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How Fast Do Northern Hardwoods Grow?

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How Fast Do Northern Hardwoods Grow[1]

THE KNOWLEDGE of the rate at which trees grow in virgin forests, after clear cutting and under selective logging, is indispensable in any forest calculations or forest practice. The enactment of the Forest Crop Law, which brought under its operation about 175,000 acres of cut-over land during the first year, the example set by several progressive lumbermen in selective logging, and the general public interest in the future of the cut-over land focused attention acutely on what may be expected from cut-over land in the way of growth and returns in the course of the next few decades.

The state, in contributing to the counties and townships 10 cents for each acre registered under the Forest Crop Law, expects to recoup its investment from the yield of the forest land within the next 50 years. It is, therefore, of importance for the state to have information as to what this yield may be, as upon it will depend the economic soundness of the present law. The private timber owner, who enters into a contract with the state under the law, must also know what the future growth on his land will be, as upon it, again, depends the economic soundness of his enterprise. The counties which may establish their own forests must also know, as well as the state itself in the management of the state-owned forests, what the future returns from their investment will be. In short, does the growth on the cut-over land justify the expenditures which the state, the county, and private timber operators are making?

There has been a great deal of guessing as to the forest growth on cut-over land, some optimistic, some pessimistic. To get at definite figures of growth, the Lake States Forest Experiment Station undertook, in cooperation with the College of Agriculture of the University of Wisconsin, a study of the growth that is taking place in old virgin stands, on clear cut areas, and in partially cut-over forests. Since the most important forests in Wisconsin are the northern hardwoods, the study was confined to the typical northern hardwood stands composed of sugar maple, yellow birch, hemlock, basswood, with admixture of beech, elm, white cedar, balsam fir, occasional white pine, and other species characteristic of the northern part of the state.

[1] The authors gratefully acknowledge their indebtedness to several Wisconsin lumber companies, particularly the Goodman Lumber Company of Goodman, Wisconsin; Russell Watson of the firm of Banzhaf and Watson, Consulting Foresters of Milwaukee, Wisconsin, in locating suitable areas for study; to the members of the field party, J. Lee Deen and Thomas Lotti, who faithfully assisted in the field measurements; to Joseph Kittredge, Jr., and S. R. Gevorkiantz of the Lake States Forest Experiment Station staff, to the former for helping plan the study and to the latter for assistance in computing the field data. The table and graph for predicting future growth is entirely the work of S. R. Gevorkiantz.

Location and Areas Studied

Most of the field work was done in Florence, Forest, and Marinette counties, although some areas were examined also in Oneida and Langlade counties, as well as one area in Iron County, Michigan. The region covered by the study is shown by cross-hatching on the attached map (Figure 1). In all,

FIG. 1.—AREA COVERED BY THE GROWTH STUDY.

28 sample plots were examined. Of these, four could not be used in the final computation because of the many factors involved which obscured the main purpose of the study. The 24 plots which were used as a basis for the conclusions aggregated close to 112 acres. Of these, eight acres were in virgin

forest. A list of the exact location, size, and character of forest of each plot studied is presented in Table 1.

Method of Study

A study of the rate of volume growth in virgin forests, on clear cut land, and in partially cut stands, was made on plots representative of each set of conditions. There was no difficulty in finding virgin stands of hardwood forests, since Florence and Forest counties still contain many such stands. It was thought that it would be difficult to find stands which were partially

TABLE I.—LOCATION, AREA, AND CHARACTER OF CUTTINGS IN SAMPLE PLOTS

Plot No.	Location	Area	Character of stand	Years since cutting
		Acres		
1	Florence County (T38N R17E S7)	10	Partially cut—light	14
2	Iron County, Mich. (T42N R35W S26)	4	Partially cut—moderate	16
3	Florence County* (T38N R17E S7)	10	Partially cut—moderate	17
4	Florence County (T40N R17E S28)	9	Partially cut—moderate	15
5	Florence County (T39N R16E S4)	5	Partially cut—moderate	25
6	Florence County (T40N R16E S30)	5½	Partially cut—heavy	24
7	Florence County (T38N R16E S35)	3½	Partially cut—heavy	30
8	Florence County (T40N R16E S34)	7	Partially cut—heavy	26
9	Langlade County (T33N R9E S15)	2	Partially cut—heavy	24
10	Forest County (T36N R15E S16)	7	Partially cut—very heavy	28
11	Langlade County (T31N R14E S31)	5	Partially cut—very heavy	32
12	Forest County (T34N R15E S33)	2	Partially cut—very heavy	27
13	Florence County (T40N R16E S28)	11	Partially cut—very heavy	26
14	Florence County (T38N R16E S25)	7	Partially cut—very heavy	11
15	Forest County (T35N R15E S9)	5½	Partially cut—very heavy	23
16	Forest County (T35N R14E S13)	7	Clean cut	18
17	Oneida County (T35N R15E S9)	3	Clean cut	24
18	Florence County (T38N R16E S35)	1	Virgin stand	—
19	Florence County (T39N R16E S3)	1	Virgin stand	—
20	Forest County (T34N R15E S21)	1	Virgin stand	—
21	Florence County (T40N R17E S29)	1	Virgin stand	—
22	Forest County (T35N R15E S9)	1	Virgin stand	—
23	Florence County (T40N R17E S29)	1	Virgin stand	—
24	Marinette County (T36N R16E S5)	2	Virgin stand	—

* Plot No. 3 is the same as plot No. 1. It was cut, however, twice and, therefore, was treated as two separate plots.

cut 25 or 30 years ago. This, however, proved not to be the case. As a matter of fact the prevailing method of logging about 30 years ago was partial cutting or what may now be called selective logging. The method of logging followed two or three decades ago was dictated, not by any desire of perpetuating the forest, but by market conditions. Only the largest trees and trees of certain species were cut; the rest, not having market value, were left standing. Strange as it may seem, the areas most difficult to find were those which had been cut clean. Although there is an abundance of recent clear cuttings, old clear cuttings, particularly cuttings which escaped fire, were not easy to find.

Only such areas which have escaped fires were chosen for study. It is evident that growth on cut-over and repeatedly burned land gives no true idea of the potential growth of such land. As a matter of fact, repeated fires may delay regrowth of cut-over land indefinitely.

The first step was to trace, as far as possible, the history of the cutting, namely, the date of logging, the amount of merchantable timber removed in the original cut, and the amount left. To get at the amount of growth that took place on the cut-over land since last cutting, it was necessary to determine several facts on the ground: (1) the date of logging, (2) the amount removed in the original cutting, (3) the present stand of merchantable timber on the area, (4) the amount of timber lost since first cutting through decay and windfall, and (5) the growth in diameter of the trees left after last logging operation.

After having gotten these field data, the amount of timber left at the time of the first cutting and the actual growth in volume that took place since last logging were determined by computation.

1. Where the date of logging was unknown, it could readily be ascertained from the change in the width of rings in the trees left at the time of the first cutting; also by the age of the sprouts.

2. The amount of timber removed in the first logging was determined by means of strip surveys, one chain wide and ten chains long, or one acre in extent, run by compass through the forest. On these strips the old stumps and tops were located.[2] From the size of the stump, the distance of the top from the stump, together with the knowledge of the number of logs and the merchantable contents for trees of different diameters, the amount removed per acre in the first logging was ascertained.

3. The present merchantable stand was found by the usual cruising method. The diameters of trees at breast height were measured with calipers, the number of logs in trees of different diameters estimated, and by means of volume tables the trees' merchantable content in board feet was found.

[2] In this connection it may be of interest to note the relative rapidity at which stumps and tops of different species decay. Basswood decays first of all, followed by sugar maple, yellow birch, hemlock, elm, and white cedar in order given. Elm and hemlock stumps were found almost intact 25 years after logging, and white pine stumps were in a perfect state of preservation 35 to 40 years after first logging.

4. The amount of loss through decay and windfall was determined by actual measurement of the trees that died or were wind-thrown since the last logging.

5. The growth in diameter was gotten by means of increment borings of a portion of the trees on each strip having at present a diameter of 10 inches breast high and over. Close to 2,000 trees were bored into to find the rate of growth 20 years before cutting, and for the entire period since cutting. (Figure 2) These measurements were further checked by complete stem

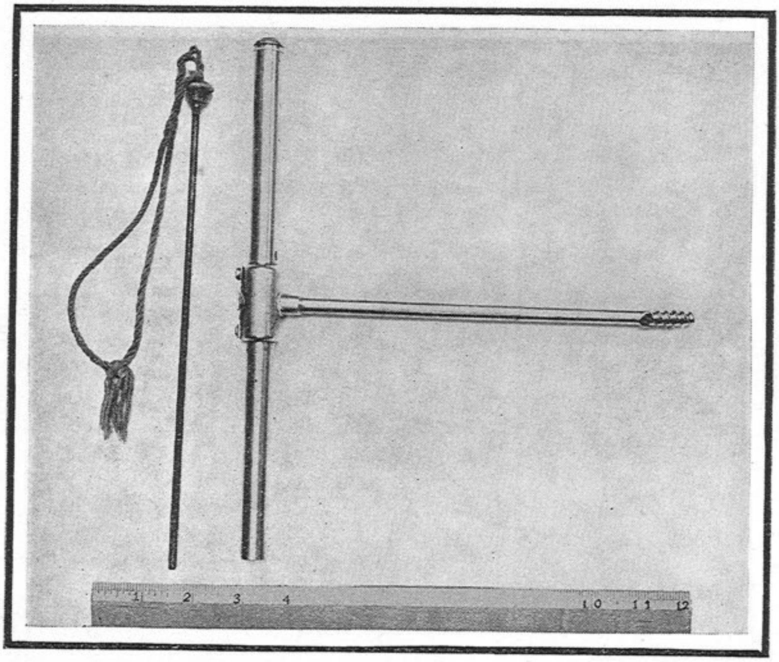

FIG. 2.—INCREMENT BORER USED IN OBTAINING CORES FROM STANDING TREES.

analyses and measurements taken directly on recently-cut stumps. Several trees of different diameters in each plot were cut into eight-foot sections and the rings counted on each cross section and in this way the rate at which the trees grew in height, diameter, and volume before and after cutting was found.

