

Partial Cuttings in Northern Hardwoods of the Lake States

Twenty-Year Experimental Results

By

F. H. EYRE and W. M. ZILLCITT

**Lake States Forest Experiment Station
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United States Department of Agriculture, Washington, D. C.

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Partial Cuttings in Northern Hardwoods of the Lake States: Twenty-Year Experimental Results¹

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INTRODUCTION

In the nineteen twenties the hardwood lumber industry of the Lake States faced a critical decision. There was an excess of mill capacity over stumpage available for long-continued operations. Some mills had a limited future; others had enough timber to last them a long time. But all such concerns began to consider what the future held.

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Public foresters urged hardwood owners to adopt a system of partial or "selective" cutting,⁴ looking ultimately toward sustained-yield forestry, in which growth balances cut. There was a general belief supported by carefully conducted mill-scale studies that it did not pay to cut small-sized trees for lumber. A greater return per thousand board-feet was realized when cutting was confined to the larger timber (144).⁵ Theoretically northern hardwoods seemed well suited to partial cutting (53, 127). If through partial cutting the life of the old-growth forest could be extended, then in time the prolific second-growth which came in after the earlier logging would gradually catch up and there would be timber enough for a prosperous hardwood industry.

To adopt a partial-cutting policy and place timber operations on a sustained-yield basis or even to embark on a two-cut liquidation plan (119) posed many financial (13, 44), managerial, and other problems to the timberland owner. Some mills have curtailed production so as approximately to balance cut against growth. One company has not only accomplished this objective (22), but through integrated utilization and more complete fabrication of the manufactured product, has more than doubled the man-hours of employment per unit of timber cut—a remarkable achievement (59). On the other hand, another company, for example, although practicing good silviculture in the woods, is exerting such little control over the total volume being cut that there is grave danger that the first cycle of cutting will be completed long before the timber is ready for a second cut (12). A large number of timberland owners, because of limited stumpage, difficulties in financing, high local taxes, or other reasons, have continued to liquidate their timber, and the dependent mills have closed down.

Certain timberland and mill owners have tried partial cutting, given it up, and then gone back to it. Others without mills to support have steadily practiced some form of partial cutting for over 20 years. Some companies have recently switched from clear cutting to partial cutting and seem intent on continuing the method. Merely changing the type of cutting does not, of course, bring cut into balance with growth, but on the whole much progress has been made in that direction. There are well over a million acres of northern hardwood forests on large holdings both in private and public ownership on which a start toward sustained yield has been made (140).

The situation in the farm woods and on other small forest properties also varies. In areas where land clearing is still going on, some small woodlots have been liquidated in recent years.

⁴ There has been much confusion concerning the selection method of cutting. Most of it has arisen through the wide use of the popular terms "selective logging" or "selective cutting," which have been applied quite indiscriminately to many kinds of cuttings. In this bulletin the terms "selection system" or "selection method" will be used only when referring specifically to this kind of silvicultural treatment. The term "partial" rather than "selective" will be applied to the various degrees of cutting employed in preliminary attempts at northern hardwood silviculture.

⁵ Italic numbers in parentheses refer to Literature cited, p. 111.

More commonly, however, the farm woods have been subjected to a continuous "culling" or "high grading" which has decreased the proportion of desirable growing stock. Nonetheless, substantial headway has been made toward better forestry. In the aggregate, a large area of farm woods occupied by northern hardwoods presents good possibilities of carrying on a form of forest practice that would foster continuous income.

The area of uncut old-growth hardwoods has now dwindled to about a million acres, chiefly in the Upper Peninsula of Michigan, whereas that of partially cut timber has become materially greater and is continually increasing. Moreover, advanced second-growth made up partly of a remnant of old trees and partly of younger timber which has grown into sawlog size has already helped to maintain a substantial sawmilling, veneer, and wood-working industry (fig. 1).

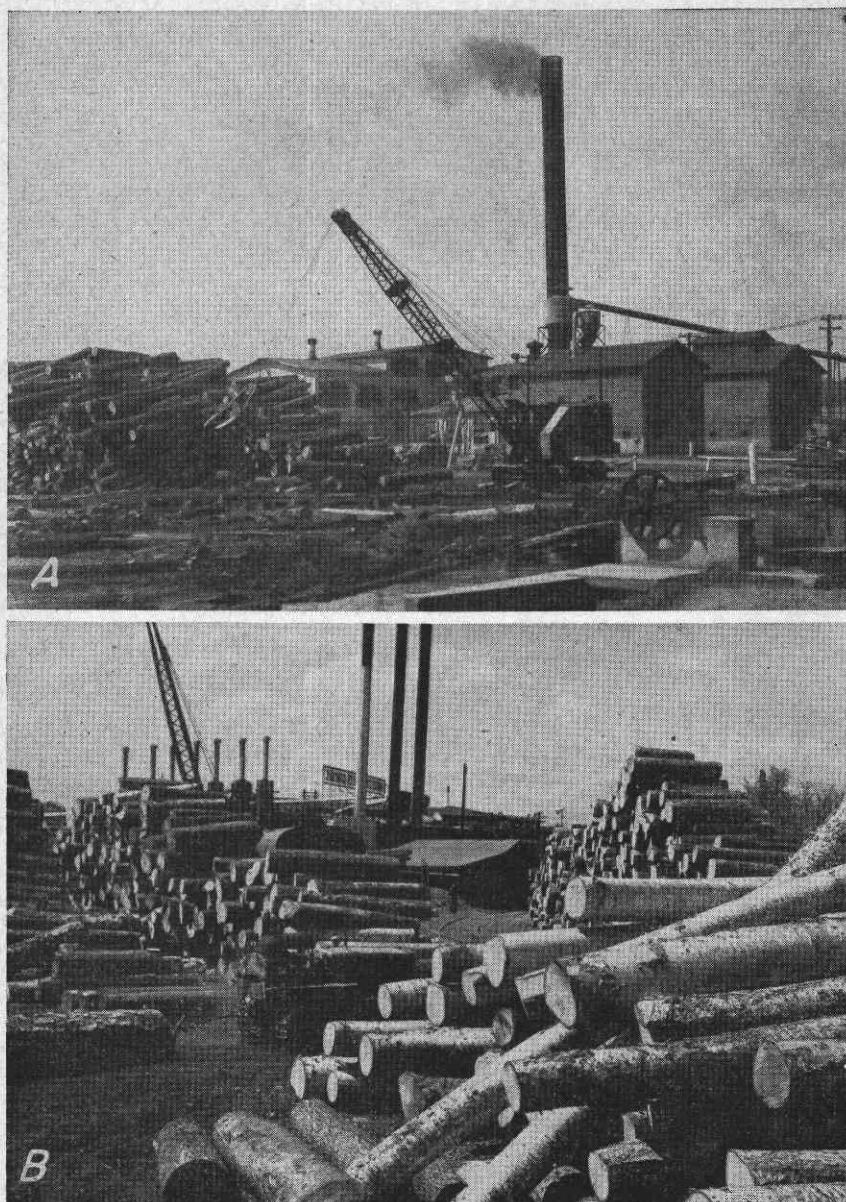
One stumbling block to progress has been the lack of experience to follow in applying partial cutting. It should be remembered that clear cutting had been the practice for generations. In fact, it is surprising that so much partial cutting was undertaken. No one had given the method a thorough trial, and reliable information on many aspects of partial cutting was lacking. There was an obvious need for research on ways of handling northern hardwoods.

For this reason, tests were started in 1926 on the Upper Peninsula Experimental Forest at Dukes, Marquette County, Mich. (fig. 2), to try out partial cuttings and to compare them with the commercial practices then prevailing. The original experimental area comprised a half section of cutover hardwood land donated by the Cleveland-Cliffs Iron Company and a half section of old-growth northern hardwoods, for which the company, under a cooperative arrangement, was to retain cutting rights for 20 years (later extended to 40 years). Purchase of some 4,000 acres in 1935 and subsequent land exchanges with the State of Michigan increased the total Federal ownership of the experimental forest to almost 6,000 acres in 1951, and the area has now been incorporated into the Hiawatha National Forest.

During the 6 years following establishment of the experimental area, various trials of partial cuttings and comparative clear cuttings were made. From the beginning of the agitation for partial cutting, it has been anticipated and repeatedly stated that a good test of this practice would require at least 15 or 20 years to carry out. Twenty years have now elapsed since most of the earlier trials on the Upper Peninsula Experimental Forest were started. There are 20-year records for eight cutting units and a 15-year record for an additional unit, and a good deal of supplemental material. Besides the experimental cuttings, almost 1,800 acres have been logged once in a "pilot-plant" test and 850 acres have been cut over twice since 1926.

Progress reports on various aspects of these cutting experiments⁶ have been issued from time to time (40-43, 136-142).

⁶ The experiments have also served a most useful purpose as field demonstrations for 25 years, and have been viewed by thousands of individuals.



F-467829, 420070

FIGURE 1.—Raw material from the northern hardwood forest supports a substantial sawmilling, veneer, and woodworking industry in the Lake States: A, moving hemlock logs from deck to pond at a Wisconsin sawmill; B, deck of high-quality yellow birch veneer logs at a Michigan veneer plant.

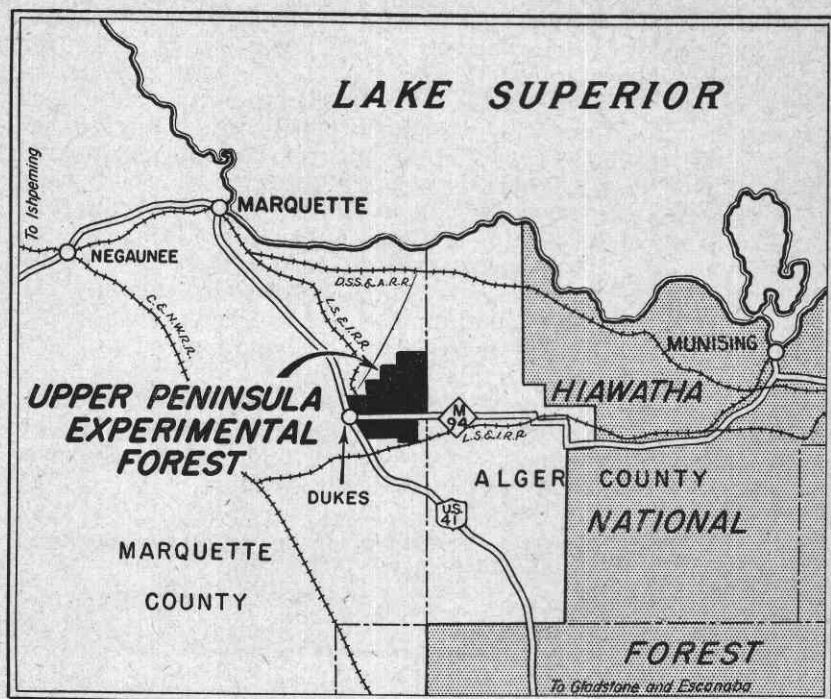


FIGURE 2.—Location of Upper Peninsula Experimental Forest, Marquette County, Mich.

This bulletin presents a more comprehensive report. Experimental findings obtained largely in Upper Michigan have been supplemented with information from other sources, bearing on the specific problem. The results are believed to be generally applicable in the Lake States in northern hardwoods, especially where sugar maple is an important component.

Timberland owners, timber operators, and managers of public forests who are making first or second partial cuttings in northern hardwoods, those who still are clear-cutting old growth, and even those who are operating in advance growth of younger timber should be interested in these experimental results. Forest managers who have had extensive experience of their own in partial cutting should find it profitable to compare results on their properties with those presented here.

CHARACTERISTICS OF THE NORTHERN HARDWOOD FOREST

EXTENT AND COMPOSITION

The northern hardwood forest, sometimes referred to as "hemlock-hardwood" (145) or "hemlock-white pine-hardwood" (99), covers a large part of the so-called northern pine region

of eastern North America (53). In a broad sense, this forest is transitional between the relatively simple boreal forest of conifers lying to the northward (66) and the more complex deciduous forests of the Central States. In the Lake States (Michigan, Wisconsin, and Minnesota) northern hardwoods⁷ aggregating some 9½ million acres (26) for the most part occupy the heavier soils of glacial origin on the level to rolling uplands (figs. 3 and 4). Within this region, lands which support hardwoods range in elevation from about 600 feet along Lake Huron to 2,000 feet above sea level in the Porcupine Mountains of the Upper Peninsula of Michigan. A continental climate generally prevails with a strong contrast between summer and winter temperatures. Weather statistics for a few selected stations are given in table 1 (126). Annual precipitation ranges from about 25 inches to 35 inches; by far the greater part falls during the spring and summer. Length of growing season generally exceeds 110 days and is considerably longer close to the Great Lakes. However, it may be as short as 82 days in some localities.

TABLE 1.—*Climatic summary for selected stations within the northern hardwood region (126)*

Station	January average	July average	Maxi- mum	Mini- mum	Growing season	Average annual precipitation
	° F.	° F.	° F.	° F.	Days	Inches
Milaca, Minn.	9.0	69.7	108	-44	131	25.33
Hayward, Wis.	9.3	67.5	102	-50	112	28.85
Wausau, Wis.	14.2	68.4	107	-40	130	31.06
Florence, Wis.	12.3	66.1	104	-39	107	30.45
Ironwood, Mich.	12.2	67.2	104	-37	125	33.92
Ewen, Mich.	10.3	64.2	101	-49	82	31.28
Marquette, Mich.	17.4	65.3	108	-27	158	31.73
Charlovoix, Mich.	21.7	68.2	99	-33	157	28.47
Lake City, Mich.	19.4	69.7	106	-41	123	24.65

In pioneer times northern hardwoods were more extensive than they are today. Since they occur on the more fertile soils and the topography is favorable, large areas have been cleared for farms, especially in the southern part of the region where the climate is milder. Additional large areas that have been logged off⁸ are regenerating to hardwoods or are already occupied by second growth.

Cutover areas that have subsequently burned have mostly come in to aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), or pin cherry (*Prunus pensylvanica*), and with improved fire protection are in various stages of natural conversion back to northern hardwoods. Some areas are held by a heavy grass

⁷ The maple-basswood forests, considered by some ecologists (10) to be a separate region, have not been segregated in this report.

⁸ In earlier days practically all land thus cleared went into farms, but for some time there has been a growing realization that most of the northern forest area is not well suited to agriculture.



F-400764, 352536

FIGURE 3.—A, Old-growth hardwood-hemlock in Sturgeon River Valley, Ottawa National Forest, Mich.; B, mature stand of northern hardwoods, Upper Peninsula Experimental Forest, Marquette County, Mich.

sod. At present the important commercial stands of northern hardwoods are mostly confined to the Upper Peninsula of Michigan and northern Wisconsin, although in the southern parts of these States there are many farm woods containing merchantable hardwood forests (fig. 4). Northern Minnesota hardwoods are generally of poorer quality (132).

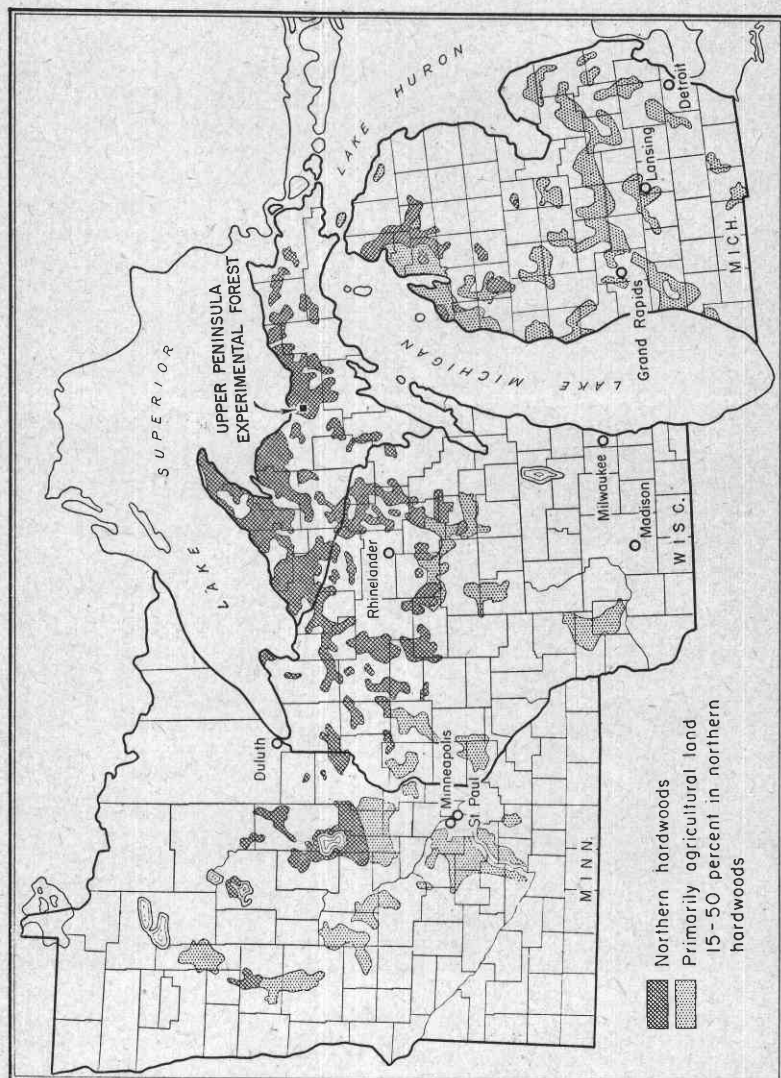


FIGURE 4.—Location of principal forests of northern hardwoods (generalized from map by R. N. Cunningham and H. C. Moser, Lake States Forest Experiment Station, Forest Service, 1940).

The size-class distribution of northern hardwoods in the region is in reasonably good balance although too great a proportion is in small sizes. Of the total area 23 percent, or over 2.2 million acres, is classed as sawtimber. This is composed of both old growth and second growth. Some 18 percent is in poletimber, 43 percent is in seedlings and saplings, and 16 percent is poorly stocked (26). Old-growth stands average nearly 10,000 board-feet net per acre (International rule) and second-growth, 3,800 board-feet (27). There is, of course, a considerable range in volume and this depends largely on how much hemlock is present. Hemlock grows more densely than the hardwoods and tends to raise the average wherever it is present.

The Forest Survey, from which these statistics were drawn, considers the northern hardwoods to be one "mixed" type. Actually, however, the northern hardwood forest includes a number of separate forest types and subtypes. While it was in progress The Michigan Land Economic Survey recognized the following distinct upland hardwood types and type symbols: M—hard (sugar) maple, beech, elm, basswood, yellow birch; Mb—hard maple, beech, yellow birch; Mc—hard maple, elm, basswood, yellow birch; My—hard maple, yellow birch (92).

The Society of American Foresters lists the following group of types in the Northeast and Lake States as making up the northern hardwoods: (1) Sugar maple-beech-yellow birch, (2) sugar maple-basswood, (3) sugar maple, and (4) yellow birch. Hemlock is listed separately from the hardwood group (109). Number 1 may or may not contain beech in the mixture in the Lake States depending on locality. Number 4 seldom appears as a pure type in this region except on very small areas. An additional type, hemlock-yellow birch, should probably be recognized. Beech-sugar maple, more characteristically a type of the Central States, occurs also in southern Michigan. Since it is closely related to the northern hardwoods, it is included in the Forest Survey statistics.

Considering the northern hardwood forest as a broad type or group of types and including with it the hemlock type and its variants, the principal component species are sugar maple (*Acer saccharum*), eastern hemlock (*Tsuga canadensis*), yellow birch (*Betula lutea*), American basswood (*Tilia americana*), American beech (*Fagus grandifolia*), and American elm (*Ulmus americana*). Associated species are eastern white pine (*Pinus strobus*), balsam fir (*Abies balsamea*), eastern hophornbeam (*Ostrya virginiana*), and red maple (*Acer rubrum*). Northern red oak (*Quercus borealis*) and rock elm (*Ulmus thomasi*) are important associates in some localities. The oak is prominent in the more southerly portions of the northern hardwood forest in the region.

Besides the main associates there are a number of less common ones which include white ash (*Fraxinus americana*), black cherry (*Prunus serotina*), white spruce (*Picea glabra*), and northern white-cedar (*Thuja occidentalis*). As the northern hardwoods grade off into the central hardwoods, there appear many of the species more typical of forests farther south such as white oak

(*Quercus alba*), butternut (*Juglans cinerea*), bitternut hickory (*Carya cordiformis*), and shagbark hickory (*C. ovata*). Westward toward the prairie green ash (*Fraxinus pennsylvanica* var. *lanceolata*) and bur oak (*Quercus macrocarpa*) become associates.

Species composition of the old-growth northern hardwood forest varies within the region from east to west and north to south. These variations, probably the result of climatic and soil differences, are illustrated in table 2, which is based on over 1,200 sample plots taken systematically by the Forest Survey. The characteristic species of all four regions is sugar maple, which in no section averages less than 25 percent of the trees. The most variable are hemlock, beech, yellow birch, and basswood. Hemlock occurs commercially throughout the Upper Peninsula of Michigan and northeastern Wisconsin, but never was found in commercial stands in extreme northwestern Wisconsin (105a) or in Minnesota.

Beech occurs in eastern Wisconsin (east of the Wolf River), does not extend into the western part of the Upper Peninsula of Michigan or Minnesota, but is found throughout the Lower Peninsula of Michigan. Yellow birch has a limited distribution in Minnesota. The northern hardwood forest in western Upper Michigan and in northeastern Wisconsin is largely sugar maple-hemlock-yellow birch; in northern Lower Michigan, sugar maple-beech-elm; and in north-central Minnesota, sugar maple-basswood (table 2).

TABLE 2.—Regional variation in composition of old-growth northern hardwood forests (from Forest Survey data, 1936)

[Percent of total number of trees 2 inches and larger]

Species	Western Upper Michigan	North- eastern Wisconsin	Northern Lower Michigan	North- central Minnesota
Sugar maple.....	33.9	25.9	34.8	29.8
Hemlock.....	23.8	28.6	8.3	
Yellow birch.....	12.3	10.6	1.4	(1)
Basswood.....	2.1	7.4	8.3	37.6
Beech.....	.3	5.4	18.3	
Elm ²	.9	5.9	13.4	3.1
Miscellaneous conifers ³	16.4	4.8	.4	11.7
Miscellaneous hardwoods ⁴	10.3	11.4	15.1	17.8
All species.....	100.0	100.0	100.0	100.0

¹ Less than ½ of 1 percent.

² Mostly American elm.

³ White spruce, balsam fir, and eastern white pine.

⁴ White ash, paper birch, red maple, hophornbeam, black cherry, white oak, red oak, and aspen.

ECOLOGICAL POSITION, REPRODUCTIVE CAPACITY, AND SPECIES CHARACTERISTICS

The old-growth northern hardwood forest is characteristically a climax⁹ forest; that is, it is in "the final stage of a succession

⁹ As used here the term means climatic climax. Ecologists also consider a physiographic or edaphic climax, which does not seem to apply to northern hardwoods.

which continues to occupy an area as long as climatic or soil conditions remain unchanged" (110). Climax forests are very tolerant of shade, and to qualify as such should be able to reproduce themselves on the forest floor or in small natural openings without the aid of major disturbances such as fire.

Northern hardwoods are aggressive and more quickly recapture the site after logging than do most conifer types in the Lake States. Thus the northern hardwood forest is comparatively stable ecologically. Studies in the Lake States (68) and in the East (116) point out that even after complete clearing the forest returns to its type when fire is kept out.

Large quantities of seed are produced by the northern hardwood forest. An indication of the numbers disseminated in a good seed year was obtained through seed-trap records. The average seed production ranged from 8 million per acre in an area subjected to partial cutting to 11½ million in the uncut forest (table 3). Sugar maple predominated, but yellow birch seed was also present in large numbers.

Only a small percentage of the numerous seeds produced ever germinate, but enough do come through to keep the forest floor carpeted with young seedlings, chiefly sugar maple. In dense spots on the Upper Peninsula Experimental Forest, there may be more than a million seedlings per acre. But only about one-fifth of them were found to survive the second year. In this locality only 3 percent may be expected to reach a height of over 5 feet and a diameter above ½ inch because of losses from such causes as frost, drought, and severe competition. Nature is so prolific in her seeding habits in the hardwood type that, despite heavy mortality, sufficient seedlings survive to provide abundantly for future stands.

TABLE 3.—*Number of seed produced per acre, northern hardwood type, Upper Peninsula Experimental Forest (September 1, 1934–September 1, 1935)*¹

Species	Uncut stand ²	Partially cut stand ²
Sugar maple.....	8,560,000	4,302,000
Yellow birch.....	2,706,000	3,739,000
White spruce.....	118,000	19,000
Red maple.....	102,000	14,000
Eastern hophornbeam.....	51,000	27,000
Northern white-cedar.....	32,000	17,000
American elm.....	7,000	
Total.....	11,576,000	8,118,000

¹ Based on catch of five seed traps in each stand.

² The composition of these stands was over 80 percent sugar maple, about 15 percent yellow birch, and the remainder other species.

There is considerable variability in the behavior of the species common to the northern hardwood forest. Accordingly, in order to provide a background against which the results of cutting may be viewed, it is desirable to summarize the silvical characteristics of the more important species that comprise the northern hardwoods. This has been done in table 4.

TABLE 4.—*Silvical characteristics of the more important species of the northern hardwood forest*¹

SUGAR (HARD) MAPLE

Soil and site requirements	Shade tolerance and place in succession	Longevity and size	Reproductive capacity		Windfirmness and sensitivity to exposure	Relative growth rate and response to release
			Seeding characteristics and seedbed requirements	Sprouting ability		
Best on well-drained, moist, fine sandy loam or loam but will grow on lighter and heavier soils; pH 5.5 to 7.3 (134).	Very tolerant (6), one of most shade-enduring of eastern hardwoods; typically a climax species (60).	Long-lived, up to 350 years or longer (54); commonly 28 inches and occasionally 36 inches d.b.h.; 70 to 90 feet tall and sometimes taller.	Seed 6,100 per lb.; good crops every 2-3 years (48); disemination to moderate distance; readily germinates on leaf litter; most aggressive re-producer in type (55) and advance reproduction often prolific.	Sprouts from stumps under 6 inches in diameter may develop into large trees but those from large stumps do not mature.	Windfirm; can stand considerable shock from sudden exposure (40); severely exposed trees may die in tops but frequently recover; young trees sometimes sunscald.	Slow to moderate for type, but persistent; great capacity to respond after long suppression.

AMERICAN BEECH

Soils similar to sugar maple; pH 5.0 to 7.0 and over; 2	Very tolerant (6), fully as tolerant as sugar maple and perhaps more so; typically climax.	Not quite as long-lived as sugar maple and a smaller tree.	Seed heavy (1,600 per lb.); crops every 2-3 years (48); disemination limited by its weight but rodents may extend; much seed consumed by birds and rodents; weevils may ruin many seeds (25); readily germinates on leaf litter; seedlings persistent.	Sprouts vigorously from small stumps and also produces root suckers (17); sprouts from large stumps do not ordinarily mature in Lake States.	Windfirm; may be damaged by excessive exposure (74) and subject to sunscald due to thin bark. In East, suffers from drought and adverse winter weather (112, 115).	Slow but responds well to release.
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YELLOW BIRCH

Sandy loam to loam; will tolerate poor drainage better than sugar maple; pH 4.8 to 6.0 (154); closely associated with hemlock.	Moderately tolerant (6); not typically climax and decreases in numbers as stands mature.	Long-lived up to 300 years where it is dominant; large tree up to 40 inches d.b.h. and sometimes larger; 70 to 90 feet tall and may be taller; wide-spreading crown.	Small seed (447,000 per lb.); good crops every 2-3 years (48); widely disseminated by wind during fall and winter; requires openings for reproduction (35), (74); also moist seedbed of mineral soil or decayed wood (105); reproduction not successful on leaf litter; seedlings suffer in competition with more tolerant maples.	Sprouts fairly vigorously from small stumps but "water sprouts" on large stumps usually soon die out.	Reasonably windfirm but more sensitive to sudden exposure than other northern hardwoods (62), (66), especially in heavy partial cuttings (40), but in moderate to light cuttings stands up fairly well (79).	Slow to moderate, does not respond to release as well as sugar maple except in very favorable situations (39).
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EASTERN HEMLOCK

Sandy loam and loam; less exacting than sugar maple and will tolerate sites less well drained and more acid (pH 4.0 to 6.0). ³ Frequently but not exclusively on swamp borders and moist benches and flats.	Very shade tolerant but some tendency to give way to sugar maple over long periods (117); seedlings in open hemlock forest usually deciduous (24) and in some localities is single arborescent species lacking young plants (68). Less hemlock in second-growth than in old-growth.	Maximum age in excess of 400 years (64); d.b.h. of 45 inches and heights of 100 feet or a little greater.	Seed light (187,000 per lb.); good crops every 2-3 years and lighter crops in intervening years (48); wind-disseminated during fall and into winter for some distance. Rarely reproduces on duff except when good seed year followed by wet years (61). Reproduction in quantity only at long intervals (61, 75). Mass establishment of seedlings probably coincides with some occurrence that opened canopy (118) or seedlings then present released by catastrophe. Contention that fire needed to reproduce hemlock (89) is refuted (61). Seedlings come in on decaying wood (60), moss, or mineral soil. Windfalls have influenced reproduction in virgin forest (117).	Does not sprout-----	Fairly windfirm (52, 195) except on moist situations but suffers much in heavy fall storms when hard-woods are bare of leaves. Subject to windshake which lowers quality for lumber. Old timber very sensitive to opening up and droughts (108). Roots extremely sensitive to injury from road cuts (52), or skidding. Sensitivity to exposure related to degree of opening and certain crown characteristics (92).	Slow but will respond very well to release when of sufficient thrift to withstand opening up (62, 89, 146). After establishment, seedlings may be suppressed for years (51), but respond to opening of canopy (28), unless drought or heat kills them (124).
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EASTERN WHITE PINE

Most common on soils more sandy than preferred by northern hard woods but makes excellent growth on loams once it is ahead of the hard woods.	Intermediate in shade tolerance (6); is a sub-climax species; and is succeeded by sugar maple and other hardwoods; probably started after fire in mixture with aspen and paper birch which was invaded later by tolerant hardwoods (60).	Long lived, reaching age upwards of 400 years, heights 40-50 feet greater than associated hardwoods and diameters of 4 feet and greater. Now exists only as remnants among the hardwoods, as pines were "high-graded" out of the stands 50-60 years ago.	Seeds fairly frequently but does not reproduce under hardwoods. More than incidental openings necessary to bring in white pine (118).	Does not sprout-----	Windfirm-----	Moderate but persistent to advanced age.
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Footnotes at end of table.

TABLE 4.—*Silvical characteristics of the more important species of the northern hardwood forest*¹—Continued
RED MAPLE

Soil and site requirements	Shade tolerance and place in succession	Longevity and size	Reproductive capacity		Windfirmness and sensitivity to exposure	Relative growth rate and response to release
			Seeding characteristics and seedbed requirements	Sprouting ability		
Soil requirements similar to hemlock, but also occurs on well-drained uplands.	Moderately tolerant (60). Does not persist in final climax association.	Moderately long-lived. Nearly as large as sugar maple.	Spring seedler with crops almost every year.	Vigorous sprouter, probably next to basswood in this respect.	Fairly windfirm.	Rapid juvenile growth. Larger trees have moderate rate of growth.
AMERICAN BASSWOOD						
Best on well-drained loams with abundant moisture and pH from 5.5 to 7.3 (134).	Tolerant but less so than sugar maple or hemlock. A climax species but not typically so (60). Probably some disturbance needed for basswood to hold a place in old-growth stands.	Not quite as long-lived as sugar maple but probably up to 250 years. Usually taller than sugar maple and fully as large in diameter. Especially well-formed for hardwood.	Seed 5,000 per lb.; good crops almost every year, beginning as early as 15 years; disperses seed from early fall till spring; germinates best on mineral soil (48).	Most vigorous sprouter of the type. Sprouts even from large stumps develop into good trees.	Generally windfirm except on shallow soils.	Moderate to fast (146). Responds well to release.
AMERICAN ELM						
Associated with northern hardwoods where site a little wetter than average. Prefers moist loams of lowlands, small depressions in alluvial deposits. Will tolerate pH of 5.5 to 8.0 (134).	Moderately tolerant (60), but not one of climax species (60). Gives way to sugar maple in old stands on uplands but persists on wetter sites.	Probably not as long-lived as sugar maple. Trees grow as large as 55 inches d.b.h. and exceed 100 feet in height in northern hardwood stands.	Fairly light seed (68,000 per lb.). Prolific seedler beginning at about age 15. Good crops in most years and light ones in older years (48). Bears seed in spring which is immediately wind-disseminated to considerable distance. Seed germinates almost at once in any small opening if moist.	Sprouts fairly vigorously from small stumps.	Due to wide-spreading root systems is fairly windfirm even though not deep-rooted.	Seedling growth rapid. Larger trees make moderate to fairly fast growth for the type.

¹ Based partly on the literature as cited and partly on unpublished observations by the authors and co-workers at the Lake States Forest Experiment Station over a period of nearly 30 years.

² Letter from Dr. S. A. Wilde, University of Wisconsin, February 29, 1952.

SOILS AND SITES

The soils of the Lake States occupied by the northern hardwood forest are described and the broad associations outlined on a map in the U. S. Department of Agriculture Yearbook for 1938 (125). A comparison of the soil map with forest type maps reveals that northern hardwoods are found mostly on podzol and gray-brown podzolic soils. By far the greater part of present northern hardwood forests of the Lake States occur on soils of the podzol group, although many of these soils are not highly podzolized. Within this broad group three geographic associations of soils in this region are important in any consideration of northern hardwoods. They are (1) the Iron River-Milaca, (2) the Ontonagon-Trenary, and (3) the Roselawn-Rubicon areas.

The Iron River-Milaca areas include soils very typical of those on which northern hardwoods occur. They are located south of Lake Superior and around the head of that lake. Surface features range from nearly level plains to morainic ridges and bare knolls. These soils were derived from glacial materials and have characteristic podzol profiles. Much of the area is quite stony. In Minnesota the original forest cover was not so typically northern hardwood and the type grades off to spruce-fir, especially to the north.

The Ontonagon-Trenary group of soils occupies a number of relatively small areas in the northern parts of the Lake States. They, too, are typically covered with a northern hardwood forest. They lie definitely within the region of podzol soils but are only in part podzols because the highly calcareous parent materials have inhibited the development of the podzol profile. The Ontonagon and associated soils border the present Great Lakes and were derived from lake-laid sediments. The Trenary soils are podzols, developed from rather sandy calcareous till, occupying gently rolling or undulating areas. The Onaway soils, which have been grouped with the Ontonagon-Trenary soils, are important in the northern part of lower Michigan and northeastern Wisconsin. They developed from highly calcareous, gravelly glacial till and are not definitely podzols except where exceptionally sandy.

The Roselawn-Rubicon association includes very sandy podzol soils, the largest area of which is in the northern part of lower Michigan. They were derived from glacial drift composed of very sandy materials, mostly quartz, with little or no calcareous constituents. In general, these soils are too sandy for hardwoods, but in some areas hardwoods do well even though the topsoil is quite light in texture. In this group the Emmett and Kalkaska soils are analogous to Roselawn-Rubicon soils but have developed under a dense hardwood forest, and the features of the podzol are more strongly expressed in the soil profile. These soils and the Roselawn will support fairly good hardwoods, but the Rubicon is definitely too sandy. Some areas of Roselawn-Rubicon soils that originally supported stands of white pine with an understory mixture of hardwoods are now strongly held by the latter, pine being almost entirely absent.

The gray-brown podzolic soils, which show only slight podzolization, were developed under hardwood and mixed hardwood-coniferous forest. They occur generally to the south of the podzols. Within this group of soils in the Lake States are (1) the Miami-Kewaunee areas, (2) the Fayette-Boone areas,¹⁰ and (3) the Almena areas. The Miami-Kewaunee areas in southern Michigan and eastern Wisconsin consist of rolling to hilly moraines, undulating till plains with marked depressions, nearly level outwash plains, and old lake beds. The parent soil materials were glacial drift, mostly calcareous. With a mixture of parent materials and wide variation in drainage, the soils are generally complex. Forests in this area consist chiefly of farm woodlots since much of the land is now devoted to agriculture. Oaks are more prevalent in the forest mixture than they are farther north.

The Fayette-Boone areas include light-colored soils developed mainly from loess over glacial drift, limestone, or sandstone along the valley slopes of the Mississippi River and for a short distance along its tributaries. The Fayette soils are usually loams or silt loams; the Boone soils are more sandy. The surface varies from gently to sharply rolling with little flat land but is closely adjacent to areas of prairie. The forest is confined chiefly to farm woods. Like the Miami-Kewaunee area, the Fayette-Boone areas include a good deal of oak in mixture with sugar maple and basswood.

Good northern hardwoods usually grow on the loam soils. However, the exact textural classification (whether sandy loam or clay loam, etc.) has less significance in silviculture than type of humus, degree of podzolization, structure, and ground-water level (134). A summary of the potentialities of loam soils for forestry purposes under five headings as they occur in Wisconsin is drawn largely from Wilde et al. (134) as follows:

1. *Melanized loams* are unleached loams with incorporated "mull" humus represented by nonpodzolic or weakly podzolic phases of Kennan, Spencer, Antigo, Marathon, and Miami loams or silt loams. Soil reaction varies from pH 5.7 to 7.0. Melanized loams are rich in soil fauna. Although they do not occupy a large area, they are highly productive, especially for sugar maple and basswood.

