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Oak Forests of Northern Michigan

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Large areas of land in the northern part of the Lower Peninsula of Michigan are characterized by scrubby-looking clumps of oak sprouts three to 15 feet high, scattered in the low brush (Figure 1). Much of this land, particularly in the northern and eastern counties, has been burned over many times and the last fire has usually occurred within a few years. Each fire has killed most or all of the trees. Often the blackened stems of small trees killed in the last fire remain. In places, occasional larger fire-scarred oaks or thick-barked Norway pines have survived. It is not surprising, considering their appearance, that these oaks are looked upon as worthless scrub and are often called "scrub oak."

Fig. 1.—TYPICAL "SCRUB OAK" LANDS, OSCODA COUNTY

These much-burned oak forests occupy chiefly the dry, sandy, gravelly, morainal hills and a part of the high sandy plains of glacial stream valleys in an irregular belt from Muskegon, north and east to Alcona and Alpena Counties. Large areas of the type are found in Muskegon, Oceana, Newaygo, Lake, Manistee, Grand Traverse, Crawford, Roscommon, Ogemaw, and Oscoda Counties. The areas in which oaks predominate are shown on the map, Figure 2. The sandy outwash plains which are predominantly and more commonly occupied by jack pine than by oak are not included in the shaded portion of the map or, except incidentally, in the subject matter of this bulletin. The area of the oak lands north of a line between Muskegon and Bay City is estimated to be about one and a third million acres. Such an area is too large to be

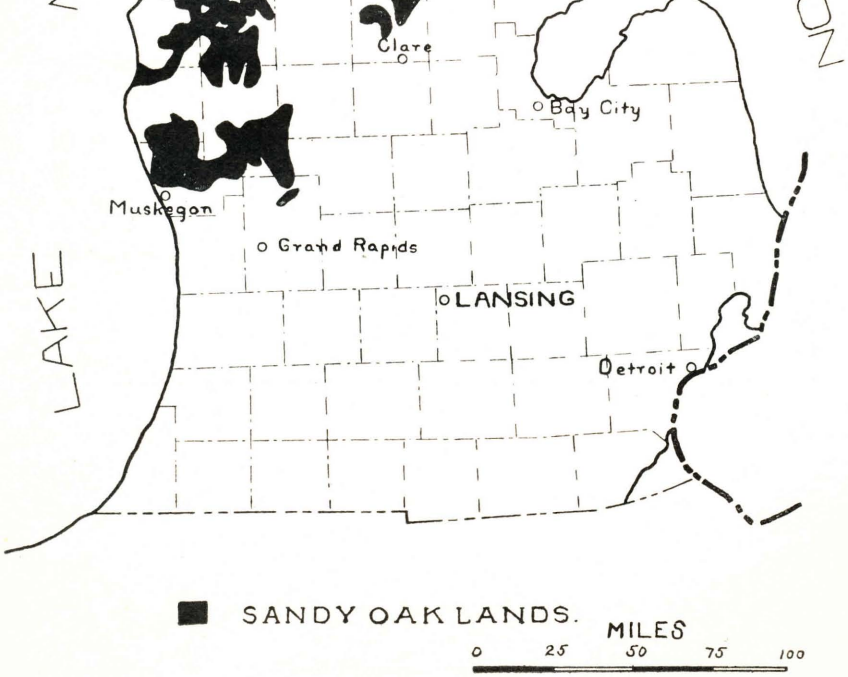

Fig. 2.—Location of "scrub oak" land in the northern part of the Lower Peninsula of Michigan.

neglected and emphasizes the need for a study of the problems of the best use of these oak lands.

On the more level portions, settlers, in the past, have tried to farm and have usually failed. These lands contribute in some counties a large share to the tax-delinquent lists which indicates that they are not considered worth paying the taxes of 10 cents or 15 cents an acre a year. Where fires have burned recently, the tree growth is so small that it has no present sale value and is generally believed to be of doubtful future value. These lands have, however, a considerable value for game cover which value is being realized more fully each year.

Possible Solutions

The problem of the "scrub oak" lands may be resolved into a series of questions to be answered in so far as may be possible. Will these lands become more valuable as the oaks grow older and larger? Will they become more valuable with the progress of natural conversion from oak to pine? Can they be made more valuable by proper forest management of the oak? Can they be made more valuable by conversion of oak to pine by planting?

As a basis for answering these and related questions, 77 different sample areas were studied intensively during the summer of 1926. Stem analyses were made of 142 sample trees from these areas. The sample plots were distributed in representative stands in the counties where the oak occupies large areas. Special attempts were made to find and analyze sample areas which would represent the future development of the present stands under more effective fire protection and forest practices. Obviously, this amount of data is not conclusive for a forest type occupying one and a third million acres, but it is believed that the conclusions are suggestive and reasonably reliable.

HISTORY AND ORIGIN OF THE "SCRUB OAK" FORESTS

Original Forests

The old charred stumps which still remain, indicate that the "scrub oak" lands were originally timbered with pure Norway pine or a mixture of white and Norway pine. The present old growth forest in Interlochen State Park offers an example of the original forest which has been preserved adjacent to a typical area of "scrub oak." This stand consists of a few large trees of white and Norway pine with an understory of varying sizes of oaks and other species. The composition of the stand is shown in Table I. Such areas are now exceedingly rare. However, the evidence which now remains indicates that the original forest in general probably contained a larger proportion of Norway pine and jack oak and less white pine, red oak, red maple, and beech, than the stand shown in Table I.

A pine forest 60 to 80 years old in the heart of the oak hills region in Ogemaw County also shows the present prevalence of oak, particularly of smaller sizes, in the stands which formerly were pine. The figures are

be merchantable at the time of logging in the region. Many of the larger trees have old fire scars at the bases but there was no evidence of recent fires. The more than 7,000 red oak seedlings to the acre illustrates the ability of the comparatively few oaks which were present in the old pine stands to seed in abundantly under the pine.

Table II. Seventy-Year-Old Pine Forest: Ogemaw County

Stand Table

D. B. H. Inches	NUMBER OF TREES PER ACRE*						
	White Pine	Norway Pine	White Oak	Red Oak	Black Oak	Red Maple	Large-tooth Aspen
½ or less	666	100	33	7133	33	133	33
1							
2							
3							
4							
5		3					
6	3	3	3				
7	3		7	3		7	
8	16		3	3	7		
9	3	3	10	20	3	3	3
10	10						
11	3	3		14	7	3	
12	3			7			
13	10	3		7			
14	3				3		
15	3						
16	10			3			
17	3						
18				3			

*Basis 0.3 acre.

The presence of scattering white, black, and red oak in the forests of white and Norway pine was noted in Clare and Lake Counties by Beal in 1888 (1). White and red oak in the white pine and Norway pine types, and scarlet oak in the jack pine type in Roscommon and Crawford Counties were recorded by Livingston in 1905 (11). A second growth forest of white, Norway and jack pine, jack, white and red oaks, and other species about 50 years old which came in on a sandy ridge in Benzie County following a fire in the original forest of pine and oak at that time, is described by Waterman (23). The constant presence of red oak and white oak in the Norway pine, white pine upland type in Manistee County, is brought out by Harvey (8). In the stand which he studied, he found the white oak to be more commonly represented than red oak in trees from 8 to 22 inches in diameter. Neither species was represented in as large numbers as the pines but formed an inconspicuous part of the stand as a whole.

There is, therefore, ample evidence of the presence of the oaks in the original old growth white and Norway pine forests which once occupied these sandy "scrub oak" lands. (Figure 3).

Fig.3—Oak sprouts following fires in Norway pine forest, Chippewa National Forest, Minnesota. If the pines were cut and the slash burned, this would become "scrub oak" land.

Results of Cutting—Mixed Stands

Lumbering began in this region of Michigan about 80 years ago. The first sawmill on the West Shore was established at Manistee in 1841. Mio, as a representative of the later development of pine lumbering, was settled in 1880. Much of the early logging took only the large choice

few years after logging. Many of them were set intentionally to clear the land and no one tried to stop them except when buildings or a village were threatened. Some of the fires, like that of October 8, 1871, which started by destroying the city of Manistee and swept east entirely across the State, are matters of historic record. Most of them are not recorded but the trees themselves afford ample evidence of the fires. Out of the 77 plots chosen for the most part to represent areas as little burned as could be found, 66 showed evidence of one or more fires with an average of three fires since the origin of the predominating stand. This record could include only fires serious enough to scar the older trees or to kill some of them and thus start a new crop of sprouts. Fifty-three of the plots had been heavily burned two or more times, with an average period of nine years between fires. Doubtless many less severe fires had left no definite evidence of their passage.

Further evidence of the prevalence of fires up to within the last 15 years is found in the fact that over 60 per cent of the area of oak lands in the five counties in the Lower Peninsula covered by the Land Economic Survey is in the 0-3 inch diameter class. These sizes correspond to ages of less than 15 years.

The fires which burned on the average every nine years were hot enough to scar or kill many of the oaks of moderate size in spite of the fact that owing to their thick bark they are the most fire resistant species with the possible exception of the larger pines which have their crowns above the reach of a ground fire. These fires killed all of the smaller pines and other species, leaving only an open stand of fire-scarred oaks. The new crops of oak sprouts after each fire have formed the prevailing present stands. Thus, repeated fires are responsible for the extensive stands composed almost exclusively of small oak sprouts which characterize the "scrub oak" lands.

THE "SCRUB OAK" FORESTS

Although commonly called "scrub oak," none of the oaks on these sandy lands in northern Michigan are really "scrub oaks," as are the species in the east and south which never attain the size of merchantable timber.

