Pinus monticola Dougl. ex D. Don Western White Pine

Pinaceae Pine family

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Western white pine *(Pinus monticola),* also called mountain white pine, Idaho white pine, or silver pine, is an important timber tree. Its lightweight, nonresinous, straight-grained wood exhibits dimensional stability that makes it particularly valuable for sash, frames, and doors, interior paneling, building construction, match wood, and toothpicks. Western white pine grows rapidly to a large size; one of the largest standing trees measures 200 cm (78.6 in) in d.b.h. and 72.8 m (239 ft) tall in the mountains near Medford, OR.

Habitat

Native Range

Western white pine (fig. 1) grows along the west coast from latitude 35" 51' N. in southern Tulare County, CA, to latitude 51" 30' N. near Butte Inlet in southern British Columbia. Along the west coast, the species grows on Vancouver Island, in adjacent British Columbia, southward through Washington and Oregon, and in the Cascade Mountains (7). It is also found in the Siskiyou Mountains of southern Oregon and northern California, in the Sierra Nevada of California, and near Lake Tahoe, NV

In the interior, western white pine grows from latitude 52" 30' N. near Quesnel Lake, BC, southward through the Selkirk Mountains of eastern Washington and northern Idaho, and into the Bitterroot Mountains in western Montana. Its southernmost interior limit is in the Blue Mountains of northeastern Oregon (latitude 44" 14' N.). Isolated populations are found as far east as Glacier National Park, MT. It attains its greatest size and reaches its best stand and commercial development in the Inland Empire, which includes northern Idaho and adjacent sections of Montana, Washington, and British Columbia (28).

Climate

The portions of Vancouver Island, the Cascade Mountains, and the Siskiyou Mountains that are within the range of western white pine have cool maritime climates, with wet winters and dry summers. Precipitation varies considerably throughout

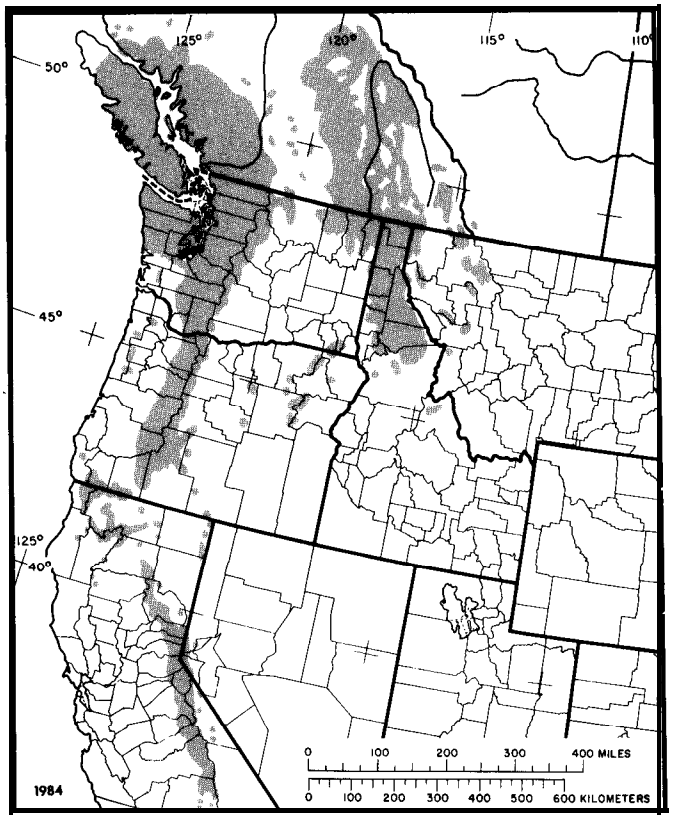

Figure *l-The native range of western white pine.*

the region depending on elevation and exposure. Variation with latitude from northern Oregon through British Columbia is small, however (25). In general, precipitation on Vancouver Island and in the Cascade Mountains averages from 1500 to 2010 mm (59 to 79 in) per year while precipitation in the Siskiyou Mountains averages from 510 to 1520 mm (20 to 60 in) per year. The winter snow line varies with latitude and averages 600 m (2,000 ft) elevation, with dense heavy snowpacks common. Occasionally, vegetation and the forest floor are coated with a layer of ice from glaze storms. Temperatures of the Vancouver Island-Cascade Mountain portions of the western white pine range vary from a low of -18" C (0° F) to a maximum of 38" C (100° F). January is usually the coldest month in the region and July and August are the warmest. Frost-free days range from 200 days in coastal areas to 90 days in the Cascades.

