Pinus resinosa Ait. Red Pine

Pinaceae Pine family

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Red pine *(Pinus resinosu),* also called Norway pine, is one of the most extensively planted species in the northern United States and Canada. It is a medium-size tree with lightweight, close-grained, pale reddish wood used primarily for timber and pulpwood. Trees 97 cm (38 in) in d.b.h. and 43 m (141 ft) tall in Michigan are among the largest living specimens.

Habitat

Native Range

Red pine (fig. 1) is confined to the Northern Forest region and the southern fringe of the Boreal Forest region. It grows in a narrow zone about 2400 km (1,500 mi) long and 800 km (500 mi) wide around the Great Lakes and the St. Lawrence River, most of it within or closely adjacent to the area glaciated during the late Pleistocene (76). Its range extends from Cape Breton Island, Nova Scotia, Prince Edward Island, New Brunswick, southern Quebec, and Maine, westward to central Ontario and southeastern Manitoba, southward to southeastern Minnesota and eastward to Wisconsin, Michigan, southern Ontario, northern Pennsylvania, northern New Jersey, Connecticut, and Massachusetts. It also grows locally in northern Illinois, eastern West Virginia, and Newfoundland (53).

Climate

Red pine is native to areas with cool-to-warm summers, cold winters, and low to moderate precipitation. Within red pine's natural range the average January temperatures vary from -18” to -4” C (0° to 25° F) and the average July temperatures from 16° to 21” C (60” to 70” F). Average annual maximum temperatures range from 32” to 38°C (90° to 100° F), and average annual minimum temperatures range from -23” to -40” C (–10° to -40” F).

Average annual precipitation is from 510 to 1010 mm (20 to 40 in) throughout much of the range but reaches 1520 mm (60 in) in some eastern localities. The average growing season precipitation ranges from 380 to 640 mm (15 to 25 in), and the average annual snowfall ranges from 100 to 300 cm (40 to 120 in>. Summer droughts of 30 or more days occur commonly in the western half of the range. The frost-free period ranges from 80 to 160 days, although it may be as short as 40 days northeast of Lake Superior in Ontario. The northern limit of red pine is related to length of frost-free period and closely parallels the 2” C (35° F) mean annual isotherm.

Soils and Topography

Natural stands of red pine are confined largely to sandy soils. They are most common on Entisols followed in order by Spodosols, Alfisols, and Inceptisols. Common materials are glaciofluvial and aeolian in origin, and lacustrine deposits and loamy and finer till soils are less frequently occupied. Red pine commonly grows on dry soils low in fertility, but it is also found on a variety of sites including organic debris over rock outcrops and some structured lacustrine red clays, where it may be somewhat stunted, however. Red pine is rarely found in swamps but is common along swamp borders. It does not grow where the surface soil is alkaline, although it grows on dry, acid soils overlying well drained limestones or calcareous soils. Although it can grow well on silt loams, red pine grows 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. It grows especially well (height growth may be doubled) on naturally subirrigated soils with well aerated surface layers and a water table at a depth of 1 to 3 m (4 to 9 ft) in Wisconsin. Best plantation development is made on soils that range from moderately drained to those without substantial moisture stress *(8,11,16,24,55, 90,91,95,100).*

In typical old growth stands in the Lake States the organic layer (L, F, and H layers) seldom builds up to a depth of more than 5 to 13 cm (2 to 5 in), and its ovendry weight increases with stand density from 12 300 to 84 100 kg/ha (11,000 to 75,000 lb/acre). Beneath is a gray, leached layer of sandy soil 15 to 20 cm (6 to 8 in) thick overlying a brownish layer of sandy soil 1 or more meters (3 or more feet) thick. Sometimes discontinuous bands or lenses of finer textured material are found at depths up to 3 m (9 ft) and their silt-plus-clay content improves the productivity of red pine. In dry summers almost all available moisture may be withdrawn to a depth of 0.6 to 2.1 m (2 to 7 ft) or more.

Red pine grows satisfactorily on soils that, in the upper 25 cm (10 in), have a pH of 4.5 to 6.0, a bulk

