mortality. Mortality exceeded ingrowth for yellow birch, basswood, ironwood, aspen, balsam fir and other hardwood species. None of the cutting methods favored intolerant species.

3/ Includes American elm, white birch, black ash, black cherry, and red oak.

Diameter Growth

Diameter growth at breast height varied by original tree-size class, cutting treatment, beginning stocking level, and species. Sawtimber-sized trees (9.6 inches d.b.h. and larger) grew faster than pole-sized trees (4.6 to 9.5 inches d.b.h.) during the three measurement periods (table 2). The combined 15-year data show that poles averaged only 0.15 inches growth per year in diameter, while saw logs averaged 0.20 inches per year.

Table 2.--Periodic average annual diameter growth per tree for poles and saw logs by cutting method and years after cutting
(In inches)

POLES

Cutting method	Years after cutting: 1 to 6	7 to 10	11 to 15	15-year average
Control	[1/]0.12 a	0.10 a	0.09 a	0.10 a
90 sq. ft.	.12 ab	.10 a	.12 b	.11 a
75 sq. ft.	.14 bc	.12 b	.15 c	.14 bc
60 sq. ft.	.16 c	.14 b	.15 c	.15 bc
Crop tree	.20 d	.18 c	.15 c	.18 c
Diameter limit	.22 d	.23 d	.18 d	.21 d
Average	.16	.14	.14	.15

SAW LOGS

Cutting method	1 to 6	7 to 10	11 to 15	15-year average
Control	.17 a	.15 a	.13 a	.15 a
90 sq. ft.	.19 ab	.17 ab	.18 b	.18 ab
75 sq. ft.	.20 ab	.18 abc	.19 b	.19 bc
60 sq. ft.	.22 ab	.24 c	.22 bc	.22 cd
Crop tree	.24 b	.21 abc	.19 b	.21 bcd
Diameter	no trees	.22 abc	.25 c	[2/].23 cd
Average	.20	.20	.19	.20

1/ Treatment values within a column followed by the same letter are not significantly different at the 0.05 level.
2/ Except a 9-year period for the diameter limit treatment.

Cutting treatments leaving the lowest basal area densities (60 square feet or less) had the highest annual growth rates per tree. Pole trees in the diameter limit treatment grew about twice as fast as those in the control while saw-log trees in this same treatment grew about 1.5 times as fast as those in the control. However, because of the low residual stocking (21 square feet) in the diameter limit treatment, total growth per acre was reduced and the site was not fully utilized by growing stock for at least 6 years after the 1951 cut.

Cutting treatments that reduced basal area to 75 square feet or lower improved growth response on poles throughout the 15-year study period. Diameter growth response of poles in light selection cuts (90 square feet) was not improved.

During the first 6 years after cutting, annual diameter growth rates for saw-log trees were similar for all cutting treatments, ranging from 0.17 inches per year for control trees to 0.24 inches per year for trees in the crop tree treatment. During the last 5-year period, the average annual saw-log-tree growth rate of only 0.13 inches in the control was significantly lower than in all other treatments. During this same period the highest growth rate was 0.25 inches per year for saw-log trees in the diameter limit treatment.

Diameter growth also varied by species. Basswood and white ash grew faster than sugar maple but yellow birch was the slowest growing hardwood species in these stands. In managed stands growth rates of 2.0 to 2.5 inches per decade can probably be maintained on saw-log trees after low-vigor trees are harvested. Without cutting, growth rates of 1.0 to 1.5 inches per decade can be expected.

Average diameter growth of trees increased as stand density decreased (fig. 2). Diameter growth of sawtimber-sized trees averaged 0.2 inch or more per year at stand densities below 75 square feet of basal area per acre. At 125 square feet, the highest density studied, sawtimber grew 0.13 inch per year. At the same time, pole-sized trees averaged 0.2 inch or more per year at stocking levels below 40 square feet of basal area compared with only 0.1 inch per year at stocking levels above 110 square feet. These are stand averages, however, and diameter growth of individual trees varied considerably depending on species, growing space, initial tree vigor, age, crown class, and crown vigor.