2. *Podzolic loams* are moderately leached loams with some incorporated humus and a substantial layer of free organic matter, and are represented by moderately leached phases of Kennan, Almena, Antigo, Marathon, and Miami loams and silt loams. These soils are transitional between melanized soils and podzols. The reaction varies, as a rule, within the narrow range of pH 5.0 to pH 6.0. In the virgin forest podzolic loams are occupied by hemlock and mixed hardwoods, also balsam fir and white spruce.

Usually 50 percent or more of the cover is sugar maple. Yellow birch is present much more commonly in the association where hemlock is prominent. Thus, "yellow birch is a true companion of hemlock" (134). Organic layers lack earthworms and contain only small numbers of bacteria and actinomycetes but have an abundant population of fungi. Both hemlock and yellow birch attain their maximum growth in these soils.

3. *Loam podzols* are strongly leached and compacted or cemented loams with raw humus and are represented by podzol phases of Kennan and Almena loams and silt loams and the Iron River series. These soils have a well-

¹⁰ The nomenclature given in this section on soils has been revised in accordance with the suggestion of F. D. Hole, University of Wisconsin.

developed podzol profile, are quite strongly acid (pH 3.7 to pH 5.2), and support hemlock, yellow birch, and sugar maple. Hemlock usually predominates and the sugar maple is of poor quality. The presence of hardpan makes for shallow rooting.

4. *Melanized gley loams* are unleached or slightly leached loams with incorporated humus and mottled gley substratum and are represented by Almena, Auburndale, and Adolf loams and related series. Such soils are moderately acid (pH 5.3 to pH 6.5) and have impervious substrata at a shallow depth. Sugar maple and associated hardwoods are found on these soils, but despite a layer of crumb mull humus and abundant moisture, they show poor form due to insufficient aeration. Removal of tree cover on such soils may decrease transpiration enough to raise the ground water table. These soils tend to grade off into the ash-elm forest type and are not the best northern hardwood sites.

5. *Podzolized gley loams* are leached loams underlain by a gley (often mottled) horizon and are represented by podzolized phases of lower Almena, Auburndale, Adolf, and Poskin loams, silt loams, and clay loams. These soils usually occur close to swamps where ground water is high or on uplands where there is a "perched" water table. They are apt to be very acid and waterlogged and are more typical of areas occupied by elms, spruce, balsam fir, and black ash (ash-elm type) than the northern hardwoods. Where sugar maple is present, it is of poor quality.

Westveld (131) related soils and sites for northern hardwoods in northern Michigan. The range found was not very great (site index varied only from 70 to 90), but of more importance, 92 percent of all plots studied occurred in the upper two site classes. Had the study included northern Minnesota, doubtless there would have been more representation in lower sites. He noted that American elm and basswood were ordinarily somewhat taller and yellow birch shorter than sugar maple in the same site. Elm and basswood in mixture increased yields.

Roe (104) grouped some 60 soil types (on which the northern hardwood forest type is the potential forest cover) into categories based on soil-moisture relationships and soil texture. He also attempted to group soil types by site but, like Westveld, found the range in mean site index to be narrow.

INJURIOUS BIOLOGICAL AND PHYSICAL FACTORS

Insects, diseases, and physical factors of environment all must be reckoned with in the management of northern hardwood forests. Some appreciation of the injurious biological factors is needed in order to prescribe workable cutting recommendations. The physical factors of weather and fire must also be constantly kept in mind because they may cause damage necessitating salvage operations.

Insect Pests

The more common deciduous trees of the northern hardwood forest—sugar maple, yellow birch, beech, basswood, and American elm—are not usually considered to be particularly subject to insect damage in the Lake States, but occasionally certain insects become troublesome.¹¹ Hemlock may at times be seriously affected. The

¹¹ Only the insects observed to be important in the forest are covered here, no attempt being made to include all those that damage shade trees.

more important insects may be grouped into: (1) Defoliators, (2) borers, and (3) sucking insects, as indicated in the following tabulation:

Organism	Damage caused
Defoliators:	
Fall cankerworm (<i>Alsophila pomentaria</i>).	Favorite hosts are elms and basswood (64). Has partially defoliated stands of sugar maple in Upper Michigan.
Spring cankerworm (<i>Paleacrita vernata</i>).	Do.
Linden looper (<i>Erannis tiliaria</i>) . . .	Sometimes defoliates rather extensive areas of basswood, maples, and other hardwoods (25). This has happened in Lower Michigan.
Hemlock looper (<i>Lambdina fiscellaria</i>).	Has caused heavy mortality in hemlock in some years. Infestations in Michigan and a very serious one in Wisconsin recorded. Attacks more severe where hemlock predominant than in mixed stands. Hemlock and balsam fir favored, but yellow birch, maple, and other species sometimes attacked. One defoliation may be fatal to hemlock (25, 62).
Forest tent caterpillar (<i>Malacosoma disstria</i>).	Defoliates aspen seriously, and also attacks a variety of other hosts including sugar maple, basswood, red oak, and American elm (69). Basswood and red oak may be quite seriously defoliated.
Basswood leaf-miner (<i>Baliosus ruber</i>).	Mines out leaves of basswood particularly (25).
Walkingstick (<i>Diapheromera femorata</i>).	Red oak, basswood, and cherry, the favored hosts, may be killed or injured badly by three complete defoliations (70). Spread is slow because insect is wingless (25).
Green-striped maple worm (<i>Anisota rubicunda</i>).	Feeds on maple, often causing severe defoliation (25).
Borers:	
Bronze birch borer (<i>Agrilus anxius</i>).	Attacks dying birches. May hasten death of overmature or defective yellow birches after logging, and of drought-affected trees (25, 65).
Carpenterworm (<i>Prionoxystus robiniae</i>).	Attacks elm and maple. Burrows cause serious deformities and permit entrance of fungi (25).
Flat-headed apple tree borer (<i>Chrysobothris femorata</i>).	Attacks beech, elm, and many other hardwoods when their vigor is declining (64). May cause death of the entire tree or killing of local patches of cambial area.

Organism	Damaged caused
Borers—Continued Hemlock borer (<i>Melanophila fulvoguttata</i>).	Attacks green hemlock weakened by drought and other causes (25). Extensive dying of hemlock on the Menominee Indian Reservation in Wisconsin during the 1930's was first attributed to this insect which was present in epidemic numbers, but an intensive study indicated that the severe and prolonged drought was the primary cause (108). Heavy wind damage contributed to the build-up of the insect. Graham (62) supports these conclusions by studies in Michigan.

Sucking insects:

Beech scale (*Cryptococcus fagi*)... A European insect found on beech in the East. It is commonly associated with the fungus *Nectria* with resulting mortality (25). Not yet noted in Lake States.

Defoliators do not ordinarily kill many hardwood trees except weak ones but decrease the growth rate of these trees by lessening the leaf surface. In many softwood species, however, a single complete defoliation often results in death. Attacks by defoliators thus have a much more serious effect on hemlock than on the associated hardwoods.

The borers that injure northern hardwoods probably cause more damage in the aggregate than defoliators or sucking insects because many of the borers tend to girdle trees or work in the wood itself. In this way they decrease timber value directly, or indirectly by providing entrance for decay organisms. Damage by borers occurs most often in trees weakened by wind damage, drought, and other physical causes.

Sucking insects seldom kill hardwoods, but like defoliators they cause injury especially to leaves, which results in lessened growth.

Diseases

Most diseases causing decadence or death of northern hardwoods and their main conifer associate, hemlock, are attributed to fungi, the more important of which may be grouped into two classes: (1) Those that cause wood rots, and (2) those that cause bark lesions or cankers (fig. 5). Another class, the leaf diseases, is much less significant from a forestry standpoint. Among the wood-rotting fungi, those that cause heart rot are the most damaging. Since they work in heartwood, trees are not attacked until they have reached an age when heartwood has been formed. The causal organism usually gains entrance through some wound such as a broken branch, a crack, a logging or fire scar, or other injury that exposes heartwood. Much remains to be learned about the rate

Estimated prevalence of parasitic fungi causing heart rots and cankers of the important northern hardwoods and hemlock—Continued

Organism	Incidence and damage caused by organism
<i>Pholiota adiposa</i>	Common in basswood, occasional in yellow birch and rare in hemlock (87). Blamed for the common hollow-buttedness of basswood.
<i>Poria obliqua</i>	Sterile clinker-like bodies on yellow birch usually associated with this fungus (7). A conk indicates a rot column of 15 linear feet or more in the heartwood (8).
<i>Poria subacida</i>	Attacks balsam fir especially (81).
<i>Polyporus balsameus</i>	Rare in hemlock (87).
<i>Polyporus glomeratus</i>	Common in sugar maple (87). Causes white to light brown spongy heart rot (8). Fruiting bodies rarely form until tree has been dead several years (19).
<i>Polyporus schweinitzii</i>	Occasional in hemlock. Causes brown cubical rot and butt rot (87). ¹
<i>Stereum murrayi</i>	Rare in sugar maple (87).
<i>Ustulina vulgaris</i>	Rare in beech (87). Although reported as rare in the Lake States, it commonly infects sugar maple sprouts through parent stump or from dead companion sprouts in the East (20).
<i>Eutypella</i> sp. ²	Common in sugar maple. Infection occurs on young trees and persists to advanced ages (87). Cankers usually close to ground may be 5 feet long. Trees over 5 inches d.b.h. seldom killed outright (28) (fig. 5).
<i>Hypoxyylon pruinatum</i>	Occasional in sugar maple (87). Primarily in aspen where it does great damage.
<i>Nectria</i> spp.	Common in yellow birch, occasional in sugar maple, basswood, and American elm, rare in beech (87). Some species cause target-like cankers as a result of repeated callus growth. Infection believed to take place early in life of tree (?). Other species such as <i>Nectria coccinea</i> serious in East (114).
<i>Schizoxylon</i> sp. ³	Rare in sugar maple (87). Occurs in suppressed trees under 3 inches d.b.h. (28).

¹ Other wood-rotting fungi injurious to hemlock are *Ganoderma tsugae* and *Polyporus borealis*.

² Probably *Eutypella parasitica* (28).

³ Probably *Schizoxylon microsporum* (28).

Sap-rotting fungi in most instances are not killers and rotters of living tissue but work in dead sapwood. Exposure of sapwood through some wound that injures or removes the bark usually results in an area of dead tissue where fungi can grow. Sap rots progress more rapidly than heart rots, and the rotting away of sapwood soon exposes heartwood to attack by heart-rotting fungi. In catastrophes sap-rotting fungi are important because their work limits the period in which salvage operations are practical. They must be considered also in determining the time of year when logging may be carried on and how long a period may safely elapse between felling and sawing.

Daedalea unicolor, a sap-rotting fungus, is worthy of special mention. This fungus not only causes a sap rot of hardwood

slash (7) but also is parasitic on living trees and is associated with decay and cankers of sugar and red maples and paper birch (18). It has also been found on sunscalded living trees in New York (113). It is especially common on trees of sprout origin; in these it enters the trunk through dead or companion sprouts. It spreads from sprout to sprout in clumps of sugar or red maples (18). The fungus decays the heartwood and grows out through the sapwood to the cambium, which it kills, thus causing a canker. Therefore, cankers are not usually noticed until the trunk is far gone with rot. Fruiting becomes conspicuous after the tree breaks off. *Polyporus resinous* causes a sap rot of basswood and other hardwoods (7).

Decay in northern hardwoods of sprout origin may have much significance. Although this question has received no special attention in the Lake States, Campbell (17) observed in the Northeast that decay enters directly through the "old stump wound," the opening left at the base of sprouts by the decay of the parent stump. This source of infection, however, was found to be unimportant in stands under 30 years old. Thus sprouts from young trees that have not formed heartwood are much less susceptible to decay. Sprouts originating high on the parent stump had larger stump wounds than those originating at the base. Low sprouts from small stumps 2 to 4 inches in diameter were considered relatively safe from decay. "The essential thing is not the stump size but the age at which the old stump wound is completely healed" (17).

A defect in sugar maple known as mineral stain or mineral streak, in which deep olive or greenish-black discolorations disfigure the wood of living trees, is common in some localities. The cause is unknown but the term has some foundation in fact, in that certain minerals have been found to be associated with the stain (106). It is also thought that such stains may originate from old wounds (21a).

The Dutch elm disease and phloem necrosis are serious enemies of the elm in the Central States and the former has now appeared in southern Michigan. A malady known as birch "dieback" has caused heavy losses in yellow and paper birch stands in the Northeastern States and eastern Canada (67, 98). Whether birch is subject to similar "dieback" in the Lake States has not been fully determined.

"Leaf spots and blights are caused by a large number of fungi. They seldom occur in such quantities as to be of economic importance except during periods of continued warm moist weather. Two leaf spots that appear to be caused by species of *Gloeosporium* and *Phyllosticta* are common in the Lake States, especially on sugar maple" (87).

That insects and disease have not been more destructive in the old-growth northern hardwoods in the past may be attributed in large measure to the composition and age-class pattern of the forest. Some insects and diseases attack a wide variety of trees, but most of them have species preferences or at least do not injure all species equally. Therefore, a mixed forest such as northern

hardwoods should be a relatively "safe" forest. An all-aged forest is also a better risk than one with large contiguous tracts of a single age class because organisms do not usually attack trees of all ages with the same intensity (63). Northern hardwoods, as will be seen later, have many age classes. They are thus in a favorable position, and practices that preserve desirable mixtures and ages are to be recommended.

Thrifty trees are relatively resistant to attack, and any cutting practice that raises stand vigor should decrease the hazard from insects and disease. Practices that shorten the rotation should increase the proportion of sapwood and thus decrease heart rot. Since sprout hardwoods may become infected with rot that enters from the parent stump, seedlings are much to be preferred as reproduction.

Damage by Animals

The northern hardwoods provide food and cover for wildlife and are capable of supporting considerable wildlife populations without undue damage to the forest. Where there is a reasonable balance between food supply and population, both wildlife and timber can be grown together. At times, however, game populations, because of insufficient harvest, have increased to the point where immense damage is done, not only to the productiveness of the forest for timber, but also to the carrying capacity of the wildlife range. So it has been with white-tailed deer (*Odocoileus virginianus*). Where there is an overpopulation of deer, repeated browsing stunts and deforms reproduction (5, 123). In a broad, large-scale survey of the deer situation in Wisconsin, Swift (123) compared the degrees of damage done to various kinds of trees. He pointed out that of the important timber species, the maples are probably the most heavily used as deer food. He considered it doubtful that the maples would have survived under the current (1949) deer population, if maple reproduction were not so abundant. In northern Wisconsin from two-thirds to three-fourths of maple seedlings had been damaged. He concluded that, "If we are to have continuing forests of hard maple in our state, we must reduce our present deer herd!"

From such a survey it may be inferred that deer do not ordinarily prefer yellow birch,¹³ because fewer damaged birches are noted. This can be misleading. Browsing more readily kills the birch outright, leaving fewer seedlings to record, whereas browsing merely stunts the maple.

From 20 to 25 percent of all elm seedlings found had suffered from browsing in the Wisconsin survey of damage. Three-fourths of all seedlings of basswood, a preferred food for deer, were browsed. Hemlock was found to be reproducing itself only on Indian reservations where deer populations were low; elsewhere deer helped to keep it clipped back to the ground (123). In an area

¹³ Yellow birch appears to be browsed more heavily on the Upper Peninsula Experimental Forest and adjacent areas than the maples. This may be due in part to the fact that birch reproduces best along skid roads and trails which are used by the deer as routes of travel.

of northern hardwoods on the Argonne Experimental Forest in Wisconsin that had been closed to hunting for 20 years, a special survey was made of deer damage on 480 fifth-acre plots. More than 85 percent of the tree seedlings were observed to be heavily browsed (5).

Snowshoe hares (*Lepus americanus*) and cottontail rabbits (*Sylvilagus floridanus*) also nip off seedlings, and when their populations reach high peaks, as they do periodically, heavy damage results. The hare has been partly responsible for the failure of hemlock reproduction to become established (123). Hares also cut off large numbers of small birches. They may be as destructive to trees as deer. In fact, most of the northern hardwoods are nipped to some extent. Basswood may be damaged also by cottontails.

Red squirrels (*Sciurus hudsonicus*) occasionally cut off tip branches, but their populations usually do not reach such peaks as those of hares. Hence, the squirrels have not yet become serious pests to the northern hardwoods.

Of much more account in this respect is the porcupine (*Erethizon dorsatum*) which feeds on the cambium of trees. This brings about "partial or complete girdling which may result in breakage, lower quality of timber, less merchantable height, and sometimes death" (120). Basswood, sugar maple, and hemlock were found to be severely damaged where there were four or more porcupines per 40 acres. One feature of porcupine injury is its cumulative effect due to repeated damage to the same tree over several years. Yellow birch is one of its preferred species. Hemlock also rates high in food preference, but since porcupines chiefly consume the foliage of this species the total damage is much less.

Ruffed grouse (*Bonasa umbellus*) and sharp-tailed grouse (*Pedioecetes phasianellus camprestris*) feed on buds of beech and yellow birch and relish the seed of beech (34) as do deer and other animals. However, the pressure of grouse is not heavy enough to be much of a factor in timber management and certainly they are to be welcomed in the forest.

Beaver (*Castor canadensis*) occasionally cut down yellow birch and other hardwoods, but they prefer aspen, so any damage they do to northern hardwoods is not ordinarily of much consequence. Occasionally flooding caused by beaver dams kills hardwoods on low ground.

The damaging effect of domestic livestock on reproduction of hardwood trees is so widely understood and recognized that no attempt will be made here to discuss it. Suffice it to say that grazing of such stock is incompatible with timber growing in the northern hardwood forest type.

Physical Factors Causing Injury

In the presentation of silvical characteristics of the various species composing the northern hardwood forest (table 4), some attention has already been given to physical factors such as drought, exposure, and windstorms. Tornadoes that rip through narrow strips of country following a general course from south-

west to northeast are not uncommon, especially in Wisconsin, and have caused extremely heavy losses locally. Such catastrophic storms are no respecters of species. Where they hit they destroy hardwoods and conifers alike, and silvicultural practices can do little to reduce such damage. However, prompt salvage before decay and insects take their toll of felled trees will permit recovery of most of the timber values.

Fire is another enemy that may threaten the forest. It must be said, however, that the uncut northern hardwoods, growing on soils fairly retentive of moisture and creating heavy shade which protects the forest floor from excessive drying, are about as free from fire as any other major forest type in the region. At any rate, most old-growth stands show little evidence of past fire damage. But some areas of hardwoods adjacent to pine lands where slash fires ran at will during the pine lumbering days suffered considerably. One case has been reported in which a light leaf fire in an old-growth stand was followed by abundant yellow birch reproduction (128). At the same time, the fire so injured the trees as to cause the introduction of serious butt rot. Very destructive fires in large areas of hemlock-hardwood slash, following clear cutting, also damaged hardwood timberlands severely. One major cause of fires was eliminated when logging locomotives went out of use.

Glaze (sleet) can cause serious injury to northern hardwoods. Perhaps once in a generation an unusually severe glaze storm occurs. Buttrick (14) describes one that took place in Lower Michigan in February 1921. In old-growth hardwoods the damage was exceptionally heavy. Large sugar maples had their main limbs wrenched out and second-growth trees stood as bare poles after the side branches were stripped off. Conifers weathered the storm much better. Similar observations were reported in New York (113) where damage was negligible to hemlock but serious to hardwoods following a severe glaze. Beech and maple, exposed after the glaze opened up the stand, were sunscalded and later infected with sap-rotting fungi. Tops of injured basswood and ash, however, sprouted back and made a good recovery, with little damage from sap rot (113).

Injury from the severe glaze of March 1936, which damaged 6 million acres in Pennsylvania and New York, increased with size of tree and age of stand (31). Conifers suffered much less than hardwoods, which argues for keeping hemlock in the stand. Glaze damage among hardwoods may be greatly magnified by subsequent decay due to the injuries caused by the storm, especially where heartwood is exposed (16). Breakage of small top branches with no exposure of heartwood does not increase the decay hazard to merchantable portions of the tree. Injuries and scars caused by glaze may provide entrance for boring insects.

Heavy wet snow may occasionally damage a hardwood forest, but such storms usually come at a time when leaves are absent. One such storm reported in Wisconsin (45) did considerable damage, but conifers suffered more than the hardwoods. Hemlock was less injured than most other conifers.

AGE AND STAND STRUCTURE

Old-growth northern hardwoods as they occur in the Lake States present an all-aged appearance. All sizes up to 28 or 30 inches d.b.h. (diameter at breast height) or larger and at least several age groups are normally represented. This is well illustrated by diameter and age data for sugar maple and hemlock collected in the northern part of the Lower Peninsula of Michigan. Representation in all ages up to 350–400 years and all diameters up to 32–36 inches d.b.h. was found (54). In the work reported here, a few hemlocks even older were encountered. On the Upper Peninsula Experimental Forest age counts did not reach such high figures for these species but came fairly close to those mentioned above. Ages of over 320 years have been recorded for yellow birch in Upper Michigan and even greater in the Lower Peninsula.¹⁴ Old basswood is so commonly hollow that it is difficult to obtain age records. From these specific data it is readily apparent that old-growth forests of northern hardwoods are essentially all-aged in character.

Significant as maximum age or natural rotation is, the diameter distribution is a much more important consideration in the silviculture and management of an uneven-aged forest of long-lived trees.

Diameter does, of course, roughly reflect age, and the very large and old trees may be more defective than smaller ones. Cull in northern hardwoods, however, tends to be spread throughout the size classes, though it is somewhat higher in the older trees. On the other hand, trees more than 28 inches in diameter may be entirely sound. Since northern hardwoods attain ages in excess of 200 years without necessarily becoming defective, the question of age can be subordinated. It is the size-class distribution of sound trees that really matters in management of northern hardwoods, and age is not a limiting factor.

Size-class distribution of trees present in old-growth northern hardwoods can perhaps be best illustrated by stand tables and graphs (tables 5 and 6; fig. 6). The two stand tables were compiled from Forest Survey data, one for the eastern half of the Upper Peninsula of Michigan and the other for the western half. All diameter classes are quite well represented up to 24 inches d.b.h. The fairly even diminution in numbers of trees from the small sizes to the large will not prevail on every acre, but such a distribution will be found on any sizable tract. This is quite typical of a balanced uneven-aged forest (96). In heavy merchantable stands, however, there is usually a considerable excess of large trees and plenty of small seedlings and saplings, but often a scarcity of trees in the middle classes (43).

Numbers of trees alone, however, do not fully express stocking. Data on basal area are also needed to complete the picture. The same data expressed in terms of basal area after adjustment to 1-inch diameter classes are shown in figure 6 together with data

¹⁴ Letter from Professor F. C. Gates, Kansas State College, March 22, 1951.

BASAL AREA

	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.
2	1.50	0.28	0.17	0.04	0.02	0.43	0.64	0.08	0.03	3.11
4	1.89	1.42	.42	.11	.04	.75	1.14	5.24	0.14	5.38
6	1.75	.60	.60	.17	.05	.80	1.39	6.12	.35	6.47
8	2.32	2.00	.89	.17	.08	.86	1.75	8.10	.55	8.65
10	3.02	2.52	1.24	.21	.08	.86	1.65	9.58	.79	10.37
12	4.26	3.18	1.74	.22	.09	.83	1.21	11.53	1.01	12.54
14	5.15	3.33	2.03	.27	.12	.92	.94	12.74	1.09	13.83
16	6.11	3.76	2.68	.31	.14	1.06	.74	11.76	1.19	15.95
18	6.13	3.85	2.22	.41	.07	.69	.53	11.70	1.48	15.78
20	7.09	4.25	2.75	.42	.15	.48	.39	15.53	1.31	16.84
22	3.96	4.06	2.30	.42	.13	.32	.16	11.35	1.29	12.64
24	2.51	3.74	2.07	.22	.19	.19	.13	9.05	1.26	10.31
26	1.55	2.95	1.66	.17	.15	.15	.07	6.64	.81	7.45
28	.81	1.89	1.16	.17	.17	.04	.04	4.28	.56	4.84
30	.29	1.76	1.79	.10	.10	.05	.05	3.14	.64	3.78
32	.17	.83	.50	.17	-----	-----	.06	1.73	.28	2.01
34	-----	.70	.32	-----	.06	-----	-----	1.14	.25	1.39
36	-----	.14	-----	-----	-----	-----	-----	.14	.14	.28
38	-----	.08	-----	-----	.08	-----	.08	.24	.08	.32
40	-----	-----	-----	-----	-----	-----	-----	-----	.09	.09
42	-----	.10	-----	-----	-----	-----	-----	.10	-----	.10
Total	48.52	41.74	23.94	3.39	1.72	8.52	10.97	138.80	13.34	152.14

¹ Miscellaneous hardwoods include red maple, black ash, American hophornbeam (ironwood), black cherry, white ash, paper birch, and beech.

² Miscellaneous conifers include balsam fir, white spruce, northern white-cedar, and eastern white pine.

Source: Forest Survey data, 1936.

BASAL AREA

	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.
2.....	1.11	0.24	0.57	0.10	0.02	0.03	0.74	3.74	0.07	3.81	
4.....	1.79	.29	1.66	.26	.02	.08	1.37	4.40	.22	4.62	
6.....	.95	.62	1.05	.33	.03	.08	1.53	5.57	.44	6.01	
8.....	1.50	1.15	1.50	.54	.03	.11	1.61	6.63	.77	7.40	
10.....	2.02	1.32	2.02	.70	.02	.03	1.42	8.66	1.02	9.68	
12.....	2.98	1.81	2.61	1.11	.07	.04	1.18	10.90	1.76	12.66	
14.....	3.65	2.36	2.93	1.60	.06	.04	.87	12.73	1.73	14.46	
16.....	5.19	2.26	2.61	2.16	.06	.03	1.22	13.81	1.97	15.78	
18.....	4.80	3.25	1.66	2.14	.04	.11	.74	13.91	2.07	15.98	
20.....	4.34	2.75	1.24	2.01	.11	.11	.24	11.13	1.70	12.83	
22.....	3.19	2.06	.79	1.34	.03	.08	.11	7.97	1.16	9.13	
24.....	2.83	2.26	.28	1.26	.09	.09	.12	7.23	1.16	8.39	
26.....	1.66	1.74	.15	.96	.04	.07	.07	4.23	.59	4.82	
28.....	.90	1.16	.04	.68	.09	.09	.04	3.00	.30	3.30	
30.....	.59	.73	-----	.39	.05	.10	.03	2.16	.10	2.26	
32.....	.22	.62	-----	.28	.11	.11	-----	1.45	.30	1.84	
34.....	.06	.19	-----	.19	-----	.06	-----	.50	.19	.69	
36.....	-----	.14	-----	-----	.14	-----	.07	.35	.14	.49	
38.....	-----	.08	-----	-----	-----	-----	-----	.16	.08	.24	
40.....	-----	.09	-----	-----	.09	-----	-----	.18	.09	.27	
42.....	-----	-----	-----	-----	.10	-----	.09	.19	.09	.28	
44.....	-----	-----	-----	-----	-----	-----	-----	-----	.11	.11	
Total.....	36.78	25.12	18.11	16.25	.87	1.53	10.29	119.64	16.24	135.88	

¹ Miscellaneous hardwoods include red maple, black ash, American hophornbeam (ironwood), black cherry, white ash, and paper birch.

² Miscellaneous conifers include balsam fir, white spruce, northern white-cedar, and eastern white pine.

Source: Forest Survey data, 1936.

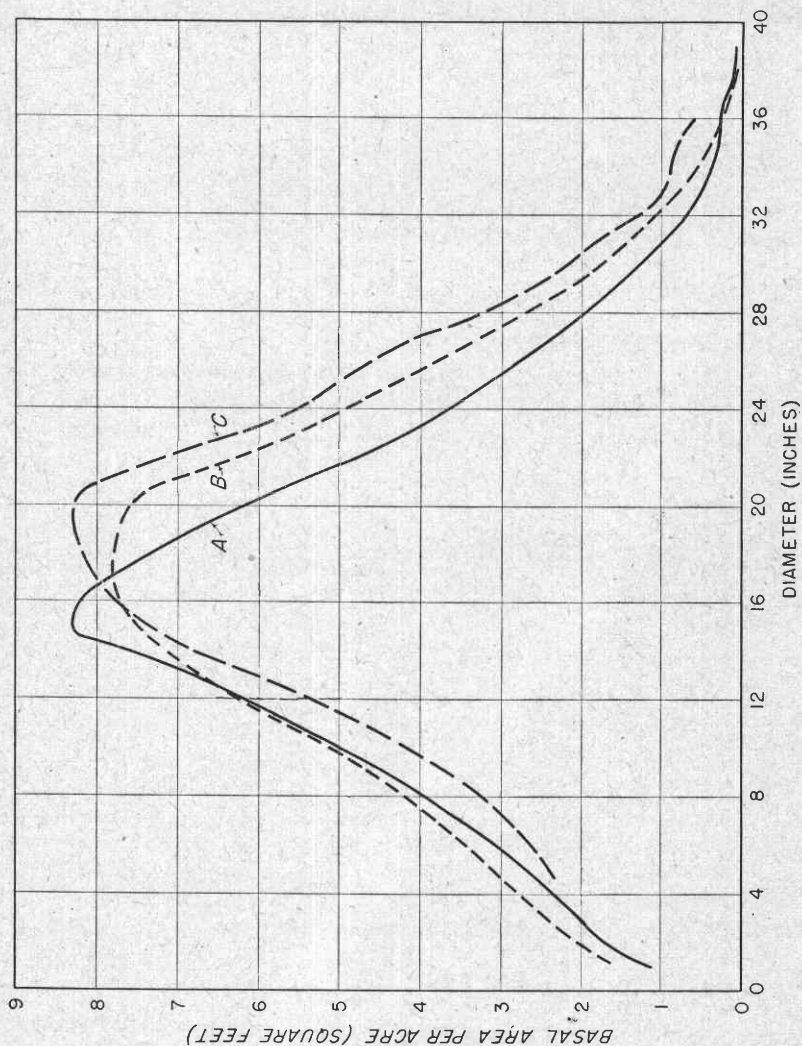


FIGURE 6.—Basal area per acre by 1-inch diameter classes, old-growth northern hardwood type: A, East half Upper Peninsula of Michigan; B, west half Upper Peninsula; C, Upper Peninsula Experimental Forest.

for a stand on the Upper Peninsula Experimental Forest. The latter is a compact 6,000-acre tract, whereas the other stand data apply to several million acres. The curves are essentially the same. Basal area stocking characteristically tends to be heaviest in the 17- and 18-inch diameter classes. Since these curves and tables are based on fairly large samples, they should be reliable. They clearly show a good distribution of size classes.

RELATIVE VALUE OF COMPONENT SPECIES

Important as the ecological implications may be in managing a timber stand, the relative value of the wood of the various species will of necessity strongly influence any forest practice recommendations. The northern hardwood forest ranks high economically among forest types. Most of the component species command high prices, but dollar values and the relative worth of single species may change with the years and shifts in utilization practices. The following rating of species is on the basis of recent prices, beginning with the most valuable:

Sawtimber

- | | |
|-----------------|-----------------|
| 1. Yellow birch | 6. White spruce |
| 2. Basswood | 7. Red maple |
| 3. Sugar maple | 8. Beech |
| 4. Red oak | 9. Hemlock |
| 5. American elm | 10. Balsam fir |

Pulpwood

1. White spruce
2. Balsam fir
3. Hemlock

These ratings assume equal quality logs and are presented mainly to bring out the differences inherent in the quality of the wood as expressed by prices currently paid for logs and pulpwood. Yellow birch is by far the most valuable tree. At present the best grades of yellow birch logs may command a price at least one-third higher than its closest competitor. Basswood and sugar maple follow and are usually of about equal value, basswood being the higher-priced in some localities and sugar maple in others. Red maple of good quality brings a fairly high price as saw timber, but a large proportion of the trees are culls. Hemlock is well down the list, and it usually sells for only one-fourth to one-third what the better hardwoods bring. At times in the past hemlock has been difficult to market.

SUMMARY OF CHARACTERISTICS

The northern hardwood forest of the Lake States is transitional between the conifer forest of the North and the pure hardwoods characteristic of the Central States. It occupies the better podzolic soils. Sites within the commercial range are generally good. This forest is not homogeneous but is made up of several subtypes and variants. It is composed of a mixture of species, mostly hardwoods, but some hemlock and other conifers usually are present.

Composition varies in different parts of the region, but sugar maple is the key tree throughout. Primarily it is a climax forest. Most component species are tolerant of shade, but there are gradations from the very tolerant sugar maple, beech, and hemlock through tolerant basswood to the moderately tolerant American elm and yellow birch.

All of the important components are long-lived trees. Generally the species present are fairly wind-firm. Because of their mixed composition, they are reasonably resistant to insects and diseases, but in old stands much wood rot is present. Sensitivity to exposure varies considerably. Sugar maple can withstand disturbance and exposure to a high degree; basswood and elm exhibit a reasonable resistance, but yellow birch and especially hemlock are sensitive. Most species, particularly sugar maple, respond quickly and well to release from competition.

Likewise there is variability in regeneration requirements. Most species seed frequently and abundantly, but the ease with which they regenerate on the forest floor differs. For example, sugar maple seedlings readily penetrate the leaf litter and are found everywhere even under heavy shade. Both yellow birch and hemlock are more exacting and require especially moist seedbeds. Yellow birch also needs more light. Hemlock and other species suffer serious browsing from deer and snowshoe hares where there are concentrations of these animals.

Old-growth stands exhibit all-aged characteristics and appear suited to uneven-aged management with, however, variations in practice to perpetuate the more valuable components and to insure a mixed forest in the future.

The principal component hardwoods are very valuable for their wood, yellow birch leading in this respect. Sugar maple and basswood also command high prices. Hemlock timber usually sells for less than one-third what the better hardwoods bring.

MANAGEMENT OF MATURE STANDS

PROBLEMS OF SILVICULTURE AND MANAGEMENT

Most forests of northern hardwoods containing mature timber urgently need attention and present problems both of silviculture and management. Stands are mostly wild and uncared-for. Usually much needs to be done to place such forests in good productive condition. Often there are too many large, old trees and not enough of intermediate size. There is need to regenerate the more valuable species. Timber quality should be maintained and gradually improved. In short, the forest needs treatment by the ax, but how? How do various degrees of partial cutting work out? Is the selection system adapted to Lake States conditions? What results can be expected from group selection, diameter-limit, or clear-cutting methods?

In striving for a silvicultural solution, the management implications should not be overlooked; there is the ever-present problem of how to utilize mature timber but preserve a growing stock

sufficient to assure a continuous flow of raw material to support industries. Thus, many factors must be considered such as (1) rate of growth, (2) cull, (3) mortality, (4) stand structure, (5) timber quality, and (6) costs and returns.

DESCRIPTION OF EXPERIMENTAL AREA AND CUTTINGS

Solution to problems of silviculture and management have been sought mostly through experimental cuttings, managing a forest tract on a "pilot-plant" scale, and by means of related studies on the Upper Peninsula Experimental Forest. Within this area, the half section of mature hardwoods handled in cooperation with the Cleveland-Cliffs Iron Company (see p. 3) is the site of most of the intensive cutting experiments described in the following pages. This cooperative experimental tract is situated on mainly level but well-drained land and is forested mostly with northern hardwoods but supports swamp types in low places. This report deals only with the northern hardwood portions. The upland soils are quite uniformly good and are a part of the Ontonagon-Trenary group previously described (p. 15).

Two rather detailed soil surveys of the cooperative experimental tract were made in 1929. One was by the Michigan Land Economic Survey in which two soil types underlying the permanent sample plots were noted: Chatham loam and Trenary sandy loam to loam (fig. 7). Both are slightly acid to slightly alkaline (pH 6.5-8.0) and medium textured. Trenary sandy loam is rated as site index 90 (highly productive) except where stony or shallow (131). Chatham loam is certainly equally productive.

Wilde and Scholz (133), in the other soil survey, made a genetic classification of the soil. According to this classification, the area covered by permanent plots, which sample the experimental cuttings, occupies three kinds of soils: Dark forest soil (slightly podzolized loam), podzol (loamy podzol), and swampy podzol (fig. 7). The report lists the slightly podzolized loam as high, the loamy podzol medium to high, and the swampy podzol low in productivity. Measurements of growth for 20 years, however, do not indicate any important difference between the first two soils; both are good. Both soil examinations denote pretty general uniformity in the productivity of the soil on the several plots, and this is confirmed by growth behavior. In general, the site can be considered medium to good for the northern hardwoods of the Lake States region. Dominant trees in mature stands reach 100 feet in height. The larger merchantable trees average two and one-half 16-foot logs.

The climate is rather typical of that already described (table 1) for the northern Great Lakes region. Precipitation averages about 34 inches per year, one-third falling as snow. The highest temperature recorded at the experimental forest to date is 102° F.; the lowest, -42° F. The mean temperature for the growing season, June 1 to September 30, is 60° F.