Species of Oak and their Ranges

All of the five oaks of the "scrub oak" lands are tree species, which, when given a chance, make merchantable timber. The five species are white oak (*Quercus alba* Linnaeus), jack oak (*Q. ellipsoidalis* E. J. Hill), red oak (*Q. borealis* Michaux f.), black oak (*Q. velutina* LaMarck), and scarlet oak (*Q. coccinea* Muenchhausen). The white oak occurs from Menominee, Grand Traverse, and Crawford Counties, southward to Texas and western Florida and west to southern Minnesota and eastern Iowa. Red oak extends from Quebec, the north shores of Lake Huron and northern Minnesota, south to Pennsylvania, central Minnesota, southern Wisconsin, Iowa, and in the mountains to North Carolina. Jack oak is found from eastern Minnesota, northern Wisconsin, and northern Michigan, south into Iowa, Illinois, and Indiana. Black oak reaches its northern limit in central Michigan and was found commonly only in the strip of sandy oak lands along the west side of the Peninsula from Muskegon to Traverse City. Its general range extends from Maine and Vermont to Iowa and south to western Florida and eastern Texas. Scarlet oak is found from Maine through southern Ontario and central Michigan to southern Wisconsin and Missouri. It extends southward to Oklahoma, Indiana, Illinois, and the District of Columbia. Although it is supposed to reach the northern limit of its range in southern Michigan, a few specimens were found as far north as Oscoda County.

With the exception of scarlet oak, the other species all formed important constituents of the stands. Scarlet oak was found only sparingly. It is much less generally distributed than the jack oak and is unimportant. Jack oak is a species which has been described comparatively recently and has evidently been called scarlet oak in the past by some of those who have worked in the region.

Jack, black, and scarlet oaks are variable and are difficult to distinguish at best. Fortunately, however, the three species seem to be comparatively similar in habits so that the distinction between them is not essential for most practical purposes. Fortunately also, scarlet oak is not common and the black oak is largely confined to the western side of the Peninsula whereas jack oak predominates in the central and northern part. The foliage of younger plants less than eight or 10 years old is rarely characteristic of older trees. The size and form of leaves in the lower and upper parts of the crown of the same tree are often so different that it is hard to believe that they came from the same tree.

The late G. B. Sudworth offered the following notes based on his experience of the most useful characteristics to distinguish these three species: "As a rule jack oak uniformly has much smaller winter buds rarely exceeding ⅛ of an inch in length as compared with buds of scarlet and black oak which are longer, often from over ⅛ to ¼ of an inch long. Jack and scarlet oak are very similar in the form of their

of jack oak and white oak with small proportions of Norway pine, jack pine, red maple, and black cherry are found on the slopes and dry, morainal ridges. (3) White oak-black oak type. White oak and black oak with or without smaller proportions of jack oak and red oak and other species including red maple, large-tooth aspen, sassafras, white pine, Norway pine, jack pine, and black cherry are found on the sandy plains southward along the Lake Michigan side of the Peninsula. (4) Red oak type. Red oak with red maple and varying proportions of white oak, large-tooth aspen, white pine, Norway pine, paper birch, and sometimes sassafras are found as a type on the better soils of slopes and ridges. Variations in these types and transitions between them are frequently found. For some purposes, distinctions between the four principal types are not essential. They correspond, however, to differences in soil, topography and other physical factors and also represent differences in growth and development of the trees themselves which may often be useful.

Those who have worked in the region have noted corresponding distinctions on the oak lands. Sherrard (16) working in Roscommon County in 1902, distinguished oak flats, oak ridge, and jack pine plains. Harvey (7) in Lake County, classified the oak lands into black oak-white oak and jack pine-oak.

For the present and for some time in the future, the other species which are associated with the oaks may be considered comparatively unimportant. The pines have as great or greater value than the oaks but they are found with the oak on only a small fraction of the total area. Where jack pine predominates in mixture with oak as it does in parts of Lake County and elsewhere, the stands were considered to be of the jack pine type and hence not a part of the present project. Where oak predominates, the jack pine is being superseded and usually forms a

minor and unimportant part of the stand. The red maple, aspen, paper birch, and black cherry occur as scattered individuals with the oaks and are not likely to grow to merchantable size on the poor sandy soils. In the southwestern part of the region, sassafras persists and multiplies after fires and may become a troublesome weed tree.

Occurrence of Oak Types in Relation to Soils

The distribution of the four types of oak forest which have been described corresponds quite closely to the distribution of certain soil types which have been mapped and described in the Soil Survey reports of the United States Bureau of Soils and in the maps and reports of the Michigan Land Economic Survey.*

The following soil types on which the oak types were found are those which have been named and described in the Soil Survey reports:†

The jack oak grows chiefly on the Grayling, Ottawa, and to some extent on the Roselawn sands.

The jack oak-white oak type is found chiefly on the Roselawn sands and occasionally on the Roselawn sandy loam and Grayling sand.

The white oak-black oak type occurs usually on the Plainfield and Coloma sands and to a less extent on the Rubicon sand and Ottawa fine sand.

The red oak type is found on the Roselawn sand and sandy loam, Rubicon sand, Kalkaska sand, Plainfield fine sand, and Emmet sandy loam.

These soils comprise a group of closely similar upland well-drained soils which may be described in general as sands or light sandy loams to depths of three to five feet or more. They are characterized by a very thin humus layer, low moisture content, low moisture-holding capacity, acid reaction to three feet or more, and low fertility. The Grayling sand, characteristic of the jack pine plains as well as of the jack oak type, is the poorest of the group and represents the limit at one extreme on which, of the oaks, only jack oak or a little white oak will grow. At the other extreme, the red oak with other oaks and associated species is found on some of the sandy loam or fine sandy soils which have low to fair humus content, low to medium moisture-holding capacity, acid surface soil and a limy sub-soil within reach of tree roots. These are soils of medium fertility, although they are often too rough or stony for agricultural development. The jack oak-white oak and white oak-black oak mixtures occur on the soils which are intermediate in character between the two extremes just mentioned. The vertical profile of these soils beginning at the surface includes a thin layer, ¼ to 1 inch thick, of leaf litter and humus, a thin layer usually less than 1 inch of dark-colored mineral soil heavily mixed with humus, a more or less well-defined layer of gray soil 1 to 10 inches thick, and a brown layer 1 to 12 inches thick underlaid by a sub-soil of yellowish or straw colored sand more or less mixed with gravel. In most places, the dark humus, the gray, and the brown layers are thin and inconspicuous.

The soil properties of the different forest and soil types overlap and do not show marked distinctions. They may therefore be combined for

*The counties for which surveys and maps are available in the oak region include, Ogemaw, Roscommon, Manistee and Wexford.

†The assistance of J. O. Veatch in the identification of the soil types is gratefully acknowledged.

the smallest amount of soil moisture expressed as the percentage of dry weight at which plants can exist. If the actual moisture content of these soils, due to excessive drainage and evaporation during periods of dry weather, were reduced below the hygroscopic coefficient heavy mortality among the trees and other vegetation would result. It is probable that deficient moisture in the soil during dry periods in these sandy soils does actually cause heavy losses among small seedling trees.

Sites and Site Indices

The differences in soil type are associated not only with differences in the composition of the oak forests but also with differences in site quality and in productivity for forests of essentially the same composition. Thus, Roselawn sand represents a distinctly better site quality for jack oak than does Grayling sand; Roselawn, Rubicon, and Plainfield sands represent poor sites for white oak; Coloma sand is better but still only a moderately good quality site; and Roselawn sandy loam represents a good site.

The height growth or total height of dominant trees, those which have had ample light and growing space in relation to their age, furnishes a measure of the productivity of the soil which is convenient to determine and which is comparatively free from the effects of differences in density of the forest cover. The site index is the figure for the average total height of the dominant trees in the stand at 50 years of age, the average height which dominant trees in a younger stand will have, or, in an older stand, are assumed to have had, at 50 years. Figure 4 gives the curves of site index for the oak forests of northern Michigan.

Certain kinds of trees and smaller plants are associated with the oaks only on the better sites and may therefore be used to indicate favorable growing conditions for the oaks. These include northern white pine,

dogwood (*Cornus circinata* L'Her and *Cornus paniculata* L'Her), choke cherry, hawthorn, false foxglove, bedstraw, wood betony, and pyrola. Certain other species are associated with oak stands on the medium or better than medium quality sites. These include viburnum (*Viburnum acerifolium*), Canada Mayflower, twisted stalk and rattle snake plantain. No species were found which were confined to or indicated consistently only the poor sites. The occurrence of any one or more of the foregoing species, however, may be taken as an indication of a better than average site for oak.