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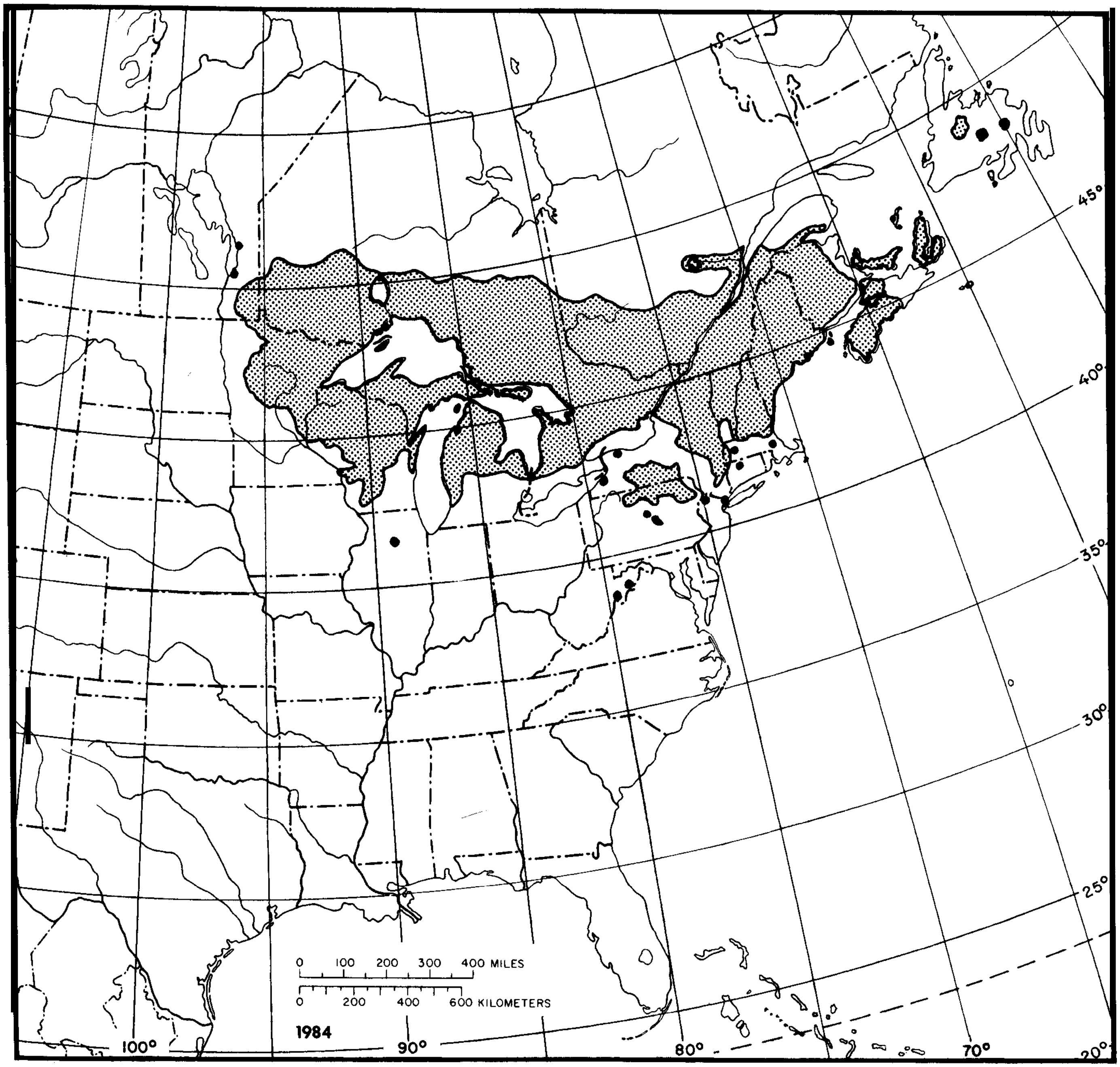

Figure *l-The native range of red pine.*

density of about 1.30 g/cm³ (0.75 oz/in³), a silt-plus-clay content of 10 to 40 percent, available water storage capacity of 6 to 23 percent, a base exchange capacity of 2 to 11 milliequivalents (meq) per 100 g, organic matter content of at least 1.7 percent, total nitrogen content of 1100 to 1700 kg/ha (1,000 to 1,500 lb/acre), available phosphorus of 34 to 146 kg/ha (30 to 130 lb/acre), available potassium of 126 to 157 kg/ha (112 to 140 lb/acre), exchangeable calcium of 0.80 to 2.00 meq per 100 g, and exchangeable magnesium of 0.20 to 0.45 meq per 100 g *(3,4,5,12,36, 76,991.*

In the Lake States and Ontario, red pine grows most commonly on level or gently rolling sand plains or on low ridges adjacent to lakes and swamps, at elevations from 240 to 430 m (800 to 1,400 ft) above sea level. In the East it is found not only on outwash plains but also on mountain slopes and hilltops. It grows chiefly at elevations between 210 and 400 m (700 to 1,300 ft) above sea level in New England, and up to 820 m (2,700 ft) in the Adirondacks.

The West Virginia outliers are found at an elevation of 945 to 1290 m (3,100 to 4,200 ft) above sea level. In Canada the production of red pine increases from pine ridges to pine plains to pine uplands *(44,76,87)*.

Associated Forest Cover

In parts of the northern Lake States, Ontario, and Quebec, red pine grows in extensive pure stands and in the Northeast and eastern Canada in small pure stands. More often it is found with jack pine ***(Pinus banhsiana),*** eastern white pine (F! ***strobus),*** or both. It is a common component in three forest cover types: Red Pine (Society of American Foresters Type 15), Jack Pine (Type 1), and Eastern White Pine (Type 21) and is an occasional associate in one, Northern Pin Oak (Type 14) (26,901.

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)),*** and bear oak ***(Q. ilicifolia).*** On somewhat better soils (fine sands to loamy sands), in addition to the foregoing, associates may be eastern 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 sandy loam and loam soils, red pine's associates include sugar maple ***(Acer saccharum),*** eastern white pine, American basswood ***(Tilia americana),*** red maple, balsam fir, paper birch ***(Betula papyrifera),*** yellow birch ***(B. alleghaniensis),*** American beech ***(Fagus grandifolia)***, northern red oak, eastern hemlock ***(Tsuga canadensis),*** white spruce ***(Picea glauca),*** white ash ***(Fraxinus americana),*** red spruce ***(Picea rubens)***, northern white-cedar ***(Thuja occidentalis),*** and eastern hophornbeam ***(Ostrya uirginiana).*** Growing with red pine in the West Virginia outlier are eastern white pine, pitch pine ***(Pinus rigida),*** Virginia pine ***(P. uirginiana),*** table mountain pine ***(P. pungens),*** sweet birch ***(Betula lenta),*** northern red oak and bear oak. In northeastern Illinois the woody plant associates include northern red oak, white oak, American hornbeam ***(Carpinus caroliniana),*** hackberry ***(Celtis occidentalis),*** and roundleaf serviceberry ***(Amelanchier sanguinea).*** All the associates of red pine grow only as understory except eastern white pine and occasionally jack pine or aspen. When found with hardwoods, red pine usually is a minor but dominant component of the stand *(76,87)*.