Before cutting, the stands on this experimental area exemplified the climax forest, well advanced. More than 80 percent of the

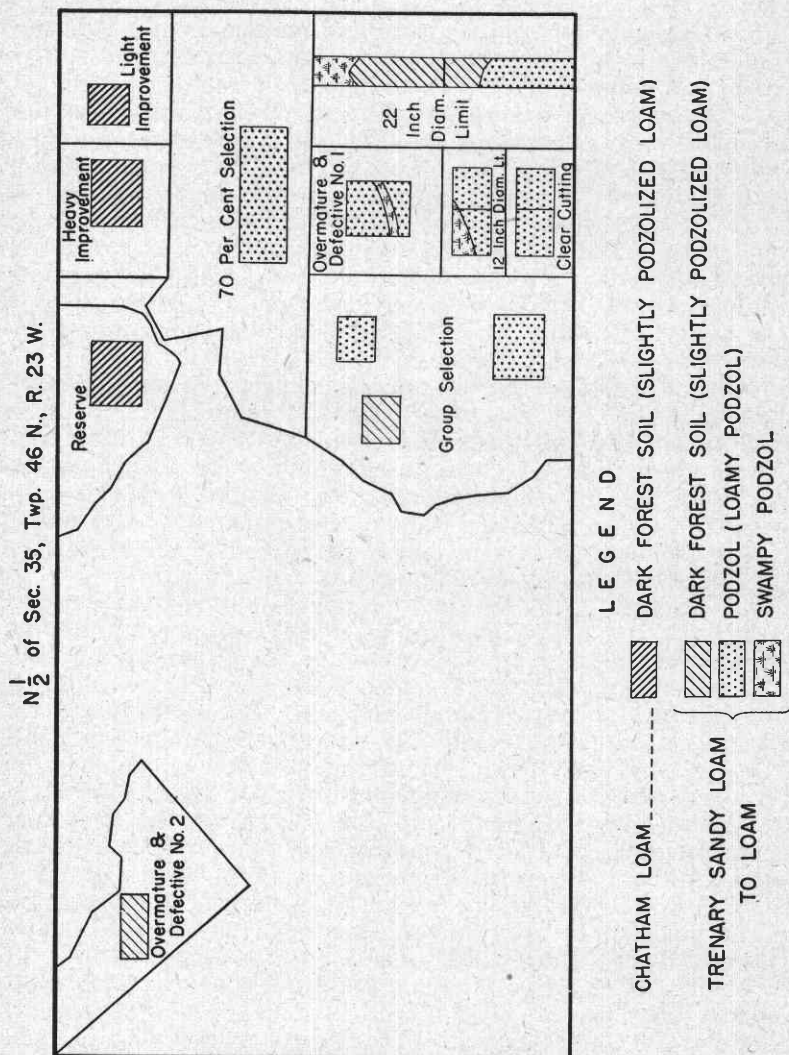


FIGURE 7.—Soils underlying permanent sample plots (shaded areas), cooperative experimental area, Upper Peninsula Experimental Forest.

trees 5 inches d.b.h. and up were sugar maple (table 7). Small reproduction was abundant in nearly all stands before cutting. More than 90 percent of the saplings and seedlings were sugar maple. The chief associate here was yellow birch. Many of the large trees were 300 or more years old, and cull in uncut stands ran as high as 40 percent. The only cutting prior to 1926 was a very light "high-grading" for elm, basswood, and the largest white pine during the period 1906 to 1910. This probably removed less than 5 percent of the stand and in many places left it virtually untouched.

TABLE 7.—*Number of trees per acre before logging, cooperative experimental area, Dukes, Mich.¹*

Diameter class ² (inches)	Species							Total
	Sugar maple	Yellow birch	Amer- ican elm	Eastern hophorn- beam	Balsam fir	Other conifers ³	Other hard- woods ⁴	
5.....	11.9	1.1	0.5	1.0	0.6	0.1	0.5	15.7
6.....	10.1	.9	.4	.6	.8	.1	.4	13.3
7.....	8.0	.7	.4	.3	.7	.1	.3	10.5
8.....	6.5	.7	.2	.2	.1	.1	.3	8.1
9.....	5.7	.5	.2	.2	.2	.1	.3	7.2
10.....	5.1	.6	.1	.1	.1	.1	.2	6.3
11.....	5.7	.6	.1	.1	.1	.1	.1	6.8
12.....	5.2	.4	.1	—	—	.1	.1	5.9
13.....	5.5	.3	.1	.1	—	.1	.1	6.2
14.....	4.6	.5	—	—	—	.1	.1	5.3
15.....	4.5	.4	—	.1	—	.1	.1	5.2
16.....	4.7	.5	.1	—	—	—	.1	5.4
17.....	3.9	.6	—	—	—	—	.1	4.6
18.....	3.9	.4	—	—	—	—	.1	4.4
19.....	3.3	.4	—	—	—	—	—	3.7
20.....	3.2	.4	—	—	—	—	.1	3.7
21.....	2.9	.3	—	.1	—	—	—	3.3
22.....	2.5	.2	—	—	—	—	—	2.7
23.....	2.0	.2	—	—	—	—	—	2.2
24.....	2.2	.2	—	—	—	—	—	2.4
25.....	1.8	.2	—	—	—	—	—	2.0
26.....	1.3	.3	—	—	—	—	—	1.6
27.....	.9	.1	—	—	—	—	—	1.0
28.....	.6	.1	—	—	—	—	—	.7
29.....	.5	.1	—	—	—	—	—	.6
30.....	.3	.2	—	—	—	—	—	.5
31.....	.2	—	—	—	—	—	—	.2
32.....	.3	.1	—	—	—	—	—	.4
33.....	.2	.1	—	—	—	—	—	.3
34.....	.1	.1	—	—	—	—	—	.2
35+.....	.1	.2	—	—	—	—	—	.3
Total.....	107.7	11.4	2.2	2.8	2.6	1.1	2.9	130.7

¹ Based on tally of 72 acres in Cleveland-Cliffs cooperative area adjacent to cutting plots.

² Includes trees 4.6 inches d.b.h. and up. The uncut reserve sample plot shows 166 trees per acre in trees 2 inches to 4 inches d.b.h., mostly sugar maple.

³ Includes eastern white pine, white spruce, and northern white-cedar.

⁴ Includes basswood, red maple, and black ash.

Since the experimental area is favored by good markets, integrated utilization has been possible. The better grades of hardwood logs find ready sale in Marquette, Munising, Gladstone, and Escanaba, Mich. (fig. 2). Veneer buyers from Wisconsin plants visit the area regularly. Local sawmills buy tie cuts and sawlogs.

Small, low-grade logs are purchased for mine timbers by nearby iron mines. Hardwood logs normally unmerchantable because of small size or defect and limb wood 4 inches or more in diameter can be marketed at the wood distillation plant in Marquette. Softwood pulpwood can be sold readily to Upper Michigan and Wisconsin mills.

A series of nine experimental cuttings and a reserve unit were established by 1932. These were set up as single unit tests. Nonetheless, several of the cuttings were fairly similar so that an element of replication is provided. It cannot be said that all of these cuttings constitute a comparison of silvicultural methods in the true sense. Moreover, the names used are those chosen at the time of cutting and do not always express important differences in treatment. All together, the experimental units provide considerable variability in the intensity of silvicultural treatment, a wide range in degree of stand removal, and strong contrast in residual stocking (table 8; figs. 8 and 9).

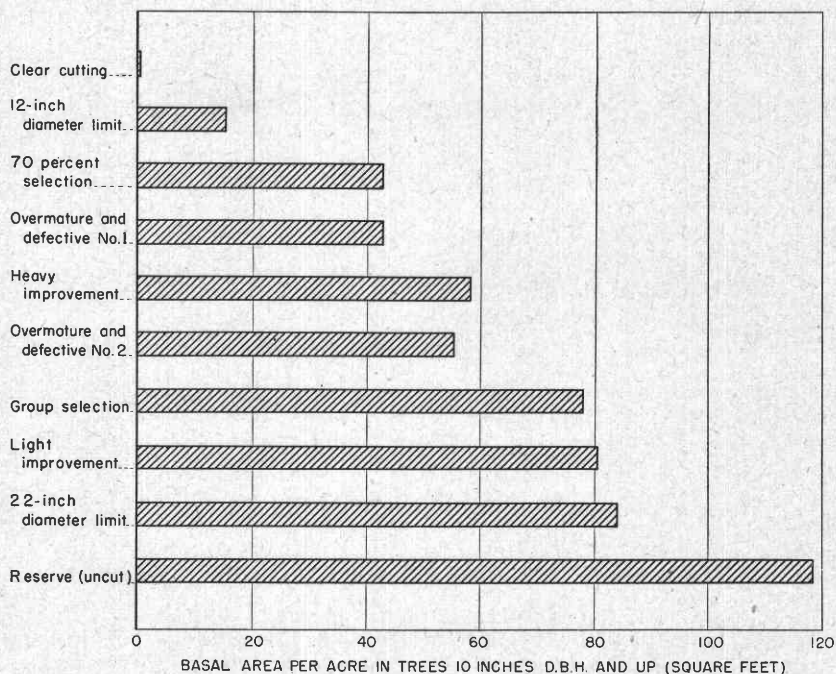


FIGURE 8.—Residual growing stock on permanent sample plots, Upper Peninsula Experimental Forest.

Residual stocking in merchantable trees ranged from zero board-feet on the Clear Cutting to 9,290 board-feet¹⁵ on the Reserve unit (table 8). In the partial cuttings, trees were selected

¹⁵ All board-foot volumes presented in this bulletin, except as otherwise noted, are by the Scribner log rule.

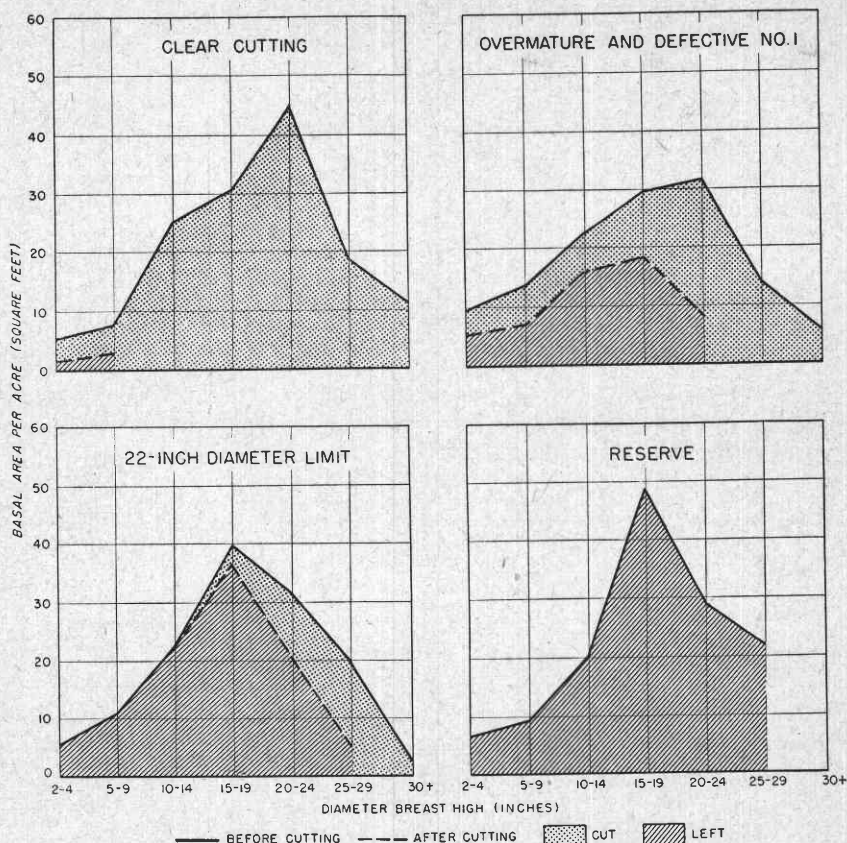


FIGURE 9.—Basal area per acre by diameter groups before cutting and immediately after cutting on the sample plots of four units.

for removal, either singly or in groups, on the basis of condition for the most part. Three cuttings were essentially diameter limits.

GROWTH AND MORTALITY UNDER DIFFERENT KINDS OF CUTTING

To appraise the effectiveness of a method of cutting or degree of stocking, there is need for measures of stand behavior. The growth and mortality that occur after stand treatment provide such yardsticks. For reliable information on these points, long-time records are needed. Permanent sample plots established on each unit following cutting and on the Reserve area furnish such a record (table 8). Each tree 2 inches d.b.h. and larger was given a permanent number, and its total height, merchantable height (in the case of the larger trees), and diameter at breast height were measured and recorded. Repeat measurements of sample plots at 5-year intervals form the main basis of the growth and mortality data presented here, supplemented by data from other areas on the experimental forest.

TABLE 8.—*Description of experimental cuttings; Upper Peninsula Experimental Forest, Duques, Mich.*

Cutting unit	Area	When cut or established	Basis of selection	Net volume removed per acre	Net residual volume per acre	Proportion of gross volume removed	Permanent sample plots on unit	General appraisal of effectiveness
Clear cutting-----	<i>Acres</i> 5	Early winter, 1927-28.	Everything merchantable cut, including chemical wood down to 5 inches d.b.h.	<i>Board-feet</i> 10,740	<i>Board-feet</i> 0	<i>Percent</i> 100	<i>Acres</i> 2	Good stand of second growth now on area. Many years until next cut of sawlogs. Even-aged stand now developing.
12-inch diameter limit--	5	Early winter, 1927-28.	All trees 12 inches d.b.h. and larger marked plus some smaller defective or injured trees.	7,300	410	90	2	Reproduction abundant. Diameter growth rapid. Quality poor because of excessive liminess. Considerable dieback in crowns. Stand essentially even-aged.
70-percent selection----	30	Fall, 1930-----	Most overmature and defective trees together with those over 17 inches d.b.h. marked. Some defective trees retained to achieve more uniform spacing.	3,500	3,200	68	4	Mortality heavy the first few years because of poor trees retained and exposure due to heavy cutting. Since then growth has been good.
Overmature and defective No. 1.	10	Early winter, 1927-28.	All overmature and defective trees marked, regardless of size or position in stand.	4,900	3,540	62	2	Mortality low; growth good and on sound, thrifty trees. Reproduction developing well. Stand structure good for uneven-aged silviculture.
Heavy improvement-----	8	Nov. and Dec. 1928.	All overmature and defective trees marked, regardless of size.	3,470	5,400	46	2	Growth slow for first 10 years—good since then. Reproduction developing well.
Overmature and defective No. 2.	13	Fall and early winter, 1932-33.	All overmature and defective trees marked, regardless of size or spacing.	4,200	5,500	59	1	Growth more rapid than any other cutting in series. No mortality. Stand structure good for uneven-aged silviculture.
22-inch diameter limit--	19	October, 1926-----	Most trees over 22 inches d.b.h. cut, together with some defective small trees.	2,350	7,360	29	4	Many trees cut were sound, vigorous and making good growth. Some trees left were defective and unhealthy. Gross annual growth has been satisfactory. Reproduction developing well.
		Recut, summer 1943.	Defective trees left in first cutting removed.	1,580	8,480	24	-----	Reduced mortality; improved growth.

Light improvement....	8	December, 1928 ..	Only the most decadent trees removed, irrespective of size.	1,570	7,890	24	1	Growth consistently good; mortality light.
Group selection ¹	32	Early winter, 1929	All merchantable trees in small groups up to one-third acre cut. Very worst trees removed between openings.	3,190	8,400	45	4	Reproduction of yellow birch good. Growth stimulation to edges of openings. Mortality high between openings.
		Recut, fall 1944	Small openings enlarged. Defective trees removed between openings.	1,980	8,160	27	-----	Reduced mortality; facilitated more yellow birch regeneration.
Reserve	9	1927	No cutting	0	9,290	0	2	Growth has been sporadic, mortality would probably offset growth over longer period.

¹ Because of the special nature of this cutting, data from it are not combined with those from other cuttings in this series in the stocking and valuation studies to be described later.

Growth in Twenty Years Following Cutting

Gross and Net Board-Foot Growth

Of all units commonly used to express growth, the board-foot is probably of most practical interest. So many of the higher-value products in this country are marketed by the board-foot that to the manager of hardwood forests it is apt to be the basic unit. It has the disadvantage of being determined by several different log rules which vary substantially. In the northern Lake States two rules are in use, the Scribner and the International ($\frac{1}{4}$ -inch kerf). Scribner rule is used in this report.¹⁶

Board-foot increment for the 20-year period varied greatly on the several cuttings. Periodic gross average annual growth ranged from 24 board-feet per acre on the Clear Cutting to 295 board-feet on Overmature and Defective Cutting No. 2 (table 9). On only three units (the Clear Cutting, the 12-Inch Diameter Limit Cutting, and the Reserve) was gross annual growth less than 200 board-feet per acre. In the first two instances, trees of board-foot size or those nearing merchantable diameter were either eliminated completely or reduced drastically in the cutting. On the reserve area, growth was slow because of high mortality and the crowded stand.

TABLE 9.—Gross average annual growth per acre in board-feet by cutting units for four 5-year periods¹

Unit	Period				20-year average
	First 5 years	Second 5 years	Third 5 years	Fourth 5 years	
	<i>Board-feet</i>	<i>Board-feet</i>	<i>Board-feet</i>	<i>Board-feet</i>	<i>Board-feet</i>
Clear cutting.....	² 0	³ 3	²⁵ 25	⁶⁴ 64	²⁴ 24
12-inch diameter limit.....	² 86	⁹⁸ 98	¹⁸² 182	³¹⁴ 314	¹⁷³ 173
70-percent selection.....	² 112	²⁵⁰ 250	³⁰⁴ 304	²⁸² 282	²³⁹ 239
Overmature and defective No. 1.....	¹⁶⁵ 165	²¹¹ 211	²⁹² 292	³⁵⁵ 355	²⁵⁶ 256
Heavy improvement.....	¹⁵⁰ 150	¹⁹² 192	³⁰⁰ 300	²⁸⁵ 285	²³² 232
Overmature and defective No. 2.....	²⁵⁵ 255	³⁰² 302	³²⁹ 329	-----	² 295
22-inch diameter limit.....	² 255	²¹⁰ 210	²⁵¹ 251	¹⁵⁴ 154	² 229
Light improvement.....	²³⁵ 235	²⁷⁶ 276	²⁵⁴ 254	²⁶⁵ 265	²⁵⁸ 258
Group selection.....	² 106	¹⁵² 152	²⁴⁴ 244	³⁰² 302	² 203
Reserve—no cutting.....	² 191	^{—19} —19	¹⁰⁵ 105	²⁰ 20	⁷⁰ 70

¹ Mortality deducted but no deduction for cull. Scribner rule used. Figures in this table vary in some instances from those shown in earlier progress reports because in some cases trees less than 9.5 inches d.b.h. were included and insufficient attention was paid to differences in merchantable height between plots. Results given here are all on a comparable basis.

² Plots established after start of growing season; consequently, first period not full 5 years.

³ 15-year average.

⁴ 2-year period, because of recutting. For the first 5 years following the second cutting, growth averaged 254 board-feet per acre per year.

⁵ 17-year average.

⁶ Second cutting made at end of third period.

In calculating gross board-foot growth, deduction has been made for mortality but not for cull, which in old-growth hardwoods in the northern Lake States normally exceeds 30 percent. Consequently, until the cull in standing timber is greatly reduced

¹⁶ See appendix for description of a method of converting tree volumes from Scribner Rule to International $\frac{1}{4}$ -Inch Rule.

through good silvicultural practice, it is much more realistic to appraise results in terms of net volume.

Cull was accordingly estimated as closely as possible on each unit under discussion by the method¹⁷ developed on the experimental forest at Dukes by Zillgitt and Gevorkiantz (142). Using the criterion of net average annual board-foot growth (table 10) marked differences appear between the cuttings. Overmature and Defective Cutting No. 2 is far above the others, with an average net growth of 252 board-feet. Overmature and Defective Cutting No. 1 (fig. 10) and the Light Improvement Cutting both made a periodic average annual growth of nearly 200 board-feet per acre.

TABLE 10.—*Net average annual growth per acre in board feet by cutting units for four 5-year periods*¹

Unit	Cull factor used	Period				20-year average
		First 5 years	Second 5 years	Third 5 years	Fourth 5 years	
	Percent	Board-feet	Board-feet	Board-feet	Board-feet	Board-feet
Clear cutting.....	17.6	² 0	² 2	21	53	20
12-inch diameter limit.....	21.2	² 68	77	143	247	136
70-percent selection.....	20.7	² 89	198	241	224	190
Overmature and defective No. 1.....	22.1	129	164	227	277	199
Heavy improvement.....	24.4	113	145	227	215	175
Overmature and defective No. 2.....	14.6	218	258	281	—	³ 252
22-inch diameter limit.....	19.8	² 205	168	201	⁴ 124	⁵ 184
Light improvement.....	24.0	179	210	193	201	196
Group selection.....	23.3	² 81	117	187	232	⁶ 156
Reserve—no cutting.....	36.7	² 121	—12	66	13	44

¹ Reduced for cull as well as mortality. Scribner rule used.

² Plots established after start of growing season; consequently first period not full 5 years.

³ 15-year average.

⁴ 2-year average.

⁵ 17-year average.

⁶ Second cutting made at end of third period.

With the exceptions of the two lightest cuttings (22-inch Diameter Limit and Light Improvement) and the Reserve, net growth has consistently increased with each 5-year period (table 10) on most plots. It will be interesting to observe at what future time stocking on the several cuttings reaches the stage where this trend is reversed.

A net average annual growth of 200 board-feet on a well-stocked acre should be well within the realm of possibility for managed northern hardwood stands on good upland sites in the Lake States.¹⁸ The best cuttings approached this figure or exceeded it during the 15- to 20-year period under discussion, although the growing stock was old. When the area becomes well and uniformly stocked with thrifty, productive trees of good quality, growth prospects should be even more promising.

¹⁷ See appendix for a description of the method of cull determination.

¹⁸ In any application of these figures, a word of caution is necessary. It should be kept in mind that the results are for stocked areas only and do not include any nontimbered or unproductive land, small areas of which are normally thrown together with timbered areas in large-scale cruises.



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FIGURE 10.—Moderate partial cutting which has grown at the rate of approximately 200 board-feet per acre per year net for 20 years. Photo taken in 1929, 2 years after logging.

Growth Percent

Growth percent is one facet of the relationship between growth and residual stocking. In this series of experiments, the best cuttings on the basis of board-foot increment were not necessarily the most impressive in growth percent (table 11). The greater the quantity of merchantable timber left, the smaller was the volume growth percent (fig. 11). The high rate of increase of the stands with light residual stocking should not be misconstrued. Because of the small size and poor quality of the material in such stands, the recovery value is low. Results shown in figure 11 from 20-year sample-plot records almost coincide with those obtained by a short-time increment boring study carried out in 1929 in Wisconsin and upper Michigan (146).

Ingrowth

In any kind of cutting that leaves a residual growing stock below the minimum merchantable size, a certain amount of ingrowth will take place. As defined here, ingrowth is the board-foot volume of trees that have reached 9.6 inches d.b.h. during any of the four 5-year periods of measurement. For subsequent periods the growth of these same trees was not considered as ingrowth.

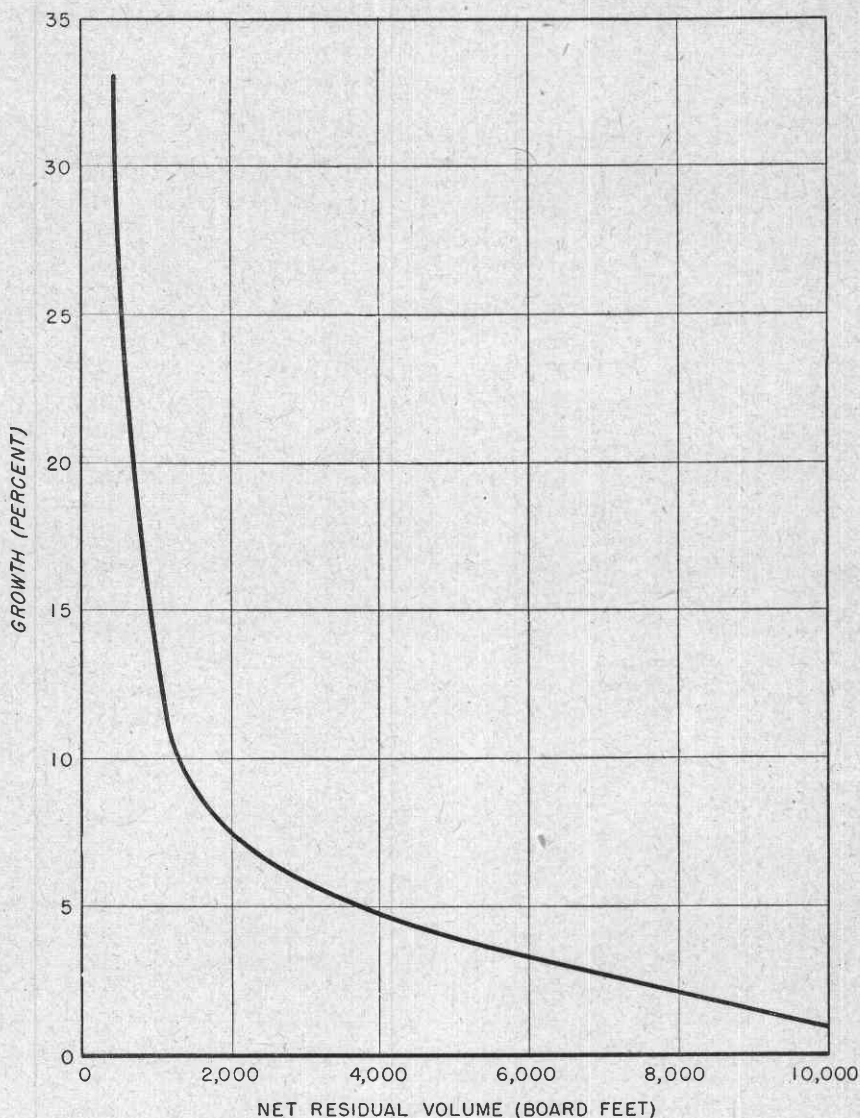


FIGURE 11.—Growth in percent in relation to volume, based on 20-year growth on sample plots.

Annual ingrowth, so defined, does not constitute a very large portion of the total annual growth (table 12). This is readily accounted for by the deficiency of pole-size trees in the original stands. Ingrowth did not seem to be related to the amount of growing stock left on the partial cuttings. It accounts for over half the growth on the clear cutting, but here only a few trees have reached board-foot size, so the total growth is not at all

TABLE 11.—*Growth percent for 20-year period by cutting units*¹

Unit	Residual net volume	Net average annual growth per acre	
		Board-feet	Percent
Clear cutting.....	0	20	
12-inch diameter limit.....	410	136	33.2
70-percent selection.....	3,200	190	5.9
Overmature and defective No. 1.....	3,540	199	5.6
Overmature and defective No. 2 ²	5,500	252	4.6
Heavy improvement.....	5,490	175	3.2
22-inch diameter limit ³	7,360	184	2.5
Light improvement.....	7,890	196	2.5
Reserve.....	9,290	44	.5

¹ Trees 9.6 inches d.b.h. and up.² 15-year record.³ 17-year record.TABLE 12.—*Annual ingrowth per acre by cutting units (84)*

Unit	Proportion of gross saw-timber volume removed	Pole-size trees left ¹	Poles reaching saw-timber size in—				Average annual ingrowth for 20 years ²	
			0-5 years	0-10 years	0-15 years	0-20 years	Gross volume, Scribner	Proportion of total growth
	Percent	Number	Number	Number	Number	Number	Board- feet	Percent
Clear cutting.....	100	4.50	0.0	0.5	4.5	10.5	14	58
12" diameter limit.....	90	13.00	3.5	9.5	18.5	28.5	28	16
70-percent se- lection.....	68	12.75	3.2	7.7	14.2	16.0	34	14
Overmature and defective No. 1.....	62	14.00	3.0	6.5	12.0	18.0	34	13
Overmature and defective No. 2.....	59	6.00	3.0	6.0	8.0		³ 20	7
Heavy improve- ment.....	46	12.00	2.0	5.0	10.5	14.5	29	12
Group selection.....	45	14.75	1.0	4.8	8.0		³ 22	13
22" diameter limit.....	29	17.75	3.0	6.5	11.3	12.0	⁴ 27	12
Light improve- ment.....	24	6.00	2.0	5.0	5.0	9.0	17	7
Reserve.....	0	17.00	1.0	2.0	4.5	5.5	10	14

¹ Trees 7, 8, and 9 inches d.b.h.² Trees were calculated as ingrowth during the first 5-year period that they reached saw-timber size, but not during subsequent periods.³ 15-year average.⁴ 17-year average.

significant. The number of trees reaching sawtimber size generally increased with each measurement throughout the first 15 years following logging. As the deficiency in pole-size trees is made up, the proportion of total growth accounted for by ingrowth may be expected to increase.

The relative proportion of ingrowth by species is very similar to the species composition of the original stand, as might be expected. However, there is some tendency for sugar maple to increase its proportion of ingrowth on light cuttings and to decrease on heavy cuttings (84).

Cubic-Foot Growth

Growth as it applies to sawtimber stands is usually presented in terms of board-feet in the Lake States, but there is growing interest in total volume growth as expressed in cubic feet. This is due to the increased use of dense hardwoods for pulpwood. Such utilization will undoubtedly influence the future management of northern hardwood stands in the region.

Periodic average annual growth in cubic feet (table 13) for trees 4.6 inches d.b.h. and greater on the Dukes cuttings follows about the same pattern on the several units as that of board-foot increment (tables 9 and 10). The two Overmature and Defective cuttings and the Light Improvement cutting have made the best records—over 86 cubic feet per acre per year on the average. Overmature and Defective Cutting No. 2, ranking first in board-foot growth by a substantial margin, is about equal here to Overmature and Defective Cutting No. 1. The Clear Cutting would show more growth if trees below 4.6 inches d.b.h. were included, as many on the unit have not yet reached this minimum limit of merchantability. Over a longer period, this cutting should be more impressive in cubic-foot increment.

TABLE 13.—Cubic-foot growth per acre, by cutting units

Unit	Residual volume	Average annual growth for 20 years by diameter groups ¹		
		4.6 to 9.5 inches, inclusive	9.6+ inches	Total
	<i>Cubic feet</i>	<i>Cubic feet</i>	<i>Cubic feet</i>	<i>Cubic feet</i>
Clear cutting.....	59.37	10.45	8.89	19.34
12-inch diameter limit.....	686.33	11.93	44.58	56.51
70-percent selection.....	1,823.62	5.48	59.34	64.82
Overmature and defective No. 1.....	1,732.20	19.06	67.84	86.90
Overmature and defective No. 2 ²	2,284.67	14.56	71.85	86.41
Heavy improvement.....	2,359.31	6.26	67.00	73.26
Group selection ²	3,383.00	5.85	55.39	61.24
Light improvement.....	3,142.80	9.56	76.78	86.34
22-inch diameter limit ³	3,500.83	6.36	64.64	71.00
Reserve.....	4,954.29	3.40	14.78	18.18

¹ Includes stem, top, and branches to a 4-inch top diameter inside bark. "Diameter groups" refers to tree diameters measured outside bark, at breast height.

² 15-year record.

³ 17-year record.

Basal Area Increase

There is still another unit of measure for stand change which is useful in certain situations. Basal area may be used as a common denominator for comparing stocking in widely scattered stands. In the experimental cuttings, basal area increase in merchantable trees 9.6 inches d.b.h. and greater varied during the period of observation from a maximum of 1.962 square feet per acre per year to a minimum of 0.384 square foot (table 14), the moderate cuttings ranking near the highest. When all trees 1.6 inches d.b.h.

and over were included, the average annual basal area increase per acre varied from 0.497 to 3.475 square feet, being greater in the heavier cuttings.

TABLE 14.—*Basal-area increase by cutting units for 20 years*¹

Unit	Residual basal area 1.6+ inches	Average annual growth per acre by diameter group			
		1.6-4.5 inches	4.6-9.5 inches	9.6+ inches	Total
	<i>Square feet</i>	<i>Square feet</i>	<i>Square feet</i>	<i>Square feet</i>	<i>Square feet</i>
Clear cutting.....	3.562	2.453	0.582	0.388	3.423
12-inch diameter limit.....	25.642	1.374	.581	1.520	3.475
70-percent selection.....	49.741		.257	1.641	² 1.898
Overmature and defective No. 1.....	55.109	.217	.738	1.792	2.747
Overmature and defective No. 2 ³	61.440		.633	1.962	² 2.595
Heavy improvement.....	68.546	.395	.248	1.606	2.249
Group selection ³	92.238	.381	.232	1.020	1.633
Light improvement.....	92.436	.165	.389	1.723	2.277
22-inch diameter limit ⁴	100.410	.159	.259	1.559	1.977
Reserve.....	134.161	.022	.091	.384	.497

¹ Mortality deducted.

² Does not include trees under 5 inches in diameter.

³ 15-year record.

⁴ 17-year record.

Diameter Growth and Height Changes

Diameter and height growth largely determine volume increment. In uncut old-growth stands, diameter growth is generally quite slow. Zon and Scholz (146) report results from increment borings in virgin stands as follows.

Species:	Years required to grow 1 inch in diameter
Basswood	7
Sugar maple	10
Beech	11
Hemlock	11
Yellow birch	12
Elm	12

The uncut reserve plot at Dukes, which was predominantly sugar maple, grew at the rate of 10 years to the inch for two decades (table 15), thus exactly confirming the earlier study.

Trees released through partial cutting obviously will grow faster than those in uncut stands. In stands given some release by logging of conifers and the more valuable hardwoods, sugar maple was found to range from about 6 to 9 years in the time required to grow an inch in diameter in central New York (30). In a study of growth response in sugar maple 15 years after a light cutting in northern Michigan, growth rate increased about 15 percent. The growth put on following cutting did not change the form of the trees (136). Growth of sugar maple at Dukes following a commercial clear cutting in 1911 accelerated rapidly. Rate of diameter growth in sample trees often quadrupled in 5

TABLE 15.—Average annual diameter growth on different cuttings over a 20-year period

Kind of cutting	Basal area per acre ¹		Average diameter growth per year by diameter group				
	2+ inches	10+ inches	5-9 inches	10-14 inches	15-19 inches	20+ inches	All trees 10 inches d.b.h. and over
	<i>Square feet</i>	<i>Square feet</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>	<i>Inch</i>
No cutting (reserve).....	134	118	0.07	0.10	0.11	0.10	0.10
Light ²	98	83	.12	.14	.14	.12	.14
Intermediate ²	62	52	.20	.19	.17	.16	.18
Heavy.....	41	34	.24	.20	.19	.16	.20
Clear.....	4	—	.28	(4)	—	—	—
Group selection ³	9	83	.10	.14	.13	.11	.13

¹ At time of plot establishment. The percent of gross volume removed on the first five of these cutting units was 0, 28, 55, 75, and 100, respectively.

² 15-year or 17-year average on a few of the plots in these cuttings.

³ Does not include 2- to 4-inch trees on some plots.

⁴ Trees 9.6 inches and over removed in cutting.

years and in two cases increased from 0.5 inch during the 5 years ending in 1911 to 2.4 inches during the next 5-year period.¹⁹ Twenty-year sample-plot averages at Dukes show that in round numbers the heavy cuttings required 5 years to grow an inch in diameter; the intermediate ones, 6 years; and the light, 7 years (table 15).

All sizes of trees in the experimental cuttings grew faster than those in the reserve plot and the response was in general directly proportional to the degree of opening. The stimulation was most noticeable in the smaller diameter classes (fig. 12). Individual cross sections of well-favored sugar maples have been observed at Dukes which increased 1 inch in diameter in 2 to 3 years. In general, however, any northern hardwood of good vigor, on a good site and reasonably free to grow, should increase 1 inch in diameter in 5 or 6 years.

In order to determine how trees of different diameters responded in board-foot increment, the growth made during a 20-year period was calculated for each inch class for three selected plots. The results were then reduced to an annual basis and presented as a percent of the original volume in the class (fig. 13). The advantage of the moderate cutting in stimulating growth in trees from 10 to 18 inches d.b.h. is obvious, as is the leveling off of growth in those over 22 inches in size within the cuttings and reserve area.

Total height is commonly employed as the indicator of site productivity and the better height development on better sites means greater growth. Not much is known of the effect that a given degree of partial cutting may have upon height. Whether or not it will vary with different kinds of management is still pretty much a matter of conjecture.

¹⁹ WRAY, ROBERT D. A STUDY OF THE GROWTH RESPONSES OF RESIDUAL SUGAR MAPLE AFTER COMMERCIAL CLEAR CUTTING. Master's thesis, School of Forestry and Conservation, Univ. Michigan. 45 pp. (typewritten). 1947.

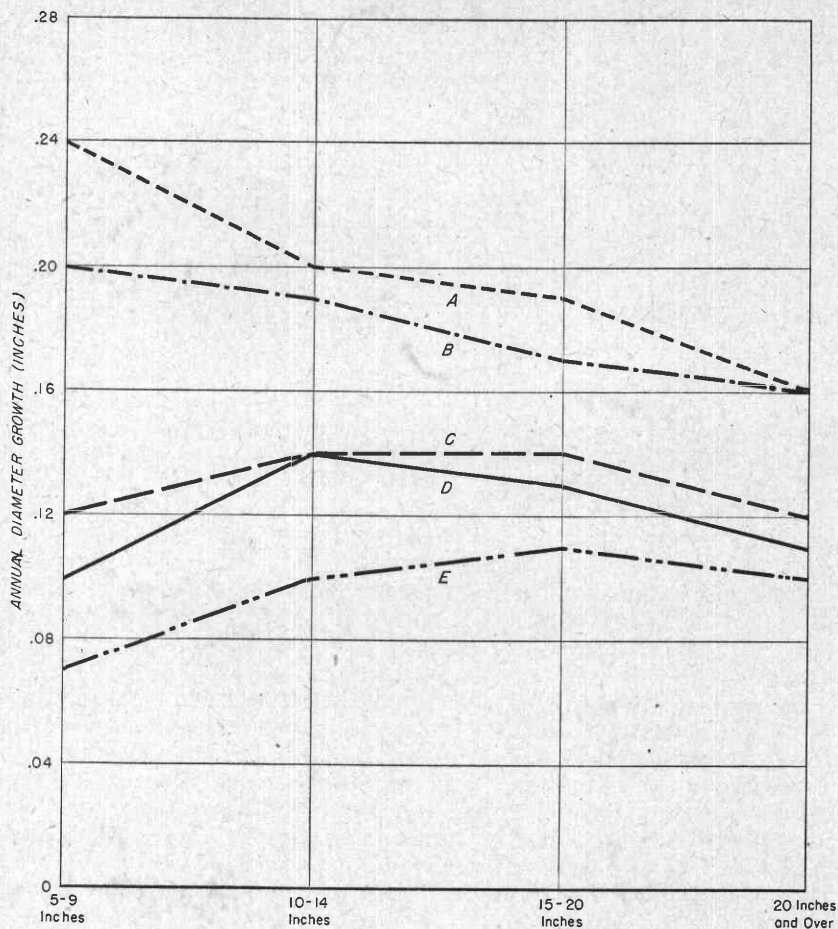


FIGURE 12.—Average diameter growth on different cuttings over 20-year period. A, Heavy; B, intermediate; C, light; D, group selection; E, reserve.