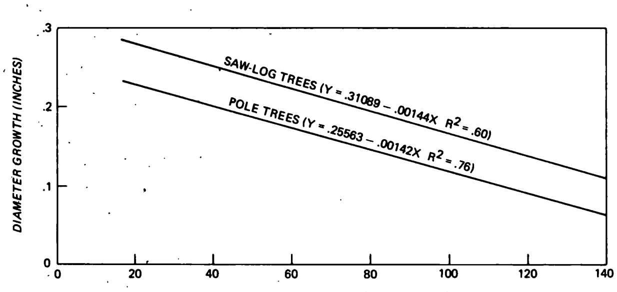

Figure 2.--Relation of mean annual d.b.h. growth of pole- and saw-log-sized trees to beginning basal area per acre (all trees 4.6 inches d.b.h. and larger, site index 65 at age 50 for sugar maple).

Cubic-Foot Volume Growth

For all cutting treatments, average gross and net cubic-foot volume growth were similar over the 15-year period. Gross total cubic-foot volume growth averaged from 111 to 136 cubic feet per acre per year for the six cutting treatments (table 3). Net cubic-foot volume growth ranged from 102 to 123 cubic feet per acre per year. During the first 6-year period after cutting, net growth was significantly lower on the 8-inch diameter limit cut than on any other cutting treatment, averaging only 82 cubic feet per acre per year. But over the 15-year period significantly higher ingrowth on the diameter limit treatment offset differences in survivor growth rates between treatments so that average total cubic-foot production was similar regardless of the cutting treatment used.

Periodic gross and net annual cubic-foot volume growth varied with beginning basal area stocking in hardwood stands (fig. 3). Gross cubic-foot volume growth increased rapidly up to a stocking level of 45 square feet, continued increasing at a reduced rate until peaking at 95 square feet, then declined slightly at higher stocking levels. Net cubic-foot volume followed a similar pattern up to 95 square feet, but dropped sharply above 115 square feet due to increasing mortality.

Cordwood Volume Growth

Average annual gross and net cordwood growth, like total cubic-foot growth, were about the same for all six cutting treatments. Net cordwood growth averaged about 1-1/4 cords per acre annually over the 15-year study period.

Gross and net cordwood growth on <u>pole-sized</u> trees were significantly higher in the 8-inch diameter limit cut than in any of the other cutting treatments. In this treatment, net cordwood growth in pole-sized trees averaged 0.70 cords per acre per year, as compared with a range of 0.05 to 0.33 cords per acre per year for the other cutting treatments.

In general, average annual net cordwood volume growth in all trees over 4.6 inches d.b.h. peaked at 1-1/3 cords per acre per year at 95 square feet

Table 3.--Average annual gross and net total cubic foot volume growth, survivor growth, ingrowth, and mortality on all trees 4.6 inches d.b.h. and larger by cutting method (15-year basis)1/

(In cubic feet per acre per year)

Cutting method	Survivor growth	Ingrowth2/	Gross growth	Mortality	Net growth
Control	127	5	132	20	112
90 sq. ft.	121	5	126	11	116
75 sq. ft.	118	5	123	9	113
60 sq. ft.	112	11	123	7	116
Crop tree	125	11	136	13	123
Diameter limit	84	27	111	9	102
$S_{\bar{x}}$	6.0	2.2	7.0	4.8	9.7

1/ Values in the same column enclosed by a bracket are not significantly different (0.01 level) using Duncan's new multiple range test.

2/ Into 4.6 inch d.b.h. class.

