Pinus contorta Dougl. ex. Loud. **Lodgepole Pine**

Pi naceae Pine family

James E. Lotan and William B. Critchfield

Lodgepole pine *(Pinus contorta)* is a two-needled pine of the subgenus *Pinus.* The species has been divided geographically into four varieties: *P. contorta* var. *contorta,* the coastal form known as shore pine, coast pine, or beach pine; *P. contorta* var. *bolanderi,* a Mendocino County White Plains form in California called Bolander pine; *P. contorta* var. *murrayana* in the Sierra Nevada, called Sierra lodgepole pine or tamarack pine; and *l? contorta* var. *latifolia,* the inland form often referred to as Rocky Mountain lodgepole pine or black pine. Although the coastal form grows mainly between sea level and 610 m (2,000 ft), the inland form is found from 490 to 3660 m (1,600 to 12,000 ft).

Habitat

Native Range

Lodgepole pine (fig. 1) is an ubiquitous species with a wide ecological amplitude. It grows throughout the Rocky Mountain and Pacific coast regions, extending north to about latitude 64” N. in the Yukon Territory and south to about latitude 31” N. in Baja California, and west to east from the Pacific Ocean to the Black Hills of South Dakota. Forests dominated by lodgepole pine cover some 6 million ha (15 million acres) in the Western United States and some 20 million ha (50 million acres) in Canada.

Climate

Lodgepole pine grows under a wide variety of climatic conditions (52). Temperature regimes vary greatly. Minimum temperatures range from 7” C (45” F) on the coast to -57” C (–70° F) in the Northern Rocky Mountains. Maximum temperatures range from 27” C (80° F) along the coast and at high elevations to well over 38” C (100° F) at low elevations in the interior. Average July minimums frequently are below freezing at high elevations. Lodgepole seedlings are relatively resistant to frost injury in some locations *(16,42)* and often survive in “frost-pockets” where other species do not.

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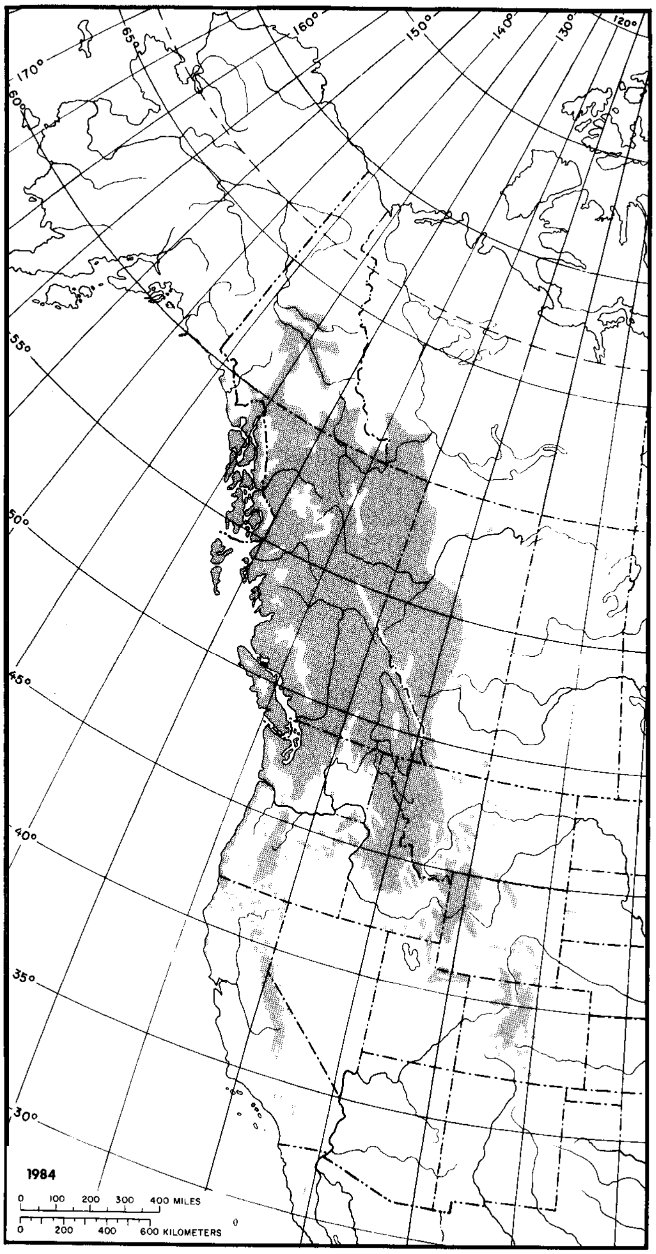

Figure *l-The native range of lodgepole pine.*

At low elevations in the interior, lodgepole pine grows in areas receiving only 250 mm (10 in) of mean annual precipitation, whereas it receives more than 500 mm (200 in) along the northern coast. Many interior sites often are low in summer rainfall.

Seasonal distribution of precipitation is significant; snowfall supplies most of the soil water used for rapid growth in early summer. Temperatures are frequently favorable for germination after snowmelt, and germination occurs rapidly. Lodgepole is very intolerant of shade and generally grows best in full sunlight.

Soils and Topography

Lodgepole pine grows on soils[1] that vary widely but are usually moist. Growth is best where soil parent materials are granites, shales, and coarse-grained lavas (24,271; other soils have developed from glacial till of widely varying composition, Recent, Tertiary, and Oligocene alluvium and colluvium (from such sources as quartzites and argillites), limestone of the Belt geologic series, pumice, and volcanic ash. Lodgepole pine is seldom found on the generally drier soils derived from limestone. In Canada, however, extensive stands occur on calcareous glacial tills (56). Glacial drift provides a balance of moisture and porosity on which the species seems to thrive, as in Alberta, where it grows better on glacial tills than on alluvial soils or lacustrine deposits. In Montana, highly calcareous soils derived from dolomitic limestone usually do not support lodgepole pine, subalpine fir *(Abies Zasiocarpa),* and Engelmann spruce *(Picea engelmannii)*, although they do support Rocky Mountain Douglas-fir *(Pseudotsuga menziesii* var. *glauca).* Nevertheless, soils developed in colluvium from other types of limestone and calcareous glacial till do support stands of lodgepole pine.

