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Management of Jack Pine Stands in the Lake States[1]

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INTRODUCTION

Jack pine (*Pinus banksiana*), although the smallest and shortest lived of the pines native to the Lake States, has long since ceased to be considered a weed tree. Partly because the more valuable pines of the region have been almost exhausted, but also because of its own merits, for the past 15 or 20 years jack pine has been assuming greater economic importance. Attention has accordingly been directed toward working out a satisfactory forest-management practice for the species.

Jack pine finds its chief use in the manufacture of paper pulp, especially for high-grade kraft wrapping papers and fiberboard (*37*).[4] This use has expanded rather strikingly. In 1920, pulp mills in the United States used about 40,000 cords[5] of jack pine; in 1937, about 300,000 cords (fig. 1).

[1] Received for publication October 13, 1943.

[2] For some of the data used the authors are indebted to other staff members of the Lake States Forest Experiment Station. Most of the data dealing with reproduction on the Huron National Forest were taken by P. O. Rudolf and R. A. Farrington; some of those on methods of slash disposal were supplied by J. A. Mitchell. The tests on the Chippewa National Forest were conducted chiefly by Paul Zehngraff and H. L. Shirley, in cooperation with Forest Supervisor C. E. Knutson. The statistical material on regional volume and growth was collected and compiled by the Forest Survey staff, under the direction of R. N. Cunningham. The statistics on stand growth and yield were supplied by S. R. Gevorkiantz. Assistance in computations was furnished by personnel of the Work Projects Administration, Official Project 665-71-3-69, Sponsor University of Minnesota, and Official Project 01-2-71-126, Sponsor Lake States Forest Experiment Station.

[3] Maintained by the U. S. Department of Agriculture at University Farm, St. Paul, Minn., in cooperation with the University of Minnesota.

[4] Italic numbers in parentheses refer to Literature Cited, p. 59.

[5] Wherever the cord is referred to in this bulletin it means 128 cubic feet of stacked wood.

In strength jack pine occupies an intermediate position among the softwoods common to the Lake States (*17*). Lumber manufactured from it is somewhat variable in working quality and frequently knotty; hence it cannot compare with lumber from the highly prized old-growth eastern white pine (*Pinus strobus*). Yet for rough construction on farms, the building of resort cabins, and other uses not requiring fineness of texture or great strength, jack pine lumber is entirely satisfactory and is widely used. It serves equally well for mine timbers and piling (fig. 2, *A*), railroad ties, posts, cabin logs, and fuel. In recent years the cut of jack pine for lumber and miscellaneous products has approximately equaled that for pulpwood.

Jack pine forests in the Lake States (Minnesota, Wisconsin, and Michigan) are estimated to contain 2,678,000 M feet, board measure (International ¼-inch rule) of saw timber and 8,038,000 cords of

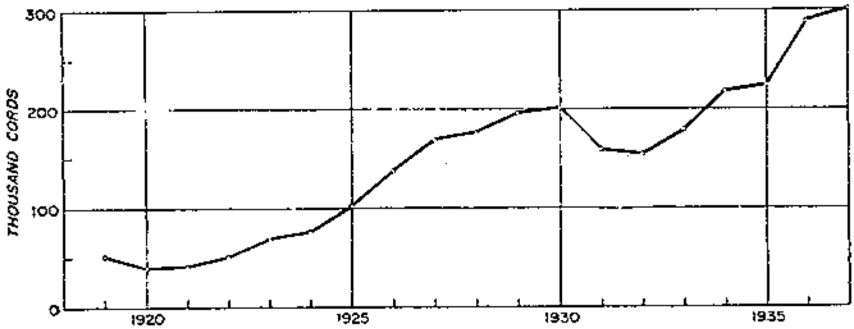

FIGURE 1.—Annual consumption of jack pine pulpwood in the United States, 1919–37. Compiled from Bureau of the Census data. Some of the data include small quantities of imported jack pine; so far as possible, the so-called jack pine reported from Maryland and North Carolina has been excluded.

pulpwood.[6] In cubic volume, jack pine now ranks above all other conifers in the Lake States except eastern hemlock (*Tsuga canadensis*). The existing stands of merchantable jack pine timber in the Lake States have particular economic significance because the region's old-growth forests have nearly all been cut. They will go far toward supplying the existing timber industries of the region under the stress of emergency demands and maintaining them until the young forests have grown to usable size.

Silvically, jack pine has exceptional merits. It can maintain itself on the poorest of sandy soils, where other conifers can scarcely survive, thus making it possible to utilize land otherwise worthless. It grows rapidly, producing merchantable material at an early age. It lends itself readily to artificial propagation; for this reason and because much of the 2,661,000 acres of deforested pine land in the region meets its requirements, it is highly favored in reforestation. Jack pine has also a remarkable capacity for reproducing itself after fire, and because of this characteristic it has helped immeasurably to cover the scars left by destructive logging and fire. But this quality cannot be taken for granted. Jack pine does not always reproduce abun-

[6] CUNNINGHAM, R. N., and MOSER, H. C. FOREST AREAS AND TIMBER VOLUMES IN THE LAKE STATES. U. S. Forest Service Lake States Forest Expt. Sta. Econ. Notes 10, 84 pp., illus. 1938. [Processed.]

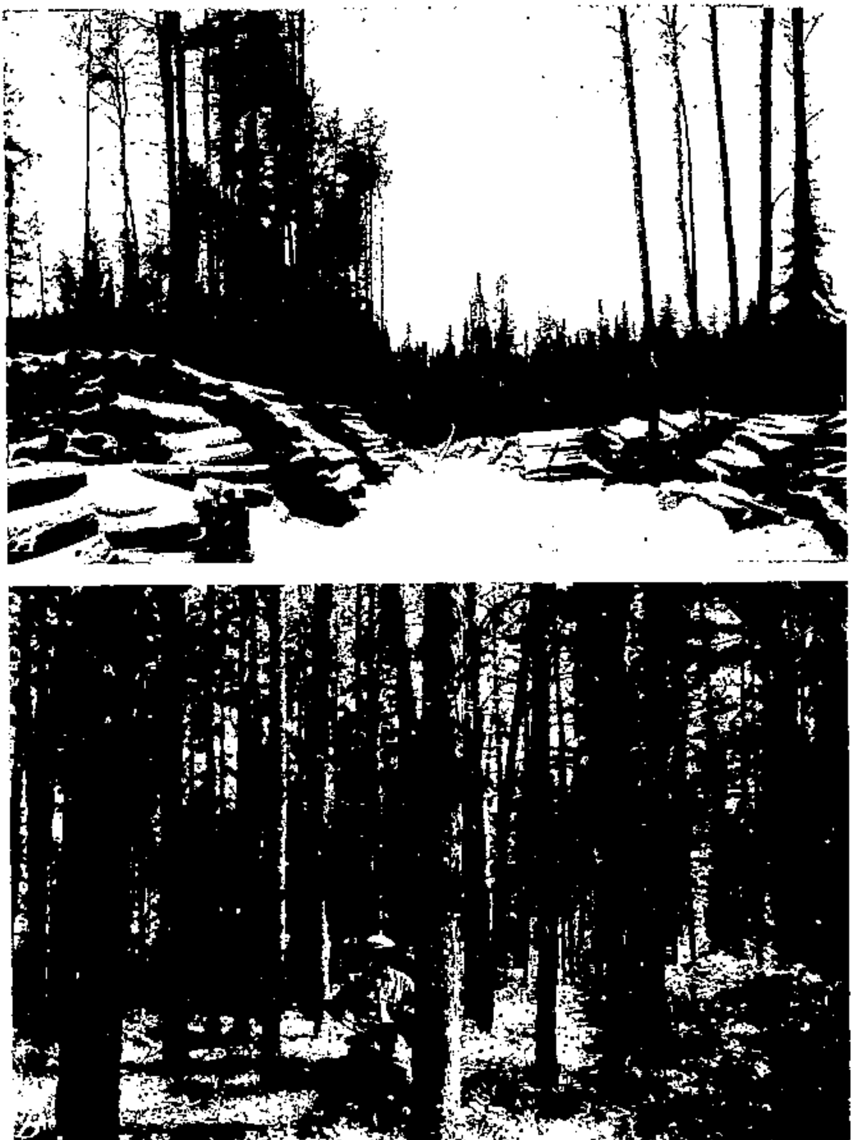

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FIGURE 2.—Jack pine reaches its best development in Minnesota. *A*, Jack pine logging operation in the northeastern part of the State; "timbers" and "poles" for use in local iron mines. *B*, This good-quality stand on the Chippewa National Forest, aged 70 years, has a volume of about 10,000 board feet per acre in trees over 7.5 inches in diameter.

dantly after fire; on some burned areas it has not come back at all. On many logged but unburned areas, also, jack pine has failed to reproduce. In order to gain information needed as a basis for management of jack pine, the Lake States Forest Experiment Station has for the past 14 years been studying factors governing natural reproduction of the species. Careful attention has been given to seed production, the conditions essential to the opening of the cones, and characteristics as to seed dispersal and germination. Repeated trials have been made of various degrees of cutting, slash-disposal methods calculated to encourage reproduction, and seedbed-improvement methods such as scarification of the forest floor. This publication presents the results of these studies, together with results of related research and forest administrative experience having to do with the management of jack pine.

DISTRIBUTION AND SUCCESSION

Range and Existing Stands

Jack pine is adapted to a cool climate and occurs farther north than any other pine of the North American continent. Its natural range

Figure 3.—Generalized botanical range of jack pine (*16*). This species occurs farther north than any other American pine. It is capable of enduring low precipitation and wide ranges in temperature, typical of an inland climate.

extends across Canada almost from coast to coast and in the United States includes northern New England and the greater part of Michigan, Wisconsin, and Minnesota (*27*) (fig. 3). Although found along sections of the eastern coast of North America, it is characteristically an inland species tolerating a wide range of growing conditions. Even within the Lake States portion of its range, climate varies strikingly. The frost-free period averages 163 days in places in southwestern Michigan (*31*), as low as 96 days in northern Minnesota (*29*), and less than 80 days in parts of the Upper Peninsula of Michigan (*30*). Annual precipitation averages as much as 33.67 inches at South Haven in southern Michigan (*33*) and as little as 21.95 inches (*32*) at Cass Lake in northern Minnesota.

Commercial stands of jack pine within the United States are limited to the Lake States. In the Lake States the jack pine type covers 6 percent of the total area now forested, being outranked in this respect by the aspen-birch, northern hardwood, oak, and spruce-fir types. A field survey (citation in footnote 6) has shown that the Lake States now contain some 2,700,000 acres of jack pine forest, nearly half of which is merchantable. The merchantable stands include 326,500 acres of saw timber (of which 4,400 acres is old growth) and 929,800 acres of cordwood-size timber; areas classed as restocking comprise 1,449,700 acres. Moreover, much of the region's deforested land has potential value for growing jack pine.

Nearly half the area and three-fourths of the present volume of jack pine forests in the region are located in Minnesota, the greatest concentration of mature timber being within the Superior National Forest, in the northeastern part of the State. Michigan has the second largest area: Wisconsin is second in volume. Figure 4 and table 1 indicate in some detail the location of the principal stands.

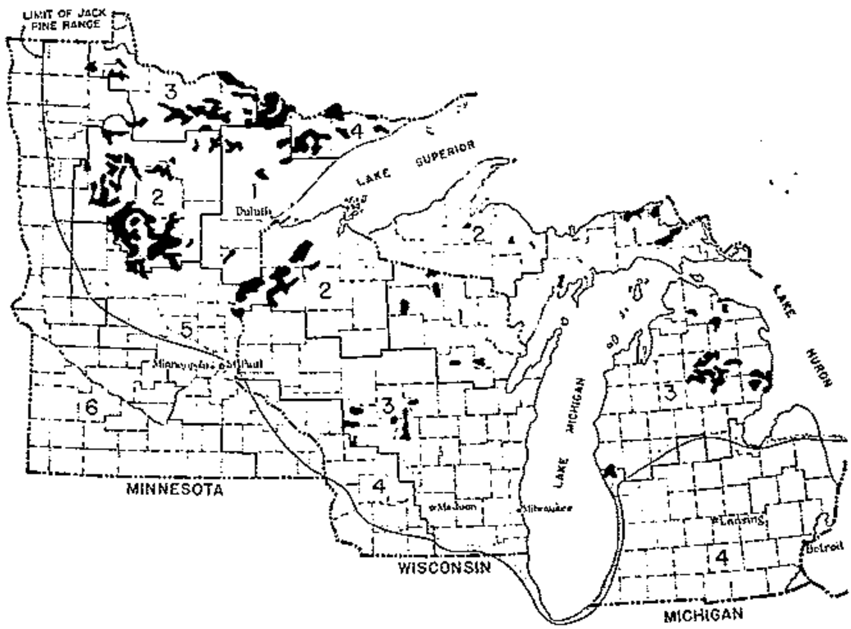

FIGURE 4.—Location of principal pine forests in the Lake States. Most of the stands are of the jack pine type. Numerals indicate the Forest Survey units, as listed in table 1.

According to somewhat rough computations of current growth and drain, the cubic-foot growth of jack pine timber in the Lake States is approximately offset by the loss through use and waste. It is estimated that during the next few years the annual drain upon merchantable stands of jack pine in the Lake States by cutting, fires, insects, and diseases will average 50,400,000 cubic feet. Annual growth in the decade 1935–44 is expected to average 59,100,000 cubic feet, or about 17 percent more than the estimated drain; hence for the time being there is no absolute shortage of jack pine in the region.

TABLE 1.—*Distribution of jack pine timber in the Lake States, by Forest Survey units*

State and unit [1]	Area		Volume	
	Acres	*Percent*	*M cu. ft.*	*Percent*
Minnesota:				
1. Cloquet	121,600	4.5	94,340	6.9
2. Central Pine	480,800	17.8	243,670	17.9
3. Rainy River	100,400	3.7	69,950	5.1
4. Superior	554,800	20.5	622,830	45.7
5. Hardwood	6,400	.2	1,750	.1
6. Prairie	2,100	.1	1,990	.1
Total	1,266,000	46.8	1,034,430	75.8
Wisconsin:				
1. Northeastern	83,000	3.1	33,000	2.4
2. Northwestern	264,000	9.8	77,000	5.7
3. Central	299,000	11.0	67,000	4.9
4. Southwestern	19,000	.7	4,000	.3
Total	665,000	24.6	181,000	13.3
Michigan:				
1. East Half Upper Peninsula	190,000	7.0	34,000	2.5
2. West Half Upper Peninsula	43,000	1.6	12,000	.9
3. North Half Lower Peninsula	530,000	19.6	102,000	7.4
4. South Half Lower Peninsula	12,000	.4	1,000	.1
Total	775,000	28.6	149,000	10.9
Regional Total	2,706,000	100.0	1,364,430	100.0

[1] For location of units, see fig. 4.

However, stocking, distribution of age classes, and geographic location of merchantable timber are all somewhat faulty from the point of view of sustained-yield production. Some of the remaining merchantable timber is situated in the less accessible districts (table 1), where it may be out of reach economically. The volume of mature timber that will be ready for cutting during the next few decades under a conservative form of management in the region as a whole is roughly calculated, with allowance for losses from natural causes, at 42,500,000 cubic feet per year.

Local distribution of jack pine is strongly influenced by the character of the soil. Apparently capable of getting along on a minimum of nutrients and moisture, jack pine tends to occupy the sandiest soils of the region. Often it is found on the driest, poorest sands. Although logging and fire have enabled it to spread to some of the better soils, it characteristically occurs on sand plains whose soils are decidedly acid in reaction, usually of glacial-outwash origin, and level or slightly rolling. These lands are popularly known as jack pine plains or pine barrens.

Typical of the poorer sandy soils is the Grayling sand of Michigan, the distinguishing characteristics of which are its loose consistency, single-grained texture, and perviousness to moisture (*34*)). To a depth of 3 to 4 feet or more moisture content averages very low, and fertility is correspondingly low. The original tree growth on this soil probably consisted mainly of jack pine, with some red pine (*Pinus resinosa*), a scattering of eastern white pine, and mixtures of scarlet oak (*Quercus coccinea*), black oak (*Q. velutina*), northern pin oak (*Q. ellipsoidalis*), and northern red oak (*Q. borealis*). The present stands consist mainly of jack pine, in thickets or scattered in association with small oaks or quaking aspen (*Populus tremuloides*). Somewhat better from a timber-producing standpoint are two other very sandy soils on which jack pine commonly occurs, the Roselawn sand in Michigan and the Plainfield sand in Wisconsin. The original forest growth on the Plainfield sand consisted largely of red pine and jack pine, often of large size, with some eastern white pine (*7*).

The best jack pine in the Lake States occurs in Minnesota (fig. 2, *B*), despite the fact that rainfall is less abundant there than in Wisconsin and Michigan. An explanation of this is that the soils supporting jack pine in Minnesota are generally more fertile than those farther east. Examples of Minnesota soils on which jack pine grows are the Menahga sand, the Cass Lake fine sand, and the Kinghurst loamy sand. Red pine is at present associated with jack pine more commonly in Minnesota than in Wisconsin or Michigan, another fact indicative of a better soil. Oaks are less frequent associates of jack pine in Minnesota.

Although commonly a tree of the sand plains, jack pine occurs also on the heavier rock-outcrop soils that spread over a fairly wide area on the Superior National Forest. These soils, thin but moderately fertile, mantle the geological formation known as the Laurentian or Canadian Shield. Chief among the associated species on these soils are aspen, black spruce (*Picea mariana*), paper birch (*Betula papyrifera*), balsam fir (*Abies balsamea*), and white spruce (*Picea glauca*). Jack pine is notably absent from the deep fertile loams typically occupied by the northern hardwood forest.

Role of Fire and of Logging

Fire has had more influence than any other factor on distribution of jack pine both in the original and in the present forests of the Lake States. It was mainly due to fire that jack pine, although a shorter-lived, smaller species than red pine and eastern white pine, nevertheless maintained a position of importance in the dense virgin forests of the region. Fire running through mature uncut stands of jack pine, or of jack pine mixed with red pine and other trees, encourages reproduction of the jack pine at the expense of associated species because of the former's peculiar seeding habits. Like lodgepole pine (*Pinus contorta latifolia*) (*2*), but unlike most other forest trees, jack pine does not shed much of its seed at the time of seed ripening (fig. 5). By far the greater part of the seed remains sealed in the closed cones, which persist on the branches for many years, usually until opened by fire. Although a fire sweeping through a jack pine stand kills nearly all the vegetation, the insulation afforded by the thick cone scales preserves much of the seed unharmed. The heat of the flames, usually of too brief duration to destroy the cones, opens the scales and releases the seed onto soil that is practically bare (*11*). The fire thus simultaneously prepares a favorable seedbed, reduces plant competition, and releases an immense number of seed.

When a hot fire passes through a stand, seed begins to fall almost immediately. A pole stand 40 to 45 feet tall on the Huron National Forest in Michigan (fig. 6) may be cited as an example. In May 1937, seed dissemination began after a hot fire had burned through most of the crowns, and was practically completed within 4 days.

Even a light fire may suffice to start the opening of the cones, although after such a fire the opening probably does not proceed so fast

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FIGURE 5.—Jack pine branch bearing cones of several annual crops, all still tightly closed. Usually on a living branch the cones remain closed unless subjected to high temperatures, as by a forest fire. Thus great quantities of seed accumulate.