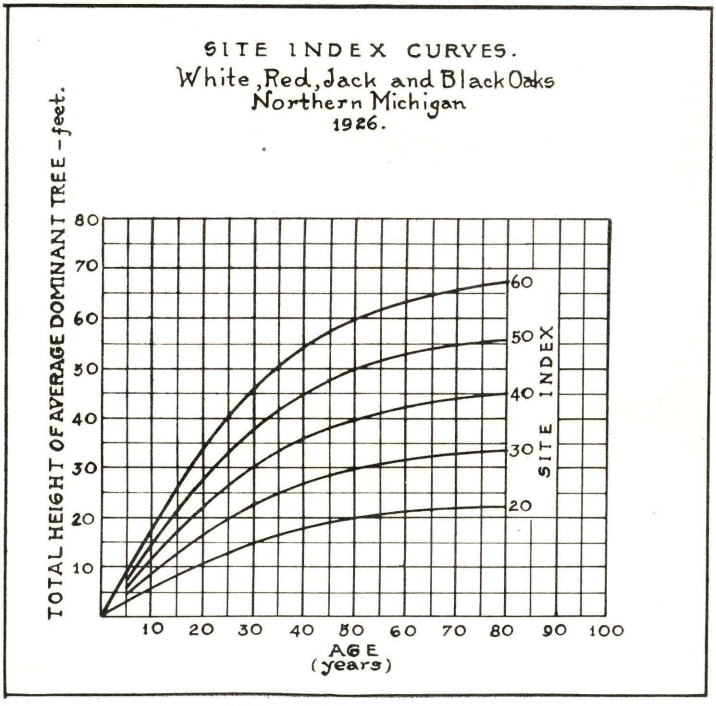

Fig. 4.—Site index curves.

Stands

The oaks on the sandy oak lands vary widely in size and density and condition. Unfortunately, most of the stands which are more than 10 years old and which, therefore, contain trees more than two inches in diameter have been burned over at least once and often several times. Each fire has killed some trees and scarred others. Those that are killed are replaced by groups of sprouts from the stumps. Thus, the existing stands characteristically contain a comparatively small number of larger trees more or less fire scarred with larger numbers of smaller trees of different ages occurring as groups of sprouts. The variation in the history and consequent present condition of the stands makes it difficult to give general figures which will be at all applicable. However, by selecting small areas which represent better than average conditions, it is possible to get some idea of what the oak stands will produce if they are protected from fire.

110	90	90	90

These figures represent rough averages of the better stands that were measured and indicate the number of trees that are found in existing well-stocked stands of corresponding ages. It is probable, therefore, that

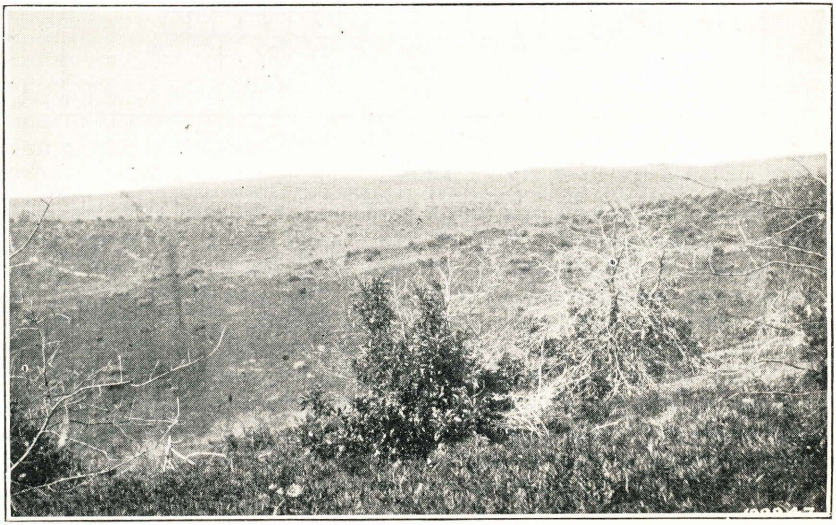

Fig. 5—The "scrub oak" lands at their worst. Only scattered clumps of jack oak sprouts remain.

well-stocked stands under forest management will contain a larger number of trees than those given. Occasional stands were found which did have decidedly more trees than the figures indicate; for example, one 57-year stand had 530 trees per acre.

It is true, however, that most of the present stands have smaller numbers of trees than those indicated. For example, it is not uncommon to find stands as young as 40 years which have less than 100 trees to the acre of one inch D. B. H. or over. Few stands were found which did not have at least 50 trees to the acre, Figure 5. Apparently, even repeated fires, since they cannot burn the roots in the soil, rarely reduce the number of trees in the sandy oak lands below this minimum of 50.

Another and more reliable measure of stocking is the basal area per acre which is defined as the total cross-sectional area at 4½ feet from the ground of all the trees on an acre. On the good sites with site indices of 40 and over and on the poor sites with site indices less than 40 for well-stocked stands, the basal areas are indicated in the following table:

Table V. Basal Area Per Acre

Age Years	Good Sites	Poor Sites
	Basal Areas in Sq. Ft.	Basal Areas in Sq. Ft.
10	11	6
20	26	15
30	57	30
40	74	50
50	86	68
60	92	77
70	97	..
80	101	..
90	104	..

As in the case of number of trees, however, the majority of the stands are not as well-stocked as the above figures would indicate. On the good sites, basal areas at 40 years as low as 40 sq. ft. and at 60 years as low as 50 sq. ft. are not unusual. On the poor sites at 60 years, there may be only 30 sq. ft. of basal area per acre. Occasional areas had exceptionally large basal areas per acre as, for example, one 40-year stand with 86 sq. ft., and a 65-year stand with 110 sq. ft. These figures, which stand out above the values for most of the better-stocked stands which were measured, suggest that it will be possible to grow stands of oak in the future under forest management which will yield higher volumes than can be expected from the present stands.

Comparison of the figures for basal area and number of trees per acre with those for the northeast as given by Frothingham (5) also indicates that even the better existing oak stands in northern Michigan are not as well-stocked as the sites would support. At corresponding ages, the Michigan stands are decidedly inferior both in number of trees per acre

lands are most prevalent indicate that the oak forests are sufficiently well-stocked to be promising on only about one-third of their area and are too poorly stocked to make merchantable stands on more than one-fourth of the area. On the remainder, they will have a moderate or low value where they are favorably located with respect to markets. On the whole, the present condition of the oak forests in northern Michigan, as judged by the open, widely-spaced stands over large parts of the area, is not favorable to the production of high yields of wood products or of high money returns to the acre.

VOLUMES OF TREES OF DIFFERENT SIZES

For use in estimating the contents of standing timber, volume tables have been prepared to show for sound trees of different diameters and heights the volumes in cubic feet, in cords and in board feet by the International rule, one-eighth inch kerf. The International rule gives results in board feet which closely correspond to the amounts of lumber which are obtained from logs sawed in a reasonably efficient mill. The rule is thus fair to both the buyer and seller of standing timber and is to be recommended in preference to the Scribner or other log rules which over-run or under-run, depending on the sizes of the logs, what is actually obtained in the saw mill. The values in the volume tables are rarely accurate for individual trees but should give close results for large numbers of trees such as are estimated or measured over considerable areas. The volume table figures are given in Tables VI, VII, and VIII. The values are limited to small sizes because stands of larger trees are almost non-existent in the region at the present time. The figures in

these tables are for sound, reasonably straight logs and make no allowance for defects such as rot, crook, or shake. Allowances in percentage reductions for these defects should be made for each tract as the timber is estimated.

Table VI. Volume Table for Second-Growth Oaks in Cubic Feet

Quercus ellipsoidalis, Quercus alba, Quercus borealis, Quercus velutina

Diameter breast high	Total height of tree—feet											Basis
	15	20	25	30	35	40	45	50	55	60	65	
	Total Volume—Cubic Feet											
Inches												Trees
2	.22	.29	.37	.4								7
3	.39	.51	.64	.77	.9	1.0						14
4	.6	.8	1.0	1.2	1.4	1.6	1.8	2.0				23
5	.9	1.2	1.5	1.8	2.1	2.4	2.7	2.9	3.2			26
6		1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.4			20
7			2.7	3.2	3.7	4.3	4.8	5.3	5.9			20
8				4.1	4.8	5.5	6.2	6.9	7.6	8.2		11
9				5.2	6.0	6.9	7.8	8.6	9.5	10.3		4
10					7.3	8.4	9.4	10.5	11.5	12.6	13.6	6
11						10.1	11.3	12.6	13.9	15.1	16.4	2
12						11.9	13.4	14.8	16.3	17.8	19.3	1
13						13.7	15.5	17.2	18.9	20.6	22.3	
Basis	1	8	9	28	27	18	24	15	3	1		134

Volume includes stump, stem, and top without bark.
Cubed in 8-foot sections by Smalian's formula.
Block indicates the extent of the original data.
Difference between total volume of trees used as a basis and volume as taken from the table—0.08 per cent.
Average deviation of individual tree volumes from interpolated tabular volumes—8.3 per cent.

Table VII. Volume Table For Second-Growth Oaks in Cords

Diameter breast high	Total height of tree—feet										
	15	20	25	30	35	40	45	50	55	60	65
	Total Volume—Cords										
Inches											
4	.008	.011	.014	.016	.019	.022	.024	.027			
5	.012	.016	.020	.023	.027	.031	.034	.038	.042		
6		.020	.025	.030	.035	.040	.045	.050	.055		
7			.032	.039	.045	.052	.058	.065	.072		
8				.049	.057	.065	.074	.082	.091		
9				.061	.071	.081	.091	.10	.11	.12	
10					.085	.098	.11	.12	.13	.14	.16
11						.12	.13	.15	.16	.17	.19
12						.14	.15	.17	.18	.20	.22
13						.16	.18	.19	.21	.23	.25

Standard cords, 4 x 4 x 8 feet.
Total volume of peeled stem.
Compiled from total cubic-foot volume table by dividing the volume per tree by the number of cubic feet per cord for each D. B. H. class as given in United States Forest Service Bulletin 96.
Block indicates the extent of original data.
Basis same as given in total cubic-foot volume table.

