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SILVICAL *Characteristics* OF...

RED PINE

(*Pinus resinosa*)

by

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M. B. Dickerman, Director

FOREST SERVICE

U.S. DEPARTMENT OF AGRICULTURE

THE SILVICAL REPORT SERIES

During 1907 and the following several years the U. S. Forest Service issued a series of silvical leaflets which covered the broad characteristics of a considerable number of major timber species. Since then much new knowledge has accumulated--some of it published in a variety of sources. There is also a considerable store of unpublished silvical information in the files of the forest experiment stations, the forest schools, and some other agencies. To compile this information systematically and make it available to foresters generally, the Lake States Forest Experiment Station is preparing reports on 15 individual species. Similar reports are being prepared by the other Forest Service experiment stations. When completed, these individual species reports will provide the basis for a comprehensive manual of silvics for the important trees of the United States, to be published by the U. S. Forest Service.

This report is one of the series being prepared by the Lake States Station. A preliminary draft was reviewed by several members of our own Station staff and by a number of well qualified staff members of other forest experiment stations, colleges, and universities; Federal, State, and Provincial forestry organizations; and forest industry. Their comments helped the author to make this report more complete, more accurate, and more up to date. Especially helpful reviews were submitted by Professor Earl E. Stone, Jr., of the Department of Agronomy at Cornell University, David B. Cook of the New York Conservation Department, Fred Wilson, formerly of the Wisconsin Conservation Department, and Professor I. C. M. Place of the Department of Forestry and Wildlife Management at the University of Wisconsin.

Every effort has been made to ensure the accuracy and completeness of the information concerning the silvical characteristics of each species consistent with a brief treatment of the subject. We shall appreciate it, however, if any errors or omissions of important information are brought to our attention.

M. B. Dickerman

M. B. Dickerman, Director

Cover design: The photograph shows mature red pines in the Lake States, generally of good form and development. The drawing represents red pine foliage and cones.

CONTENTS

SILVICAL CHARACTERISTICS OF RED PINE

(*Pinus resinosa* Ait.)

by

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Red pine is a medium-to-large coniferous forest tree native to the northeastern quarter of the United States and adjacent Canada. It is the only continental American representative[2/] of the Old World group (*Lariciones*) which includes Scotch pine (*Pinus sylvestris*). Its scientific name refers to its purported resinous nature, although it has the lowest resin content of the hard pines (64).[3/] The common name is appropriate because of the pale red color of the heartwood and the reddish color of the bark. This tree also is commonly called Norway pine, especially in the Lake States. This name was first used by early English explorers of the North Atlantic Coast region because they thought it was the same as the (Scotch) pine of Norway (4). Occasionally it is known as hard pine, pig iron pine, pitch pine, yellow pine, and shellbark Norway (19, 32).

DISTRIBUTION

The botanical range of red pine (79) extends from Newfoundland and Quebec west to Ontario and southeastern Manitoba, south to northeastern Minnesota, Wisconsin, Michigan, northern Pennsylvania, New York, Connecticut, and Maine (fig. 1). In other words it occurs in a relatively narrow zone about 1,500 miles long and 500 miles wide around the Great Lakes and the St. Lawrence River. It occurs locally also in northeastern West Virginia (22, 33) and in northeastern Illinois (21). Except for the West Virginia outliers, the present range of red

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1/ Maintained by the Forest Service, U. S. Department of Agriculture, at St. Paul 1, Minn., in cooperation with the University of Minnesota.

2/ *Pinus tropicalis*, of limited distribution in western Cuba and the Isle of Pines, also is included in the *Lariciones*.

3/ Underlined numbers in parentheses refer to literature cited at the end of the report.

pine from southeastern Wisconsin eastward lies within or closely adjacent to the area glaciated during the late Pleistocene (32). It was formerly most abundant and grows to the largest size in the northern parts of the three Lake States (114).

The commercial range[4/] is more restricted than the botanical range (fig. 1), but it may be increasing. Natural stands of red pine were of spotty occurrence and minor importance in the Northeast, but this species has been planted extensively both inside its natural range and to the south of it in the Northeast, the Lake States, and neighboring north central states.

HABITAT CONDITIONS

In general red pine grows in areas characterized by cool-to-warm summers, cold winters, rather low-to-moderate rainfall, sandy soils, and level-to-rolling topography. It occurs chiefly on areas where the soil is acid and has good drainage and aeration and where there is little severe plant competition. Red pine is confined to the Northern Forest region and the southern fringe of the Boreal Forest region.

Climatic Factors

Within the natural range of red pine the average January temperatures vary from 0° to 25° F. and the average July temperatures from 60° to 70°. Average annual maximum temperatures range from 90° to 100° and the highest temperatures ever observed are about 5° higher. Average annual minimum temperatures vary from -10° to -40° and the lowest temperatures ever recorded are about 20° lower. Average annual precipitation ranges from 20 to 40 inches over most of the range, but reaches 50 to 60 inches in some eastern localities. The average warm season (April to September, inclusive) precipitation varies from 15 to 25 inches. The average annual snowfall ranges from 40 to 120 inches (137, 138). Summer droughts (periods of 30 or more days without measurable precipitation) occur commonly in the western half of the range (64). The average date of the last killing frost in the spring ranges from April 30 to June 15, and of the first killing frost in the fall from August 15 to October 10. On the average the frost-free period ranges from 80 to 160 days, although it may be as short

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4/ Commercial range is defined as the distribution of the species as a major or important component in the type, now or in the past, regardless of whether it is now being utilized.

RED PINE (Pinus resinosa)