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FIGURE 6.—When a young stand of jack pine is destroyed by fire, the coarse litter and nearly all competing vegetation is burned and a favorable seedbed results, as is evident in this pole stand of jack pine on the Huron National Forest, just after a fire in May 1937.

as after a hot fire. It has been found that the resinous seal of the cone scales can be broken, without damage to the seed, by immersing the cones in boiling water for 30 seconds, and that if the cone scales are then exposed to moderately dry air they open within a few days

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FIGURE 7.—After a fire the persistent cones (still plainly visible on the branches in this 18-year-old stand), opened by the heat, reseeded the area, with the result that 2-year-old seedlings (too small to show in the photograph) number 6,400 per acre.

sufficiently to release seed. If suitable temperature and moisture conditions prevail after seed dispersal, germination takes place promptly; and if favorable weather continues during the first growing season the stand of jack pine may be successfully regenerated.

A second fire following within a few years may kill all seedlings that came in after the first fire and reduce the area to a waste of brush or grass. However, if a longer period intervenes the second fire may result in a second and perhaps more abundant restocking of the area through seeding from cones produced on the young growth (fig. 7). Jack pines produce viable seed when as young as 4 years and in appreciable quantities when only 6 or 8 years old. A fire occurring in growth of the latter age may do nothing more disastrous than set the stand back a few years. This characteristic has greatly assisted jack pine in maintaining its place in the forest (fig. 8).

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FIGURE 8.—A dense stand of jack pine seedlings that originated after a forest fire in northern Minnesota.

As a result of the logging operations of 30 to 60 years ago, and of the fires that followed them, the stand of jack pine today outnumbers that in the original forest, doubtless largely because the species was so little utilized in those big lumbering operations. Although jack pine was in many cases cut and sold as red pine, it was utilized less closely than red pine, and much that was too small to be merchantable remained standing. The fires that subsequently burned through the slashings killed both the advance reproduction and the few remaining seed trees of eastern white pine and red pine, at the same time removing duff and vegetation from the surface of the ground. Fire also killed the residual jack pines, but caused their cones to open and thus brought about reseeding to jack pine.

Stands that existed as reproduction at the time of heavy exploitation and those that originated immediately thereafter have grown to merchantable size. This second-growth timber has formed the bulk of the jack pine cut during recent years.

Clear cutting with windrowing of slash, which is the usual method of logging second-growth stands of jack pine, has not generally been followed by successful reproduction (fig. 9). Many observations throughout the region testify to this. Of nine representative areas where definite surveys were made, only one had adequate reproduction. On one, reproduction was fair. On the seven others it was poor. Logged areas on sandy land commonly come in to grass and brush interspersed with patches of jack pine and oak. On loamy soils in the rock-outcrop region of northeastern Minnesota where aspen is mixed with jack pine, aspen sprouts up thickly after a harvest cut. Reproduction of jack pine was observed to be generally poorer in Michigan than in Minnesota. On experimental areas and na-

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FIGURE 9.—This privately owned tract in northwestern Wisconsin is shown as it appeared 8 years after clear cutting. Many similar commercially logged areas have failed to reproduce.

tional-forest timber-sale areas cut over during the period 1926–34, where both clear cutting and partial cutting were tried, reproduction has likewise been almost uniformly disappointing (*5*). A survey by Russell Watson[7] of many commercial cuttings of all kinds and circumstances in Michigan led to the conclusion that except where fire happened to intervene in just the right way, jack pine has failed almost completely to reproduce after cutting.

Even where fire followed closely after logging, few stands have reproduced adequately. It may well be asked why the occurrence of fire after cutting has not brought about as good reproduction in later years as it did in the days of large-scale lumbering. The answer would appear to lie in the fact that at the time of the first logging

[7] WATSON, R. JACK PINE IN MICHIGAN. U. S. Forest Serv., North Cent. Region. 1937. [Processed.]

absolute clear cutting was not practiced and many jack pines were left standing. Today clear cutting is the rule, and fire running

FIGURE 10.—Understory of balsam fir in a 70-year-old stand of jack pine on the Superior National Forest. Frequently, if no fire occurs, jack pine stands on loamy soils are invaded by balsam fir, black spruce, and white spruce.

through a cut-over area does not cause reseeding because practically no seed trees remain and the unopened cones contained in the slash are largely consumed.

Succession in the Absence of Fire and Cutting

Without the action of fire, jack pine does not readily succeed itself in nature, but tends to give way to a different type of forest—one more tolerant of shade. On sandy soils, as was shown by Kittredge (*10*) on Cass Lake sand, the usual succession after jack pine is first red pine, then eastern white pine, then a hardwood type composed of sugar maple (*Acer saccharum*), basswood (*Tilia glabra*), and northern red oak. More recent observations on the Chippewa National Forest, Minn., indicate that the red pine and white pine stages are sometimes absent. In such cases jack pine is replaced first by alder (*Alnus incana*), hazelnut (*Corylus americana*), beaked hazelnut (*C. rostrata*), paper birch, and quaking aspen, which are then followed by either the sugar maple-basswood association or spruce-fir, even though the soil may be too poor for good growth of the latter. On the better sandy soils the jack pine stage may last through only one natural rotation (100 to 120 years); on the poorer, such as those of Michigan, it may persist considerably longer because of the inability of more exacting species to occupy the site.

In northeastern Minnesota on the loamy soils covering the Laurentian Shield, jack pine that is free of fire and cutting is in one rotation almost completely replaced by more shade-tolerant species (fig. 10). Certain areas on the Superior National Forest supported fairly heavy stands of jack pine saw timber, mostly 80 to 120 years old, when cruised in 1922. A recruise of these areas in 1936–38 indicated that during the 14- to 16-year interval the jack pine saw timber had practically ceased to exist. Living trees remained only here and there, surrounded by snags and fallen timber. The areas are being taken over by black spruce, white spruce, balsam fir, and paper birch. The composition of two typical jack pine stands on the Superior National Forest is shown in table 2. The preponderance of spruce and balsam fir and the scarcity of jack pine among the trees 0.5 inch d. b. h.[8] or less clearly indicate the trend of succession. These small trees are seedlings that have come in naturally under the overstory of jack pine. If the stands remain uncut, the type will gradually change from jack pine to spruce-fir.

Table 2.—*Composition of 2 mature jack pine stands with understory on loamy soil on the Superior National Forest, in trees per acre* [1]

Species	70-year stand		80-year stand	
	0.5+ inch d. b. h.	0–0.5 inch d. b. h.	0.5+ inch d. b. h.	0–0.5 inch d. b. h.
	Number	*Number*	*Number*	*Number*
Jackpine	614	45	205	0
Aspen	0	0	65	[2] 357
Paper birch	100	135	40	90
Balsam fir	52	810	0	10
Spruce [3]	36	390	117	380
Others	0	225	0	17
	Acres	*Acres*	*Acres*	*Acres*
Basis, plot areas	.5	.067	4.0	.3

[1] D. b. h.=diameter at breast height, or 4.5 feet above average ground level.
[2] Suppressed suckers, which have little chance of surviving.
[3] Mostly black spruce.

[8] D. b. h.=diameter at breast height, or 4½ feet.

On some jack pine areas, particularly on the better soils, broadleaved shrubs, such as hazelnut, beaked hazelnut, mountain maple (*Acer spicatum*), and green alder (*Alnus crispa*), form such a dense understory that even balsam fir, one of the most tolerant conifers in the Lake States, cannot easily become established. When the jack pine has eventually died of old age, the hardwood shrubs are likely to occupy these sites for some time, later to be replaced very slowly by balsam fir, white spruce, and black spruce.

REPRODUCTIVE CAPACITY

Seed Supply

An important fact in the consideration of the reproductive capacity of jack pine is that the cones are generally serotinous, the scales remaining closed for long periods, sometimes for many years. Some variation in this characteristic exists, however. In the southern part of the range, and near the border of the prairie in Minnesota, cones are observed to be largely nonserotinous; also occasional trees elsewhere, even in the northern part of the Lake States, bear cones that open without delay. In most instances scale closure persists, with a consequent accumulation of seed in unopened cones from season to season.

In order to obtain a definite measure of the accumulated supply of seed in a representative stand of jack pine, all cones were picked during the fall of 1935 from an acre of well-stocked mature timber growing on a good site on the Chippewa National Forest, Minn., and the seed extracted. The yield was 12.9 pounds. A similar test the same year in well-stocked timber occupying a medium site on the Superior National Forest, Minn., indicated a seed yield of 13.5 pounds per acre. An interesting feature of the data, which are presented in table 3, is the large proportion of seed that came from cones more than 4 years old. In a very poorly stocked stand growing on a low-quality site on the Huron National Forest, Mich., a fairly analogous study made in 1937 indicated a yield somewhat lower.

Table 3.—*Quantity of seed stored in cones on living jack pine trees*[1] *on 2 national forests in Minnesota*

Year of cone ripening	Cones per acre		Seed per acre	
	Chippewa	Superior	Chippewa	Superior
	Bushels	*Bushels*	*Pounds*	*Pounds*
1935	2.92	2.78	1.04	1.75
1934	5.11	1.74	2.99	1.01
1932–33	4.17	2.69	1.56	1.39
1931 or earlier	26.33	24.14	7.31	9.35
Total	38.53	31.35	12.90	13.50

[1] As determined from cones collected in the fall and winter of 1935–36.

The large quantity of seed contained in the cones on living trees is all the more significant because of the small size of the seed. Jack pine has the smallest seed of any native North American pine. The number of seed per pound, according to tests of 99 collections made over a period of several years at the Lake States Forest Experiment Station, ranges from 71,000 to 177,000 and averages 130,600. A mature stand thus may have an accumulated supply, in unopened cones, of as many as 2 million seed per acre.

Seed stored in cones on the tree remain viable in high proportion for many years. Carefully extracted and cleaned seed from cones 1 to about 15 years old collected on the Superior and Huron Forests germinated 62 to 89 percent (table 4). The average run of seed collected and extracted under the mass-production methods of national-forest practice for use in artificial reforestation germinates in somewhat lower proportion.

From the data presented in table 4 it is evident that few seed stored in cones on the trees lose their viability in the first 5 to 10 years. The seed may remain in fairly good condition for a much longer period. One investigator reports having found that a lot of seed extracted from cones 16 years old was 82 percent viable.[9]

TABLE 4.—*Viability of 3 lots*[1] *of seed stored in cones for different periods*

Time since cones matured (years)	Lot 1	Lot 2	Lot 3
	Percent	*Percent*	*Percent*
1–2	84	89	80
3–4	83		
3–6		78	82
5 or more[2]	62		

[1] Viability was determined by germination tests of 1,000 seeds to an age class in lot 1, collected at Ely, Minn., and of 200 to an age class in lots 2 and 3, collected at Roscommon, Mich.

[2] The age of the oldest cones was estimated at 15 years, and may have been much greater.

SEED DISSEMINATION

SEED FALL FROM LIVE TREES

In the absence of fire, only a small portion of the current crop of jack pine seed, and an even smaller fraction of the accumulated supply, escapes from the cones and falls to the ground in any year. The fall during a 5-year period as determined by use of seed traps (fig. 11) at three locations in Minnesota and Michigan averaged from 2,700 to 10,600 per acre (table 5), or less than 0.5 percent of the total supply commonly stored in the cones of well-stocked stands. Germination tests of seed from the seed-trap collections indicated a viability of 56 percent, which checks rather closely with the results of tests of general collections made for reforestation. The greatest recorded monthly yield of seed from live trees was the 28,000 seeds per acre collected at Roscommon, Mich., in October 1938. This unusual fall of seed took place during a very dry period, under an open stand of scrubby but full-crowned trees. Since it has been found that under natural conditions ordinarily not more than one or two seeds in a thousand produce seedlings that survive to the age of 2 years, the average quantity of seed annually disseminated is totally inadequate for satisfactory regeneration except under unusually favorable conditions as to soil and

[9] SHEN, H. L. VIABILITY OF THE SEED OF JACK PINE FROM CONES RETAINED IN THE TREES FOR VARIOUS PERIODS OF TIME. 1936. (Unpublished thesis, University of Minnesota.)

weather. It may be concluded, therefore, that jack pine is not dependable as a seed tree.

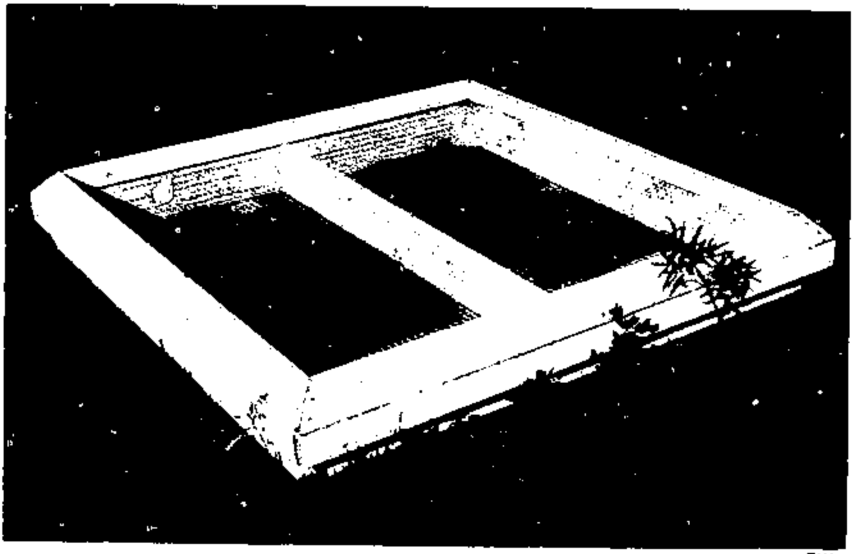

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FIGURE 11.—Seed trap, 3.3 by 3.3 feet having an area of 0.00025 acre. The coarse screen lets seeds in but keeps out birds and rodents; a fine screen beneath retains the seeds.

TABLE 5.—*Average annual fall per acre of jack pine seed from seed trees during the 5-year period August 1, 1933–July 31, 1938, at 3 different locations*

Period	Huron [2]	Roscommon [3]	Superior [4]
	Number	*Number*	*Number*
August	320	294	3,924
September	0	467	557
October–April	640	4,145	2,318
May	560	640	2,718
June	880	80	314
July	320	820	730
Total	2,720	6,446	10,561

[2] Well-stocked uncut stand (10 traps), Huron National Forest, Mich.
[3] Open scrubby stand (24 traps), Roscommon, Mich.
[4] Heavy mature stand 60 percent cut (18 traps, of which 10 were set out for 3 years only), Superior National Forest, Minn.

On warm sites, however, particularly in the southern and southwestern extremities of its range, jack pine trees disperse seed freely. In general, seed dissemination from cones on the tree is most likely to occur during warm, dry weather. In rare instances cones have been known to open and shed seed in midwinter. Open cones are found most frequently on short, open-grown trees on south slopes, where exposure to heat is greatest.

DISPERSAL OF SEED FROM SLASH AND DEAD TREES

Cones of jack pine cling persistently to the branches after the trees are felled and the stems cut into logs; only a few are knocked off in the process of logging. Thus cutting merely transfers the accumulated seed supply—which, as has been shown, may be as much as 2 million seed per acre—from the treetops to the slash. Because the air is warmer near the ground surface, the result is to raise the temperature of the cones and consequently to accelerate their opening. This acceleration, however, varies greatly with conditions affecting degree of exposure of the cones and with their precise height above the ground.

Seed dispersed from opened cones in lopped and scattered slash may amount to half or even two-thirds of the total supply. Following a 50-percent cutting of a well-stocked mature stand on the Superior National Forest, data were obtained through a test in which branches bearing known numbers of cones were placed over seed traps. Counts of the seed shed from these cones were made at monthly intervals, except in winter, over a period of 2 years. The data were then adjusted to a per-acre basis by the number of cones in the slash on an acre of the cut-over land as determined by counting the cones on 100 milacre quadrats. The results were as follows:

	Seeds per acre		Seeds per acre
February-July 1935	0	August 1936	60,400
August 1935	20,800	September 1936	7,000
September 1935	19,200	October 1936-April 1937	4,900
October 1935-April 1936	11,400	May 1937	0
May 1936	11,200	June 1937	9,600
June 1936	33,800		
July 1936	380,000	Total	558,300

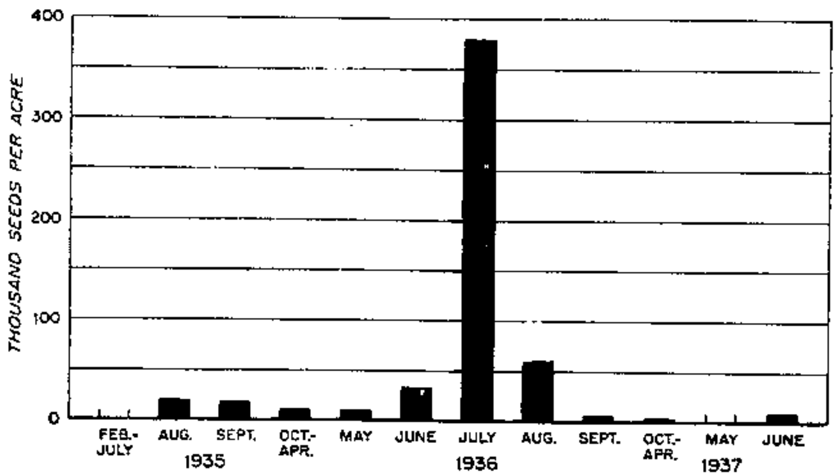

FIGURE 12.—Dispersal of jack pine seed from slash after a 50-percent cutting of a well-stocked mature stand in February 1935.

The comparatively high rate of dissemination during 1936 may be explained by the fact that it was an exceptionally warm, dry year. Dispersal of seed was greatest during the hottest months of the summer, but it continued at a moderate rate in the fall and spring (fig. 12).

In another study, on the Huron National Forest, 12 seed traps were placed on a series of cutting plots. The slash was lopped and scattered uniformly, without reference to the traps, so that the seed subsequently caught represented directly a definite proportion of the total quantity of seed disseminated. Several degrees of cutting were tried. In the first 25 months after logging, the seed fall recorded per acre was as follows: Clear cut, 1,152,000; two-thirds basal area removed, 884,000; one-third basal area removed, 161,000; no cutting, 17,000 (fig. 13). Cutting tests indicated that 48 percent of the seed was sound.

Seed is dispersed freely from lopped and scattered slash, but if slash is in piles or windrows only the cones around the edges and at the top release their seed, the others usually remaining tightly closed. Only seed released from cones around the edges has any chance of reaching a favorable seedbed.