Operators cutting oaks in northern Michigan at present often do not utilize the trees as closely and therefore get less volume for trees of corresponding sizes than the tables indicate. On two cutting operations where measurements were made, it was found that for trees 10 to 12 inches in diameter at breast height, only one 8-foot tie was cut with a top diameter of eight or nine inches inside bark. From trees 12 to 23 inches in diameter at breast height, from one to one and a half 16-foot logs were cut to diameters in the tops ranging from 10 inches for the smaller sizes up to as much as 13 or 15 inches for the larger sizes.

It is often advisable not to cut the trees which are less than 12 inches in diameter from which it is possible to obtain only a small volume of product usually of low grade and value. In the larger trees, however, which yield one or more good logs, it should be the aim to utilize the stem to as small a diameter in the top as possible. The larger branches may also be used wherever there is a market for cordwood or other products which may be obtained from the smaller sized pieces.

Tie specifications may be obtained from any railway agent. The specified dimensions in Michigan for the different grades are as follows:

All ties shall be eight feet long. They shall measure as follows through both sections between 20 and 40 inches from the middle of the tie:

Grade	Minimum Dimensions Sawed or Hewed Top and Bottom Inches
1	6 x 6
2	6 x 7
3	6 x 8, 7 x 7
4	7 x 8
5	7 x 9

Grades 4 and 5 of oak are readily absorbed in almost any quantities by the steam railroads. In order, however, to obtain a tie of these two grades, the standing tree must usually be not less than 13 inches in diameter outside bark at breast height so that the top of the eight-foot section will have a diameter of 11 inches inside bark. Trees 11 inches in diameter at breast height will have a diameter inside bark of nine inches eight feet above the stump and will produce one tie of grades 1 or 2. These low grade ties are not always marketable in large quantities to the steam railroads and it is often better to arrange to sell them to electric roads. White oak is more durable and therefore commands a slightly higher price than red, black, or jack oak.

DEFECTS AND DECAY

A large proportion of the defects and decay in the present stands of oak in northern Michigan has been caused directly or indirectly by fires. Most of the larger trees above six inches in diameter, and many of the smaller ones, have been scarred at their bases by one or more fires. Each severe fire enlarges the scar, and, although the trees gradually extend callouses over the scar from each side, the frequent recurrence of fires has usually prevented the closing of the wounds. The exposed wood dies and checks and fungi which cause decay thus gain entrance and work into the heartwood. As a result, a considerable number of the oaks have areas of rot at their bases. The decay in the center was found usually to be limited to an area only one to four or five inches in diameter. The decay along the fire scars just beneath the exposed surface was rarely deep enough to cause an appreciable reduction in the volume of the butt log. Fortunately oak wood is unusually resistant to decay and the rot usually does not extend more than one or two feet above the stump. In only four out of 30 trees which showed rot at the base was decay found as far up as the top of the first eight-foot section above the stump.

Ring shake of small diameters in the larger trees, which also begins along the calloused fire scars, is another rather common form of defect in the first foot or two above the stump. Not uncommonly insect galleries about half an inch in diameter were found at different points in the heartwood of the trees. They were probably the work of a carpenter worm. These galleries would cause some degrade of boards through which they passed, but they would not in any case cause any large aggregate percentage of the volume of the tree to be defective.

Even in those oak stands which have been damaged by repeated fires and thus exposed to attack by fungus diseases and other causes of defect, the total amount of defect or decay due to all causes will usually be less than 5 per cent of the gross volume of the trees and rarely more than 10 per cent.

GROWTH

The heights of dominant trees at different ages probably provide the most useful information on height growth because, first, they are the basis for site determinations by the use of the site index, and, second, the dominant trees include the ones which will remain throughout the life of the stand and furnish the largest part of the volume of wood when

The average figures correspond to the heights attained on an average site. The maximum figures correspond to a very good site and the minimum to a poor site. The averages for white oak by itself are two or three feet lower than the figures for the other four oaks combined. The minimum is quite similar whereas the maximum for white oak is five to 13 feet lower than for the jack, red, and black oaks. On the sandy soils the oaks rarely exceed 55 or 60 feet in height at any age. The figures for the average heights of the dominant trees in the table may be used to represent the average heights of stands on the better sites at corresponding ages.

The average diameters at breast height of the oak stands at different ages, excepting only the poorest, are shown in tabular form below.

Table X. Diameter of Oaks at Different Ages

Age Years	Average D. B. H.	Average Dominant or Maximum Average D. B. H.
10	1.3	1.4
20	2.5	2.7
30	3.7	4.0
40	4.6	5.2
50	5.5	6.4
60	6.3	7.4
70	7.0	8.4
80	7.7	9.4
90	8.4	10.3

The figures in the second column are based on all the trees of the given age in each stand. The average trend of increase of diameter with age was read from the curve fitted to these points. The third column contains the average diameters of all the trees in the better stands. The figures may also be taken to represent the diameters of the average dominant trees in average stands. As the stands approach merchantable size, the better stands or the dominant trees are one to two inches larger in diameter than the average tree in the average stand.

For ties or lumber, a stand should have an average diameter at breast height of at least 9 or 10 inches in order that there may be at least 50 trees per acre larger than 10 inches in diameter. Therefore at past and present rates of growth, these oak stands would have to be 100 years old or older in order to be considered merchantable for ties or saw timber. It has been shown, however, that in some cases on good sites more rapidly growing stands may produce as many as 50 trees to the acre 10 inches in diameter and over at the age of 80 years. This corresponds with the evidence in the growth data that some stands under better growing conditions reach average diameters of nine inches in 70 years. On the other hand, stands which have been severely and repeatedly burned, may average only six inches in 80 years. There is a slight difference in the rate of diameter growth as between red and jack oak on the one hand and white oak on the other. Dominant trees of the former species are usually one or two inches larger in diameter at 40 years than the white oak or than the average dominant trees represented in the third column of Table X.

Growth in Volume

The present stands of oak in northern Michigan have small volumes and low rates of growth. This is due to a combination of causes including repeated fires in the past, poor soils and sites, and the fact that all but the red oak are at the northern limits of their ranges and are therefore growing in a comparatively unfavorable climate.

If the stands of oak are even-aged or consist predominantly of trees of the same age, the growth may be expressed conveniently as the yield per acre at different ages. The yield figures may then be converted into rate of growth expressed as mean annual growth per acre by dividing the yields by the corresponding ages. On this basis the figures in the following table represent the total volumes in cubic feet and in cords and the mean annual growth in cubic feet per acre.

damaged by fire.

The average annual growth of only 20 cubic feet per acre per annum corresponding to the yield of 13 cords in 50 years is notably low by comparison with the growth of oaks in other regions (5 and 19) or with the growth of pines and aspens in the same region and even on the same soil types. Many of the existing stands, however, are growing even more slowly than these figures indicate. Examples may be mentioned of stands 30, 55, 60, 80, and 96 years old which have mean annual growth rates of only six to nine cubic feet per acre per year. The yields and growth rates of the better stands which are comparatively well-stocked are distinctly more favorable than those for the average stands. At 50 years they have averaged 31 cubic feet per acre per annum corresponding to a total yield of 19 cords. This is still a very moderate rate of growth for stands which are well-stocked. A few individual areas measured show somewhat higher rates, for example, a 42-year-old stand had grown at the rate of 36 cubic feet per acre per year, and a 35-year-old stand had grown 46 cubic feet. Even the best rates of growth which were found are low in comparison with the growth of jack pine which produces 50 to 70 cubic feet per acre per annum on the poorest of these same sandy soils.

It may be noted that the best growth was found in those stands which were comparatively well-stocked, which were grown on sites represented by site indices of over 45 and which had been protected from or had escaped fires at least during the last 20 or 30 years. The variability and small amount of the available data do not justify the presentation of generalized figures for rates of growth for different site classes or for different degrees of stocking or different combinations of species of oak.

Although it may sometimes happen that the yield of the well-stocked stand on a poor site may be equal to that of a poorly stocked stand on a good site, it is generally true that the better the site or the better the stocking, the higher will be the growth or yield per acre at any given age. These two factors are more important in their effect on growth than are differences in the proportion of different kinds of oak in the stand.

In using the figures of growth and yield in predicting the future growth on any specific area of oak, a comparison of the basal area of the specific stand with the figures for comparatively well-stocked stands given in Table V will provide a conservative indication of the amount by which the volume at any age may be expected to under-run or exceed the yield as given in the preceding table. For example, if a 30-year stand is found to have, at the present time, a basal area of 30 square feet to the acre, which is about one-half of the 57 square feet at 30 years shown in Table V, it may be expected to have not less than one-half of the yield of 1800 cubic feet at 60 years as shown in Table XI.

Only a few of the areas measured were old enough to have sufficient volume in board feet to be considered merchantable. The three best stands had 3,800 board feet to the acre at 47 years, 4,500 board feet at 65 years and 6,100 board feet at 116 years, respectively. At the other extreme, a 96-year-old stand had only 3,000 board feet to the acre.

The two areas of oak which had been cut recently were 70 and 116 years old respectively and did not yield more than five or six thousand board feet, International scale, to the acre. Actually, considering the rather poor utilization of the trees, the cut was probably less than 5,000 board feet to the acre.

All the evidence on growth and yield of the oaks supports the conclusion that their growth is slow at best and to that extent the holding of lands covered with such young growth is economically unattractive. This does not mean, however, that the oak stands over a large proportion of the sandy oak lands will not produce merchantable stands of timber for ties or lumber if they are allowed to grow for the necessary 80 or 100 years. Undoubtedly, protection from fire and forest management will help to build up the soils and improve the density, vigor, and rate of growth. This may result in merchantable yields in shorter periods of time. It also suggests the desirability of introducing some more rapidly-growing species to develop in mixture with the oak, a possibility which will be taken up in a later section.