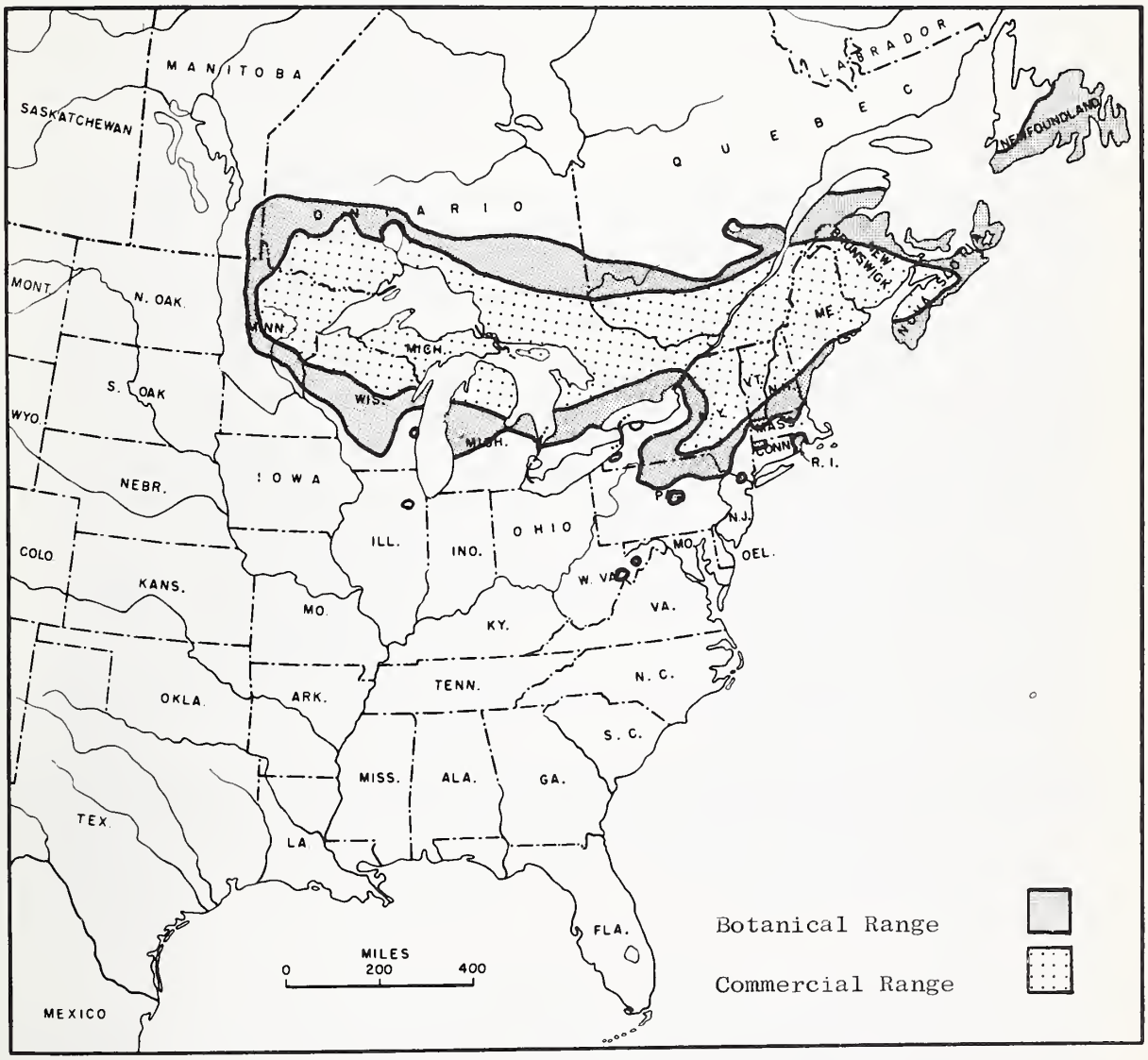

Figure 1.--Botanical and commercial range of red pine.

as 40 days northeast of Lake Superior in Ontario (20, 138). Over much of the species range, however, frosts may occur in any month of the year.[5/] The northern limit of red pine is related to length of frost-free period and closely parallels the 35° mean annual isotherm (60, 137).

Edaphic Factors

Natural stands of red pine are confined pretty largely to soils of the Podzol region: Melanized sands, podzolic sands, sandy podzols, and the better drained gley-podzolic sands (147). The species grows best on deep, loose, very well-drained, loamy sands, or gravels, but will thrive on a variety of sites including organic debris over rock outcrops and some structured lacustrine red clays which apparently restrict the hardwoods (38, 145).[5/] It requires a better soil than does jack pine (Pinus banksiana), but will thrive on a poorer soil than will eastern white pine (P. strobus). Red pine occurs rarely in swamps;[6/7/] it is somewhat more common on swamp borders where the roots can reach the water table (26). It does not occur where the surface soil is alkaline, although it grows on dry, acid soils overlying well-drained limestones or calcareous soils (32, 74).

Red pine occurs only sporadically on heavier soils, probably because of its inability to compete with more aggressive species and because of root injuries known to occur on some such soils (40, 70, 97, 135). The best developed individual trees, however, are those growing with white pine or hardwoods on the better soils (26).

In typical old-growth stands in the Lake States there usually is a humus layer that, because of rapid decomposition, seldom builds up to a depth of more than 2 inches. Beneath that is a gray leached layer of sandy soil 6 to 8 inches thick, overlying a brownish layer of sandy soil several feet thick (119). In dry summers almost all available moisture may be withdrawn to a depth of 2 to 7 feet or more (119).[8/]

5/ Conzet, Grover M. 1913. A qualitative and quantitative study of the seed production and reproduction of Norway pine (Pinus resinosa). Unpub. Master's Thesis, Univ. of Minn., 89 pp., illus. (Typescript.)

6/ Unpublished information from Prof. J. T. Curtis, University of Wisconsin, in letter of 8/28/56 on file at Lake States Forest Experiment Station.

7/ Unpublished information from Prof. I. C. M. Place, University of Wisconsin, with letter of 6/7/56 on file at Lake States Forest Experiment Station.

8/ Unpublished information from Prof. Earl L. Stone, Jr., Cornell University, in letter of 6/13/56 on file at Lake States Forest Experiment Station.

Its requirements have not been worked out in detail but red pine makes reasonably good growth on a large variety of soils which have a pH of 4.5 to 6.0, a silt-plus-clay content of 10 to 40 percent, a base exchange capacity of 2 to 11 m.e. per 100 g., an organic matter content of at least 1.7 percent, total nitrogen content of 0.03 to 0.04 percent, and available P_2O_5 of 40 to 60 pounds per acre and K_2O of 40 to 200 pounds per acre (7, 39, 109, 129, 145, 146, 147). The height growth of dominant trees (site index) gave a good correlation with the total nitrogen content of the A_1 and A_2 soil horizons and a fairly high correlation with the moisture equivalent of those layers in a Connecticut plantation (66).

The weight of dry organic matter returned to the soil annually by red pine is about the same as that recorded for several other forest trees (83). In several stands studied in the Lake States and the Northeast, the ovendry weight of litter falling in a 12-month period ranged from about 1,750 to 3,400 pounds per acre (9, 23, 90). In one of these stands (a 24-year-old plantation on a podzolic silty clay loam in central New York) the dry weight litter fall per acre by periods was as follows: May 15 to July 1, 72 pounds; July 1 to August 20, 60 pounds; August 20 to October 3, 1720 pounds; and October 3 to May 27, 1516 pounds. This freshly fallen litter contained the following nutrients expressed as percent of ovendry weight: Calcium, 0.58; magnesium, 0.18; potassium, 0.35; phosphorus, 0.07; and nitrogen, 0.69. The amounts of nutrient elements in pounds per acre returned to the soil annually were: Calcium, 19.5; magnesium, 6.3; potassium, 11.8; phosphorus, 2.4; and nitrogen, 23.2 (23). The litter had a pH of 4.15 (its water suspension) (95).