These growth measurements made it possible to arrive fairly accurately at the number of inches that trees of different diameters grew since last logging. By deducting the diameter growth which the trees made since cutting, from their present diameters, it was possible to reconstruct the size of the same trees and, therefore, their volume at the time of logging. With the knowledge of the present merchantable stand per acre, the knowledge of the amount of timber left at the time of logging and the loss that occurred through decay and windfall since logging, it was a comparatively simple operation to arrive at the growth in board feet that took place after logging; all that was necessary was to deduct from the present merchantable volume of the stand, the volume of the same trees which were left at the time of logging and further reduce the amount by the loss in board feet that occurred through decay and windfall, also since last logging operation.

In the case of virgin stands, diameter growth was measured back for 20 years. By deducting the amount of growth made during the last 20 years from the present diameter of the trees, the size and the volume of the same trees 20 years ago was ascertained and consequently also the growth in board feet during the interval.

Growth in Virgin Stands

Virgin Hardwood Forest is an All-Aged Forest: A virgin hardwood forest is characterized by such species as sugar maple, yellow birch, and hemlock;

TABLE II.—DISTRIBUTION OF TREES BY SPECIES AND DIAMETER CLASSES IN VIRGIN HEMLOCK-HARDWOOD FOREST

(Average of 8 acres in Forest, Florence, and Marinette Counties)

Diameter breast high class	Sugar maple	Yellow birch	Hemlock	Basswood	Elm	Balsam fir	White cedar	Ironwood	Total	Per cent of total trees in each diameter class
Inches										
5	3	1	4	1	..	..	..	2	11	8.0
6	4	1	6	..	1	..	..	2	14	10.0
7	3	..	5	1	..	2	1	..	12	8.0
8	2	2	5	..	..	..	..	..	9	6.0
9	4	1	6	..	1	..	..	1	13	9.0
10	1	1	4	1	..	..	..	..	7	5.0
11	3	1	3	..	2	..	..	..	9	6.0
12	4	2	3	1	..	..	2	..	12	8.0
13	3	2	2	..	1	..	..	..	8	6.0
14	3	1	2	..	2	..	..	..	8	6.0
15	2	1	1	1	..	..	..	..	5	3.5
16	3	2	1	..	..	..	..	..	6	4.0
17	3	1	1	1	1	..	..	..	7	5.0
18	2	1	1	1	..	..	..	..	5	3.5
19	1	1	..	..	..	..	..	..	2	1.0
20	2	1	..	..	..	..	..	..	3	2.0
21	1	..	..	1	1	..	..	..	3	2.0
22	1	1	..	1	..	..	..	..	3	2.0
23	1	..	..	..	..	..	..	..	1	1.0
24	..	..	2	..	..	..	..	..	2	1.0
25	1	..	..	1	..	..	..	..	2	1.0
26	..	..	..	..	..	..	..	..	....	....
27	..	..	..	..	1	..	..	..	1	1.0
28	..	..	..	..	..	..	..	..	....	....
29	..	..	..	..	..	..	..	..	....	....
30	..	1	..	..	..	..	..	..	1	1.0
Total	47	21	46	10	10	2	3	5	144	
Per cent	33.0	15.0	32.0	7.0	7.0	1.0	2.0	3.0		100.0

there may be some variation in the presence or absence of such secondary species as beech, basswood, or elm, but sugar maple and yellow birch are the species which give character to the forest. In the old hardwood stands as they occur in Florence, Forest, and Marinette counties, maple constitutes 32 per cent by volume, yellow birch 19, hemlock 18, elm 13, and basswood 17 per cent of the entire merchantable stand.

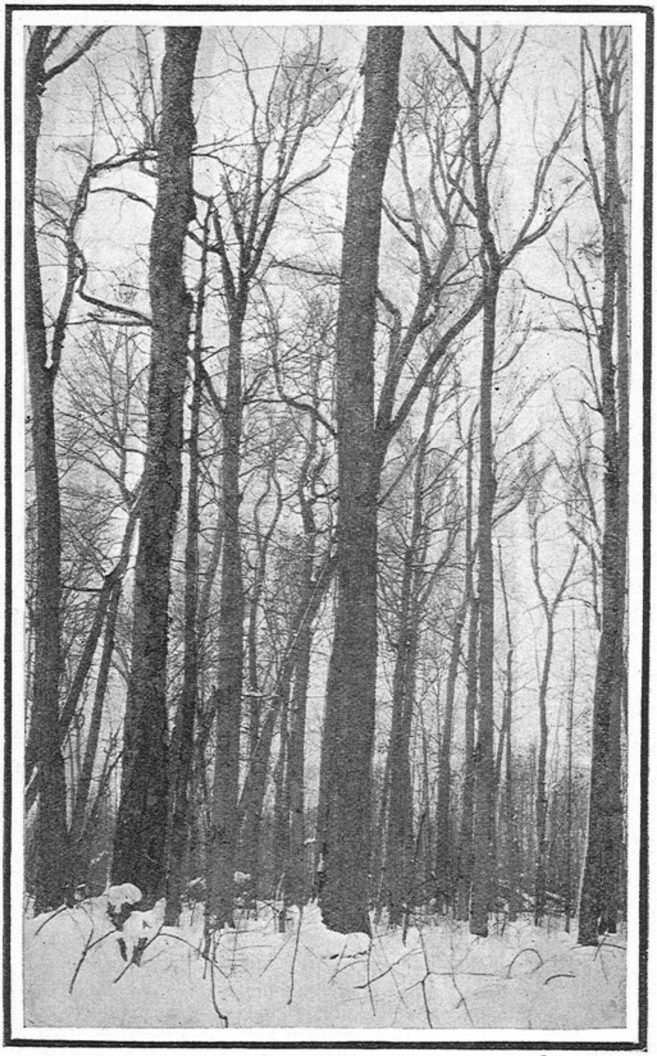

FIG. 3.—VIRGIN NORTHERN HARDWOOD FOREST. ALL SIZES AND AGES OF TREES ARE PRESENT.

This forest is made up of trees of all ages from small seedlings that may have come up only the year before to trees 250 years old, and of all sizes from a seedling less than one-half inch to trees often as large as 36 inches in diameter. As a matter of fact, one of the characteristic features of an old northern hardwood forest is the presence in large quantities of trees of small sizes. The number of trees gradually decreases as their size increases. A tally of all trees, by species and diameters in a virgin stand immediately reveals this picture. (Table II.)

Out of a total of 144 trees per acre, 59 are trees between five and nine inches in diameter, 72 from 10 to 20 inches, and only 13 trees are above 20 inches in diameter. This number does not include trees below five inches in diameter—the sizes most abundant in the stand and which may run into thousands per acre. (Figure 3)

Growth in Diameter is Slow.—The rate of growth in diameter of trees in virgin stands as determined by nearly 2,000 borings, although it varies with the species, is as a general rule very slow. It takes from about seven to twelve years to add by growth one inch in diameter at breast high.

In getting the average diameter growth records, badly suppressed trees were left out of consideration; this growth therefore, is that made by the larger trees in the stand.

Growth in Board Foot Volume is Large.—In virgin stands, although the actual diameter growth of individual trees is very small, this growth is laid on many large, already merchantable trees. The aggregate growth per acre, therefore, is large. A concrete example will illustrate the point.

In virgin stands, a sugar maple between 10 and 20 inches in diameter increases its volume by 24 board feet for every inch of diameter growth, while for a tree in the 20 to 25 inch diameter class an inch of diameter growth adds 40 board feet. Since it takes sugar maple 10 years to grow one inch in diameter, it means that the smaller trees grow at the rate of 2.4 board feet per year while the larger trees grow at the rate of 4 board feet per year.

By applying the rate of diameter growth as given in Table III to the virgin stand as described in Table II the merchantable volume of the stand 20 years ago was obtained. A comparison of the present volume with that

TABLE III.—DIAMETER GROWTH OF TREES IN VIRGIN STANDS

Species	Years required to grow 1 inch in diameter
Basswood	7
Balsam fir	8
White cedar	9
Sugar maple	10
Beech	11
Hemlock	11
Yellow birch	12
Elm	12

of 20 years ago shows that the stand has made a growth of 4,253 board feet during this interval, or 213 board feet per acre per year. (Table IV.)

TABLE IV.—VOLUME PER ACRE BY DIAMETER CLASSES IN AN AVERAGE VIRGIN STAND NOW AND 20 YEARS AGO. (AVERAGE OF 8 ACRES)

Diameter Breast High class	Volume in board feet	
Inches	1928	1908
10	141	248
11	361	321
12	535	490
13	481	224
14	853	655
15	540	820
16	720	480
17	1140	280
18	850	670
19	420	810
20	740	470
21	1110	300
22	980	1100
23	370	370
24	880	......
25	980	670
26	......	......
27	820	......
28	......	480
29	......	......
30	720	......
Total	12,641	8,388

Growth Counterbalanced by Windfall and Rot.—The trees in the virgin stand which in the aggregate now represent a merchantable volume of 12,641 board feet, 20 years ago had a volume of only 8,388 board feet or have added by growth in the last 20 years 4,253 board feet, or about 213 board feet per acre per year. This is true if only the same trees are considered in both cases but is not true if the merchantable volume of the present stand is compared with that of the same stand 20 years ago.