MATURITY AND ROTATION

The culmination of the mean annual growth was shown in the preceding section to come at about 50 years. This becomes unimportant as a factor in deciding on the rotation age when it comes so far in advance of the ages at which the oaks will become merchantable for anything but cordwood. After 50 years, however, the rate of growth is declining so that the rotation age should be set as early as the stands will produce attractive yields of ties or saw timber. This age varies from as high as 120 or 140 years for open stands on poor sites to as low as 70 years

years old and the sprouts from trees 100 years old are likely to be few and poor. If, on any area, it were desirable to grow crops of oak for cordwood by a system of sprout reproduction, a rotation of 40 or 50 years should serve the purpose.

REPRODUCTION

The oaks reproduce effectively both by seed and by sprouts from the stump or root collar of trees which are cut. Reproduction from seed depends first upon the production and distribution of the seed and second, on the germination and survival of the seedlings.

Seed Production and Dissemination

The oaks begin to bear acorns when they are three to five inches in diameter and 20 to 45 years old. The acorn crops vary widely not only in different years but also between individual trees and stands even in the same year. Counts of the acorns on some 47 trees in the season of 1926 indicated that the intermediate and suppressed trees yield few or no acorns. Dominant jack oaks four inches in diameter had from 0 to 265 acorns. Those eight to nine inches in diameter had from a few to 1,430 per tree. White oaks seven inches in diameter had from 6 to 950 acorns per tree and a 10-inch red oak had 710. Probably these figures are low in comparison with what would be produced by older well-stocked stands during good seed years. This is indicated by figures given by Korstian (10) who found black and white oaks from 10 to 27 inches in diameter producing on an average a little over 4,900 acorns per tree, and a 20-inch red oak with 20,388 acorns.

In the present stands, mostly less than 70 years old and less than seven inches in average diameter, the production of acorns is probably too scattered to provide for seed reproduction except in occasional favorable years or over a long period of time. This is due in part to the consumption of the acorn crop in most years by birds, squirrels, and other animals. Korstian (10) concluded that 80 to 90 per cent of acorns were thus consumed. On the other hand, a certain number of acorns are carried considerable distances in this way and are then dropped or hidden without being recovered. This is one of the chief means by which the acorns are disseminated and the distribution of the oaks extended beyond the areas on which they are growing. Of the acorns collected from different trees, insects, probably species of nut weevil, were found to have damaged up to 15 per cent.

The germination and early survival of the oaks is well treated by Korstian (10) and in the absence of direct evidence his conclusions may be considered applicable to Michigan. They include the following: White oak acorns germinate promptly in the autumn while those of red, black, and scarlet oak and others of that group hold over until spring. The covering of leaf litter which falls after the acorns have been shed usually affords necessary protection for germination and survival. The leaf litter and the shelter of the older trees is important for the regeneration of oak by seed. Acorns cannot withstand the amount of heat usually generated in fires in the leaf litter. White oak acorns are more susceptible in this respect than are those of red, black, or scarlet oak. The data in regard to the germination and establishment of the acorns of the different oaks on the sandy lands of northern Michigan are incomplete. They may be supplemented, however, and a more satisfactory indication of the reproduction of the oaks may be obtained by consideration of the regeneration of sprouts and seedlings which are already established on the ground.

Seedlings

The term seedlings is used to include trees which have started from seed in distinction from those which started from older roots or stumps. There are more established seedlings in the oak stands than would be indicated by the seed supply. The number varies widely and depends upon the inter-action of several factors including the age of the parent stand, the period of time since the last fire and the number of trees to the acre of seed-bearing size and age. All of the stands which had not been burned over within 15 years and most of the stands over 30 years old which had not been burned within eight years had 150 or more established oak seedlings to the acre. This is not a large number, but, if it is taken in connection with the number of sprouts which occur with the seedlings on almost every acre, it affords the nucleus for a reasonably good future stand.

If seedlings were to be depended upon wholly for reproduction and 800 to the acre were set as a minimum number to form a satisfactory stand, that number would rarely be found except in stands which are over 35 years old and which have not been burned within nine years. On the whole, reproduction of the oaks by seeding is satisfactory if fires are kept out for 10 or 15 years after the trees reach ages of 35 or more

Fig. 6.—Young oak sprouts following repeated fires on land originally forested with pine, Alpena county.

This repeated vigorous sprouting has occurred where the periods between fires have been short and where at least a certain proportion of the sprouts came from young roots. Evidence as to the age at which vigor of sprouting declines was not obtained, although in the East it has been found to be at about 50 years (5). Sometimes, however, stumps may sprout vigorously at much older ages. For example, in Figure 7 is shown a stump of a red oak in northern Michigan 230 years old with vigorous sprouts eight years old and 16 feet tall.

As better protection from future fires permits the oak stands to mature to 100 years, it is likely that the sprouting capacity of the stumps will be less, but, at the same time, the number of seedlings will increase and tend to maintain a satisfactory total regeneration. This change in the relative proportion of sprouts and seedlings, depending on the recent occurrence of fire, is indicated by the fact that the 16 plots on which the number of sprouts was less than the number of seedlings to the acre were, with one exception, those which had not been burned within 11 years.

Fig. 7.—Vigorous red oak sprouts 16 feet tall from base of stump of tree 230 years old, Ontonagon county.

The number of sprouts from a single stump is large at first and decreases as the sprouts grow older. Thus, a three-year-old stand of sprouts had an average of nine sprouts per stump and one of the stumps had as many as 33 sprouts. By the time they are 10 years old the numbers have generally decreased to five per stump; by 20 years to three; by 30 years to two; and, after 30 years, usually only one of the original sprouts remains. Occasionally, however, there may be two or three

of this character would include the thinning of clumps of sprouts to leave only one or two of the best stems in each clump. The weed species, such as red maple and sassafras and the cherry and aspen which are not promising species on these sandy soils, should be cut wherever they are interfering with oaks or pines. These cuttings can be made most cheaply when the trees are small enough so that they can be cut with a single blow of an axe or machete.

The first cutting should be confined to trees which are crowded or will crowd better species or individuals within the period before another cutting is made. Too heavy cutting is to be avoided because it is desirable to leave as much cover as possible to re-establish the layer of leaf litter and humus which holds moisture in the soil and to build up the fertility of the poor sandy soils. A second improvement cutting or thinning in 20 or 30 years, if practicable, should again remove unimportant species or the poorer stems in crowded groups. A small amount of merchantable cord wood might be obtained from this cutting to compensate in part for its cost. Theoretically these cuttings should be made lightly and often, but practically they must usually be limited to not more than two heavier ones at longer intervals. The cuttings should aim, therefore, to give the reserve trees sufficient space for growth until another cutting, while at the same time maintaining the forest cover.

Cuttings in merchantable stands should be partial rather than clear so that any young growth already established may have some protection for a few years after the cutting and so that conditions may be favorable for the establishment of new seedlings. Probably, a crude shelterwood cutting in which about one-half the volume in the poorer trees is removed in the first cutting and the remainder in the second cutting 10 to 20 years later would give reasonably good results.

Costs, Returns, and Profits

The cost of growing a crop of oak timber or of holding young growth until it reaches merchantable size depends upon several considerations, namely, the size of the investment, the amount of taxes and fire protection, the number of years required for a forest to mature, and the interest rate on the funds invested. It has been pointed out that much of the sandy oak land has no sale value at the present time. However, for the purpose of the following calculations, it will be assumed that the land value is $1.00 an acre. Protection from fire on these lands where the hazard is high would cost 5 cents an acre a year. Taxes average in the neighborhood of 10 cents per acre a year. The costs may then be calculated for any periods and at any desired interest rate. If it is assumed that the cost of growing the forest is just equal to the returns from the sale of the timber products, the stumpage value per thousand board feet which the oak must have to earn different rates of interest may be computed by dividing the total cost or return by the yield in thousand board feet per acre. This yield may be taken as about the average of the present merchantable stands or 5,000 board feet to the acre.

TABLE XII. Cost of producing a thousand board feet of oak stands yielding 5,000 board feet per acre after 60, 80, and 100 years at 3, 4, and 5 per cent with taxes of 10 cents an acre and fire protection at 5 cents an acre annually, with a land value of $1.00 per acre.

Interest rate, per cent	Period of Growth in Years		
	60	80	100
3	$5.87	$11.57	$21.86
4	9.04	20.95	47.03
5	14.14	38.85	104.40

The stumpage price for second growth oaks in the Lake States in 1924 and 1925 averaged $6.84, and, for old growth, $10.88 per thousand board feet. It is impossible to predict what the prices may be after 60 or more years, but they will almost certainly be higher than they are at present. If $10.00 is taken as a conservative estimate of the future stumpage value, the figures in Table XII indicate that yields of 5,000 board feet of oak to the acre will result in a profit of a little over 4 per cent on the investment and costs for a 60-year period and of less than 3 per cent if the growing period is 80 years or more. Stands 40 years old may be held for the 60 years until they are merchantable with the expectation of a 4 per cent return. Younger stands, 20 or 30 years old, will only yield that rate of interest when they are well stocked and growing on good sites.

The period of growth may also be shortened by measures which will stimulate the rate of growth of the oaks. Such measures include cleanings, improvement cuttings, and thinnings which can be made in young stands at costs of three to seven dollars an acre. Spaeth (17) concludes

northern white pine, grow naturally on the sandy oak lands and are the logical species to be first considered in connection with the natural conversion of oak to pine. In the original forest, Norway and white pine were the predominating species and the oaks were subordinate. The soils and climate are, therefore, suited to the restoration of the pines provided other factors which have resulted from the cutting and burning of the areas are not prohibitive.