A study in mature undisturbed stands of red pine in north central Minnesota showed that the ovendry weight of unincorporated organic matter in the forest floor was about 38,000 pounds per acre (8). The forest floor contained 37 to 54 percent volatile matter, 46 to 64 percent ash, 0.6 to 0.9 percent of both nitrogen and CaO, and 1.6 to 1.7 percent of both nitrogen and CaO in the volatile matter (7).

Physiographic Conditions

Where it is most abundant in the Lake States and Ontario, red pine grows most commonly on level to gently rolling sand plains or on low ridges adjacent to lakes and swamps. There elevations generally run from 800 to 1400 feet above sea level. Sometimes red pine is found on rocky hills or on the rocky shores of lakes and streams (60). In the East it occurs not only on outwash plains but also on mountain slopes, on hilltops (often underlain by porous limestone or sandstone beds), on gravels, and on outcrops of shale (32). In New England it grows chiefly at elevations between 700 and 1300 feet above sea level.

In New York red pine grows from elevations near sea level to more than 2000 feet above sea level in the Adirondacks (32) and up to 2700 feet in one locality (81). The larger West Virginia outlier occurs at an elevation of 3800 to 4300 feet above sea level. It is confined to the west side of a ridge on a steep slope (22). The smaller outlier is growing on rocks at the summit of the mountain (33).

Biotic Factors

In parts of the northern Lake States, Ontario, and Quebec, red pine grows in relatively extensive pure stands. In the Northeast small pure stands are not uncommon (32). More often it occurs in mixture with one or both of its common associates, jack pine and eastern white pine. It is a component of the following cover types recognized by the Society of American Foresters: Red pine, type 15; jack pine, type 1; and white pine, type 21 (125).

On the coarser, drier soils, common associates of red pine are jack pine, quaking aspen (Populus tremuloides), bigtooth aspen (P. grandidentata), scrubby oaks (chiefly northern pin oak (Quercus ellipsoidalis) in the Lake States and bear oak (Q. ilicifolia) in the East), and paper birch (Betula papyrifera) or gray birch (B. populifolia) and sometimes pitch pine (Pinus rigida) in the East (26, 28).9/ On somewhat better soils (fine sands to loamy sands), in addition to the foregoing, there may be white pine, red maple (Acer rubrum), black cherry (Prunus serotina), northern red oak (Quercus rubra), white oak (Q. alba), chestnut oak (Q. prinus), balsam fir (Abies balsamea), black spruce (Picea mariana), and occasional specimens of the better hardwoods. On the sandy loam and loam soils red pine's associates include sugar maple (Acer saccharum), white pine, American basswood (Tilia americana), red maple, balsam fir, paper birch, yellow birch (Betula alleghaniensis), American beech (Fagus grandifolia), red oak, white ash (Fraxinus americana), eastern hemlock (Tsuga canadensis), red spruce (Picea rubens), white spruce (P. glauca), northern white-cedar (Thuja occidentalis), and eastern hophornbeam (Ostrya virginiana) (26, 28, 97, 125).9/ The West Virginia outlier includes white pine and bear oak as associates. In northeastern Illinois the woody plant associates include red oak, white oak, American hornbeam (Carpinus caroliniana), hackberry (Celtis occidentalis), and serviceberry (Amelanchier spp.) (21). Other than white pine, sometimes jack pine, and, at red pine's younger ages, aspen, paper birch, and gray birch, all the associates of red pine occur as an understory to it. Under varying conditions jack pine may occur either in the overstory or the

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9/ Conzet: See footnote 5 on page 3.

understory. Where hardwoods occur, red pine usually is a minor component of the stand.

A large number of shrubs and herbs grow with red pine. The most commonly associated shrubs include Canada blueberry (Vaccinium canadense), lowbush blueberry (V. angustifolium), sweetfern (Comptonia peregrina), bearberry (Arctostaphylos uva-ursi), prairie willow (Salix humilis), American hazel (Corylus americana), beaked hazel (C. cornuta), striped maple (Acer pensylvanicum), dwarf bushhoneysuckle (Diervilla lonicera), Jerseytea ceanothus (Ceanothus americanus), sand cherry (Prunus pumila and P. pumila var. susquehanae), and American fly honeysuckle (Lonicera canadensis) (28, 97, 115, 120). Most typical of the nonwoody associates are eastern bracken fern (Pteridium latiusculum) and checkerberry wintergreen (Gaultheria procumbens), although a number of other species including trailing-arbutus (Epigaea repens) commonly grow with red pine. As compared to the poorer soils, bracken is less abundant and herbs much more abundant on the better soils (28). Mycorrhizae are formed on the roots of red pine seedlings by at least two species of Hymenomycetes, one of which is Boletus luteus (63) and another B. felleus (147).

A number of the birds and mammals common to the Northern and Boreal Forest regions are associated with red pine. These animals, however, do not occur exclusively with red pine but are associated with the many other species and forest types also found in those regions. The animals that directly affect the survival, growth, or development of red pine are discussed in the following sections.

LIFE HISTORY

Within its natural range and on the sites to which it naturally is adapted, red pine follows a distinct pattern of reproduction, growth, and development. Not only its inherent characters but also many environmental factors influence this pattern. Much of red pine's life history seems bound up with fire and with areas of relatively low rainfall. It is essentially a drought-hardy, rather undemanding, fire-hardy, rather intolerant species, commonly growing in even-aged stands or groups.