It is evident that while the trees that have lived through the last 20 years have actually grown at the rate of 213 board feet per acre per year, a number of the larger trees have gone down, with the result that the total merchantable stand today is no greater than that 20 years ago. If a 26-inch tree drops out of the virgin stand, it represents roughly a volume of 500 board feet. Two years annual increment of 426 board feet per acre would not replace this loss.

There are no accurate records of the actual loss in virgin stands through windfall, decay, and other causes. Such records can be obtained only by careful observations continued over a number of years in the same stand. Such a study has been started at the Upper Peninsula Forest Station, but it will take some time before reliable figures are available. In the meantime, conclusions as to the losses must be drawn from the fact that the merchantable volume of virgin stands remains stationary in spite of the growth that is taking place in it, and from a few meagre actual records. It is accepted as axiomatic that in virgin stands the growth is counterbalanced by decay and windfall. If the growth is 213 board feet, we must assume that the loss is the same.

This is substantiated by a few records of the actual loss through windfall and rot that is taking place in virgin stands. One lumber company in Wisconsin, in the summer of 1926, removed the windfalls from an area one-quarter mile wide and three miles long, taking one-eighth mile on each side of the logging railroad. This area covered about 480 acres. The timber removed from this area was as follows:

Maple	350	logs	amounting	to	34,610	board	feet
Birch	84	"	"	"	7,820	"	"
Hemlock	664	"	"	"	82,230	"	"
Basswood	285	"	"	"	35,520	"	"
Total	1,383	"	"	"	160,180	"	"

Since among these, many hemlock trees have been blown down from four to five years prior to the cleaning up, 80 per cent of the hemlock logs were deducted in arriving at the annual loss through windfall. This left 852 logs with a total volume of 98,510 board feet or 205 board feet per acre. This occurred, however, during the summer of 1926, a year of abnormally strong winds. To get an estimate of what the windfall may be during normal years, this amount was further reduced one-third. The average normal loss through windfall in virgin stands per acre per year was thus found to be 137 board feet. This however, is the loss through windfall alone. The same company when it added to the loss through windfall the estimated annual loss caused by rot and other natural mortality, brought up the total annual loss to 227 board feet per acre. This figure is close to the growth of 213 board feet in virgin stands found by this investigation and corroborates the theoretical assumption that in virgin stands growth equals decay. The gross increment in a virgin forest is large, but the net growth is nil.

The all-aged virgin hardwood forest, barring exceptional epidemics of insect or fungus attacks and abnormal windfalls, maintains its merchantable volume indefinitely. The popular idea that old hardwood forests must be cut immediately or otherwise they will deteriorate, is not supported by facts. On the other hand the actual growth in a virgin forest, while very large is an economic loss since it remains unutilized. If the over-mature timber—and this is the timber that is most likely to be windthrown or deteriorate—were utilized in time, it would serve a useful purpose, while the growth would replace the amount of timber removed in the form of over-mature trees. Theoretically, if not practically, virgin forest could be cut at the rate of 213 board feet per acre per year without reducing its merchantable contents.

Growth on Clean-Cut Areas

Diameter Growth.—The growth in diameter for the great number of seedlings which spring up on a clear-cut area after logging in a hemlock-hardwood forest is not as rapid as might be supposed. It is true that trees that escape the axe at the time of cutting make a remarkable growth in diameter after logging.

FIG. 4.—A CLEAN CUT-OVER AREA LOGGED EIGHT YEARS AGO.

The few sugar maple trees from 5 to 12 inches in diameter which remained after logging on a plot in Forest county (Table V) made an average diameter growth of 5.1 inches in the following 24 years.

The average diameter growth made by the same trees during the 24-year period immediately preceding cutting was only 1.9 inches. The extremely rapid rate of diameter increase made by the hold-overs is not equaled or even closely approached by the growth of young saplings which constitute the greatest per cent of the total number of trees per acre.

In the stand which sprang up within 24 years after clean cutting, 61 per cent of the total number of trees per acre fall into the 2 and 3-inch diameter classes; 91 per cent of all the trees are 6 inches or less in diameter. The average diameter for trees which have come in since cutting is 3.2 inches.

TABLE V.—DISTRIBUTION OF TREES BY SPECIES AND DIAMETER CLASSES IN A CLEAN-CUT HEMLOCK-HARDWOOD STAND 24 YEARS AFTER LOGGING. ONE ACRE. (AVERAGE 3 ACRES.) FOREST COUNTY, WISCONSIN

Inches Diameter Brest high	SPECIES									Total	Per cent of total number of trees in each diameter class
	Yellow birch	Bass-wood	Sugar maple	Elm	Aspen and paper birch	Iron-wood	Hem-lock	Green ash	Bal-sam fir		
	Total Number										
2	111	56	45	30	4	25	..	2	2	275	35
3	88	50	22	21	7	10	..	3	1	202	26
4	39	40	14	9	9	4	2	2	2	121	15
5	18	20	9	4	16	2	..	2	..	71	9
6	6	8	9	4	16	4	1	1	1	50	6
7	......	3	6	1	9	2	2	1	1	25	3
8	......	1	3	1	6	1	2	..	..	14	2
9	......	....	3	....	2	1	4	..	..	10	1
10	......	....	4	....	1	....	1	..	..	6	1
11	......	....	2	....	....	....	1	..	..	3	
12	......	....	1	....	....	....	1	..	..	2	1
13	......	....	1	....	....	....	1	..	..	2	
14	......	....	1	....	....	....	..	..	..	1	
15	1	....	1	....	....	....	..	..	..	2	
16	......	....	1	....	....	....	..	..	..	1	1
17	......	....	1	....	....	....	..	..	..	1	
18	......	....	1	....	....	....	..	..	..	1	
Total	263	178	124	70	70	49	15	11	7	787	

FIG. 5.—A 26-YEAR-OLD MIXED STAND OF YELLOW AND BLACK BIRCH AVERAGING 3.4 INCHES IN DIAMETER AND 39 FEET IN HEIGHT.

(Courtesy of Pennsylvania Department of Forests and Waters.)

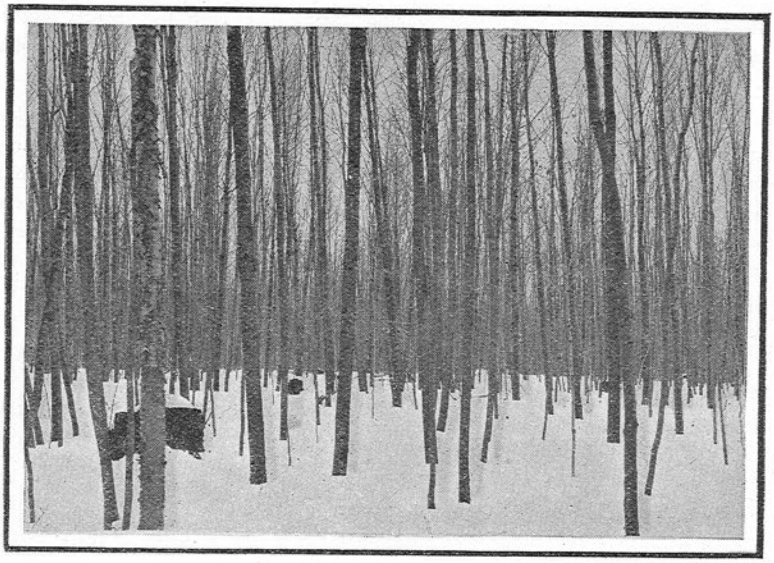

FIG. 6.—A 30-YEAR-OLD STAND, PRINCIPALLY BLACK BIRCH, AVERAGING 3.4 INCHES IN DIAMETER AND 40 FEET IN HEIGHT.

(Courtesy of Pennsylvania Department of Forests and Waters.)

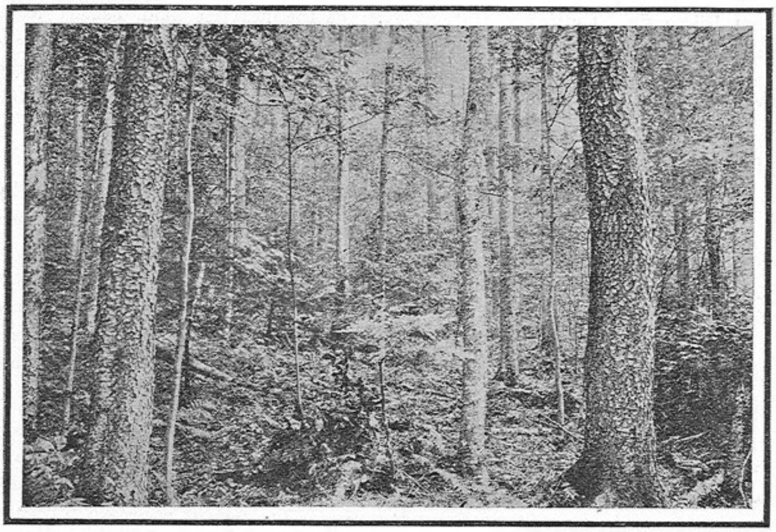

FIG. 7.—AN 80-YEAR-OLD BEECH-BIRCH-MAPLE STAND AVERAGING 9.6 INCHES IN DIAMETER AND 71 FEET IN HEIGHT.

(Courtesy of Pennsylvania Department of Forests and Waters.)