Factors Influencing the Conversion Process

Almost all of the many complex and interacting elements which influence the natural reproduction of the pines are involved in the conversion of oak to pine. Little is known of the part played by these involved elements or of their relative importance. In the brief period of the present study, no attempt was made to measure the light or climatic factors and only a few determinations were made of the soil properties. Certain other factors, however, were evaluated and something may be said of their probable effects. They include the natural reproduction, both advance growth and from seed trees, protection and distribution of seed, fire, exposure, shading, and competition.

Advance Growth of Pine in the Original Forest

The old growth forest of Norway and white pine was irregular and had frequent openings. The pine, and particularly white pine reproduction, was usually found abundantly in those openings. For example, the area of old growth pine examined in Interlochen State Park had 650 white pines to the acre less than one-half inch in diameter in a comparatively dense area not favorable to the reproduction of pine. A younger, denser stand of pine in Ogemaw County had 666 white pine and

100 Norway pine seedlings to the acre. A mature stand of pine and oak near Traverse City had 550 small white pines to the acre. Germination of pines was common on unburned areas of the Norway-white pine formation at Manistee according to Harvey (8).

Considerable proportions of this advance growth pine would have survived the old pine logging if fires had not burned through the slashings. Actually only occasional remnants of it remain as scattering small trees in the oak stands. One example was found in a red oak stand 53 years old, which had 60 white pine to the acre 4 to 12 inches in diameter a little older than the oak in mixture with it. More often the advance growth of pine is now represented by scattered trees of 4 to 12 inches in diameter as large or a little larger than the oak. Sometimes there are as many as five to the acre but usually less than one on five acres. On most of the large areas of oak lands, they have been entirely eliminated. Thus, the advance growth from the virgin forest which would have provided for natural conversion if it had not been destroyed by fires is now only locally a factor in the conversion process.

Fig. 8.—Norway pine seed trees on open oak lands, Ogemaw State Forest.

Sources of Seed

The old growth pine forest produced enormous quantities of white pine seed at intervals of three or four years and Norway pine seed every six or seven years. The logging which was done in the fall and winter of good seed years was often followed by abundant crops of pine seedlings. Like the advance growth, however, they have been destroyed by fires.

In the early pine logging, only the best of the timber was cut, consequently, smaller trees and defective trees of large size were left. Mature pines, such as these, with their trunks free of branches are highly resistant to fire and many of them survived either as scattered individual trees or as groups of pines which were left because they were below merchantable size. Examples of this latter case are still found

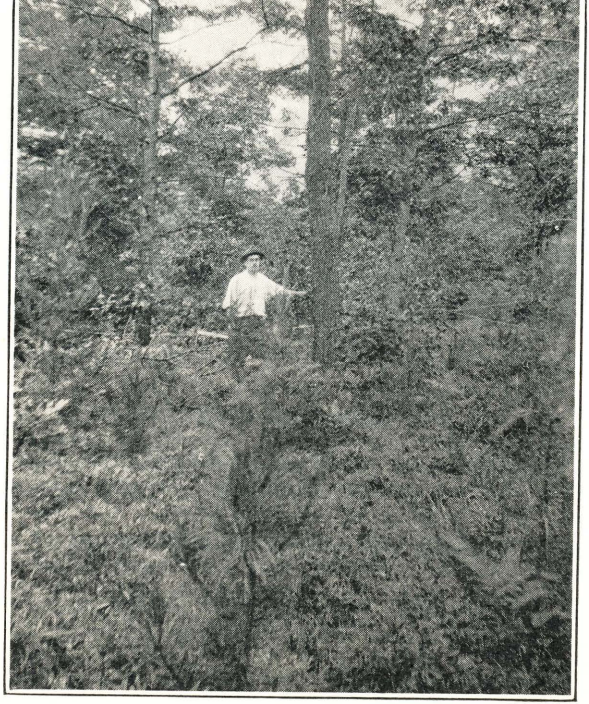

Fig.9—Pine coming in naturally under oak, Ogemaw county
Photo by courtesy Mich. Land Economic Survey.

The seed trees that remain, although they produce seed, are not effective in reforesting the oak lands as a whole; first, because they are too few, and, second, because the hot, dry sites covered with sod and brush are unfavorable for the establishment of seedlings. These conditions are now probably more unfavorable than they were for the first few years after logging. Livingston (11) mentions that white and Norway pine seedlings can grow on the cut-over lands and were abundant in Roscommon County in 1902. At the same time and place, Sherrard (16) mentions the presence of scattered white and Norway pine which were left after logging. As early as 1888, Beal (1) noted that there were only a few young pines left in Lake County after the fires. The Michigan Land Economic Survey, in its report on Ogemaw County after having mapped the pine seed trees concludes, "The number of seed trees is wholly inadequate to establish a second crop of pine within any reasonable time because to all appearances the Norway pine is not restocking these areas very fast." They also cite an example of an excellent stand of young Norway and white pine five to 25 years old coming in under oak. Figure 9. The best of the old growth pine was logged 40 years before and the balance was taken out 16 years before the date of the survey so that the reproduction came from the trees left after logging. They concluded, "Norway and white pine will seed in under the oak if there are any seed trees and if fire is kept out."

Similar evidence was obtained in several places. Sometimes a part of the pines which served as seed trees are still standing and as often they have been cut or have died. The essential data from the nine oak plots which best exemplify the conversion of oak to pine through the agency of trees which survived the old logging are given in the following table:

Table XIII. Pine Reproduction in Selected Oak Stands

Oak Type		White Pine					Norway Pine				
Species	Age	No. per Acre		Range of Ages	Range of Diam.	No. Additional Seed Trees within 300 ft.	No. per Acre		Range of Ages	Range of Diam.	No. Additional Seed Trees within 300 ft.
		Seedlings	Larger				Seedlings	Larger			
White and red	78	2500	15	53	8–11	100	.....	.....	.....	.....	2
Black and white	65	550	90	37–49	2–9	100	.....	.....	.....	.....	.....
Black	32	234	29	20	1–2	4	33	.....	.....	.....	2
White	38	150	5	48	12	.....	.....	10	31	2–6	.....
Jack	35	50	.....	.....	.....	.....	350	5	.....	1	1
White and red	41	150	.....	.....	.....	2	100	.....	.....	.....	2
Red	40	.....	350	27–30	1–4	1	.....	280	.....	1–4	.....
Black	48	.....	170	30	1–4	.....	.....	.....	.....	.....	.....
Jack	34	.....	.....	.....	.....	.....	.....	35	16–27	1–6	.....

The most abundant pine reproduction, 2,500 to the acre, was found on an area well supplied with seed trees over eight inches in diameter which were survivors of the old logging and fires. The 48-year black oak stand is an example of a good representation of small pines in a stand from which all pine seed trees have disappeared. Yet these small pines must, considering their ages, have originated from seed trees left after the original logging. Some of the examples seem to indicate that even one or two good pine seed trees may be effective in reseeding the

Fig. 10—Mixture of oak and jack pine, Huron National Forest, Oscoda county.

most of the larger jack pines have been killed by fires, but thanks to the ability of jack pine trees less than 10 years old to produce seed abundantly after fires, jack pine seedlings and saplings up to four inches in diameter were represented by from 50 to 375 trees to the acre on 12 of the 77 areas examined. Jack pine requires plenty of light and space to develop and consequently was found with the oaks only where the crown density made less than 50 per cent shade. In some cases, the 5 to 30 jack pines per acre over four inches in diameter had been partially effective in reseeding oak areas where fires had not burned for more than eight years. The mixture of jack pine and oak, however, is not stable. The oak is tending to replace the jack pine both after fires by reason of its persistent sprouting and also in the absence of fire because it is more tolerant of shade and longer lived. Thus, jack pine is not effective in promoting the conversion of oak.

On the whole, the present sources of pine seed on the oak lands are insufficient to re-establish the pines in satisfactory numbers in any reasonable period.

Fires

The present lack of pine reproduction on lands that formerly supported splendid stands of pine is due primarily to fires. A single fire will totally destroy young growth of pine which may be in its path up to the time that the pines are 25 years old. The conversion of oak to pine in the future cannot succeed unless thorough and effective protection from fires is provided. The dry sandy exposed oak lands have a high fire hazard and their protection is not easy but it is the first essential for conversion from oak to pine.

Shade, Competition and Exposure

Young pines are readily susceptible to damage and many of them die during the first year or two after germination. During this period, the shade of the oaks and the accumulation of leaf litter further the establishment of the pines. As the pines grow older, on the other hand, the growth of those under the crowns of larger oaks is noticeably retarded. This may be due either to the shade or to the competition of the oak roots or to a combination of the two. Figures for 31 under-plantings 5 to 15 years old of Norway and white pine chiefly on the Michigan State Forests show that the average annual height growth of the Norway pines close to larger oaks was only one-third of that for all the planted trees. Similarly the suppressed white pines showed only two-thirds the annual height growth as compared with the average for all the planted white pines. Expressed in another way, if the average annual height growth of all the Norway and white pines was one foot, the suppressed Norway pine averaged only one-third and the white pine only two-thirds of a foot annually. This reduction in growth is so marked that it suggests that it is unwise to plant pines close to larger oak trees. Norway pine is less well adapted to under-planting than is white pine.