Seeding Habits

Flowering and Fruiting

Depending on the locality and the individual season, red pine flowers from April to June, the cones ripen from mid-August to October of the second year, and seed fall begins at the time of cone ripening and may continue through the winter and into the next summer (84, 139).[9/] For example during 10 years in northern Lower Michigan, flowering took place during the latter half of May (5-year record), seeds began to ripen about mid-September, and about 70 percent of them were dispersed from then to mid-December, although some dispersal continued until the following August in some years. From year to year soundness of the dispersed seed varied from 14 to 63 percent.[10/]

In Ontario the small cone first becomes visible in late May or early June at the distal end of the growing shoot, but it is first differentiated as a primordium during the previous growing season (84). Pollination occurs during late May or early June, while the productive ovule-bearing scales are large, red, and separated from each other, and the cone is about 4 millimeters long. Thereafter, the cone scales close together tightly. By late July, when the cone is 10 to 12 millimeters long, it ceases to grow for the season. Actual fertilization does not take place until mid-July of the second year when cone growth is completed and the fully developed seed coats have hardened, or about 13 months after pollination (48, 84). At that time the cone is 37 to 50 millimeters long (84, 106). The cones turn from green, to purple, to chestnut brown as they ripen. A high proportion of the seeds are viable when the cones have become purple with reddish-brown scale tips (or have a specific gravity of about 0.80 to 0.94), but natural dispersal is deferred until the cones are completely brown (106). The cones themselves usually fall the next spring or summer, although some may remain on the tree 2 or 3 years.

Seed Production and Dissemination

Under favorable growth conditions planted red pines have been known to produce staminate flowers at 5 years and ovulate flowers at 9 years of age (99). There is a record of viable seed production by 12-year-old planted red pine trees 1 to 2 inches in diameter at breast height, and

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9/ Conzet: See footnote 5 on page 3.
10/ Unpublished data, Lake States Forest Experiment Station.

8 to 10 feet tall (100). Normally, however, seed production begins at about 20 to 25 years in open-grown trees and at 50 to 60 years in closed stands (149).[11/] Seed production usually is best in trees from 50 to 150 years of age and continues at a diminished rate almost until death, usually at 200 or more years (139, 149).

Good seed crops are produced at intervals of 3 to 7 years with light crops in most intervening years (139). Locally there may be occasional crop failures. Bumper cone crops are produced only once every 10 or 12 years.[11/]

Only about 45 percent of the scales on a typical red pine cone produce viable seed. At each end there are from 2 to 10 barren scales. Adjacent to them are scales with undeveloped ovules that produce wings but no seeds. At the time of pollination there are 30 to 110 (average 60 to 90) ovules capable of becoming seeds. Ordinarily only about 50 percent of these ovules actually become seeds (84). The average number of viable seeds per normal cone probably is about 20 and usually ranges from about 14 to 45 (84, 106).[11/] Long cones have more scales and a greater seed production capacity than shorter cones. Cones produced in the upper third of the crown produce more good seeds than those at lower levels, and those borne on the terminals of main branches at each crown level produce more than cones borne on terminals of laterals (84). Seeds borne above the middle of the cone have higher viability than those borne closer to the base.[11/] The number of cones produced per tree in a mature medium-stocked stand during a good seed year ranges from 50 for unthrifty trees, to 200 for average run trees, to 400 for very vigorous and partly open-grown trees, to 725 for open-grown trees.[11/] In overstocked stands only a few trees may produce cones and the seed fall may average less than 10 seeds per tree (49). Some trees are consistently good and others consistently poor cone producers.[11/] Medium-stocked mature stands have shed from 75,000 to 110,000 seeds per acre in a moderately heavy seed year (120). In a poorly stocked 40- to 50-year-old stand in Lower Michigan the dispersal of good seed per acre over a 10-year period ranged from 8,000 to 20,000 and averaged about 10,000.[12/]

Dewinged and commercially cleaned seed averages about 52,000 per pound (range 30,000 to 71,000) (139). Unfanned seeds, containing many that are unfilled, run over 80,000 to the pound (86).[11/]

The cones open best on hot still autumn days when there is little wind to carry the seeds far.[11/] Seeds may be disseminated up to 900 feet from the seed trees (149), but the effective range as measured by

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11/ Conzet: See footnote 5 on page 3.
12/ Unpublished data, Lake States Forest Experiment Station.

established seedlings is not much over half the tree height (about 40 feet on the average); it is very low at a full tree height (150).[13/]

Factors Limiting Seed Production

Several agencies act to reduce red pine seed crops: (1) Prolonged rainy weather at the time of pollination may seriously diminish seed set (139); (2) the red pine cone beetle (Conophthorus resinosae) and other insects partly or completely prevent normal cone development, especially in isolated, open-grown trees (In one instance such insects destroyed 98 percent of the young second-year cones on an open-grown red pine.[14/] In mature stands studied in northern Minnesota they destroyed 16 percent of the cones and damaged an additional 15 percent);[13/] (3) red squirrels (Tamiasciurus hudsonicus) often cut cone-bearing branch tips in the fall and occasionally in the winter or spring (25, 101) (On open-grown trees they may completely destroy both the current and succeeding years' cone crops although damage usually is less in stands (101). They destroy some cones 10 to 15 days before the seeds are viable, but do most of their cone-cutting after that time (106));[13/] (4) a study in northern Minnesota showed that trees injured by fire during the past year produced only about 25 percent as many cones as did similar uninjured trees--older fire injury did not seem to affect cone production;[13/] (5) white-footed mice (Peromyscus spp.), the red-backed vole (Clethrionomys gapperi), and chipmunks (Eutamias minimus and Tamias striatus) eat large quantities (as much as 50 percent of that reaching the ground) of seed (45, 120, 133); (6) birds such as goldfinches (Spinus tristis), juncoes (Junco hyemalis), song sparrows (Melospiza melodia), white-throated sparrows (Zonotrichia albicollis), and many others also consume red pine seed (45, 120); (7) an unidentified witches'-broom, occurring chiefly on trees in stand borders and in the open, reduces cone production on the infested branches.[13/]

Vegetative Reproduction

In nature red pine does not reproduce vegetatively. Only with great difficulty can stem cuttings be rooted artificially regardless of treatment. Leaf bundles from 2-year red pine seedlings immersed to a

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13/ Conzet: See footnote 5 on page 3.
14/ Unpublished data, Lake States Forest Experiment Station.

depth of 2 millimeters for 12 to 24 hours in 10^{-6} or 10^{-7} M concentration of methoxone (2-methyl, 4-chlorophenoxyacetic acid) and then planted out in boxes in the greenhouse rooted well (up to 68 percent) (71).

Dormant red pine scions kept over winter in a deep freeze (0° F.) can be field-grafted successfully on to red pine and Scotch pine stocks in the spring, especially if the grafts are covered for a time with kraft, or polyethylene plus kraft, bags (67). Successful grafts have also been made on eastern white pine and Mugho pine (Pinus mugo mughus) (2). Grafting is rarely successful on jack pine stocks.