Extensive stands of lodgepole pine (var. *latifolia*) occur on soils classified as Inceptisols or Alfisols in the interior forests. Although the species commonly grows on Andepts and does well on these soils in some areas, the Boralfs and Ochrepts probably support better tree development and more extensive stands. Frequently lodgepole pine soils on Boralfs and Ochrepts have cryic soil temperature regimes. In the Blue Mountains of Oregon lodgepole pine does well on Andepts, where it is nearly always found on volcanic ash or alluvial material overlying residual basaltic soils, at elevations between 910 and 2130 m (3,000 and 7,000 ft). The ash cap soils are deeper and hold more moisture than the residual soils.

The coastal form of lodgepole pine (var. *contorta)* is often found on Histosols (peat bogs or muskegs) in southeastern Alaska, British Columbia, and western Washington, and on dry, sandy, or gravelly sites farther south along the coast on Inceptisols, Alfisols, and Ultisols.

Soil properties and soil moisture often favor lodgepole pine locally over other species. Lodgepole pine grows on wet flats and poorly drained soils in the Cascade Range in Washington and Oregon, and the Sierra Nevada in California. Soils with underlying hardpan support lodgepole pine to the exclusion of such species as ponderosa pine *(Pinus ponderosa),* redwood *(Sequoia sempervirens),* or Douglas-fir in the Sierra Nevada, eastern Oregon, and Mendocino County, CA. Lodgepole pine also grows on level sites with and without high water tables in central Oregon where frost tolerance during germination allows its establishment to the exclusion of other species. Extensive stands are found in these areas on well drained sites above 1600 m (5,250 ft), with patterns of occurrence attributed to past fires.

On infertile soils, lodgepole pine is often the only tree species that will grow. Nevertheless, experiments have demonstrated significant growth increase from fertilization, particularly nitrogen (15).

Lodgepole pine thrives in a wide variety of topographic situations. It grows well on gentle slopes and in basins, but good stands are also found on rough and rocky terrain and on steep slopes and ridges, including bare gravel. Northern and eastern slopes are more favorable than southern and western aspects (3).

Associated Forest Cover

Lodgepole pine grows both in extensive, pure stands, and in association with many western conifers. The forest cover type Lodgepole Pine (Society of American Foresters Type 218) (26) exists as a pure (80 percent or more) component of basal area stocking, as a majority (50 percent or more), or as a plurality (20 percent or more). The cover type includes all recognized subspecies of *Pinus contorta.*

Lodgepole pine is a component in 27 of the 55 SAF western forest cover types. In the Northern Interior (Boreal) group it is represented in White Spruce (Type 201), White Spruce-Aspen (Type 251), White Spruce-Paper Birch (Type 202), Paper Birch (Type 252), and Black Spruce (Type 204).

It is a component in all six high elevation cover types: Mountain Hemlock (Type 205), Engelmann Spruce-Subalpine Fir (Type 206), Red Fir (Type 207), Whitebark Pine (Type 208), Bristlecone Pine (Type 209), and California Mixed Subalpine (Type 256). At middle elevations in the interior it is a minor component of seven other types: Interior Douglas-Fir

[1]Soils were classified in consultation with Richard Cline of the USDA Forest Service, Forest Environment Research Staff, Washington, DC; Hal Hunter of the Soil Conservation Service, Bozeman, MT, and Carl Davis, Gallatin National Forest, Bozeman. MT..

(Type 210), Western Larch (Type 212), Grand Fir (Type 213), Western White Pine (Type 215), Blue Spruce (Type 216), Aspen (Type 217), and Limber Pine (Type 219). In the North Pacific forests, it is a component in Coastal True Fir (Type 226), Western Redcedar-Western Hemlock (Type 227), Western Redcedar (Type 228), Douglas-Fir-Western Hemlock (Type 230), Port Orford-Cedar (Type 231), and Redwood (Type 232). At low elevations in the interior it is associated with Interior Ponderosa Pine (Type 237) and in the South Pacific forests it is a component of Jeffrey Pine (Type 247).

Lodgepole pine, with probably the widest range of environmental tolerance of any conifer in North America, grows in association with many plant species *(30,50,59,60)*. The lodgepole pine forest type is the third most extensive commercial forest type in the Rocky Mountains.

Lodgepole pine's successional role depends upon environmental conditions and extent of competition from associated species. Lodgepole pine is a minor seral species in warm, moist habitats and a dominant seral species in cool dry habitats. It is often persistent even on cool and dry sites and can attain edaphic climax at relatively high elevations on poor sites. Fire regimes have played a role in this successional continuum, especially where repeated fires have eliminated a seed source for other species (27). Lodgepole pine may even overwhelm a site with seed stored in serotinous cones. It has four basic successional roles *(50)*:

Minor Seral-A component of even-aged stands rapidly being replaced by shade-tolerant associates in 50 to 200 years.

Dominant Seral-The dominant cover type of even-aged stands with a vigorous understory of shade-tolerant species that will replace lodgepole pine in 100 to 200 years.

Persistent-The dominant cover type of even-aged stands with little evidence of replacement by shade-tolerant species.

Climax-The only tree species capable of growing in a particular environment; lodgepole pine is self-perpetuating.

Life History

The following statements apply principally to lodgepole pine in the most important part of its range; namely northern Colorado, Wyoming, Montana, northern Utah, Idaho, eastern Oregon, western Alberta, and southern British Columbia.