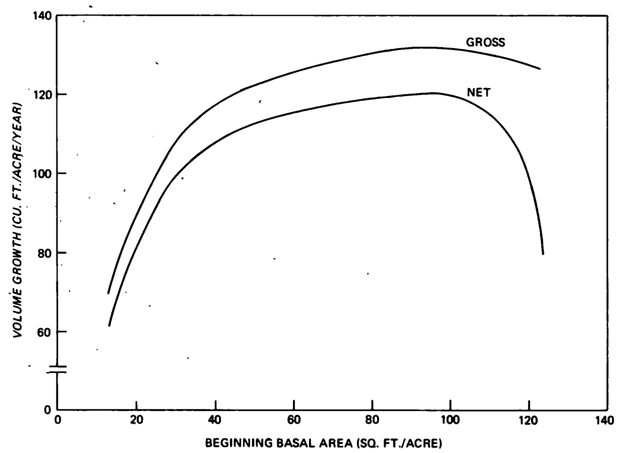

Figure 3.--Relation of periodic annual gross and net cubic-feet volume growth to beginning basal area per acre (all trees 4.6 inches d.b.h. and larger, site index 65 at age 50 for sugar maple).

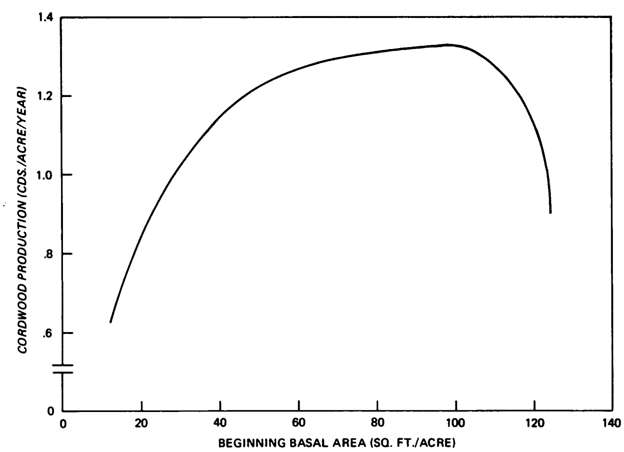

Figure 4.--Relation of annual net cordwood production in pulpwood and saw-log-sized trees to beginning basal area per acre (all trees 4.6 inches d.b.h. and larger, site index 65 at age 50 for sugar maple).

of basal area (fig. 4). When beginning stocking levels were below 50 square feet or above 110 square feet, net cordwood production dropped off sharply.

Cordwood growth in pole-sized trees in a given stand is strongly related to the beginning basal area stocking in saw-log (9.6 inches d.b.h. and larger) trees. For example, cordwood growth in pole-sized trees ranged from about 1 cord per acre annually with no saw-log-sized trees present to almost no cordwood growth with 75 square feet or more of saw-log-tree stocking.

Board-Foot Volume Growth4/

Average annual gross and net Scribner board-foot volume growth, survivor growth, ingrowth, and mortality of saw-log-sized trees are shown for each cutting treatment in table 4. In fifteen years, gross and net board-foot growth were significantly higher on the more lightly cut treatments than on either the 60 square-foot selection cut or the diameter limit cut. Average annual board-foot

4/ Cull volume has not been deducted.

Table 4.--Average annual gross and net Scribner board-foot volume growth, survivor growth, ingrowth, and mortality on saw log-size trees (9.6 inches d.b.h.+) by cutting method (In board feet per acre per year)

Cutting method	Survivor growth	Ingrowth1/	Gross growth	Mortality	Net growth
Control	2/279a	73a	352a	18a	334a
90 sq. ft.	288a	72a	360a	13a	347a
75 sq. ft.	275a	74a	349a	11a	338a
60 sq. ft.	183b	73a	256b	7a	249b
Crop tree	219ab	93a	312a	24a	288ab
Diameter limit	21c	54a	75c	4a	71c
$S_{\bar{x}}$	30	12	24	10	25

1/ Into 9.6 inch d.b.h. class.

2/ Values followed by the same letter in a column are not significantly different (0.01 level) using Duncan's new multiple range test.

survivor growth was best on the 90 square-foot per acre selection cut, but differences in survivor growth rates between the 90 square-foot selection cut, the 75 square-foot selection cut, the crop-tree release cut, and the control treatment were not statistically significant. Ingrowth into the saw-log size class (9.6 inches d.b.h. and larger) was similar for all cutting methods, averaging 73 board feet per year.