Seedling Development

Establishment

Red pine seed has no dormancy and has an average germination capacity of 75 percent (139). It germinates chiefly at temperatures above 60° F. in the late spring or early summer when moisture and seedbed conditions are favorable. Seedling emergence is best at temperatures between 70° and 86°; it is poor below 60° (104). Occasionally there is some pregermination in the fall (41). In northern Minnesota successful seedling establishment was noted only in those years with rainfall over 4 inches for May, June, and July or a little less if followed by good rainfall the latter part of the growing season.[15/] If rainfall is deficient before germination begins the seeds can lie over for 1 to 3 years before germinating.[15/] Heavy seed produces heavier seedlings than lighter seed, and the heavier seedlings make better height growth for at least the first 10 years than do lighter seedlings (69).

Red pine seeds may germinate but they will not grow beneath dense brush, on heavy litter or sod, or on recent burns where there is a heavy cover of ashes (26).[15/] Seedlings become established only in partly shaded places where grass and litter are not thick or where mineral soil is exposed. For example, five times as many seedlings were established on mineral soil as on undisturbed surfaces in northern Minnesota (120). Good germination (90 to 100 percent) occurs under conditions which favor high moisture content in the seed, such as a fine sand seedbed, a water table within 4 feet of the soil surface, some shade, abundant precipitation, and light covering of the seed (51, 133). Germination is satisfactory at a range of soil reactions but is

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15/ Conzet: See footnote 5 on page 3.

reduced at pH 8.5 or higher (104). Most old-growth stands appear to have been established following fire, presumably in combination with a good seed year and not too thick a layer of ashes (102, 127).[15/]

Approximately 35 percent of full sunlight, or an overstory crown density of 0.67, offers satisfactory conditions for the establishment of red pine seedlings (56, 119). Establishment is uncertain with light values below 17 percent. It is precluded beneath hazel brush where the light values are under 5 percent although very young seedlings can exist in less than 3 percent light (17, 119). After they have grown above the sparse ground cover that favored germination and early survival, the number of seedlings per acre seems to increase with light up to full daylight. The height growth of the red pine seedlings also increases up to 63 percent of full daylight, and their dry weight increases up to full light (89, 119).

Age of mother tree appears to affect time of flushing; in first-year seedlings it is earliest in progeny of mother trees 80 to 120 years old, and latest in progeny of very young trees under 30 years old and old trees over 121 years in age (112).

During the first summer seedlings may develop taproots 6 to 18 inches long (149). Early rooting depth is fostered by the presence of a water table within 4 feet of the soil surface.[16/] The optimum range of soil reaction for seedling root growth extends from about pH 4.7 to 6.0 (104).

15/ Conzet: See footnote 5 on page 3.
16/ Unpublished data, Lake States Forest Experiment Station.

Figure 2.--Abundant red pine reproduction established under a mature stand given frequent light cuts, north central Minnesota.

The following silvicultural methods have been recommended as favoring regeneration of red pine (fig. 2): (1) Use a two-cut shelterwood system applied before the stand loses its vigor; or preferably, (2) use intensive forest management with frequent thinnings and light improvement cuttings up to about age 80; some advance reproduction may build up after age 80 as partial harvest cuttings begin; about age 120; during good seed years, begin shelterwood cuttings; if brush is heavy, scarify the ground with a disk plow and use supplemental planting where needed; keep the stand fairly open, and make the final cut at about age 140 (45).

Early Growth

The time that shoot growth begins and ends varies with the season within a locality and with climatic conditions over the range of red pine. Over a period of 5 to 9 years in the Upper Peninsula of Michigan, shoot elongation began about mid-May; leafing began about 5 days later; winter buds were formed about August 8; and height growth

ceased about 1 month later.[17/] Height growth, excluding elongation of the winter bud, was completed in an average of 83 days. Measurements in other localities and other years showed periods of 45 to 63, 50 to 60, 70, 84, 86 to 88, 105, and 123 days (13, 30, 31, 46, 53, 58, 73, 91). The rate of shoot growth is rapid at first and then diminishes; 90 percent may be completed during the first half of the period. In north central Minnesota terminal shoot growth began in the spring when the mean weekly air temperature was 56° F. and the current soil temperatures ranged from 56° at the surface to 42° at a depth of 24 inches (77). The amount of shoot growth seems to be related to the amount of rainfall in the previous growing season (91). During the peak growth period, 60 percent of leader elongation occurs at night; best growth is made on cool nights (73). The period of growth is progressively less from primary to secondary to tertiary shoots (53).

The period of cambial growth begins a little later than shoot elongation and is only about two-thirds completed when shoot growth ceases. The roots continue to grow after cambial growth stops (73). In New Hampshire, for example, in 10-year-old red pines there is a great surge of growth in the leader, roots, and cambium about the same time in early June. After this the needles reach their maximum growth rate, followed by a second high of cambial growth. After nearly all growth is completed and a full complement of needles is functioning, the roots reach a second maximum rate of elongation (73). Radial growth seems to be related closely to the precipitation of the current season, especially in the early part of the growing season (37).

The foliage-bearing area of a tree is important not only as an expression of tree vigor but also as a measure of tolerance to certain kinds of insect attack. A close estimate of the total length of needle-bearing internodes can be obtained if the tree height and number of living branch whorls is known. For example, in Lake States plantation trees 3 to 15 feet tall this relationship can be expressed as follows: $Y = 0.349X - 0.832$, where Y = tree height (in feet) times number of living branch whorls, and X = length of the needle-bearing internodes in meters (43).

Red pine seedlings usually grow slowly in the wild, especially if they are shaded (planted stock ordinarily grows much faster). At the end of the first year wild seedlings often are less than 0.1 foot tall; after 4 or 5 years the growth rate begins to speed up but it may take 15 or 16 years for overtopped seedlings to reach breast height; for many years thereafter height growth may average about 1 foot per year (26, 102). In the Northeast growth during the same stage of development

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17/ Unpublished data, Lake States Forest Experiment Station.

may average closer to 1.5 feet annually.[18/] In a dense stand of seedlings (over 10,000 per acre) ranging from 9 to 16 years in age, height varied from 0.5 to 14.0 feet; 41 percent of the plants were dominant, 29 percent codominant, and 30 percent were suppressed.[19/]

In the field red pine roots penetrate to a depth of about 4 inches the first year (133). Root development varies with soil texture and moisture conditions. In Connecticut 7-year-old red pines developed roots which penetrated deeper, were larger, spread farther, branched less, developed more mycorrhizal roots, and had fewer roots in the A horizon on a loamy sand (silt plus clay content 19 percent) than on a fine sandy loam (silt plus clay content 42 percent). There was a strong tendency to form a taproot but it was not always present. Heavy branching occurred immediately under the root collar. In both soils the roots were concentrated heavily in the B horizon where nutrients were abundant. The roots spread beyond the limits of the crowns (54). Trees 12 to 14 years old in northern Michigan showed rather similar development, with maximum depth penetration of about 6 feet and lateral roots ranging in length up to 3 times the tree height but with less pronounced taproot development (36). On dry sand plains in Lower Michigan, however, the roots of 10- to 13-year-old red pines had penetrated no deeper than $1\frac{1}{2}$ feet and had a lateral spread of 5 to 7 feet, about $1\frac{1}{2}$ times tree height (105). On coarse sands in central Wisconsin functional root grafts are not uncommon in red pine. They may be of considerable ecological importance in sustaining weak trees in the stand during droughts and in serving as a vector for root rots (76).