Reproduction and Early Growth

Flowering and Fruiting-Male and female strobili generally are borne separately on the same tree in this monoecious species, with female flowers most often at the apical end of main branches in the upper crown, and male flowers on older lateral branches of the lower crown. The reddish purple female flowers grow in whorls of two to five and are 10 to 12 mm (0.4 to 0.5 in) long. The pale yellow to yellowish orange male flowers are crowded clusters of catkins at the base of new shoots and are 8 to 14 mm (0.3 to 0.6 in) long. It is not uncommon to find a dominance of maleness or femaleness on individual trees.

Table l-Time of pollen shedding in natural stands of lodgepole pine *(20,52*, modified)

Stand location	Elevation'		Years observed	Date of peak shedding
	m	*ft*		
Vancouver, BC	—	—	2	Middle to late May
Northwestern Washington	150	500	10	May 12
Mendocino White Plains, California	—	—	1	June 9
Northern Cascades	1200	4,000	—	Mid-June
Northern Idaho; western Montana	—	—	10	June 13
Central and eastern Washington and Oregon	790 to 1300	2,600 to 4,250	—	June 13
Southeastern Alberta (subalpine forest)	—	—	10	June 22
Sierra Nevada, California	1820	6,000	3	June 22
Central Montana; Yellowstone region	—	—	10	June 25
Northern Utah	2190	7,200	2	July 12
Southern Idaho	2070	6,800	1	July 7
Northern Idaho; western Montana	670 to 1265	2,200 to 4,150	10	June 6
Eastside Montana; Yellowstone National Park	975 to 2060	3,200 to 6,750	10	June 17

'Dash indicates data are not available.

Pollen generally matures in mid-May to mid-July (table 1) *(20,52)*. The time at which pollen matures appears to be related to elevation and climate.

Seed cones usually mature in August, September, or October, more than a year after pollination. Inland forms and high elevation stands apparently mature earlier than coastal forms or low elevation stands. Cones open in early September in the Northern Rocky Mountains. Cone maturity is indicated by a change in color from purple-green to light brown (54).

Seed Production and Dissemination— Lodgepole pine produces viable seed at an early age, commonly 5 to 10 years; germination percentage is as high as that of seed borne by mature trees. Pollen flowers have been observed on 2-O seedlings in the Lucky Peak Nursery near Boise, ID.

Lodgepole pine is a prolific seed producer. Good crops can be expected at 1- to 3-year intervals, with light crops intervening. The cones withstand below freezing temperatures and are not generally affected by cone- and seed-feeding insects. Only squirrels and coreid bugs are significant seed predators. Seed production should not be taken for granted, however. Complete seed crop failures have occurred at 2800 m (9,200 ft) in northwest Wyoming for 2 to 4 years in a row (42).

Cone production of individual dominant and codominant trees can vary from a few hundred to a few thousand per tree (37). Cones are persistent, and serotinous (closed) cones accumulate for decades. Annual production may run from 173,000 to 790,000 seeds per hectare (70,000 to 320,000/acre) with half to one-third available for annual seedfall (27). An annual seedfall of 99,000 to 222,000 seeds per hectare (40,000 to 90,000/acre) was found in central Montana (58). These figures might be considered typical for interior lodgepole pine where some portion of the trees are of the serotinous type. In Oregon, where the nonserotinous cone habit is prevalent, seedfall ranged from about 35,000 to over 1.2 million/ha (14,000 to 500,000/acre) *(21)*. Most years seedfall was on the order of hundreds of thousands per hectare. Where stored seeds are in the millions per hectare (in closed cones), the number of seeds stored is probably 10 times that of seeds produced annually (3 *7)*.

Although the number of fully developed seeds per cone varies from as few as 1 to 2 to as many as 50, a normal average for large cone lots in the Rocky Mountains is from 10 to 24 seeds per cone (42). Sierra Nevada populations range from 5 to 37 seeds per cone *(20)*.

The serotinous cone habit varies over wide geographic areas as well as locally (37). Serotinous cones are not common in eastern Oregon, rare in coastal populations, and absent in the Sierra Nevada and southern California and Baja California populations (20). Although common in the Rocky Mountains, this cone habit varies considerably (37). Many stands in the Rockies have less than 50 percent serotinous-cone trees.

Lodgepole pine has long been regarded as a fire-maintained subclimax type. Its ability to regenerate in extremely dense stands to the exclusion of other species can be attributed to the closed cone habit. Millions of seeds per hectare are held in reserve for many years and are readily available to germinate on the seedbed prepared by fire. Recent evidence seems to indicate that fire selects strongly for the closed cone habit (49).

Serotinous cones do not open at maturity because of a resinous bond between the cone scales. The bonds break with temperatures between 45" and 60" C (113" to 140° F) *(48)*, and cone scales are then free to open hygroscopically. Large quantities of seeds are thus available for regenerating a stand following fire. Closed cones at or near the soil surface (less than 30 cm or about 12 in) are also subjected to temperatures from insolation sufficient to open them and may provide seed in harvested areas. Some seeds may be damaged by fire, however, particularly in fires burning in logging slash.

Seeds stored in serotinous cones on the tree remain viable for years. Apparently, prolonged viability can be maintained so long as cones or seeds are not in contact with the ground. Once cones are on the ground, cones open. Damping-off fungi may infect the seed, rodents may feed on the seeds, or germination may occur; for the most part, seeds are not stored in the soil.

Lodgepole pine has relatively small seeds for pine. Seed weights vary considerably, ranging from 2.3 mg (0.04 grains) per seed in the Interior of Canada to 11.4 mg (0.18 grains) per seed in the Sierra Nevada (20). Lodgepole pine seeds average about 298,000 cleaned seeds per kilogram (135,000/lb) for varieties *contorta*, 258,000/kg (117,000/lb) for *murrayana*, and 207,000/kg (94,000/lb) for *latifolia* (54). Density of seedfall 20 m (66 ft) from the timber edge is only 10 to 30 percent of that at the timber edge for stands in the Rocky Mountains (fig. 2) (42). Dispersal of sufficient seed to adequately restock an area often is only about 60 m (200 ft) *(23,38)*. Prevailing winds, thermal effects, or scudding on the snow may disperse seeds far beyond these distances, however.