Yields

Calculated yields by treatment in the two harvest cuttings are given in table 5. Yields for various products are given to aid managers with different product objectives. Products actually harvested included saw logs, pulpwood from poles, and a limited amount of pulpwood from the tops of saw-log trees. In terms of cubic-foot volumes cut per acre, the diameter limit cut had the heaviest cut in 1951 with 1,600 cubic feet harvested per acre. The crop-tree treatment had the next highest cut with 694 cubic feet per acre, followed closely by heavy, medium, and light selection cuts. The selection cuts in 1961 yielded another 705 to 824 cubic feet per acre.

Board-foot yield in 1951 was greatest in the heavy diameter limit cut--3,617 board feet per acre. Yields from the other treatments ranged from about 800 to 1,600 board feet per acre. About 1,500 board feet per acre were

Table 5.--Total volume cut per acre by cutting treatment and product in 1951 and 1961

Cutting treatment	Cubic-foot1/		Scribner board-foot2/		Cull3/	Cordwood volume4/				
						Poles		Tops of saw logs		Poles and saw logs
	1951	1961	1951	1961		1951	1961	1951	1961	1951 and 1961
	Per acre	Per acre	Per acre	Per acre	Percent	Per acre	Per acre	Per acre	Per acre	Per acre
Check	0	0	0	0	--	0.00	0.00	0.00	0.00	0.00
90 sq. ft.	430	705	835	1486	19.4	1.44	2.06	.35	.76	11.99
75 sq. ft.	542	824	1264	1800	9.9	1.17	2.19	.50	.82	14.59
60 sq. ft.	647	789	1626	1491	10.1	1.12	2.98	.57	.78	15.26
Crop tree5/	694	14	1455	24	15.8	2.19	.15	.44	.04	7.56
Diameter limit5/	1600	0	3617	0	9.2	4.21	.00	1.05	.00	17.25

1/ Includes the peeled volume of stump, stem, tip, and branches to a 4.0 inch d.i.b. top of all trees 4.6 inches d.b.h. and larger.

2/ Includes all trees 9.6 inches d.b.h. and larger to a variable top but not less than 8.0 inches d.i.b. Board-foot volumes listed are net volumes without deductions for cull.

3/ Average 1951 woods and millrun cull percent of saw-log volume.

4/ Peeled 8.3 foot lengths to a 4-inch d.i.b. top for poles (4.6 to 10.5 inches d.b.h.) and saw logs (9.6 inches and larger) and stem and limbs above the last log to a 4-inch d.i.b. top for tops and saw logs. Saw logs were not actually harvested as cordwood but are presented as such for total cordwood values.

5/ Material was essentially all cut in 1951.

harvested from each of the three selection treatments in 1961. Cull percent in 1951 was generally low, averaging 11.5 percent of the gross volume cut.

Cull percents in the selection treatments and the crop-tree treatment were higher than in the diameter limit treatment. This is because all saw-log-sized trees of quality were cut in the diameter limit treatment, while poor-quality trees were favored for cutting in the other treatments.

Saw logs produced in the 1951 cut averaged 8.4 percent Grade 1; 21.4 percent Grade 2; and 70.2 percent Grade 3. Future cull percentages should be lower and percentages of better grade logs are expected to be higher from the improvement cuts in the selection and crop-tree treatments. The smaller size and poorer quality of the growing stock in the diameter limit cut make it less attractive for future log and veneer production, but more attractive for pulpwood production.

Stumpage returns from the first cut ranged from $55 per acre for the diameter limit treatment to a low of $13 for the light selection cut (table 6). In the other treatments, stumpage returns per acre averaged $15 for medium selection, $17 for heavy selection, and $15 for the crop-tree treatment. The second cut in the winter of 1961-1962 was limited to the three selection treatments. Stumpage returns from this cut were still low, averaging $21 per acre. Future returns should be higher with grade improvement from selection cutting and because sugar maple stumpage values have increased from $14 to $15 per thousand in 1951 to $32 to $40 per thousand in 1972.

Residual Volumes

Early dollar returns have been low from our selection treatments in second-growth stands because we have been concentrating on building up the residual volumes and basal area stocking of desirable trees in the larger diameter classes. In addition, we have not been cutting growth.