Factors Limiting Seedling Development

A number of factors act to hinder germination and early survival:

1. Summer droughts and high surface soil temperatures frequently kill or injure young red pine seedlings--exposure to temperatures of 136° F. for 2 hours will kill 4-year-old red pine transplants in dry air (relative humidity 13 to 25 percent); a similar exposure at 131° will kill the needles and buds and injure the plants (122). Lower temperatures and shorter exposures prove lethal under moister conditions (82, 122). Drought resistance varies with the condition of the plants: Frequent watering and high nitrogen contents decrease resistance, and increasing phosphate content improves resistance (124).

18/ Unpublished information from D. B. Cook, New York Conservation Department, on file in letter of 6/8/56 at Lake States Forest Experiment Station.

19/ Conzet: See footnote 5 on page 3.

2. Sudden drops in temperature in the early fall, for example from 32° to 18° F. prolonged for 24 hours or less, will kill young red pine seedlings (16, 50).

3. Unidentified insects often consume seedlings shortly after they germinate (51).

4. The competition of subordinate vegetation seriously hinders reproduction (123).

5. Post-emergent damping-off, birds, rodents, trampling by large animals, and smothering by litter also kill young red pine seedlings (133).

Although the establishment period is critical, many factors continue adversely to affect survival and growth of red pine during the seedling stage: (1) The pine bark aphid (Pineus strobi) feeds on new growth of young trees (45); (2) the pine root-collar weevil (Hylobius radicis) occasionally kills trees 8 to 12 years old (45); (3) several sawflies (Neodiprion lecontei, N. sertifer, N. abbottii, N. nanulus nanulus, N. compar, and Diprion frutetorum, Acantholyda erythrocephala, and A. zappei) defoliate and often kill seedlings up to about 5 feet tall (35, 103, 142); (4) the pales weevil (Hylobius pales) sometimes kills seedlings in logged areas within 1 or 2 years after cutting (14); (5) the jack pine budworm (Choristoneura pinus) sometimes causes severe damage to young red pines growing beneath mature jack pines (35, 45); (6) the Saratoga spittlebug (Aphrophora saratogensis) alone or with the associated burn blight (Chilonectria cucurbitula) has damaged or killed considerable planted red pine up to about 15 feet tall in recent years (45); (7) the European pine shoot moth (Rhyacionia buoliana) deforms red pines up to about 20 feet tall planted south of their natural range and sometimes attacks trees growing within the southern portion of their natural range (35, 52, 111); (8) the Zimmerman pine moth (Dioryctria zimmermani) sometimes badly injures planted red pines up to 15 or 20 years in age (35); (9) white grubs (Phyllophaga rugosa, P. tristis, and related species and genera) cut the roots and may thus induce mortality in dry years (45); (10) the Allegheny mound ant (Formica exsectoides) sometimes kills trees up to 15 years old (35); (11) a leaf rust, caused by Coleosporium solidaginis, has caused some defoliation to natural seedlings and planted trees (32, 45); (12) in poorly drained areas south of the natural range of red pine, trees may be killed by a root disease probably caused by insufficient aeration and possibly by Phytophthora cinnamomi (70, 135); (13) a leaf cast, caused by Lophodermium pinastri, has injured red pine seedlings in the nursery after heavy frosts in the fall (126); (14) the snowshoe hare (Lepus americanus), in periods of peak population, often kills young red pine seedlings, although in more average years only about 5 percent of the

seedlings may be injured--rabbit nipping may kill up to 18 percent of the seedlings and reduce height growth about 25 percent on those which survive (3, 75, 87, 136, 141); (15) the white-tailed deer (Odocoileus virginianus) at times is destructive to red pine seedlings although they are classed as a starvation food for the deer; over a wide territory about 10 percent of the seedlings may be severely damaged (27, 47, 132, 136); (16) pocket gophers (Geomys bursarius) may sever the roots and cause the death of trees;[20/] (17) the grazing of cattle and horses may damage red pine up to about 10 years old although seldom causing death (130); (18) a dense overstory or brush may retard growth seriously and weaken the seedlings (29); (19) late frosts (June) sometimes kill the young shoots and retard growth for at least two seasons (72); (20) unusually severe winter conditions may cause some defoliation and occasional mortality in trees up to 12 feet tall (134); (21) in severe drought years red pines up to 4.5 feet tall may die, especially where there is little or no protective overstory (121); (22) high soil surface temperatures, usually in open situations, may also injure or kill seedlings less than 1 inch in diameter at the base;[20/] (23) fires at this stage usually kill the seedlings, although after they are about 8 feet tall they are more resistant than commonly associated species (45).[21/]

Sapling Stage to Maturity

In the forest, red pine normally is a tall, slender tree with a smooth, straight, clear bole of little taper (see picture on cover). Young trees have long pyramidal crowns of stout horizontal branches (tilted slightly upwards near the tip of the tree) in regular whorls. Old trees have short, broad, flattened crowns with relatively heavy branches (97).[21/] The root system is well developed in old trees. There are a vast number of stout lateral roots with branches descending at acute angles to give the tree strong support and make it windfirm (97).[21/] The bulk of the horizontal root system is confined to the upper soil layers (A and B horizons); most of these roots are less than 0.05 inch in diameter. The total number of roots per unit of soil area in the upper layers decreases as growing space increases. Vertical penetration in trees 28 years old on sandy soils exceeds 9 feet (1).

20/ Unpublished data, Lake States Forest Experiment Station.
21/ Conzet: See footnote 5 on page 3.