The annual seedfall from nonserotinous cones helps in restocking relatively minor disturbances in the stand, in maintaining the presence of lodgepole pine in mixed stands, and in expanding conifers into

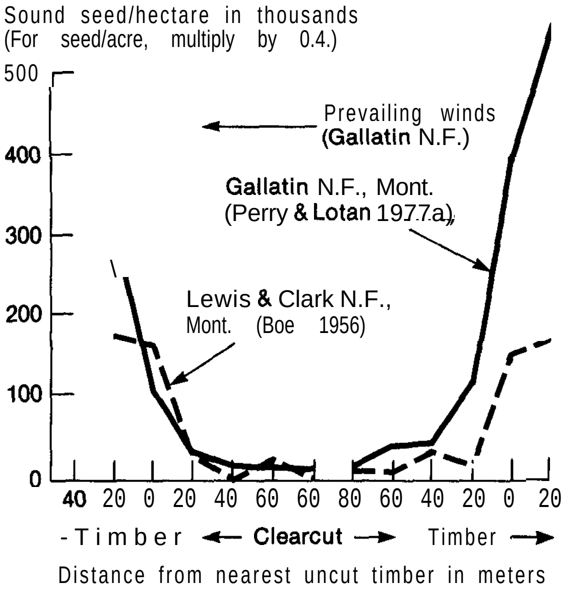

Figure 2—*Sound seed per hectare as a function of distance from the nearest timber edge.*

other vegetative types. Seldom do we find stands without some trees of the open-coned type. The efficacy of this seed source can be seen in the dense stands of lodgepole pine along road cuts, powerline rights-of-way, and ditches or where disturbance occurs near lodgepole pine stands (fig. 3).

Studies of seedfall have shown variation in the number of seeds released soon after cone maturation, but most, seeds (80 to 90 percent) are released before the following growing season (27).

Where large amounts of seed are stored in serotinous cones, a most effective means of seed dispersal in clearcuts is from cones attached to the slash and those knocked from the slash and scattered over the forest floor during slash disposal. Many cones on or near the ground are opened by normal summer soil surface temperatures *(35).* In Montana 83 percent of the cones on the ground opened the first year on south slopes compared to 40 percent. on north slopes. Maximum seed release from serotinous cones near the ground takes place during the first year of exposure. In fact, cones may open after the first few minutes of exposure to temperatures high enough to break the resinous bonds.

In slash, serotinous cones that are well above the ground behave like those on a tree—they remain closed, and stored seeds remain viable for years.

Seeds in unopened cones and those released from the slash may also be lost to rodents, fungi, and other destructive agents. Seeds from closed cones are usually available only for the first growing season following harvest, but stocking from open-cone seed sources can continue to increase for several years.

Slash disposal on areas where regeneration is planned from serotinous cones must be carefully planned and executed. Seed supply will be largely destroyed if slash to be burned is piled before cones have had a chance to open (38). Piling slash should be delayed until sufficient cones have opened to assure adequate stocking. Piling then scatters seeds and opened cones and helps prepare the seedbed. Piling slash after germination can also decrease stocking because young seedlings are trampled or buried.

Broadcast burning may hasten release of seeds from cones not in a position to open from high soil-surface temperatures. Some seeds will be destroyed, however; the amount will vary with fire intensity.

Seedling Development-Germination under field conditions is good if climate and seedbed are favorable. Best, germination occurs in full sunlight and on bare mineral soil or disturbed duff, free of competing vegetation. Germination is epigeal. Temperatures fluctuating between 8” and 26” C (47” and 78” F) favor germination. Adequate soil moisture is required for germination and survival during the critical few weeks following germination *(34,51,55).* In southwest Montana and southeast Idaho, 75 to 90 percent of a season's total germination occurred

Figure 3—*Lodgepole pine regeneration in Colorado.*

during the 2 weeks following snowmelt in late June *(34)*, when the soil was saturated and temperatures were favorable. Germination can be delayed if cones do not open during the previous summer.

Although lodgepole pine germinates well on most organic seedbeds, such materials tend to dry faster than mineral soil and seedlings often die in this seedbed. Lodgepole pine seeds have little need for stratification and germination depends largely upon temperature *(20)*. At optimum temperatures and moisture, almost 100 percent of the seeds germinate rapidly.

Both shading and competition inhibit germination and survival. Newly germinated seedlings are relatively insensitive to temperature extremes. Because residual overstory following partial cutting usually does not provide the most favorable conditions for regeneration, clearcutting is generally recommended. On some areas, however, lodgepole pine has established itself in the shade of lightly cut or uneven-aged stands and may persist for many years in the understory. Some of these trees eventually may establish a crown sufficient to permit reasonable growth.

Drought is a common cause of mortality among first-year seedlings; losses vary with soil type and seedbed condition. Greatest losses occur on soils with low water-holding capacity, and duff and litter. Well decomposed organic material, incorporated in the soil, enhances seedling survival, however. Disturbed mineral soil seedbeds generally produce the best germination and survival *(34,40,41)*. Shading has been demonstrated to help under drought conditions in Wyoming *(10)*.

Drought losses usually decline considerably after the first growing season. First-year seedlings are particularly vulnerable because of a relatively shallow root system *(34,47)*.

Young, succulent seedlings may die because of high soil surface temperatures (13). By 2 to 4 weeks of age, seedlings are able to withstand soil surface temperatures higher than 60" C (140" F), which commonly occur at high elevation sites. Freezing temperatures may kill seedlings either directly or by frost heaving. In much of the range of lodgepole pine, however, frosts occur regularly throughout the growing season and seedlings from different sources vary in frost resistance *(16)*. The amount of frost heaving varies considerably by soil type, location, and year of occurrence but can cause significant losses.