Some foresters have felt that northern hardwood trees grown under the selection system will not attain the height of trees present in the virgin forest or grown in even-aged stands. This much is known from the plot records: on the heaviest cuttings (clear cutting and 12-inch diameter limit) a different relationship between height and diameter has become apparent over a 20-year period since cutting. These trees have built up rapidly in diameter while suffering some dieback in the crowns. The same effect, but to a lesser degree, is noticeable on the 70-percent selection area (fig. 14) and on the two moderately heavy overmature and defective cuttings. On the lightly cut plots it is not apparent.

Stands grown under the selection system may not attain the greatest total height. However, in old-growth hardwoods merchantable height is currently of more direct importance than total height because of the emphasis upon board-foot volume. As yet

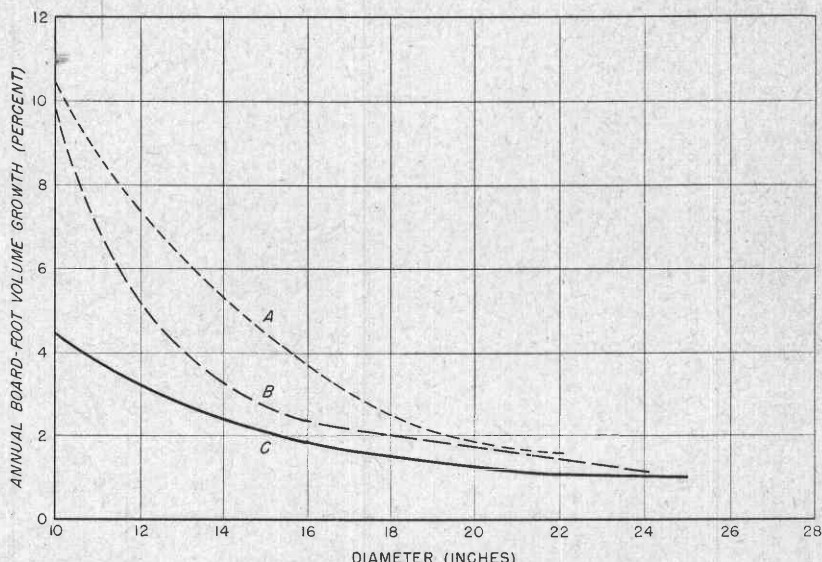


FIGURE 13.—Annual board-foot volume growth in percent for sugar maple trees of different diameter classes (20-year average). A, Moderate cutting (Overmature and Defective No. 1); B, light cutting (Light Improvement); C, reserve area (no cutting).

there is no indication that merchantable length will suffer appreciably through moderate partial cutting.

Maximum merchantable height is reached long before maturity in northern hardwoods. Sugar maple slows down in development of merchantable height by the time it reaches 17 inches d.b.h.²⁰ At 20 inches d.b.h. there is no further increase in merchantable height with size, although the top branches continue to grow upward. Continued studies are needed to explore fully the height growth of northern hardwoods and its relationship to method of cutting.

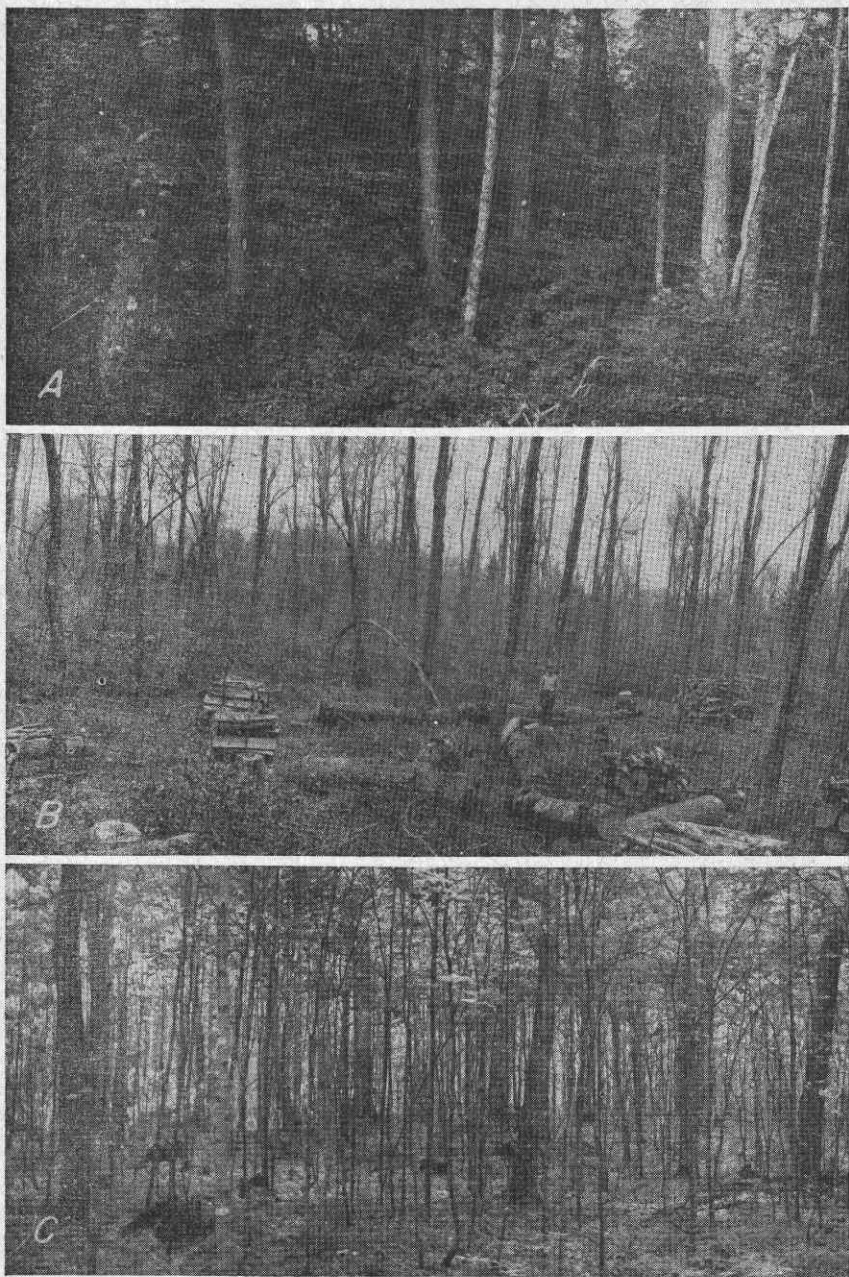
Reduction of Mortality Through Partial Cutting

In the analysis of stand increment in foregoing sections, trees that died during the 20-year period were deducted from all growth figures. Mortality, however, is such an important consideration in the conversion of old-growth stands to thrifty forest that its extent and character have been given special study (40).

Specifically, three sources of information were available for the study:

1. The 24 acres of *permanent sample plots* (table 8, col. 8) in the co-operative experimental area which date from 1926. Records of these are the most precise and cover a 20-year period for most plots.

²⁰ ENGLE, LAMONT G. VOLUME AND VALUE GROWTH OF SUGAR MAPLE IN UPPER MICHIGAN. Master's thesis, School of Forestry and Conservation, Univ. of Michigan, 41 pp. (typewritten), 1949.



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FIGURE 14.—Heavy partial cutting. *A*, Before logging. Blazed trees indicated for removal. *B*, Immediately after logging in 1930. Some trees in this stand became stag-headed but recovered. *C*, Same area after 22 years. Saplings and small poles now occupy the openings.

2. The *entire cutting units* (table 8, col. 2), a total of 174 acres, excluding the clear cutting but including a separate 40-acre virgin area. Records were maintained for 12 years beginning in 1929.

3. *Diagrammed inventory plots* in which all trees 9.6 inches d.b.h. and over were mapped and numbered in 1940-42 for the enlarged experimental forest "pilot plant" test. There are 472 such plots, each 1/5 acre in size, totaling 94 acres, suitable for this study. The average period of observation slightly exceeded 6 years.

On the permanent sample plots mortality was fairly closely related to stocking but not entirely so. Mortality in board-feet proved to be highest in the uncut reserve area, next highest in the lightly cut plots, next in the heavy cuttings, and lowest where an intermediate stocking of about 4,700 board-feet net per acre was left (table 16). The Group Selection cutting represents a special case. Here the failure to remove sufficient poor risk trees between the clear-cut patches resulted in heavy mortality and rather slow growth. This was corrected after 15 years by a light improvement cut over the whole area. Mortality occurred in all diameter classes on most plots. That the average mortality on all the cutting plots was only one-fourth of that in uncut timber is perhaps the most noteworthy feature of the entire study.

TABLE 16.—*Growth-mortality relationship on permanent sample plots over a 15- to 20-year period*

Cutting method	Residual stand per acre	Basal area per acre ¹		Average annual mortality			Average annual volume growth	
		1.6-inch d.b.h. and up	9.6-inch d.b.h. and up	Volume		Basal area	Gross ²	Net ³
				Gross	Net			
	<i>M board-feet</i>	<i>Square feet</i>	<i>Square feet</i>	<i>Board-feet</i>	<i>Board-feet</i>	<i>Square feet</i>	<i>Board-feet</i>	<i>Board-feet</i>
No cutting (reserve)	9.3	134	118	153	97	1.23	70	44
Light cuttings	7.5	98	83	43	34	.35	235	186
Intermediate cuttings	4.7	462	52	10	8	.10	254	200
Heavy cuttings	2.3	441	34	22	17	.22	217	172
Group selection cuttings	8.4	92	83	46	35	.35	*170	*130

¹ At time of plot establishment. The percent of gross volume removed in the first four of these units was respectively 0, 28, 55, and 75.

² Mortality has been deducted but not cull.

³ Reduced for mortality and for estimated cull in stand. In the cuttings cull varied from 15 to 24 percent and was 37 percent in the uncut reserve plot.

⁴ Trees 4.6 inches and over for some of the plots in this group.

⁵ 15-year average.

Type of loss was recorded on the permanent plots. Breakage represented a major loss in all except the very heaviest cuttings. It occurred most often where there was some serious defect on the bole, such as butt rot, canker, or large limb scar. Some trees, however, died standing but the cause of death in most cases could not be determined. Root disturbance due to road construction or logging and changes in drainage conditions appeared partly responsible in some instances. Uprooting accounted for the smallest losses, except in the heavy cuttings. Accordingly it may be con-

cluded that the important species in the hardwood stands are fairly well rooted and reasonably resistant to windthrow, except on wet or shallow soils.

Mortality was compared for four 5-year periods on the various cutting plots. The losses in the intermediate cuttings showed a slight decrease from period to period, while those in the heavy cuttings were greater at first and then remained rather constant. In the light cuttings, mortality tended to build up during each successive 5-year period following cutting as the stands filled up and became more like an uncut forest.

Results from the studies of the whole cutting units, the second source of data, strongly support those just summarized from the permanent sample plots. In uncut stands, average annual mortality exceeded 100 board-feet per acre and almost equaled growth. In partial cuttings it was only one-fifth to one-third as great as in uncut stands. Cuttings heavy enough to remove a fair majority of poor-risk trees reduced mortality more than the very light cuttings. On the other hand, the very heavy cuttings suffered serious losses due to exposure of residual trees. Intermediately cut stands had the lowest mortality losses. Mortality occurred in all diameter classes.

Various species reacted differently on the several cutting plots and units. Sugar maple lost relatively little. Yellow birch, a sensitive species, suffered greater losses than sugar maple, especially on the heavier cuttings. On the light to intermediate cuttings it appeared to be almost as good a risk as sugar maple.

Postlogging mortality in northern hardwoods has been attributed to changes in physical factors of environment (65). Results here support this observation for yellow birch but not for sugar maple. The condition of a maple tree appeared to be much more of a factor in its survival than any change in environment caused by logging. An exception was the extremely heavy cuttings. Even here, many of the maples whose tops died recovered later. Sugar maple is a hardy, resilient tree. Fortunately, it is the one of greatest volume in the northern hardwoods of the Lake States.

Although most of the mortality data were for pure hardwoods, the diagramed inventory plots (the third source) provide some comparative data on partially cut hemlock-hardwood, hemlock, and ash-elm types over a short period. Mortality in the hemlock type was heavy and that in ash-elm was considerably greater than in well-drained upland hardwoods. Partially cut hemlock, unless in thrifty stands, has generally been considered susceptible to heavy mortality. These overmature stands were no exception.

In a special study of hemlock mortality, Graham (62) found that after partial cutting, hemlocks with heavy crowns suffered less from exposure than those with small crowns and that the decadence was in proportion to the amount of exposure. He felt also that direction of exposure was significant and that hemlock and birch should be protected on the south and west by more hardy species. This observation was confirmed indirectly by results at Dukes where loss of hemlock trees in partially cut transitional

hardwood-hemlock type was not excessive and was considerably less than in the pure hemlock type. Mortality in hemlock was confined chiefly to trees that died standing. There was little breakage or windfall.

In the analysis of the diagramed inventory plots, losses during a short period in relation to residual volume of timber were compared for the several species in the different types (table 17). Sugar maple again is shown as the best risk. Although there was high loss in hemlock, some benefits to reproduction may result from the partial cutting. The total loss in board-feet in the hardwood area was in very close agreement with the other studies where a similar light type of cutting prevailed, thus corroborating previous conclusions. The light cutting employed did not remove enough trees of poor risk, but the loss was strikingly lower than in the uncut area.

In general, mortality losses in partially cut old-growth northern hardwoods appear to be proportional to the amount of rot and certain other defects in the stand. Thrifty stands will be encountered occasionally where trees unmerchantable because of defect and trees of poor risk can largely be removed in one partial cutting. More commonly, however, some poor-risk trees must be retained temporarily to prevent excessive opening of the stand. Here there is need for a salvage program to utilize trees which die between regular periodic cuts. Salvage of small per-acre volumes is dependent upon a good road system. Moreover, good roads are indispensable for a managed forest.

The experimental results show that mortality losses need not be a deterrent to use of partial-cutting methods. At least on the experimental forest at Dukes, the degree of cutting that results in maximum growth also results in lowest mortality losses. This fact constitutes one of the more encouraging aspects of northern hardwood management.

Logging Damage

The logging of any forest by a partial cutting method will unavoidably injure the residual stand to some extent. Damage consists of breakage of advance growth and scarring of large residual trees. Stem or bole scars may induce disease and thus cause serious defect.

To obtain information on logging damage, tree records for 18 acres of sample plots on the experimental cuttings were examined. Trees now merchantable, which were scarred on the bole at the time of logging 20 to 25 years ago and at that time showed no evidence of disease, were tallied. The present condition of the scarred trees was also recorded as follows.

	Number	Percent
Trees with logging scar on bole (1926-32)	69	100
Trees now cankered or with advanced butt rot (1951)	20	29
Trees with scars healed or only minor defect present (1951)	49	71

TABLE 17.—Percent of residual net volume¹ lost annually through mortality on diagramed plots

Species	Northern hardwood						Hardwood-hemlock (cut-over)	Hemlock (cut-over)		Ash-elm (cut-over)	
	Cut-over			Uncut				Stand volume	Annual loss	Stand volume	Annual loss
	Stand volume	Annual loss	Percent	Stand volume	Annual loss	Percent					
All species.....	Board- feet 8,033	Percent 0.42	Board- feet 7,624	Percent 1.58	Board- feet 6,938	Percent 1.04	Board- feet 7,699	Percent 2.16	Board- feet 6,037	Percent 1.41	
Sugar maple.....	6,435	.31	4,121	1.58	838	1.07	100		155		
Yellow birch.....	1,027	.88	1,947	1.59	2,218	.68	732		927		
Red maple.....	146	.68	323	2.48	1,302	.84	1,293	1.70	876	1.48	
Hemlock.....	84	1.19	778	1.80	2,380	1.51	4,762	2.67	492	4.07	
American elm.....	170	1.18	176	.57			49		140		
Black ash.....							205		2,987	1.14	
White-cedar.....							448		250	7.20	
White spruce.....							53	32.08	189		
Miscellaneous.....	171	2.58	279	2.36	200	2.50	57		21		

¹ Net board-feet per acre in residual stand after cutting. The cutting removed some 1,200 to 1,300 board-feet per acre, net, in the hardwood and ash-elm types and from 2,000 to 3,000 board-feet, net, in the hemlock-hardwood and pure hemlock types.

² Includes small quantities of black ash, white cedar, and white spruce in some instances.

This is by no means a complete study and should not be interpreted as such. Still, it gives evidence that 30 percent of the stem logging scars in this case were serious defects from 20 to 25 years later, and suggests the advisability of frequent cuttings at rather short intervals to remove damaged trees before defect becomes serious. However, the 20 defective trees were distributed over 18 acres or at the rate of 1 tree per acre, so the damage cannot be considered excessive.

Many tops and branches are broken or damaged in felling large trees. Just how serious this top damage may be depends on whether heartwood is exposed by the breakage. If heart rot starts in broken tops or where large branches are torn off, the decay progresses slowly downward in the tree. Where only sapwood is exposed, the top may recover and not decay, although it will remain permanently misshapen. Pathological studies of the long-time effect of logging injuries on residual trees are now under way.

Breakage has received special consideration in experimental cuttings. In the first operations at Dukes, only 2.1 percent of the total number of trees above 2½ inches in diameter in the original stand were broken in both light and heavy partial cuttings. Most of them were small—from 3 to 8 inches d.b.h.

A later check was made in 1943 during the second partial cutting of a 19-acre tract. It was a light cut, averaging about 1,600 board-feet of logs and 5 cords of chemical wood per acre. The loss of advance reproduction (trees 2 to 10 inches d.b.h.) on a 4-acre sample is summarized as follows.

Cause of loss:	Number lost per acre	Percent of total in class
Felling	12	5
Skidding and decking	10	4
Total	22	9

Four additional trees per acre of the same size class, or 2 percent, were damaged by logging but not beyond recovery. Only one tree of sawlog size, a 16-inch sugar maple, was destroyed on the entire 19 acres and this was salvaged at the time of logging. If care is used, the losses can generally be held to one sawlog tree per acre, which is salvaged, plus a few small ones. Somewhat greater losses can be expected with heavier cuts. Cutting of trees for skidways and decking grounds can be directed toward defective or poorly formed specimens. The losses in small trees are not particularly serious with the abundant natural reproduction usually present in the northern hardwood forest.

During 1946 a comparison was made of skidding damage by small tractors and by horses (36). More small trees were injured by the tractor than by horses, but damage was nominal in both cases. Thirteen trees were damaged per acre by the tractor as against 10 by the horses.

Eugene Fobes of the Forest Products Laboratory suggests that a different sequence in the logging operation than is ordinarily used would reduce skidding damage. He recommends that skid

trails be laid out for their full length before cutting is started. Then felling and skidding should start at the back end of the unit and move forward so as to be concluded at the place logs are assembled. In this way, trees to be cut close to the landing act as buffers for those selected for retention, and the residual trees receive fewer butt and root injuries. Such a scheme would necessitate logging two adjacent units concurrently so that the felling crew could be shifted back and forth to avoid dropping logs across the skid trail while skidding is in progress.

Precautions which help to keep logging damage at a low level on partial-cutting operations are necessary in good management. Men working in the woods must be impressed with the need for care (44, 94). Measures required to accomplish this purpose are as follows.

1. *Directed or planned felling.*—Hardwoods are big enough, valuable enough, and have few enough stems per acre to justify individual tree marking. One mark per tree can indicate the desired direction of fall. If a large tree is definitely committed to fall in one direction, do not depend upon another in the line of fall for the residual stand. Mark this tree also.
2. *Advance location of roads, decking grounds, and main skid trails.*—Locate improvements to take full advantage of existing old roads and openings. Start felling and skidding from the far end of the skidroad and finish at the landing or loading area. Locate clearings for decking grounds, buildings, and other logging improvements in areas having poor trees or poorly formed or diseased reproduction wherever possible.
3. *Use of equipment no larger than necessary.*—The smallest tractors and other moving equipment adequate to handle the loads will inflict the least damage on the residual stand.
4. *Care in equipment operation.*—Given similar conditions and identical equipment, the careful worker will do less damage than the careless worker, be it skidding, power-saw felling, or any other woods job. Therefore, "sell" the workers on the merits of sparing advance growth.
5. *Complete instruction.*—There is no substitute for "know-how." Judicious placement of older, more experienced workers on the woods operation will help in instructing other workers.
6. *Close supervision.*—Probably more than anything else, close supervision is the key to minimizing logging damage.

Logging damaged can be kept within reasonable limits on partial-cutting operations by exercising care and employing suitable equipment. Sparing residual stands from unnecessary damage should pay good dividends.

STOCKING, STAND STRUCTURE, AND CUTTING CYCLE

Definitions of the stocking and stand structure needed to provide good growth for continuous yield are basic to any plan for the wise handling of northern hardwood stands. They are needed as guides to follow in reducing overstocked stands and in building up understocked stands to desirable levels. Without such knowledge it is difficult to set specific goals of management.

Optimum Stocking in Merchantable Timber

The importance of the growth-stockings relationship has been given due recognition in experimental work. Fifteen-year data from the experimental cuttings were analyzed in 1947 to determine the growth possible with a variety of residual stocking levels (138). Records for 20 years are now available.

The net average annual growth for each cutting was plotted over net residual volume and a curve was fitted (fig. 15). Growth was limited on one end of the curve by lack of growing stock and on the other end by competition and mortality. If the stands had been under management for a longer period and were generally more thrifty, growth might have been better in the higher stockings.

From this curve, net average annual growth for a series of residual volumes in trees 10 inches d.b.h. and up, ranging from 0.5 to 9.5 thousand board-feet, was obtained as follows.

<i>Net volume in M board-feet</i>	<i>Basal area in square feet</i>	<i>Net average annual growth per acre in board-feet</i>
0.5	17	85
1.0	22	108
1.5	28	128
2.0	32	148
2.5	36	165
3.0	40	181
3.5	44	196
4.0	48	209
4.5	52	218
5.0	56	225
5.5	60	230
6.0	64	230
6.5	68	223
7.0	74	209
7.5	80	186
8.0	88	155
8.5	99	117
9.0	110	72
9.5	124	21

Growth ranged from 21 to 230 board-feet annually per acre. Annual growth exceeded 200 board-feet wherever stocking was not less than 4,000 and not greater than 7,000 board-feet per acre. Maximum growth occurred here with a residual stocking of about 6,000 board-feet. On better sites the desirable stocking would, no doubt, be somewhat greater. Studies of Allegheny northern hardwoods in Pennsylvania (74) indicated maximum growth where residual stocking was somewhat higher than 6,000 board-feet, but these eastern stands had different composition including much black cherry and white ash, were younger, and probably were on a better site.

Since board-foot volumes are strongly influenced by changes in site, optimum stocking in terms of basal area should prove more constant over wide areas. In the present study, best growth resulted with a residual stocking of 64 square feet of basal area in trees 10 inches d.b.h. and larger. However, growth was good where residual stocking ranged from 50 to 75 square feet per acre, thus agreeing closely with results in New Hampshire (78).

Optimum stocking may also be considered from the point of view of the rate of interest return on the investment. No attempt has been made to study this question currently. Some light is

thrown on it, however, by an analysis made of the experimental cuttings in 1946-47 using log grades, prices, costs, and taxes prevailing at that time, and 15-year growth records then available (137).

Compound and simple interest earned during 5-, 10-, and 15-year periods (cutting cycles) under sustained yield were computed for each unit. These in turn were related to residual growing stock and the curved values determined (table 18). In this analysis, a residual volume of 3.5 M board-feet (44 square feet of basal area) per acre with a 15-year cutting cycle turned out to be the best investment. Such stands earned at the rate of 4.7 percent simple or 3.6 percent compound interest. A cutting cycle of 15 years was superior to those of 5 and 10 years for most stockings.

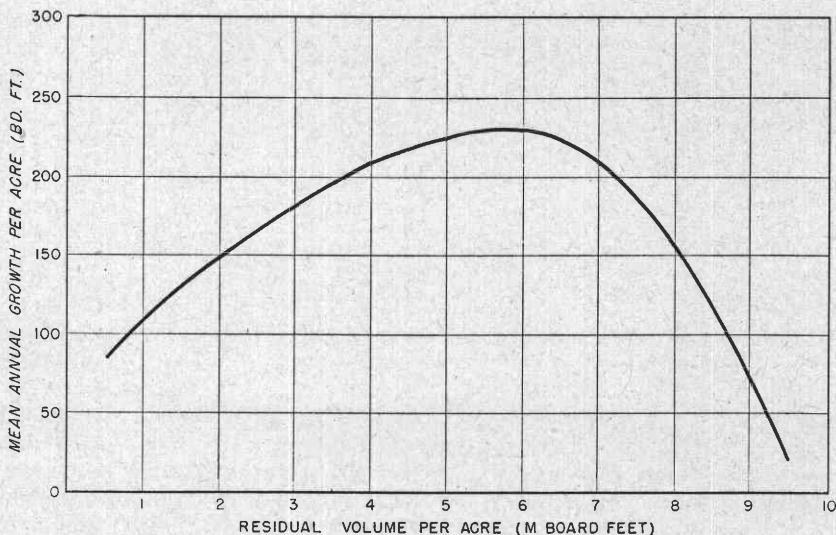


FIGURE 15.—Twenty-year average annual net growth per acre with different residual volumes.

At least 3.0 percent compound interest was earned by residual volumes of from 3.5 to 4.5 M board-feet in trees 10 inches d.b.h. and up per acre, with a 10-year cutting cycle; and by residual volumes of from 2.5 to 5.5 M board-feet with a 15-year cycle. Fixed costs acted to reduce the financial advantage in removing accumulated growth at 5-year intervals. The growth in terms of grades was determined on the basis of the proportions of grades in the total stands, yet growth actually accrued on the perimeter of the trees where the lumber grade is highest. Had this point been considered, the optimum stocking would probably have been calculated a little higher. Optimum stocking for highest interest return is thus seen to be lower than optimum stocking for best growth.

How should the forest manager reconcile these differences? To a certain extent, the answer will be found in the objective of management. Many private companies are concerned with grow-

TABLE 18.—*Return on investment from sustained yield with different residual volumes and cutting cycles*

Residual stand per acre ¹		Interest earned					
		5-year cycle		10-year cycle		15-year cycle	
Volume (Mboard-feet)	Basal area	Com- pound	Simple	Com- pound	Simple	Com- pound	Simple
	<i>Square feet</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
0.5	17	0.0	0.0	0.0	0.0	0.0	0.0
1.0	22	.1	.1	.4	.4	.5	.5
1.5	28	.2	.2	1.0	1.1	1.4	1.5
2.0	32	.4	.4	1.7	2.0	2.4	2.6
2.5	36	.6	.6	2.3	2.8	3.1	3.7
3.0	40	.8	.9	2.8	3.2	3.5	4.5
3.5	44	1.1	1.2	3.0	3.4	3.6	4.7
4.0	48	1.4	1.4	3.1	3.4	3.5	4.6
4.5	52	1.6	1.6	3.0	3.4	3.4	4.3
5.0	56	1.7	1.8	2.9	3.2	3.2	4.0
5.5	60	1.9	2.0	2.8	3.1	3.0	3.7
6.0	64	1.9	2.0	2.5	2.9	2.8	3.3
6.5	68	1.9	2.0	2.3	2.6	2.5	2.9
7.0	74	1.8	1.8	2.0	2.2	2.1	2.4
7.5	80	1.6	1.6	1.7	1.9	1.8	2.0
8.0	88	1.3	1.3	1.3	1.4	1.4	1.5
8.5	99	1.0	1.0	.9	1.0	.9	1.0
9.0	110	.6	.6	.4	.4	.5	.5
9.5	124	.2	.2	.0	.0	.0	.0

¹ Trees 10 inches d.b.h. and larger.

ing the greatest volume of merchantable timber in order to keep expensive plants in operation. Most publicly owned properties will probably be handled to produce high growth. Private timberland owners who have no wood-working establishment may be more concerned with the interest return on the timber itself.

Because the economic study did not give credit for increased value increment on larger trees and there is now a greater spread in grade values than when the study was made, the optimum stocking of 3,500 board-feet for interest earned is probably somewhat low. Since stockings of from 4.5 M board-feet to 5.5 M board-feet are good both from the point of view of interest earned and from the point of view of growth, there is a considerable zone of overlap. This suggests a compromise the forest manager can make if he wants to steer a middle course. Holding in the neighborhood of 5.5 M board-feet (60 square feet of basal area) in trees 10 inches d.b.h. and up per acre will be close to the growth optimum for sites and stands similar to those on the Upper Peninsula Experimental Forest. This volume should also return 3.0 percent compound interest or more with a 10- or 15-year cutting cycle.

For the absolute maximum in interest return, the economic study suggested somewhat lower stockings than the compromise figure given in the preceding paragraph. On the other hand, it should be clearly understood that with lower stockings there may be danger of stand deterioration in condition and quality, and that harvest cuts must be at longer intervals.

No margin of safety in case of high natural losses was taken into consideration in the study. Some such allowance should be provided for prudent management. Therefore, for most private holdings and for public forest areas, a stocking of 65 to 75 square feet of basal area in trees 10 inches d.b.h. and larger is recommended on the basis of present knowledge. The economics of cutting to this level of stocking is now undergoing "pilot plant" testing on a 1,400-acre unit of the Upper Peninsula Experimental Forest.

Stand Structure Required for Continuing Production

The future productivity of a stand of northern hardwoods depends on attaining a total stocking that not only approaches the optimum but also has a suitable distribution of sound trees in the different size classes. The question of how to distribute growing stock by size classes is as important as that of how much to hold. Age is of much less importance here than it is in an even-aged forest of short-lived species. Northern hardwoods reach ages of 200 years or more without necessarily becoming defective.

Most heavy merchantable old-growth stands have an excess of larger trees and plenty of seedlings and saplings, but often a scarcity of trees in the middle size classes. It is the large trees of good quality that provide the profit. To produce them the stand must at all times contain a sufficient number of well-formed, vigorous trees of small and medium sizes, ready to grow into larger diameters.

What is the effect of different kinds of cutting on the size-class pattern? Stand structure, as reflected by basal area immediately after cutting and 20 years hence, has varied a great deal according to treatment in the experiments at Dukes (fig. 16), (43). The old-growth reserve area has changed very little. The light partial cuttings (the 22-Inch Diameter Limit, the Light Improvement, and Heavy Improvement) have gained in saplings, lost in the middle-sized group, and gained in the larger trees. The intermediate cuttings (Overmature and Defective Cuttings Nos. 1 and 2), which left less growing stock, have gained considerably in stocking under 9 inches d.b.h. and generally also in larger trees. The clear cutting has made tremendous gains in small trees but contains no large trees.

Clear cutting and diameter-limit cutting to a low size class generate a type of stand more even than uneven-aged. Moreover, too great a proportion of the stand is in small diameters to represent much quality increment.

The two Overmature and Defective cuttings, taken together, have developed a distribution of size classes that appears likely to continue to produce merchantable timber without any serious lapses.

In terms of board-feet, the light cuttings (22-Inch Diameter Limit and Light Improvement) have made good growth in the larger diameters but have lost in the 10- to 14-inch group—the critical point in stand structure in northern hardwoods in this

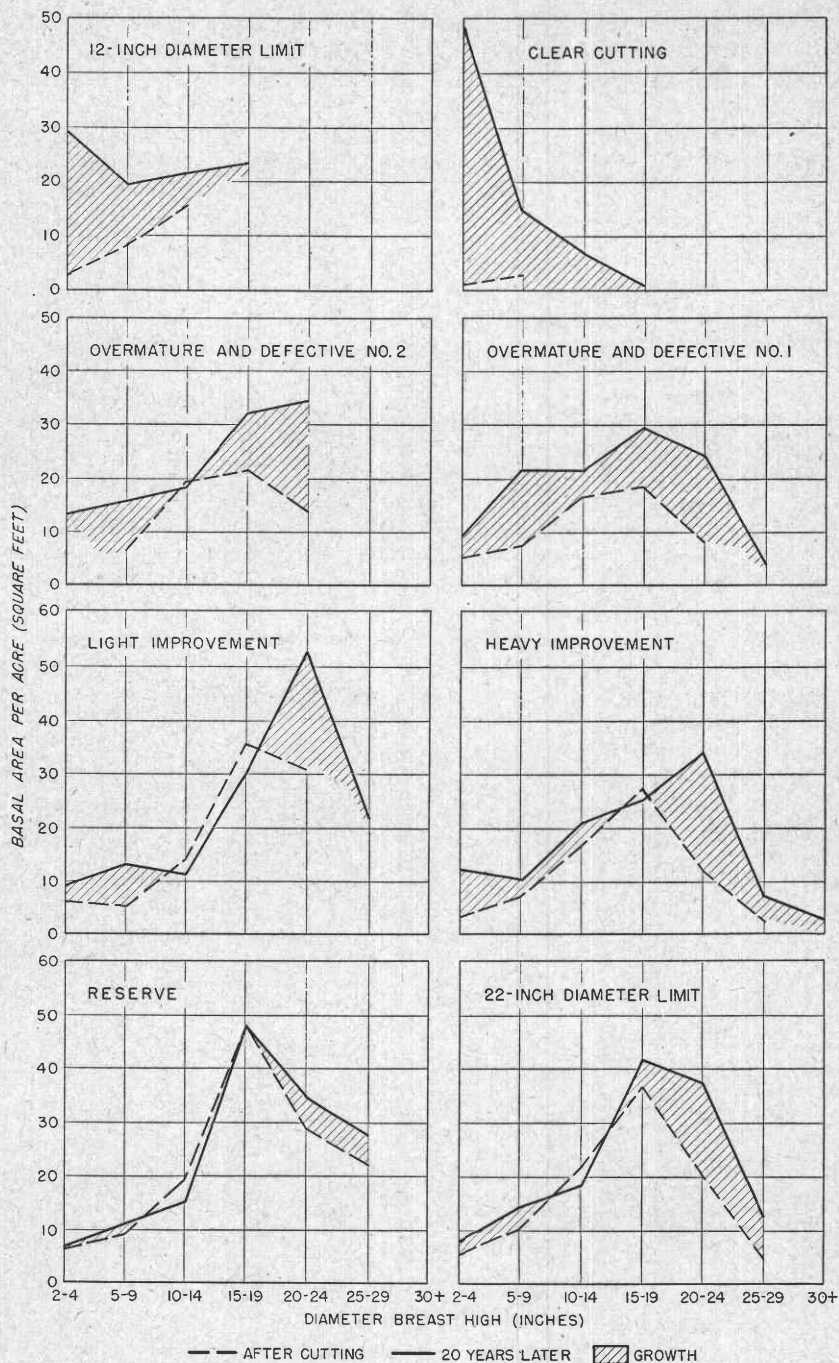


FIGURE 16.—Basal area per acre by diameter groups immediately after cutting and 20 years later on different cutting plots.

locality (figs. 17 and 18). There is likelihood, however, of some future improvement in this respect because of growth of 5- to 9-inch trees but not as much improvement as in the two inter-

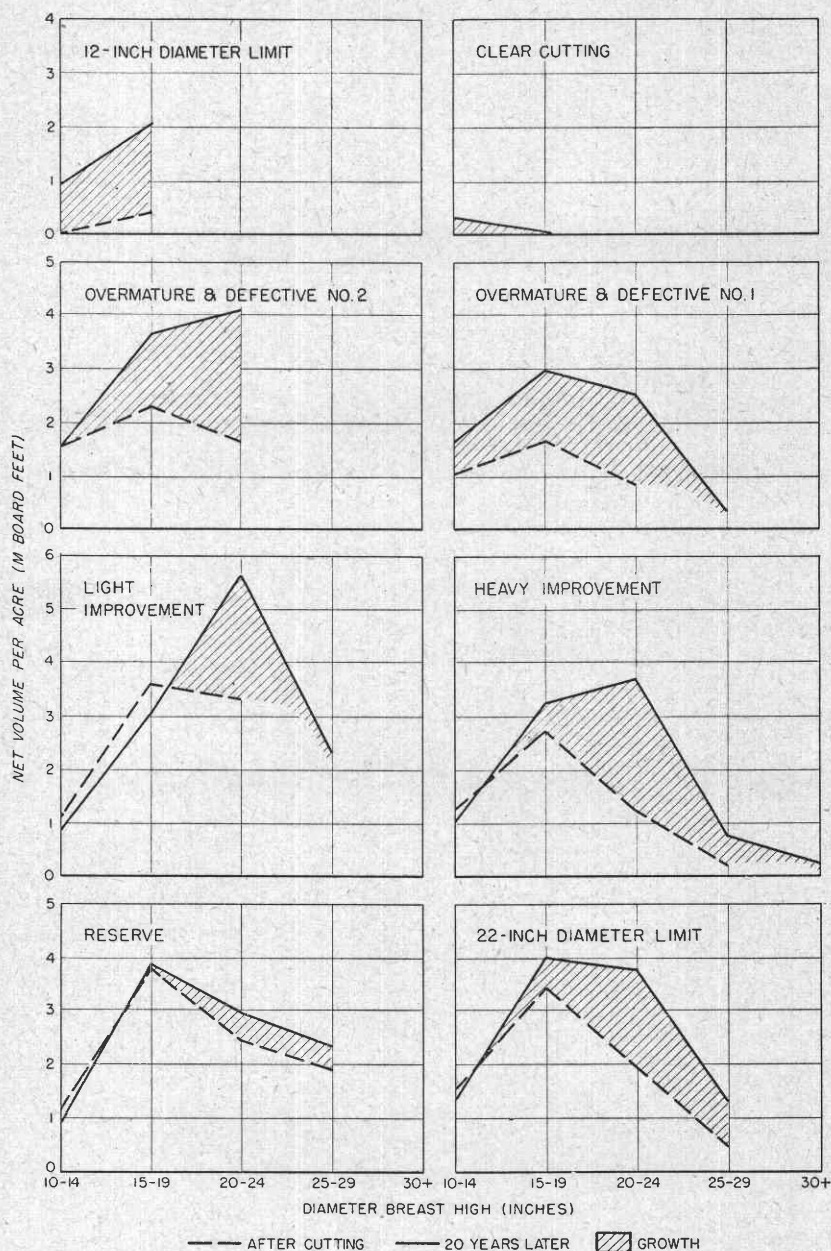


FIGURE 17.—Board-feet per acre by diameter groups immediately after cutting and 20 years later on different cutting plots.

mediate cuttings. The Overmature and Defective (intermediate) cuttings have made excellent board-foot increment—No. 2 the best of any cutting (fig. 17). No. 1, however, seems to have a better size-class distribution of this increment. These stands are still growing rapidly and have not yet reached a point where another cut is needed to stimulate growth.