In addition to the competition of the oaks, the seedling pines must contend with a heavy sod of grasses, sweet fern, blueberry and other vegetation which completely occupy the ground in the younger and less dense stands of oak. The competition of this vegetation must become a serious cause of losses to pine seedlings in critical periods of drouth.

Exposure may include two forms of possible damage and loss among the pine seedlings, namely, excessive temperatures and frost or winter killing. Surface soil temperatures, in openings in a forest large enough so that they are not shaded during several hours in the middle of the day, may go as high as 122 to 152°F., on days when the air temperature in the shade is 85 to 100°F. Gleason (6) records a maximum of 140° at the surface of the soil in Michigan north of the area of oak lands. Toumey and Neethling (20) obtained numerous readings above 122° with a maximum of 152° in southern New Hampshire. Their experiments further showed that surface soil temperatures of 122 to 139°F., or over were often fatal to young seedlings of white and Norway pine. It is reasonably certain that the openings in the oak stands in Michigan are subject to equally high temperatures during hot periods in July and August. Many first year pine seedlings which start in openings are undoubtedly killed in this way. Others succumb for lack of moisture in the surface layers of soils which dry out excessively in drouth periods

ment. As fire protection is improved, the distribution and spread of pine reproduction may be expected to radiate out from existing centers at an increasing rate and thereby, in time, to have a much larger effect than at present in promoting the mixture of pine with oak.

After the pines have become established, the question logically presents itself; what growth may they be expected to make and in how many years will they reach merchantable size?

Growth of Pines

The rate and period of growth of the pines are important both in considering the time required for them to become merchantable and in the outcome of the competition between oaks and pines. For a period of 10 to 20 years after germination, white and Norway pine grow slowly. Thereafter the rate of growth of the pines increases and they grow rapidly both in diameter and height until they attain merchantable size at 60 to 80 years.

Growth in Height and Diameter of Individual Trees

The average heights and diameters of dominant and of suppressed trees of white and Norway pine at different ages are shown in the following table. Columns are also included for comparison giving the average heights and diameters of the oaks at corresponding ages. The dominant trees include chiefly those which have come up in openings where they had ample space for growth in contrast with the suppressed trees which were close to or under the crowns of larger oaks. The growth of the two species of pine is closely similar and the data available do not justify attempting to separate them.

Table XIV. Diameter and Heights of White and Norway Pine at Different Ages on Oak Lands

Age Years	Diameters breast high[1]			Heights[1]		
	Dominant trees Inches	Suppressed trees Inches	Average for oaks Inches	Dominant trees Feet	Suppressed trees Feet	Average for oaks Feet
10	1	0.1	1.3	6	2	13
20	3	1	2.5	16	7	23
30	6	3	3.7	28	16	32
40	8	5	4.6	40	26	38
50	10	7	5.5	51	34	42
60	12	...	6.3	60	41	44
70	13	...	7.0	68	47	46
80	13[2]	...	7.7	74	50	48

[1]Values read from curves fitted to measurements of 36 trees.
[2]The apparent cessation of diameter growth is due to rounding off of the figures to the nearest inch. Actually diameter growth continues to a much greater age.

The difference in the growth of the dominant as compared with the suppressed trees is large. For example, at 50 years the dominant trees are 10 inches in diameter and 51 feet high as compared with seven inches and 34 feet for the suppressed trees. The average diameter growth for all the pines in a well-stocked mixed stand of oak and pine would be between the figures for dominant and suppressed trees. White and Norway pine are merchantable for saw timber when they are 12 inches in diameter, or even a little less. According to the table, the dominant trees reach this size at 60 years. If then the conversion process has provided a sufficient number of pines to the acre, the stand as a whole might become merchantable when 60 to 70 years old.

Relation to Growth of Oaks

Comparing the dimensions of the pines with those of the oaks at the different ages, it is noticeable that the pines grow more slowly than the oaks during the first 10 or 20 years. In diameter growth, the dominant pines overtake and pass the oaks by the time they are 20 years old, and the suppressed trees do the same by the time they are 40 years. In height, the dominant trees overtake the oaks at 35 years, and the suppressed at 70 years. It should be mentioned that the figures for suppressed trees do not strictly represent the height growth which might be made by the same trees over the 80-year period. This is because many of the trees which have heights of two to seven feet at 10 and 20 years have died before they are 50 years old. Therefore, the heights of the suppressed trees at the older ages represent those individuals which were less seriously crowded. The heights of the dominant pines exceed even the maximum growth of the oaks before the age of 65 years. The important thing to be concluded from these figures is that the pines which are not too badly suppressed, after a slow start, overtake and pass

ment Station.

Only two stands were found which may be considered to represent roughly the outcome to be desired in a natural conversion to white and Norway pine. One was a stand of oak principally 124 years old which had 1,400 cubic feet or about 5,600 board feet to the acre of white and Norway pine in addition to an equal amount of oak. Another example was provided by a stand 60 to 80 years old in which the pine predominated over the oak and had a volume of 1,700 cubic feet or about 6,800 board feet to the acre plus 1,300 cubic feet of oak. These two examples indicate more nearly than the general figures what may be expected in volume production from stands in which the conversion to pine is reasonably successful and complete.

Natural conversion of oak to pine so far has not been successful either in the proportion of the oak area which is in process of conversion or in the density of the pines on the occasional small areas where they have gained a foothold. What can be done to supplement and accelerate the conversion process?

MAN'S ASSISTANCE IN THE CONVERSION PROCESS

There are several ways in which the conversion of oak to pine can be hastened by the application of certain measures of forestry. They include chiefly protection from fire, proper methods of cutting and planting.

Protection From Fire

The fire protection organization of the State of Michigan is becoming more effective each year and will doubtless continue to improve. The fire hazard on the dry sandy oak lands is high, however, and with an organization which, owing to limited appropriations, can provide only the equivalent of one man to about 80,000 acres for fire protection work, there are certain to be some oak areas burned in bad fire seasons. It has been emphasized that fire protection is essential to the establishment and development of pine on these lands. An improved protection by the State is therefore needed and, in addition, special protection by the owners of areas which have an established growth of pines. The employment of a special man, preferably a local resident, for fire protection during the two months of dry weather each spring and fall for an area of 5,000 to 10,000 acres should not cost more than 5 cents an acre. This in connection with the State lookout and detection system should provide satisfactory protection. At present the areas with pine may be too small and scattered to justify special protection, but as plantations of pine are established on a large scale, it will become more advisable. Intensive protection, including a highly developed system of plowed fire lines, has already proved effective and demonstrated its value in minimizing the fire losses in the large pine plantations on the Michigan State Forests within the "scrub oak" region.

Cuttings in Oak Forests

The growth, and probably also the per cent of survival of the pines under the oaks, is reduced by the competition of the larger oak trees. The denser the oaks, the greater is the reduction. The growth of pines can undoubtedly be maintained and probably stimulated and a larger proportion of them brought to maturity by partial cuttings or thinnings of the oak to release the pines from suppression. The aim of such cuttings should be to give the individual pines overhead light and growing space for several years thereafter without creating openings so large that they may be damaged as a result of exposure.

The time and degree of cutting will depend upon several considerations such as the relative size of oaks and pines, the density of the oak and the condition of the pine. The important one in so far as conversion is concerned is the condition of the pines. Whenever any large number or proportion of them have a spindling thin-crowned appearance due to suppression, the need of a thinning or release cutting of the oak is indicated. A release or disengagement cutting can be made cheaply when the oaks are still small enough to be partly cut through with a machete and bent over, thus discouraging a new crop of sprouts.

Such release cuttings modified in four different ways were tried experimentally by Byers (3) in a scrub oak stand in Pennsylvania seven years after it was planted to white pine. The four cuttings included:

1. Removal of all of the natural growth.

2. Removal of the natural growth with the exception of some of the most promising specimens of oak and chestnut.

3. The tops of all the natural growth were lopped and allowed to remain on the area.

These conclusions are not strictly applicable to Michigan where the sites are poorer, where the oaks form a large proportion of the tree growth and the stands are more open and irregular. These differences would tend to postpone the age at which release cuttings become necessary and make them less expensive. In the more open stands, one cutting at five to seven years would probably be sufficient to save most of the pines.

If the oaks are larger, it may sometimes be advisable to postpone cutting until the pines are 15 to 20 years old and 5 to 10 feet high. Although many of them may be more or less suppressed at this period, there is good evidence that considerable numbers will survive and be able to benefit by the cutting. They are then ready to enter upon a period of rapid height growth. Thus, with the start they already have, they are not likely to be overtaken and again suppressed by the oak sprouts as a result of the cutting.

The third favorable time for a cutting is when the oaks become large enough to be marketable for ties, logs, or cordwood. In this case, a partial cutting or thinning should pay for itself and provide for both the release of the suppressed pines and the stimulation of the establishment of a new crop of oak and pine seedlings. An example of the results 20 years after cutting in a white oak stand 20 to 90 years old in New York State has recently been described by Spaeth (17). Fifty-seven per cent of the hardwood by volume and by number of trees was cut to release advance growth white pine one to six inches in diameter occurring at the rate of 48 trees to the acre. There were also two good white pine seed trees on the area. Twenty years later the young pines were well established and they had increased in number to 890 to the acre.

Norway pine suffers more from suppression than white pine and therefore should be released more promptly wherever it is being crowded by the oaks. Both Norway and white pine respond to release by putting on increased growth for some years after the cutting. In this respect white pine responds more generously than Norway. Whether the increased growth following cuttings which bring in no immediate return will eventually pay for the cost of making them plus interest on the investment can only be learned after experience with such cuttings becomes available. However, it has been shown that pines grow more rapidly than oaks and it is certain that in moderately dense stands of oak it will be necessary to release the pines in order to save them. This is confirmed by Byers' (3) experiments from which he concluded that not more than 15 per cent of the white pine seedlings planted on scrub oak barrens will survive if they are not liberated after planting.