Lodgepole pine seedlings are poor competitors and competition from grass is often most detrimental. The Douglas-fir/pinegrass habitat type is one of the most difficult sites for lodgepole pine regeneration, particularly if the regeneration effort is delayed until a firm sod cover is established.

Grazing animals, particularly cattle, can cause seedling mortality by trampling. Sheep actually seek the succulent new "candles" in the spring and nibble needles and small branches if other feed is not abundant.

A common problem of regenerating lodgepole pine stands is overstocking, which results in stagnation at early ages. Many sites are stocked with tens of thousands and even hundreds of thousands of trees per hectare.

If trees are well distributed, stocking should not exceed 1,240 to 1,980 stems per hectare (500 to BOO/acre) between 5 years and 20 years of age *(17)*. Proper distribution and full utilization of the site, however, may require establishment of 2,470/ha (1,000/acre) and thinning to obtain proper spacing. There is also potential for significant genetic gains from selection of elite trees when thinning.

An average height of 3.6 m (12 ft) and d.b.h. of 5 cm (2 in) on fully stocked 20-year-old stands was found on above average sites in Montana (27). Average heights of 2.0 m (6.7 ft), 4.2 m (13.8 ft), and 7.6 m (24.9 ft) were found on low, medium, and high sites in 20-year-old stands in the Foothills Section of Alberta (for density class 1,240 stems per hectare or 500/acre at 70 years of age) *(32)*.

Lodgepole pine height growth begins earlier than any of its associates except other pines and larch *(53)*.

Vegetative Reproduction-Lodgepole pine can be grafted successfully, but results vary depending upon the clone *(20)*. Natural sprouting has been observed on the Bitterroot National Forest in Montana. Branches not severed often become leaders on stumps left in thinning operations.

Lodgepole pine cuttings are relatively easy to root. Adventitious roots have been developed artificially from &year-old lodgepole pine (by air-layering) after treatment with either indole-acetic or indole-butyric acid *(17)*.

Callus tissue cultures and liquid cell suspensions have been produced from seedling hypocotyl tissue, excised embryos, and actively growing shoots.

Sapling and Pole Stages to Maturity

Because lodgepole pine has little taper and thin bark it produces a higher volume of wood for a given diameter and height than many of its associates. Natural pruning is relatively poor, but limbs generally are of small diameter and lumber yields are good.

Table 2-Relationships among stand age and stocking level, and tree development and typical yield in natural stands of lodgepole pine, summarized for medium sites in Montana and Idaho (site index 22.9 m or 75 ft at base age 100 years)[1]

Age	Stocking		Average height of dominants		Average stand diameter		Total cubic volume		Merchantable volume		
yr	*trees/ha*	*trees/acre*	*m*	*ft*	*cm*	*in*	*m^3/ha*	*ft^3/acre*	*m^3/ha*	*ft^3/acre*	*fbm/acre*
20	1,240	500	5.5	18	8.6	3.4	16.1	230	–		
	19,770	8,000	3.0	10	4.1	1.6	28.0	400	–		
50	1,180	479	12.5	41	16.5	6.5	144.9	2,070	130.2	1,860	5,100
	15,200	6,150	9.1	30	6.9	2.7	165.9	2,370	–	–	–
80	1,030	418	18.0	59	20.6	8.1	285.6	4,080	266.0	3,800	12,100
	7,500	3,034	14.6	48	9.1	3.6	280.0	4,000	–	–	–
110	850	344	22.3	73	23.6	9.3	385.7	5,510	363.3	5,190	18,200
	4,600	1,861	18.9	62	11.4	4.5	357.0	5,100	273.0	3,900	8,400
140	680	275	25.3	83	26.7	10.5	448.7	6,410	426.3	6,090	23,200
	3,070	1,243	22.3	73	14.0	5.5	416.5	5,950	301.0	4,300	10,300

[1]Compiled from unpublished yield tables furnished by D. M. Cole, USDA Forest Service, Intermountain Research Station, Bozeman, MT. Cubic volumes are from trees 11.4 cm (4.5 in) in d.b.h. to a 7.6 cm (3 in) diameter top. Board foot volumes are from trees larger than 16.5 cm (6.5 in) in d.b.h. to a 15.2 cm (6 in) diameter top.

Growth and Yield-Growth and yield of lodgepole pine is greatly affected by stand density *(31)* (fig. 4) as well as by environmental factors *(2,6,22,46)*. In fact, site index curves have been developed with corrections for effects of stand density.

Maximum yield in the Rocky Mountains was 280 m^3/ha (20,000 fbm/acre) at a density of 1,980 trees per hectare (800/acre), but only 21 m^3/ha (1,500 fbm/acre) at a density of 4,450/ha (1,800/acre), assuming 5 fbm/ft^3; original figures were in board feet *(27)*.

In extreme cases 70-year-old stands with 247,000 trees/ha (100,000 trees/acre) averaged only 1.2 m (4 ft) in height and less than 2.5 cm (1 in) in diameter at ground level.

Yields of 168 to 224 m^3/ha (about 12,000 to 16,000 fbm/acre) can be found in old-growth Rocky Mountain lodgepole pine. Yields of more than 336 m^3/ha (about 24,000 fbm/acre) are the result of a fortuitous combination of favorable initial stocking, good site quality, and absence of mountain pine beetle and dwarf mistletoe.

Relationships among age, stocking levels, and development in natural stands were summarized for medium sites in Montana and Idaho (site index 22.9 m or 75 ft at 100 years) (table 2). Under light to moderate stocking, live crowns are 25 to 60 percent of total height.