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FIGURE 18.—Large poles of yellow birch and sugar maple left after partial cutting, Upper Peninsula Experimental Forest. Trees of this size class are usually inadequately represented in old-growth stands.

To qualify as truly desirable growing stock for uneven-aged silviculture, the stocking should be such that will result in satisfactory increment of high-quality material for a given cutting cycle and a size-class distribution that will insure continuous yield. What is the proper proportion of small, intermediate, and

large trees immediately after cutting? The evidence in case histories of stand development just presented provides some clues. The two Overmature and Defective cuttings (figs. 16 and 17) which distributed the cut among all sizes and reduced the growing stocks to about 60 square feet of basal area (10 inches d.b.h. and over) not only maintained the fairly good stand structure provided by nature, but improved it by bringing in size classes not well represented in old growth.

Guided by the average size-class distribution of these two cuttings, the evidence provided by stand development, and their own judgment, the authors drew a basal-area curve representing desirable stocking after cutting (43). The curve of desirable stocking was, in turn, converted into number of trees and basal area per acre (table 19). No trees over 24 inches d.b.h. are included since growing them any larger appears to lack economic justification, as will be explained later.

TABLE 19.—*Desirable stocking per acre for good continuous growth*

Diameter at breast height (inches)	Desirable stand after cutting	
	Trees	Basal area
	Number	Square feet
2.....	118	2.6
3.....	53	2.6
4.....	31	2.7
	202	8
5.....	21	2.9
6.....	15	2.9
7.....	12	3.2
8.....	9	3.1
9.....	8	3.5
	65	16
10.....	7	3.8
11.....	6	4.1
12.....	5	3.9
13.....	5	4.6
14.....	5	5.3
	28	22
15.....	4	4.9
16.....	4	5.6
17.....	3	4.7
18.....	3	5.3
19.....	3	5.9
	17	26
20.....	2	4.4
21.....	2	4.8
22.....	2	5.3
23.....	1	2.9
24.....	1	3.1
	8	20
Total.....	320	92

It is believed that a stand such as represented in table 19 will remain thrifty and if cut at fairly short intervals (8 to 12 years) will maintain good periodic growth on a continuous basis. In any application the figures should, of course, be rounded off. Stand structure and stocking have also been studied in Pennsylvania by Meyer (96), but his recommendations on stocking are believed to be too high for Lake States conditions. Where the cutting cycle is increased to 15 or 20 years, the stocking of larger trees shown in table 19 could probably be safely reduced by about 15 percent.

In stands where the distributional pattern is undesirable and deficiencies exist in one or more size groups, a period of adjustment will be necessary. During this period, a variable cutting cycle may be advisable or it may be necessary to forgo a cut or two. At best it may require concentrating the cut in certain diameter groups until better distribution is attained.

In the case of Overmature and Defective No. 1 cutting in this series, the residual stocking was considerably below the optimum (fig. 19). After 20 years, stocking has increased to a level somewhat above that of the suggested optimum and deficiencies in certain size classes have been made up. It is still close enough to the optimum residual stocking so that good growth can be expected for some years to come. Here, where the residual stocking was reduced considerably below the recommended optimum, the cutting cycle may well be as long as 30 years.

The stocking on Overmature and Defective No. 1 cutting illustrates the flexibility with which the manager of a northern hardwood forest can approach the matter of length of cutting cycle. If it suits his management objectives best and stand conditions permit, he may cut at intervals as short as 5 years. If he so elects, he can reduce his growing stock to a level below the optimum guide and withhold the next logging until stocking exceeds optimum by a substantial margin. Of course, such considerations as rot progression and mortality, growth response following cutting, maintenance of quality, and the advantage of financial returns at shorter intervals place some limit on the degree of cutting and the period during which stocking can build up. Generally the trend is toward shorter cutting cycles as management becomes more intensive.

The guide (table 19) should be useful to anyone handling northern hardwood forests in the Lake States under an uneven-aged form of management. The user should remember that this interim guide was developed in one locality and is based on only 20 years' observations of stand behavior. While it is believed to be fairly reliable, it will no doubt be revised and refined as more data become available.

GROWING QUALITY TIMBER

Individual trees that make up the northern hardwood forest vary a great deal in value, condition, vigor, growth rate, and other characteristics. These features may be referred to collectively as tree quality, of importance in the management of any type, but especially so for hardwoods because of their wide spread in value. One of the chief aims of management in these stands is to replace the poorly formed and defective trees with growing stock of better quality.

What Size of Tree To Grow

In hardwoods, quality is closely related to size. "The bigger they are, the better" is a prevailing philosophy among foresters because it is well understood that the unit value per thousand

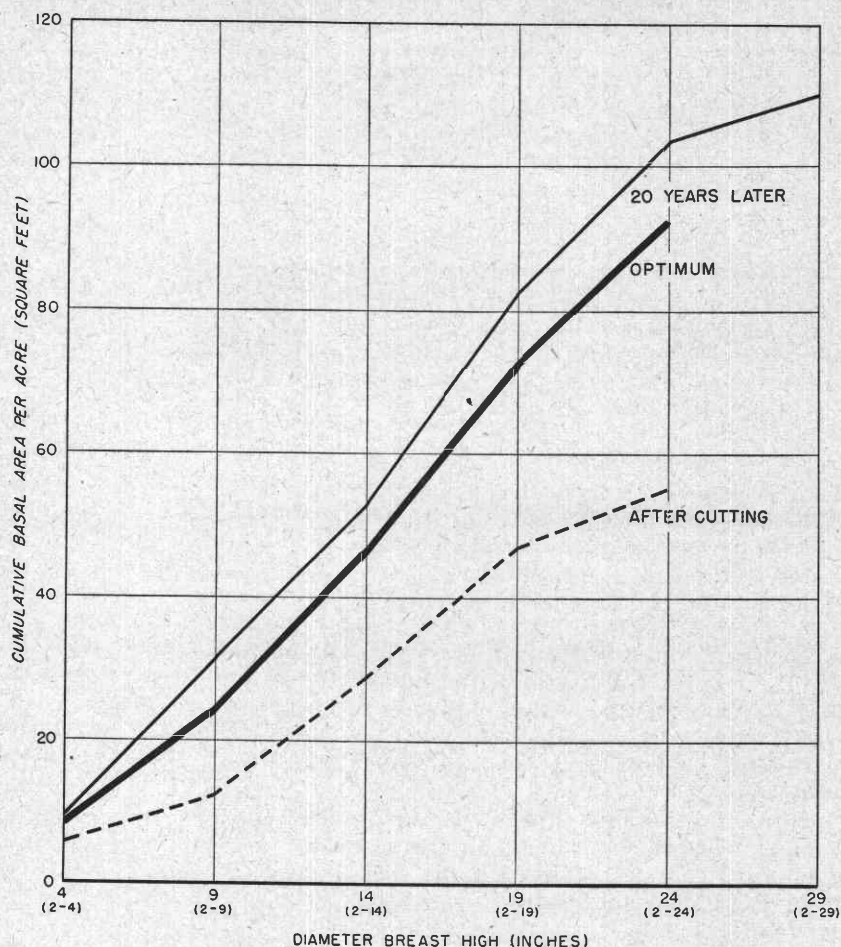


FIGURE 19.—Stocking in cumulative basal area per acre immediately after cutting and 20 years later on Overmature and Defective No. 1 cutting compared with optimum residual stocking.

board-feet of lumber is greater for large trees than for small ones (9, 122). Thus as hardwoods increase in diameter their value increases automatically (42). In fact there is a double benefit because production costs generally decrease as the size of the tree and the logs in it become larger (82, 145). This, of course, does not apply to the greatly oversized tree that is difficult to handle with standard equipment.

A comprehensive study relating tree size of northern hardwoods to value for lumber was published in 1930 (145). Costs and prices have since changed a great deal, but the relationships expressed in grades should be generally applicable today for the kind of timber that was sampled. Lumber grades in this study were much higher in large trees, both sugar maple and yellow birch

(table 20).²¹ The unit value of green lumber (mill scale) from 25-inch sugar maple trees was almost twice that for 9-inch trees, and in yellow birch the spread was greater. Mill-scale studies made at Trout Creek, Mich., in 1942 showed similar trends (46).

TABLE 20.—Percentage yield of lumber in specified grades (green condition), by diameter classes of sugar maple and yellow birch trees (145)

Diameter breast high (inches)	Sugar maple					Yellow birch				
	FAS	Select	No. 1 Com-mon	No. 2 Com-mon	No. 3 Com-mon	FAS	Select	No. 1 Com-mon	No. 2 Com-mon	No. 3 Com-mon
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
9		0.6	8.2	12.3	78.9	0.5	0.5	6.9	24.4	67.7
10		1.2	9.6	13.5	75.7	1.3	1.2	9.0	22.5	66.0
11	0.4	1.7	10.9	14.5	72.5	2.2	1.8	11.1	20.7	64.2
12	.9	2.1	12.3	15.3	69.4	3.1	2.6	13.0	19.4	61.9
13	1.4	2.8	13.7	15.8	66.3	4.0	3.2	14.6	18.3	59.9
14	2.3	3.2	15.1	16.0	63.4	4.8	3.8	15.9	17.5	58.0
15	3.2	3.6	16.4	16.2	60.6	5.7	4.5	16.9	17.1	55.8
16	4.1	4.2	17.7	16.1	57.9	6.6	4.9	18.0	16.8	53.7
17	5.0	4.7	18.8	16.1	55.4	7.4	5.3	18.8	16.6	51.9
18	5.8	5.2	20.3	15.9	52.8	8.3	5.8	19.5	16.7	49.7
19	6.6	5.6	21.8	15.8	50.2	9.2	6.2	20.1	16.7	47.8
20	7.5	6.0	23.1	15.7	47.7	10.0	6.7	20.8	16.8	45.7
21	8.3	6.6	24.3	15.5	45.3	11.0	7.2	21.5	16.9	43.4
22	9.1	7.1	25.5	15.3	43.0	12.1	7.7	22.4	16.9	40.9
23	10.0	7.6	26.6	15.0	40.8	13.3	8.2	23.4	16.9	38.2
24	10.9	8.1	27.6	14.6	38.8	14.5	8.9	24.3	16.9	35.4
25	11.8	8.6	28.7	14.1	36.8	16.2	9.6	25.4	16.9	31.9

When trees of good quality are marketed as veneer logs rather than sawed into lumber, the relationship of size to value is somewhat different. For example, even the top log of a sugar maple tree of 20 inches d.b.h. will meet the minimum size requirements for veneer logs. Any increase beyond that size is, of course, a value increase, but the rate per thousand feet remains the same. However, the willingness of some buyers to accept more defect in veneer grade in the larger logs is of some advantage.

A completely satisfactory basis for determining economic diameter limits to which northern hardwoods should be grown is lacking. Nevertheless, some work on this subject has been done using tree records from experimental cuttings. Engle²² concluded that it was extremely doubtful if sugar maple trees could be grown larger than 19 inches d.b.h. with a 3-percent compound interest return on the investment. His conclusion was based upon the application of log grades with no attempt to carry the calculations through to lumber. The suggested diameter limit was substantiated to some extent by two other considerations: (1) Merchantable height does not increase in trees above 19 inches d.b.h., hence it is futile to hold a tree beyond this size in the hope of getting more logs. (2) Logging costs per thousand board-feet decrease very little in trees over 19 inches.

²¹ This relationship does not hold for hemlock. Lumber from larger trees is no more valuable; in fact, lumber sawn from big trees is sometimes worth less because they have more wind shake.

²² See footnote 20, p. 51.

In an earlier informal study on the basis of the same plot records and considering only log grades, it was concluded that 20 inches is about the economic diameter limit for sugar maple on the experimental area. At that size the top log in an average tree is of veneer size. The investment is high at this stage, and it is impossible to realize as much as 3 percent compound interest by holding the tree longer, since there is only a straight-line rise in value as volume becomes greater.

A later local study explored the economic limit further, using lumber grades instead of log grades. From this it was decided tentatively that 23 inches is about the maximum size that trees in a northern hardwood stand, predominantly sugar maple, could be grown for lumber and continue to earn 3 percent compound interest.²³

The studies referred to here are incomplete and do not fully agree. However, they provide some basis for suggesting that from an economic standpoint (based only on a 3-percent compound interest rate) hardwoods should be grown to a diameter not larger than 23 inches d.b.h. and probably less.

There are, of course, other aspects to consider in deciding on size of timber to grow. One such is volume growth. What growth can be expected in various diameter classes in partially cut northern hardwoods? In term of average annual board-foot growth, differences between size classes have been fairly well defined in certain experimental cuttings, at least for sugar maple. In all cases, growth tended to level off above 22 inches d.b.h. (fig. 13). This tendency indicates that there would be no advantage in growing trees to a larger size so far as volume growth rate is concerned.

If mortality losses were concentrated in certain diameter classes, it would also affect the decision on the size of tree to grow. But, as pointed out earlier, mortality does not seem to be related to diameter.

Obviously there is need for some flexibility in deciding the exact size to grow northern hardwoods because few stands have an ideal size-class distribution. For example, a thrifty 25-inch tree might be occupying a space that could not be utilized promptly by smaller trees, especially those of pole size, which are often deficient in numbers. In this case, it would be reasonable to hold such a tree until a better distribution is achieved.

Considering both the economic and silvicultural evidence, a size limit of 24 inches d.b.h. is tentatively recommended for management under conditions similar to those on the Upper Peninsula Experimental Forest. Neither this nor any other limit will suit all managers or meet all situations. Certain industries with specific product requirements may place special value on material of a given size. On the other hand, a timberland owner without a wood-products plant, governed by no such restriction, will produce material of varied size to fit the open market demand for stumpage or primary products.

²³ Longwood, F. R. Unpublished data, Lake States Forest Experiment Station.

What Kind of Trees To Grow

Much more than the size must be considered in growing hardwood sawtimber. A stand is only as good as the trees in it. The quality and vigor of the individual trees will, to a large extent, dictate the kind of timber that will be grown.

Because hardwood trees in unmanaged stands normally contain much defect, it is often easier to choose the trees for removal than to select those for retention. The great tendency of the marker inexperienced in hardwoods is to cut too heavily because he sees something wrong with every tree. Although the stand contains few perfect trees, there is fortunately a range from good to poor. This range exists not only in value but also in vigor and risk. Trees to be cut do not need to be vigorous but must be of a certain grade or quality to warrant a commercial operation. The better the markets the more flexible is the choice of kinds of trees to cut.

On the other hand, trees to be left must possess a capacity for development into valuable timber in the future. They should be vigorous enough to grow rapidly, have a form suitable for the laying on of merchantable wood, and be sound enough to withstand the elements until the time of the next cutting (fig. 20).

The North Central regional office of the Forest Service devised a tree classification to aid in grading trees. This scheme provides for 10 tree classes which make possible the segregation of trees into value and vigor groupings. The value classification is determined by the grade of the butt log or the first log in the tree above the butt-off section (47).²⁴

In 1941 this classification scheme was applied to five experimental cutting units and the reserve area at Dukes. In 1952 growth for each tree was determined from sample-plot records for two 10-year periods and compared to tree class after reduction to an annual basis. Because the cuttings were established at different times, the dates covered were not the same for all plots. When the groupings took into account both vigor and value, the relationships were inconsistent. Therefore, value classes within each vigor class were combined into an average figure. The resulting figures showed in each case a small but consistent relationship between tree class and diameter growth, indicating clearly that tree vigor can be judged with accuracy (table 21).

Strikingly enough, trees of poorest vigor on the heavily cut plots grew more rapidly than those of best vigor on the uncut reserve and nearly as fast as those of best vigor on the light cuttings. This emphasizes the strong effect of release. Evidently release is fully as important as tree class in its effect on diameter growth. Nonetheless if careful selection is consistently carried out there should ultimately be a genetic improvement in the growing stock.

²⁴ See Appendix for complete details.



F-243132

FIGURE 20.—Sugar maple, 13 inches d.b.h., of desirable form. Upper Peninsula Experimental Forest.

TABLE 21.—Average annual diameter growth by vigor classes of trees 10 inches d.b.h. and up during two periods

Experimental unit	Total basal area ¹	Average annual diameter growth						Trees measured
		First decade			Second decade			
		Good vigor	Medium vigor	Poor vigor	Good vigor	Medium vigor	Poor vigor	
70-percent selection.....	<i>Square feet</i> 49.74	<i>Inch</i> 0.194	<i>Inch</i> 0.178	<i>Inch</i> 0.145	<i>Inch</i> 0.219	<i>Inch</i> 0.207	<i>Inch</i> 0.174	<i>Number</i> 168
Overmature and defective No. 1.....	55.11	.189	.168	.137	.215	.203	.177	78
Heavy improvement.....	68.55	.183	.155	.124	.215	.182	.169	81
Light improvement.....	92.44	.155	.170	.125	.148	.159	.135	51
22-inch diameter limit.....	100.41	.167	.155	.135	.175	.161	.152	199
Reserve.....	134.16	.121	.111	.087	.123	.126	.096	120

¹ At time of plot establishment.² Records on this plot are for 15-year and 5-year periods, respectively. Area cut over second time in 1943.

Effect of Cutting on Quality Change

The question is often raised as to whether timber grown in stands that have been partially cut declines in quality. The chief measure of quality in trees of size merchantable for sawtimber is log grade.²⁵ In order to determine the effect that partial cutting in a mature stand had on log grade, several experimental cuttings were given a special examination 15 years after logging. Little difference was noted between the light and heavy cuttings and the uncut reserve stand except in the percentage of No. 1 grade. This dropped sharply wherever the cutting removed more than two-thirds of the gross volume (table 22). Following heavy cutting, such as the 12-inch diameter limit, there was a definite decrease in quality due to a pronounced lowering of crowns through development of large branches following epicormic sprouting.

Epicormic sprouting, or the formation of "water sprouts" from dormant buds on the main stems of hardwood trees, has long been a matter of concern to foresters. The following tabulation, taken from a tally of residual trees on a 70-percent partial cutting in Upper Michigan 7 years after logging, illustrates what may occur.

Breast-high diameter (inches)	Percent badly stem sprouted	
	Yellow birch	Sugar maple
4.....	31	7
6.....	90	10
8.....	54	2
10.....	19	6
12.....	20	0
14.....	5	0
16.....	22	0

²⁵ See Appendix for outlines of hardwood log grades.

TABLE 22.—*Log grade proportion 15 years after cutting*

Gross volume removed in first cutting (percent)	Log grade proportion					
	No. 1 ¹	No. 2 ¹	No. 3 ¹	Mine timber ²	Chemical wood ³	Total
	Percent	Percent	Percent	Percent	Percent	Percent
0.....	20	40	27	2	11	100
24.....	19	55	19	1	6	100
46.....	27	38	20	6	9	100
62.....	20	39	32	5	4	100
68.....	17	48	22	7	6	100
90.....	4	39	32	17	8	100

¹ Graded to the Office of Price Administration specifications contained in MPR 348, Amendment No. 8, 1944.

² In practice some Grade No. 3 logs would probably be marked for this product. In the study only logs unfit for Grade 3 but still acceptable at the mines were included.

³ Any volume within the merchantable portion of the tree to 8-inch top too poor to make the four better grades.

In this heavy cutting, yellow birch was most seriously affected and sugar maple moderately. A very high proportion of the birches examined showed some stem sprouting. The sprouting on sugar maple was attributed not so much to epicormic shoots as to greatly stimulated growth of small puny branches following release from suppression (128).

An additional measure of the extent of change in tree quality due to stem sprouting following different degrees of cutting was obtained from a study of experimental cuttings in 1942. The clear length was measured on sample trees (mostly sugar maple) and compared with original measurements made some 15 years earlier. Epicormic sprouting in these plots was little greater on the light cutting than on the uncut area (table 23). Rather surprisingly, there was some "feathering" on the uncut reserve plot. This was around openings caused by natural mortality of large trees. The sprouts here were sparse and often confined to one side of the tree. There was a little more sprouting in the moderately cut area than on the light cutting but not so much as to be alarming. Some trees actually increased their clear length. Trees which did not change were in the uncut stand for the most part and in the light cutting, as might be expected. The reduction in clear length was, of course, greatest in the heavy cutting, as was brought out in studies of this question in other localities (71a, 77).

TABLE 23.—*Epicormic sprouting in relation to degree of cutting, approximately 15 years after cutting*

Type of cutting	Proportion of board feet cut	Proportion of trees			Trees measured
		With greater clear length	With no change in clear length	With reduced clear length	
	Percent	Percent	Percent	Percent	Number
No cutting.....	0	10	38	52	58
Light.....	29	15	29	56	68
Moderate.....	62	27	11	62	82
Heavy.....	90	13	5	82	63

It is evident that extreme cutting of northern hardwoods should be avoided wherever high future timber quality is an objective of management. It would appear, though, that moderate partial cuts (up to 50 percent or so of volume) should not increase stem sprouting markedly or lower the log grade if a careful marking job is done with no attempt to "high grade" the stand.

Demand for Birdseye and White Wood

Special wood qualities or characteristics that affect the sale value of sugar maple should be mentioned here. One of these is the birdseye figure formerly in great demand for furniture. In recent years, the demand for birdseye maple has fallen off to such an extent that at present no special effort is made to segregate logs having this characteristic. Just what causes birdseye is not fully understood, but in one small-scale study birdseye was observed to be much more common in logs that had grown under suppressed conditions than in fast-grown logs (71).

White wood or sapwood is another characteristic that influences the value of sugar maple. Logs with a high proportion of sapwood are favored when purchased for special products such as bowling pins. Likewise, lumber cut from sapwood or with sapwood on one side brings a higher price than heartwood lumber.

A study of the width of sapwood in sugar maple trees and of the factors affecting it was conducted in Upper Michigan in 1938 and 1940 (11). There was no relationship to age. The trees that showed the highest rate of diameter growth also had the greatest amount and width of sapwood. This is strong evidence that management of northern hardwood stands for high rates of growth will automatically favor production of sapwood in sugar maple, the predominant species. Since sugar maple loses nothing in strength and specific gravity from rapid growth, there can be little conflict of aims here. A large proportion of sapwood is just another advantage accruing from what forest managers aim for anyway—the most rapid growth possible without opening their stands so much as to cause serious epicormic sprouting and dieback of crowns.

NATURAL REGENERATION

Obtaining regeneration in the northern hardwood forest is a relatively simple matter. Unless the area has been burned, planting or other special methods of establishing new growth are rarely needed. Ample reproduction in the form of advance seedlings and sprouts is usually present. The main problem is how to obtain suitable representation of the various species. The quality of the reproduction must also be considered.

Quality of Reproduction after Partial Cutting

Some foresters and managers of hardwood timber have felt that reproduction following partial cutting is more apt to be

suppressed and misshapen than that resulting from clear cutting. Others have maintained that reproduction in partially cut stands may actually be superior because of the smaller proportion of stump sprouts. In order to obtain some data on which to base an informed opinion, six of the experimental cuttings and the uncut Reserve area were studied in 1948, some 16 to 22 years after the tests were installed (139). All living reproduction of merchantable species 0.6 inch d.b.h. and larger was tallied on randomized strips on the permanent sample plots. Sugar maples made up the larger part of the tally. Each tree was classified on the basis of origin (seedling, seedling-sprout, or sprout), relative position in its age class, form, condition, and clear length (table 24).

TABLE 24.—Percentage of reproduction possessing various attributes, by degree of cutting

Degree of cutting	Attribute					Total trees *
	Good origin ¹	Good position ²	Good form ³	Good condition ⁴	Good clear length ⁵	
	Percent	Percent	Percent	Percent	Percent	Number
100 percent (clear cutting).....	60	58	81	89	64	779
90 percent.....	7	55	85	90	69	613
62 percent.....	76	59	83	97	63	492
46 percent.....	86	73	83	94	62	387
24 percent.....	90	89	85	89	55	253
No cutting (reserve).....	96	82	75	85	55	320
Group selection.....	87	64	77	94	53	565

¹ Seedling or seedling sprout.

² Dominant, codominant, or intermediate.

³ Straight to moderately crooked.

⁴ Vigorous; no rot.

⁵ Free of branches for at least half of length.

⁶ On 0.5 acre each cutting.

In general, the proportion of trees with *good origin* (seedling or seedling-sprout) was greatest on the lighter cuttings. On the heavier cuttings there were more stumps in full light, hence more sprout development. The proportion of trees with *good position* (dominant, codominant, or intermediate) was also greater on the lighter cuttings. This apparently is due to the fact that the fewer trees in the reproduction class have more room and so are less likely to be suppressed. On the clear cutting, many small trees were dying from suppression. The proportion of trees with *good form* and the proportion in *good condition* varied little from cutting to cutting. The Reserve ranked lowest in both attributes.

The proportion of trees with *good clear length* (free of branches for at least half of total height) was rather constant through the heavier cuttings. It fell somewhat in the lightest cutting and the uncut Reserve where there were fewer trees and, hence, fewer trainers. It was low also in the Group Selection cutting where there was more side light because of the openings and where the proportion of yellow birch was greater. Because of the small size

of the trees (approximately 0.6 inch to 4 inches d.b.h.), it is probably unwise to consider clear length as a strong factor in rating them as good or bad. Considering the other attributes together, the proportion of good trees (table 25) increased progressively from clear cutting to light improvement cutting (24 percent of the volume removed). The Reserve area had a lower proportion than the light cutting. The proportion in the Group Selection cutting was also less, which was to be expected for a series of clear-cut openings with little cutting between them.

TABLE 25.—*Number and proportion of good trees (reproduction) per acre*¹

Degree of cutting	Good trees ²	
	Number	Percent of total
100 percent (clear cutting).....	414	27
90 percent.....	420	34
62 percent.....	394	40
46 percent.....	414	53
24 percent.....	310	61
No cutting (reserve).....	340	53
Group selection.....	522	46

¹ Based on tally of reproduction on 0.5 acre in each cutting.

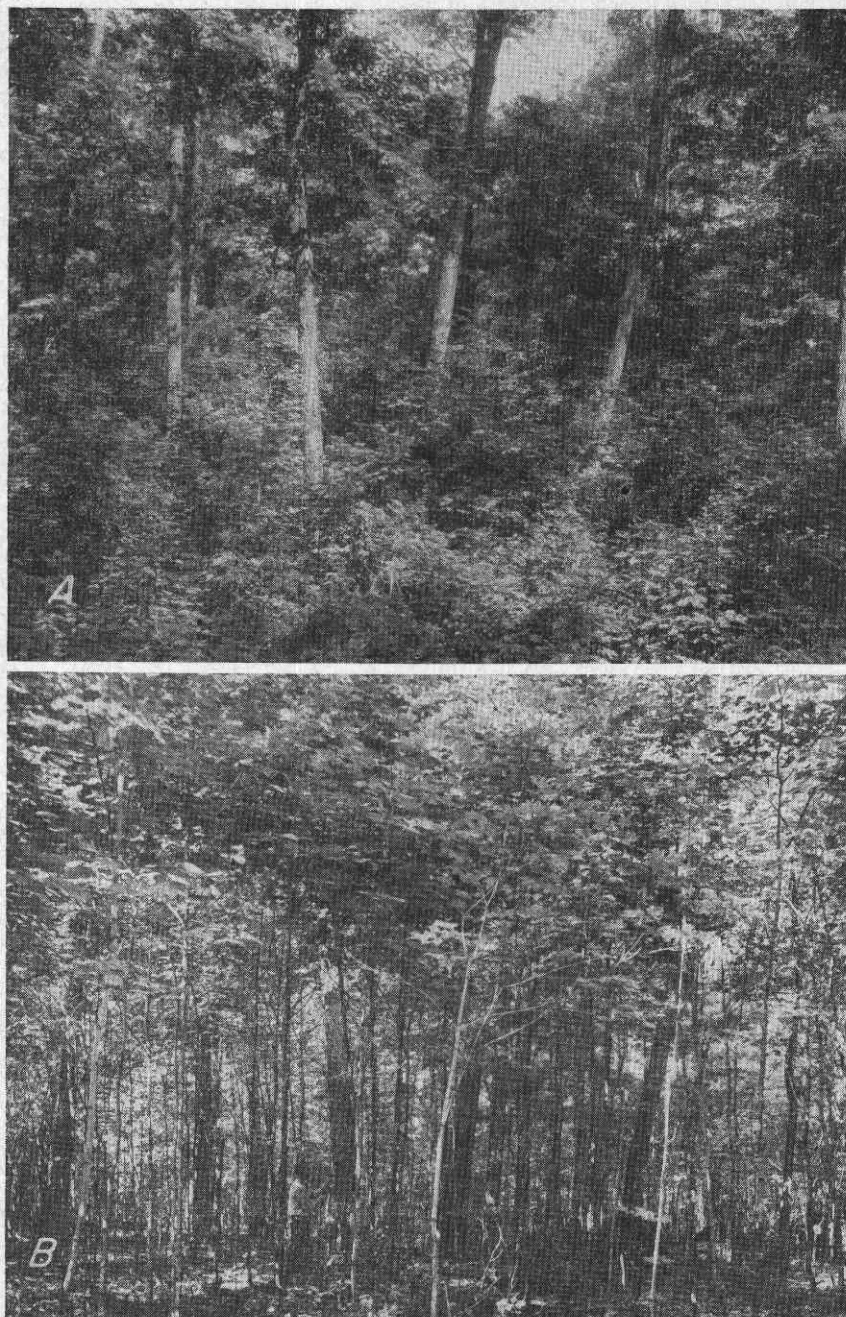
² Seedling or seedling sprout; dominant, codominant, or intermediate; straight to moderately crooked; and vigorous—free of rot.

In number of good trees per acre, there was little difference between the various cuttings (table 25). The number was relatively low in the 24-percent cutting and the Reserve, but high in the Group Selection. In all the cuttings there appeared to be sufficient reproduction of good quality for satisfactory future stands. The partial cuttings seem to be in the strongest position in this respect, since there are fewer poor trees in competition with the good ones.

In this study, reproduction following partial cutting was found to be fully as good as on clear-cut areas. One explanation is that even moderate single-tree selection cuttings tend to be groupwise. Clear cutting of these groups causes openings with sufficient light for satisfactory height and diameter growth in the first few critical years following germination. The openings are small enough, however, to prevent heavy invasion of competing shrubs or excessive sprout development. Fairly dense, even-aged patches of small trees develop, in which there are enough trainers to shade out side branches and promote good form and quality on the dominant individuals.

Special Cutting for Less Tolerant Species

The chief problem in the regeneration of northern hardwoods managed under the selection system is one of composition. Sugar maple is so aggressive and so tolerant that in light partial cuttings it tends to increase its already large proportion at the expense of yellow birch and other more light-demanding species (fig. 21). This was shown in New York in 1920 (91). It is an undesirable



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FIGURE 21.—Dense reproduction of sugar maple. A, Two years after light partial cutting; B, same area 13 years later.

condition because: (1) A stand of mixed species is more resistant to insect and disease attacks than a pure stand, and (2) yellow birch is the most valuable species in the Lake States. It seems desirable to increase rather than decrease the proportion of yellow birch in future stands.

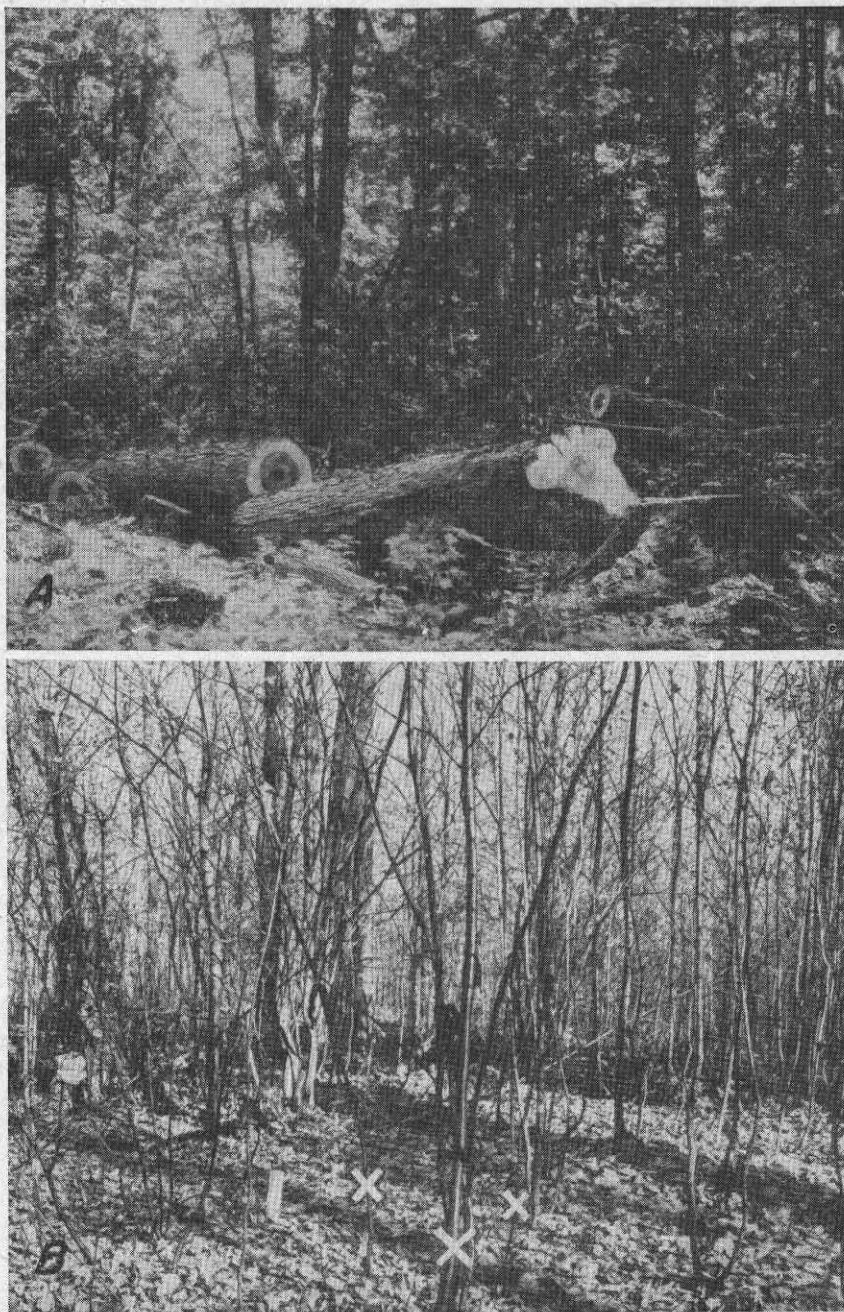
A study was made in 1944 (141) to determine the effect of the various degrees of stand opening on regeneration of yellow birch. Examination of Forest Survey stand tables for the northern hardwood-hemlock type in northern Wisconsin and the Upper Peninsula of Michigan disclosed that yellow birch was holding its proportion following commercial clear cutting in all areas except those classed as restocking (table 26). Reduction of seed trees in the closer utilization of recent years, heavy deer population in spots, and the fact that trees less than 1.0 inch d.b.h. were not tallied in the survey may have accounted for the deficiency in this one class.

On the Upper Peninsula Experimental Forest, reproduction tallies were made of trees from 2.5 feet in height through 3 inches d.b.h. on five units where the cutting varied from 24 to 100 percent. Reproduction of yellow birch was then compared with the total numbers of all species for each cutting. In none of the cuttings did the yellow birch reproduction reach the proportion found in old-growth stands. The proportion, however, was greater in the heavy cuttings than in the light ones.