In old-growth northern hardwoods on a similar site Eyre and Zillgitt (1953) reported a maximum net growth rate of 295 board feet5/ per acre per year over a 15-year period, with a residual volume of 6,300 board feet per acre. Their net growth with cull deducted increased with three successive 5-year periods to 281 board feet per acre per year. In our selectively cut second-growth stands, net growth averaged 311 board feet4/ per acre annually over a 15-year period, with beginning residual volumes of 1,650 to 3,100 board feet per acre. During the last 5-year period our maximum annual net growth averaged 356 board feet4/ per acre on the light selection treatment. Ingrowth only accounted for 55 board feet of this net growth figure.

5/ Gross growth minus mortality without deduction for cull.

Table 6.--Stumpage returns in dollars per acre by cutting treatments in 1951 and 1961

Cutting treatment	Stumpage return 19511/	19612/	Total
Check	0	0	0
Light selection	12.85	22.96	35.81
Medium selection	15.05	29.42	44.47
Heavy selection	17.14	15.35	32.49
Crop tree	14.64	0.12	14.76
Diameter limit	55.40	0	55.40

1/ Actual stumpage returns from scaled and graded material on plots in 1951.

2/ Estimated from volume cut on plots using 1951 cull percentages and stumpage values by species in 1961. No estimate of cull percent or grade recovery was made in 1961.

In 1961, the beginning of this maximum growth period, the light selection treatment had the highest basal area stocking in saw-log-sized trees (57 square feet per acre) and the largest residual volume (4,955 board feet per acre) of the three selection treatments. Thus, we feel that an annual net growth rate of 300 board feet per acre can be maintained by selection cutting to basal area densities of 60 to 90 square feet per acre, once a suitable size-class distribution is obtained on sites that average 65 feet at age 50 years for sugar maple.

The 1966 residual volumes in the selection cuttings ranged between 3,900 and 6,800 board feet per acre (table 7), indicating continued high board-foot production. The 1972 estimated value of these stands is also shown in the table. So far, we have not been cutting growth. After the next (third) cut we expect to be able to harvest growth in the form of large-diameter, high-value trees on a sustained yield basis. Residual stand volume on the crop tree treatment reached 5,800 board feet per acre in 1966. This volume was concentrated in better quality trees, which indicates potentially high board-foot production and high-quality yields in the future. The 1966 residual volume for stands in the diameter limit treatment averaged only about 1,100 board feet per acre. Current annual production is low and there will be a long time interval before quality saw-log material can be harvested.

Stand Structure

During the 15-year study, stand structure has changed considerably due to ingrowth, natural mortality, and recutting in the selection stands.

Table 7.--Residual volumes per acre 15 years after the initial cut in terms of various products and 1972 saw-log values[1]

Cutting treatment	Cubic-foot volume[2]	Scribner board-foot volume[3]	1972 saw log values[4]	Poles	Tops of saw logs	Poles and saw logs
			Dollars per acre	Cords	Cords	Cords
Check	3,920	8,318	266	11.73	3.69	41.75
90 sq. ft.	3,120	6,835	219	8.74	3.28	33.34
75 sq. ft.	2,707	5,936	190	6.88	3.16	28.91
60 sq. ft.	2,301	3,901	125	9.02	2.61	24.15
Crop tree	3,192	5,788	185	11.48	3.87	33.69
Diameter limit	1,972	1,083	35	14.07	1.98	19.96

1/ No deduction was made for cull.
2/ Peeled, stump, stem, and tip.
3/ To a variable top but not less than 8.0-inch d.i.b.
4/ Using $32 per M for woodsrun hardwood saw logs with no deduction for cull, managed stands should be worth considerably more.
5/ Peeled 8.3-foot lengths to a 4-inch d.i.b. top for poles (4.6 to 9.5 inches d.b.h.) and saw logs (9.6 inches d.b.h. and larger) and the stem and limbs above the last log to a 4-inch d.i.b. top for tops of saw logs.