Cones on the branches of felled or standing dead trees do not shed much seed. This was indicated in an investigation of comparative seed dispersal from cones attached to lopped and scattered slash, felled trees, and girdled trees (*12*). The seeds released from a total

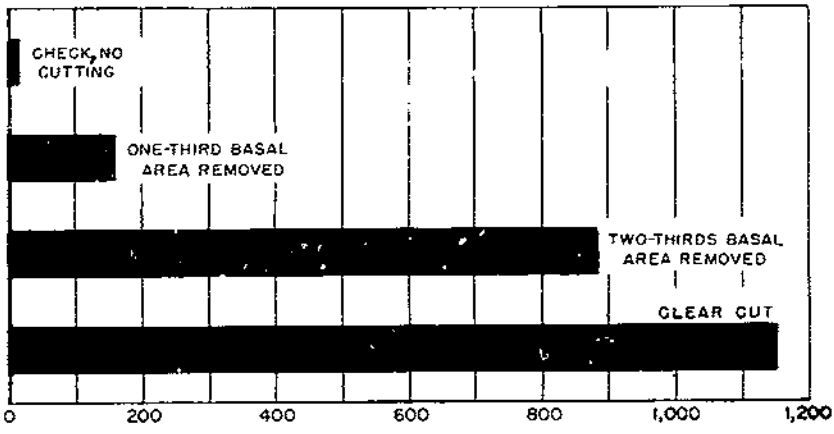

FIGURE 13.—Dispersal of jack pine seed, as related to degree of cutting during the 25 months following logging, as indicated by collections in seed traps on the Huron National Forest.

of 230 cones were counted. Seed was dispersed freely from lopped and scattered slash during the midsummers of the first two years and to a slight extent during that of the third year (fig. 14). The second summer, when the greatest dispersal took place, was by far the hottest of the three. Little seed was distributed from cones on the felled and girdled trees during any of the three years. The reason for the difference is that cone opening ordinarily results from exposure to high temperature, whether suddenly in the brief period of a forest fire or in the longer process of heating by the sun. The cones on the lopped and scattered branches were situated 1 inch to 1 foot above the ground surface, where air temperature was highest; those on the felled trees were 1 to 5 feet above the ground, and those on the girdled trees 20 to 40 feet.

Prompt and complete opening of cones is assured only if they are close to the ground. Under northern Minnesota conditions, cones lying on the ground fully exposed to the sun open in about a week of hot weather, and those suspended 6 inches above the ground open only after 1 or 2 months of such weather. As distance above the ground increases, opening becomes progressively slower, so that at a height of 4 or 5 feet cones may open only after 2 or 3 years or may stay closed indefinitely (fig. 15).

Temperatures of 130° to 150° F. on the bare forest floor have been recorded regularly during warm, dry summer weather near Ely, Minn. Observations that such heat is ample to open cones in the forest substantially agree with Rietz's statement (*18*) that to obtain good cone opening for artificial extraction, temperatures must be 140° F. or higher. Within a space of only 4 to 5 inches above the surface of the ground, air temperature often diminishes by more than 30°: and

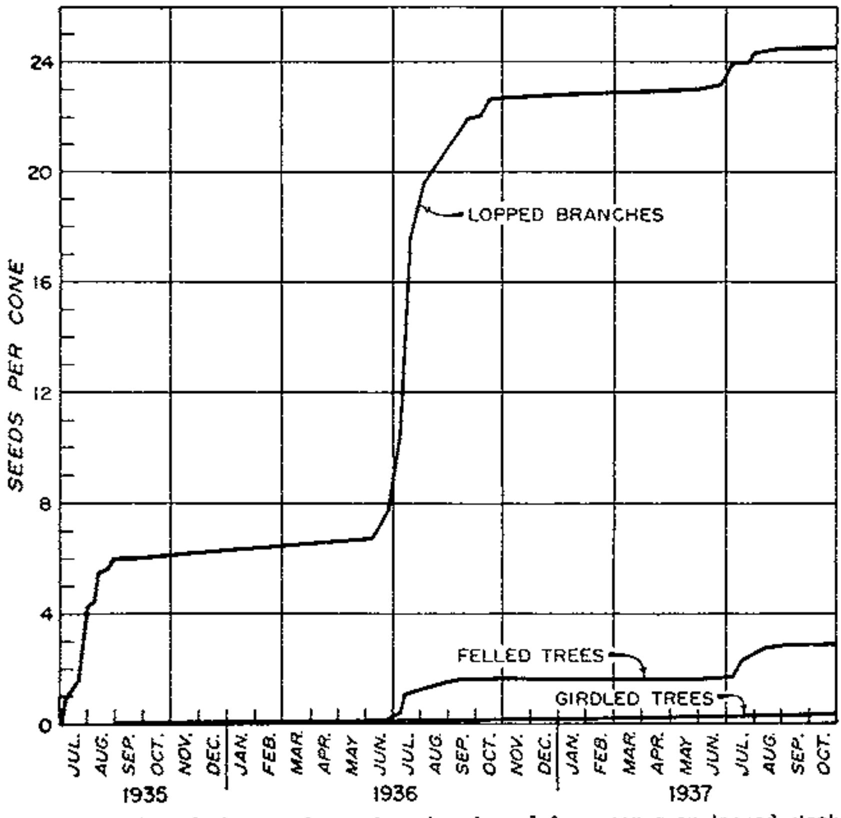

FIGURE 14.—Cumulative numbers of seeds released from cones on lopped slash, on felled trees, and on girdled trees. Basis: dispersal from 230 cones.

at a height of 1 foot, on warm, clear days, the difference may reach 35°.

In one observed instance, cones in slash protruding above snow opened during a period of subzero weather that immediately followed a relatively warm, wet period. Possibly frost action was responsible.

Destruction of Seed by Birds and Rodents

Seed of jack pine is palatable to a number of common birds and rodents, and this may at times have an important influence on reproduction. Observations made immediately after the Welcome Lake fire of May 1937 in a jack pine stand on the Huron National Forest show how seriously birds can deplete a heavy fall of seed. The very hot fire left a bare, blackened ground surface, upon which freshly fallen seeds were plainly visible because of their light brown wings. Most of the jack pine seed fell within 4 days after the fire. Counts at the end of that time showed from 11 to 36 seeds per square foot

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FIGURE 15.—Cones from a freshly felled tree exposed for 2 months, showing that degree of opening varies inversely with distance from the ground.

(479,000 to 1,568,000 per acre). Immediately great numbers of grackles, blackbirds, robins, and other birds flocked onto the burn and began to work it over. After a week, all the birds had left. The small quantity of seed later observed on the ground and the sparse reproduction that followed gave evidence that the birds consumed practically all the seed.

Pine squirrels (*Sciurus hudsonicus*) gather and store jack pine cones, but not in any great amount, it is believed, except when other food is scarce; otherwise, such large quantities of cones could hardly accumulate on the trees. Jack pine cones are hard and tough, and the seeds are so small that the work of getting them out probably almost offsets their food value to a squirrel.

The extent to which rodents may consume seed dispersed from slash is illustrated by seed counts made in 1938 on a portion of the Superior National Forest where a stand of mature jack pine had been clean cut the previous winter and the slash lopped and scattered. Opening of the cones proceeded rapidly during July, and most of the seed was released early in August. On September 5 a search was made under the cones for seed. In the course of several hours, a total of 1,500 seeds were found or were accounted for by the presence of seed coats and wings or seedlings. Of this number 75 percent had been destroyed, within a month after they escaped from the cones. In seed-sowing experiments on the Chippewa National Forest rodents have been observed to consume seed within 2 hours after it was placed on the ground.

Germination Requirements

In the regeneration of most conifers, seed that falls soon after maturing usually germinates at some definite period, such as the spring following ripening. Jack pine seed, which may fall at almost any time during spring, summer, or autumn, will germinate quickly if temperature and moisture are favorable—under best conditions, within a week or 10 days after it is dispersed.

Under favorable moisture conditions, jack pine seed will germinate rapidly whenever the 10-day mean maximum air temperature is 65° F. or higher. This was determined by sowing seed in the field at Ely, in northeastern Minnesota, on 11 different dates over a 12-month period. Every lot of seed sown while the 10-day mean maximum temperature was 65° F. or higher began to germinate within 20 days and stopped germinating when the temperature dropped lower. Every lot sown during periods of lower temperature germinated the following spring soon after the 10-day mean maximum reached 65° F.

Throughout the Lake States, rains normally are common during the growing season,[10] so that adequate moisture for germination may become available at any time during this period. In the study just described, in which no artificial watering was done, germination occurred in May, June, July, August, and September. The seed had been sown on rather well decomposed litter, over which sticks were then laid crisscross (simulating logging slash) to shade it and retard drying. At the same time a parallel series of sowings was made on coarse, poorly decomposed litter, which was left exposed to full sunlight. In the latter case the seed did not germinate in great numbers except in early spring, when the moisture content of the litter was maintained at a high level by the very wet condition of the underlying soil and the high relative humidity.

Germination of jack pine varies greatly according to character of soil surface (*6*, *11*). Clearly, for this species the best natural

[10] United States Forest Service. Probability of rainfall during the fire season in the Lake States region. U. S. Forest Serv. Lake States Expt. Sta., 21 charts. 1936 [Processed.]

germinating medium that can be provided in the forest is mineral soil (table 6). Burned duff, such as that left by slash burning or a forest fire, is somewhat less favorable. Duff that has been torn up mechanically and somewhat mixed with the underlying soil is better than undisturbed duff. Wood in an advanced stage of decomposition favors germination, but is scarce on jack pine land.

TABLE 6.—*Germination and survival of spring-sown jack pine on 4 kinds of soil surface*[1]

Kind of soil surface[2]	Germination	First-year survival, in terms of—	
		Seedlings germinated	Seed sown
	Percent	*Percent*	*Percent*
Undisturbed duff	17	41	7
Scarified and shaded soil	47	41	19
Burned duff	49	70	34
Bare mineral soil	63	84	53

[1] Survivals are averages for 2 separate years of sowing, 1937 and 1938, on the Superior National Forest; germination tests indicated the seed to be 80 percent viable before sowing.

[2] The wilting coefficients of the 4 soil surfaces, as determined by the centrifuging method, were as follows: Undisturbed duff, 76.6 percent; scarified duff, 55.5 percent; burned duff, 54.2 percent; and bare mineral soil, 14.1 percent.

The fact that mineral soil gives better results as a germinating medium than partially decomposed organic materials is explained by (1) its lower wilting coefficient, which makes it easier for seeds to absorb moisture, and (2) the far smaller size of the particles composing it and their greater uniformity, which permit closer contact of the soil and of the moisture it bears with the seeds. Mineral soil has a much greater advantage over duff when precipitation is slight than when it is abundant.

MORTALITY AMONG YOUNG SEEDLINGS

Young seedlings of jack pine, although larger than those of some northern conifers, are nevertheless small, tender plants, susceptible to many destructive factors and having a rather high rate of mortality during the first year. Fire, heat, drought, frost heaving, winter injury, insects, and disease can and often do cause severe losses, and sometimes completely destroy a year's crop of seedlings.

It has been found that soil surface temperatures above 122° F., if they continue for a period of 2 hours, endanger young conifer seedlings (*28*). Laboratory experiments have shown injury to tissue at temperatures several degrees lower (*23*). Within the range of jack pine, such temperatures commonly occur during a part of each summer. Figure 16, summarizing surface temepratures recorded for plots on the Superior National Forest, a locality much cooler than some parts of the Lake States, illustrates the frequency of such temperatures in a year of normal rainfall (1937) and a moderately dry year (1938). Soil surface temperatures up to 175° F. have been recorded within the jack pine region (*20*). Undoubtedly high surface temperatures cause heavy losses among the young seedlings, especially if the plants do not have shade during part of the day or the surface soil becomes dry and is not cooled by evaporation. Such conditions occur much more frequently on sandy soils than on loamy soils, which usually support more dense vegetation.

Temperature varies considerably with soil-surface material. The maximum surface temperatures of both burned and undisturbed duff, for example, far exceed those of loamy mineral soil, according to the data taken on the Superior National Forest (fig. 16). The high temperature of the natural duff surface probably resulted from its characteristically very dry condition. That of the burned duff surface can be attributed to its almost equally dry condition plus its blackness, which causes greater absorption of heat.

In a study of forest plantations, including jack pine on the Michigan sand plains, Rudolf (*20*) found drought a primary cause of mortality. The surface layer of the light sandy soils common in Michigan dries out rapidly, subjecting young seedlings to drought conditions

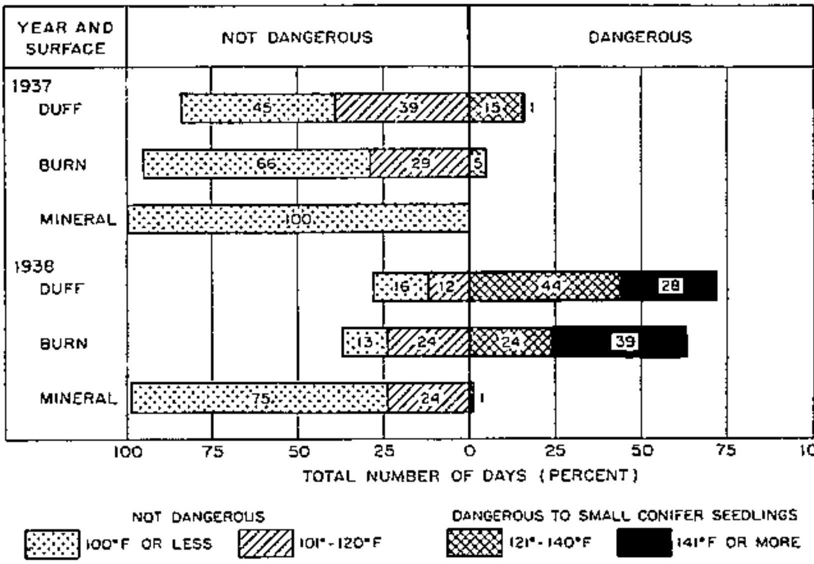

FIGURE 16.—Frequency of high temperatures on different soil surfaces during a period of normal rainfall (June 15–August 31, 1937) and a drier season (1938), on an area on the Superior National Forest from which jack pine timber was clear cut in March 1937.

even though larger plants nearby, with their deeper roots, may not be affected at all. It may be inferred that drought is a major hazard to young natural reproduction of jack pine on cut-over areas of sandy soils in the Lake States.

Winter-killing sometimes wipes out virtually an entire stand of seedlings, if because of late germination the seedlings have failed to harden off. For example, on some areas of the Huron National Forest that had been cut over experimentally in August 1935, the cones did not open until midsummer of 1936, an exceedingly hot, dry period when dispersal of seed was quite complete. Rains in August caused a highly abundant germination—on scarified soil, 90,000 seedlings per acre. During the following winter the seedlings had practically no protective covering of snow and more than 90 percent of them died. Similar results were obtained in experimental cuttings in 1936 on the Chippewa National Forest. A less important factor in mortality is frost heaving. Although probably of little consequence on light, sandy soils, it causes considerable losses on loamy soils.

Highest survival follows early spring germination, according to results of experimental sowings on different dates during 1937 and 1938 on the Superior National Forest. Seedlings from seed sown October 1, November 15, and April 1, which germinated in early spring, had higher survival rates than those which began to grow later in the season from other sowings (fig. 17).

Insects cause major losses among young jack pine seedlings, at least during some years and in some localities. White grubs (*Phyllophaga* spp.), according to L. W. Orr of the Bureau of Entomology and Plant Quarantine, are probably the most important insect pests of the young seedlings and have been particularly destructive in the

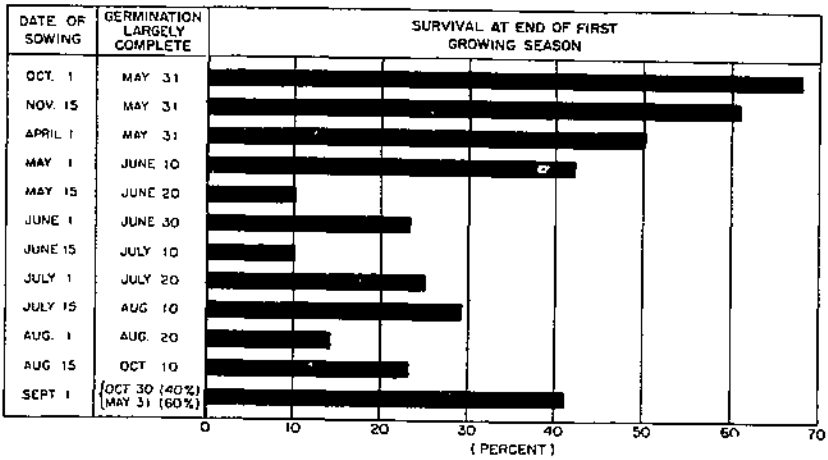

FIGURE 17.—Survival of jack pine seedlings in relation to date of sowing and to period of germination. (Of the seedlings resulting from the September 1 sowing, about 40 percent germinated in the fall and 60 percent in the spring.)

lighter soils of parts of the Upper Peninsula of Michigan and on the Chippewa National Forest in Minnesota. Grasshoppers have been very injurious in certain areas, particularly on the Manistee National Forest in Michigan, where they have caused complete destruction of many acres of 1- and 2-year-old plantations. Older seedlings are subject to attack by numerous other insects, particularly several species of sawflies (*Neodiprion* spp.). The white pine weevil (*Pissodes strobi*) will infest jack pine and is causing a considerable amount of deformed growth in some areas. A variety of the spruce budworm (*Cacoecia fumiferana*) will defoliate seedlings growing underneath scattered mature trees, but seldom becomes abundant if mature trees are absent. The pine chafer beetle (*Pachystethus oblivia*) has severely defoliated seedlings as well as older trees on parts of the Manistee National Forest. Several species of scale insects, particularly the pine tortoise scale (*Toumeyella numismaticum*), are destructive to young stands. According to reproduction survival studies made during 1937–38 on the Superior National Forest, insects were responsible in both years for slightly more than 60 percent of the losses, which were confined to newly germinated seedlings. Most of the destruction was caused by a species of grasshopper (*Camnula pellucida*), a very small caterpillar (*Halisidota* sp.), a sawfly larva (*Empria* sp.)[11] and the spruce budworm. These insects killed the tiny seedlings by eating the tops.

Nipping of terminal shoots or of whole small plants by the snowshoe hare (*Lepus americanus phaeonotus*) and white-tailed deer (*Odocoileus virginianus borealis*) is often an important hazard to jack pine seedlings. The hare is particularly destructive in northern Minnesota, where jack pine lands are interspersed with swamps, the margins of which offer the hare a suitable environment. During periods when the hare population is high, very few seedlings escape injury if they are situated among or close to weeds or brush tall enough to furnish cover for the hares.

Deer cause less dangerous injury because they do not remove such a large proportion of the tree, eating only the terminal shoots of the leader and upper lateral branches. However, a single browsing by deer sets the nipped trees back a year. Repeated annual browsing stunts the growth and may ultimately result in death. In one plantation on the Superior National Forest inspected 2 years after planting, Aldous (*1*) found that of 1,196 jack pine trees examined, 73 percent had been browsed by deer.

Fungi frequently cause losses among young jack pine seedlings. The studies made in 1937–38 on the Superior forest indicated that on loamy soils damping-off fungi caused mortalities of 26 and 9 percent, respectively, in the two years. It seems probable, however, that on lighter sandy soils mortality from this cause is less. The needle rust fungus (*Coleosporum solidaginus*) has attacked young jack pine seedlings in both natural and planted stands in northeastern Minnesota in three recent years. This fungus destroys needles that are 1 or more years old. Because of the conspicuous orange-yellow spores that cover the infected needles after the fruiting bodies break, it has created considerable alarm, but according to observations during several years when it was epidemic this fungus does not cause any serious reduction in the growth rate of vigorous seedlings.