TABLE 26.—*Relation of yellow birch trees to total stand in various size classes in northern hardwoods*

District	Old-growth sawtimber	Second-growth sawtimber	Cordwood	Restocking
	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
East half, Upper Peninsula, Mich.....	9.2	12.2	8.4	4.2
West half, Upper Peninsula, Mich.....	12.3	11.4	12.0	11.5
Northeastern Wisconsin.....	10.5	7.8	9.9	6.5
Northwestern Wisconsin.....	12.3	13.3	12.1	5.3
Weighted average.....	10.9	11.4	10.7	7.7

Difficulties in reproducing yellow birch had been anticipated from the start of research work on the experimental forest. Hence, the special Group Selection cutting was established in 1929. Tallies made on ten of the openings in the 1944 study (table 27) demonstrated that the special method of cutting increased the proportion of yellow birch in the young stands (fig. 22). In openings less than 0.1 acre in size the proportion was 18.1 percent. In larger openings it was somewhat less, apparently because of the invasion of shrubs such as hazel (*Corylus cornuta*) and scarlet elder (*Sambucus pubens*). Yellow birch undoubtedly seeded in as well in the larger openings but was choked out later by the competing shrubs. The need for partial shade may have been met more successfully in the smaller openings. In all openings on the Group Selection and also in the other cuttings, the larger birch



F-433642

FIGURE 22.—A, Group Selection cutting, 1930. B, Opening in one of groups 15 years after cutting, showing yellow birch reproduction. (Marked with white X).

TABLE 27.—*Reproduction 15 years after cutting by group-selection method: average number of trees per acre 2.5 feet high to 3 inches d.b.h., inclusive*

Size of opening	All species ¹	Yellow birch				Basis, quadrats
		Below 1'' d.b.h.	1'' to 3'' d.b.h.	Total		
	<i>Number</i>	<i>Number</i>	<i>Number</i>	<i>Number</i>	<i>Percent</i>	<i>Number</i>
Less than 0.1 acre.....	5,517	568	433	1,001	18.1	75
0.1 to 0.2 acre.....	7,066	375	302	677	9.6	81
Over 0.2 acre.....	5,567	135	340	475	8.5	109
Average all openings.....	5,996	380	366	746	12.4	265
Between openings.....	2,706	15	0	15	0.6	265

¹ Sugar maple strongly predominated in all cases. No brush species are included in total.

reproduction maintained through 15 years an advantage in height over other species of the same age group.

A reexamination was made of the reproduction in these group-selection cuttings in 1952, 8 years after the first tally and 23 years after the first cutting. This disclosed some decrease in the proportion of birch in the smaller openings—those less than 0.1 acre—but little change in larger openings. The smaller openings, however, still had a greater proportion of birch than the larger ones. The decrease in the smaller openings suggests that release cuttings to favor birch should have been made in the small sapling stage. After 23 years yellow birch had fallen behind sugar maple in height, which is further evidence of the need for release.

In cutting experiments in New Hampshire, yellow birch regeneration has also proved most successful on patch cuttings (50). Environmental studies of the germination and early survival of yellow birch in Quebec by Linteau (83) have further demonstrated the need for restricting the size of opening and preparing a proper seedbed if satisfactory regeneration of the species is to be obtained.

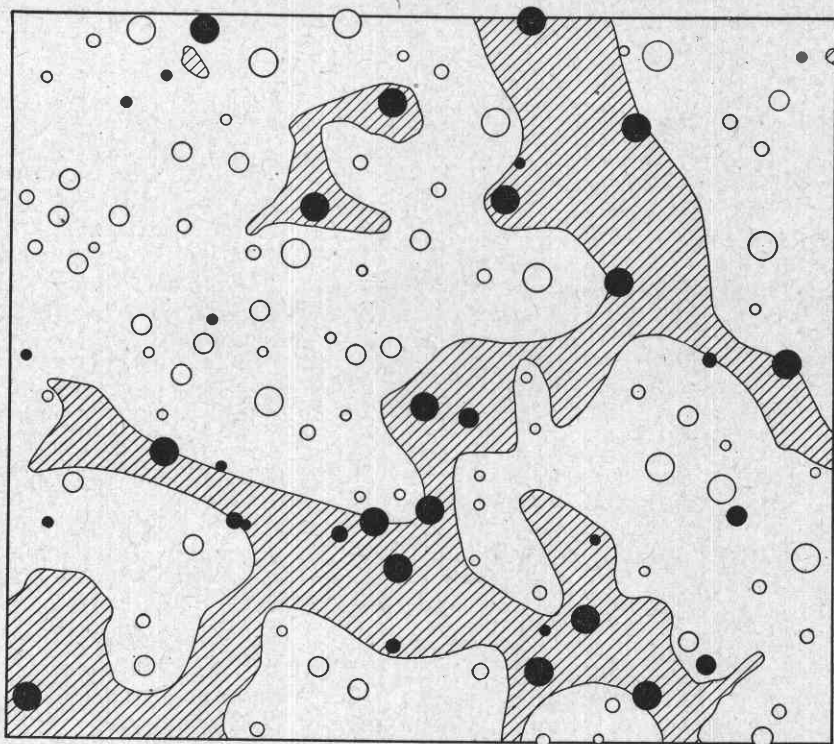
Three requirements seem to be essential to satisfactory yellow birch reproduction under partial cutting: (1) Provisions for sufficient light by creating small openings throughout the stand; (2) assurance of an ample seed supply by leaving seed trees within 300 to 400 feet of openings in dense stands; (3) exposure of mineral soil by logging in the summer or fall when the ground is not covered with deep snow.

American elm, another light-demanding species, and probably basswood, should also benefit whenever these requirements are met.

It has been demonstrated that less-tolerant trees can be regenerated naturally by special group cuttings. Similar results can be accomplished, although perhaps to a somewhat lesser degree, with a modification of moderate individual-tree selection cutting. Such cuttings tend to result in a group- or patch-wise pattern of openings (fig. 23), whether intended originally or not. If seed trees are retained where needed and the usual emphasis

on leaving an unbroken canopy slightly decreased, reproduction of light-demanding species can be stimulated to a certain extent.

The marker can well afford to pay attention to this important aspect of northern hardwood regeneration. It is his responsibility and within his power to maintain a better representation of species than would result from a straight individual tree selection without regard to composition. He can do this rather simply by letting natural openings develop and by leaving seed trees he might otherwise remove. The desired results can be made more certain by logging when the ground is free from deep snow.



LEGEND

- | | |
|---------------------------|---------------------|
| ○ TREES 4.6" - 9.5" DBH | ○ LIVING TREES |
| ○ TREES 9.6" - 14.5" DBH | ● STUMPS |
| ○ TREES 14.6" - 19.5" DBH | ▨ OPENING IN CANOPY |
| ○ TREES 19.6" AND OVER | |

FIGURE 23.—Stem map of a partial cutting in mature northern hardwoods, showing patchy openings in crown canopy.

The possibility of mechanical scarification with disks or other implements should not be overlooked. It has been employed to advantage in reproducing pine in the Lake States and might

prove useful with northern hardwoods in some instances. There may be a place, also, for stand improvement measures in favoring preferred species (see section on timber stand improvement).

SLASH DISPOSAL AND FIRE PROTECTION

The fire problem in northern hardwoods is far less acute than in most other types, but it cannot be ignored. Northern hardwoods will burn, given the proper weather conditions and a spark. Many of the serious forest fires in the Lake States around the turn of the century were attributed to heavy accumulations of slash following logging. It is still an important consideration, but in northern hardwood stands slash is a far lower hazard than it is in pine forests. Special protective measures are required only where hemlock or other conifers are present.

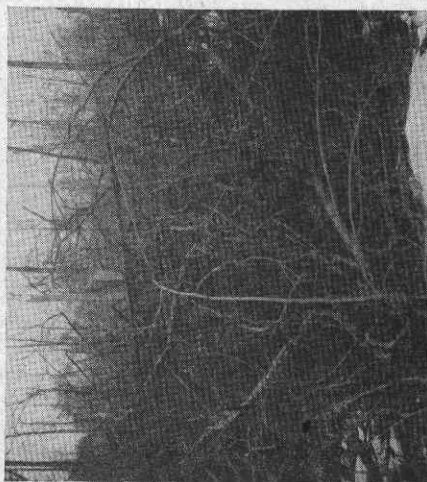
Once started, slash fires in the northern hardwood type are very difficult to control. With so much debris on the ground, as is common after heavy cuttings in northern hardwood stands, fireline construction is a laborious process and the dense fuel holds fire for a long period. The intense heat generated makes close approach difficult and ignites snags which scatter fire. Birch snags, because of their flammable bark, are especially troublesome. Even light surface fires seriously damage young growth and residual trees.

Northern hardwood slash rots in a comparatively short time (fig. 24). Under average conditions small slash of sugar maple, yellow birch, basswood, elm, and beech almost completely disappears in 4 to 7 years after logging. Small slash of white pine and hemlock, when present in the hardwood stands, may still burn after 12 to 15 years. Large material from felled hardwood trees (tops, defective logs, etc.) also long remains a hazard in dry weather. The wood of yellow birch rots somewhat faster than that of sugar maple. On the other hand, yellow birch bark lasts longer. Elm resists decay more than other northern hardwoods. Hemlock remains dangerous in slashings as long as 20 to 30 years (107).

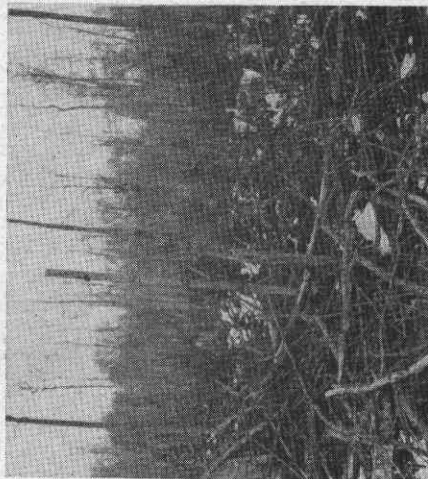
In northern New England, lopped slash was found to decay about as the wood of the several species varied in durability. Some species, especially yellow birch, are liable to waterlogging. When this happens, the rate of decay decreases. The value of slash lopping is questioned (111).

In a Lake States study in 1931, four measures for reducing the fire hazard from slash were listed: (1) Close utilization, (2) selective logging (partial cutting), (3) complete or partial disposal of slash, and (4) special protection for dangerous areas until the slash ceases to be an extra hazard (143).

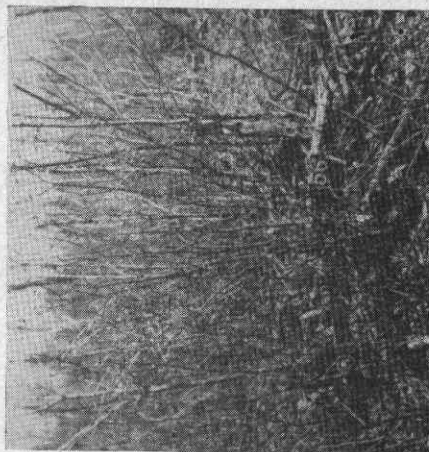
In another report made in 1931, it was observed that partial cutting and close utilization effectively reduce the quantity of slash (table 28). Over four times as much slash accumulated in clear-cut hemlock-hardwood as in pure hardwoods. On hardwood areas without hemlock, the amount of slash increased directly with the degree of cutting, as would be expected (1). Partially



1928



1930



1936

FIGURE 24.—Decay of pile of hardwood slash on the Upper Peninsula Experimental Forest.

TABLE 28.—*Relationship of degree of cutting and intensity of utilization to the quantity of slash (1)*

Type of forest and kind of cutting	Sawlog volume cut per acre	Percent of original sawlog volume cut	Percent of ground covered by slash of various depths				Slash space (depth x area) per acre
			1'-10'	4"-1'	1"-4"	All depths	
Hemlock-maple-birch: ¹	<i>Board feet</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Cubic feet</i>
Selective ² -----	9,040	77	8	13	-----	21	11,540
Clear cut-----	8,594	97	34	7	-----	41	60,740
Maple-birch: ³							
Selective-----	3,505	39	1	4	3	8	2,250
Selective-----	4,523	44	2	5	20	27	4,640
Selective-----	6,773	68	2	10	18	30	5,950
Clear cut-----	10,372	100	4	12	8	24	11,040
Clear cut-----	11,984	100	4	20	8	32	13,360

¹ Sawlogs only were utilized.² Cut was mostly of very large trees.³ Sawlogs and chemical wood utilized.

cut stands are less apt to be a hazard than clear-cut areas because they have much less wind movement and more shade, so that slash dries out slowly.

In view of the relatively low flammability of hardwood timber, rapid decay of hardwood slash, and improved utilization, a fire protection plan for northern hardwoods under management should include the following measures.

1. Reduce slash to as small dimensions as local utilization outlets will permit. Do not pile small slash, but let it lie where it falls. Piling it retards the process of decay and interferes with reproduction.
2. Lop hemlock and other coniferous slash so that it will lie as close to the ground as possible. (On the Experimental Forest at Dukes the maximum accumulation permitted is 30 inches in height.) Utilization of tops for pulpwood usually accomplishes this automatically.
3. Provide for quick fire suppression. This involves:
 - a. A good road system (essential both for protection and for other management activities such as timber removal).
 - b. Lookout towers.
 - c. Adequate equipment (including bulldozers that can push firelines through slash) and a trained organization.
4. Employ special patrols of high-danger areas when burning conditions are critical or when smoke from going fires makes detection of new fires difficult for towermen. Fires in northern hardwoods in flat terrain can often be detected by odor before they are visible to the lookouts.

Slash disposal and fire protection in general are less of a problem in northern hardwoods than in most other types. In that respect the manager of such forests is fortunate. He must not, however, take too much for granted and must allow for emergencies in his plans and in his budget.

HEMLOCK STANDS—A SPECIAL PROBLEM

In the results of studies presented up to this point, hemlock has been given only minor consideration. Yet in many northern hardwood forests in the Lake States, hemlock is one of the principal species and the most important conifer in the type. Here manage-

ment becomes more complex (fig. 25) if hemlock is to be maintained in the mixture and satisfactory regeneration of desirable species obtained.

Although there is a considerable background of ecological information, silvicultural tests with stands containing hemlock have been much less comprehensive than in the maple-birch-beech combination. Nevertheless, by drawing upon information obtained from research and experience, an attempt will be made to illustrate the special nature of the problems of northern hardwood management where hemlock is present in quantity. With full acknowledgment that complete understanding of the subtype is lacking, tentative recommendations for cutting will be given.



F-467830

FIGURE 25.—Stands running heavily to overmature hemlock present a difficult partial-cutting chance. Partial cutting, northeastern Wisconsin, 1941.

Difficulties of Management

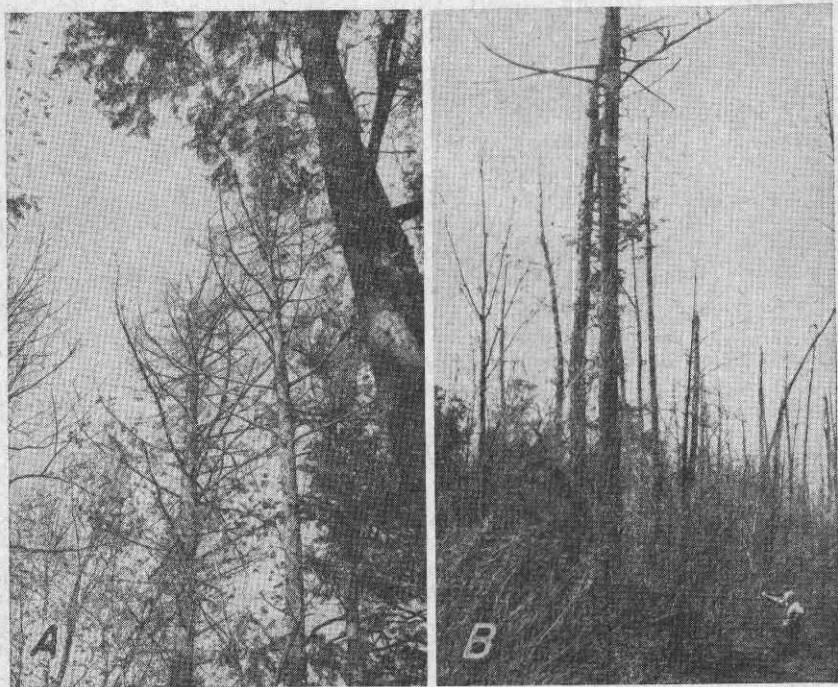
Certain clues explaining the behavior of hemlock and its response to cutting are to be found in the section dealing with "Ecological Position, Reproductive Capacity, and Species Characteristics," the one on "Reduction of Mortality Through Partial Cutting," and in other earlier sections of this bulletin. An evaluation of the basic characteristics of hemlock discloses that it is not a dependable reproducer, is highly sensitive to root disturbance and exposure when the stand is opened, and produces timber of relatively low value.

Hemlock is a preferred wildlife food and excessive deer and snowshoe hare populations have been very important factors in preventing seedlings from developing. It is obviously unwise to

have confidence that a species with such stringent regeneration requirements will continue to be well represented in a managed forest. With high sensitivity to exposure, hemlock will be hard to maintain in any system of partial cutting. Hemlock suffers from drought even in uncut stands (fig. 26, A). For all these reasons, hemlock is difficult to manage. Because of these difficulties there has been an inclination on the part of many practicing foresters not to be concerned about what happened to hemlock.

Past Cutting Experience

Most hemlock stands in the Lake States have been clear cut. After some years of brush and grass, these areas tend to convert to hardwoods, usually with strong representation of red maple and some sugar maple but with yellow birch in skidroads. Sometimes there is a partial understory of balsam fir, hemlock, and occasionally spruce. The grass and brush stage is often quite prolonged; very much so where deer are abundant. Where fire followed logging, aspen and other postfire species have taken over. Generally, there has been heavy loss of merchantable timber following partial cutting (fig. 26, B).



F-467832, 467831

FIGURE 26.—A, Dead hemlock in uncut old-growth stand following drought period. Northeastern Wisconsin, 1941. B, Dead hemlock in heavy partial cutting made approximately 12 years previously and followed by extensive period of drought. A dense growth of hardwood saplings occupies the area. Northeastern Wisconsin, 1941.

One of the earliest partial-cutting projects of record in hemlock-hardwood was begun on an 80-acre tract in northeastern Wisconsin in 1924-25. The stand had numerous hemlocks under sawlog size—many more than is common. About 35 percent of the volume was removed (129). Temporary growth plots established in 1936 on the same 80 acres disclosed good growth and little mortality (33). The stand was given another partial cut in 1936-37. Examination of this same stand in 1941 and again in 1951 showed no mortality of consequence and the stand gave a visual impression of thrift. On adjacent areas, however, either because the timber was more overmature or because of heavier cutting, the mortality has been high, necessitating frequent salvage operations. Reproduction is mostly maple (both red and sugar) with not much yellow birch.

There has been considerable experience in handling hemlock on the Menominee Indian Reservation in Wisconsin. In a statement made immediately after several drought years when mortality was high, it was suggested that cutting should start with the premise that hemlock is going to die and that it will not live under management practice (2).

In a large partial-cutting program in Upper Michigan, more mortality was reported in mixed hemlock-hardwood than in the true hemlock type (39). However, the results were generally satisfactory under both conditions, which is rather surprising in view of the trouble experienced in other parts of the region. The success of these cuttings may be due to their location close to Lake Superior, where the relative humidity is normally higher than at points farther inland.

This is borne out in a check of 198 trees (95 hemlock, 53 yellow birch, and 50 others) along a half-mile compass line on an area of hemlock-hardwood within about 2 miles of Lake Superior near Marquette, Mich. Nearly 70 percent of the stand had been removed in 1944. During the following 6 years only 5 trees in the sample died as a direct result of exposure and shock. Growth in board-feet was four times mortality (86).

Partial-cutting experience in hemlock-hardwood and in hemlock stands on the Upper Peninsula Experimental Forest now extends over 10 years. The first units logged were marked to remove most of the defective and overmature hemlock. At the same time, defective hardwood trees were also selected for cutting. The residual stand declined in vigor and many hemlocks died. Later operations were somewhat more encouraging. In these, the most overmature and defective hemlock trees were cut but removal of hardwood trees was restricted to the very worst individuals—those which could not possibly survive until the next scheduled logging in 10 years. Marking of the trees in this manner left a greater residual stand.

Subsequent mortality of hemlock continued to be fairly high (table 17) but was less in the hardwood-hemlock transition than in pure hemlock. Salvage operations at short intervals have been necessary in both the pure hemlock and in hemlock-hardwood

stands. It seems, however, that removing the hemlock in several operations, although not as advantageous economically as one clear-cutting, gives reproduction of desirable species a better chance for establishment and development.

The light partial cutting has brought in a great deal of red maple reproduction and, to a lesser extent, sugar maple, on a site too wet for best development of the latter. Yellow birch also started prolifically along skid trails where mineral soil was exposed, but where there is much overhead cover it is fast being shaded out (86a). However, where openings are present in the overhead canopy, the birch is pushing ahead and seems likely to succeed. In places, there is also considerable balsam fir and even hemlock. Both are overtopped by the faster growing hardwoods but having great tolerance to shade will probably survive.

Following partial cutting in patches of pure hemlock and in mixed hardwood-hemlock stands throughout the region, the bulk of the reproduction is almost invariably hardwood. The eventual conversion of most of these stands to hardwoods with a much smaller proportion of hemlock in the second growth than in the virgin forest seems inevitable. On moist sites along roadsides or on skid trails where mineral soil has been exposed in logging, some hemlock reproduction and much yellow birch can be observed. In uncut stands hemlock reproduction, when present, is almost always along rotted logs. Following exposure by heavy cutting, patches of advance hemlock reproduction that originated in this manner often die rather quickly.

Hemlock apparently enjoys a more secure position in the northern hardwood forests of the Northeastern States. More and better distributed precipitation probably accounts for this. Merrill and Hawley (95) even thought it possible to convert mixed hardwood-hemlock stands to hemlock in southern New England. They felt that by thinnings and improvement cuttings in the hardwood stand, the hemlock understory could be favored. Eventually the hardwood overstory would be removed, permitting the understory to develop into a pure stand of hemlock.

In the Lake States, advance reproduction of hemlock is rarely present in sufficient quantity to justify attempting such a conversion. However, the fear sometimes expressed that the species will disappear completely seems entirely unfounded. Second-growth stands contain much less hemlock, but it is by no means wiped out and there is a fair prospect that it will stabilize at a much lower level of occurrence than prevailed in the old-growth forest. There is a prospect, too, that younger stands may be less sensitive to exposure and hence easier to handle.

Suggested Cutting Methods

Hemlock at best seems destined to be a subordinate tree among northern hardwoods. Only because of great tolerance to shade and slow but persistent growth during centuries of development in the virgin forest did it become dominant or even an important codominant tree in the stand. Retaining a certain proportion of

hemlock in order to maintain a mixed forest is, however, desirable. What then should be recommended for its treatment? The answer depends first on the condition of the stand and whether it is in mixture with the less sensitive hardwoods.

There is an occasional stand of thrifty hemlock-hardwood and even small patches of fairly pure hemlock having good vigor. Where such exist, light partial cuttings that remove less than one-third of the stand have given promise of success in maintaining a productive forest. Mature stands of hemlock-hardwood, where favored by moist atmosphere along the Great Lakes, also have been handled on a partial-cutting basis with a reasonable degree of success. A protective screen of the more exposure-resistant trees, such as sugar maple, should be left on the south and west sides of the sensitive hemlock (62) wherever possible in partial cuttings.

Attempts to apply selection cuttings to overmature hemlock stands generally have met with little success. There is much likelihood, however, that superior reproduction of the more desirable hardwoods will result if the old hemlock is removed in a series of 4 or 5 light shelterwood cuttings rather than in one clear-cutting operation. Special effort should be made in these cuttings to provide small openings, of particular benefit to the valuable yellow birch which can flourish on hemlock sites. Logging should be done in the summer and fall so as to expose mineral soil and thus provide a good seedbed.

In any hemlock operations other than clear cutting, plans should be made from the start to salvage timber that may die. Logging the residual stands every 3 to 5 years, or even oftener if necessary, should be the normal procedure; otherwise there is much chance of loss. The prospects of conducting salvage operations on an efficient basis are vastly improved now that roads have replaced railroads in Lake States logging.

RECOMMENDED SILVICULTURAL METHODS FOR MATURE HARDWOOD STANDS

Selection System

The selection method of cutting ²⁶ with certain modifications is well suited to mature northern hardwoods of the Lake States (fig. 27). The main elements leading to this conclusion are: (1) The principal species with some exceptions are tolerant to shade and easy to reproduce; (2) the favorable size-class distribution aids materially in placing a property under sustained-yield management under an uneven-aged system; (3) the component species are all long-lived; (4) there is great capacity for growth response following release; (5) since there is a mixture of species and age

²⁶ "Removal of the mature timber, usually the oldest or largest trees, either as single scattered trees or in small groups at relatively short intervals, commonly 5 to 20 years, repeated indefinitely, by means of which the continuous establishment of natural reproduction is encouraged and an uneven-aged stand is maintained" (110).

classes, resistance to insects and diseases is relatively high; (6) there is a strong financial advantage in removing mostly large trees and permitting smaller ones to grow into high-grade products.

The desirable features of the selection method, as applied to northern hardwoods, are now generally recognized in the Lake States. In this connection it is of interest to compare the present recommendations with those made in earlier days. In 1915, Frothingham (53) stated: "The selection method is very well adapted to hardwood forests from a silvicultural but not from a logging point of view. The removal of carefully selected trees uniformly throughout the stand affords an excellent means of controlling the subsequent composition, and insures a sustained yield of increasing quality." He listed several disadvantages of the method, chief among which were: (1) The low value of the first trees removed; (2) the many roads needed and heavy handling charges in logging scattered trees; and (3) the complexity of the system, requiring high-order technical attention. He concluded that the selection system was not yet applicable in this country except when management involves some object other than money returns.

This realistic appraisal of the advantages and disadvantages of the selection system written over 35 years ago shows remarkable insight. The advantages of the selection system remain; most of the disadvantages mentioned have disappeared or diminished with



F-420106

FIGURE 27.—Partial cutting in hardwood-hemlock stand in which 40 per cent of volume was removed. Ottawa National Forest, Michigan, 1942.

developments in the intervening years. Greatly improved opportunities for closer utilization, better road construction machinery, the availability of trucks instead of railroads for hauling (29), and the increased number of foresters on the job to provide technical attention, have all combined largely to dissolve the difficulties that loomed so large in 1915.

In contrast to the selection method, clear cutting (fig. 28) stimulates undesirable sprout growth; may cause invasion of brush, grass, or inferior tree species; increases costs per thousand boardfeet; and prematurely removes many trees just when they are making high-value increment. This type of harvest cutting provides no opportunity for improvement of the genetic characteristics of the future growing stock such as that which could be achieved by retaining superior trees under a selection system. Moreover, use of this method accentuates the difficulty of placing a property of old-growth forest under management. To bring about continuous yield would necessitate holding certain tracts containing fairly heavy stands of overmature timber for the greater part of a rotation, during which time there would be high mortality and little or no growth. On the other hand, clear cutting of small areas of highly defective timber may be the only feasible method to apply. It also favors the light-demanding species.

Modifications To Favor Yellow Birch

It should be recognized that the more light-demanding species do not reproduce effectively under the selection method. Especially is this true of yellow birch, the most valuable tree in the northern hardwood forest. In order to establish yellow birch, application of the group-selection method is advocated whereby the mature timber is removed in small groups rather than by single trees. Openings of about 0.1 acre in size should be created within seeding distance of seed trees. Logging when snow is absent or light will stir up the ground, thus providing a more favorable seedbed. It seems probable that mechanical scarification by disks or other equipment would also be beneficial. Once birch is established, release cuttings may be necessary to make sure it does not become crowded out by sugar maple. American elm will profit by similar practices.

It is not the intention here to recommend the group-selection method indiscriminately, but only where suitable conditions prevail. For example, where there are defective maples close to yellow birches that could be left as seed trees, the single-tree selection system could well be modified to create a group opening by removing the maples and leaving the birches.

Stands running heavily to overmature hemlock constitute a particularly difficult problem. In such stands yellow birch is a close associate of hemlock. Both the hemlock and birch are very sensitive to exposure, and partial cuttings have not been very successful. In this subtype, the selection system is not advocated. Although good experimental proof is lacking, there is considerable



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FIGURE 28.—Commercial clear cutting of northern hardwoods near Eagle River, Wis. 1939.

evidence that better reproduction will occur if the old stand is removed in several shelterwood cuttings.

Marking Under the Selection System

In marking northern hardwood timber for cutting under the selection method it is necessary to consider cutting cycles, stocking levels, age-class distribution, and the potential of the trees to be retained in terms of risk and growth. Northern hardwoods vary considerably from acre to acre and section to section. Individual property owners may have special objectives or be subject to extraordinary pressures. Accordingly, it is not possible to prescribe rules that can be applied indiscriminately to all stands and situations. The following flexible guides, however, should prove helpful.

The cutting cycle should be short enough to prevent excessive decay started by old logging wounds and long enough to accumulate an operable volume. Cutting cycles, however, should be adjusted to particular market and other situations. Obviously, growing stock should not be allowed to increase to a point where growth stagnation and excessive defect will occur. On the other hand, extremely short cycles are not economically sound in most cases. A cutting cycle of from 8 to 12 years should be effective on the average with the increasing accessibility of Lake States timber.

Because of the importance of obtaining desirable stocking, mature northern hardwood stands should be marked so as to

leave from 65 to 75 square feet of basal area per acre in trees 10 inches d.b.h. and over for a cutting cycle of approximately 10 years. For sites similar to the Upper Peninsula Experimental Forest, this will mean leaving a residual volume of from 6,000 to 7,000 board-feet, Scribner, and more on better sites.

The size-class distribution presented below should be employed as a rough guide towards which to mold the stands.

<i>Diameter group (inches)</i>	<i>Trees per acre (number)</i>	<i>Basal area (square feet)</i>
2-4.....	202	8 } 24
5-9.....	65	16 }
10-14.....	28	22 }
15-19.....	17	26 } 68
20-up.....	8	20 }
Total.....	320	92

The suggested stocking goals may not be reached on a given property until one or several cuttings correct any faulty distribution of size classes, excessive irregularities of spacing, and poor tree condition. In the first marking, most good trees may have to be retained regardless of size or position. The same may be true for several additional cuts. Although as many undesirable trees as possible should be removed, some must be retained temporarily in order to prevent excessively large openings.

The stocking and size-class distribution goals should be attained as soon as distribution and tree condition in the stands permit. Some temporary overcutting of growth may be required to reduce heavy stockings to the level of best growth. Within the suggested controls of stocking and age-class distribution, future quality of the stand should be the main guide in deciding what trees to cut or leave. The best quality trees should be retained wherever possible. The defective ones and those of high risk or low growth potential should be removed from all diameter classes wherever markets permit (fig. 29).

In marking, many individuals have found the tree classification (47) developed by the North Central Region of the U. S. Forest Service to be of help, particularly in training new men. (See Appendix for details.) Whether or not marking is according to a specific system of tree classes such as that mentioned, there must be a conscious effort constantly to improve stand condition. As the general level of quality in northern hardwood stands rises, so also will the chances for good volume growth and satisfactory financial return improve.

TREATMENT OF SECOND GROWTH

CHARACTERISTICS OF SECOND-GROWTH STANDS

Second-growth northern hardwoods differ somewhat from virgin forest or old-growth stands that have undergone a light to moderate partial cutting. Old-growth timber tends to be all-aged and has a fairly desirable distribution of size classes suitable for



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FIGURE 29.—Partial cutting operation, Nicolet National Forest, 1943. Approximately 35 percent of volume has been removed.

an uneven-aged type of management. Second-growth stands may or may not have such a distribution. In the absence of fire, the character and condition of second-growth stands depend largely on how the preceding stand was cut (15).

Large-scale lumbering of hardwoods in the northern portion of the Lake States got under way about the time pine logging began to taper off. During the earlier hardwood operations, cutting was less heavy than it was later. Many large trees considered then to be unmerchantable were left standing, as well as large poletimber. Such operations did not disturb the uneven-aged character of the forest as much as later heavier cuttings, although they did remove the best quality trees. After a period of 35 to 40 years, stands so treated have again become merchantable and are commonly referred to as second-growth sawtimber. Actually they consist of a remnant of large trees from the original stand, some of which are wholly unmerchantable, a sprinkling of small sawlog trees that were of pole size at the time of the original cutting, and a wealth of small trees that have come in since logging or were present as small seedlings or saplings at that time.

Stands cut heavily in the logging of the old forest are now essentially even-aged second-growth (fig. 30). Most are still quite young and unmerchantable, but some are fairly well advanced in age. Good illustrations of the latter are those originating from the old clear-cuttings for charcoal in Upper Michigan and in northern Wisconsin where all trees down to small cordwood size

were cut. One such stand near Munising, Mich., cut over 60 years ago, was studied recently. The diameter distribution of this stand is characteristic of an even-aged forest and differs greatly from an uneven-aged stand where the old cutting was less drastic (fig. 31). Stands originating from absolute clear cuttings are of good quality and contain a fair proportion of stems of seedling origin, many of which were present as advance reproduction prior to logging. They have, however, taken a long time to grow to small sawtimber size.

Two stands which more or less exemplify the two conditions just described have been under observation on the Upper Peninsula Experimental Forest for 20 years (table 29). In stand No. 1 all trees down to small cordwood size were cut. In stand No. 2 only the sawlog trees above 12 inches d.b.h. were removed. The stand cut only for sawlogs has grown very well and in another 10 years will have a fairly good stocking of sawlog-size trees but will leave much to be desired as to quality of timber. The small-diameter trees will probably thin themselves to some extent. This stand can undoubtedly be handled by uneven-aged management if in future cuttings a real effort is made to create a good spread in size classes.

These two stands in their state 20 years after cutting are compared with the previously recommended stocking in number of trees for continuous management in the following tabulation.

<i>Diameter group (inches)</i>	<i>Recommended stocking (after cutting)</i>	<i>Stand No. 1 (complete clear-cutting)</i>	<i>Stand No. 2 ("commercial" clear-cutting)</i>
2-4.....	202	1,224.0	852.0
5-9.....	65	78.0	82.5
10-14.....	28	10.0	29.0
15-19.....	17	.5	16.0
20-24.....	8		

This illustrates further that stand No. 2 can be handled under uneven-aged management, since it is deficient only in the very largest sizes. The heavier clear cutting (stand No. 1), on the other hand, after 20 years is no more than small cordwood and has a much more even-aged pattern.

By and large, most second-growth stands fall between these extremes. Generally they are still too recently logged to have much sawlog material but they have good volumes of cordwood. They are neither wholly even-aged nor all-aged, but have elements of both kinds of forests. How they develop in the future will depend on how timber stand improvement measures and intermediate cuttings are applied.

Besides differences in size and age-class pattern, second-growth stands also differ from old-growth in their proportion of the different species (table 30). Sugar maple, the key tree, holds its own in all size classes. Yellow birch tends to fall off in the reproduction class but is almost equally represented with other species in the second-growth sawtimber and poletimber. Elm and basswood both increase, the latter by prolific sprouting,



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FIGURE 30.—Even-aged stand of northern hardwoods 25 years after clear cutting. Upper Peninsula Experimental Forest, 1944.

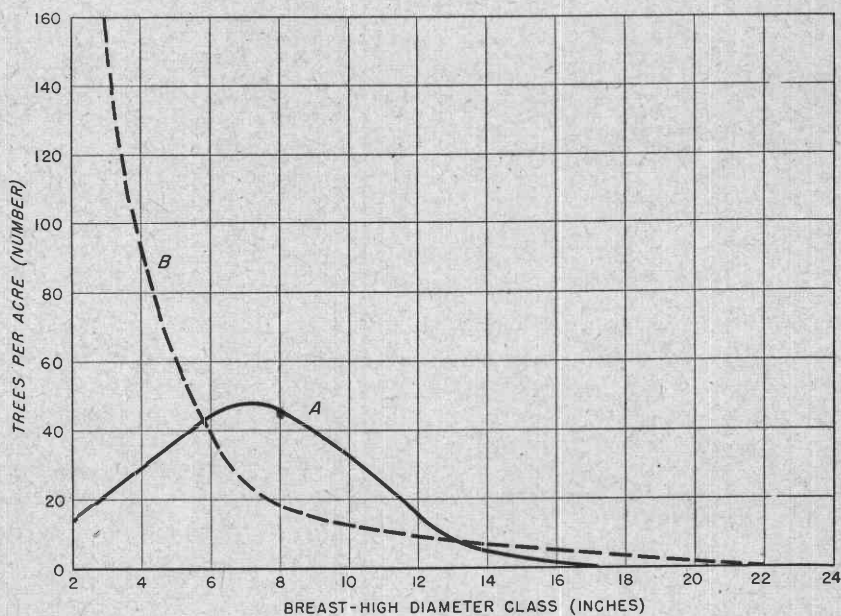


FIGURE 31.—Number of trees per acre of two second-growth stands: A, Even-aged stand 60 years after clear cutting for charcoal; B, uneven-aged stand 35 years after a sawlog operation.