The most common shrubs associated with red pine include Canada blueberry ***(Vaccinium canadense),*** low sweet blueberry ***(V. angustifolium),*** sweetfern ***(Comptonia peregrina),*** common bearberry ***(Arctostaphylos uva-ursi),*** prairie willow ***(Salix humilis),*** American hazel ***(Corylus americana),*** beaked hazel ***(C. cornuta),*** striped maple ***(Acer pensylvanicum),*** dwarf bush-honeysuckle ***(Diervilla lonicera),*** New Jersey tea ***(Ceanothus americanus),*** sand cherry ***(Prunus pumila*** and ***P. susquehanae),*** fly honeysuckle ***(Lonicera canadensis),*** serviceberries ***(Amelanchier*** spp.), raspberries ***(Rubus*** spp.), trailing arbutus ***(Epigaea repens)***, and spireas *(Spiraea* spp.) *(26,76,87)*.

Life History

Reproduction and Early Growth

Flowering and Fruiting-Red pine is monoecious; the flowers appear between April and June. The female flowers, 2 to 4 mm (0.1 to 0.2 in) long, are borne mostly in the middle third of the crown (in the upper third in older trees), and the purple male flowers, 10 to 20 mm (0.4 to 0.8 in) long, are borne in the lower crown. In Ontario and northern Minnesota, the cone first becomes visible in late May or early June, although the cone primordia are differentiated in June to August of the previous year. Pollination occurs during late May or early June when the cone is about 4 mm (0.2 in) long. By late summer the cone is 10 to 15 mm (0.4 to 0.6 in) long and stops growing for the season. Insects, weather extremes, and other damaging agents may cause the loss of 60 percent of the cones between the first and second year of their development. The remaining cones begin further growth the next spring, but actual fertilization does not take place until mid-July of the second year (13 months after pollination) when cone growth is completed and the fully developed seed coats have hardened. At that time the cone is 37 to 50 mm (1.5 to 2.0 in) long *(37,52,56)*.

Seedfall begins at the time cones ripen and continues throughout the winter and into the next summer, although the bulk of it can be deferred by cool, wet weather (which retards cone opening). The heaviest and most viable seed falls the first month. From year to year, soundness of the dispersed seed varied from 14 to 86 percent in Michigan and Manitoba; it was highest in the best crop years *(19,74,76,81)*.

Above-normal temperatures in April, July, August, and September, 2 years before cone maturity, favor cone production. Cone production is better on branches that are young, thick, long, and on the south side of the tree.

Many 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 (they float in kerosene), but they are not dispersed until the cones are completely brown (specific gravity about 0.60). The cones themselves usually fall the next spring or summer, although some may remain on the tree 2 or 3 years *(37,52,57,76)*.

Seed Production and Dissemination-Under favorable growing conditions planted red pines have produced staminate (male) flowers at age 9, ovulate (female) flowers at age 5, and viable seed at age 12. Normally, however, seed production begins at about 15 to 25 years in open grown trees and at 50 to 60 years for those in closed stands. Seed production usually is best in trees from 50 to 150 years of age with an average. cone production per tree of about 18 liters (0.5 bushel). The final cone yield (number of survivors/number of female flowers initiated) ranges from 0 to 81 percent from year to year and often is only about 20 percent.

Good seed crops are produced at intervals of 3 to 7 years with light crops in most intervening years (about one year in four may have little or no seed production). Bumper cone crops are produced only once every 10 to 12 years *(31,56,76,90)*.

Only about 45 percent of the scales on a typical red pine cone produce viable seed. At the time of pollination a typical red pine cone has from 30 to 110 (average 60 to 90) ovules that are capable of becoming seeds, but only about half of them actually develop. Cones produced in the upper third of the crown produce more good seeds than those at lower levels, and cones borne on main branch terminals produce more than those borne on lateral terminals.

Cone production per tree improves as stand density decreases. The number of cones produced per tree in a mature medium-stocked stand during a good seed year averages 50 for unthrifty trees, 200 for medium trees, 400 for vigorous and partly open grown trees, and 725 for open grown trees. In seed production areas in the northern Lake States-with 200 to 250 trees per hectare (80 to 100/acre), there may be about 87,500 cones per hectare (35,000/acre) in a good crop year and 17,500/ha (7,100/acre) in a low crop year *(57,58,76)*.

In dense stands less than 20 percent of the trees may produce cones, and the seedfall may average less than 10 seeds per tree. Hence, thinning helps increase red pine cone production per tree, and the recommended average spacing between trees for seed production areas is one-half the average height of dominant and codominant trees. Applying fertilizers also may improve cone production on trees 45 years of age or older with well-developed crowns. Some trees are consistently good and others consistently poor cone producers. Up to 751,000 sound seeds per hectare (300,000/acre) have been found in southeastern Manitoba, and 2,767,000/ha (1,120,000/acre) in Minnesota *(19,20,23,30,74,76)*.