In the Sierra Nevada where western white pine grows, the mean annual precipitation varies from

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760 to 1500 mm (30 to 59 in). Except for occasional summer thunderstorms, this total falls entirely as snow. The temperature of the area averages between -9" C (15" F) in February to 27" C (80° F) in July and August, with maximum temperature near 37" C (98° F) and a minimum temperature near -32" C (-26" F). In the Sierra Nevada, frost-free days of the western white pine range average between 90 and 180 days, but killing frosts can occur at any time.

The climate of the Inland Empire in the western white pine range is influenced by the Pacific Ocean some 400 km (248 mi) to the west. The summers are dry, the majority of the precipitation occurring during the fall and winter. Precipitation averages between 710 and 1520 mm (28 and 60 in), distributed seasonally as follows: 35 percent, winter; 24 percent, spring; 14 percent, summer; and 27 percent, fall (28). Snowfall averages 262 cm (103 in) but ranges from 122 cm (48 in) to 620 cm (244 in). Annual temperatures in the inland range of western white pine average from 4" to 10" C (40" to 50" F) with extremes of -40" and 42" C (-40" and 107" F). The growing season for western white pine in the Inland Empire is irregular depending on location and year but averages between 60 and 160 days (28).

The boundaries of the western white pine range in the Inland Empire are limited at the lower elevations by deficient moisture and at the upper elevations by cold temperatures. The southern boundary of the type in the Inland Empire is not fixed by insufficient precipitation alone, but by a balance of precipitation and evaporation (28).

Soils and Topography

A wide variety of soils support western white pine along the west coast of Washington and Oregon (II). The species reaches its best development on deep, porous soils but is most common on poor, sandy soils. The soils are derived from a wide variety of parent material but are generally moderately deep with medium acidity. Organic matter content is usually moderate, and textures range from sandy loam to clay loam. The majority of the soils in which western white pine grows have been classified as Spodosols. In the Puget Sound area, extensive stands of western white pine grow on soils originating from glacial drift.

Soils of the Inland Empire western white pine region are very diverse. Soil depths range from 25 cm (10 in) to over 230 cm (90 in) and have developed from decomposed granite, schist, quartzite, argillite, sandstone, and shale. Most often, the more rocky soils have developed from basalt, glacial deposits, alluvial deposits, or lacustrine deposits (28). In the Inland Empire, the upper soil layers that support western white pine are composed of loess or loessial-like material. As along the west coast, most of the soils that support western white pine in the Inland Empire are Spodosols.

The pH of soils supporting western white pine in the Inland Empire ranges from 4.5 to 6.8 with a mean near 5.4 (6). The cation exchange capacity of these soils ranges from 20.5 to 28.5 meq/100 g with a mean of 25.1 meq/100 g. Mean concentrations of potassium, calcium, and magnesium are 0.5, 10.5, and 0.8 meq/100 g, respectively. Nitrogen content of soils of the Inland Empire western white pine range varies from 0.14 percent to 0.48 percent with a mean of 0.25 percent.

Western white pine grows at a wide range of elevations. In interior British Columbia, it grows at elevations up to 450 m (1,480 ft), while on Vancouver Island it is normally found at elevations up to 1200 m (3,940 ft) and has been found at elevations over 1500 m (4,920 ft). In western Washington, western white pine is found growing at sea level (near Puget Sound) and up to 910 m (2,980 ft) in elevation in the Cascades. Farther south in the western Cascades, it grows between elevations of 600 and 1850 m (1,970 and 6,070 ft). On the eastern side of the Cascades, it is found growing between elevations of 350 and 1450 m (1,150 and 4,760 ft). In the Olympic Mountains, the species ranges from sea level to an elevation of 550 m (1,800 ft). In the Siskiyou Mountains, western white pine is found at elevations from 1830 to 2140 m (6,000 to 7,020 ft). Farther south in the Sierra Nevada, it usually grows at elevations from 1830 to 2300 m (6,000 to 7,550 ft) with occasional trees at elevations of 3350 m (10,990 ft).