Growth Rates and Sizes Attained

For the first 60 years height growth on average sites in Minnesota averages about 1 foot per year. Between 60 and 100 years the rate is about 1/2 foot per year. For the next 40 years the rate is only about 1/5 foot per year (45). After that age height growth almost stops, although diameter growth continues at a slow rate until death (15, 26). The oldest tree age recorded is 307 years although a tree estimated to be 400 years old has been measured on the Chippewa National Forest in north central Minnesota (149).[22/] During the first 20 years at least, height growth on sands may be about doubled by the presence of a water table within 4 to 8 feet of the soil surface (39).

Normally mature red pines are about 70 to 80 feet tall with breast high diameters up to 36 inches, although trees have attained 150 feet in height and 60 inches d.b.h. (114). In Minnesota well-stocked unmanaged red pines at 140 years (rotation age) attain the following dimensions and merchantable yields (45):

Item	Site class		
	Good	Medium	Poor
Average diameter (breast high) - inches	15.5	13.2	10.7
Average height of dominants - feet	104.0	88.0	67.0
Total number trees per acre	143.0	186.0	262.0
Total basal area - square feet	187.0	177.0	164.0
Merchantable yield, cubic feet[1/]	7,350.0	5,300.0	3,550.0
" " , cords[2/]	98.0	71.0	48.0
" " , board-feet[3/]	32,500.0	20,500.0	11,600.0
" " , additional cords[4/]	21.0	20.0	19.0

1/ Gross volume, excluding bark, of trees 5 inches d.b.h. and larger to a top diameter of 4 inches inside bark.

2/ Same material for which cubic-foot volume was computed, piled with bark on, in standard cords 4x4x8 feet.

3/ Net volume, Scribner rule, of trees 8 inches and larger d.b.h., to variable top diameters (minimum 6 inches inside bark); volumes reduced by 15 percent for woods and mill cull.

4/ includes volume in small trees and tops of sawlog-size trees.

22/ Unpublished information, Lake States Forest Experiment Station.

Rather comparable yields have been reported from other areas (97, 102, 115, 128). Yields (including thinnings and other intermediate cuts) over the rotation age can be increased up to 100 percent by management (18, 45).

Of course natural stands commonly are understocked so average yields shown by the Forest Survey[23] are considerably less than those given on the previous page. Assuming a normal distribution of age classes, average yields and mean annual increments in the Lake States vary with intensity of management by sites as follows:

Site class	Average yields[1] per acre		Average annual increment[1/2] per acre	
	Unmanaged	Intensive management	Unmanaged	Intensive management
	Cubic feet	Cubic feet	Cubic feet	Cubic feet
Good	2,093	3,186	28.5	57.1
Medium	1,431	2,195	20.2	40.4
Poor	987	1,512	13.4	26.8

1/ Gross volume, excluding bark, of trees 5 inches d.b.h. and larger to a top diameter of 4 inches inside bark.

2/ Mean annual increments cited are for entire rotation age (140 years).

Reaction to Competition

Red pine is less tolerant than common associates other than jack pine, the aspens, paper birch, and gray birch. Based on a scale which ranges from 10.0 for eastern hemlock to 0.7 for the aspens, red pine rates 2.4 along with black ash (Fraxinus nigra) and black cherry (55). Another classification includes red pine in the fourth lowest of five tolerance classes (12). The species may be relatively more tolerant in the seedling stage than later, especially where moisture is abundant, but even here growth is very slow under cover.

23/ Unpublished data, Lake States Forest Experiment Station.

As stated on previous page, most natural red pine stands are understocked, but occasionally there are dense sapling stands (up to 20,000 stems per acre) (44, 117). Stands 15 to 20 years old with less than 2,500 trees per acre seem able to thin themselves, but denser stands stagnate (44). Dense stands respond well to thinning (44, 115, 116, 117, 118, 131, 140). To age 43 on an excellent site red pine has made full volume growth when thinned to an average spacing of 20.5 percent of height of dominants, with thinnings timed by each 7 or 8 feet of added height growth. The spacing percent figure should be increased during the latter part of the rotation. Height growth of dominants was retarded after spacing became closer than 15 percent of height (148). The range of stand density for full volume growth remains to be determined, but for any species the range of optimum stand density is both lower and narrower on the poorer sites (144).

Wider spacings foster greater diameter development but lower total volumes per acre (5). On good sites basal area growth ceases when a level of about 250 square feet per acre is reached (6).

Red pines overtopped by oaks and red maple for as long as 40 years have responded to release (96).

In dense stands dominance is well expressed by age 10 to 15.[24/] At wider spacings the differentiation into crown classes occurs later, usually after 20 to 30 years. In fully stocked stands the percentage of trees in the dominant and codominant classes increases regularly from about 45 in stands with an average breast high diameter of 2 inches, to 75 at 10 inches, and 90 at 14 inches (109). In stands of lower density the proportion of dominants will be higher.

Beginning at the age of about 25 years in dense stands red pine prunes itself better than any other northern conifer with the possible exception of tamarack (26, 44). Even in dense stands, however, there may be relatively little natural pruning the first 40 years (11). In more open stands natural pruning is delayed to a greater age. On some infertile sands, however, lower branches die off even where crown closure does not occur.[25/]

In the absence of fire or other catastrophes the ecological succession in the Lake States is from jack pine to red pine to white pine and finally to northern hardwoods; the rate of succession is likely to be more rapid on the better sites (45, 74). On the coarser, more infertile sands succession apparently stops short of the northern hardwood

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24/ Conzet: See footnote 5 on page 3.

25/ Unpublished information from Prof. E. L. Stone, Jr., Cornell University, in letter of 6/13/56 on file at Lake States Forest Experiment Station.

climax; red pine may be a long-persisting subclimax on some of these sites. In much of eastern Canada and northern New England, the succession may be to spruce-fir and hemlock rather than northern hardwoods.[26/]

Limiting Factors in Sapling to Mature Stages

Although red pine has fewer serious enemies than most other species within its range, the following cause damage or mortality in sapling to mature trees:

1. Fire will wipe out seedling and small sapling stands, but with advancing age red pine becomes more and more fire resistant--much more so than white pine. Mature trees sometimes are scorched to a height of 40 feet without being killed. Repeatedly burned old-growth trees usually are sound beneath the "catfaces", possibly because the wood is impregnated with resin (143).

2. Trees weakened by drought, storm, or other injuries sometimes are attacked by pine sawyer beetles (Monochamus spp.), bark beetles (Ips pini, Dendroctonus valens, Orthotomicus caelatus), and also the bark weevil (Pissodes approximatus) (45, 85).[27/]

3. The pine gall weevil (Podapion gallicola) sometimes kills branches on both young and old trees (45).

4. The pine chafer (Anomala oblivia) sometimes defoliates and appreciably injures red pine (45).

5. The black carpenter ant (Camponotus herculeanus pennsylvanicus) sometimes enters through fire scars and causes serious damage to butt logs (45).