The number and basal area of stems in the sawtimber-size class increased, while the number and basal area of stems in the pole-size class decreased (tables 8, 9). Increases in number of trees and basal area of stems in the largest d.b.h. class were most rapid following heavy selection cutting and crop-tree release, because diameter growth was faster at lower densities. The structure and stocking in sapling-size trees (2-4 inch d.b.h. class) in 1961 was also better in the heavy selection treatment than in the light and medium selection treatments. Although we still have too many pole-size trees (5 to 9 inches) and too few large saw-log trees (20 to 24 inches d.b.h.), the stand structure has greatly improved on all selection treatments and is approaching a distribution that should result in sustained yield. The size-class distribution recommended by Eyre and Zillgitt (1953) can be obtained with the third cut, except in the 20-24 inch class. The frequency distribution of trees by diameter classes in the crop-tree treatment in 1966 was similar to the distribution recommended for selection stands. Of course, the 1951 diameter-limit cut left an essentially even-aged residual stand.

Board-Foot Growth and Stocking

Beginning stand basal area in either saw-log- or pole-sized trees is a good indicator of future annual net board-foot growth. This is true for both all-aged and even-aged management. A model was developed from 54 combinations of beginning basal area stocking and corresponding board-foot yields from our cutting study (fig. 5). The main stands of trees used in constructing the model were young and rapidly increasing in merchantable height.[6] Therefore, we do not expect the high growth rates shown in the model to be sustained continuously. However, peaks on the model for different combinations of stocking are meaningful for maximum board-foot growth.

Yields averaging 300 board feet annually should be possible once a balanced structure is obtained under all-aged management. At this time there is no reason to believe that mean annual increment would be any higher or lower under even-aged management.

At extremely high densities (above 130 square feet of saw logs and poles), net board-foot growth rates fall off sharply because of mortality. We had only four combinations of gross saw-log- and pole-sized basal area densities that exceeded 120 square feet per acre, with the highest combined density being 133 square feet. More data at high densities are required to better define the levels where mortality is important in reducing yields.

6/ Individual small saw-log trees increased as much as 16 feet in merchantable height (to a variable top diameter but not less than 8 inches d.i.b.) in 15 years, but height improvement averaged only about 4 feet for a given saw-log d.b.h. class. Merchantable heights in the larger saw-log size classes were probably "set" by large limbs that were present before cutting in 1951. Any improvement that has occurred in the larger size classes was due to cutting, gradually eliminating residual trees with short merchantable boles.

Table 8.--Average number of trees per acre after cutting in 1951, before and after cutting in 1961 and 1966, and 15-year net changes by d.b.h. class and cutting treatment

Cutting treatment	D.b.h. class					
	2 to 4[1]	5 to 9	10 to 14	15 to 19	20 to 24	Total 10+
Recommended structure for selection cutting[2]	202	65	28	17	8	53
Beginning structure all treatments combined	--	184	44	9	<1	54
90 square feet basal area						
1951	155	169	46	7	0	53
1961	135	140	65	17	1	83
1961 cut	--	-23	-14	-4	0	-18
1966	--	115	55	18	1	74
15-year change[3]	--	-54	9	11	1	21
75 square feet basal area						
1951	111	144	42	5	0	47
1961	95	123	63	15	0	78
1961 cut	--	-26	-16	-5	0	-21
1966	--	87	56	15	0	71
15-year change[3]	--	-57	14	10	0	24
60 square feet basal area						
1951	203	163	25	3	0	28
1961	172	173	43	10	1	54
1961 cut	--	-38	-14	-5	0	-19
1966	--	126	43	7	2	52
15-year change[3]	--	-37	18	4	2	24
Crop tree						
1951	225	159	25	3	0	28
1961	225	161	55	7	1	63
1966	--	150	67	9	1	77
15-year change	--	-9	42	6	1	49
Diameter limit						
1951	255	112	0	0	0	0
1961	221	192	9	0	0	9
1966	--	196	29	0	0	29
15-year change[3]	--	84	29	0	0	29
Check						
1951	183	203	41	9	0	50
1961	165	173	63	16	2	81
1966	--	151	67	20	4	91
15-year change[3]	--	-52	26	11	4	41

1/ Sapling counts were made in 1957 (1951 column) and 1961.
2/ Eyre and Zillgitt (1953).
3/ Includes 1961 cut.