Seeds are light. Cleaned seed averages about 115,000/kg (52,000/lb) and ranges from 66,000 to 156,000/kg (30,000 to 71,000/lb).

The cones open best on hot, still autumn days when there is little wind to carry the seeds far. Seeds may be disseminated up to 275 m (900 ft) from the parent tree, but the effective range, as measured by established seedlings, averages about 12 m (40 ft).

Several factors may reduce red pine seed crops: prolonged rainy weather at the time of pollination; fire injury; many species of insects which consume the flowers and seeds or damage the cones; squirrels, mice, and other animals and several songbirds which eat the seeds or damage cone bearing branches; and an unidentified witches' broom *(49,76)*.

Seedling Establishment and Development-In nature red pine stands become established following fire, the only natural agent capable of providing most of the conditions required for natural red pine reproduction. Summer surface fires with an energy output rate less than 700 kW/m of front (200 Btu/(s·ft)) can provide a satisfactory seedbed, kill back some competing tree species, reduce brush competition the first few years, reduce cone insect populations, and produce an open overstory canopy. Given such a fire, other conditions such as the following would be required to ensure the establishment of a new red pine stand: a good red pine seed crop, not too thick a layer of ashes, weather conditions favorable for seed germination and seedling establishment, and subsequent freedom from fire for several decades. Based on observations of old growth stands in north-central Minnesota such a combination of conditions in a given locality may occur only about once in 75 to 100 years *(21,61,* 76,961.

Germination is epigeal(45). Most seedlings emerge when the temperature is from 21" to 30" C (70" to 86" F). In northern Minnesota, seedlings were established only in those years with rainfall more than 100 mm (4 in) for May, June, and July, or a little less if followed by good rainfall the latter part of the growing season. If rainfall is deficient, the seeds can lie over for 1 to 3 years before germinating. Occasionally a few seeds germinate in the fall. Heavy seeds produce heavier seedlings than do lighter seeds, and the heavier seedlings outgrow the lighter seedlings for at least the first 10 years.

Red pine seeds may germinate, but seedlings do not grow beneath dense brush, on heavy litter or sod, or on recent burns with a heavy cover of ashes. Germination is best under conditions that favor high moisture content in the seed, such as a fine sand seedbed, thin moss or litter, a water table within 1.2 m (4 ft) of the soil surface, some shade, abundant precipitation, and light covering of the seed. Germination is satisfactory at a range of soil reactions but is reduced at pH 8.5 or higher. Young seedlings grow best on soil media with good moisture retention, a high cation exchange capacity, and low pH—5.1 to 5.5. Germination is inhibited by full sunlight for 4 hours or more per day *(2,21,29,45,69,70,76)*.

Approximately 35 percent of full sunlight offers satisfactory conditions for red pine seedlings to become established and they can achieve maximum height growth in as little as 45 percent of full sunlight up to age 5. Establishment is uncertain with light values below 17 percent, although very young seedlings can exist in less than 3 percent light. Because decreasing light levels diminish root weight more than top weight, shade grown seedlings are smaller in all dimensions (stem length and dry weight of stem, foliage, and roots) except needle length than those grown in full sunlight, and the average rate of photosynthesis is higher in shade grown shoots. After they have grown above the sparse ground cover that favored germination and early survival, the number of seedlings per hectare seems to increase with light up to full daylight. The height growth of the red pine seedlings also increases with increasing sunlight up to 63 percent of full daylight, or up to 6 hours of full sunlight, and their dry weight increases up to full light *(44,54,76)*.

The age of the mother tree appears to affect the time of flushing in first-year seedlings; it is earliest in progeny of mother trees 80 to 120 years old, and later in progeny of trees less than 30 years old and trees more than 121 years old *(76)*.

The time that shoot growth begins and ends varies with the season within a locality and with the climatic conditions over the range of red pine. Reserves in old needles contribute up to 80 percent or more to total shoot elongation, and phloem-translocated reserves from main branches, main stem, and roots contribute most of the balance. Terminal shoot growth begins in the spring when the mean weekly air temperature is about 10° C (50” F) and the current soil temperature is from 13.3” C (56° F) at the surface to 5.6” C (42” F) at a depth of 61 cm (24 in); this growth is completed in 43 to 123 days depending upon the locality and season *(48,71,76)*.

The period of cambial growth begins a little later than shoot elongation and is only about two-thirds completed when shoot growth ceases. In seedlings, summer wood formation begins when needle elongation stops. The roots continue to grow after cambial growth stops. 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 of elongation. Radial growth seems to be closely related to the precipitation of the current season, especially in the early part of the growing season *(25,76)*.

Red pine seedlings usually grow slowly in the wild, especially if they are shaded. At the end of the first year, wild seedlings often are less than 3 cm (1 in) tall. After 4 or 5 years the growth rate begins to increase, but seedlings usually take 4 to 10 years to reach breast height (1.37 m or 4.5 ft) and overtopped seedlings may take 15 to 16 years. For many years thereafter height growth may average about 0.3 m (1 ft) per year in the Lake States and Ontario and 0.5 m (1.5 ft) per year in the Northeast *(76,90)*.