Mortality of seedlings due to physical and biological causes is strongly influenced by character of seedbed. In the experiments conducted on the Superior forest, survival, like germination, was best on mineral soil and poorest on undisturbed duff (table 6). The mineral soil, in this case a sandy loam highly retentive of moisture, did not dry out rapidly like the duff; consequently losses from drought and heat were lighter. Burning the surface of the duff reduces its thickness and also increases the proportion of fine material by adding ash and small particles of charcoal; hence the burned surfaces were intermediate between the mineral soil and the duff in ability to hold moisture and supply it to the seedlings.

Losses caused by insects were consistently higher on the undisturbed duff surfaces than on the burned or the mineral surfaces. Perhaps insects preferred the undisturbed duff because the coarse organic mate-

[11] The three insects just named were identified by A. G. Ruggles, State entomologist, Minnesota Department of Agriculture, Dairy, and Food.

rial provided some element of protection, such as cover, color, or suitable temperature, or perhaps overwintering eggs or larvae were destroyed by removal and burning of the duff.

Initial Growth of Seedlings

Under favorable conditions, jack pine grows more rapidly in the seedling stage than any other conifer native to the Lake States, with the possible exception of eastern larch (*Larix laricina*). Best conditions for its early growth are (1) full sunlight; (2) fertile, well-drained soil; (3) water sufficient to keep the soil moist and its surface cool; (4) moderate summer temperatures; and (5) freedom from injurious insects, diseases, and plant competition.

Seedlings grown naturally on the Superior National Forest on freshly cut-over land kept free of competing vegetation averaged 2.7

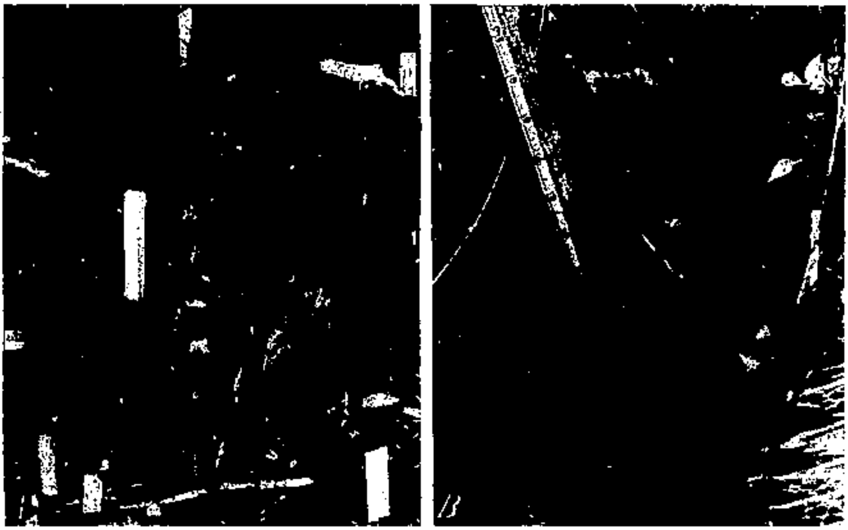

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FIGURE 18.—The effect of competing vegetation on 3-months-old jack pine seedlings coming in on burns. *A*, Sturdy, vigorous seedlings on a burned surface that has been kept free of competing vegetation. *B*, Spindly seedlings in competition with sedge (*Carex* spp.) of the same age.

inches in height at the end of one growing season and 10.6 inches at the end of two. In one recorded instance a seedling on a fresh burn attained a height of 27 inches in 2 years.

Although jack pine seedlings can grow on sterile, droughty soils, they are very responsive to their environment. Unlike the seedlings of most other conifers in the region, they do not during the first growing season form definite terminal buds and cease height growth in midsummer; instead, they start and stop growth according to temperature and moisture conditions, sometimes continuing height growth late into the fall. The seedlings are very sensitive to shade and to root competition from nearby plants. Each of these factors can retard their growth seriously, and often causes reproduction to fail. The actual influence of plant competition and shade upon the growth of seedlings on good soil in seasons of adequate rainfall is shown in table 7 and figure 18. Especially noteworthy in table 7 is the much better growth after clear cutting than after partial cutting. The artificial shade values given do not by any means represent the maximum effect of slash in retarding seedling growth that may result from an actual cutting operation in jack pine.

On very dry sites, especially during drought, moderate shade from trees or tall shrubs or even from slash may exert a beneficial influence by lowering temperatures and reducing transpiration. On rather exposed plantation sites in Michigan shade has been found to facilitate establishment of red and jack pine plantations, the injurious effects of root competition being more than offset by the beneficial effect of shade on temperature and transpiration (*19*). Probably natural seedlings are similarly benefited so far as early survival is concerned.

TABLE 7.—*Influence of plant competition and shade upon 2-year-old seedlings on 2 areas, in terms of average green weight of seedling tops*[1]

Treatment of shrubby and herbaceous cover	Clear cutting		50-percent cutting[2]	
	Unshaded	Shaded	Unshaded	Shaded
	Grams	*Grams*	*Grams*	*Grams*
Removed	19.3	9.3	2.7	6.1
Left	2.8	1.7	.6	.4

[1] Sample seedlings were taken from 128 plots artificially seeded on Superior National Forest. Shade was cast by 2 layers of sticks about ½ inch in diameter laid crisscross on the seedbeds. These sticks shaded approximately 80 percent of the ground surface. After the seedlings attained a height of 2 to 3 inches, they were free from shading by the sticks but still had some shade from overhead cover on the 50-percent cutting. Here, the table shows, where vegetation had been removed, the shaded seedlings made more growth than the unshaded. This is not in conformity with the other results and is attributed to accidental variation in sampling.

[2] The light intensity, as determined by use of paired black and white Livingston atmometer spheres, was 43 percent of full sunlight.

YIELD AND ROTATION

Compared with most conifers native to the Lake States, jack pine is quick growing and fairly short-lived. It occurs chiefly in even-aged stands (fig. 19). On the better sites it has been known to grow to a height of 105 feet,[12] and there are reports of trees as large as 28 inches in diameter breast high. However, heights greater than 80 feet and diameters greater than 18 inches are uncommon, and mature trees average much smaller than this. Open-grown trees, in particular, tend to be very short and bushy, and on the poorest sites resemble apple trees in form. Jack pine has been known to reach an age of 175 years but ordinarily matures in less than half that time.

Jack pine makes especially rapid growth in the juvenile stage. Under good growing conditions, seedlings reach breast height in 4 to 6 years and a height of 20 feet in about 18 years. In well-stocked stands merchantable trees (trees at least 5 inches d.b.h.) are produced in 30 years; some of the trees of that age are smaller than 5 inches but a considerable number have diameters of 6 or 7 inches. After the trees pass the age of 50 years their growth in both diameter and height becomes progressively slower. On poor sites, height growth may fall off at an earlier age.

[12] Measured by E. G. Cheyney in Itasca Park, Minn.

Yield of Well-Stocked Stands

In well-stocked stands on good sites, pulpwood is produced in about 35 years and saw timber in 50 years. On poor sites these products cannot be obtained without greater lapses of time. Table 8 gives the yields that may be expected from well-stocked stands growing on sites of good, medium, and poor quality. Where trees smaller than 9 inches d.b.h. are utilized for saw timber, as they frequently are, much higher yields may be expected.

According to the yield table (table 8), the number of trees in a well-stocked jack pine stand on an average-quality site should be about

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Figure 19.—Well-stocked 40-year-old jack pine growing on medium-quality site in northern Minnesota.

1,700 per acre at 20 years, 875 at 30 years, and should progressively diminish to 230 at 80 years. Densities are somewhat less on good sites and considerably greater on poor sites. It should be noted, however, that a stand may be understocked in number of trees (by the yield table) and yet occupy the site completely, or actually be overstocked in basal area and volume if the trees are larger than average. Therefore in any determination of stocking as a basis for thinning or improvement cutting both number of trees and basal area should be considered.

TABLE 8.—*Yields per acre of well-stocked stands of the jack pine type in the Lake States* [1]

Main-stand [2] age (years)	Average height of dominant trees	Average diameter main stand	Main stand trees	Basal area of trees 1.0-inch d. b. h. or more	Volume [3] of trees— 9.0 inches d. b. h. or more: Scribner rule	Volume [3] of trees— 9.0 inches d. b. h. or more: International	Volume [3] of trees— 5.0 inches d. b. h. or more to a 4.0-inch d. i. b. top	
	Feet	*Inches*	*Number*	*Sq. ft.*	*Bd. ft.*	*Bd. ft.*	*Cu. ft.*	*Cords*
GOOD SITE								
20	-----	4.3	1,320	133	-----	-----	660	9
30	44	6.3	670	146	900	1,150	1,410	20
40	56	8.0	435	150	2,250	2,800	2,020	28
50	66	9.3	320	152	3,900	4,800	2,440	34
60	75	10.4	255	151	5,650	6,850	2,700	38
70	81	11.4	210	149	7,300	8,700	2,870	40
80	86	12.2	180	144	8,400	9,900	2,910	40
AVERAGE SITE								
20	-----	3.7	1,700	128	-----	-----	480	7
30	35	5.4	875	140	500	650	1,050	15
40	45	6.8	570	143	1,150	1,500	1,550	22
50	53	7.9	425	144	2,100	2,650	1,910	27
60	60	8.8	340	142	3,050	3,750	2,100	30
70	65	9.6	280	139	3,950	4,850	2,300	32
80	69	10.2	230	133	4,650	5,650	2,330	32
POOR SITE								
20	-----	3.0	2,305	119	-----	-----	290	4
30	27	4.4	1,245	131	-----	-----	690	10
40	34	5.4	840	134	-----	-----	1,010	14
50	40	6.2	635	135	800	1,050	1,290	18
60	45	6.9	510	132	1,150	1,450	1,480	21
70	49	7.5	410	126	1,550	1,950	1,580	22
80	52	8.0	330	115	1,750	2,200	1,570	22

[1] Gevorkiantz, S. R., and Duerr, W. A. METHODS OF PREDICTING GROWTH OF FOREST STANDS. U. S. Forest Service, Lake States Forest Expt. Sta. Econ. Notes 9, 59 pp. 1938. [Processed.] Site indices (average heights, in feet, of dominant stand at 50 years) represented by the 3 site classes are as follows: Good site, 66; average site, 53; poor site, 40. All diameters are at breast height (4.5 feet). International rule allows ¼-inch kerf. D. i. b.=diameter inside bark.

[2] The main stand embraces all trees that have originated during the first few years of the life of the stand, excluding scattered residual trees and any understory of younger trees.

[3] Board-foot volume is net volume to a variable top diameter inside bark, the minimum of which is 6 inches. It represents scale of merchantable sawlogs only, deductions having been made for woods cull and mill cull and for cull trees (trees that do not meet the standards of merchantability for board-foot volume and that seem to have no prospects of doing so). Cubic-foot volume is gross volume, excluding bark. Cord volume is also gross volume, but includes bark and represents the material as piled in standard cords 4 by 4 by 8 feet. To compute peeled volume in cords, use values for peeling loss given in appendix table 19. The quantities shown in cubic feet and cords are totals and are not additional to board-foot volume.

In a well-stocked stand dominants and codominants [13] ordinarily make up 50 to 80 percent of the trees, the percentage of course varying with age and site or with average diameter. The following tabulation by S. R. Gevorkiantz, based on data from several hundred plots throughout the Lake States region, shows the proportion of dominant

[13] Trees are ordinarily classified as "dominant," "codominant," "intermediate," and "suppressed," depending upon their size in relation to neighbor trees.

and codominant trees in a well-stocked stand in relation to the average diameter of the stand:

Diameter (inches):	Dominants and codominants (percent)	Diameter (inches)—Con.	Dominants and codominants (percent)
2	51.2	6	69.0
3	56.1	7	74.8
4	60.9	8	78.8
5	64.8	9	81.4

This tabulation may be useful in identifying fully stocked stands. Percentage values higher than those given would indicate that the stand was understocked; lower percentage values would tend to indicate overstocking.

Development of Stands of Various Densities

Many stands as they occur in nature are either understocked or overstocked. Trees in stands understocked but evenly spaced grow faster in diameter than those in well-stocked stands. Understocked stands also have less mortality than fully stocked ones. These facts make it possible for some understocked stands eventually to become fully stocked. Gevorkiantz and Duerr [14] have called attention to a way of estimating the rate of approach of understocked stands toward normality. By this method, growth rates for 10-year periods were estimated in percent of well-stocked stands as shown in table 8, for density classes ranging from 10 to 100 percent, as follows:

Density class (percent):	Growth rate, 10-year period (percent)	Density class (percent)—Con.	Growth rate, 10-year period (percent)
10	15.4	60	74.4
20	29.6	70	82.6
30	42.6	80	89.6
40	54.4	90	95.4
50	65.0	100	100.0

These growth rates may be applied directly to all basal area and volume values for all sites represented in table 8.

The branches of jack pine make aggressive growth and are very persistent (fig. 20). Consequently, stands made up largely of open-grown trees, known locally as the "orchard type," have little commercial value. In stands that are less severely understocked, the limbiness is not so pronounced but is still sufficient to make the trees decidely objectionable for commercial use. A few pulp-manufacturing concerns do not object to knotty pulpwood, but the demand for higher-quality pulp is causing some companies to expend much labor in chopping out black knots and otherwise cleaning the jack pine wood before chipping it for the digester. Hence it seems probable that in the future high-quality pulpwood will command something of a premium; in fact, some companies now consider jack pine worth at least 50 cents more per cord, on the stump, if clean-boled than if limby.

[14] Gevorkiantz, S. R., and Duerr, W. A. Methods of predicting growth of forest stands. U. S. Forest Serv., Lake States Forest Expt. Sta. Econ. Notes 9, 59 pp. [Processed.] 1938.

The quality of jack pine timber that can be expected from stands of various densities is obviously an important consideration. The following tabulation, based on observation of numerous stands, may

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FIGURE 20.—Mature jack pine of characteristic form and average density on site of average quality, in northeastern Minnesota. The stand was cut away from the two trees in the foreground.

be helpful as a rough guide in estimating the future possibilities of young stands. It applies only to average or better sites where trees are uniformly well distributed.

Trees per acre at 20 years:	*Ultimate crop*
Less than 100	Orchard type. Trees mostly too limby to make merchantable timber, but some extremely knotty, low-value logs produced on better sites. Much waste, due to rough character of material and multiple stems. Long live branches persisting almost to ground line until maturity.
100–400	Trees limby, but majority yielding rough merchantable logs and mine timbers. Some material objectionable for pulp on account of large knots and difficulty of peeling. The denser stands likely to reach full stocking in basal area at 50 years. Limbs decidedly shorter than in orchard type. Limbs up to 25–30 feet dead but persisting until maturity.
400–800	Stocking intermediate between poor and good. Fairly good-quality logs, mine timbers, and pulpwood produced, about half of all trees reaching maturity. Good growth until maturity without thinning, but improvement thinnings for pulpwood at 35–40 years desirable. Large diameters reached more quickly than in denser stands, but some tendency toward knottiness. Probably fully stocked in basal area at about 40 years.
800–1,500	Stocking close to ideal, about one-third being crop trees. Growth fairly good; stocking probably full at 30–35 years. Yield increased and quality improved by pulpwood thinnings at about 35 years. Natural pruning fairly rapid; limbs dead up to one-half height of tree.
Over 1,500	Merchantable material produced, but diameter growth rate very slow. Mortality rate high. Commercial thinnings for pulpwood not possible until stands over 40 years old. Thinnings at 10–20 years desirable. Very dense stands (2,500 and up) sometimes mature at under-sawlog size. Limbs small, short, and timber clean.

After fire jack pine may come in very densely, sometimes 20,000 or more per acre. In such instances the trees are too crowded to make good development and the whip-like stems are very susceptible to breakage by snow. Natural thinning takes place very slowly except on the better sites; consequently stands containing as many as 5,000 stems per acre at 20 years are not uncommon. Although overstocking results in the development of the straightest, cleanest-boled trees, it is highly undesirable. Overstocked stands on poorer sites, if not thinned, may grow so slowly in diameter that they never get beyond the pulpwood stage, even at maturity, and because many of the trees are undersized, may not yield much pulpwood.

Factors Affecting Longevity

The great amount of logging done in the Lake States since about 1870 and the extensive fires that have swept the region's pine lands have left very few groups of jack pine trees more than 90 or 100 years old.

Jack pine begins to decline in vigor at 50 to 70 years, and this decline is usually well advanced before the trees reach 80 years. Basal area in well-stocked stands begins to diminish at about 60 years on all sites (table 8). In younger well-stocked stands the crowns of the trees crowd closely together, but as age increases and the oppressed trees die the openings thus left usually are not closed by the adjacent crowns and the roots of the older trees occupy the soil less fully. Low vegetation, both shrubby and herbaceous, increases greatly in density on the better soils; stands 85 years old commonly have a luxuriant undergrowth of hazelnut 6 feet or more in height (fig. 21). Ordinarily, except on the most favorable sites, jack pine may be considered mature when 70 years of age.

As jack pine becomes mature it can be injured severely by various destructive agents including drought, glaze, wind, defoliating insects,

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FIGURE 21.—The dense understory of hazelnut beneath this 85-year-old stand of jack pine, growing on sandy loam, shows that the trees no longer fully utilize the soil.

wood-boring and bark beetles, and decay organisms. Younger trees are subject to attacks by the same agents, but excessive mortality is not so likely to occur in stands less than 50 years old. Of course fire, also, is a destructive agent; aside from its outright physical effects, which are not discussed here, it may exert a delayed but serious influence in conjunction with some of the other causes of loss.

Glaze together with wind is particularly destructive. In early April of 1940, a heavy glaze and the accompanying wind felled approximately 30 million feet of timber on the Chippewa National Forest, most of which was jack pine. Especially severe damage was done in stands of slender poles on exposed slopes and ridges and on areas adjacent to lakes and swamps.

A severe July windstorm in 1932 destroyed some 300,000 cords of timber, principally jack pine, on the Superior National Forest. A similar July storm on the Chippewa National Forest in 1940 caused the windthrow of some 30 million board feet of timber much of which was jack pine.

The 10-year drought in northeastern Minnesota that culminated in the almost unprecedentedly dry year of 1936 was followed by the death of many 60- to 80-year-old jack pines during the 3-year period 1937–39. Drought, although probably the most important, was only one of the factors believed to be responsible for these losses. A sudden intense outbreak of the jack pine variety of spruce budworm, the habits of which have been described by Graham (*8*), took place in 1936 on the Superior National Forest, and more extensive although moderate epidemics followed in 1937 and 1938. The budworm attacked jack pine on the Chippewa forest also in 1936, and by 1939 had spread to about 20,000 acres of 70-year-old timber that had been weakened by the drought. Some 15 or 20 percent of the stand has died, and additional losses are expected. Several species of sawflies were found to be present along with the budworm and may have contributed somewhat to the losses. Pine sawyer beetles (*Monochamus spp.*) and a bark beetle (*Ips pini*) followed. It is impossible to say what proportion of the losses in this instance should be assigned to each of the various contributing agents. He attributed the losses primarily to overmaturity of the stand and to the effect of the drought. *Armillaria mellea* was found to be a minor factor.