CONCLUSIONS AND RECOMMENDATIONS

Individual tree diameter growth rates were best at lower densities. However, sites were not fully occupied until stand density reached about 35 square feet of basal area per acre. Furthermore, live limbs were much more abundant following cutting to the lowest density (21 square feet of basal area per acre), especially in the second log (Godman and Books 1971).

Periodic basal area growth and cubic-foot volume growth were similar over a wide range of stand densities. Net annual cubic-foot production was relatively constant in stands containing between 50 and 115 square feet of basal area per acre. Annual gross and net basal area growth peaked at 45 square feet of residual basal area per acre, but annual basal area survivor growth was relatively constant between 45 and 100 square feet of basal area per acre.

The best management practices for second-growth hardwood stands depend primarily upon the owner's objectives and then upon stand conditions and species composition on the land in question. Owners interested only in producing pulpwood or other bulk products can manage their stands over a wide range of residual stand densities without losing cubic-foot or cordwood volume growth. Owners interested in producing continuous yields of white ash, basswood, yellow birch or more intolerant species should manage under some even-aged system. If advanced sugar maple reproduction is present at stand regeneration time, sugar maple understory control would be required to obtain a high proportion of valuable intolerant species (Tubbs and Metzger 1969).

Table 9.--Basal area stocking per acre after cutting in 1951, before and after cutting in 1961 and 1966, and 15-year net changes by d.b.h. class and cutting treatment

Cutting treatment	D.b.h. class					
	2 to 4 1/	5 to 9	10 to 14	15 to 19	20 to 24	Total 10+
Recommended structure for selection cutting 2/	8	16	22	26	20	68
Beginning structure all treatments combined	--	45	33	13	<1	47
90 square feet basal area						
1951	8	44	34	9	0	43
1961	7	39	48	24	2	74
1961 cut	--	-8	-10	-6	0	-16
1966	--	32	42	26	3	71
15-year change 3/	--	-12	8	17	3	28
75 square feet basal area						
1951	6	38	31	7	0	38
1961	5	35	47	22	0	69
1961 cut	--	-8	-13	-8	0	-21
1966	--	25	41	22	0	63
15-year change 3/	--	-13	10	15	0	25
60 square feet basal area						
1951	10	36	18	5	0	23
1961	9	45	31	14	2	47
1961 cut	--	-11	-11	-6	0	-17
1966	--	33	30	10	4	44
15-year change 3/	--	-3	12	5	4	21
Crop tree						
1951	12	38	18	4	0	22
1961	10	43	39	10	2	51
1966	--	42	48	14	3	65
15-year change	--	4	30	10	3	43
Diameter limit						
1951	13	21	0	0	0	0
1961	10	47	6	0	0	6
1966	--	52	18	0	0	18
15-year change 3/	--	31	18	0	0	18
Check						
1951	9	50	30	14	0	44
1961	8	47	46	24	5	75
1966	--	42	48	29	10	87
15-year change 3/	--	-8	18	15	10	43

1/ Sapling counts were made in 1957 (1951 column) and 1961.
2/ Eyre and Zillgitt (1953).
3/ Includes 1961 cut.

Early release treatments might also be required to maintain favorable growth of moderately tolerant and intolerant species.

The selection system is well suited to owners whose objectives are to produce high-quality sugar maple saw logs and sustain the "big tree look." Earlier workers in the Lake States and the Northeast recommended leaving a residual stand containing between 70 and 85 square feet per acre (in trees 5 inches d.b.h. and over) for best growth and quality development (Eyre and Zillgitt 1953, Arbogast 1957, Jacobs 1969, Leak et al. 1969). Our data generally parallel these findings, but we feel that the first cut in overstocked pole-sized stands can be heavier than previously recommended in the Lake States. Based on a 3-square-foot annual net growth rate, a stand thinned to 50 square feet of saw logs and poles would reach Eyre and Zillgitt's (1953) recommended 85-square-foot level in about 12 years. Cutting down to a minimum residual stocking level of 65 square feet per acre (in trees 4.6 inches d.b.h. and over) as suggested by Trimble (1970) would probably be safer from the standpoint of logging damage and unexpected mortality. In these same stands Godman and Books (1971) also found that tree quality improved with increasing residual basal area densities.