The productivity of the site is reflected by the average annual height growth above breast height or better, above 2.4 m (8 ft), ranging from 25 to 66 cm (10 to 26 in) for poor to good sites *(6,13,76,90)*.

Vegetative Reproduction-In nature red pine does not reproduce vegetatively. Only with great difficulty can stem cuttings or leaf bundles be rooted artificially regardless of treatment, and no successful propagation of red pine by tissue culture methods has yet been reported.

As many as 84 percent of cuttings, taken during the summer from side branches of 3-year-old red pine seedlings, took root in sand under mist if the stock plants had been fertilized heavily and the cuttings had been treated with indolebutyric acid and water. The rooted cuttings at 1 year were equal to or better than 2-O nursery grown seedlings (76).

Dormant red pine scions kept overwinter at -18” C (0° F) can be field grafted successfully onto red pine and Scotch pine *(P. sylvestris)* stocks in the spring. Successful grafts also have been made on eastern white pine and Mugho pine *(P. mugo)*. Side veneer grafting of dormant scions on potted rootstock forced in the greenhouse in February has been successful in northern Wisconsin. Grafting is rarely successful on jack pine stocks. Semisucculent shoots from 12-year-old red pine trees were successfully cleft grafted on g-year-old Scotch pine in the field; the shoots were collected and on the same day were

Figure *2-Edge of stand in northern Lower Michigan, showing typical stem form and crown habit of mature red pine.*

grafted on current season's shoots that had just completed height growth. Incompatibility of interspecific grafts, however, appears to be a serious problem *(28,47,64,76)*.

Sapling and Pole Stages to Maturity

In the forest, red pine normally is a tall, slender tree with a smooth, straight, clear bole of little taper (fig. 2). Young trees have long pyramidal crowns of stout horizontal branches (tilted slightly upwards near the top of the tree) in regular whorls (one produced each year). Occasionally a second flush produces lammas shoots in late summer. Old trees have short, broad, flattened crowns with heavy branches. The rate of branch extension, and hence, crown width, diminishes with age and largely ceases when the canopy closes. The quantity of foliage per tree and branch diameter also decrease with increasing stand density, although foliage weight per unit area increases at close spacings until the canopy closes. In Lake State stands the dry weight of above ground parts was about 20 percent for the crown (about one-third foliage) and 80 percent for the bole. Stump and roots weighed about 20 percent of the above ground portions. Removal of the stump and main root system can greatly reduce the macronutrients on the site, but atmospheric and precipitation nutrient inputs over a rotation can more than offset this removal. The center of gravity was at about one-third the height above the butt *(7,46,76,85, 88,90)*.

Growth and Yield-Cambial growth occurs as springwood cells during the period of active elongation and high auxin synthesis. Summerwood cells are produced following the cessation of terminal growth and consequent reduction in auxin synthesis. The transition from springwood to summerwood varies from season to season in timing and duration and from tree to tree but apparently is associated with seasonal depletion in soil moisture *(76)*.

The amount and distribution of wood growth on the stem are determined largely by crown size and distributions *(51)*.

For the first 50 years height growth on average sites in Minnesota averages about 30 cm (12 in) per year. Between 50 and 100 years the rate is more than 15 cm (6 in) per year. For the next 30 years the rate is only about 7.5 cm (3 in) per year. From 130 to 150 years it drops to 3 cm (1 in). After 150 years height growth almost stops, although diameter growth continues at a slow rate for several years longer. The oldest tree age recorded is 307 years although a tree estimated to be 400 years old was measured on the

Table 1-Characteristics of unmanaged 140-year-old red pine stands on three sites in Minnesota

Item	Site quality Good	Medium	Poor
Average d.b.h., cm	39	33	27
Average ht. of dominants, m	32	27	20
Trees/ha	353	460	647
Basal area, m^2/ha	43	41	38
Merchantable yield, m^3/ha			
Total[1]	514	371	248
Lumber[2]	387	244	138
Topwood and small trees	132	126	120
Average d.b.h., in	15.5	13.2	10.7
Average ht. of dominants, ft	104	88	67
Trees/acre	143	186	262
Basal area, ft^2/acre	187	177	164
Merchantable yield			
Total, ft^3/acre[1]	7,350	5,300	3,550
Lumber, fbm/acre[2]	32,500	20,500	11,600
Topwood and small trees, cords/acre	21	20	19

[1]Gross volume, excluding bark, of trees 12.7 cm (5 in) in d.b.h. and larger to a top diameter of 10.2 cm (4 in).
[2]Net volume of trees 20.3 cm (8 in) and larger in d.b.h., to a variable top diameter (minimum 15.2 cm (6 in) inside bark); volumes reduced by 15 percent for woods and mill cull.

Chippewa National Forest in north-central Minnesota.

Normally, mature red pines are about 21 to 24 m (70 to 80 ft) tall, with d.b.h. up to 91 cm (36 in), although trees have attained 46 m (150 ft) in height and 152 cm (60 in) in d.b.h. *(17,76).*

Height growth reflects site quality and the amount of overhead shade or growth disruption, as by terminal feeding insects or other pests; it is greatest on the best sites and least on poor sites or those with a heavy overstory or severe pest damage (table 1). If red pines make up the overstory, the average height of dominant and codominant trees at 50 years (site index) is used to measure site quality, In northern Minnesota the site index ranges from about 14 m (45 ft) for poor sites to 23 m (75 ft) for very good sites *(13,100).* In southeastern Minnesota there are planted stands 26-37 years old with site indices of 27-29 m (90-95 ft) (Donald H. Prettyman, personal communication).