Some losses of small pine will occur in the cutting. They should be negligible in release cuttings in sapling stands and would be heaviest where a merchantable cut of ties or logs was taken. Even in the latter case, however, with reasonable care on the part of the loggers the loss should not exceed 25 per cent.

On the whole, release cuttings offer an effective means of saving and encouraging the development of the pines in the oak stands and may also prove in the end to be distinctly profitable.

Seeding and Planting to Introduce Pines

The two chief methods of artificial reforestation are by sowing the seed on the planting site and by planting nursery-grown seedlings. Sowing the seed of Norway pine broadcast and in seed spots was tried extensively in 1910 and 1911 on the sandy lands on the Huron National Forest and failed. These areas were more open and exposed and had less oak cover than the "scrub oak" lands but otherwise were quite similar. Eighty to 90 per cent of the seed spots had seedlings in May following the sowing, but almost all of them were killed by the heat of the hot sun of late June and July according to Piper, (14). The few which germinated from the broadcast sowing were killed in the same way. White pine would suffer more than Norway in this respect. Seed-sowing, therefore, cannot be recommended until its effectiveness has been demonstrated.

Another difficulty in sowing pine seed is that it is likely to be consumed by rodents, animals, and birds before it germinates. Finally, on the sandy oak lands which are comparatively easy to plant, the cost of seed and seeding is nearly as much as the planting stock and the results so far have been much less satisfactory.

Planting

The other method of introducing pines on the oak lands is the planting of nursery-grown stock. Wild pine seedlings are too scarce in the region to be considered for transplanting. Considerable areas have been planted with nursery stock on the oak lands of the Michigan State Forests from which the possibilities of planting may be judged.

should be commenced as soon as possible after the frost is out of the ground and before the season's growth is started. The spring planting season will be between April 1 and June 10 in the part of Michigan under consideration. In the fall, trees may be planted in September and continuing through October. Planting should be avoided, if possible, in either season after more than 10 days of drought.

Size of Stock

Most of the under-plantings on the oak lands have been made with seedling stock which had not been transplanted in the nursery. The few plantations set out with transplanted stock do not indicate any marked superiority in either growth or survival and certainly not enough to justify the greater cost. One year old seedlings are too small to be set out. Two year old seedlings of Norway pine are most extensively used and have proved as satisfactory as older stock. They may be recommended as representing the best combination of low cost and satisfactory results. Under-plantings of different aged white pine seedlings give the results shown in the following table:

Table XV. Per Cent of Survival in Under-Planting with White Pine Seedlings of Various Ages

Age of Seedlings Years	Per Cent of Trees Living	Basis, Number of plantations
1	16	1
2	50	13
3	61	7

Two-year white pine seedlings of good vigorous stock carefully planted may be expected to be reasonably successful although three-year seedlings, as in the instances above, have generally proven superior and are recommended.

Slit and hole planting are the two chief methods usually used for under-planting oak stands. The former consists of setting the seedlings in slits made with a spade or specially constructed thin metal wedge on a handle and then closing the slit with a second thrust of the blade just in front or behind the seedling. In the hole method, the hole is dug with a spade or mattock, the roots are put in place and the earth filled in around them and tamped down. Either method may be used in combination with plowed furrows wherever plowing is possible. The furrows tend to increase the survival and growth of the planted trees during the first few years. A majority of the under-plantings on the Michigan State Forests have been made by the slit method in furrows. Plowing has been successful in oak stands with as high as 45 per cent cover. The furrows cannot be straight as they must go around trees, but this is not a drawback since the seedlings in any case should not be planted close to larger trees.

Number of Trees to Plant to the Acre

On open land or where the growth of oak is very sparse the planting of about 1,200 trees to the acre is recommended. This is equivalent to planting the trees about six feet apart each way. Where the oaks are denser, the spacing of the planted seedlings must be made correspondingly wider and more irregular. Starting with 1,200 to the acre as the standard number in the open, the number to be planted in oak stands should be reduced probably by a little more than the number of oaks to the acre. For example, if there are already 300 oaks, the number of pine seedlings to be planted should be 1,200 minus 300 or 900, probably 700 or 800 to the acre. Eight hundred to 1,000 seedlings to the acre, the equivalent of uniform spacing of seven by seven feet, may be suggested as the most likely number to be suitable for planting on the larger part of the oak lands at the present time. The difficulty with the irregular rows is to make sure that the whole area to be planted is covered systematically. Furrows obviate the difficulty because they can be seen and followed readily. Otherwise, it is quite essential that the planters work side by side and that the man at the end adjacent to the previous planting keep his row roughly parallel to the last row planted, if necessary by a series of flags or markers.

Under-Planting and Planting After Cutting

The meagre evidence available indicates that white pine may be planted successfully either in a recently burned area of small oak sprouts or under a stand of oak already approaching maturity. Figure 11. On recent burns, where the clumps of oak are few and scattered, white pine seedlings are likely to suffer from exposure. Norway pine is better adapted for planting in the openings. For a crop of pulpwood which will mature at 40 or 50 years, one year seedlings of jack pine would also be suitable. Jack pine, however, will not survive in the shade of the oaks. White pine may be used on suitable soils more successfully than either Norway or jack pine where the seedlings will have some shade and protection

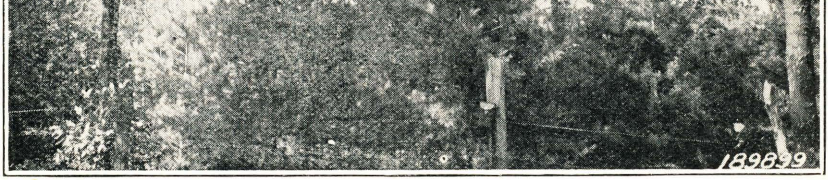

Fig. 11.—White pine, 16 years after planting under oak, Lake county.

another before the pines reach merchantable size. Older stands of oak which are under-planted with white pine should be thinned before the pine is 20 years old. As more of the oak stands approach maturity, the introduction of pine may prove to be more easily accomplished by under-planting 10 or 15 years before cutting or after a preliminary light cutting of the oak than by waiting until after the final cutting to plant the cut-over land.

Costs of Planting

Planting pine seedlings at the rate of 900 to the acre on the sandy oak lands should cost between $6 and $10 an acre. These costs include those of nursery stock, labor, equipment, and overhead when cheap stock and reasonably efficient planters are used. The $6 would apply to open sites planted to seedlings by the slit furrow method. Ten dollars should cover the planting of 3-year transplants on brushy areas or in dense stands by the use of the mattock-hole method. Seedlings of Norway and white pine may be purchased at reasonable prices upon application to the Department of Forestry, Michigan State College, East Lansing, or to the State Department of Conservation, Lansing.

ADVANTAGES OF OAK AND PINE

The probable profits in growing oaks have been shown to be not over 4 per cent. Plantations of pine should yield 10,000 to 15,000 board feet to the acre in 60 to 80 years. On this basis and using planting costs of $6 to $10 an acre, land value of $1 an acre and annual taxes and fire protection of 15 cents an acre, as in the calculations for oak, the pines by themselves will have to have future stumpage values of about $15 a thousand board feet to earn 4 to 5 per cent on the investment. This is about the present stumpage value of white pine and would seem to be a conservative future value. The planted pine, therefore, even when it carries the costs and expenses of the growing period, may be expected to return about 1 per cent larger profit than the oaks alone. The yield of oak in mixture with the pine would provide a small additional profit. In other words, conversion of oak to pine by planting, although it involves an investment of $6 to $10 an acre for 60 to 80 years, will pay. In addition, the maintenance of the mixture of oak and pine on these soils is probably the best practical means of building up their fertility and increasing the rate of forest growth.

CONCLUSIONS

The 1,300,000 acres of so-called "scrub oak" lands in the northern part of the lower peninsula of Michigan were originally covered with a mixed forest of large Norway and white pine with a numerous although subordinate representation of oaks. Logging and repeated fires have eliminated the pines. The oaks alone have persisted by their ability to sprout after each fire.

The present forest is composed chiefly of young and under-stocked stands of white, red, jack, and black oaks, which, if protected from fire, will grow to make ties and saw logs when 80 to 100 years old. They are growing at rates of only 1/5 to 1/3 of a cord per acre per year. The probable profits in letting the oak grow to merchantable size will be less than 4 per cent.

Natural conversion of oak to pine is taking place on not over 10 per cent of the area. Owing to the small number of pine seed trees, the spread of the pines is proceeding very slowly. The pines grow faster and produce higher yields at earlier ages than the oaks on these lands. Where natural conversion is taking place, therefore, it will increase the value of the lands and should be encouraged by every possible means.

Effective fire protection is essential for the upbuilding of the soil, the improved growth of the oaks and the conversion of the oak lands to pine whether by natural or artificial means.

White and Norway pine seedlings in mixture can be planted successfully on the oak lands at costs of $6 to $10 an acre. Planting will be necessary to convert most of the area to pine.

Release cuttings will be necessary for the development of the pines and may reduce the growth period by 20 or 30 years.

The introduction of Norway and white pine in mixture with the oak is advisable and will increase the growth, yields, and profits from these lands to 4 or 5 per cent.

The oak lands are by no means as valueless as they are often represented.

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