In northern Idaho and contiguous parts of Washington, Montana, and British Columbia, western white pine usually grows between 500 m (1,640 ft) and 1800 m (5,910 ft). Here the topography is usually steep and broken with V-shaped and round-bottomed valleys. Western white pine can grow on a variety of slopes and aspects but is most common along moist creek bottoms, lower benches, and northerly slopes. The most extensive bodies of western white pine are found in the wide river bottoms, less steep lower slopes, and in the more gently rolling country of the Priest, Coeur d'Alene, St. Joe, and Clearwater River basins (28).

Associated Forest Cover

Western white pine is represented in 18 forest cover types of western North America and Canada. It is the key species in Western White Pine (Society of American Foresters Type 215) (9). In this type,

western white pine constitutes a plurality of stocking, but many other species such as grand fir **(*Abies grandis*),** subalpine fir **(*A. Zasiocarpa*),** California red fir **(*A. magnifica*),** lodgepole pine *(Pinus* **contorta),** ponderosa pine *(P.* **ponderosa),** western larch *(Larix* **occidentalis),** western redcedar **(*Thuja plicata*),** western hemlock **(*Tsuga heterophylla*),** Douglas-fir **(*Pseudotsuga menziesii*),** Engelmann spruce **(*Picea engelmannii*),** and mountain hemlock **(*Tsuga mertensiana*)** may also be present. Most often the western white pine component of Type 215 is even aged with an understory containing multiaged trees of the more shade-tolerant species such as western hemlock and western redcedar. Occasionally, light overstory components of more intolerant species, such as western larch and lodgepole pine, may also be present.

In the 17 other cover types, western white pine is a common component, along with many other species, including Pacific silver fir **(*Abies amabilis*)**, white fir **(*A. concolor*),** noble fir **(*A. procera*),** Port-Orford-cedar **(*Chamaecyparis lawsoniana*),** incense-cedar **(*Libocedrus decurrens*),** Sitka spruce **(*Picea sitchensis*),** whitebark pine *(Pinus* **albicaulis),** foxtail pine *(P.* **balfouriana),** limber pine *(P. flexilis)*, sugar pine *(P.* **lambertiana),** Jeffrey pine *(P.* **jeffreyi),** Pacific **yew** *(Taxus* **brevifolia),** Pacific madrone **(*Arbutus menziesii*),** bigleaf maple *(Acer* **macrophyllum),** red alder **(*Alnus rubra*),** quaking aspen **(*Populus tremuloides*),** and paper birch **(*Betula papyrifera*).** These cover types are as follows:

205	Mountain Hemlock
206	Engelmann Spruce-Subalpine Fir
207	Red Fir
210	Interior Douglas-Fir
212	Western Larch
213	Grand Fir
218	Lodgepole Pine
224	Western Hemlock
226	Coastal True Fir-Hemlock
227	Western Redcedar-Western Hemlock
228	Western Redcedar
229	Pacific Douglas-Fir
230	Douglas-Fir-Western Hemlock
231	Port-Orford-Cedar
237	Interior Ponderosa Pine
247	Jeffrey Pine
256	California Mixed Subalpine

In northern Idaho and eastern Washington, the most important habitat types in which western white pine grows are ***Tsuga heterophylla* / *Clintonia* uniflora, *Thuja plicata* / *Clintonia* uniflora,** and ***Abies grandis* / *Clintonia uniflora*** (6). Western white pine is a major seral species in the ***Tsuga heterophylla* / *Clintonia uniflora*** habitat type in western Montana and is also present in several others (21). Western white pine is present in several vegetative associations, communities, and zones in western Oregon and Washington but is a major constituent only of the ***Tsuga heterophylla*** zone in the Puget Sound area of Washington *(5,11,14)*.