Diameter growth improves with increasing live crown size, which in turn is affected by stand density. The length of live crown in relation to total tree height ranges from 7 percent in dense stands to 75 percent in open stands *(35,50,72,86,90).*

Rooting Habit-During the first summer, seedlings may develop taproots 15 to 46 cm (6 to 18 in) long. Early rooting depth is fostered by the presence of a water table within 1.2 m (4 ft) of the soil surface and a loose soil. Lateral growth usually outstrips vertical growth after the first year. Most root elongation takes place in the spring and early summer with a second spurt in early fall; prevailing soil moisture and temperature conditions influence the timing and intensity of growth *(59,76,90,98).*

The usually well-developed root system in old trees tends to be wide spreading and moderately deep. There are numerous stout lateral roots (and often a taproot) with vertical branches (sinkers) descending at acute angles and often some ascending to within 13 mm (0.5 in) of the surface, giving the tree strong support and making it windfirm. The root system is more extensive on loamy sands than on fine sandy loams.

The lateral roots radiate in an irregular oval shape from the tree at irregular intervals, usually remaining within 10 to 46 cm (4 to 18 in) of the surface and sometimes attaining a length greater than tree height in stands up to 9.4 m (31 ft) tall. They may grow as much as 104 to 130 cm (41 to 51 in) in a year, but usually much less. By 45 to 50 years stem height is twice the length of the longest laterals. Fine roots develop along the main laterals. If unhindered by competition of neighboring trees, the longest laterals may extend 12.2 m (40 ft) beyond the crown limits. In stands, however, the lateral roots are forced to share growing space with root systems of a number of other trees. For example, in an Ontario plantation the roots of a red pine 8.2 m (27 ft) tall extended into the growing space of 23 other trees, and its own space was invaded by the roots of 11 trees.

Both central and lateral vertical roots occur, and these commonly penetrate from 1.5 to 4.6 m (5 to 15 ft) and grow slowly after the first 10 years. Generally the taproot and other vertical roots tend to go through rather than around materials that are difficult to penetrate (in contrast to white pine roots that tend to go around such obstacles).

Red pine roots die back in soils seasonally saturated for more than 3 months and their downward growth is restricted if soil drainage is poor. Hardpan, gley near the surface, coarse compacted soils, and those with bulk densities exceeding 1.40 g/cm^3 (0.81 oz/in^3) stunt root systems *(16,27,76, 89,90).*

Mycorrhizae formed on the roots of red pine seedlings by *Boletinus pictus, Tylopilus felleus, Cenococcum graniforme, Gomphidius superiorensis, G. vinicolor,* several species of *Suillus* and *Scleroderma aurantium* improve the uptake of soil moisture and mineral nutrients *(39,67,68,73).*

Natural root grafts, usually 10 to 36 cm (4 to 14 in) below the soil surface, are common in red pines past 15 years old, especially where there is pressure as when two roots grow over or adjacent to a stone. The majority of trees in a stand may be connected directly or in directly with one to six other trees. Grafting is more common among large roots, but occasionally small roots are joined with larger ones. Thinning seems to stimulate an increase in root grafts. Such grafts may transmit diseases (such as ***Heterobasidion annosum*),** silvicides, and fertilizers but they also retard insect and disease effects on the stumps of cut trees, sustain weak trees during droughts (by transmitting moisture and nutrients), increase windfirmness, and keep girdled trees alive for several years *(32,43,44,76,90,92).*

Reaction to Competition-Red pine is less shade tolerant than common associates other than jack pine, the aspens, paper birch, and gray birch ***(Betula populifolia).*** Based on a scale that ranges from 10.0 for eastern hemlock (extremely shade tolerant) to 0.7 for the aspens (extremely shade intolerant), red pine rates 2.4 along with black ash ***(Fraxinus nigra)*** and black cherry ***(Prunus serotina).*** Other classifications include red pine in the fourth lowest of five tolerance classes (intolerant). Red pine becomes more intolerant as the environment becomes warmer. Although seedlings may be more tolerant than older trees, they grow very slowly under cover.

Most natural red pine stands are understocked, but an occasional sapling stand may be dense with as many as 49,400 stems per hectare (20,000/acre). Stands 15 to 20 years old with fewer than 6,200 trees per hectare (2,500/acre) seem able to thin themselves, but denser stands stagnate. Dense stands respond well to thinning. To age 67 on an excellent site in Wisconsin, red pine has made full volume growth when thinned periodically from age 32, to an average spacing of 20 percent of height of dominants. Thinning was done after each 2.1 or 2.4 m (7 or 8 ft) of added height growth. Height growth of dominants was retarded after spacing became closer than 15 percent of height. The range of stand density for full volume growth remains to be determined. Although stand density is important in the control of size and quality of timber trees, red pine volume growth varies little over a wide range of stocking conditions (14 to 34 m^2/ha or more basal area, or 60 to 150 $ft^2/acre$). On good sites basal area growth ceases when it reaches a level of about 57 m^2/ha (250 $ft^2/acre$) *(11,17,22,76,90,101).*

Diameter growth begins earliest, is fastest, and continues longest in dominant trees. The reverse is true of suppressed trees. Overhead cover restricts height growth, but red pines overtopped by oaks and red maple for as long as 40 years have responded to release.