Rot does not frequently progress to such an extent as to reduce the scale of merchantable timber until the trees are at least 60 years old, according to the findings of Weir (*36*), who stated that the two most important rot-causing fungi in jack pine are *Trametes pini* (now *Fomes pini*) and *Polyporus schweinitzii*. Weir observed that decay occurs at an earlier age in the moist situations of northern Minnesota and Canada than on "dry pine barrens." Owing to greater prevalence of red rot, loggers commonly discriminate against the older timber, which they call "red jack" because of the reddish color of its rather large-flaked bark, in favor of the younger or "black jack" timber, which has dark-gray or blackish bark.

In a study made in 1933 Frank Kaufert found that of 143 trees examined in an 80-year-old jack pine stand, 35 percent contained decay (practically all caused by *Fomes pini*), and that of 33 trees showing fire scars, 79 percent contained decay. After a survey of cuttings Russell Watson [15] concluded that light surface fires have been responsible for the high percentage of rot found in jack pine in the Lower Peninsula of Michigan. Where such fires have been numerous, the rotations have to be 10 to 20 years shorter than where fire has never run through the stand. Results of increment borings made by Watson in more than 2,000 jack pine trees are presented in table 9. Trees of advanced age generally showed more evidence of decay than young trees, but decay was very much greater among fire-scarred trees.

[15] See footnote 7, p. 11.

TABLE 9.—*Relation of past fires to decay in jack pine, in percent of trees showing decay*

Age (years)	Fire-scarred trees	Trees not fire scarred	Age (years)	Fire-scarred trees	Trees not fire scarred
	Percent	*Percent*		*Percent*	*Percent*
40	0	0	70	35	15
50	20	3	80	45	20
60	27	8	90	60	30

From the pathological studies and from the other evidence presented it may be concluded that except where fire has weakened the trees, making them more subject to breakage by wind (fig. 22), rot has less influence on the length of the natural rotation than the general decline in vigor that makes the trees susceptible to drought and insect attack.

ECONOMIC ROTATION

The desirable time for cutting jack pine timber depends on the size and quality of the trees, market for the products, the prices obtainable, growth rate, and total yield.

The mean annual growth of jack pine in cords reaches its highest point at about 40 years on good sites, at about 43 years on medium sites, and at about 50 years on poor sites (table 10). However, the average annual growth is not much lower for some years before and after the culmination, so that the forest manager has considerable latitude in choosing a time to cut.

In general, it is recommended that pulpwood rotations be about 50 years on good and medium sites and 55 years on poor sites, because the somewhat heavier stand volumes resulting from the longer rotations tend to reduce logging costs proportionately. Moreover, the risk and expense of regenerating the stand recur less frequently. On the other hand market conditions, operating costs, declining vigor of the stand, or threatened losses from destructive agents, such as insects, may make it good business practice to cut earlier. These recommendations apply to unthinned stands only.

TABLE 10.—*Mean annual increment of pulpwood* [1] *per acre in well-stocked stands of jack pine*

Age (years)	Good site	Medium site	Poor site	Age (years)	Good site	Medium site	Poor site
	Cords	*Cords*	*Cords*		*Cords*	*Cords*	*Cords*
20	2.45	0.35	0.20	50	0.68	0.54	0.36
25	.60	.45	.28	55	.66	.52	.30
30	.67	.50	.33	60	.63	.50	.35
35	.70	.53	.35	65	.60	.48	.33
40	.70	.55	.35	70	.57	.46	.31
45	.70	.55	.36				

[1] Unpeeled volume of trees 5.0 inches d. b. h. or more to 4.0-inches top d. i. b. (inside bark).

Usually it is advisable to hold stands to ages 60 or 70 years, in order to obtain trees of sawlog and mine-timber sizes, which command higher prices than pulp timber. Sometimes, if the timber remains thrifty, the rotation should be extended to 80 years. This is risky, however, and is not recommended as a general practice. On the other hand, the timber must not be cut too early; when merchantable products first become available value growth is usually at its peak.

For a number of years after the trees reach merchantable size, their annual growth is likely to be more valuable than that of smaller trees,

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FIGURE 22.—Such basal scars permit decay organisms to enter and so predestine the tree to wind breakage—an indirect loss due primarily to fire.

partly because the stems are free of branches. Softwood saw timber that will cut out reasonably clear lumber should sell at a better price for manufacture by local mills than smaller saw-timber material, which yields knottier lumber and more of which is wasted in sawing. Mine timbers, the principal requirements for which are relatively large diameter (8½- to 16-inch top) and absence of rot, rather than straightness or freedom from knots, command a particularly high price in the iron-mining districts of northern Minnesota. In localities where mine timbers can be marketed they are an excellent product to grow, even though they require longer rotations than pulpwood. Piling, also, brings relatively high prices, but it too requires a comparatively long growing period.

The prices of stumpage and unmanufactured products vary considerably from place to place and time to time, but a few representative figures showing current prices during the period 1937 to 1940 will serve to give some idea of the market value of jack pine. Jack pine pulpwood stumpage generally brings 75 cents to $2 per cord, the price varying, of course, with distance to mills, quality of timber, ease of logging, and general market conditions. Pulpwood delivered at the mill brings $4.50 to $8 per cord if unpeeled, $5.50 to $10.50 per cord if peeled. Saw-timber and mine-timber stumpage ordinarily brings from $2 to $5 per thousand feet b. m., although prices paid have gone as high as $7.85 per thousand board feet for mine timbers and $10 per thousand for piling. The United States Forest Service standard rate for sawlogs is $3.50 per thousand. Jack pine lagging brings from $7.50 to $8.50 per cord (192 cubic feet) delivered at the mines in northern Minnesota. Sawlogs sell at $8 to $15 per thousand board feet delivered at the mill. Mine timbers, the highest-priced product usually made from jack pine, bring from $25 to $35 per thousand feet b. m. delivered at the mines.

INCREASING QUALITY AND YIELD THROUGH THINNING

Among the present young forests of jack pine in the Lake States overstocking occurs less frequently than understocking,[10] but crowded stands need to be thinned if they are to make the best possible growth. Even where the average density is not high there are likely to be many overstocked patches. Jack pine, though it needs full light and does not develop properly under the shade of other trees, is slow to thin itself naturally. If overstocked stands are thinned intelligently, they will be improved silviculturally and will increase appreciably in potential value. Periodic thinning, if confined to merchantable trees that would die naturally, will substantially increase the yield during a rotation.

Until recent years, despite the need, thinnings in jack pine have scarcely been attempted except on an experimental scale. Since 1933, however, through the use of Civilian Conservation Corps and other unemployment relief labor available for improvement of public forests, some 20,000 acres of jack pine stands in the Lake States have been thinned (fig. 23, *A* and *B*).

Noncommercial Operations

If thinning is to be done before salable products are available, work in small sapling stands—those up to 10 feet in height—offers the best prospect of a return on the investment. Some inexpensive measure, such as hacking the tops out of some of the saplings, is sufficient to

[10] Cunningham and Moser, cited in footnote 6, p. 2.

release the more promising trees and to reduce the number of stems. Any longer-lived species that may be present, such as red pine, can easily be favored in this operation.

The record of a 90-acre tract of 10-year-old jack pine in northern Minnesota thinned by the C. C. C. in 1933 serves to show the cheapness and effectiveness of thinning small saplings. According to Bjorn O. Vegheim, junior forester, C. C. C. Camp S-54, Big Fork, Minn., the stand contained 3,000 to 5,000 trees per acre when the project was undertaken, the taller trees averaging about 10 feet in height. It was thinned to a density of 2,700 trees per acre at a cost of 1.2 enrollee man-days per acre. Six years later the stand was thrifty, the crowns had filled out, and the dominant trees had grown to an average height of almost 18 feet.

Stands of large saplings and small poles, trees 1 to 8 inches d. b. h., containing 1,500 to 5,000 stems per acre, are of common occurrence. Usually they range from 20 to 40 years in age. The thinning work

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FIGURE 23.—*A*, Unthinned plot in a 20-year-old jack pine stand on a medium-quality site on the Superior National Forest, Minn.; *B*, adjacent thinned plot.

of the C. C. C. on public lands has been done chiefly in stands of this description.

Thinning in such stands where no market exists for small material should be done from below; that is, the smaller, weaker trees should be removed rather than the larger dominant ones, since the latter are likely soon to become merchantable. The yield table for fully stocked stands of jack pine constructed by Wackerman, Zon, and Wilson (*35*) has been successfully used as a guide by the C. C. C. in determining how many stems per acre to leave in stands of various sizes and ages.

The usual practice has been to thin to the number of trees per acre shown by the yield table for an age 10 years in advance, or 5 years ahead in localities where it seems likely that commercial thinning or improvement cutting will soon become possible. A stand 30 years of age on a medium-quality site would thus be thinned to the 850 stems per acre indicated by the yield table for a 40-year-old stand. Examples showing results in two representative stands thinned in this manner are given in table 11. This method of determining how many trees to leave is easy to apply and has the great advantage of assuring uniform work by relatively inexperienced men.

At times, however, the use of unadjusted yield-table values for number of trees may reduce the growing stock too severely, especially where a stand is greatly overstocked in numbers. In deciding how much to thin, basal area should always be considered along with number of trees. For instance, the number of trees may be high but the basal area about average, in which case overthinning might result from following the table mechanically. Yield-table scales of densities should consequently be used only as a guide to good judgment. National-forest thinning rules now restrict spacing to a maximum of 6 by 6 feet for young pole stands. With such a stocking there should be sufficient trees for a commercial pulpwood thinning later.

TABLE 11.—*Examples of thinnings based on yield-table values, on medium-quality sites, Superior National Forest*

Item	Stand per acre [1]				Average diameter	Total volume	
	Trees		Basal area				
	Number	*Percent*	*Square feet*	*Percent*	*Inches*	*Cubic feet*	*Percent*
37-year-old stand:							
Before thinning	1,618	100	153	100	4.2	3,139	100
After thinning	604	37	73	48	4.7	1,605	51
20-year-old stand: [2]							
Before thinning	3,216	100	107	100	2.5	(3)	----
After thinning	1,208	38	64	60	3.1	(3)	----

[1] Minimum d. b. h. of trees tabulated, 0.5 inch.
[2] Views of this stand appear as figure 23.
[3] Not calculated because of the small size of the trees.

Thinning is not such a time-consuming undertaking if work done to enhance aesthetic values and to dispose of slash is held to a reasonable limit. Time spent in trimming the poles, felling dead and dying trees, and burning tops and limbs usually equals and often greatly exceeds that required in the thinning itself. Some work of this sort may be necessary along roadsides; but the type of slash created is not a very serious fire hazard and complete slash disposal by burning cannot be justified economically.

In applying any method of thinning, it is important to remove trees of poor form and thin crown, diseased trees, and injured trees that have been weakened mechanically or may develop rot. The principal things to watch for in jack pine are (1) the globose swellings of gall rust caused by *Cronartium cerebrum*, (2) stem cankers of sweetfern rust caused by *C. comptoniae*, (3) partial or complete girdling of the upper bole by porcupines, and (4) basal scars resulting from surface fires or from barking by snowshoe hares.

Commercial Operations

Although little has been done as yet toward adapting thinning methods to commercial practice, there would seem to be many excellent opportunities throughout the region for getting stands of poles thinned on a commercial or self-supporting basis. If the pulpwood market continues to improve, such opportunities will increase. The minimum top diameter for pulpwood bolts is 4 inches, which means that trees as small as 5 inches d. b. h. contain merchantable wood. There is also a limited market for conversion wood, or low-grade pulpwood used for fiberboard and insulating material. Conversion wood, which sells at a lower price than ordinary pulpwood, is made from trees as small as 4 inches d. b. h. utilized to a 3-inch d. i. b. top. Since it is considered economically feasible to cut as little as 3 to 5 cords per acre, it should be possible to thin overstocked jack pine stands two or more times before the final cut.

Thinning pole stands from below (that is, taking the cut entirely from the smaller trees in the stands) could not be generally introduced into commercial practice, because the trees thus removed would in many instances be too small to be merchantable. The type of thinning used will necessarily vary with the number of trees per acre. In stands 30 to 55 years old, well stocked as to basal area but having a large number of stems per acre, the thinning will have to be carried out mostly from above (that is, among the larger, taller trees) if merchantable trees are to be cut. Stands having a moderate number of stems may be thinned partly from above and partly from below. Stands having still fewer but larger trees may be thinned entirely from below.

A series of experimental thinnings established in 1940 in 31-year-old jack pine serves to illustrate how commercial thinning may be applied to stands of various densities (table 12). On plot 1, the trees being of small average diameter, thinning was chiefly from above; but on plot 2, with a slightly larger average diameter, thinning was both from above and from below. On plot 3, the trees being of relatively large size, thinning was more generally from below. In each stand the thinnings produced about 4 cords of pulpwood per acre together with a smaller quantity of fuel wood, which came mostly from tops. Basal areas were reduced to 99 square feet, 92 square feet, and 74 square feet respectively on plots 1, 2, and 3. Given an available pulpwood market, such thinnings could readily be carried out as commercial operations.

Table 12.—*Material removed per acre in thinning 31-year-old jack pine*

Plot No.	Density of stand		Pulpwood removed			Fuel wood cut, in addition
	Trees	Basal area	Standard [1]	Conversion [2]	Total	
	Number	*Square feet*	*Cords*	*Cords*	*Cords*	*Cords*
1	1,283	122	2.00	2.00	4.00	2.60
2	1,104	114	2.00	1.75	3.75	1.92
3	568	93	2.62	1.38	4.00	1.25

[1] To 4-inch top inside bark.
[2] To 3-inch top inside bark.

On plot 1 another thinning for conversion pulpwood should be possible after 5 to 10 years. Plot 2 can probably be thinned again after about 10 years for standard pulpwood. Plot 3 may not be ready for another thinning until 15 years have elapsed, but at that time it should be possible to take not only puplwood but also some mine timbers—a much more valuable product. The trees on plot 3 were practically all of merchantable size; therefore, if present commercial practice had been followed, this thrifty young stand would have been clear cut, with consequent destruction similar to that shown in figure 24. Clear cutting should not be practiced except for stands that have reached full maturity.

By carrying out commercial thinnings it should be possible to increase appreciably the total yield during the rotation and to develop

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FIGURE 24.—Remnant of a thrifty young stand of mixed jack and red pine in northern Minnesota clear cut just when making its best growth; the undersized trees left standing have been broken off by snow and wind, whereas a light thinning on a commercial basis would have left enough for mutual protection.

stands containing larger and more valuable trees. Any financial returns from the sale of material thus removed would help to defray the cost of keeping the stand until maturity. Such thinnings are therefore recommended as good forest management.

EFFECTS OF THINNING

Insufficient time has elapsed for accumulating extensive records of results from the C. C. C. thinnings described above, but repeated checks by many foresters have in most cases shown acceleration in diameter growth of the remaining trees.

One such case may suffice to show what can be expected. The 37-year-old stand represented in table 11 was examined 4 years after thinning. Increment cores were taken from crop trees on both the thinned and the unthinned plots. Compared with the rate for the 4 years prior to thinning, the diameter growth rate of the unthinned trees was 17 percent greater, but that of the thinned trees was 67 percent greater.

Growth in total cubic volume may or may not be increased by thinning, but the growth rate of merchantable wood is almost certain to be increased if the thinning is done intelligently. In 27-year-old jack pine in northern Minnesota, greatly overstocked in number of trees but not in basal area, a heavy thinning resulted in an increase in rate of volume growth of the remaining trees during the first 5 years, whereas light thinning was followed by 5-year growth at a rate lower than that of the check plot (*21*). At the end of 10 years both thinned plots showed better growth in diameter and in volume than the unthinned plot (*22*).

It is likely that the rates of growth of thinned jack pine will tend to decrease gradually to those of fully stocked stands as the stands approach full stocking in basal area. A knowledge of how soon the thinned stands close in and fully occupy the soil would be an aid to judgment in deciding how heavily to thin. The reaction of a slightly overstocked 20-year-old stand on the Chippewa forest to thinnings of varying severity in 1929 is of special interest in this connection.

Remeasurements of the experimental sample plots after 5-year and 10-year intervals indicated that the 20-percent thinning was back to normal stocking in basal area in 5 years; the 34-percent thinning was back to normal in 10 years (table 13); the 44-percent thinning was not quite back to normal in 10 years; and the 65-percent thinning will apparently require 20 years to return to normal. The decision as to which of these methods is best depends upon intensity of management. For small farm woodlands or other areas where frequent light cuttings for fuel and poles are feasible, 20- to 30-percent thinnings are best. Where a second thinning must be delayed until a large cut of pulpwood or other products can be made on a strictly commercial basis, removal of roughly half the trees seems about right. The heavier thinnings, however, create some likelihood of an undesirable increase in the density of shrubby and herbaceous vegetation.

What causes growth to speed up after thinning? The ecological changes following a thinning of 27-year-old jack pine that resulted in acceleration of growth were studied by Schantz-Hansen (*22*). Although the increase in rate of growth was roughly proportional to the increase in light, Schantz-Hansen concluded that in all probability it was caused not by the increase in light but by changes in associated factors. He noted that where the stand had been heavily thinned a soil temperature permitting rapid root growth was reached somewhat earlier in the season than where no thinning had been done. This is in agreement with the general observation of many foresters that snow disappears sooner in the spring under thinned than under unthinned stands of jack pine. In this study it was found that 10 years after thinning the total leaf area was 33.8 percent greater on the heavily thinned plot and 18.2 percent greater on the moderately thinned plot than on the unthinned plot.

TABLE 18.—*Growth in basal area per acre of a 20-year-old stand of jack pine on the Chippewa forest in the first 10 years after thinnings of varying severity made in 1929*

Plot No.	Original basal area	Thinning	Basal area after thinning			Basal area in terms of normal density	
			Immediate	10 years later	Annual increase	Immediate	10 years later
	Sq. ft.	*Percent*	*Sq. ft.*	*Sq. ft.*	*Percent*	*Percent*	*Percent*
29	101	0	101	139	3.8	109	112
30	100	20	80	129	6.1	89	106
28	103	34	68	122	7.9	77	103
26	97	44	54	114	11.1	62	98
27	104	66	36	93	15.8	40	78

A scattering of trees usually die during the first year or two after thinning, a few are bent to the ground or broken by snow or glaze, and others are snapped off or uprooted by windstorms. Some are attacked and killed by *Ips* bark beetles—a few apparently sound trees but mostly trees that have been severely scorched by the heat from burning slash. In recent years, the weakening effect of droughts may also have played a part in *Ips* infestations. The losses from all causes, so far as present experience shows, are not severe enough to justify changing the thinning methods.

The ultimate results of thinning young jack pine cannot be satisfactorily appraised until the timber crop is ready for harvest, but the following benefits are at present indicated: (1) Larger and straighter timber than in old-growth stands; (2) less rot; (3) greater assurance that trees on poor sites will reach merchantable size before becoming decadent; (4) better species composition in the case of mixed stands; (5) greater total yield, if the products of thinning are utilized; (6) shortening of the rotation. Timber that has been thinned while young should therefore be easier to market than dense unthinned stands. The beneficial effect of thinning should in the end be reflected in better stumpage prices, greater latitude in choice of time of cutting, and wider selection in kinds of product to cut.