It is doubtful whether the best possible diameter growth for thrifty, even-aged second-growth stands, following clear cutting, would be more than 4 inches in 24 years—hardly large enough even for chemical wood.

These growth figures obtained in Wisconsin are corroborated by a similar study of the northern hardwood forest recently conducted by the Department of Forests and Waters in Pennsylvania. A 26-year-old mixed stand of yellow and black birch averages only 3.4 inches in diameter and 39 feet in height. (Figure 5.) A 30-year-old stand, principally of black birch, similar to our yellow birch, was found to average 3.4 inches in diameter and 40 feet in height—growth figures very comparable with those obtained in Wisconsin. (Figure 6.)

It would seem that from 75 to 80 years at least are required to grow northern hardwood trees after clean cutting to a minimum sawlog size of 10 inches in diameter at breast height. This, again, is corroborated by the study of hardwood growth in Pennsylvania, where a birch-beech-maple stand in 80 years had attained 71 feet in height and 8.6 inches in diameter. (Figure 7.)

Some 100 complete stem analyses taken on areas which have been heavily logged from 11 to 32 years ago prove conclusively that at least 80 years would be necessary to grow 10-inch hardwood or hemlock sawlogs.

Growth in Board Foot Volume.—A clean-cut forest area is one from which about 90 per cent of the original timber was taken by logging. It is doubtful whether a 100 per cent clean cutting is ever made in hardwood stands in northern Wisconsin. Cutting operations even of the heaviest kind, usually leave a few scattered trees of from 5 to 12 inches in diameter. These trees, providing fire is kept out, furnish the only source of sawlog timber during the first 25 to 40 years after logging. It is only after 80 years and more often 100 years that the young growth that springs up after clean cutting begins to furnish sawlog material.

What a clean-cut forest looks like, 24 years after logging, is illustrated by an actual tally. Table V, already referred to, shows the distribution of trees by kinds and sizes on one acre in a clean-cut hemlock-hardwood stand 24 years after logging. As may be seen, 91 per cent of the 787 trees are below 7 inches, and only 9 per cent are above 7 inches, and of this 3 per cent are at present of sawlog size. This shows that at the time of logging 24 years ago a few trees were left which were merchantable at that time or became merchantable since then.

No clean-cut areas were found which were logged 80 or 100 years ago. It would be unfair, of course, to draw conclusions as to the growth of clean-cut areas in board feet after the lapse of only 24 years, as there was practically no merchantable timber available at that time. The nearest approach to clean-cut areas would be heavily cut stands which are now 80 years old. Such stands were found in close proximity to the clean-cut areas and, therefore, can serve as an illustration of what the clean-cut areas may produce in 80 years after logging. One such plot was measured. Its average age was 80 years. The average diameter for sugar maple in the present stand was 9.9 inches; maple constitutes 84 per cent of the present volume of 4,412 board feet; yellow birch, basswood, elm, and hemlock make up the remaining 16 per cent of the total volume. The average diameter for all species is somewhat less than for sugar maple. The total volume of 4,412 board feet, divided by 80 years, or the averge age of the stand, gives an annual increment of 55 board feet.

Growth in board feet which took place on two plots, in one which was cut practically clean and now has a stand 24 years old, in another which also was cut almost clean and now has a stand whose average age is 80 years is given in Table VI.

TABLE VI.—GROWTH IN BOARD FOOT VOLUME ON CLEAN-CUT AREAS

Original stand	Amount cut in logging	Per cent of original stand removed by logging	Present stand	Average age of stand	Average annual growth per acre per year
bd. ft.	bd. ft.		bd. ft.	years	bd. ft.
16,245	15,523	96	1,462	24	61
10,158	9,039	89	4,412	80	55

The growth in volume on so-called clean-cut areas may, therefore, be accepted as being from 55 to 65 board feet per acre per year.

It must be borne in mind that although the two plots are classed as clean cut areas, neither of them were cut clear of every merchantable tree. If this were the case, the first plot would not have had any merchantable timber of any kind in 24 years. As has already been shown under the discussion of diameter growth on clean-cut areas, a stand that originates on a clean cut area within 24 years will have an average diameter of only about four inches, that is, no merchantable volume that can be measured in board feet. The reason why the first plot shows any board foot content at all is that about two per cent of the stand left was merchantable at time of first logging and several other trees which ranged between eight and ten inches in diameter have become merchantable since. It is on account of these trees that there is any board foot growth on this clean-cut area. As has already been pointed out, there is hardly a clean cutting in the state, unless it has been burned, that does not contain a few merchantable trees or trees approaching merchantability. Since such clean cuttings are typical of the northern part of the state, they may be considered characteristic although this is not true of areas that have been stripped completely of every merchantable tree or trees down to six inches in diameter, as may happen in the case of cuttings for chemical wood. On the second plot 89 per cent of the original stand was removed.

Loss Through Natural Mortality Low.—There is one redeeming feature in cutting hemlock hardwood stands clean. The average annual growth, low as it is, is practically net growth. In cutting a stand clean, defective trees are taken along with the sound ones. Subsequent volume growth will produce more board feet of good lumber at the mill than material cut from virgin stands.

Growing Sawlog Timber a Long Time Investment.—The possibilities of growing successive crops of timber on clear-cut areas is not very attractive under present conditions. No investor wants to wait from 80 to 100 years for returns on his money, especially when the chances are that fires may wipe out the entire stand within 10 years after logging. With the increased efficiency in fire protection, once the critical period of the first 10 or 15 years is past, the chances of growing timber on clean-cut areas will be much better. This discussion is confined to the growing of timber of sawlog size only. If the timber is to be utilized for chemical wood or small dimension stock, the outlook for even-aged young growth of hardwoods on previously clean-cut areas may be more promising. For the growing of sawlog timber, however, the factor of the long-time investment remains, and this makes the prospects of growing sawlog timber on clean-cut areas unattractive.

Growth in Partially-Cut Stands

Diameter Growth.—A paritially-cut forest area is one from which only a part of the original volume has been removed by logging. In the case of the plots studied, the amounts removed in the first cutting range from 26 to 96 per cent of the original stand.

One of the direct results of partial cutting in the hemlock-hardwood forest is a decided increase in the rate of diameter growth for the trees left uncut. This accelerated growth is due to the reduced crowding of the trees which are left, their greater enjoyment of light, and greater amount of nourish-

FIG. 8.—STAND LEFT AS A RESULT OF PARTIAL CUTTING.

ment and moisture made available in the soil by removal of the older trees. The rate of acceleration in diameter growth is influenced by the severity of the cutting, the species left, and the quality of the soil. The size of the trees has apparently no perceptible effect on the rate of acceleration in diameter growth after cutting. An attempt to compute the average rate of diameter growth after a heavy partial cutting separately for trees from 10 to 20 inches in diameter and for trees from 20 inches and up, showed that there is practically no difference. If there is, it is so negligible that the error induced in growth calculation by the assumption that trees grow at the same rate, irrespective of size left at the time of cutting, will be very small.

Of the three factors named, severity of cutting and the species left are of the most importance. The heavier the cutting and the fewer trees left on the area, the greater is the rate at which they grow both in diamter and volume. As the growth in volume depends on the growth in diameter and in height, and since the growth in height is of little consequence in merchantable trees which have attained their greatest merchantable length, the increased growth in volume must be due, therefore, largely to the accelerated growth in diameter.

How the severity of cutting affects the rate of diameter growth of the trees left on the ground may be correctly demonstrated by a simple computation. If the 17 plots examined are divided into three groups according to the amount of timber removed and the rate of increase of diameter of the prevailing species is determined for each group, separately, the results are these: (Table VII.)

TABLE VII.—GROWTH IN DIAMETER OF SUGAR MAPLE AFTER VERY HEAVY, HEAVY, AND MODERATE PARTIAL CUTTINGS

Average amount of merchantable timber left	Per cent of original stand removed	Average diameter growth during 10 years following cutting	Character of cutting
Board feet		Inches	
525	89 to 96	2.1	Very heavy
1907	63 to 85	1.6	Heavy
5193	26 to 58	1.5	Moderate

The species of the northern hardwood forest are arranged tabularly and graphically (Table VIII and Figure 9) in the order of their increase in diameter growth as a result of the opening up of the stand. Northern white cedar and balsam fir are included in this list, because occasionally these two species occupy an important place in the hardwood forest. The averages as given in the table are based on some 2,000 borings collected on 17 different areas in five northeastern counties of the state and in stands from which from 26 to 96 per cent of the volume of the original stand was removed by cutting.

TABLE VIII.—AVERAGE DIAMETER GROWTH IN PARTIALLY-CUT HEMLOCK-HARDWOOD STANDS BEFORE AND AFTER CUTTING

Species	YEARS 5 Before cutting	5 After cutting	10 Before cutting	10 After cutting	15 Before cutting	15 After cutting	20 Before cutting	20 After cutting	Per cent of increase
	Inches								
Basswood	.8	1.0	1.5	2.0	2.1	3.0	2.8	4.1	46
Balsam fir	.7	1.0	1.4	2.2	2.0	3.4	2.7	4.4	63
White cedar	.6	.8	1.1	1.8	1.7	2.7	2.2	3.7	68
Beech	.5	.9	.9	1.9	1.4	2.8	1.8	3.8	111
Sugar maple	.5	.8	1.0	1.6	1.6	2.5	2.0	3.3	65
Hemlock	.5	1.0	.9	1.8	1.4	2.5	1.8	3.3	83
Yellow birch	.4	.6	.9	1.2	1.3	1.8	1.7	2.5	47
Elm	.4	.6	.9	1.3	1.3	1.9	1.7	2.5	47

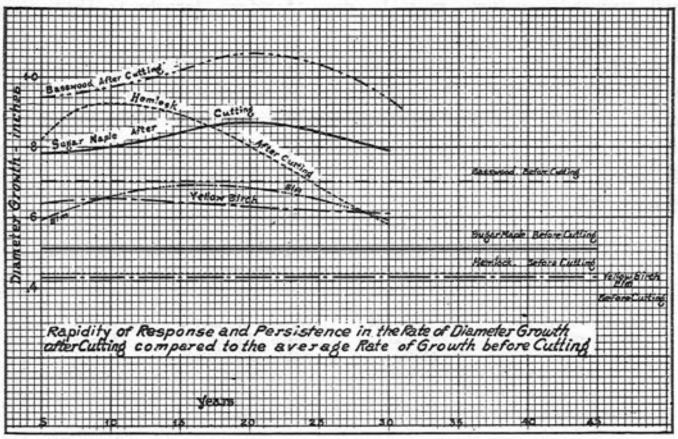

FIG. 9.—RATE OF DIAMETER GROWTH IN NORTHERN HARDWOOD STANDS AS INFLUENCED BY SELECTIVE LOGGING

Each species responds differently to increased light and growing space.