In dense stands dominance is well expressed by age 10 to 12. At wider spacing the differentiation into crown classes occurs later, usually after 20 or 30 years. In fully stocked stands the percentage of trees in the dominant and codominant crown classes increases from about 45, when average d.b.h. is 5 cm (2 in), to 90, when d.b.h. is 36 cm (14 in). In less dense stands the percentage of dominants and codominants is higher.

Beginning at about age 25 in dense stands, red pine prunes itself better than any other northern conifer except tamarack. Even in dense stands, however, there may be little natural pruning during the first 40 years. In more open stands pruning is delayed to a greater age. On some infertile sands, however, lower branches die off even if crowns are not closed.

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. On the coarser, more infertile sands, succession apparently stops short of the northern hardwood climax and red pine may be a long-persisting subclimax. In much of northern New England and eastern Canada, succession may be to spruce-fir and eastern hemlock. In northeastern Minnesota it may be to spruce-fir alone rather than to northern hardwoods *(66,76).*

Because the crown is not only the source but also the regulating center for all wood growth, silviculturists can manipulate the stand and some features of site to influence both the quantity and quality of wood desired on various parts of the tree bole. They can thin, prune, fertilize, drain excess moisture, and control insects and diseases to this end under specific circumstances *(51).*

Because of its shade intolerance, red pine grows best in even-aged groups or stands and is well adapted to even-aged management. Depending on conditions and management objectives either the shelterwood system (fig. 3) or clearcutting followed by planting or seeding may be used. Natural red pine stands in the Lake States commonly are understocked and produce average yields about one-third those produced by well stocked unmanaged stands. Yet even in these understocked stands yields can be increased by about 50 percent with intensive management. For well stocked stands, yields (including intermediate cuts) can be about doubled if managed wisely *(13,14,17,76,101).*

Figure *3-Abundant red pine reproduction established under a mature red pine stand given frequent light cuts, Chippewa National Forest, north-central Minnesota.*

Damaging Agents-Although red pine has had fewer serious enemies than most associated species when growing under conditions natural to its native range, nevertheless it is damaged by a number of agents. When grown on less acid, finer textured, and more poorly drained soils and under milder climatic conditions than those to which it is adapted, red pine is subject to damage by additional destructive agents.

The following hinder red pine seed germination and early survival: summer drought and high surface soil temperatures; sudden drops in temperature in the early fall, prolonged for about 24 hours, and winter drying of foliage; unidentified insects that consume seedlings shortly after they germinate; competition of subordinate vegetation; postemergent damping-off (usually caused by fungi of the genera ***Rhizoctonia, Fusarium, Pythium,*** and ***Phytophthora),*** birds, rodents, flooding, trampling by large animals, and smothering by litter; and large doses of herbicides *(29,76,90,94).*

Beyond the early establishment stage red pine may be killed or seriously damaged by many physical and biotic environmental factors.

Fire may kill red pines in stands up to 21 m (69 ft) tall. Ice and sleet storms and very strong winds have caused serious breakage and windfall in red pine stands. Spray from de-icing salt (sodium chloride) along well traveled highways has caused red pine mortality and poor growth. Spring flooding for 20 days kills red pine *(21,60,76,90,92,93,96).*

About 100 insect species are known to feed on red pine, but only a few usually cause mortality or serious injury. Several sawflies ***(Neodiprion lecontei, N. sertifer, N. abbotii, N. nanalus, N. pratti pratti, N. compar, N. pinetum, Diprion frutetorum, D. similis, Acantholyda erythrocephala, A. pini,*** and ***A. zappei)*** defoliate and often kill seedlings, and some of them damage older trees also. Trees in young stands, especially plantations, may sustain mortality or serious injury from the Saratoga spittlebug ***(Aphrophora saratogensis),*** the Zimmerman pine moth ***(Dioryctria zimmermani),*** the red pine shoot moth ***(D. resinosella)*** or the Allegheny mound ant ***(Formica exsectoides).*** The red pine scale ***(Matsucoccus resinosae),*** especially in the Northeast, kills or severely injures red pines from seedlings to mature trees. The European pine shoot moth ***(Rhyaciona buoliana)*** frequently deforms young red pine. White grubs (such as ***Phyllophaga rugosa, F! tristis, Diplotaxis sordida,*** and ***Serica*** spp.) cut the roots of the seedlings and often induce mortality in dry years *(10,34,75,76,102).*

In periods of peak population, the snowshoe hare and the cottontail often kill or reduce height growth of red pine seedlings. When preferred foods are lacking, white-tailed deer browse or destroy red pine seedlings. Porcupines girdle red pines from sapling to mature trees *(9,76).*

The North American strain of scleroderris canker ***(Gremmeniella abietina)*** has caused the loss of a number of young plantations in the Lake States; in the Northeast, the European strain of scleroderris canker has killed mature red pine. Needle cast diseases can retard growth of red pine and kill small trees. These include ***Lophodermium pinastri*** and ***Scirrhia acicola.*** Sirococcus tip blight ***(Sirococcus strobilinus)*** can cause failure of natural regeneration when overstory trees are infected. ***Coleosporium asterum*** stunts the growth of new shoots while sweetfern blister rust ***(Cronartium comptoniae)*** deforms young trees. In nurseries, ***Cylindrocladium scoparium*** occasionally causes severe losses through root rot, damping off, and needle blight, and annosus root rot ***(Heterobasidion annosum)*** and the shoestring root rot ***(Armillaria mellea)*** cause death of trees in planted and natural stands *(7,39,63,65,68,76,82, 83,90).*

Special Uses

Red pine has been grown primarily for the production of wood for lumber, piling, poles, cabin logs, railway ties, posts, mine timbers, box boards, pulpwood, and fuel. It has been one of the most extensively planted species in the northern United States and Canada, not only for wood production but also for dune and sandblow control, snowbreaks, windbreaks, and Christmas trees. Even when wood production is the main goal, red pine forests often are managed throughout their rotation for other uses such as recreation, wildlife habitat, and watersheds.