Mature sizes vary greatly between stands. In the Rocky Mountains, most trees at 140 years of age were 18 to 33 cm (about 7 to 13 in) in d.b.h. and 18 to 25 m (about 60 to 80 ft) in height (27).

Trees in the Blue Mountains of Oregon average 30 cm (about 12 in> in d.b.h. and 23 m (about 75 ft) tall at 100 years of age. Sierra Nevada trees the same age are larger, averaging 42 cm (about 16 to 17 in) in d.b.h. and 28 to 30 m (about 90 to 100 ft) tall. Coastal trees are smaller but vary greatly. Mature trees range from 15 to 50 cm (about 6 to 20 in) in d.b.h. and only 6 to 12 m (20 to 40 ft) tall. Dwarf lodgepole pines are only about a meter (2 to 5 ft) tall and are found along the coast in Mendocino County, CA. This small size is thought to be caused by a highly acid hardpan.

Growth of lodgepole pine is often so stagnant that stand culture is not practical. Early management and control of stocking greatly affects growth and yield of lodgepole pine stands *(17)*. Average annual growth in old-growth unmanaged stands in the central Rocky Mountains only was 0.4 to 0.6 m^3/ha (about 25 to 40 fbm/acre) because of large numbers of small trees and a high incidence of dwarf mistletoe

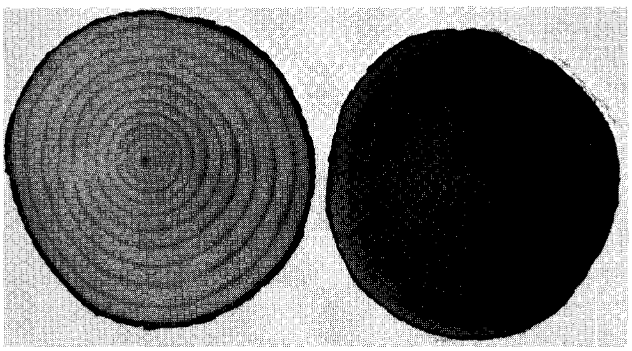

Figure 4—*Spacing greatly affects lodgepole pine diameter growth. Section on left comes from a 17-year-old tree; the one on the right, a 1 17-year-old tree, Cherry Creek, Gallatin National Forest, MT.*

(4). (Calculations assume 5 fbm/ft^3; original figures were in board feet). Annual net growth may be increased to 2.1 to 5.6 m^3/ha (about 150 to 400 fbm/acre) by controlling stand density and reducing dwarf mistletoe infection *(5,25)*.

Control of stand density offers the greatest opportunity for increasing productivity of any readily available management practice (table 2).

Culmination of total cubic volume occurs as early as 40 years in severely stagnated stands, and between 50 and 80 years for overstocked, but not greatly stagnated, stands. Merchantable volume culmination in stands of the latter type occurs between 110 and 140 years, depending on merchantability standards.

Thinning of young overstocked and stagnating stands can restore growth potential and redirect it into merchantable-size products. With more complete utilization (lower merchantable d.b.h. and top diameters), most of the yield increase possible from thinning is attained with the first entry, a stocking control thinning *(17)*.

Rooting Habit-The root system of lodgepole pine varies considerably in form, depending on soil type. Root growth is particularly important during the critical first year. Root growth of 12.7 to 15.2 cm (5 to 6 in) was reported for seedlings growing on prepared seedbeds in Montana and Idaho (34). First-season seedlings had an average root depth of only 9.6 cm (3.8 in) on scarified, unshaded seedbeds in the central Rocky Mountains (47). Seedlings growing near grass competition usually do not penetrate beyond 5 or 6 cm (about 2 in).

Taproots and vertical sinkers are common, but where a hardpan or water table is encountered, the taproot may die, bend, or assume a horizontal position. Planting may affect root configuration. Taproots of seedlings planted with "J-roots" often grow horizontally for many years before sinkers develop.

Because of its shallow root system, lodgepole pine is susceptible to windfall, particularly after stands are opened by harvesting. Windfirmness varies with stand density, soil conditions, and topography. Shallow roots are common above hardpan or in shallow, rocky soils.

Reaction to Competition-Lodgepole pine is very intolerant of shade and competition from other plant species. Occasionally seedlings become established under a forest canopy, but these individuals rarely do well. In spite of its shade intolerance, lodgepole pine maintains itself in dense stands for long periods, often for 100 years or more.

In the absence of fire, lodgepole pine is usually succeeded by its more tolerant associates, such as Engelmann spruce and subalpine fir. Succession proceeds at variable rates, however, and is particularly slow in some high elevation forests.

Pure stands of lodgepole pine persist for varying lengths of time. In northern Idaho and central Oregon, stands begin to break up at 80 to 100 years, while stands at higher elevations, such as in Montana, southern Idaho, Utah, and Wyoming, last for several hundred years. Pure stands in and around Yellowstone National Park contain 300- to 400-year-old trees, with several groups of younger even-aged trees. These stands no doubt originated as even-aged stands but have been breaking up for more than two centuries.

The ability of lodgepole pine to regenerate at the expense of other species is due not only to cone serotiny but also to seed viability, germinative energy, early rapid growth, and ability to survive a wide variety of microsite and soil situations (39).

Compared to its associates, lodgepole pine is intermediate in its needs for water, requiring more than Douglas-fir and ponderosa pine and less than Engelmann spruce and subalpine fir. On some sites, lodgepole pine appears to compete well for water, however, and grows where other species may be excluded because of lack of water *(45,57)*; on others it appears to be tolerant of high water tables *(14,43)*. It is also intermediate in its tolerance to extremes of temperature (27).

Lodgepole pine shows good response to thinning at an early age (fig. 5) *(17)*. Heavily stocked stands must be thinned before stagnation occurs. The best age for thinning varies with site and density. Poor sites and overstocked stands particularly must be thinned as early as age 10.