Of all species, basswood after cutting makes the largest absolute diameter growth in inches. Thus, in 20 years after cutting basswood attains a diameter growth of 4.1 inches, beech only 3.8 inches, sugar maple and hemlock only 3.3, and yellow birch only 2½ inches. This difference in growth, however, is inherent in the species themselves even in the virgin stand. It simply means that basswood is a faster growing species than either sugar maple or hemlock under all conditions. It does not express, however, the actual rate of acceleration in diameter growth due to the opening of the forest. If measured by the actual percentage of increase in diameter growth, hemlock is the one that next to beech responds most energetically to opening up of the forest. The slowest increase is made by yellow birch and elm.

The ability of the different species to reach their greatest acceleration in diameter growth after cutting and to maintain it, varies widely. Hemlock, ten years after cutting, reaches its peak in diameter growth acceleration. Immediately after reaching its peak the rate in diameter growth begins to fall. The diameter growth within the last five years of the 30 year period is .58 inches, or only 62 per cent of the growth it made in the second five-year period following logging. The trend of the diameter acceleration curve for hemlock indicates that 35 to 40 years after partial cutting, the growth rate will be practically the same as in the virgin stand. The average increase in diameter at breast high for hemlock in the virgin stand is .44 inches for each five-year period.

Sugar maple and basswood compare favorably in the manner in which they respond in diameter growth to heavy partial cutting. Both species make the greatest diameter growth within 15 to 20 years after logging. The actual diameter growth for the fourth five-year period following logging is 1.07 inches for the basswood and .87 inches for the sugar maple. As the stands left by partial cutting grow older and the competition of the trees for light and space increases, the rate of growth of both basswood and sugar maple begins to decline, more rapidly for basswood than for sugar maple. The diameter growth for basswood during the last five years of a 30-year period after cutting is only 88 per cent of its maximum growth of 1.07 inches made during the fourth five-year period after cutting. For sugar maple, it is 91 per cent of its maximum growth of .87 inches attained by it at the end of the fourth five-year period after cutting. From the trend of the curves of accelerated growth in basswood, it is clear that the rate of growth in diameter will approach that which basswood had in virgin stands within 40 years after cutting. Sugar maple will reach that rate within a period of 50 to 60 years.

Of the important commercial tree species, elm and yellow birch show little response in diameter growth after partial cuttings. Elm makes the best diameter growth midway between the third and fourth five-year period following cutting, that is seventeen to eighteen years after logging. The maximum diameter growth attained by an elm following the heavy partial cutting is .69 inches in five years. The rate of diameter growth of elm in the virgin stand in reached in partially cut stands in about 35 to 40 years after logging. Yellow birch responds quickly but feebly to opening up of the forest. A maximum diameter growth of .65 inches in five years is reached ten years after a heavy selective cutting has been made. The species, however shows a decided tenacity to maintain a constant rate of acceleration in diameter growth once the stand has been opened up, in part, by logging. Twenty years after the peak of .65 inches is reached, the rate of diameter growth is still 94 per cent of the maximum. The number of years required to bring the diameter growth again down to the rate made in the virgin stand before cutting, is more or less hypothetical but is probably in the neighborhood of 50 or 60 years.

The effect of partial cutting on the diameter growth of hemlock and sugar maple may be clearly seen on the cores obtained from these trees. (Figure 10.) The drawings are exact reproductions of increment borings.

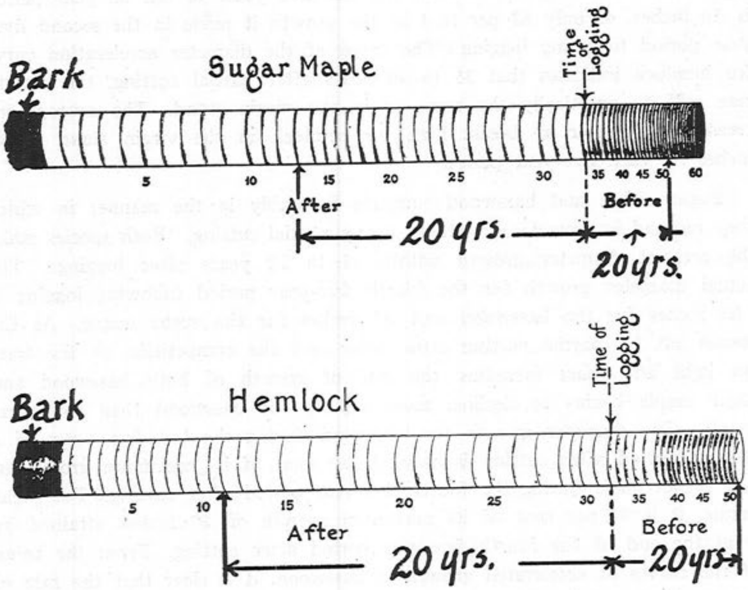

FIG. 10.—A COMPARISON OF THE WIDTH OF THE ANNUAL RINGS OF HEMLOCK AND SUGAR MAPLE BEFORE AND AFTER THE STAND HAD BEEN OPENED UP BY A HEAVY PARTIAL CUTTING.

The hemlock core typifies growth for that species made in a partially-cut hardwood stand in Langlade County. The original stand was exceptionally heavy, 18,556 board feet. Logging removed 83 per cent of the total volume of 15,347 board feet. Some 4,420 board feet of merchantable timber was left. This residual stand, along with the smaller trees which were unmerchantable at time of cutting, has increased to 9,105 board feet in 32 years after logging. The gross average annual increment for the stand is 205 board feet. Diameter growth, actual, for the 20-year period following cutting is about 4½ times as great as for the 20-year period immediately prior to cutting, or .45 inches and 2.05 inches respectively. The core further shows the effect of competition for light and moisture as the stand thickens up and the trees attain larger sizes. It will be noted that the last 10 or 12 annual rings are spaced more closely on the hemlock core than those for the first 20 years after logging. This slowing down of diameter acceleration is the normal tendency in partially-cut stands, when after 25 years or more, the trees begin to be crowded again.

The good diameter growth, after partial cutting, made by hemlock in Langlade County is equaled or even excelled by sugar maple upon one area examined in Florence County. The maple core is more or less typical for the diameter growth of sugar maple in partially-cut stands. The area has been logged twice. Thirty-three years ago, 2,628 board feet of basswood was cut per acre. Sixteen years later, 5,513 board feet of elm per acre was logged off the area. Both cuttings stimulated the diameter growth of the trees left uncut. The diameter growth, actual, for the 20-year period following the first cutting was 2.00 inches as compared to .55 inches for the 20 years immediately prior to the same cutting. The beneficial effect of the heavy second cutting is shown by the wide spacing of the last 15 annual rings. Nothing could illustrate better the effect of the severity of cutting on diameter acceleration than the spacing of the annual rings on this maple core. The light cutting of 33 years ago stimulated diameter growth less than the heavy cutting made 16 years later.

Growth in Board Foot Volume.—The annual growth per acre in partially cut stands was found to vary from 102 to 240 board feet. The average annual growth for the 17 plots aggregating close to 104 acres was, in round figures, 145 board feet. (Table IX.) This figure may be accepted as the

TABLE IX.—GROWTH IN PARTIALLY-CUT STANDS
(Based on 104 acres.)