On sandy farmland in the Lake States, narrow strips (usually 3 to 8 rows) of red pine have been planted at intervals to reduce wind-caused soil erosion in the fields. Similarly, narrow strips have been planted along roads to control snow drifting and to improve scenic aspects. Red pine has been planted to help control sand dunes near Lake Michigan and also to control "sandblows" that develop when cover is removed from light sandy soils. Such stands should be managed to retain long live crowns and to maintain good vigor without losing essential reduction of wind velocities.

Red pine stands are popular places for hiking, camping, and other recreational activities, especially when the trees are large and located near a lake or stream. Red pine forests used for recreation should be managed to maintain a high proportion of large old-growth trees.

Red pine stands produce litter (more than 9000 kg/ha or 8,000 lb/acre at age 15) that helps prevent erosion by absorbing moisture, but they also contribute to moisture depletion in the top 1 m (3.3 ft) of soil. Such stands also increase the snowpack water content and consequently the spring snowmelt runoff over that of unplanted areas or those growing deciduous trees. The water yield of red pine stands in Minnesota was less than for aspen stands and decreased with stand density. Well stocked young red pine stands intercept some precipitation (average throughfall is 87 percent and stem flow 2 percent of precipitation).

The management of red pine stands should be coordinated with that of other types on a watershed so as to deter soil erosion and maintain an even flow of high quality water.

Although red pine stands generally are considered poor habitat for game birds and animals, they provide cover, nesting sites, and some food for many species of birds and animals. For wildlife purposes the stands should be managed in patches so as to provide an array of conditions from small openings to mature groups *(13,14,15,18,38,77,78,79,80,97)*.

Genetics

Red pine is uniform morphologically and apparently very old. Fossil records from Dakota sandstone show that an upland pine *(Pinus clementsii* or ***P. resinosipites*** or both) markedly resembling red pine occurred in southern Minnesota during the Cretaceous period. During periods of glaciation, red pine was forced to migrate to the south and then returned north with the retreat of the glaciers. Indications are that after the most recent glaciation red pine migrated west, principally north of Lake Michigan, from a refuge in the Appalachian Highlands (76,103).

Population Differences

Although appreciable natural variation between red pine stands within a region has been noted, it appears to reflect largely nongenetic environmental effects. Actually, variation in progeny means from individual trees can be as great as, or greater than, that between population or provenance means. Conclusions from an Ontario study were that the variation pattern of red pine was predominantly random from stand to stand. In a Wisconsin study, family differences contributed the bulk of the variation observed with differences among stands and seed collection regions contributing little.

Despite the unusual uniformity of the species, occasional red pines have been found with fastigiate branching, unusually slender branches, markedly suppressed lateral branching, or dwarf habit. Very small occurrences of albino or chlorophyll-deficient mutant seedlings, and tetraploid seedlings have been reported. Red pine shows only minor inbreeding depression following selfing-an indication that it carries few deleterious mutant genes. In Ontario individual open grown red pine trees showed differences in susceptibility to attack by ***Neodiprion lecontei*** *(1,28,33,40,42,76)*.

Races

Seed source studies have disclosed small, but statistically significant differences among provenance means for survival, phenological traits, size and growth rates, photoperiodic response, lammas frequency, and wood quality. For plantations up to age 20, the difference between the overall mean and the mean of the best provenance has been about 10 percent for height growth. Very young seedlings have shown greater differences and older trees less. Red pine from the Angus, ON, area has shown enough promise to be used for establishing seed orchards in Ontario and adjacent areas.

Some effects of climate noted for red pine indicate that northern sources may have smaller seeds, seedlings with fewer cotyledons, lower frequency of lammas growth, and less frost sensitivity. Provenances from different climatic regions have shown differences in height growth and several other attributes, but variation between provenances within climatic regions is also present. In general, red pine traits show broad regional adaptation and broad regional differences as well as random occurrence *(28,41, 42,84).*

Hybrids

No authenticated interspecific hybrids involving red pine have been found in nature. A *Pinus nigra* var. *austriaca x P. resinosa* cross previously reported no longer is considered a valid red pine hybrid. Many additional hybridization attempts in the United States and Canada have failed, although one cross with Austrian pine and one with Japanese red pine *(Pinus densiflora)* using highly irradiated (200 000 R) red pine pollen have been reported from Ontario. One tree of each cross survived at age 10. The trees were about 1 m (3 to 4 ft) tall, and each showed some hybrid characteristics (105).

The growth rate of hybrids between provenances was intermediate between those of the parent provenances and showed no evidence of heterosis.

The best opportunity for genetically improving red pine, therefore, is to incorporate small genetic gains in large numbers of seedlings when red pine is a major part of large-scale reforestation programs *(28,42,47,62,90,104).*

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