Diameter growth acceleration is usually greatest in heavy thinnings; cubic volume and basal area growth are usually greatest in light thinnings (27). Although mechanical thinning, as with bulldozer strips, is a convenient alternative, obtaining a proper response (36) is difficult.

At older ages, growth response is strongly correlated with crown size, vigor, and amount of release provided (27). Attempts at partial cutting of mature and over-mature stands have resulted in little gain or even negative net volume growth *(1,28)*.

Lodgepole pine can be maintained best in a vigorous, productive forest by using a silvicultural method that regenerates even-aged stands (38). This often may be accomplished by clearcutting (fig. 6) and by relying upon natural regeneration or planting. Planting provides an excellent opportunity for initial stocking control and/or genetic improvement.

Damaging Agents-The mountain pine beetle *(Dendroctonus ponderosae)* is the most severe insect pest of lodgepole pine. The epidemics that periodically occur in many lodgepole pine stands seriously affect the sustained yield and regulation of managed stands.

Adult beetles attack lodgepole pine in July or August, introducing bluestain fungi (8). The beetles construct egg galleries in the phloem where larvae feed and together with the fungi, girdle and kill the tree. Larvae overwinter in the tree, complete development, and emerge as adult beetles in the spring.

Harvesting has been considered as a means of preventing mountain pine beetle epidemics *(19).* Silvicultural practices in an integrated program for controlling losses to mountain pine beetle have been suggested *(9,18).* No mortality occurred in heavily thinned stands in Oregon where vigor ratings were high (44).

The mountain pine beetle has played an historic role in the dynamics of lodgepole pine ecosystems. By periodically invading stands and creating large amounts of fuels, which are eventually consumed by fire, creating favorable conditions for regeneration *(12,39),* the beetle has increased the probability that lodgepole pine will reoccupy the site at the expense of other species.

Another aggressive bark beetle that attacks lodgepole pine is the pine engraver *(Ips pini).* Ips commonly develops in logging slash, especially slash that is shaded and does not dry quickly. Prompt slash disposal is an effective control measure. Ips also can build up in windthrows.

Other insects that can be damaging local pests are the lodgepole terminal weevil *(Pissodes terminalis)*, which can be destructive to elongating terminal leaders; larvae of the Warren's collar weevil *(Hylobius warreni),* which girdles roots and the root collar; larvae of the weevil *Magdalis gentilis,* which mine branches; various sucking insects, such as the pine needle scale *(Chionaspis pinifoliae)*, the black pineleaf scale *(Nuculaspis californica)*, and the spruce spider mite *(Oligonychus ununguis);* and several defoliating insects, among which are the lodgepole sawfly *(Neodiprion burkei)*, the lodgepole needle miner *(Coleotechnites milleri),* the sugar pine tortrix *(Choristoneura lambertiana),* the pine tube moth *(Argyrotaenia pinatubana),* and the pandora moth *(Coloradia pandora) (7).*

Dwarf mistletoe (particularly *Arceuthobium americanurn)* is the most widespread and serious parasite affecting lodgepole pine *(11,29). A. americanum* seeds are forcibly ejected from the fruit for distances as great as 9 m (about 30 ft). The sticky seeds adhere to the foliage of potential host trees. The proportion of trees visibly infected can double each 5 years between the ages of 10 and 25, with nearly a third of the trees infected at age 25 (29).

Figure *5-With adequate spacing early growth of lodgepole pine is rapid. This lodgepole pine grew 102 cm (40 in) in 1 year, Scalp Mountain, Kootenai National Forest, MT.*

Rate of spread in young stands is about 0.3 to 0.5 m (1.0 to 1.5 ft) per year, with the fastest rate in dense stands. In many areas, more than 50 percent of lodgepole pine forests are infected. Dwarf mistletoe infection results in reduced diameter and height growth, increased mortality, reduced wood quality, decreased seed production, and overall decreased vigor.

Both harvesting and fire can greatly lessen the rate of spread and rates of infection. Effective control can be accomplished by clearcutting and locating boundaries of the unit to minimize reinfection from surrounding stands. Fire can effectively limit spread of dwarf mistletoe by eliminating sources of infection and establishing vast acreages of dwarf mistletoe-free areas.

Lodgepole pine is subject to attack by many fungal pathogens *(33)*. These fungi are responsible for reduced growth and considerable cull and mortality. They also contribute in no small measure to the large amounts of logging residues that commonly occur when lodgepole pine is harvested.

One of the most serious diseases in lodgepole pine is a stem canker caused by ***Atropellis piniphila.*** Cankered stems are usually useless for lumber or posts and poles. Stem cankers of rust fungi cause extensive mortality, growth loss, and cull in lodgepole pine. Of these comandra blister rust ***(Cronartium comandrae)*** is the most serious. The western gall rust ***(Peridermium harknessii)*** is especially damaging; trunk cankers can cause cull in logs and can kill seedlings and saplings. Because this rust does not require an alternate host, it can directly reinfect pines. Other fungi attack lodgepole pine and may cause serious losses in wood production. Examples are needle casts (such as ***Elytroderma deformans*** and ***Lophodermella concolor);*** root rots (such as ***Armillaria mellea*** and ***Heterobasidion annosum)***; and wood decays (such as ***Phellinus pini*** and ***Peniophora pseudo-pini)***.

Seed and seedling diseases are not usually damaging, although locally several mold fungi are as-

Figure 6-*A 20-year-old lodgepole pine clearcut in Moser Creek, Gallatin National Forest, MT.*

sociated with seed losses in germination, and rotting and damping-off can affect young seedlings.

Because of its relatively thin bark, lodgepole pine is more susceptible to fire than Douglas-fir and many other associates. It is less susceptible than Engelmann spruce or subalpine fir. Mortality from beetle epidemics often creates large amounts of jackstrawed fuel, which ignites easily from lightning and other sources and hampers fire control efforts.