HARVESTING THE CROP AND RENEWING THE STAND

Harvesting the timber crop in a manner that assures successful regeneration is the crucial requirment in managing a jack pine forest. Recommendations on methods of cutting, ground preparation, and slash disposal for promoting prompt natural preproduction are based on the experimental findings and observations outlined in foregoing sections. In brief, these indicate that (1) jack pine seedlings usually grow best in full sunlight, (2) reproduction should have an even start with low vegetation, (3) mineral soil is the best seedbed, (4) cones attached to slash contain the seed needed for reproduction, and (5) cones must be placed on or close to the ground for prompt opening and release of seed. Application of these findings must vary with character of forest, density of undergrowth, and kind of topography and soil.

CLEAR CUTTING IN PURE STANDS

When a pure stand of jack pine has reached maturity at about 70 years, the aim in management should be to harvest the timber and to obtain reproduction immediately, while seed from the slash is available and before grass, herbs, and shrubs become firmly established. Little dependence can be placed on seed trees, for, except on south slopes and in the southern and southwestern portions of the range of this species, only an insignificant proportion of the large supply of seed stored in the cones of living jack pines (table 3) is annually dispersed (table 5). If sufficient seed is to be dispersed naturally, it must come from cones in the slash, and the heavier the cut the greater will be the quantity of seed in the slash (fig. 13).

Also, as was previously stated, jack pine seedlings usually must be free of overhead shade if they are to grow satisfactorily (table 7); and they must make a quick start if they are to outstrip rapidly encroaching herbs and shrubs. For these reasons clear cutting of mature timber (together with scattering of slash and scarification of soil) is recommended as a general practice. The fact that promiscuous clear cutting as practiced in the past did not induce successful regeneration is not significant; it was largely due to windrowing of the slash and failure to prepare a suitable seed bed.

Before the facts leading to a recommendation of clear cutting were well understood, partial cutting was advocated for pure stands of jack pine. It was thought that the residual stands would respond to release, thus increasing the yield, and that the partial cover might facilitate regeneration, particularly of more shade-tolerant species, such as eastern white pine, red pine, and white spruce.

In 1926, experimental plots to test three kinds of partial cuttings were established on both the Chippewa and Superior National Forests in 55- and 60-year-old jack pine timber. On all these plots cutting failed to accomplish a material increase in reproduction of the more tolerant conifers, and jack pine reproduction was distinctly unsuccessful. From the standpoint of growth of the residual timber, also, the results were chiefly negative; on all three of the Chippewa plots and on two of the three Superior plots the subsequent 10-year merchantable growth proved to be less than in adjoining uncut stands (table 14).

Measurements showed that diameter growth of individual trees did accelerate after partial cutting, but volume growth per acre in all but one of the partial cuttings was less than in the uncut stands, primarily because of the reduction in growing stock. The one instance (the diameter-limit cutting in the Superior series) in which partial cutting increased the volume growth per acre can be explained by the fact that a large number of trees 4 and 5 inches d. b. h. were left. These trees grew to merchantable size (5.5 inches d. b. h) during the 10 years after cutting. Sixty-year-old jack pine having the density of this particular stand (936 trees per acre) is not common, so the method has little possibility of extensive application in stands of this age class. However, it could be successfully applied in thinning practice to stands 40 to 45 years in age.

Although jack pine in some situations may root to a depth of 6 or 8 feet, on the thin, rocky soils of northeastern Minnesota its root system is exceptionally shallow. A 60-percent experimental cutting of 12 acres of 80-year-old timber on shallow soils on the Superior National Forest was followed within 2 years by death of 30 percent of the residual stand, chiefly through windfall. Under such conditions clear cutting is nearly always desirable. In somewhat younger stands experimental cuttings indicated that to resist the onslaught of the winds the residual stand must contain at least 50 percent of the basal area; but such heavy stands would mean decidely too much shade and root competition for good development of jack pine reproduction.

TABLE 14.—*Merchantable growth after partial sawlog and pulpwood cuttings in nearly mature*[1] *jack pine, 1926*

Cutting method, Chippewa series	Basal area per acre cut	Growth per acre 1927–36[2]	Cutting method, Superior series	Basal area per acre cut	Growth per acre 1927–36[2]
	Percent	*Board feet*		*Percent*	*Cords*
Check	0	4,345	Check	0	5.8
Light selection	22	3,282	5.5-inch diameter limit	48	8.9
Heavy selection	51	2,414	Thinning from below	59	2.1
6-inch diameter limit	82	885	Heavy selection	67	4.1

[1] Ages in 1926: Chippewa stand, 55 years; Superior stand, 60 years.
[2] The growth on the Chippewa plots is shown in board feet (over 7.5 inches d. b. h.) and that on the Superior plots in cords (over 5.5 inches d. b. h.) because the 2 stands were best suited for cutting into sawlogs and pulpwood respectively.

Any scattering of better species, such as red pine and eastern white pine if apparently windfirm, or some of the oaks if sound, can well be left to form a small nucleus of the new stand, in which a mixture of species is always silviculturally desirable. Such residual trees, blocks of younger age classes, and patches of other forest types that may be mixed in with the jack pine tend to keep the clear cuttings to small size. On hot, dry southerly or westerly exposures and open exposed flats in the warmer part of the range of jack pine a special effort should be made to leave a partial stand of jack pine and other species as a protective measure. The shade of these trees will limit surface temperatures and evaporation rates to points at which seedlings can germinate and survive, and the trees will probably contribute a small but continuing supply of seed for regeneration of the forest.

GROUND SCARIFICATION

Providing a suitable seedbed is an essential feature of successful natural regeneration of jack pine under the clear-cutting method. It has been shown clearly by the experimental evidence (table 6) that mineral soil may be four times as efficacious as duff in promoting prompt germination and twice as effective in assuring satisfactory early survival. Exposure of the mineral soil by scarification of the forest floor, carried out either before or after clear cutting, appears to have considerable advantage over burning. Burned duff is a fairly good medium, but no dependable method of burning has been evolved for use in preparing a seedbed. To run fire through a stand before cutting would greatly reduce the value of the timber for pulpwood, since even small particles of charcoal in the wood are decidedly objectionable to the manufacturer of paper. Moreover, it has not been demonstrated that fire can be used in this manner without excessive expenditure for control. On the other hand, scarification is free of the risks of fire, is highly beneficial in promoting reproduction, and in most cases is necessary if adequate natural regeneration is to be obtained after cutting.

Scarification has the greatest potentialities on areas of sandy soils where the stand of jack pine is fairly dense. Good judgment must, however, be used in deciding whether a site is suitable for this treatment; otherwise money is likely to be wasted. In occasional instances jack pine sites that have been cut over or otherwise deforested are already partially restocked with advance reproduction of jack pine and other species, which scarification would destroy. An old stand where only a few scattered jack pines remain and an undergrowth of shrubs has already claimed the site, is another instance; the jack pine seed supply is limited and poorly distributed, and tree seedlings would face a hard struggle with the established shrub growth. Such a site can be brought back to forest productivity most readily by planting with good-sized stock. Sites strewn with boulders are difficult to treat and are hard on equipment, and the surface that can be treated successfully is too small to insure profitable results.

A number of different scarifying implements have been used on jack pine lands with varying degrees of success. In the first attempts at scarification the duff was stripped off with mattocks and rakes and piled. This led to the establishment within 2 years of more than 10,000 seedlings per acre (*11*); but the cost of this hand work was unreasonably high. In later tests of ground scarification, trials were made of such crude implements as a limby log dragged by a horse. Makeshifts of this kind proved inefficient. The ordinary spring-tooth harrow was next used, under very favorable conditions. Although the treatment resulted in establishing a large number of seedlings per acre, this implement was not satisfactory where there was much ground cover. The type of disk harrow commonly used to maintain firebreaks does fairly good work in scarification, but is not rugged enough to be entirely satisfactory.

Plowing furrows at intervals of 8 to 12 feet with a double-moldboard planting plow has been tried with a dual objective—if seedlings did not immediately catch in the plowed furrows the ground would at any rate be prepared for planting. But the percentage of ground area exposed by furrowing was not great enough to encourage much natural reproduction, and most of the seedlings that germinated were smothered by leaves of hardwood trees and shrubs that lodged in the furrows.

The most promising tool thus far used is the Athens-type disk plow, reduced to the width of a tractor (fig. 25). In 1940, sacrification trials with this equipment resulted in establishment of 7,900 well-distributed seedlings per acre on a new clear cutting. Tested for 5 years, the Athens plow has proved highly efficient in exposing mineral soil and appears to be strong enough to stand up under hard use.

How thoroughly the disking should be carried out depends to some extent on the character of the forest floor. In some places a double disking, the second at right angles to the first, although necessarily costing more, may be necessary for adequate exposure of mineral soil. On the national forests in Minnesota where Athens-type disk plows powered with 35-horsepower crawler-type tractors have been in operation on rather brushy areas, satisfactory cross disking has required about 2 tractor hours per acre.

Preliminary tests with two disks drawn tandem fashion have given promising results. As more experience is gained doubtless other modifications and improvements both in methods and in design of equipment will be possible.

Scarification may be carried out before clear cutting or afterwards. If done beforehand there is no slash to interfere with the operation of equipment, but in well-stocked stands it is somewhat difficult to dodge between trees with a crawler tractor. If not done shortly before cutting, vegetation promptly sprouts back and the effectiveness of scarification is decreased.

Experience thus far indicates that scarification can be more efficiently conducted after logging when the equipment can ride over

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FIGURE 25.—Athens-type disk plow, drawn by crawler tractor, used to prepare soil for natural reproduction; after clear cutting, if the slash is lopped and scattered, seed from the quickly opening cones will find a favorable seedbed.

stumps and better coverage of the area is possible. Reproduction then has an even start with all weeds and brush. The main disadvantage is the burying of some cones by the disk.

The effectiveness of scarification may be judged by the degree of exposure of mineral soil. Second-year results of scarification tests on the Chippewa Forest indicate (table 15) that, in general, the more complete the scarification, the more seedlings per acre.

If there are insufficient cones to provide adequate seed for natural reproduction, work done in scarification is not lost since it puts soil into excellent condition for supplemental seeding or planting. Promising early results have been obtained both by planting 200 to 400 red pine nursery transplants per acre, and by dropping small pinches of jack pine seed on exposed mineral soil and covering lightly with the foot. The use of red pine trees for such planting is particularly desirable on the more fertile soils where there is an opportunity to improve the composition of the future forest.

SCATTERING OF CONE-BEARING BRANCHES

Under the clear-cutting method as recommended for jack pine, the key to reproduction is the proper distribution of the cone-bearing branches, often containing 500,000 to 2,000,000 seed per acre. In order to obtain prompt opening of cones and release of seed, the small cone-bearing branches should be lopped and scattered (fig. 26,) over the exposed mineral soil. The heavier limbs usually have no cones attached to them.

The closer the cones are to the surface the better. Temperatures

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FIGURE 26.—The jack pine has been clear cut and the slash lopped and scattered: to promote reproduction scattered red pines have been left to seed in with the jack pine.

at the ground surface are sufficiently high during warm weather to cause cone opening, but the air only a foot above the surface is so much cooler than even at such heights cone opening may be delayed, resulting in undesirably late germination.

Since experimental tests show (fig. 17) that the earlier in the spring the cones open and shed their seed, the more likely are the seedlings to survive, cone-bearing slash should be lopped and scattered before the warm season (cone-opening time) comes on. With disposal thus provided for, fall, winter, and early spring all appear to be satisfactory seasons for cutting. If timber is cut in midsummer and the slash is lopped and scattered immediately, seed dispersal may take

TABLE 15.—*Number of seedlings on plots with different percents of mineral soil exposed, counted 2 years after scarification* [1]

Exposure of mineral soil (percent)	Basis		Seedlings—	
	Milacre [2] quadrats	Stocked quadrats	Per stocked quadrat	Per acre
	Number	*Percent*	*Number*	*Number*
0	44	4.5	1.0	45
10–20	42	28.8	1.4	405
30–40	42	59.5	2.2	1,285
50–60	23	60.9	3.7	2,260
70 or more	6	100.0	5.8	5,835

[1] Data taken on an area on the Chippewa National Forest scarified in 1937.
[2] Milacre means 1/1000 acre.

place soon thereafter, but should seedlings as a result germinate in late summer or early autumn, they run the risk of winter-killing. If cutting must be done in midsummer it would be advisable to bunch the slash and not scatter it until the hot weather has passed. Then the cones will not open until the following spring or early summer.

With close utilization of wood and thorough lopping and scattering of slash, it is rather surprising how little debris is left. The fire hazard is not high, but in some cases the slash is sufficiently heavy to offer mechanical obstruction to young seedlings; care must then be taken to place only the cone-bearing slash over prepared soil.

Disposal of slash by burning is not only unnecessary in connection with scattering but is also undesirable, since it destroys the seeds in the cones attached to the branches. Before the seeding characteristics of jack pine were fully understood, however, burning was recommended as a method of bringing about reproduction. Sterrett (*25*), commenting on national-forest practices in 1920, said that in Minnesota it was sometimes considered necessary to lop and scatter the slash and burn it in order that the cones might open and let out the seed. Some foresters still believe that the way to get jack pine reproduction is to run a "light" fire through the slash to open the cones. A number of experimental attempts have been made to follow such recommendations, but without success (*6*). The fire, if it runs at all, is hot enough to destroy most of the cones, and also any advance reproduction. The good reproduction that has sometimes followed broadcast burning of slash is probably due rather to seeding from residual trees, the cones of which were opened by the fire, than to seeding from the slash.

PARTIAL CUTTING IN MIXED STANDS

Jack pine sometimes occurs in mixture with one or more species such as red pine, white pine, black spruce, aspen, paper birch, jack oak, and red oak. In such cases partial cutting provides a way of favoring more valuable species at the expense of others.

In forests of mixed red and jack pine particularly, partial cuttings have a real place in management. Red pine not only is more windfirm than jack pine, but also lives much longer. In such stands the jack pine should be harvested in a series of partial cuttings, in which some of the larger and rougher red pines may also be removed if the stand runs heavily to this species. The smoother red pines that have been well pruned by natural processes should be left to develop into high-quality saw timber. Neither slash disposal nor reproduction is an urgent consideration in such cuttings.

The money returns from partial cuts are good because only the larger trees of comparatively high current value are handled. A cutting of this type carried out by Paul Zehngraff in a mixed red and jack pine stand on the Chippewa forest removed 2,245 board feet per acre (almost all jack pine) or 13 percent of the basal area. Since the trees were rather large, they were sold as mine timbers at $7.50 per M board feet in contracts with the prevailing rate of $3.50 per M for average jack pine sawlogs. In the second or any later operation, in order to maintain a high yield, somewhat less volume should be cut

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FIGURE 27.—A desirable light partial cutting in a 70-year-old stand of mixed jack pine and red pine in which 3,000 board feet per acre of large jack pines have been removed.

than has been added by growth since the last previous cutting. This practice has been followed successfully in recent years on the Chippewa forest, where market conditions make it feasible to cut as lightly as 1,000 to 2,000 feet b. m. per acre (fig. 27).

In northeastern Minnesota black spruce commonly occurs in association with jack pine. Although this species is more valuable as timber, favoring it in cutting has so far proved unsuccessful because of excessive windfall losses. In order to bring through black spruce in such mixed stands it would be necessary to remove the jack pine in a series of very light partial cuttings. This is probably not now economically feasible. Moreover, black spruce on upland soils is susceptible to butt rot, which lessens its wind-firmness.

The choice between jack pine and broadleaved species should be based in part upon the character of the soil. If the soil is fertile, it is almost impossible to maintain jack pine for more than one rotation in competition with aspen or paper birch. On poor soils, most broadleaved trees not only have little commercial value but offer less competition to jack pine. They should be thinned out somewhat if the material can be disposed of, but not to the extent of transforming the stand into pure pine. Hardwoods, in general, are superior to pine as soil builders. To some extent, they may act as insect retardants. Oaks, of course, provide mast for deer.

Partial cutting must be conservatively applied, since excessive opening up of the overstory encourages the development of an understory of shrubby or herbaceous plants, which may make it difficult to obtain pine reproduction. When the time comes for the final cut and the stand is to be regenerated, either naturally or artificially, low vegetation is a hindrance, in that it provides shelter for snowshoe hares and seed-eating rodents, interferes with germination of tree seedlings, and competes with the seedlings for water and light needed for growth.

Jack Pine Slash as a Fire Problem

Jack pine slash is greatly overrated as a fire menace. Slash burning on jack pine land is actually a wasteful and ineffective measure (*4*). At most, the breaking up of slash into small blocks has merit as an advance measure for suppressing fire. In attacking a fire with hand tools, it is helpful to have some previously cleared lines from which to work. For this purpose a few lines may be needed as supplements to natural barriers and logging roads.

The current notion that jack pine slash is a great fire hazard is something that has been passed down from a previous era. During the early days of logging in the Lake States, when extensive continuous stands of eastern white pine and red pine timber were clear cut, a slash fire often started a conflagration that did untold damage. Today cutting areas are generally small, no wide expanse of slash exists, and the pine slash present is mostly that of jack pine, which is much less dense than the slash from heavy stands of eastern white or red pine, especially after lopping. Moreover, it has come to be recognized that slash fires, although hot, do not spread particularly fast. This was brought out by an investigation made during 1938, by Russell Watson under the direction of J. A. Mitchell of the Lake States Forest Experiment Station. In the jack pine type it is the lighter fuels, such as grass, that carry fire rapidly. Quick action with heavy machinery makes it possible to control fires in jack pine slash and to construct fire lines rapidly through the slash on a going fire.

In any event, jack pine slash disintegrates rather rapidly and does not remain a fire hazard for long (fig. 28). On the basis of observations on commercial cuttings in Wisconsin, Zon and Cunningham (*38*) estimated about 7 years as the average time. It may last that long where it is bunched in large windrows, but if lopped and scattered it is not likely to remain an important fire hazard for even 7 years. Slash lopped and scattered on experimental cutting areas on the Superior

FIGURE 28.—After a short period of decomposition, jack pine slash is less of a fire hazard than the grass. *A*, Freshly cut jack pine slash, not lopped or scattered, on dry sand plains near Roscommon, Mich. *B*, Same view 4 years later; no scarification or scattering of cone-bearing branches was done to promote reproduction.

National Forest in 1927 practically disappeared within 5 years. Slash treated similarly in 1931 at the Michigan Forest Fire Experiment Station, Roscommon, Mich., broke down as quickly into a layer only a few inches deep mixed with the grass.

The slash-disposal policy for the national forests[17] of the Lake States has as its primary purpose reduction of the fire hazard, but recognizes that slash disposal can be so managed as to assist in reproduction.

It is obvious from the wording of the State slash-disposal laws in Michigan (*9*), Wisconsin,[18] and Minnesota (*15*) that they have been designed to aid in fire protection only, with little realization of their effect on natural reproduction. For clean-up along highways piling and burning is the usual slash-disposal practice specified, although swamper burning (burning as the cutting progresses) is less expensive and more satisfactory from a fire-protection standpoint.[19] Swamper burning is a particularly safe method when applied under such conditions that fire will not run, and it kills less advance reproduction than other methods of disposal by burning.