Our data from 45- to 60-year-old stands show that at least 50 square feet of saw-log trees with not more than 60 square feet of pole trees are required to produce 300 board feet (net Scribner) per acre annually. Diameter growth rate on saw-log-sized trees averaged 2 inches or more per decade at stand densities below 75 square feet of basal area per acre. Diameter growth is stimulated at lower densities (Eyre and Zillgitt 1953, Arbogast 1957) and the recommended balanced

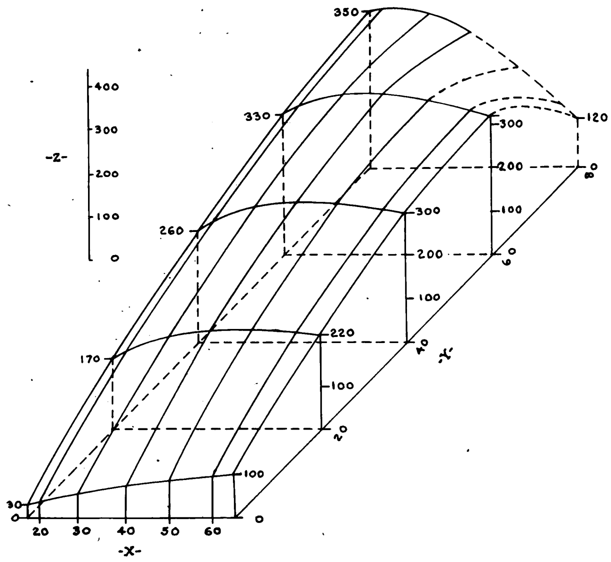

Figure 5.--Relation of periodic annual Scribner net board-foot growth (Z) to beginning basal area of all trees 4.6 to 9.5 inches d.b.h. (X) and beginning basal area of all trees 9.6 inches d.b.h. and larger (Y).

size-class distribution is attained faster. If the first cut creates stands meeting the minimum structure or diameter distribution requirements, sufficient numbers of trees will be available for cutting at 10-year intervals (table 10).

Second-growth northern hardwood stands on good sites (65 feet at 50 years) in the Lake States at this stage of development can be expected to produce sustained growth of 3,000 board feet every 10 years.

However, all annual growth should not be cut until the recommended size-class distribution is attained. Many variations in stocking, structure, composition, and quality occur in unmanaged second-growth hardwood stands depending upon past stand history and site conditions. In many cases, stands are overstocked with pole trees and understocked with saw-log trees. The tendency in marking for the first cut is to "sweeten" the cut by marking too heavily in the larger saw-log classes and to leave large numbers of pole-sized trees. The first cut in an overstocked pole stand should be primarily from below. Only those large-diameter cull and defective trees that will not live to the next cut should be removed to attain the required density (not lower than 65 square feet of basal area per acre on a 10-year cutting cycle). By concentrating the thinning in the pole-sized class the forester improves growing conditions (spacing) around better trees, improves individual growth rates by freeing more trees from competition, and attains the desired structure quicker.

The first cut in second-growth northern hardwood stands thus should be a general improvement cut that removes cull, high-risk, and poor quality growing stock throughout all diameter classes. Whether the manager is thinking in terms of uneven-aged or even-aged management at this time is unimportant as long as the average diameter of the main stand of dominants and codominants is below saw-log size. In the early stages of managing second-growth stands we can remain flexible; intermediate silvicultural treatments can be varied to meet the owner's future objectives.

Table 10.--Minimum stand structure

D.b.h. class (inches)	Minimum: Trees per acre		Minimum: Basal area per acre	
	(Number)		(Sq. ft.)	
2-4	202		8	
5-9	43		12	
10-14	19	36	17	53
15-19	13		20	
20+	4		16	
Total	281		73	

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NORTH CENTRAL FOREST EXPERIMENT STATION

50 YEARS

1923 1973