Plot number	Number years since first cutting	Original stand	Amount cut in logging	Per cent of original stand removed by logging	Present stand	Growth since logging	Average annual growth per acre per year
		Volume in board feet					
1	14	10,025	2,628	26	9,752	2,569	184
2	16	9,432	5,059	54	7,749	3,845	240
3	17	9,467	5,513	58	6,044	2,326	137
4	15	10,216	6,442	63	4,320	919	61[1]
5	25	11,028	7,273	66	6,044	3,280	131
6	24	11,709	8,245	70	6,955	3,817	159
7	30	11,200	7,945	71	5,956	3,068	102
8	26	12,203	8,760	72	6,484	3,455	133
9	24	10,087	7,801	78	6,536	4,358	182
10	28	8,365	6,885	82	5,372	4,016	143
11	32	18,556	15,347	83	9,105	6,548	205
12	27	17,252	14,415	84	6,324	3,943	146
13	26	10,563	9,000	85	5,515	4,468	172
14	11	11,140	9,586	86	2,770	1,592	145
15	23	10,158	9,039	89	4,412	3,517	153
16	18	13,284	12,688	95	2,465	2,088	116
17	24	16,245	15,523	96	1,462	1,268	53
Average	24	11,269	8,222	80	5,752	3,096	146

[1] Area, although included in the average, is on the face of it abnormal. The reasons for no acceleration of growth are discussed later on.

possible growth in stands cut selectively provided it applies to large areas and stands cut very heavily, heavily, and moderately. It does not apply to comparatively small individual stands cut, for instance, to a definite diameter limit. To determine more accurately the growth in board foot volume in stands cut with different degrees of severity one must clearly understand and take into account the several factors which affect volume growth in partially-cut stands. As has already been brought out in the discussion of accelerated diameter growth in partially-cut stands, three factors affect the future volume growth of the remaining stand. (1) The amount of timber removed in logging or the severity of cutting. (2) The species left and (3) Site, meaning soil quality and growing conditions. In the case of volume growth the factors which control, most of all, the volume growth of the remaining stand during the next 20 to 30 years is (1) Severity of cutting (amount of timber removed). (2) The number and size of unmerchantable trees left at time of cutting. The effect of these two factors upon the growth of the remaining stand after a selective logging will be made clear by reference to Tables 11, 12, and 13. These three tables present a picture of the stand as it was left after a *very heavy*, heavy, and moderate partial cutting. The figures given in the table are average for a number of plots cut approximately in the same way. The average figures in Table X are

TABLE X.—DISTRIBUTION BY SPECIES AND DIAMETER CLASSES IN STANDS CUT OVER VERY HEAVILY[1]

(Based on 13½ Acres)

Diameter breast high	SPECIES							Total merchantable and unmerchantable trees
	Sugar maple	Yellow birch	Hemlock	Basswood	Elm	Balsam fir	Total	
Inches	Number of trees							
5	6	..	1	1	1	1	10	
6	5	2	2	..	1	..	10	
7	6	..	2	1	1	..	10	
8	4	..	1	..	..	..	5	
9	4	1	2	1	..	..	8	43 (unmerchantable)
10	3	..	1	..	1	..	5	
11	2	..	..	..	..	..	2	
12	2	..	1	..	..	..	3	
13	..	..	..	..	..	..	..	
14	1	..	..	..	..	..	1	
15	..	..	..	..	..	...	..	
16	..	..	..	..	..	..	....	
17	..	1	..	..	..	..	1	
18	..	..	..	..	..	..	....	
19	..	..	..	..	..	..	....	
20	..	..	..	..	..	..	....	12 (merchantable)
Total	33	4	10	3	4	1	55	

[1] From 89 to 96 per cent of original stand was removed by first logging. Average merchantable stand left after logging 525 board feet. Average annual increment since first logging 120 board feet.

TABLE XI.—DISTRIBUTION OF TREES BY SPECIES AND DIAMETERS IN STANDS CUT OVER HEAVILY[1]
(Based on 55 Acres)

Diameter breast high	SPECIES							Total number of trees
	Sugar maple	Yellow birch	Hem-lock	Bass-wood	Elm	Balsam fir	Total	
Inches	Number of trees							
5	2	1	5	1	1	1	11	
6	2	..	4	..	1	1	8	
7	2	1	3	1	1	1	9	
8	2	..	3	..	1	..	6	41 (un-merchantable)
9	2	1	2	1	1	..	7	
10	2	1	2	..	1	..	6	
11	2	1	1	..	1	..	5	
12	2	1	1	..	1	..	5	
13	2	1	1	..	..	..	4	
14	1	1	1	..	..	..	3	
15	1	1	..	..	..	..	2	
16	1	1	1	..	..	..	3	
17	1	..	..	..	..	..	1	
18	..	..	..	..	..	..	..	
19	1	..	..	..	..	..	1	30 (mer-chantable)
20	..	..	..	..	..	..	....	
Total	23	10	24	3	8	3	71	

[1] From 63 to 85 per cent of original stand was removed by first logging. Average merchantable stand left after logging 1907 board feet. Average increment since first logging 148 board feet.

TABLE XII.—DISTRIBUTION BY SPECIES AND DIAMETER CLASSES IN STANDS CUT OVER MODERATELY[1]
(Based on 24 Acres)

Diameter breast high	SPECIES							Total merchantable and unmerchantable trees
	Sugar maple	Yellow birch	Hem-lock	Elm	Bass-wood	Balsam fir	Total	
Inches	Number of trees							
5	3	1	2	1	2	1	10	
6	4	1	2	..	1	1	9	
7	3	1	2	1	1	..	8	
8	3	1	2	..	..	..	6	
9	3	..	1	..	..	..	4	37 (unmerchantable)
10	2	1	1	..	1	..	5	
11	3	..	1	..	..	..	4	
12	3	1	1	..	..	..	5	
13	3	1	..	..	..	..	4	
14	3	..	..	..	..	..	3	
15	3	1	..	..	..	..	4	
16	2	..	..	..	..	..	2	
17	2	1	..	..	..	..	3	
18	1	..	..	..	..	..	1	
19	2	..	..	..	..	..	2	
20	1	..	..	..	..	..	1	34 (merchantable)
Total	41	9	12	2	5	2	71	

[1] From 26 to 58 per cent of original stand was removed by first logging. Average merchantable stand left after logging 5193 board feet. Average annual increment since first logging 174 board feet.

based on 13½ acres cut over very heavily; those in Table XI represent average figures for 55 acres cut over heavily, and the figures in Table XII are averages for 24 acres cut over moderately. They give the number of trees of different species by diameter classes from 5 to 20 inches. In addition they show the number of unmerchantable trees from five to nine inches and the number of merchantable trees ten to twenty inches in diameter left after cutting, the amounts of merchantable timber left in board feet, and the average annual growth in board foot volume during the time which has elapsed since logging and the time when the stands were measured in 1928.

It will be immediately noticed that there is a direct relationship between the average amount of merchantable timber left and the volume growth made in board feet. The larger the amount of merchantable timber left, the greater is the volume growth.

Thus in the case of very heavy cutting, where from 89 to 96 per cent of the original stand was removed and only 525 board feet were left, the average annual growth was 120 board feet; in the case of heavy partial cutting which removed from 63 to 85 per cent of the original merchantable volume and left 1907 board feet of merchantable timber, the annual growth was 148 board feet; while in the case of a moderate partial cutting in which only from 26 to 58 per cent of the original was cut leaving 5,193 board feet to the acre, the average annual growth was one hundred seventy-four board feet.

The small unmerchantable trees left at the time of cutting play an important part in the future growth of the stands. The small unmerchantable trees are the potential sawlogs of future cuttings. The place they hold as producers of annual volume growth is shown by the fact that from 20 to 64 per cent of the annual growth for the 17 areas examined accrued from small trees of unmerchantable sizes which grew into merchantability. The average annual growth for all areas is about 145 board feet. Forty per cent of 145 board feet is 58 board feet of annual growth which the trees five to nine inches in diameter contribute as their share of the total increment laid on each year.

In partially-cut stands in which the proportion of unmerchantable trees to merchantable trees is large, it is evident that the bulk of the increment must come from them and not from the merchantable trees left, hence the total annual growth in board feet, all other conditions being equal, will be comparatively small. On the other hand, where the proportion of small trees to the merchantable trees left on the ground is small, most of the increment in board feet during the first 16 to 20 years after cutting comes from the merchantable trees and the annual growth in board feet is accordingly large.

By reference again to Tables X, XI, and XII it will be noticed that the number of small trees between five and nine inches in diameter as a general rule does not vary much from one stand to another, while the number of merchantable trees and their volumes vary in accordance with the amount of timber removed. Thus the number of small unmerchantable trees above five inches in diameter is 43 in very heavily cut stands, while the number of merchantable trees left is 12, 30, and 34 respectively. The small trees assume importance only in relation to the amount of merchantable trees left.[3] Where the amount of merchantable timber left as a basis for future growth is small, the unmerchantable trees assume relatively the largest burden of producing the annual growth. Where the amount of merchantable timber left is large, the effect of the small unmerchantable trees on the annual growth is comparatively slight particularly during the first 10 or 20 years after cutting.

Percentage of Volume Growth.—If the average annual growth in the different stands studied is divided by the amount of merchantable timber left in each stand at the time of cutting and the result is multiplied by 100, the per cent at which the merchantable stand left on the ground grew annually in board feet since logging is obtained. Thus, for instance, if the average annual increment in a stand is 170 board feet per acre per year, and the merchantable volume of trees left at cutting is 3,300 board feet, then the per cent at which the stand grew in board feet is $\frac{170 \times 100}{3300} = 5.2$. It was found that the larger the amount of merchantable timber left, the smaller is the volume growth per cent; and the larger the volume growth per cent, the smaller the amount of merchantable timber left.

The reason for this is obvious. The fewer the number of merchantable trees left at time of cutting, the more vigorous is their accelerated growth. This has already been brought out in the discussion on the relation between severity of cutting and acceleration of diameter growth. While the per cent of growth is, therefore, great the total amount of volume growth made by the stand in board feet can not be large because there are only a few trees upon which this increased growth is made and only a few trees of unmerchantable size reach merchantability in the course of the next 20 or 25 years. In stands where a large amount of merchantable timber is left the acceleration in growth is also small. Yet, because of the comparatively large number of merchantable trees left, the aggregate growth in board foot volume is large. The volume growth per cent is the best indicator of the possible future growth in partially cut stands.

Prediction of Future Growth.—On the basis of the field data obtained and the relationships observed between the amount of timber left, the proportion of small unmerchantable trees in the stand and the annual volume growth in board feet, it was possible to construct a table (Table XIII) and graph (Figure 11) from which one can, by using the volume growth per cent and the amount of merchantable lumber left at time of cutting, predict average annual growth for the next 20 to 30 years.