Even along highway and other rights-of-way, where it may temporarily improve appearances, the efficacy of disposal by burning is open to question. Slash burning never eliminates the highly inflammable grass and blueberries (*Vaccinium* spp.), and in many burning operations the running together of the fires between piles favors the further spread of these and other highly inflammable plants (fig. 29). Disposal by such methods destroys the seed needed for reproduction and merely postpones the date when a desirable forest cover will be restored. Funds available for slash burning would better be spent in intensifying fire protection until the slash disintegrates.

RESTORING DEFORESTED LANDS WITH JACK PINE[20]

Adverse weather will sometimes cause natural reproduction to fail even though the best known methods of cutting, ground scarification, and slash scattering have been applied. If reproduction does not become established in 2 or 3 years after cutting, it will be necessary to resort to planting in order to restock the area. Open or very poorly stocked areas not only contribute nothing in growth but also require more than average outlay for protection. In the Lake States, protection costs per acre are nearly twice as great for nontimbered upland as for land forested with second-growth pine.[21]

Jack pine is a suitable species for restocking jack pine areas where regeneration has not taken place promptly after cutting, and for the artificial return of other deforested pine lands to productivity. It is the best of the Lake States conifers for reforesting light sands and soils badly depleted by fire, because of its hardiness, rapid early growth, and production of merchantable material in situations where

[17] Outlined in the Administrative Section of the Timber Management Handbook, U. S. Forest Serv., North Cent. Region, 178 pp. 1936. [Processed.]

[18] WISCONSIN CONSERVATION COMMISSION. WISCONSIN CONSERVATION LAWS. 1938-39. [In process of publication.]

[19] UNITED STATES FOREST SERVICE. SLASH DISPOSAL—JACK PINE. U. S. Forest Serv. Lake States Expt. Sta. Tech. Notes 59, [1] p. [n. d. Processed.]

[20] The recommendations made in this section represent essentially the standard reforestation methods in practice on the national forests in the Lake States.

[21] UNITED STATES FOREST SERVICE. RELATIVE HAZARD AND ESTIMATED COST OF PROTECTION BY FOREST TYPES—LAKE STATES. U. S. Forest Serv. Lake States Forest Expt. Sta. Tech. Notes 78, [1] p. 1934. [Processed.]

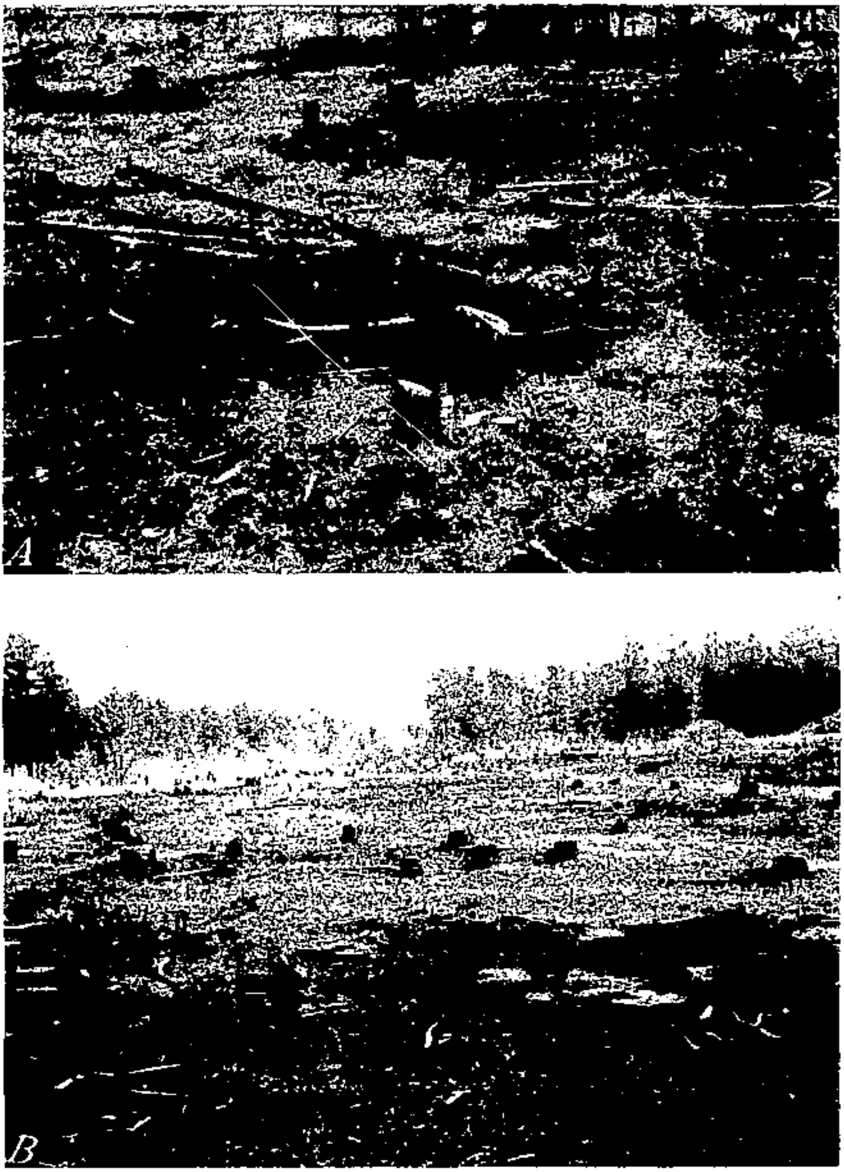

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FIGURE 29.—On both these areas, slash has been piled and burned. This method of slash disposal destroys seed supplies needed for reproduction. *A*, Burning in piles so as to avoid a clean burn is the accepted method of disposal to comply with State laws. *B*, The fire has run between the piles and destroyed almost all inflammable material. Although the fire hazard has been reduced for a year or two, inflammable vegetation developing within that period will probably create a hazard greater than the unburned slash.

growth of red pine is uncertain and eastern white pine grows poorly (fig. 30). Use of jack pine on sites that are sufficiently fertile for growing red pine, eastern white pine, or white spruce is rather questionable, since all three of the latter species produce timber crops of greater value. However, certain characteristics of jack pine tend to encourage its use for reforestation even on such sites. Because cones containing seed are always present, it is not necessary to forecast requirements of seed and store it in excess of current needs. The seed germinates promptly and vigorously in nursery beds. The seedlings can be planted successfully in the field when only 1 or 2 years old, whereas other northern conifers require 2 to 4 years in the nursery. Consequently, it is possible to institute a reforestation program with jack pine, either by direct seeding or by planting, much more quickly than with other northern conifers. Other advantages are cheapness of planting stock, superior resistance to drought, and greater capacity to outstrip brush and other competing vegetation in height growth.

Planting

Practically all jack pine planting stock used in the Lake States consists of 1- or 2-year-old seedlings. Transplants (1–1)[22] are better than either 1–0 or 2–0 seedlings; but they cost considerably more, and in most cases the seedling stock is satisfactory. Seedlings 1 year old are planted extensively on the easier sites, that is, those where vegetation is light and moisture conditions are relatively favorable. Seedlings 2 years old are used for the more difficult situations, those with heavy vegetation and those that are very open and subject to drought and high temperatures.

Good-quality 1–0 seedlings for field planting have tops about 3 inches high and roots at least 6 inches long. In some nurseries it is difficult to produce stock as large as this in one season. Seedlings 2 years old should have 4- to 7-inch tops and roots more than 7 inches long. The 2–0 stock has a strong tendency to become top-heavy and spindly, and is likely to be too tall rather than too short. These undesirable tendencies can be partly overcome by various methods, including growing the seedlings at low densities, restricting the water supply, and pruning the tops. Recently 1½–0 seedlings, produced by sowing seed in early summer and holding the plants in the seedbed until the second fall, have been tried successfully as a substitute for 2–0 seedlings. Such stock has a better balance between top and roots than 2–0 stock.

The best method of preparing sites for planting is to furrow with a heavy plow drawn by a crawler-type tractor. On excessively rocky ground or where machinery is unavailable, spots or "scalps" for planting can be prepared by cutting away 18-inch squares of the sod or litter and vegetation with mattocks, grub hoes, or similar tools. Where feasible, plowing is decidedly cheaper than hand methods and more thorough, increases the speed of planting, and has the further advantage of greatly reducing plant competition. Almost invariably, seedlings survive better in furrows than on "scalps."

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[22] In symbols classifying nursery stock, such as 1–1, the first numeral indicates number of years in the seedbed, the second numeral number of years in the transplant bed. Thus a 1–0 tree is 1 year old and a 1–1 or 2–0 tree is 2 years old.

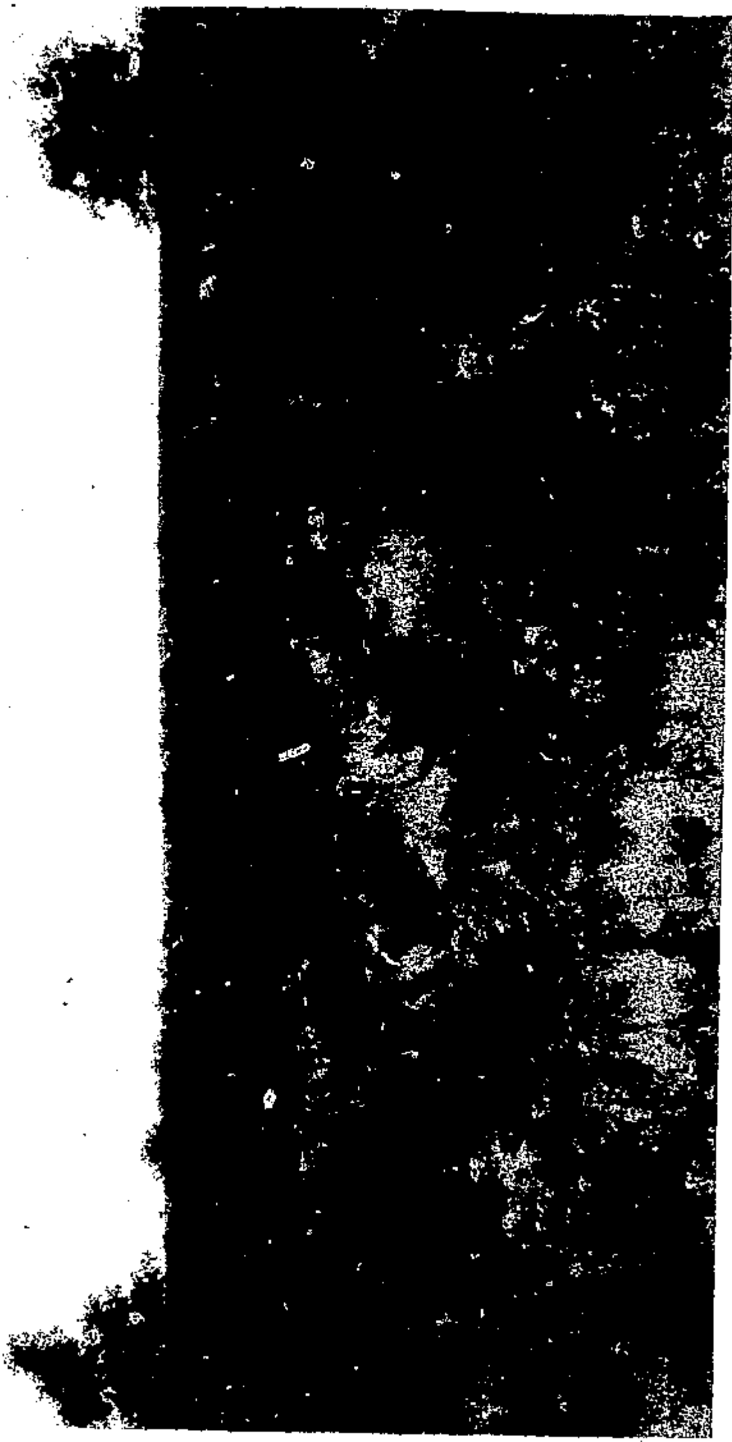

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FIGURE 30.—Jack pine plantation, 6 years old, on a central Wisconsin tract that had been badly depleted by fire. In the Lake States jack pine is the best species for reforesting such sites.

Spacing must be rather close in order to prevent the trees from becoming too limby. The practice regularly followed by the Forest Service is to space the trees 6 by 6 feet (1,210 trees per acre) on the better sites and 4 by 6 (1,815 trees per acre) on the poorer sites, where trees naturally grow more densely. In either case, the planting furrows are plowed 6 feet apart; the spacing is varied by changing the distance between trees along the furrow. One pulp and paper company now carrying on a fair-sized reforestation program plants from 1,700 to 2,700 trees per acre.

Jack pine should not be planted in pure stands over extensive tracts, because of the higher risk of insect and disease epidemics and the probability that many sites, when they have recovered from the injury caused by clear cutting and fire, will become capable of supporting more valuable species. In site requirements red pine resembles jack pine more closely than any of the other associates, and is the most suitable species for extensive planting in mixture with it, especially with natural reproduction of jack pine. Red pine is useful also for restoring open areas to productivity. Very few planting sites are actually denuded of tree growth, and most jack pine plantations contain a sprinkling of associated species, including oaks, aspen, paper birch, balsam fir, spruce, red pine, and eastern white pine.

In a reforestation project the trees may be planted in mixture by blocks or strips, if the soil and vegetation are uniform, or, if there are pronounced variations in site quality or cover conditions, by putting each species on the more appropriate sites. The latter method is being used extensively on the Nicolet National Forest, Wis., in planting various combinations of eastern white pine, red pine, jack pine, and white spruce (*14*). Row-by-row or tree-by-tree mixtures are not recommended, because of the danger that the jack pines will become limby before the other trees grow large enough to crowd them. The limby jack pines would then overtop the trees of the slow-growing species. This outcome is particularly probable on the poorer sites, where red pine survives along with jack pine but is crowded and suppressed by the more rapid-growing species.

Jack pine stock withstands handling very well in the process of transfer from nursery to field if it is given reasonable care during the lifting, moving, and setting operations. It is, of course, subject to attack by the same destructive agents as are natural seedlings. Losses in the first growing season after transplanting, however, should not be more than about 10 percent if weather and soil conditions are favorable. Spring planting is preferable. Fall planting can lead to considerable losses (*13*), attributable partly to soil desiccation before the dormant roots have time to establish a good contact with the soil, partly to frost heaving, and partly to the fact that jack pine nursery stock fails to harden off adequately in time for fall planting.

Direct Seeding

Jack pine is superior to any other Lake States conifer for direct seeding (*24*). The seeds, being unusually small, are less subject to destruction by rodents than those of the other pines. Other factors in this superiority are prompt germination and rapid growth during the first year.

The most efficient method of direct seeding is to sow with a garden drill in plowed furrows, using about 4 ounces of seed per acre. This method is less laborious than planting and, if a satisfactory catch results on the first attempt, costs only one-third to one-half as much. For direct seeding, newly cut-over areas or fresh burns have certain advantages over deforested areas of long standing. On fresh burns there is less plant competition and less danger of the seeds being eaten by rodents. A severely burned tract of approximately 300 acres on the Superior National Forest was successfully seeded by broadcast sowing in 1937. In preparation for seeding, the ground surface was torn up with a toothed harrow. That the operation as a whole was at least as expensive as planting with seedlings would have been was due to the excessive quantity of seed used—2.5 pounds per acre. On a considerable portion of this area the resulting stand was much too dense—over 15,000 trees per acre—and needed a heavy thinning when only 5 years old.

Many areas on the sandy outwash plains of Wisconsin and Michigan have a permanent water table only 2 to 5 feet below the surface, which tends to keep the surface soil mois' and relatively cool. Such sites are distinctly promising for reforestation by direct seeding (*26*).

In general, direct seeding, although cheaper and less laborious than planting, is less reliable, because of the possibility o: severe losses from seed eaters, heat, and drought and also the inability of the young seedlings to withstand plant competition as well as the larger planted stock does. Sites satisfactory for direct seeding are better-than-average "chances" for tree plan'ing. The opportunities for successful direct seeding are therefe somewhat limited, but as experience and skill in application are gained, direct seeding will undoubtedly be used more and more in reforesting suitable sites, with a considerable reduction in cost.

SUMMARY

Jack pine, once regarded as a weed tree but now extensively used for pulpwood and other forest products, has excellent possibilities for silvicultural management. The great extent of its distribution in the Lake States, nearly 3 million acres, is due chiefly to fire and to peculiar seeding habit of the tree. Closed cones accumulate on the trees until a forest fire, running through the stand, opens them and permits seed to fall on the burned soil, a favorable seedbed. Because in many cases jack pine has not regenerated successfully after logging of second-growth stands, studies have been made of the factors governing its reproduction.

These investigations, covering 14 years, indicate that in most places where jack pine is found few seed are scattered from standing trees but large quantities are stored on the trees in unopened cones. Logging transfers this seed supply to the slash. If cones lie on or close to the ground, they are opened by the heat of the sun and disperse much of the stored seed. In piles or windrows the cones tend to remain closed. Mineral soil is the most favorable medium for germination of the seed, although a burned duff surface is nearly as good. Young seedlings survive best, also, on mineral soil. They make most rapid growth in full sunlight, requiring little or no shade except in especially hot situations. In order to compete with herbaceous and other

ground vegetation young seedlings should have at least an equal start with it. Seedlings germinating in the spring or early summer have a better chance of surviving than those germinating in late summer or autumn, as the latter are more subject to winter killing.

Jack pine grows quickly and is relatively short-lived. It begins to decline in growth rate after 50 years and ordinarily matures at about 70 years. Pulpwood is produced as early as 30–35 years. Many stands of this age could well be thinned for such products and then permitted to grow into sawlogs and mine timbers, which command higher prices. Dense younger stands benefit by thinning because they are slow to thin themselves naturally and tend to stagnate.

Clear cutting with mechanical ground scarification and scattering of cone-bearing branches is generally recommended for harvesting pure stands of mature jack pine and obtaining natural regeneration. On warm exposures, however, a partial cover of forest should be left as a protective measure. Scarification with an Athens-type disk plow drawn by a tractor has proved successful. Jack pine slash is not considered to be a serious fire hazard, so that the lopping and scattering is entirely practicable. Where growing in mixture with red pine, jack pine may be removed in a series of partial cuttings. In this manner the longer-lived and more valuable red pine may be perpetuated.

Much of the large area of deforested pine land in the Lake States is suitable for artificial reforestation with jack pine. Essential requirements of successful planting are ground preparation by plowing furrows, sturdy stock, and aftercare to release seedlings from competing vegetation. Direct seeding with jack pine has been found successful on especially favorable sites.

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APPENDIX

Tables 16 to 25 will be found useful in estimating the contents of standing trees of jack pine, whether in board measure, cubic feet, cords, or piece products.

By means of table 16, the taper table, volume tables can be constructed on the basis of any desired standards—board feet or cubic feet, any specified top-diameter limit, total height or merchantable height. It is possible, for example, to determine how many bolts of different diameters or mine timbers and poles of different lengths can be cut, under any utilization practice, from trees of various sizes. Table 17, derived from table 16, shows number of pieces of mine timbers, poles, and lagging on the basis of complete utilization from a 1-foot stump to a top diameter of 3 inches inside bark—in other words, on the assumption that the trees are straight and sound and that limby poles and lagging are usable. It should be remembered that tables 16 and 17 make no allowance for the presence of cull trees, rot, sweep, crook, or excessive limbiness. In using the tables it will commonly be necessary to apply cull factors calculated for the particular stand of timber being estimated.