6. The larvae of the Zimmerman pine moth (Dioryctria zimmermani) have caused heavy loss of new shoots on mature trees (35, 45).

7. A pine tussock (Olene plagiata) sometimes defoliates red pine (35).

26/ Unpublished information from Prof. I. C. M. Place, University of Wisconsin, in letter of 6/7/56 on file at Lake States Forest Experiment Station.

27/ Unpublished information from John Risley, New York Conservation Department in letter by E. W. Littlefield of 11/27/56 on file at Lake States Forest Experiment Station.

8. Locally the Nantucket pine moth (Rhyacionia frustrana) causes heavy shoot damage to red pines.

9. The matsucoccus scale (Matsucoccus resinosae) has killed plantations in Connecticut, on Long Island, and in Westchester County, New York (62, 142).

10. The pine looper (Lambdina athasaria pellucidaria) has defoliated and killed red pine in New England (142).

11. Red pine is attacked occasionally, usually not seriously, by the pine webworm (Tetralopha robustella) (35).

12. The white-pine weevil (Pissodes strobi), with increasing frequency, attacks the terminal of red pine, although damage is not so severe as on white pine or jack pine.[28/]

13. A white stringy root rot (Fomes annosus) has caused considerable mortality in some plantations of red pine in New York and New England, especially in thinned stands.[29/]

14. An occasional overmature tree (usually not over 3 percent of the stand) contains some rot as a result of action by a number of fungi, the more important of which are Fomes pini and Polyporus schweinitzii (45).[30/]

15. The shoestring fungus (Armillaria mellea) occasionally is found invading the inner bark and cambium of the roots and lower trunk of dying trees (45).

16. Young red pines sometimes suffer from a "needle droop" apparently resulting from sudden and excessive transpiration at a time of limited moisture supply (92).

17. Severe defoliation of young red pine sometimes is caused by a needle blight resulting from infestation by the larvae of a gall midge (probably Cecidomyia pinirigidae). A fungus (Pullularia pullulans) frequently is associated as a secondary invader of dead tissue (59, 92).

18. A bark canker (Tympanis pinastri) is injurious to red pine south of its natural range in parts of the Northeast, both as a primary parasite and through its effect in allowing secondary decay to enter through lesions (61).[29/]

28/ Unpublished data, Lake States Forest Experiment Station.
29/ Risley: See footnote 27 on page 20.
30/ Conzet: See footnote 5 on page 3.

19. The porcupine (Erithizon dorsatum) occasionally does considerable damage by girdling trees about 10 to 40 or more feet tall (45).

20. Ice storms sometimes cause breakage of as many as 30 percent of the trees in dense sapling stands; at times this may have some beneficial effect as a thinning (26).

21. Windfall, though not severe, causes a rather steady small reduction in volume in medium-to-old trees (115).

22. On soils deficient in potassium, growth may stagnate severely (65).

23. Red pines planted on fine textured and poorly drained soils after initial satisfactory growth have suffered root loss and thereafter declined and died in parts of New York, Pennsylvania, and Michigan (40, 70, 135).

Generally speaking red pine is relatively free of serious enemies when growing under conditions natural to its native range. When grown on less acid, finer textured, and more poorly drained soils and under milder climatic conditions than it is adapted to, red pine is subject to damage by a greater number of destructive pests (80, 109). When planted considerably south of its natural range, red pine often has very poor growth and form.31/

SPECIAL FEATURES

For many years the wood of red pine has been marketed with that of eastern white pine, although it is somewhat harder and heavier than white pine wood. One of its first uses was for masts in sailing vessels, and red pine was purchased for that purpose by the British Navy as late as 1875. At present red pine wood is used chiefly for lumber, piling, poles, cabin logs, railway ties, posts, mine timbers, box boards, pulpwood, and fuel (19, 93).

Red pine has been among the most extensively planted species in the United States and Canada, not only for wood production but also for dune and sandblow control, snowbreaks, windbreaks, and Christmas trees (109).

31/ Unpublished information from Si Little, Northeastern Forest Experiment Station, in memo of 7/2/56 on file at Lake States Forest Experiment Station.

The oleoresin of red pine yields about 20 percent turpentine consisting of dl and d-α-pinene, 92 percent; β-pinene, 3 percent; phellandrene, 3 percent; and perhaps about 1 percent of a dextro-rotary component possessing a boiling point higher than 170° (88).

Red pine is reasonably resistant to damage from herbicides in the kinds and concentrations commonly used for control of weeds and hardwoods growing in association with it. Good control of overtopping oaks and aspens has been obtained with both aerial and ground sprays of the phenoxyacetic acid herbicides (2,4-D and 2,4,5-T) without serious damage to red pine provided these chemicals are applied after the new growth has hardened off in late summer (10, 34). Trichloroacetates (TCA) have been applied at rates up to 60 pounds per acre 3 months before red pine seed germination without damage to the pines (78).

RACES, HYBRIDS, AND OTHER GENETIC FEATURES

Red pine is a species very uniform morphologically and apparently very old. Fossil records from Dakota sandstone show that an upland pine (Pinus clementsii and/or P. resinosipites) markedly resembling red pine occurred in southern Minnesota during the Cretaceous period (24, 94). During periods of glaciation, red pine along with other species was forced to migrate to the South and then returned North with the retreat of the glaciers (57). Some of it may have migrated northward to the east of the Great Lakes and some of it to the west, thus laying the foundation for some racial differentiation.

Comprehensive seed source studies in the Lake States and the Northeast have indicated some distinct differences during the first 20 years in survival and growth related to origin. It appears that races have developed in the northern Lake States, central Wisconsin, Lower Michigan, the Northeast, and probably West Virginia (22, 68, 108). Local sources do best although there is considerable variation between sources within a region. At 18 years the local sources produced more than two and one-half times the approximate cubic volume of wood than the most distant source did (107, 108). In New York, plantations from seed of Massey, Ontario, origin seem superior to others (42).

There are some general indications that red pines from the warmer parts of the natural range as compared to those of more northern origin produce somewhat larger seeds and seedlings, less frost-resistant seedlings, and earlier flushing seedlings (16, 110, 113).

Normal vegetative cells of red pine contain 12 pairs of (24) chromosomes (98). So far no authenticated interspecies hybrids involving red pine have been found in nature or produced artificially.

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