Chinook winds following extremely cold weather occasionally cause red belt injury, particularly in Canada and Montana. Defoliation of trees is common and mortality can occur over large areas. Heavy snow can break or bend trees, particularly in dense stands with narrow crowns and intense root competition. Thinning can contribute to snow breakage, particularly if previously dense stands are opened suddenly.

Animals can cause considerable damage in thinned stands in some areas. Porcupines were attracted to thinned and fertilized stands in Montana. Pocket gophers often cover small seedlings under their entrance mounds and "winter-casts." They also feed on or clip both roots and tops. Gopher populations often explode as vegetation increases in open areas.

Special Uses

Lodgepole pine is not only an important timber species but is also a major tree cover in many scenic and recreational areas and on critical watersheds. It provides many acres of wildlife habitat and is associated with many grazing allotments throughout its range. It is important to local communities throughout the West.

Lodgepole pine is used for framing, paneling, posts, corral poles, utility poles, railroad ties, and pulpwood. As new developments such as structural particleboard become practical, the rapid juvenile growth of the species will be an advantage where gross cubic volume becomes important. Even now, with properly designed machinery, it is economically harvested, and this harvesting, properly done, can enhance watershed, forage, wildlife habitat, and scenic and recreational values.

Genetics

This summary is based on a recent review of the literature on the genetics of lodgepole pine *(20)*. The ability of some strains of lodgepole pine to grow well on poor sites and in cold climates has interested European foresters for many years. Much of what is known about the genetic diversity of the species has been learned from provenance tests, mostly in northwestern Europe. These tests have established that much of the variation observed in natural stands of lodgepole pine has a genetic basis.

Population Differences

Lodgepole pine has evolved several highly differentiated but inter-fertile geographic races that differ morphologically and ecologically:

Rocky Mountain-Intermountain Race (var. *latifolia*)—Within the extensive range of this race, the trees are relatively tall, the bark is usually thin, and the needles are long and moderately wide. Cones are produced regularly from an early age and often are serotinous. The trees are intolerant and stands are considered seral in most forest communities. The persistent cones are hard and heavy, with protuberant scales. The cones may be reflexed, projecting, or semierect on the branch. Semierect cones, common only in this race of lodgepole pine, also are common in the closely related jack pine (*Pinus* ***banksiana***), which overlaps and hybridizes with lodgepole pine in parts of western Canada. Semierect cones are present in some lodgepole stands remote from the region of overlap and may indicate earlier contacts between the two species during the Ice Age. Seeds are small, highly dispersable, retain their viability for many years in serotinous cones, and germinate rapidly without pretreatment. Seedlings have few cotyledons and juvenile growth is rapid. Local variations include a high frequency of three-needled fascicles in the Yukon, a possible Ice Age refugium of lodgepole pine, and (in stands in southern interior British Columbia and adjacent United States) the variable occurrence of thick bark, repeated stem forking, unusually fast juvenile growth, a low incidence of serotinous cones, or a high incidence of semierect cones.

Sierra-Cascade *Race* (var. *murrayana*)—In its typical form (in the Sierra Nevada and other California mountains), this is the most distinctive race of lodgepole pine, but it inter-grades with var. ***latifolia*** in the central and northern Cascades. It is inherently slow-growing in height, but diameter growth is more sustained than in other races. The trees have thin bark and reach much greater diameter-and probably greater ages-than elsewhere in the range of lodgepole pine. This race appears to have a stable ecological role and distribution that is not closely related to fire. The relatively short needles are the widest in the species. Seeds are by far the largest, and seedlings have more cotyledons than those of other races. Cones are lightweight and projecting or reflexed, with flattish scales. The cones open promptly at maturity and do not persist on the tree for long periods.

Coastal Race (var. ***contorta)*-The** thick-barked trees are relatively small, short-lived, and inherently branchy. Now mostly confined to marginal sites (muskegs, dunes, serpentine soils, rocky sites), this race pioneered forest succession in the Pacific Coast region at the end of the Ice Age. Needles are short, rather narrow, and have more stomata per unit area than the leaves of inland races. Flowering is abundant, and female strobili tend to mature earlier than the male. The cones are reflexed and persistent. Cones usually open not long after they mature, but serotiny is increasingly common toward the interior. Seeds are small to medium-sized, and germination is slower than that of the interior races. Early height growth nearly always is faster than that of inland populations at the same latitude. Local variations include a chemically distinctive northern muskeg ecotype extending south to western Washington.

Mendocino White Plains Race (var. *bolanderi*)—This race, restricted to a narrow strip of highly acid podsol soils paralleling the coast of Mendocino County, CA, is probably an edaphic ecotype derived from the contiguous coastal race. Trees are dwarfed in nature but not when planted on other sites. Female strobili mature earlier than the males. Trees are extremely heavy pollen producers, and compared to coastal trees they produce high ratios of male to female strobili. The needles are short,' narrow, and lacking in resin canals. Cones are reflexed, heavy, knobby, and often serotinous.

Del Norte Race (not named)—This poorly known race has a limited distribution on serpentine and other ultramafic soils in the low coastal mountains of Del Norte County, northwestern California. Cones are heavier and more reflexed than those of any other race and often are serotinous. This group is geographically isolated from the others, but the composition of its cortex resin suggests that it may be an offshoot of the coastal race.

Hybrids

No significant genetic barriers have been encountered in artificial crosses between geographical races of lodgepole pine. The species has been successfully crossed with jack pine and Virginia pine *(Pinus virginiana).* Crossability with jack pine is moderately high, and natural hybrids are common where their ranges overlap. Lodgepole x jack pine hybrids are fertile, but pollen abortion sometimes is high. Sierra Nevada lodgepole x jack pine hybrids are poorly adapted to jack pine's range. Artificial lodgepole x Virginia pine hybrids are difficult to produce, and most are chlorotic and dwarfed.

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