TABLE 29.—Stand and stock table per acre for two clear-cuttings immediately after cutting and 20 years later

Diameter group (inches)	Clear-cutting for sawlogs, mine timbers, and chemical wood				"Commercial", clear-cutting for sawlogs only			
	1927			Net volume	1927			Net volume
	Trees	Basal area	Trees		Basal area	Trees	Basal area	
2-4	Number 20.5	Square feet 0.95	Board-feet ---	Net volume ---	Number 1,224.0	Square feet 48.65	Board-feet ---	Net volume ---
5-9	Number 12.0	Square feet 2.61	Board-feet ---	Net volume ---	Number 78.0	Square feet 14.33	Board-feet ---	Net volume ---
10-14	Number 0	Square feet 0	Board-feet 0	Net volume ---	Number 10.0	Square feet 6.94	Board-feet ---	Net volume ---
15-19	Number 0	Square feet 0	Board-feet 0	Net volume ---	Number 5.5	Square feet .61	Board-feet 55	Net volume ---
Total	32.5	3.56	---	389	1,312.5	70.53	---	---

TABLE 30.—*Species composition of different condition classes, northern hardwood type, northeastern Wisconsin*¹

Species	Large sawtimber	Small sawtimber	Poletimber	Repro- duction
	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Sugar maple.....	25.9	24.2	26.7	24.9
Hemlock.....	28.6	16.8	14.0	6.0
Yellow birch.....	10.6	8.0	9.7	6.3
Basswood.....	7.4	7.1	10.1	10.9
Beech.....	5.4	1.6	.3	.4
Elm.....	5.9	8.1	10.8	13.0
Oak.....	.7	2.9	.7	2.7
Aspen.....	.6	1.7	2.4	14.5
Miscellaneous conifers.....	4.8	12.6	8.2	4.5
Miscellaneous hardwoods.....	10.1	17.0	17.1	16.8
All species.....	100.0	100.0	100.0	100.0

¹ Based on number of trees 3.0 inches and larger except for reproduction, which includes smaller trees.

² Mostly balsam fir.

Source: 1936 Forest Survey data.

while hemlock decreases very sharply. White pine is almost absent. There is more aspen, but it is a temporary component and is likely soon to be crowded out by the more shade-tolerant and longer-lived sugar maple. Second-growth stands usually have a greater proportion of stems of sprout origin than do old-growth stands, especially where the cutting has been heavy.

TIMBER STAND IMPROVEMENT

Second-growth stands of northern hardwoods in the Lake States give promise of producing heavy volumes of timber in the future, but many are deficient as to quality. Unmerchantable trees held over from the original stand, wolf trees of undesirable character, and too great a preponderance of red maple, aspen, hophornbeam, and pin cherry are undesirable features. Trees of all sizes may be of poor form, or infected with decay induced by logging injury, sunscald, or other causes. Cull due to poor form and pathological infection has been reported to average about 17 percent in 30- to 40-year-old Allegheny northern hardwoods (73). It is probably fully as high in the Lake States. In mixture with the defective trees, however, is usually an ample supply of trees of good quality and desirable species. For best development these need care and attention.

To produce timber of high value, efforts must be made over a long period to improve the quality of second growth. Investment of labor in cleaning (weeding) and thinning small sapling stands, girdling of undesirable trees of larger size, and pruning are some of the stand-improvement measures that are frequently advocated. All involve a cash outlay because there is no return in salable products.

A stand that is considerably mixed can of course be improved in composition by favoring the more desirable species in a cleaning operation. The relative desirability, in descending order, of species

for longtime management on soils suitable for northern hardwoods is as follows.

<i>Desirable</i>	<i>Less desirable</i>	<i>Least desirable</i>
Yellow birch	American elm ¹	Eastern hophornbeam
Basswood	Eastern hemlock	Quaking aspen
Sugar maple	Balsam fir	Bigtooth aspen
Rock elm	Beech ¹	Pin cherry
White spruce	Paper birch	
Northern red oak	Red maple ¹	
White ash		

¹ In some localities, American elm is considered very desirable; beech and red maple undesirable.

Sugar maple is nearly always abundant in sapling stands and tends to outnumber other trees. While it is a desirable species, a mixture of other trees should be encouraged. Therefore, to favor other desirable species in cleaning operations, it is necessary to discriminate against sugar maple to some extent. Cleaning of this sort must be done while stands are quite young, preferably before they are 10 years old.

Thinning dense sapling stands to improve form and increase growth rate of the best trees is another stand-improvement measure that has been tried and sometimes advocated. Stoeckeler and Arbogast (121) reported on experimental stand-improvement work in northeastern Wisconsin 8 years after treatment of an 11-year-old stand composed of sugar maple, American elm, white ash, and basswood. The site was good. For the sake of economy in thinning, only a certain number of crop trees were selected and other nearby trees were cut. Thinning was to radii of 2.5 feet and 5 feet. They concluded that thinning to about a 4-foot radius would have been suitable in the treated stands, which averaged about 2.0 inches d.b.h. Of the crop trees selected, 79 percent were still satisfactory 8 years later. Sugar maple responded best, but basswood benefited greatly by thinning sprout clumps down to three stems (fig. 32).

In the Southern Appalachians, similar thinning and release of young sugar maple gave good response (32). Favorable growth reaction is reported for early weeding of Allegheny northern hardwoods (102).

Thinning to radii of 2 to 6 feet in a 16-year-old stand composed of sugar maple, red maple, and aspen on a medium site in the Upper Peninsula Experimental Forest was less successful. Five years later it appeared that so many of the crop trees selected had dropped back to subordinate positions as to throw doubt on the desirability of the operation. The heavier thinning also caused some undesirable spreading out of limbs which, although shaded out later, slowed the early natural pruning. Exposed trees were often sunscalded.

Removal of aspen and pin cherry overtopping tolerant hardwoods has also been tried. Elimination of the aspen improved the growth of the understory sugar maple, but the benefit was insufficient to warrant the expense. Any such work should be deferred until the aspen is of sufficient size to sell as pulpwood (38). Re-



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FIGURE 32.—Nineteen-year-old basswood sprouts, Nicolet National Forest, Wisconsin, 1947. A, Clump of unthinned sprouts; B, Clump of sprouts that had been thinned to 3 stems 8 years previously.

removal of pin cherry overtopping sugar maple was found to be unnecessary. The cherry does not cast enough shade to slow down the maple appreciably; after a few years it dies out and ceases to interfere (85). Results in New England were similar (78).

Cutting wolf trees or killing them by girdling or by other methods is clearly of benefit to reproduction and sapling stands of northern hardwoods. In Wisconsin, growth response of young hardwoods released from overtopping wolf trees was found to be very striking. A single wolf tree 15 inches in diameter had suppressed young trees within a 15-foot radius. Some 95 percent of the trees girdled by ax died in 8 years. Most of them disintegrated gradually, doing no damage to the understory as they came down (121). Girdling has also proved beneficial in Vermont (80).

In a 300-tree test on the Upper Peninsula Experimental Forest, 90 percent of the trees died in 5 years, but 2 percent were still alive at the end of 12 years (37). In Quebec, excellent 10-year results were obtained from girdling an overstory of northern hardwood wolf trees and thinning the understory. Rather complete removal of overstory trees benefited saplings of yellow birch and sugar maple more than less drastic treatment (88). Mowing of misshapen seedlings to create straight seedling sprouts in a test in Vermont increased the proportion of well-formed stems but was considered uneconomical because there was originally an ample number of stems of good form (80).

Removal of wolf trees by felling does considerable damage to young growth; girdling or chemical killing may be a better method (3). Trees that die more slowly tend to come down a piece at a

time and usually damage the understory less. Ax girdling may be done by cutting a notch around the stem, by strip peeling a band of bark, or by hacking (frilling) one or two rings around the trunk. Notching, though highly effective in killing the tree, is costly. The peeling method works well only during the bark-slipping period. Hacking is sometimes used as a substitute for other hand methods (130).

Experiments in treating northern hardwoods, under way in several localities, indicate that the use of various chemicals may be a cheaper way of deadening undesirable trees. Among the chemicals being tried are ammonium sulfamate applied as crystals in cups or frills cut with an ax; hormone sprays such as 2, 4-D and 2, 4, 5,-T sprayed in ax frills or on the base of trees in emulsions of fuel oil; and sodium arsenite applied in solution to ax frills (105b) or in drilled holes. The latter chemical is poisonous to mammals so that extreme care must be used in its application. Girdling with a power saw may possibly be much more economical than doing the work with hand tools, or even with chemicals (121a).

Where the recently improved markets for short-length bolts are available or where fuel wood or chemical wood can be sold, many wolf trees can be removed at no net cost, or even at a small profit. But some are likely to be too defective or too rough for any economical utilization, and they hang on for a long time. Killing them is likely to be as worth while as any other stand-improvement measure requiring a cash outlay.

Pruning of young hardwoods in order to develop clear timber at a shorter interval than would be possible in natural stands has been suggested as a worthwhile stand-improvement measure. With the great premium on veneer quality over the ordinary woods run of hardwood logs, the advantage would be great indeed if pruning works out in practice. Pruning of pine is an accepted measure and if properly done the risk of infection with decay is not great. Hardwood pruning, however, entails much greater risks from this source. It should be safer from an infection standpoint to prune small limbs than large ones. Pruning after formation of heartwood would be more risky than when only sapwood is present. Generally pruning should be confined to limbs under 1½ inches (87).

Moss (97) gives information on costs and methods of hardwood pruning in Connecticut. He advocates use of a ladder and hand saw rather than a pole saw. He cautions against pruning limbs over 2 inches in diameter both because of labor costs and risks due to exposure to fungi. European practice is to prune oak (90), which is not highly subject to rot infection. Other hardwoods are not ordinarily pruned.

Healing of pruning scars varied greatly by species in 8-year results of a pruning test on the Nicolet National Forest. White ash healed most rapidly, followed by American elm and sugar maple. Basswood was a poor fourth (121). Recent observations elsewhere in Wisconsin of basswood pruned in 1937 and 1938 give evidence of good healing of branch scars. Yellow birch, the

highest value veneer species in the region, was not included in the Nicolet test, but a small test on it was established on the Upper Peninsula Experimental Forest in 1946. After 5 years the knots under 1 inch in diameter had healed over but larger ones had not.

These pruning tests are inconclusive because the decay factor has not been evaluated. Sections of pruned trees of the several species should be studied by a competent forest pathologist before sound recommendations for pruning northern hardwoods can be made.

POSSIBILITIES OF COMMERCIAL THINNINGS AND IMPROVEMENT CUTTINGS

With the improvement of markets for hardwood pulpwood, which is generally expected to occur, there should be opportunities for commercial thinnings in second-growth stands. Currently the possibilities for such thinning are confined to the few localities where the products can be sold for chemical wood or pulpwood. The fuelwood market is too limited to have much significance.

Lake States thinning experience in stands of commercial size is lacking, but 40-year-old Allegheny northern hardwoods—especially sugar and red maple and beech—responded well to thinnings which removed 38 percent of the volume. Yellow birch required protection from sudden exposure and did not profit by the thinning as did maple. The larger trees reacted best in these tests (76). Commercial thinnings in hardwoods are now being started experimentally on the Argonne Experimental Forest in Wisconsin and are planned for the Upper Peninsula Experimental Forest in Michigan.

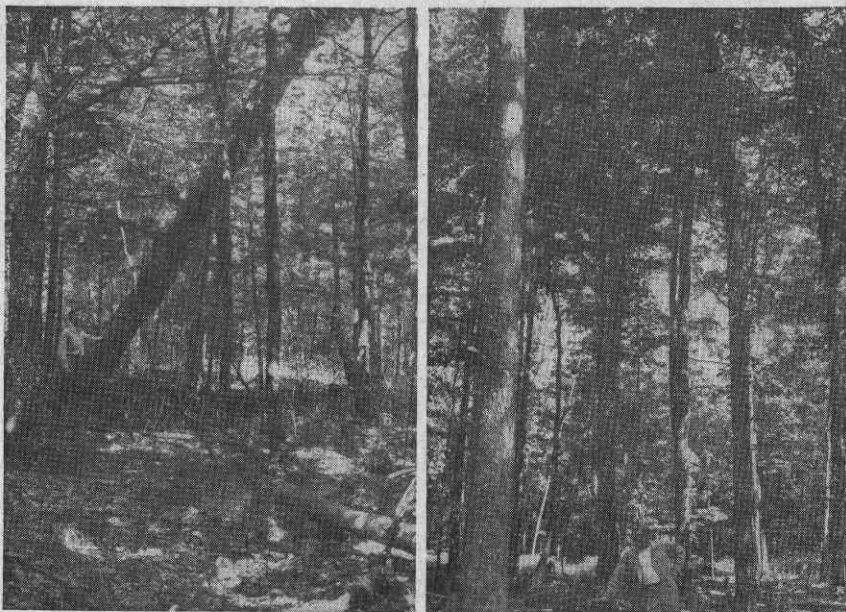
Stands that have reached the second-growth sawtimber class are merchantable for a variety of products, and improvement cuttings are a distinct possibility (fig. 33). One 40-acre second-growth stand that originated from an old-growth logging 35 years earlier on the Upper Peninsula Experimental Forest has been operated as a so-called "farm woodland" forty. Beginning in 1946, one compartment of 8 acres has been cut each year, removing approximately the amount of the estimated annual growth for the entire 40-acre tract.

At the beginning of the experiment, the estimated volume per acre was 2,866 cubic feet. During a 5-year period, 431 cubic feet per acre was removed. After 5 years the volume was 2,775 cubic feet. Thus the annual yield was 68 cubic feet per acre, somewhat more than yield tables for fully stocked stands predict (57) for ages 70 to 75.

During the 5-year period, the following products have been cut and sold from the 40-acre tract:

Saw logs	board-feet..	13,705
Chemical bolts	cords..	30.79
Chemical wood	do....	17.80
Pulpwood (softwood)	do....	39.88

The logger removed some additional volume for fuelwood for his home use.



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FIGURE 33.—Second-growth northern hardwoods, Oneida County Forest, Wis., 1944. At left, area in need of improvement and sanitation cut; at right, adjacent area after profitable improvement cut for hemlock and balsam fir pulpwood, sugar maple, and yellow birch sawlogs and fuelwood.

The volume and proportion of these items have varied from compartment to compartment. However, the returns for labor expended have been fairly consistent (table 31). The average hourly return from the five compartments involved was \$1.28. Interest and taxes were not included in the calculations, nor was stumpage, which varied from \$18.68 to \$33.48 annually. The project is set up to represent the situation of a farmer or other small woodland owner doing his own logging during slack periods. The net returns make a substantial cash addition to his income from other sources.

Products worth over \$1,700 were removed in 5 years. Yet the stand has been improved. The cubic volume is now nearly as great as it was before cutting commenced and the volume of quality trees is considerably greater. This is a small-scale illustration of what can be done.

In another somewhat similar stand (in northern Wisconsin) a mill-scale study was carried out to determine lumber grade yield, lumber values, and the economic feasibility of making improvement cuts in second growth. In this case the main stand consisted of trees 12 to 18 inches d.b.h. Some 1,120 hardwood logs (mostly yellow birch and sugar maple) were removed from a 60-acre tract and followed through the mill. Of these logs, 991 were classed as merchantable, 81 were "submerchantable" because they were below the minimum top diameter of 8 inches, and 48 were "culls" having a net scale of less than one-third

TABLE 31.—*Values, costs, and hourly returns from "farm woodland forty" by years, Upper Peninsula Experimental Forest (85a)*

Year	Roadside value of products	Skidding costs ¹	Net return ²	Time worked	Returns per man-hour
	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Hours</i>	<i>Dollars</i>
1946.....	313.73	59.40	254.33	208	1.22
1947.....	317.76	68.60	249.16	227	1.10
1948.....	323.87	27.00	296.87	220	1.35
1949.....	367.48	30.00	337.48	281	1.20
1950.....	407.10	24.78	382.32	251	1.52

¹ Cash outlay for tractor or horse; includes hire of a teamster also in 1946-48.

² Stumpage not deducted. This was as follows for 1946 to 1950: \$30.03; \$29.08; \$18.68; \$33.48; and \$22.99.

the gross scale. A high overrun in small logs tended to compensate for the low-quality lumber from such logs. Calculation of costs and returns on the operation indicated stumpage values of \$13.27 per thousand board-feet for sugar maple to \$35.83 for yellow birch. The operation was considered distinctly practical (4).

ALL-AGED VERSUS EVEN-AGED SILVICULTURE

Most second-growth northern hardwoods need improvement cuttings. How such cuttings should be made hinges on the long-time objective—whether second-growth forests should be handled under all-aged or even-aged silviculture. This basic question needs much research before positive recommendations can be made. A brief discussion of the two systems, however, may be useful to guide decisions on this matter.

All-aged silviculture, as pointed out earlier, is advocated for old-growth stands of northern hardwoods in the Lake States on the basis of silvical characteristics, experimental evidence, and large-scale trials for a period of 20 to 25 years. The stands with which the forester has to work are essentially uneven-aged (many approach an all-aged condition); there is a considerable spread in diameters, permitting partial harvest at periodic intervals with a good prospect that smaller trees will soon replace those removed; and the mixture of species and strong representation of tolerant kinds insures reproduction at least of the more shade-enduring trees. All in all, conditions appear very favorable for successful uneven-aged management of old growth.

Second-growth stands are of the same species as old growth but often in somewhat different proportion. The greatest difference, however, is in the size-class pattern. Some second-growth stands will undoubtedly develop into uneven-aged forests but with fewer age and size classes represented than in the old growth. It should be perfectly feasible to apply periodic partial cuttings to such stands and ultimately manage them under the selection system. If there is not too much zeal for immediate removal of all the larger trees simply because they contain some defect, the second growth can be molded into an all-aged forest. But it seems probable that the greater proportion of second growth

will more nearly approach even-aged conditions when it becomes merchantable. How should such stands be handled? What are the various possibilities?

Short rotation.—Markets for pole-sized trees of the so-called dense hardwoods (sugar maple, yellow birch, etc.) are very limited at present but are likely to improve. With an improved market, the temptation will be to clear-cut on a fairly short rotation. As previously described, good hardwood stands developed from clear cutting for charcoal with a fair proportion of seedling trees, but this was the first cutting in a virgin stand. The second and third clear cuttings lead to deterioration (fig. 34).

Clear cutting will tend to bring in pin cherry, aspen, and red maple. Sprouts will become much more numerous. Repeated clear cutting for chemical wood in the Allegheny northern hardwoods has resulted in marked deterioration in quality with each succeeding cut, more and more sprout stems occupying the stand (101). The size of the cutting area and the nearness of seed supplies will doubtless influence the proportion of seedlings in the new forest. The possibility of small group cuttings is worthy of investigation for owners who insist on using short rotations.

In order to avoid degrading of young stands through clear cutting, some foresters have suggested delaying the harvest until the stands are old enough to produce seed and establish advance reproduction. Growing timber to an age of, say 60 years or more, may be necessary to accomplish this. The reproduction would be



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FIGURE 34.—Twenty-five-year-old second-growth northern hardwoods recently cut over for cordwood. The "third growth" will undoubtedly contain many sprouts of inferior quality. Marquette County, Mich., 1941.

more easily established if commercial thinnings were carried out some 10 years before the final cut, but, again drawing on Pennsylvania experience, "building up of an understory of advance tree reproduction in an even-aged forest is a long-time process even after the stand reaches seed-bearing age and light conditions become favorable" (72).

Sugar maple would probably tend to dominate the reproduction. Such a plan might work out for a company needing only small-sized material, but it would not supply needs for sawtimber or veneer-quality logs. With veneer logs selling for 5 to 8 times what chemical wood or pulpwood brings, the advantage to the landowner of growing quality material on fairly long rotations is obvious.

Long rotation.—Even-aged management on a long rotation by repeated thinnings in the different crown classes as needed and carrying the best trees through to sizes larger than 20 inches d.b.h. could probably be carried out successfully in northern hardwoods if proper skill were used. The intermediate cuts (thinnings) would have to be on an improvement basis in order to favor the trees of most desirable form and species. The regeneration cuts would be by the shelterwood method or possibly by group or patch cuttings. In considering the possible use of such a system, it should be kept in mind that there will be difficulties because of the high proportion of sugar maple in Lake States hardwoods. As thinnings are made, sugar maple is almost certain to reproduce and the tendency will be for this species to capture the site before the time comes for the application of the shelterwood regeneration cut. Some supplemental treatment such as mechanical scarification may be needed to create seedbed conditions suitable for yellow birch and other species.

It is apparent that much more research is needed to settle the question of whether even-aged or all-aged silviculture is best for Lake States conditions in the long run. For old growth and certain types of second growth, uneven-aged practice seems very promising; for the bulk of the second growth now coming in, it is an open question which is best. Experiments are planned and some already are under way on the Argonne Experimental Forest in Wisconsin and elsewhere, aimed at developing best methods of handling second-growth hardwoods.

SUMMARY

Because of intense interest in partial cutting, commonly called "selective logging," in northern hardwoods of the Lake States, a series of experimental cuttings was begun in 1926 on the Upper Peninsula Experimental Forest at Dukes, Mich., on an area provided under cooperative arrangement with the Cleveland-Cliffs Iron Company. Results based on 20-year records are now available from these experiments. Much supplemental information from various places in the region has also been assembled for the benefit of owners and managers of hardwood forests.

The northern hardwood or hardwood-hemlock forest is transitional between the conifer forest of the North and the pure hardwoods of the Central States. It covers some 9½ million acres in the Lake States. Old growth has dwindled to about a million acres, but the area of partially cut timber is increasing and second growth has developed considerably; consequently over one-fourth of the total area supports timber of sawlog size. The principal components are: Sugar maple, eastern hemlock, yellow birch, basswood, beech, and American elm. The more important associates are: Eastern white pine, balsam fir, eastern hophornbeam (ironwood), red maple, and red oak. The forest is not homogeneous but is made up of a number of types and subtypes. Composition varies from east to west and north to south.

The old-growth northern hardwood forest is characteristically a climax forest. Most of the component species are tolerant of shade, fairly windfirm, long-lived, and good seed producers. With some notable exceptions and given favorable conditions, they reproduce prolifically. Details of the silvical characteristics are given for the more important species beginning with sugar maple, the key tree. Sensitivity to exposure varies considerably. Sugar maple can withstand disturbance and exposure to a high degree; basswood and elm exhibit a reasonable resistance, but yellow birch and especially hemlock are sensitive. Most species, particularly sugar maple, respond quickly and well to release from competition. Northern hardwoods generally occupy the more fertile loam and sandy loams in the podzol and gray-brown podzolic groups of soils derived from glacial materials. Within the area of commercial importance sites do not vary greatly; all tend to be fairly good.

Since the northern hardwoods are of mixed composition, insect depredations are ordinarily less serious than in many types, but defoliators and wood borers cause some damage. Diseases are usually more troublesome, especially those responsible for wood rots and cankers. The injurious insects and diseases and the damage they cause are tabulated. Animals, in particular deer, are a serious threat to reproduction in localities where populations exceed the supply of winter browse to support them. Winds of hurricane speed and tornadoes occasionally do great local damage, as does glaze. Hemlock is much less susceptible to glaze injury than hardwoods. In unmanaged overmature stands, cull is generally heavy.

Old-growth northern hardwoods tend to be all-aged and of many sizes, diminishing in numbers as the trees become larger. All ages up to 300 years and more and diameters in excess of 32 inches are normally present.

In economic value the northern hardwood forest ranks high. The important species command exceptionally good prices. Yellow birch leads in value, followed by basswood and sugar maple, then rock elm, red oak, and American elm. Hemlock timber usually sells for less than one-third what the better hardwoods bring.

Experimental cuttings involving a wide range from absolute clear cutting down through moderate and light partial cutting to uncut reserve areas provide strong contrast in residual stocking from 0 to 9,300 board-feet per acre. Annual growth per acre for 5-year intervals is presented in terms of gross and net board-feet and cubic feet over a 20-year period for the various cuttings. Net increment ranged from 20 to 252 board-feet per acre per year on sample areas. On a considerable number of cuttings it approached 200 board-feet. Data on ingrowth, height changes, basal area change, percent increment, and diameter growth are also given. Diameter growth leveled off in trees over 22 inches d.b.h. Mortality in partially cut stands was only one-fourth that in reserve areas. Intermediately cut stands had the lowest mortality, which was far exceeded by growth. Losses were lowest in sugar maple and highest in hemlock.

Breakage of residual trees in partial cutting has not been excessive. There is more concern about logging scars which may induce decay. Suggestions are given for minimizing logging damage.

An attempt has been made to define optimum stocking for best growth. On the Upper Peninsula Experimental Forest, leaving a stand of 4,000 to 7,000 board-feet or 50 to 75 square feet of basal area per acre after the first cutting gave best results for a 15-year cutting cycle. For a shorter cycle, a slightly higher residual stocking is suggested. Optimum stocking for highest interest return was found to be lower than optimum stocking for best growth, but there is a considerable zone of overlap where both are good. Suggestions are given for reconciling the differences. Recommendations are also given on desirable stocking to retain in the residual stand in terms of number of trees and their distribution by diameter classes for continued production.

Tree quality is of especial importance in hardwoods and size is one element of quality. A maximum size for growing hardwoods of 24 inches d.b.h. is suggested, though there is some evidence it should be smaller. Heavy cuttings tend to stimulate epicormic sprouting and degrade quality. Light cuttings are best for maintaining quality. However, moderate cuttings reduce quality only to a minor degree and increase growth rate. Rapid growth rate, in turn, increases the proportion of white wood (sapwood) which brings a premium in sugar maple.

Partial cuttings favor the more shade-tolerant species in the reproduction. Sugar maple in particular is fostered by such practices. Despite some apprehension that seedlings and saplings grown under partial shade would be malformed, the young trees are of good quality. In order to promote regeneration of less tolerant trees such as yellow birch, three requirements must be met: (1) Provide sufficient light by creating scattered small openings; (2) assure an ample seed supply by leaving seed trees adjacent to openings; and (3) expose mineral soil by logging in summer or fall or by mechanical scarification. Some followup release cuttings may be needed to maintain the birch after it has started.

Northern hardwoods do not represent a great fire risk but on occasion will burn, so fire hazard cannot be ignored. Even light leaf fires scar the butts of trees, thus providing entrance for decay. Slash fires burn with great intensity and are difficult to control. Partial in contrast to clear cutting lessens the slash hazard by providing shade and reducing wind movement so that the drying process is slower. Moreover, removal of only part of the stand creates less slash. Hardwood slash rots in a comparatively short time and slash lopping is not necessary. Since hemlock slash may last several times as long and is more flammable, lopping to within 30 inches of the ground is recommended where heavy concentrations exist and tops are not utilized for pulpwood or other products.

Hemlock stands present a special problem and there is insufficient information to provide a satisfactory solution. Not only is hemlock reproduction irregular and the tree sensitive to exposure, but markets are often rather poor. Most hemlock areas in the region have been clear-cut. After some years in a brush and grass stage, they tend to convert to hardwoods with, however, some conifers in mixture. Grass and brush may occupy the area for many years, especially where deer are plentiful.

The occasional pure stand of hemlock that is thrifty and not overmature can be handled by light partial cutting. Partial cuttings in mature hemlock-hardwood stands, especially near Lake Superior where climate is favorable, have met with some success. Leaving many hardwoods to protect residual hemlock is helpful. Experience thus far does not encourage the cutting of badly overmature hemlock on a continuing selection basis; mortality is too heavy. There is some evidence that superior hardwood reproduction will result if the hemlock is removed in a series of 4 or 5 shelterwood cuttings in which openings are provided for reproduction of yellow birch—a very valuable species that does well on hemlock sites. All plans for hemlock operations must provide for salvaging dead trees.

The possibilities of various cutting methods for handling northern hardwoods are discussed. The selection method of cutting is recommended for most mature stands with certain modifications to encourage yellow birch. Suggestions are given on how to mark northern hardwood stands under the selection system.

Second-growth northern hardwoods present somewhat different characteristics than old growth. The same species are present but in different proportions. The main divergence from old growth is in the size and age-class pattern, depending largely on how the old stand was cut. Earlier logging operations generally left more on the ground than later ones. The stands cut less heavily have in 35 to 40 years developed into a second-growth sawlog forest which is more or less uneven-aged, has a good distribution of size classes, and probably can be handled successfully under the selection system. The heavier cuttings, on the other hand, have developed into even-aged stands, most of which

are still too young to contain sawlogs. Whether they can best be handled by an even-aged or all-aged silviculture is an open question needing attention. All second-growth stands, however, are in need of timber stand improvement measures. Examples are given of cultural treatment in young growth and commercial improvement cuttings that pay their way.

LITERATURE CITED

- (1) ANONYMOUS
1931. SELECTIVE LOGGING AND CLOSE UTILIZATION—A SOLUTION TO THE SLASH PROBLEM IN NORTHERN HARDWOODS. *Jour. Forestry* 29: 834.
- (2) ———
1939. DESTRUCTION OF HEMLOCK BY INSECTS IS STUDIED BY NORTHERN PRODUCERS. *Amer. Lumberman*, Nov. 18, 1939, p. 46.
- (3) ARBOGAST, CARL, JR.
1950. HOW MUCH DOES FELLING LARGE CULL TREES DAMAGE THE UNDERSTORY. *Forest Serv., Lake States Forest Expt. Sta. Tech. Note* 337, 2 pp. [Processed.]
- (4) ———
1951. QUALITY OF LOGS AND LUMBER OBTAINED FROM AN IMPROVEMENT CUT IN SECOND-GROWTH HARDWOODS IN NORTHERN WISCONSIN. *Forest Serv., Lake States Forest Expt. Sta., Sta. Paper* 26, 15 pp.
- (5) ——— and HEINSELMAN, MIRON L.
1950. DAMAGE TO NATURAL REPRODUCTION BY DEER BROWSING. *Forest Serv., Lake States Forest Expt. Sta. Tech. Note* 332, 1 p. [Processed.]
- (6) BAKER, FREDERICK, S.
1949. A REVISED TOLERANCE TABLE. *Jour. Forestry* 47: 179-181.
- (7) BAXTER, DOW VAWTER
1952. PATHOLOGY IN FOREST PRACTICE. Ed. 2, 618 pp., illus. New York.
- (8) BOYCE, JOHN SHAW
1938. FOREST PATHOLOGY. 600 pp., illus. New York.
- (9) BRATTON, ALLEN W.
1946. HARDWOODS—THE BIGGER, THE BETTER: HEMLOCK—JUST GET BIGGER. *Forest Serv., Northeast. Forest Expt. Sta. Econ. Note* 2, 3 pp. [Processed.]
- (10) BRAUN, E. LUCY
1950. DECIDUOUS FORESTS OF EASTERN NORTH AMERICA. 596 pp., illus. Philadelphia.
- (11) BROMLEY, WILLARD S.
1942. SAPWOOD IN SUGAR-MAPLE TREES. *Mich. Acad. Sci., Arts, and Letters. Papers* 27 (1941), Part I, Botany and Forestry, pp. 163-168.
- (12) ———, W. S.
1948. SAWLOG FORESTRY ON INDUSTRIAL AND LARGE UNITS OF PRIVATE LAND IN THE LAKE STATES. *Proc. Soc. Amer. Foresters' Meeting*, 1947, pp. 416-420.
- (13) BUELL, B.
1937. SOME FINANCIAL ASPECTS OF SELECTIVE LOGGING. *Jour. Forestry* 35: 59-62.
- (14) BUTTRICK, P. L.
1922. STORM DAMAGE TO MICHIGAN FORESTS. *Jour. Forestry* 20: 527-532.
- (15) ———
1923. SECOND GROWTH HARDWOOD FORESTS IN MICHIGAN. *Mich. Agr. Expt. Sta. Spec. Bul.* 123. 19 pp., illus.
- (16) CAMPBELL, W. A.
1937. DECAY HAZARD RESULTING FROM ICE DAMAGE TO NORTHERN HARDWOODS. *Jour. Forestry* 35: 1156-1158.

- (17) _____
1938. PRELIMINARY REPORT ON DECAY IN SPROUT NORTHERN HARDWOODS IN RELATION TO TIMBER STAND IMPROVEMENT. Forest Serv., Northeast. Forest Expt. Sta. Occasional Paper 7, 8 pp. [Processed.]
- (18) _____
1939. DAEDALEA UNICOLOR DECAY AND ASSOCIATED CANKERS OF MAPLES AND OTHER HARDWOODS. Jour. Forestry 37: 974-977.
- (19) _____ and DAVIDSON, R. W.
1939. PORIA ANDERSONII AND POLYPORUS GLOMERATUS, TWO DISTINCT HEART-ROTTING FUNGI. Mycologia 31: 161-168.
- (20) _____
1940. USTULINA VULGARIS DECAY IN SUGAR MAPLE AND OTHER HARDWOODS. Jour. Forestry 38: 474-477, illus.
- (21) _____ and _____, ROSS W.
1941. CANKERS AND DECAY OF YELLOW BIRCH ASSOCIATED WITH FOMES IGNARIUS VAR. LAEVIGATUS. Jour. Forestry 39: 559-560.
- (21a) CAMPBELL, W. A., and SPAULDING, PERLEY.
1942. STAND IMPROVEMENT OF NORTHERN HARDWOODS IN RELATION TO DISEASES IN THE NORTHEAST. Forest Serv., Allegheny Forest Expt. Sta. Occasional Paper 5, 25 pp., illus. [Processed.]
- (22) CARR, JOHN A.
1939. FOREST MANAGEMENT BY THE GOODMAN LUMBER COMPANY. Jour. Forestry 37: 754-755.
- (23) CHEYNEY, E. G.
1942. AMERICAN SILVICS AND SILVICULTURE. Univ. of Minn. Press, 472 pp., illus.
- (24) CLAYBERG, H. D.
1920. UPLAND SOCIETIES OF PETOSKEY-WALLOON LAKE REGION. Bot. Gaz. 69: 28-53.
- (25) CRAIGHEAD, F. C.
1950. INSECT ENEMIES OF EASTERN FORESTS. U. S. Dept. Agr. Misc. Pub. 657, 679 pp., illus.
- (26) CUNNINGHAM, R. N., et al.
1950. FOREST RESOURCES OF THE LAKE STATES REGION. Forest Resource Rpt. 1, U. S. Dept. Agr., Forest Serv., 57 pp., illus.
- (27) CUNNINGHAM, R. N., and MOSER, H. C.
1938. FOREST AREAS AND TIMBER VOLUMES IN THE LAKE STATES. Forest Serv., Lake States Forest Expt. Sta. Econ. Note 10, 84 pp. [Processed.]
- (28) DAVIDSON, ROSS W., and LORENZ, ROLLAND C.
1938. SPECIES OF EUTYPELLA AND SCHIZOXYLON ASSOCIATED WITH CANKERS ON MAPLE. Phytopathology 28: 733-745.
- (29) DELANEY, RICHARD
1939. SELECTIVE LOGGING COSTS LESS. Jour. Forestry 37: 522.
- (30) DOPPEL, A. A.
1927. DIAMETER GROWTH OF HARD MAPLE. Jour. Forestry 25: 989-997.
- (31) DOWNS, A. A.
1938. GLAZE DAMAGE IN BEECH, BIRCH, MAPLE, HEMLOCK TYPE. Jour. Forestry 36: 63-70.
- (32) _____
1946. RESPONSE TO RELEASE OF SUGAR MAPLE, WHITE OAK, YELLOW POPLAR. Jour. Forestry 44: 22-27.
- (33) DUERR, W. A. and STODDARD, C. H., JR.
1938. RESULTS OF A COMMERCIAL SELECTIVE CUTTING IN NORTHERN HEMLOCK-HARDWOODS. Jour. Forestry 36: 1224-1230.
- (34-35) EDMINSTER, FRANK C.
1947. THE RUFFED GROUSE—ITS LIFE STORY, ECOLOGY, AND MANAGEMENT. 385 pp., illus. New York.
- (36) ENGLE, L. G.
1947. SKIDDING DAMAGE BY TRACTORS AND HORSES IN SELECTIVE LOGGING OF NORTHERN HARDWOODS. Forest Serv., Lake States Forest Expt. Sta. Tech. Note 277, 1 p. [Processed.]