Table 18 shows cubic-foot volume of the entire stem, including bark, of trees of different diameters and total heights. Table 19 shows volume in standard cords of the stem from a 1-foot stump to a top diameter of 3 inches outside bark. The cordwood volumes represent the material as stacked unpeeled. Peeling losses are presented in the last column in order that the volume of peeled wood may be computed. Actual utilization in the region is somewhat less complete than to a 3-inch top diameter outside bark; more commonly, jack pine is cut only to a 4-inch top diameter inside bark.

Table 20 shows the effect of different utilization standards on the volume of pulpwood obtained from jack pine trees of different diameters; that is, it shows the relative volumes of wood produced if the trees are cut to top diameter limits of 4, 5, or 6 inches inside bark instead of 3 inches outside bark (which is the utilization standard used in table 19). Although the average loss per acre depends upon diameter-class distribution, it is apparent that a slight change in utilization limit may make a considerable change in volume of pulpwood produced, particularly in stands of small timber.

Tables 21, 22, and 23 are board-foot volume tables of two kinds. Table 21 shows volume between the stump and 6-inch top diameter inside bark, and is based on total height of tree. Tables 22 and 23, on the other hand, are based on log height and show volume to a variable top. Their use requires measurement of tree height to the limit of merchantability, determined by branches, defect, or the specified minimum diameter.

Table 24 gives the percentage distribution of trees by breast-high-diameter class in normal stands. Table 25 gives the percentage relation between diameters and total heights of trees in normal stands. For example, in a stand 60 years old having an average diameter of 8 inches and an average height of 60 feet, the height of a 4-inch tree is found by use of this table to average approximately 45 feet. Accurate use of the table requires plotting of the data and reading from the curves. By means of these tables the jack pine yield table (table 8) can be adapted to any required standard of utilization and any usable product.

TABLE 16.—*Taper table for jack pine*[1]

Diameter at breast height outside bark (inches)	Total height	Diameter inside bark at height above ground in feet—										Basis, trees
		5	9	17	25	33	41	49	57	65	73	
	Feet	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*No.*
3	30	2.7	2.6	2.0	0.9	--	--	--	--	--	--	10
	40	2.8	2.7	2.5	2.0	1.2	--	--	--	--	--	23
	50	2.5	2.8	2.6	2.3	1.9	1.2	--	--	--	--	1
4	30	3.6	3.4	2.5	1.2	--	--	--	--	--	--	6
	40	3.7	3.5	3.1	2.4	1.5	--	--	--	--	--	33
	50	3.7	3.6	3.3	2.9	2.4	1.5	--	--	--	--	18
5	30	4.4	4.0	2.8	1.3	--	--	--	--	--	--	2
	40	4.5	4.2	3.7	2.9	1.8	--	--	--	--	--	22
	50	4.6	4.4	4.0	3.5	2.8	1.8	--	--	--	--	40
	60	4.6	4.5	4.1	3.7	3.2	2.7	1.8	--	--	--	2
6	40	5.3	5.0	4.2	3.3	2.1	--	--	--	--	--	18
	50	5.4	5.1	4.6	4.1	3.2	2.1	--	--	--	--	45
	60	5.5	5.3	4.9	4.4	3.8	3.1	2.1	--	--	--	13
7	40	6.2	5.7	4.8	3.8	2.4	--	--	--	--	--	6
	50	6.3	5.9	5.3	4.6	3.6	2.3	.5	--	--	--	55
	60	6.4	6.1	5.7	5.1	4.4	3.6	2.4	--	--	--	52
	70	6.4	6.2	5.9	5.5	4.9	4.2	3.4	2.3	--	--	3
8	50	7.1	6.7	6.0	5.2	4.0	2.5	.6	--	--	--	29
	60	7.2	6.9	6.4	5.8	5.0	4.1	2.8	1.0	--	--	40
	70	7.3	7.0	6.6	6.1	5.5	4.7	3.7	2.5	1.1	--	8
9	50	8.1	7.5	6.7	5.7	4.3	2.7	.7	--	--	--	25
	60	8.2	7.8	7.2	6.4	5.5	4.5	3.0	1.2	--	--	35
	70	8.3	8.0	7.4	6.7	6.0	5.2	4.1	2.7	1.1	--	15
10	50	8.9	8.3	7.4	6.2	4.6	2.9	.7	--	--	--	13
	60	9.1	8.6	7.8	7.0	6.1	4.9	3.3	1.2	--	--	23
	70	9.2	8.8	8.2	7.4	6.5	5.6	4.4	2.9	1.2	--	17
11	60	9.9	9.4	8.5	7.6	6.6	5.2	3.5	1.3	--	--	10
	70	10.0	9.6	8.8	8.0	7.1	6.0	4.7	3.1	1.3	--	21
	80	10.1	9.8	9.2	8.6	8.0	7.3	6.6	5.6	4.3	2.3	2
12	60	10.8	10.2	9.2	8.2	7.0	5.5	3.7	1.3	--	--	11
	70	10.9	10.4	9.5	8.5	7.5	6.4	5.0	3.2	1.3	--	19
	80	11.0	10.6	9.9	9.3	8.7	8.0	7.2	6.2	4.8	2.7	5
13	60	11.6	10.8	9.8	8.7	7.4	5.8	3.8	1.3	--	--	5
	70	11.7	11.1	10.1	9.0	8.0	6.8	5.2	3.3	1.4	--	13
	80	11.8	11.3	10.6	9.9	9.3	8.6	7.7	6.7	5.3	3.0	5
14	60	12.4	11.5	10.4	9.1	7.8	6.0	3.9	1.4	--	--	1
	70	12.5	11.8	10.7	9.5	8.4	7.1	5.4	3.4	1.4	--	5
	80	12.6	12.0	11.2	10.5	9.8	9.1	8.2	7.1	5.6	3.3	2
15	60	13.2	12.1	10.9	9.6	8.1	6.2	4.0	1.4	--	--	1
	70	13.3	12.4	11.2	9.9	8.8	7.3	5.5	3.5	1.4	--	2
	80	13.4	12.7	11.8	11.1	10.4	9.6	8.6	7.4	5.9	3.5	1
												655

[1] Data collected in Minnesota, Wisconsin, and Michigan in 1925-38. Table prepared by S. R. Gevorkiantz. Lake States Forest Expt. Sta. Tech. Notes 155, [1] p. 1939. [Processed.]

TABLE 17.—*Piece-product table for jack pine*[1] *(mine timbers, poles, and lagging)*

Diameter at breast height outside bark (inches)	Total height	Timbers[2]			Additional poles[3]			Additional lagging[4]
		8-foot	10-foot	12-foot	8-foot	10-foot	12-foot	
	Feet	*Pieces*	*Pieces*	*Pieces*	*Pieces*	*Pieces*	*Pieces*	*Pieces*
5	30	---	---	---	---	---	---	2.5
	40	---	---	---	1.9	---	---	2.5
	50	---	---	---	2.0	---	---	2.3
6	30	---	---	---	1.0	---	---	2.0
	40	---	---	---	2.0	---	---	1.6
	50	---	---	---	3.0	---	---	1.6
	60	---	---	---	3.6	---	---	2.0
7	40	---	---	---	2.5	---	---	1.1
	50	---	---	---	3.5	---	---	1.3
	60	---	---	---	4.3	---	---	1.6
	70	---	---	---	5.3	---	---	1.5
8	50	---	---	---	---	3.2	---	.9
	60	0.9	---	---	---	3.4	---	1.0
	70	1.0	---	---	---	3.8	---	1.1
9	50	1.6	---	---	---	2.1	---	.8
	60	2.1	---	---	---	2.6	---	.8
	70	2.4	---	---	---	2.9	---	1.0
10	50	---	1.9	---	---	---	1.3	.8
	60	---	2.4	---	---	---	1.7	.8
	70	---	2.7	---	---	---	1.9	.8
11	60	---	2.8	---	---	---	1.4	.7
	70	---	3.2	---	---	---	1.8	.8
	80	---	4.4	---	---	---	1.8	.7
12	60	---	3.2	---	---	---	1.2	.5
	70	---	3.5	---	---	---	1.4	.8
	80	---	4.9	---	---	---	1.4	.6
13	60	---	---	2.8	---	---	1.1	.6
	70	---	---	3.2	---	---	1.2	.7
	80	---	---	4.4	---	---	1.3	.5
14	60	---	---	2.0	---	---	1.0	.5
	70	---	---	3.4	---	---	1.1	.6
	80	---	---	4.6	---	---	1.2	.5
15	60	---	---	3.0	---	---	1.0	.5
	70	---	---	3.5	---	---	1.0	.6
	80	---	---	4.8	---	---	1.0	.5

[1] This table, prepared by S. R. Gevorkiantz from table 16, shows complete utilization from 1-foot stump to 3-inch top, without allowance for cull, crook, limbiness, or any other defect.
[2] To a minimum top diameter of 7 inches inside bark.
[3] To a minimum top diameter of 4 inches inside bark.
[4] Lagging 6 feet long to a top diameter of 3 inches inside bark.

TABLE 18.—*Total unpeeled volume of jack pine (35)*[1]

Diameter at breast height (inches)	Unpeeled volume, by total height in feet—														Basis, trees[2]
	25	30	35	40	45	50	55	60	65	70	75	80	85	90	
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*No.*
3	0.8	1.0	1.2	1.3	1.5	1.7	1.8	---	---	---	---	---	---	---	75
4	1.3	1.6	1.9	2.2	2.4	2.7	3.0	3.2	---	---	---	---	---	---	151
5	2.0	2.4	2.8	3.2	3.5	4.0	4.3	4.7	5.1	5.5	---	---	---	---	221
6	---	3.2	3.8	4.3	4.9	5.4	5.9	6.5	7.0	7.6	---	---	---	---	242
7	---	4.2	4.9	5.6	6.3	6.9	7.6	8.3	9.0	9.7	---	---	---	---	227
8	---	---	6.1	7.0	7.9	8.7	9.6	10.5	11.3	12.2	13.1	---	---	---	218
9	---	---	---	8.7	9.7	10.8	11.9	13.0	14.1	15.2	16.2	---	---	---	126
10	---	---	---	---	11.8	13.1	14.4	15.7	17.0	18.3	19.6	20.9	22.2	---	74
11	---	---	---	---	---	15.5	17.1	18.6	20.2	21.7	23.3	24.8	26.4	27.9	58
12	---	---	---	---	---	---	19.9	21.7	23.5	25.3	27.1	28.9	30.7	32.5	46
13	---	---	---	---	---	---	22.8	24.9	27.0	29.1	31.2	33.2	35.2	37.4	27
14	---	---	---	---	---	---	---	28.9	31.3	33.7	36.5	38.6	40.9	43.3	8
15	---	---	---	---	---	---	---	32.4	35.1	37.8	40.6	43.2	46.0	48.6	3
16	---	---	---	---	---	---	---	36.9	40.0	43.0	46.1	49.2	52.2	55.3	3

[1] Data collected in Minnesota, Wisconsin, and Michigan in 1924-25. Table prepared by form-factor method by A. E. Wackerman in 1925. Volume includes stump, stem, top, and bark. Heavy lines indicate limits of basic data.
[2] Total: 1,479.

TABLE 19.—*Merchantable cord volume of jack pine (35)*[1]

Diameter at breast height (inches)	Unpeeled volume, by total height in feet—							Basis, trees[2]	Peeling loss[3]
	30	40	50	60	70	80	90		
	Cords	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*No.*	*Percent*
4	0.01	0.02	0.03	0.03				151	
5	.02	.03	.04	.04	0.05			221	12.8
6	.03	.04	.05	.06	.07			242	12.0
7	.04	.05	.06	.08	.09			227	11.5
8		.07	.08	.10	.12	0.14		215	10.1
9		.08	.10	.12	.14	.16		126	9.0
10			.12	.15	.17	.20		74	8.4
11			.14	.17	.21	.23	0.27	58	8.1
12				.21	.24	.27	.31	46	8.0
13				.24	.28	.32	.36	27	
14				.28	.32	.37	.41	8	
15				.31	.36	.41	.47	3	
16				.35	.41	.47	.53	3	

[1] Data collected in Minnesota, Wisconsin, and Michigan in 1924–25. Table prepared by A. E. Wackerman from a merchantable cubic-foot volume table, by use of converting factors varying with breast-high diameter. Volume includes stem and bark above a 1-foot stump to a top diameter of 3 inches outside bark. Unit of measure is standard cord, 4 by 4 by 8 feet. Heavy lines indicate limits of basic data.

[2] Total: 1,404.

[3] Data on loss in stacked volume due to peeling collected on Superior National Forest in 1936–37 by Lake States Forest Experiment Station. Basis, 77 cords of wood cut into 100-inch bolts.

TABLE 20.—*Volume of stacked wood in relation to minimum top diameter*[1]

Diameter at breast height, outside bark (inches)	Volume[2] utilized per tree when utilization extends to a top of—			
	3 inches outside bark	4 inches inside bark	5 inches inside bark	6 inches inside bark
	Percent	*Percent*	*Percent*	*Percent*
5	100	60.0	0.0	0.0
6	100	77.5	42.2	.0
7	100	87.5	65.0	26.0
8	100	92.2	77.3	50.0
9	100	95.5	86.0	77.5
10	100	98.0	92.5	81.6
11	100	99.5	97.1	92.0
12	100	100.0	100.0	99.0

[1] Example: In table 19 it will be found that a 5-inch 50-foot tree has a volume of 0.04 cord if utilized to a 3-inch top, outside bark (100 percent in table 20). This table shows that the same tree, if utilized to a 4-inch top, inside bark, will yield 60 percent of 0.04 cord, or 0.024 cord. Basis, 155 cords.

[2] Of 100-inch bolts.

TABLE 21.—*Board-foot volume, Scribner Decimal C rule, of jack pine (35)*[1]

Diameter at breast height (inches)	Volume (to a 6-inch diameter inside bark) by total height in feet—											Basis, trees [2]
	40	45	50	55	60	65	70	75	80	85	90	
	10 bd. ft.	*10 bd. ft.*	*10 bd. ft.*	*10 bd. ft.*	*10 bd. ft.*	*10 bd. ft.*	*10 bd. ft.*	*10 bd. ft.*	*10 bd. ft.*	*10 bd. ft.*	*10 bd. ft.*	*No.*
7	0.2	0.5	0.8	1.3	1.6	1.9	2.1					227
8	.8	1.3	1.8	2.4	2.8	3.3	3.8	4.3				218
9	1.6	2.2	2.8	3.5	4.2	4.7	5.2	5.7				126
10		3.0	3.7	4.5	5.2	5.9	6.6	7.1	7.7	8.2		74
11			4.8	5.7	6.5	7.3	8.0	8.8	9.6	10.3		58
12				7.0	8.0	8.9	9.9	10.8	11.8	12.6	13.6	46
13				8.2	9.2	10.3	11.3	12.5	13.6	14.5	15.7	27
14					11.3	12.5	13.8	15.1	16.2	17.6	18.6	8
15					13.1	14.6	15.9	17.5	18.6	20.2	21.4	3
16					15.0	16.8	18.5	20.3	21.8	23.5	25.4	3

[1] Data collected in Minnesota, Wisconsin, and Michigan in 1924–25. Table prepared by A. E. Wackerman in 1925. Stump height, 1 foot. Heavy lines indicate limits of basic data.
[2] Total: 790.

TABLE 22.—*Board-foot volume, Scribner Decimal C rule, of jack pine (3)*[1]

Diameter at breast height (inches)	Volume (to a variable top diameter) by number of 16-foot logs—				Basis, trees
	1	2	3	4	
	10 board feet	*10 board feet*	*10 board feet*	*10 board feet*	*Number*
8	1.4				12
9	2.1	3.6			15
10	2.9	4.7	7.2	9.8	21
11	3.7	5.9	8.9	12.1	25
12	4.6	7.1	10.8	14.6	29
13	5.6	8.5	12.6	17.2	19
14	6.6	9.9	14.6	19.8	7
15	7.6	11.2	16.4	22.5	3
16	8.7	12.5	18.2	25.3	1
Basis (trees)	29	67	32	4	132

[1] Data collected in Minnesota, Wisconsin, and Michigan in 1924–30. Preliminary table, prepared by S. R. Gevorkiantz from James W. Girard's form-class taper tables in 1933. Stump height, 1 foot. Top diameter variable, not less than 6 inches. Average deviation, ±11.4 percent. Heavy lines indicate limits of basic data.

TABLE 23.—*Board-foot volume, International 1/4-inch rule, of jack pine*[1]

Diameter at breast height (inches)	Volume (to a variable top diameter) by number of 16-foot logs—			
	1	2	3	4
	Board feet	*Board feet*	*Board feet*	*Board feet*
8	22			
9	30	54		
10	38	65	96	126
11	46	77	114	151
12	55	90	133	177
13	65	103	153	203
14	75	117	174	233
15	86	132	196	261
16	97	148	220	304

[1] Prepared by Russell K. LeBarron in 1939 from table 22. Stump height, 1 foot. Top diameter variable, not less than 6 inches.

TABLE 24.—*Stand table for fully stocked, pure, even-aged forests of jack pine (3)*[1]

Diameter at breast height (inches)	Distribution of trees in terms of total, number of stems, by average diameter of stand in inches—								
	2	3	4	5	6	7	8	9	10
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	26.20	8.00	2.58	0.90	0.44	0.16	0.07	0.03	0.01
2	52.90	20.50	12.42	4.80	1.86	.76	.32	.13	.05
3	18.50	37.90	27.50	13.40	5.80	2.18	.86	.27	.10
4	2.35	18.60	29.90	24.30	13.40	6.85	2.68	1.27	.30
5	.05	5.40	18.75	26.90	22.70	13.55	7.57	3.60	1.50
6		.54	6.85	18.30	24.40	20.50	13.25	7.70	4.00
7		.06	1.70	7.70	17.40	23.20	19.25	13.00	8.00
8			.26	2.85	9.25	16.60	22.00	18.50	13.00
9			.04	.70	3.35	9.30	16.30	20.50	17.44
10				.14	1.05	4.78	10.30	16.00	19.80
11				.01	.28	1.47	4.40	9.80	15.10
12					.06	.49	2.10	5.40	10.40
13					.01	.12	.66	2.40	5.60
14						.04	.18	1.05	2.40
15							.05	.26	1.45
16							.01	.07	.45
17								.02	.18
18									.01
19									.01
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Basis (plots)[2]	1	20	34	54	60	49	26	8	2

[1] Data collected in Minnesota, Wisconsin, and Michigan in 1924-30. Table prepared by S. R. Gevorkiantz

[2] Total: 254.

TABLE 25.—*Generalized diameter-height curve (3), jack pine, aspen, and white pine*[1]

Diameter at breast height in terms of average diameter of stand (percent)	Total height in terms of average height of stand, by age class of stand—		
	20-40 years	41-80 years	81-120 years
	Percent	*Percent*	*Percent*
50	70	75	80
75	88	90	92
100	100	100	100
150	114	112	110
200	123	118	113

[1] Prepared by S. R. Gevorkiantz in 1934.

END