[3] This relationship is best expressed as the percentage of the sum of the basal area of trees between 5 to 9 inches of the total basal area of all trees, both merchantable and unmerchantable, left on the ground. (See Table XIII.)

Table XIII and Figure 11 show on the basis of the actual relationships found by the study what happens to the growth per cent and annual volume growth in stands having an original merchantable volume of 13,000 board feet, or for that matter any stand, from which merchantable timber is removed by partial cutting in varying amounts from 42 to 99 per cent of the original stand, that is, from light cuttings to practically clear cutting. These

TABLE XIII.—RELATION BETWEEN AMOUNT OF MERCHANTABLE TIMBER LEFT, VOLUME GROWTH PER CENT, AND AVERAGE ANNUAL GROWTH IN BOARD FEET

Basal area of trees 5 to 9 inches inclusive left after cutting in per cent of total basal area	Volume per acre left after cutting	Rough diameter limit cutting	Volume removed from original stand Basis: 13,000 bd. ft.	Volume growth per year in percent of total volume left after cutting	Average gross annual increment per acre	Average number of years required to grow 1,000 board ft. (Scribner gross)	Character of cutting
Per cent	(Board ft. Scribner)	Inches	Per cent	Per cent	(Board feet Scribner)		
12	13,000	....	....	1.6	210	....	Virgin stand
14	7,500	20 or 22 and up	42	2.6	195	5	Light partial cutting
15	6,000		54	3.1	185	5½	
20	3,300	14 or 16 and up	75	5.2	170	6	Heavy partial cutting
25	2,400		82	6.6	160	6	
30	1,900		86	8.1	155	6½	
35	1,550		88	9.8	150	7	
40	1,200	12 or 13 and up	91	12.0	145	7	Very heavy partial cutting
45	900		93	15.0	135	7½	
50	700		95	19.4	135	7½	
55	450		97	24.6	110	9	
60	210	11 and up	98	31.0	65	15	Clear cutting
65	100		99+		45	22	

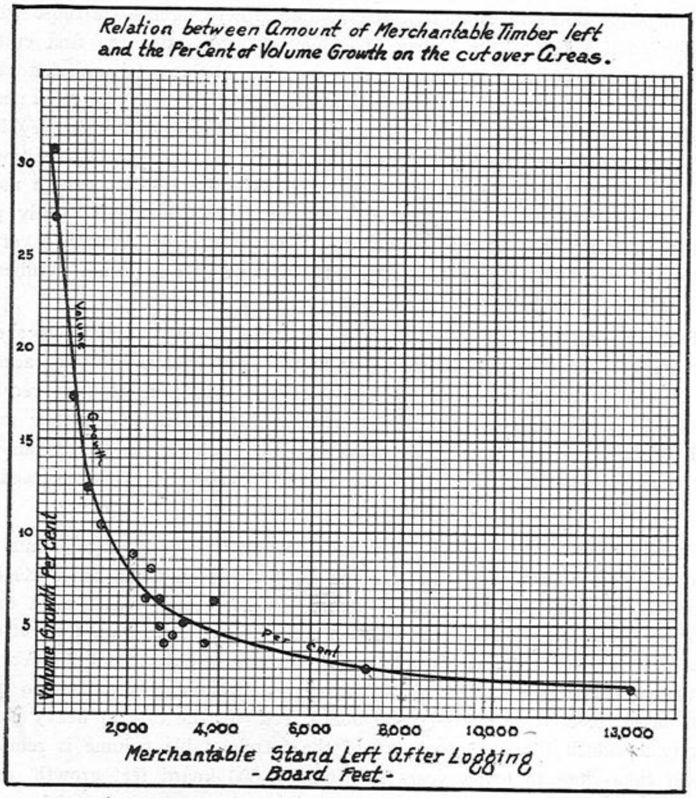

FIG. 11.—EFFECT OF SEVERITY OF CUTTING UPON THE GROWTH PERCENT MADE BY THE MERCHANTABLE STAND LEFT BY LOGGING.

relationships are found to exist actually in the stands studied in northeastern Wisconsin. It is, therefore, natural to assume that they will apply to any other stands, in the same region, of similar composition and distribution of diameter classes. This table and graph enable one, if one of the factors named in the table is known or easily determined in the field, to predict all other factors affecting the growth of the stand. The most easily determined factor is the amount of merchantable volume left on a cut-over area, and the thing that any timber owner wishes most to know is what the remaining stand will produce during the next 20 to 30 years in the form of saw-log material. If, for instance, the timber land owner finds that after selective logging, there is left 3,000 board feet in the form of merchantable trees, then according to the graph the stand may be expected to grow at the rate of 5.5 per cent per year. By multiplying the growth per cent by the amount of merchantable timber left the average annual growth for the next 25 years is obtained: $\frac{5.5\text{x}3000}{100} = 165$ board feet.

It must be borne in mind that the volume growth figures are those which actually took place in the course of about 25 years after the first cutting and refer to definite conditions at the time of cutting. In applying these figures to present cuttings the prediction must also extend only to a period of about 25 or 30 years in the future, as the conditions for which they hold true may change within that period. Much of the unmerchantable timber may become merchantable by that time and the entire rate of growth modified. The figures as given, therefore, are not yield values but merely prediction of growth for definite conditions of cut-over areas, namely, a certain amount of merchantable timber left on the ground and a certain number of small unmerchantable trees in the stand.

Furthermore, the figures of growth are gross values. Deductions should be made for decay or natural mortality in the stand which will vary according to the previous condition of the trees left, the injuries they received during the first logging, and the character of the soil in which they grow. Each timber owner will have to make his own estimate as to the amount that should be allowed for this loss. It will seldom, however, exceed 10 per cent of the annual increment.

Intervals Between Successive Cuttings.—Knowing the average annual increment per acre per year and this can be determined from Table XIII or Figure 11, it is a simple matter to figure out how many years must elapse before another cut of a definite amount may be obtained from the cut-over area. In the case of light partial cuttings in which only about 50 per cent of the original volume is removed, it will require only five years to grow 1,000 board feet, or 15 years—3,000 board feet. In the case of heavy partial cutting in which 75 to 85 per cent of the merchantable volume is removed, it will take close to seven years to replace 1,000 board feet growth, or 21 years to produce 3,000 board feet. In the case of very heavy partial cutting, in which from 90 to 95 per cent of the entire stand is removed, it may take from eight to nine years to grow 1,000 board feet, or 27 years—3,000 board feet.

By light partial cutting is meant logging which removes 50 per cent of the original stand. If the logging is confined to the largest trees only, this will correspond to a diameter limit cutting of roughly 20 inches. In heavy partial cutting where between 75 and 85 per cent of the stand is removed, and the logging again is confined only to the largest trees in the stand, the cutting corresponds to a diameter limit of between 12 and 13 inches. In very heavy partial cutting, practically the entire merchantable stand is removed, except for a few scattered merchantable trees; this means a cutting of all trees 10 inches and over in diameter breast high.

Reproduction.—Natural reproduction after partial cuttings in the northern hardwoods offers no difficulty provided fires are kept out. The ease with which the hardwood forest reproduces itself is truly remarkable. Counts of young trees made on several of the partially cut areas showed an average of 2,450 trees per acre of sizes ranging from one-half inch to four inches in diameter breast high. This does not include a vast number of young trees which are less than one-half inch in diameter. If these are included, the number of young trees that come up after partial cutting may reach 30,000 to the single acre. Of the total number of 2,450 trees, 71 per cent are sugar maple.

The general idea that these young trees are sprouts from the stumps of the old trees is not true. With the single exception of basswood, the young growth of all other species is exclusively from seed. Basswood is the only species that reproduces itself abundantly by sprouts. On one area in Florence County, the average number of healthy basswood sprouts to each stump was 16, with a maximum of 36 sprouts and a minimum of five sprouts. In all cases basswood has reproduced itself by sprouts after logging, providing the cutting has been heavy. Sugar maple, elm, and ash produce occasional sprouts, but these as a general rule do not develop into large trees in the northern part of the state.

Loss Through Windfall and Mortality.—It is a common belief among lumbermen that partial cuttings result in a large number of windfalls. The field records show that with the exception of one single area in Forest County, the loss through windfall after partial cutting is very light. Many of the areas studied have been logged over from 20 to 30 years ago, and no bad windfall losses were noticed on these areas since cutting. Violent windstorms would undoubtedly cause severe losses in partially cut stands, as they would do in virgin stands, but ordinarily these losses are insignificant and do not cut down materially the average annual increment.

A much greater loss was found through the dying of some of the trees left in the stand. About 62 per cent by volume of all dead trees tallied in the stands partially cut over 20 to 30 years ago were trees 20 inches in diameter breast high or more. The total loss per acre per year from death and windfall varied from 11 to 88 board feet, with an average of 42 board feet for all areas examined. This is a fairly heavy loss. But it cannot be laid entirely against partial cutting. It has been pointed out that 62 per cent of the average annual loss of 42 board feet per acre accrues from trees having a diameter of 20 inches or more. This means that a dead tree which has a diameter of 20 inches or more must have been nearly dead at the time the partial cutting was made, or othewise it would have been cut along with other trees of the same dimensions. Such trees, therefore, can not be considered as having died since partial cutting and should be deducted from the average annual loss of 42 board feet per acre. This leaves as the normal annual loss through death and windfall in partially-cut stands 16 board feet per acre per year. This last figure is more reasonable than the 42 board feet, which includes the loss through death of trees 20 inches or more in diameter. The larger trees now dead have died in spite of the partial cutting made 20 to 30 years ago, rather than because of it. As the average annual growth per acre for partially-cut stands is 145 board feet, the loss of 16 board feet through death and windfall constitutes 10 to 11 per cent of the annual growth in volume.