- (37) ————
1948. GIRDLING NORTHERN HARDWOOD WOLF TREES. Jour. Forestry 46: 925-926.
- (38) ————
1949. CUTTING ASPEN OVERSTORY IMPROVES GROWTH OF YOUNG HARDWOODS. Forest Serv., Lake States Forest Expt. Sta. Tech. Note 314, 1 p. [Processed.]
- (39) EWALT, RICHARD H.
1950. A REVIEW OF THE SELECTIVE LOGGING PROGRAM OF THE CLEVELAND-CLIFFS IRON COMPANY. Lake States Timber Digest. March 1950, pp. 4-5. April 1950, pp. 4, 6, 12, 13.
- (40) EYRE, F. H., and LONGWOOD, F. R.
1951. REDUCING MORTALITY IN OLD-GROWTH NORTHERN HARDWOODS BY PARTIAL CUTTING. Forest Serv., Lake States Forest Expt. Sta., Sta. Paper 24, 13 pp. [Processed.]
- (41) ———— and NEETZEL, J. R.
1937. APPLICABILITY OF THE SELECTION METHOD IN NORTHERN HARDWOODS. Jour. Forestry 35: 353-358.
- (42) ————, FRANCIS H. and ————, JOHN R.
1939. PRACTICAL CUTTING METHODS FOR NORTHERN HARDWOODS. Mich. Acad. Sci., Arts, and Letters Papers 24 (1938), Part I, pp. 197-207.
- (43) ————, F. H. and ZILLGITT, W. M.
1950. SIZE-CLASS DISTRIBUTION IN OLD-GROWTH NORTHERN HARDWOODS TWENTY YEARS AFTER CUTTING. Forest Serv., Lake States Forest Expt. Sta., Sta. Paper 21, 15 pp. [Processed.]
- (44) FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE.
1938. TIMBER MANAGEMENT AND FINANCIAL PLANS FOR THE GOODMAN WORKING CIRCLE. Region 9, Milwaukee, Wis. 83 pp. [Processed.]
- (45) ————
1939. COMPARATIVE RESISTANCE OF NATIVE WISCONSIN TREES TO SNOW BREAKAGE. Lake States Forest Expt. Sta., Tech. Note 152, 1 p. [Processed.]
- (46) ————
1942. COMPARISON OF INVESTMENT AND EARNINGS OF HARDWOOD TREES IN THE NORTHERN LAKE STATES. Region 9, Milwaukee, Wis. 69 pp., illus. [Processed.]
- (47) ————
1943. SUGGESTED HARDWOOD TREE CLASS STANDARDS FOR FARM FORESTERS. Region 9, Milwaukee, Wis. 34 pp. [Processed.]
- (48) ————
1948. WOODY-PLANT SEED MANUAL. Misc. Pub. 654, 416 pp., illus.
- (49) ————
1949. HARDWOOD LOG GRADES FOR STANDARD LUMBER. Forest Products Lab. Rpt. D1737, 15 pp., 48 tables, illus. [Processed.]
- (50) ————
1950. ANNUAL REPORT. Northeast. Forest Expt. Sta. 102 pp. [Processed.]
- (51) FRIESNER, RAY C., and POTZGER, JOHN E.
1944. SURVIVAL OF HEMLOCK SEEDLINGS IN A RELICT COLONY UNDER FOREST CONDITIONS. Butler Univ. Bot. Studies V, IV, Papers 9-14, pp. 102-115.
- (52) FROTHINGHAM, E. H.
1915. THE EASTERN HEMLOCK. U. S. Dept. Agr. Bul. 152, 43 pp., illus.
- (53) ————
1915. THE NORTHERN HARDWOOD FOREST: ITS COMPOSITION, GROWTH, AND MANAGEMENT. U. S. Dept. Agr. Bul. 285, 80 pp., illus.
- (54) GATES, F. C., and NICHOLS, G. E.
1930. RELATION BETWEEN AGE AND DIAMETER IN TREES OF THE PRIMEVAL NORTHERN HARDWOOD FOREST, Jour. Forestry 28: 395-398,

- (55) GEVORKIANTZ, S. R.
1947. CONVERTING VOLUMES BETWEEN INTERNATIONAL $\frac{1}{4}$ -INCH RULE AND SCRIBNER RULE. Forest Serv., Lake States Forest Expt. Sta. Tech. Note 283, 1 p. [Processed.]
- (56) ———, and OLSEN, L. P.
1952. CUBIC CONTENT OF SAWLOGS IN STANDING TREES. Forest Serv., Lake States Forest Expt. Sta. Tech. Note 382, 1 p. [Processed.]
- (57) ———, and DUERR, WILLIAM A.
1937. A YIELD TABLE FOR NORTHERN HARDWOODS IN THE LAKE STATES. Jour. Forestry 35: 340-343.
- (58) GLEASON, H. A.
1924. THE STRUCTURE OF THE MAPLE-BEECH ASSOCIATION IN NORTHERN MICHIGAN. Mich. Acad. Sci., Arts, and Letters Papers 4: 285-296.
- (59) GOODMAN, R. B.
1944. A WISCONSIN FOREST-FARM WORKING CIRCLE. 24 pp., Goodman, Wis. (July.)
- (60) GRAHAM, SAMUEL A.
1941. CLIMAX FORESTS OF THE UPPER PENINSULA OF MICHIGAN. Ecol. 22: 355-362.
- (61) ———, S. A.
1941. THE QUESTION OF HEMLOCK ESTABLISHMENT. Jour. Forestry 39: 567-569.
- (62) ———, SAMUEL A.
1943. CAUSES OF HEMLOCK MORTALITY IN NORTHERN MICHIGAN. Mich. Univ. School Forestry and Conserv., Bul. 10, 61 pp.
- (63) ———, S. A.
1951. DEVELOPING FORESTS RESISTANT TO INSECT INJURY. Sci. Monthly 73(4): 235-244.
- (64) ———, SAMUEL ALEXANDER
1952. FOREST ENTOMOLOGY. ED. 3, 351 pp., illus. New York.
- (65) HALL, RALPH C.
1933. POST-LOGGING DECADENCE OF NORTHERN HARDWOODS. Mich. Univ. School Forestry and Conserv. Bul. 3, 66 pp., illus.
- (66) HALLIDAY, W. E. D.
1937. A FOREST CLASSIFICATION FOR CANADA. Canada Dept. Mines and Resources. Forest Serv. Bul. 89, 50 pp., map.
- (67) HANSBROUGH, J. R., JENSEN, V. S., MACALONEY, H. J., and NASH, R. W.
1950. EXCESSIVE BIRCH MORTALITY IN THE NORTHEAST. New England Sect. Soc. Amer. Foresters, Tree Pest Leaflet 52, 4 pp., illus.
- (68) HERBERT, PAUL A.
1924. HARDWOOD LANDS AFTER LOGGING (ADEQUATE REPRODUCTION IS SECURED UNDER PRESENT METHODS OF CUTTING IF FIRE IS KEPT OUT). Mich. Quart. Bul. 7(1): 26-30.
- (69) HODSON, A. C.
1941. AN ECOLOGICAL STUDY OF THE FOREST TENT CATERPILLAR, MALACOSOMA DISSTRIA, IN NORTHERN MINNESOTA. Minn. Agr. Expt. Sta. Tech. Bul. 148, 55 pp., illus.
- (70) ———
1951. 1951—THE NORTHERN WALKING STICK'S YEAR. Minn. Farm and Home Sci. 8(3): 6-7, illus.
- (71) HOLMBERG, L. A.
1933. SUPPRESSION A POSSIBLE CAUSE OF BIRD'S-EYE IN MAPLE. Jour. Forestry 31: 968-970.
- (71a) HOUGH, A. F.
1936. EPICORMIC BRANCHING OF ALLEGHENY HARDWOODS. Forest Serv., Allegheny Forest Expt. Sta. Tech. Note 10, 2 pp. [Processed.]
- (72) ———
1937. A STUDY OF NATURAL TREE REPRODUCTION IN THE BEECH-BIRCH-MAPLE-HEMLOCK TYPE. Jour. Forestry 35: 376-378.
- (73) ———
1937. WHY TIMBER STAND IMPROVEMENT? Jour. Forestry 35: 813-822.

- (74) _____ 1943. METHODS OF HARVESTING SAW TIMBER IN THE HIGH PLATEAUS SECTION OF PENNSYLVANIA. Jour. Forestry 41: 898-903.
- (75) _____ and FORBES, R. D. 1943. THE ECOLOGY AND SILVICS OF FORESTS IN THE HIGH PLATEAUS OF PENNSYLVANIA. Ecol. Monog. 13: 299-320.
- (76) _____ and TAYLOR, R. F. 1946. RESPONSE OF ALLEGHENY NORTHERN HARDWOODS TO PARTIAL CUTTING. Jour. Forestry 44: 30-38.
- (77) JEMISON, GEORGE M., and SCHUMACHER, F. X. 1948. EPICORMIC BRANCHING IN OLD-GROWTH APPALACHIAN HARDWOODS. Jour. Forestry 46: 252-255.
- (78) JENSEN, VICTOR S. 1943. SUGGESTIONS FOR THE MANAGEMENT OF NORTHERN HARDWOOD STANDS IN THE NORTHEAST. Jour. Forestry 41: 180-185.
- (79) _____ and MACALONEY, HARVEY J. 1949. RECOVERY OF BIRCH AFTER PARTIAL CUTTING. Proc. Soc. Amer. Foresters' Meeting, 1948, pp. 298-302.
- (80) _____ and WILSON, ROBERT W., JR. 1951. MOWING OF NORTHERN HARDWOOD REPRODUCTION NOT PROFITABLE. Forest Serv., Northeast. Forest Expt. Sta. Res. Note 3, 4 pp. [Processed.]
- (81) KAUFERT, FRANK 1935. HEART ROT OF BALSAM FIR IN THE LAKE STATES WITH SPECIAL REFERENCE TO FOREST MANAGEMENT. Minn. Agr. Expt. Sta. Tech. Bul. 110, 27 pp., illus.
- (82) KIRKLAND, BURT P. 1943. PRODUCTIVITY OF LOGGING AND SAWMILL LABOR AS AFFECTED BY TREE SIZE. Jour. Forestry 41: 869-872.
- (83) LINTEAU, ANDRE 1948. FACTORS AFFECTING GERMINATION AND EARLY SURVIVAL OF YELLOW BIRCH IN QUEBEC. Forestry Chron. 24(1): 27-86.
- (84) LONGWOOD, F. R. 1951. INGROWTH FOLLOWING CUTTING IN NORTHERN HARDWOODS. Forest Serv., Lake States Forest Expt. Sta. Tech. Note 352, 1 p. [Processed.]
- (85) _____ 1951. WHY RELEASE YOUNG MAPLE FROM PIN CHERRY. Forest Serv., Lake States Forest Expt. Sta. Tech. Note 360, 2 pp. [Processed.]
- (85a) _____ 1952. SECOND-GROWTH WOODLAND CAN BE A FINANCIAL ASSET TO THE FARM. Forest Serv., Lake States Forest Expt. Sta. Tech. Note 371, 1 p. [Processed.]
- (86) _____ 1952. HEAVY MORTALITY DOES NOT ALWAYS FOLLOW PARTIAL CUTTING OF HEMLOCK-HARDWOOD STANDS. Jour. Forestry 50: 558-559.
- (86a) _____ and SALMINEN, W. A. 1952. REPRODUCTION AFTER CUTTING IN HARDWOOD-HEMLOCK STANDS. Forest Serv., Lake States Forest Expt. Sta. Tech. Note 371, 1 p. [Processed.]
- (87) LORENZ, ROLLAND C., and CHRISTENSEN, CLYDE M. 1937. A SURVEY OF FOREST TREE DISEASES AND THEIR RELATION TO STAND IMPROVEMENT IN THE LAKE AND CENTRAL STATES. U. S. Dept. Agr., Bur. Plant Ind., 52 pp., illus. [Processed.]
- (88) MACLEAN, D. W. 1949. IMPROVEMENT CUTTING IN TOLERANT HARDWOODS. Dominion Forest Serv., Res. Note 95, 19 pp. [Processed.]
- (89) MAISSUROW, D. R. 1941. THE ROLE OF FIRE IN THE PERPETUATION OF VIRGIN FORESTS IN NORTHERN WISCONSIN. Jour. Forestry 39: 201.
- (90) MAYER-WEGELYN, HANS 1936. ASTUNG (PRUNING). M. & H. Schaper, Hanover. Translation No. 264 by C. P. deBlumenthal, U. S. Forest Serv. Div. of Silvics.

- (91) MCCARTHY, EDWARD F., and BELYEA, HAROLD CAHILL
1920. YELLOW BIRCH AND ITS RELATION TO THE ADIRONDACK FOREST. N. Y. State Col. Forestry, Syracuse Univ. Tech. Pub. 10, 50 pp.
- (92) MCINTIRE, GEORGE S.
1932. THEORY AND PRACTICE OF FOREST TYPING WITH SPECIAL RELATION TO THE HARDWOOD AND HEMLOCK ASSOCIATION IN NORTHERN MICHIGAN. Mich. Acad. Sci., Arts, and Letters Papers (1931) 15: 239-251.
- (93) MARSHALL, ROBERT
1927. THE GROWTH OF HEMLOCK BEFORE AND AFTER RELEASE FROM SUPPRESSION. Harvard Forest Bul. 11, 43 pp., illus.
- (94) MARTIN, ROBERT
1945. TIMBER MARKING FOR SECOND-CYCLE CUTTING IN NORTHERN WISCONSIN. Jour. Forestry 43: 655.
- (95) MERRILL, PERRY H., and HAWLEY, RALPH C.
1924. HEMLOCK: ITS PLACE IN THE SILVICULTURE OF THE SOUTHERN NEW ENGLAND FOREST. Yale Univ., School Forestry Bul. 12, 68 pp., illus.
- (96) MEYER, H. ARTHUR
1952. STAND, GROWTH AND DRAIN IN BALANCED UNEVEN-AGED STANDS. Jour. Forestry 50: 85-92.
- (97) MOSS, A. E.
1937. PRUNING SECOND GROWTH HARDWOODS IN CONNECTICUT. Jour. Forestry 35: 823-828.
- (98) NASH, ROBLEY W., and DUDA, EDWARD J.
1951. STUDIES ON EXTENSIVE DYING, REGENERATION, AND MANAGEMENT OF BIRCH. Maine Forest Serv. Bul. 15, 82 pp., illus.
- (99) NICHOLS, G. E.
1935. THE HEMLOCK-WHITE PINE-NORTHERN HARDWOOD REGION OF EASTERN NORTH AMERICA. Ecol. 16: 403-422.
- (100) NORDIN, V. J., and CAFLEY, J. D.
1950. THE EFFECT OF DECAY ON RECOVERABLE VOLUME IN HARD MAPLE IN ONTARIO. Forestry Chron. 26(1): 38-42.
- (101) OSTROM, C. E.
1938. CLEAR CUTTING OF YOUNG NORTHERN HARDWOOD STANDS. Jour. Forestry 36: 44-49.
- (102) ——— and HOUGH, A. F.
1944. EARLY WEEDING IN NORTHERN HARDWOODS. Jour. Forestry 42: 138-140.
- (103) POTZGER, J. E.
1946. PHYTOSOCIOLOGY OF THE PRIMEVAL FOREST IN CENTRAL-NORTHERN WISCONSIN AND UPPER MICHIGAN, AND A BRIEF POST-GLACIAL HISTORY OF THE LAKE FOREST FORMATION. Ecol. Monog. 16: 211-250.
- (104) ROE, E. I.
1935. FOREST SOILS, THE BASIS OF FOREST MANAGEMENT. Forest Serv., Lake States Forest Expt. Sta., 9 pp. [Processed.]
- (105) ROTH, ELMER R., and SLEETH, BAILEY
1939. BUTT ROT IN UNBURNED SPROUT OAK STANDS. U. S. Dept. Agr. Tech. Bul. 684, 43 pp.
- (105a) ROTH, FILIBERT
1898. FORESTRY CONDITIONS AND INTERESTS OF WISCONSIN. U. S. Dept. Agr. Forest Service Bul. 16, 76 pp.
- (105b) RUDOLF, PAUL O.
1951. MINERAL CONTROL OF BRUSH AND TREE GROWTH FOR THE LAKE STATES. Forest Serv., Lake States Forest Expt. Sta. Misc. Rpt. 15, 30 pp. [Processed.]
- (106) SCHEFFER, T. C.
1939. MINERAL STAIN IN HARD MAPLES AND OTHER HARDWOODS. Jour. Forestry 37: 578-579.
- (107) SCHOLZ, H. F.
1930. HARDWOOD SLASH—HOW LONG DOES IT REMAIN A HAZARD. Jour. Forestry 28: 568.

- (108) SECREST, H. C., MACALONEY, H. J., and LORENZ, R. C.
1941. CAUSES OF DECADENCE OF HEMLOCK AT THE MENOMINEE INDIAN RESERVATION, WISCONSIN. Jour. Forestry 39: 3-12.
- (109) SOCIETY OF AMERICAN FORESTERS.
1940. FOREST COVER TYPES OF THE EASTERN UNITED STATES. Report of Committee on Forest Types. Ed. 3, Rev., 39 pp.
- (110) ———.
1950. FORESTRY TERMINOLOGY. 93 pp.
- (111) SPAULDING, P.
1929. THE DECAY OF HARDWOOD SLASH IN NORTHERN NEW ENGLAND. Jour. Forestry 27: 241-245.
- (112) ———.
1946. SUSCEPTIBILITY OF BEECH TO DROUGHT AND ADVERSE WINTER CONDITIONS. Jour. Forestry 44: 377.
- (113) ——— and BRATTON, ALLEN W.
1946. DECAY FOLLOWING GLAZE STORM DAMAGE IN WOODLANDS OF CENTRAL NEW YORK. Jour. Forestry 44: 515-519.
- (114) SPAULDING, P., GRANT, T. J., and AYERS, T. T.
1936. INVESTIGATIONS OF NECTRIA DISEASES IN HARDWOODS OF NEW ENGLAND. Jour. Forestry 34: 169-179.
- (115) ——— and HANSBROUGH, J. B.
1935. THE DYING OF BEECH IN 1934. Forest Serv., Northeast. Forest Expt. Sta. Tech. Note 20, 2 pp. [Processed.]
- (116) SPRING, S. N.
1922. REPRODUCTION OF THE HARDWOOD TYPE IN THE ADIRONDACKS. Jour. Forestry 20: 571-580.
- (117) STEARNS, FOREST W.
1949. NINETY YEARS CHANGE IN A NORTHERN HARDWOOD FOREST IN WISCONSIN. Ecol. 30: 350-358.
- (118) ———.
1951. THE COMPOSITION OF THE SUGAR MAPLE-HEMLOCK-YELLOW BIRCH ASSOCIATION IN NORTHERN WISCONSIN. Ecol. 32: 245-265.
- (119) STODDARD, CHARLES H., JR.
1939. THE "TWO CUT" SYSTEM OF FOREST LIQUIDATION IN THE LAKE STATES REGION. The Charles Lathrop Pack Forestry Foundation, Washington, D. C., 45 pp., illus.
- (120) STOECKELER, J. H.
1950. PORCUPINE DAMAGE IN A NORTHERN HARDWOOD-HEMLOCK FOREST OF NORTHEASTERN WISCONSIN. Forest Serv., Lake States Forest Expt. Sta. Tech. Note 326, 1 p. [Processed.]
- (121) ——— and ARBOGAST, CARL F.
1948. THINNING AND PRUNING OF YOUNG SECOND-GROWTH HARDWOODS IN NORTHEASTERN WISCONSIN. Proc. Soc. Amer. Foresters' Meeting, 1947, pp. 328-346.
- (121a) ———.
1952. POWER-SAW GIRDLING SAVES TIME IN TIMBER STAND IMPROVEMENT. Forest Serv., Lake States Forest Expt. Sta. Tech. Note 383, 1 p. [Processed.]
- (122) STOTT, C. B.
1943. INCREASING PRODUCTION OF CRITICAL LUMBER GRADES BY SELECTION CUTTING. Jour. Forestry 41: 734-739.
- (123) SWIFT, ERNEST
1949. WISCONSIN'S DEER DAMAGE TO FOREST REPRODUCTION. Survey, Final Report. Wis. Conserv. Dept. Pub. 347, 24 pp.
- (124) TOUMEY, JAMES W., and NEETHLING, ERNEST J.
1927. INSOLATION, A FACTOR IN THE NATURAL REGENERATION OF CERTAIN CONIFERS. Yale Univ. School Forestry Bul. 11, 63 pp., illus.
- (125) U. S. DEPARTMENT OF AGRICULTURE
1938. SOILS AND MEN. (Yearbook.) 1232 pp., illus.
- (126) ———.
1941. CLIMATE AND MAN. (Yearbook.) 1248 pp., illus.

- (127) WATSON, RUSSELL
1925. NOTES ON NATURAL REGULATION AND GROWTH OF NORTHERN
HEMLOCK AND HARDWOOD FORESTS. Jour. Forestry 23: 936-940.
- (128) ———
1937. A STUDY OF AREAS SELECTIVELY LOGGED. U. S. Forest Serv.,
North Central Region, 16 pp. [Processed.]
- (129) ——— and BANZHAF, GEORGE
1928. DISCUSSION OF SELECTIVE LOGGING WITH SPECIAL REFERENCE
TO THE SELECTIVE LOGGING PROJECTS OF THE HOLT LUMBER
COMPANY OF OCONTO, WISCONSIN. Northern Hemlock and
Hardwood Mfrs. Assn., 11 pp., illus.
- (130) WESTVELD, M.
1942. SOME EFFECTS OF GIRDLING NORTHERN HARDWOODS. Jour.
Forestry 40: 42.
- (131) WESTVELD, R. H.
1933. THE RELATION OF CERTAIN SOIL CHARACTERISTICS TO FOREST
GROWTH AND COMPOSITION IN THE NORTHERN HARDWOOD FOREST
OF NORTHERN MICHIGAN. Mich. Agr. Expt. Sta. Tech. Bul.
135, 51 pp.
- (132) WHITE, HENRY G.
1938. AN INTRODUCTION TO THE STUDY OF TIMBER QUALITY IN LAKE
STATES HARDWOODS. Mich. Acad. Sci., Arts, and Letters Pa-
pers (1937) 23: 339-348, illus.
- (133) WILDE, S. A., and SCHOLZ, H. F.
1934. SUBDIVISION OF THE UPPER PENINSULA EXPERIMENTAL FOREST
ON THE BASIS OF SOILS AND VEGETATION. Soil Sci. 38: 383-389.
- (134) ———, WILSON, F. G., and WHITE, D. P.
1949. SOILS OF WISCONSIN IN RELATION TO SILVICULTURE. Wis.
Conserv. Dept. Pub. 525-49, 171 pp., illus.
- (135) WOOD, O. M.
1930. WINDFIRMNESS OF HEMLOCK AFTER LOGGING. Forest Serv.,
Allegheny Forest Expt. Sta. Tech. Note 2, 2 pp. [Processed.]
- (136) ZILLGITT, WALTER M.
1944. GROWTH RESPONSE IN SUGAR MAPLE FOLLOWING LIGHT SELEC-
TION CUTTING. Jour. Forestry 42: 680.
- (137) ———
1948. OPTIMUM ECONOMIC STOCKING FOR NORTHERN HARDWOODS.
Forest Serv., Lake States Forest Expt. Sta., Sta. Paper
10, 13 pp. [Processed.]
- (138) ———
1948. STOCKING IN NORTHERN HARDWOODS UNDER THE SELECTION
SYSTEM. Proc. Soc. Amer. Foresters' Meeting, 1947, pp.
320-327.
- (139) ———
1950. QUALITY OF REPRODUCTION FOLLOWING PARTIAL CUTTING OF
NORTHERN HARDWOODS. Jour. Forestry 48: 324-325.
- (140) ———
1951. CONVERTING MATURE NORTHERN HARDWOOD STANDS TO SUS-
TAINED YIELD. Jour. Forestry 49: 494-497.
- (141) ——— and EYRE, F. H.
1945. PERPETUATION OF YELLOW BIRCH IN LAKE STATES FORESTS.
Jour. Forestry 43: 658-661.
- (142) ———, W. M. and GEVORKIANTZ, S. R.
1948. ESTIMATING CULL IN NORTHERN HARDWOOD STANDS WITH
SPECIAL REFERENCE TO SUGAR MAPLE. Jour. Forestry 46:
588-594.
- (143) ZON, RAPHAEL, and CUNNINGHAM, RUSSELL N.
1931. LOGGING SLASH AND FOREST PROTECTION. Wis. Agr. Expt. Sta.
Res. Bul. 109, 36 pp.
- (144) ——— and GARVER, R. D.
1927. SELECTIVE LOGGING IN THE NORTHERN HARDWOODS OF THE LAKE
STATES WITH SPECIAL REFERENCE TO THE COST OF HANDLING
SMALL AND LARGE TREES. (Advance rpt.) Northern Hemlock
and Hardwood Mfrs. Assn., 23 pp.

- (145) ——— 1930. SELECTIVE LOGGING IN THE NORTHERN HARDWOODS OF THE LAKE STATES. U. S. Dept. Agr. Tech. Bul. 164, 47 pp., illus.
- (146) ——— and SCHOLZ, H. F. 1929. HOW FAST DO NORTHERN HARDWOODS GROW? Wis. Agr. Expt. Sta. Res. Bul. 88, 34 pp., illus.

APPENDIX

COMPOSITE VOLUME TABLE

Table 32, prepared by S. R. Gevorkiantz, will be found useful in estimating board-foot contents of standing trees for most northern hardwoods. This table is based on the premise that where the same standards of utilization are employed, differences in volume for most species are of little practical consequence, especially when other sources of error such as estimates of cull and merchantability are taken into consideration.

TABLE 32.—Composite board-foot volume table for Lake States northern hardwoods (Scribner rule)

Diameter at breast height (inches)	Number of 16-foot logs per tree						
	½	1	1½	2	2½	3	4
10.....	14	30	40	-----	-----	-----	-----
12.....	28	48	66	78	97	-----	-----
14.....	40	70	96	116	141	-----	-----
16.....	54	93	129	158	191	224	-----
18.....	72	122	168	207	248	292	355
20.....	90	156	212	262	317	366	451
22.....	111	194	262	328	392	452	563
24.....	137	236	319	399	472	549	687
26.....	165	281	381	478	566	653	820
28.....	195	331	448	559	665	764	959
30.....	227	383	522	648	772	886	1,112
32.....	260	439	598	746	888	1,019	1,278
34.....	294	500	678	847	1,009	1,159	1,455
36.....	330	564	767	955	1,136	1,307	1,644
38.....	365	633	855	1,068	1,269	1,463	1,842
40.....	402	703	951	1,183	1,406	1,631	2,052

Stump height is 1 foot. Height is the number of *usable* 16-foot logs to a variable top not smaller than 8 inches inside bark.

CONVERTING FACTORS

Table 33 may be used to convert volumes given in Scribner rule in this bulletin to International ¼-Inch Kerf rule. In the Lake States, tree volumes of sawlogs usually are determined by the Scribner rule. However, the International ¼-inch rule is coming into wider use. It is now legal in Michigan, and is favored by many foresters because of its greater accuracy and closer approximation to actual lumber tally. Factors for converting volumes from one rule into another are given in the table. For many purposes the average factor for the diameter class is accurate enough. However, if the individual factors for diameter at breast height and number of logs are used, the results will be closer to the true values.

TABLE 33.—*Factors for converting Scribner rule values to International 1/4-inch rule values: to be used as divisors (55)*

Tree diameter, breast high (inches)	Number of 16-foot logs per tree							Average factor
	1/2	1	1 1/2	2	2 1/2	3	4	
10.....	0.82	0.77	0.75					0.77
12.....	.93	.84	.82	0.78				.82
14.....	.95	.89	.87	.83	0.87			.87
16.....	.92	.89	.88	.88	.90	0.91		.89
18.....	.97	.90	.89	.88	.89	.91	0.89	.90
20.....	.98	.92	.90	.89	.91	.91	.90	.91
22.....	.99	.93	.90	.91	.91	.91	.92	.92
24.....	1.03	.94	.92	.93	.92	.92	.93	.93
26.....	1.04	.94	.93	.94	.94	.94	.93	.94
28.....	1.04	.95	.94	.94	.94	.94	.94	.94
30.....	1.03	.94	.95	.94	.95	.95	.94	.95
40.....	.97	.94	.94	.95	.95	.96	.95	.95

Stump height is 1 foot. The number of 16-foot logs is for average sawlog tree or for utilization to a variable top not smaller than 8 inches inside bark.

Some individuals may need to convert board-feet to cubic feet. The following tabulation which gives the peeled volume in cubic feet per 1,000 board-feet gross, International 1/4-Inch rule, may be used for this purpose.

Breast-high diameter (inches)	Cubic feet per M board-feet	Breast-high diameter (inches)	Cubic feet per M board-feet
10	176	24	152
12	171	26	150
14	166	28	149
16	162	30	148
18	159	35	146
20	156	40	144
22	154		

This tabulation includes volume of sawlogs only—without tops or branches. It was derived from tables 32 and 33, and Technical Note 382 (56).

HARDWOOD LOG GRADES

The Forest Products Laboratory has been active in developing improved log grades for hardwoods. The latest schedule (49) provides for three grades of logs based on specifications for standard lumber grades. Clear-faced or sound cuttings of a minimum size making up a certain fraction of the total area determine the grade of a board. Similarly, each of the four faces of a log is graded as though it were a board. The three best faces of the log determine its final grade (table 34). These grades have been adopted as standard for the U. S. Forest Service.

Hardwood construction log specifications (tie and timber logs), while developed primarily for use on the Forest Survey project, are now standard for all U. S. Forest Service work.

TABLE 34.—*Hardwood log grades for standard lumber, developed by the Forest Products Laboratory*¹

Grade factors	Log Grade 1		Log Grade 2 butts and uppers	Log Grade 3 butts and uppers
	Butts only	Butts and uppers		
Diameter (minimum)	13-15	16-19 20+	11	8+
Length (minimum)	10+	10+	8-11 12+	8+
Clear cuttings (on the 3 best faces):				
Length (minimum)	7	5 3	3	2
Number on face (maximum)	2	2	2 3	Unlimited
Yield in face length (minimum)	5/6	5/6	4/6	3/6
Sweep and crook deduction (maximum)	15	15	30	50
Cull deduction, including sweep (maximum)	40	40	50	50
Sound end defects, area (maximum)	(2)	(2)	(2)	(2)

Exceptions: In ash and basswood 12 inches d.i.b. (diameter inside bark) for grade 1 butts. Grade 2, 10 inches d.i.b. must be grade 1 surface quality.

Grade 2, 11 inches d.i.b. limited to two cuttings.

Grade 2, 8-foot and 9-foot lengths limited to 12 inches d.i.b.; $\frac{3}{4}$ yield in not more than two 3 + foot cuttings.

Sweep and crook allowance reduced $\frac{1}{2}$ in logs with more than $\frac{1}{4}$ diameter in sound end defects.

60 percent cull deduction permitted in grade 2 if otherwise of grade 1 quality.

60 percent cull deduction permitted in grade 3 if otherwise of grade 2 quality.

¹ Forest Products Laboratory Report No. D1737, 1949 (49).

² Sound end defects, such as medium to heavy mineral stain in sugar maple and slight dote in yellow birch on the small end of the log, shall not exceed one-half the log diameter for grade 1 logs and for grade 2 logs under 16 inches, and not exceed three-fifths the log diameter on grade 2 logs 16 inches and larger. Excess will lower the log one grade. When the defect is not concentrated in one spot, its extent is taken as the sum of the individual occurrences.

*Hardwood Construction Log Specifications (Tie and Timber Logs)*¹

Grading factors	Specifications
Position in tree	Butt and upper.
D.i.b., small end	8 inches or more.
Length without trim	8 feet or more.
Clear cuttings.	No requirements. Not graded on cutting basis.
Sweep allowance, maximum.	$\frac{1}{4}$ d.i.b. of small end for each 8' of length. $\frac{1}{2}$ d.i.b. for 16' logs.
Sound surface defects permitted:	
Single knots	Any number, if none has an average collar diameter in excess of $\frac{1}{3}$ of log diameter at point of occurrence. ²
Whorled knots ³	Any number provided the sum of the collar diameters does not exceed $\frac{1}{3}$ the log diameter at point of occurrence.
Holes	Any number not exceeding knot size specifications if they do not extend over 3 inches into the contained tie or timber.
Unsound defects permitted:	
Surface	Any number and size if they do not extend into contained tie or timber. If they extend into contained tie or timber they shall not exceed the limits for sound knots in size and depth.
Interior	None permitted except one shake not more than $\frac{1}{3}$ the width of the contained tie or timber and one split not over 5 inches long.

¹ Forest Service, U. S. Dept. of Agriculture. Forest Survey manual, revised April 1952. Page 50a. Footnote 3 shown here was added later.

² Knot collar diameter is the average of the vertical and horizontal diameters of the limb or knot swelling as measured flush with the surface of the log.

³ Those occurring less than 6 inches apart vertically.

HARDWOOD TREE GRADES

As an aid in timber marking, in making appraisals and in helping to size up a tract of timber, the tree classification developed by Region 9, U. S. Forest Service (47), has been used to a considerable extent in the Lake States. This combines value and vigor. The value rating is determined by the grade of the butt log or the first log above the butt-off section. The vigor and risk class is determined by the visible condition of the crown, bole, and butt of the tree. Four value classes and four vigor classes are recognized, making 12 combinations as follows.

Value Groups

1. Trees, the first logs of which are grade 1 logs.
2. Trees, the first logs of which are grade 2 logs.
3. Trees, the first logs of which are grade 3 logs.
4. Trees containing a net of less than 40 percent of their gross log scale.

Vigor and Risk Groups

A. *Trees of better than average vigor.*—Must be free from visible evidence of rot. Small dead branches less than 3 inches in diameter at base of crown resulting from natural pruning are not considered defects. The position of the crown must be dominant or codominant. The top is relatively free to grow at the sides. Small trees must have sufficient room for development under the canopy. The tree is a very good risk and may safely be left under a partial cutting.

B. *Trees of average vigor.*—Visible defects are permitted in the first 8 feet of the bole. Defects on the upper bole may consist of large branch stubs and knots. For all species of oak, not more than one branch stub 3 inches or larger and dead about 10 years or longer, or 3 blind knots apparently covering knots 3 inches or larger, will be permitted. Open rot and serious frost cracks in the tops are not permitted. The top may contain not over 10 percent of the major branches dead within the green crown. Major branches include branches from the main stem and the first branches therefrom.

The crown may be either dominant, codominant, or intermediate. Intermediate trees must have sufficient room for development under the canopy. Crowns in the main canopy may be closed on all sides.

The tree is an average risk or one that has a good chance of survival or withstanding breakage or windthrow following a moderate partial cutting.

C. *Trees of low vigor.*—The position of the crown may be either dominant, codominant, or suppressed. The top is usually sparse and contains considerable limb breakage. Many large dead branches may be present. Large lower branches may have broken from the bole. The upper as well as the lower bole may contain large frost cracks. Trees may contain seams below forked tops. There may be evidence of rot in the top or base of the tree. Extensive rot at the base of the tree irrespective of crown condition will place the tree in this class. Trees must be merchantable, or contain a net of 40 percent of their gross scale.

The tree is a poor risk or one that is likely to deteriorate or be lost following a moderate partial cut.

D. *Culls.*—Trees containing a net volume of less than 40 percent of their gross scale.

Thus, a 1A tree is one in which the first log grades as No. 1 quality and the vigor and risk are in the highest category. As carried out in practice, any tree in value group 4 is usually classed as a cull (wholly unmerchantable), so that in reality only 10 classes are used.

DEDUCTION FOR CULL

There is a wide difference between gross volume and net volume in most old-growth northern hardwood stands because of heavy cull. Only with adequate allowance for cull can accurate estimates of net volume be made.

Two methods of determining cull in northern hardwoods have been developed at the Upper Peninsula Experimental Forest from a 1944 study (142). Both methods, given below, are based on an examination of outward signs of defect—such indicators as cracks, holes, or fruiting bodies of fungi. Even hollow centers can be detected by sounding with an ax. The first method is designed for special studies involving cull. The second method, simpler and more quickly applied, will suit the needs of management better.

Detailed Method of Determining Cull in Northern Hardwoods

Six classes of defects are recognized:

Class 1.—Includes small broken or dead limbs, sterile conk, ingrown bark, and small rotten burl.

Class 2.—Hidden rot, small crack, slight crook or sweep in first log, slight to moderate crook or sweep in intermediate or top log, small hole, small scar, small straight seam.

Class 3.—Large broken or dead limb, broken or dead top, large crack above first log, excessive crook or sweep in top log, large straight seam.

Class 4.—Canker above first log, active conk above first log, moderate crook or sweep in first log, excessive crook or sweep in intermediate log, large hole above first log, large rotten burl, large scar.

Class 5.—Butt rot, active conk in first log, large crack in first log, excessive crook or sweep in first log, large hole in first log.

Class 6.—Canker in first log, spiral seam.

The average percentage loss in volume caused by each class of defect is given for five merchantable heights in table 35.

In order to use the averages in table 35 to determine cull in a given standing tree, multiply its gross volume by the average cull percent for any defect present or by the sum of percents in case more than one defect is present. If the cull percent of a given tract is desired, a suitable sample is taken and record kept of total gross volume and total cull volume in the sample. Dividing this cull volume by gross volume gives an estimate of the cull percent in the stand. The cull percent computed for the sample can be used to reduce the total gross volume of the tract to net or merchantable volume.

Shortcut Method of Determining Cull Percentage in Northern Hardwood Stands

For each 20- to 40-acre tract of northern hardwoods, examine a minimum of 40 trees as they come in the stand, looking for the following defects:

Major visible defects.—Butt rot, conk, canker, large or spiral seam, large crack, large scar, large hole, large rotten burl, large broken or dead limb or fork, broken or dead top, serious crook or sweep, abnormally short merchantable length.

Minor defects.—Ingrown bark, sterile conk, small seam, small crack, small scar, small hole, small rotten burl, small broken or dead limb, slight crook or sweep.

Record the cull class for each tree on the basis of visible defects noted:

Class 1.—Trees with no major visible defect; minor defect permitted.

Class 2.—Trees with one major visible defect.

Class 3.—Trees with two major visible defects.

Class 4.—Trees with three or more major visible defects.

Determine the gross volume of each sample tree. Use board-foot volume as shown in table 32. Compute the cull volume of each tree by applying the

following percentage deductions to gross volumes: Class 1, 5; class 2, 15; class 3, 35; class 4, 60 (if 100-percent "cull" trees are excluded from the sample) or 70 (if 100-percent "cull" trees are included in the sample). Determine the gross volume and the cull volume for the entire sample. Divide the total cull volume by the total gross volume to determine the cull percent applicable to the stand.

TABLE 35.—Average percentage losses of board-foot volume by defect classes

Defect class	Average cull percent in trees having—				
	1 log	2 logs	2½ logs	3 logs	4 logs
1.....	5	4	4	3	3
2.....	9	8	6	6	5
3.....	20	17	14	13	11
4.....	26	24	20	17	15
5.....	39	35	28	25	22
6.....	56	50	41	36	32

As the number and seriousness of defects in old-growth northern hardwood stands are reduced by good management, the importance of cull in volume appraisals will diminish. With as much as 50-percent cull in overmature, decadent stands, it is a critical item. With cull reduced to perhaps 10 percent of gross volume in managed stands, it is more in line with other errors of cruising.