Change in Composition of the Stand as a Result of Cutting

Both clear and partial cuttings change the composition of the stand that follows such cuttings. Clear cutting increases the percentage by numbers of such species as basswood, yellow birch, elm, and similar kinds of trees which require more light for their growth. The change which clear cutting brings about in a stand that follows it, is well illustrated by an area examined in Forest County. The stand which followed clear cutting is 24 years old. Of the 787 trees found on an acre, yellow birch is represented by 263 trees of different diameters, basswood by 178, while hemlock and sugar maple, the two species most prevalent in virgin stands, are represented by 124 and 15 respectively. (Table V.)

Partial cutting changes the composition of the stand that follows it in reverse order. While clear cutting encourages the appearance of species which require light, partial cutting increases the percentage of sugar maple by volume in the stand, and decreases the per cent also by volume of yellow birch, elm, and basswood. What, however, is apparently an exception to this rule, is that partial cutting tends also to decrease the amount of hemlock, a shade-loving tree, in the second growth. Its disappearance after cutting must be ascribed to causes other than lack of shade. The changes brought about in the composition of a stand following partial cutting, are presented in Table XIV.

TABLE XIV.—CHANGE IN COMPOSITION, BY SPECIES AND VOLUME AS INFLUENCED BY PARTIAL CUTTING

Species	Percentage of Total Volume Taken Up by Each Species	
	In the Virgin Stand	In Partially-Cut Stands 24 Yrs. After Cutting
Sugar Maple	32	56
Hemlock	18	18
Yellow Birch	19	14
Basswood	17	2
Elm	13	7
White Cedar	1	2
Beech	0	1
Total	100	100

While sugar maple in the virgin forest forms 32 per cent of the entire volume of the stand, in stands following partial cuttings it forms 56 per cent of the total volume. Hemlock apparently holds its own, while yellow birch drops from 19 per cent to 14 per cent, basswood from 17 to 2 per cent, and elm from 13 to 7 per cent of the total volume of the stand. This increase in volume of sugar maple through partial cutting is not an undesirable change. It replaces species which have less value in most cases. Hemlock is not so valuable a species as sugar maple at the present time. Elm, too, has little value under present market conditions, and its disappearance may be an economic advantage. Yellow birch, on the other hand, is as valuable as sugar maple and should be encourged to keep its place in the stand by proper marking. Basswood is a valuable species and every effort should be made to encourage its reproduction in partially-cut stands. This is not an easy task, however. No matter how one may favor, in marking, yellow birch and basswood in selective cutting, sugar maple seems to have its way regardless of such marking to favor other species. Sugar maple must be recognized as the principal species to be dealt with in the future as a result of partial cutting. It is doubtful whether yellow birch, basswood, and elm can ever compete on even terms with sugar maple.

Comparison of Growth in Virgin Stands, on Clean-Cut Areas, and in Partially-Cut Stands

A study of the amount or growth in board feet that takes place in virgin stands, on clean-cut areas, and in partially-cut stands tends to the conclusion that the highest net growth in board feet is obtained in partially-cut stands. The reasons for this are obvious.

In virgin stands, although actual growth of individual trees is very small, this growth is laid on many large already merchantable trees and therefore the aggregate growth per acre is fairly large. The large number of old, over-mature trees, some of which are defective, make some of the more exposed ones an easy prey to wind, and furthermore they are most susceptible to attacks by fungi and insects. The killing of one large tree per acre carries with it the growth of several acres or the growth for several years on the same acre. The loss through windfall and mortality in virgin stands has been estimated in some cases as high as 227 board feet per acre per year.

On the clean-cut areas, the forest must start from very young trees and the long time, from 80 to 100 years, that it takes for them to reach a 10-inch or 12-inch size makes the growth in board feet very slow. The growth of such young stands may be very rapid in cubic feet, but they must reach merchantable size for sawlogs before there is actual growth in board foot volume. Although the loss through windfall and decay is negligible, the aggregate growth in board feet is so small and the time is so long that it makes clean cut-over areas an unattractive investment for growing timber for sawlog material.

Partial cutting combines to some extent the advantages of virgin stands with the rapidity of growth of clear cut-over areas. The original stand is opened up through the removal of a portion of the older trees. The remaining trees, therefore, have more light and greater space in which to grow. They assume, therefore, an accelerated growth characteristic of young stands on clean cut-over areas. This growth, however, being made by trees of merchantable or nearly merchantable size, is expressed in the form of board foot volume and not merely cubic foot volume. There is greater flexibility in controlling the annual growth in partially-cut stands. By varying the amount of merchantable timber left, the timber grower is in a position to control the time between the successive cuts in accordance with the needs of his mill or market conditions.

The danger from windfall is only slightly increased by partial cutting. A much greater loss occurs through the death of some of the larger trees which were already defective before the partial cutting. If the loss caused through the death of trees 20 inches and over is deducted, the normal loss in partially-cut stands is not very high, namely, from 10 to 11 per cent of the annual increment or about 16 board feet. One of the disadvantages of partial cutting is that the trees which require light for their development, such as yellow birch, basswood, and elm are gradually eliminated from the stands, and the stand is converted more and more into a pure sugar maple forest. Where yellow birch is one of the desirable species, heavy partial cuttings are indicated. Clean cutting will particularly favor the presence of yellow birch and basswood in the future stands.

As to the prevailing logging methods within recent years, with greater utilization of the small trees, tend more and more to clear cutting, and as the area of virgin stands is growing smaller and smaller, the deficiency in timber in the state will be most acutely felt in the large sawlog sized material. Partial cutting, therefore, offers a solution not merely in obtaining a higher net growth in board foot volume, but also in the kind of material that will be most needed in the course of the next 20 years. The conditions for natural reproduction in partially-cut stands are ideal, and the all-age character of the hardwood-hemlock forest lends itself admirably to partial cutting.

Conclusions

1. There can be no intelligent or wisely planned handling of the private and public forest lands in the state without a knowledge of the possible growth on them within the next 20 to 30 years.

2. Upon such knowledge depends the economic soundness of the Forest Crop Law.

3. An old virgin hardwood-hemlock forest produces about 213 board feet per acre per year. This annual growth, however, is counterbalanced by loss through windfall, decay, and death of some of the over-mature trees with the result that in a virgin forest there is no net growth. The loss through windfall and rot in virgin hardwood stands is placed by some lumbermen as high as 227 board feet per acre per year, a figure close to the annual growth for virgin stands obtained by this study.

4. An old hardwood-hemlock forest can maintain its present merchantable volume indefinitely, provided it is not visited by exceptionally severe storms or epidemic attacks of insects or diseases.

5. Under ordinary circumstances, therefore, there is no urgency of cutting an old virgin forest for fear of deterioration through overmaturity.

6. Although there is no physical loss to the forest, there is an economic loss because the growth of 213 board feet which takes place in the forest merely replaces the loss through decay and windfall and serves no useful economic purpose.

7. When a forest is cut clean of all its merchantable timber, it takes from 80 to 100 years before any sawlog material can again be cut.

8. The growth per acre per year on land cut clean of its original forest is at the rate of from 55 to 65 board feet per acre per year. This growth, in the case of complete stripping of all trees down to six inches in diameter, is not available until the stand reaches an age of from 80 to 100 years.

9. In stands cut over partially or selectively, i. e., from which only part of the original merchantable stand was removed, the growth varies from 110 to 195 board feet per acre per year.

10. The annual growth in partially cut stands will depend upon the amount of merchantable timber left at the time of cutting and also on the number and size of the small, unmerchantable trees from five to nine inches in diameter breast high left after cutting.

11. There is a definite relationship between the amount of merchantable timber, the number and size of unmerchantable trees left at the time of cutting, and the percentage at which the merchantable stand is increasing in growth.

12. On the basis of such relationship one can, by knowing the amount of merchantable timber left, find the growth per cent, and by multiplying this per cent by the amount of merchantable timber, predict the annual growth for the next 20 or 30 years.

In stands from which 89 to 96 per cent of the original merchantable volume is removed, the growth in volume during the next 20 to 30 years is at the rate of 120 board feet per acre per year.

In stands from which 63 to 85 per cent of the original merchantable volume is removed, the growth in volume during the next 20 to 30 years is at the rate of 148 board feet per acre per year.

In stands from which 26 to 58 per cent of the original merchantable volume is removed, the growth in volume during the next 20 to 30 years is at the rate of 174 board feet per acre per year.

13. Partial cutting does not increase the loss through windfall or mortality. The normal loss through these causes is about 16 board feet per acre per year, or about from 10 to 11 per cent of the average annual growth of 145 board feet.

14. Clean cutting changes the composition of the future stand. On areas cut clean, the future forest will contain more yellow birch, basswood, and elm, and less sugar maple and hemlock than was in the original forest.

15. Partial cutting encourages sugar maple at the expense of yellow birch, basswood, and elm. Continued partial cutting may, therefore, convert the forest into an almost pure sugar maple stand. This is not an economic disadvantage, as sugar maple is one of the most important trees in the northern part of the state.

16. The net growth in board feet in partially-cut stands is greater than in virgin stands and on clean-cut areas. In virgin stands the growth is large, but the loss through decay and windfall equals growth. On clean-cut areas, although there is no loss through windfall or decay, the actual growth in board feet is small. On partially-cut stands the loss through windfall and mortality is small and the absolute growth in board feet is fairly large.

17. Partial cutting promises quicker and larger returns in board feet than either virgin stands or clean cuttings.

18. All computations or future growth are for stands which were not burned over.

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