Most of the habitat types, associations, and communities in Washington, Oregon, and the Inland Empire where western white pine grows are strikingly rich in other woody and herbaceous flora *(5,6,11,14,21)*. In contrast, in the Sierra Nevada the vegetation associated with western white pine is characteristically sparse. Shrubs associated with western white pine include huckleberry *(Vaccinium* spp.), willow *(Salix* spp.), honeysuckle **(*Lonicera*** spp.), wintergreen **(*Gaultheria*** spp.), azalea **(*Rhododendron*** spp.), prickly currant **(*Ribes lacustre*),** sticky currant **(*R. viscosissimum*),** Rocky Mountain maple *(Acer glabrum)*, Greenes mountain-ash *(Sorbus* **scopulina),** princes-pine **(*Chimaphila umbellata*),** snowberry **(*Symphoricarpos albus*)**, whipplea *(Whipplea* **modesta),** ocean-spray *(Holodiscus* **discolor),** serviceberry **(*Amelanchier alnifolia*),** ninebark **(*Physocarpus malvaceus*),** rustyleaf menziesia **(*Menziesia ferruginea*),** spirea **(*Spiraea betulifolia*),** pachistima **(*Pachistima myrsinites*),** and twinflower **(*Linnaea borealis*).** Graminoids frequently associated with western white pine include sedge **(*Carex*** spp.), woodrush **(*Luzula*** spp.), Columbia brome **(*Bromus vulgaris*),** pine grass **(*Calamagrostis rubescens*),** and nodding trisetum **(*Trisetum cernuum*).** Forbs found growing with western white pine include false solomons-seal *(Smilacina* spp.), twistedstalk **(*Streptopus*** spp.), coolwort *(Tiarella* spp.), violet **(*Viola*** spp.), wild ginger **(*Asarum caudatum*),** queenscup *(Clintonia* **uniflora),** western goldthread **(*Coptis occidentalis*),** bunchberry *(Cornus canadensis)*, sweetscented bedstraw **(*Galium triflorum*)**, white trillium *(Trillium* **ovatum),** and Brewers lupine **(*Lupinus breweri*).**

Life History

Reproduction and Early Growth

Flowering and Fruiting-Western white pine is monoecious. Three complete growing seasons are required for seed to mature. Strobilus buds are differentiated during July and August of the growing season before their appearance in June the following spring (28). In northern Idaho, the oval staminate strobili are about 10 cm (4 in) long, borne in clusters of 15 to 25 on branches of the middle crown, and are distinguishable about June 1 (28); whereas, in the Sierra Nevada of California, the staminate strobili appear near the first of July Pollen dissemination in

the Inland Empire usually begins during the last week of June and can continue to the middle of July but usually averages 8.5 days.

The greenish-yellow to bright pink ovulate strobili are borne on stalks at tips of the upper branches, and in the Inland Empire become visible about mid-June of the growing season following initiation of the primordia. The erect conelets are from 1.5 cm to 4.0 cm (0.6 to 1.6 in) long at time of pollen dissemination, and they grow to 2.5 cm to 5.0 cm (1.0 to 2.0 in) long by the end of the first growing season (28).

Time of anthesis may vary over a period of 20 days and is rigidly controlled by temperatures during the weeks immediately preceding anthesis. Anthesis is delayed about 5 days per 300 m (980 ft) increase in elevation, and about 6 days per degree Fahrenheit below normal temperatures for May and June (28). In the Inland Empire, good strobilus crops in western white pine occur every 3 to 4 years, the major cycle being 4 years. Warm, dry "stress" periods, during the early summer of the 2 years before strobilus emergence, favor strobilus production. In contrast, stresses in the late summer of the year prior to emergence or during the period of emergence depress strobilus production. Within individual trees and within localities, maxima pollen shedding and ovulate anthesis practically coincide. No phenological barriers to either selfing or crossing appear to exist, but most western white pine show a moderate to strong discrimination against self-pollination. Western white pine seedlings that result from self-pollination are typically slower growing than seedlings resulting from cross-pollination (3).

Western white pine is predominantly female from first strobilus production at age 7 through age 20 (3). Cultural treatments, such as watering, fertilizing, and cultivating, usually have little effect on this characteristic, but thinning and fertilizing 40-year-old western white pine with nitrogen, phosphorus, and potassium has increased it *(1)*.

Seed Production and Dissemination-Cones of western white pine (fig. 2) become ripe during August and September of the second year after the strobilus buds are initiated. Color of ripe cones ranges from yellowish or beige-brown through reddish brown and dark brown *(17)*. Western white pine cones are about 20 cm to 25 cm (7.9 to 9.8 in) long; cones as short as 5 cm (2.0 in) and as long as 36 cm (14.2 in) have been reported. Over 18 years, 380 western white pine from 25 to 70 years old in the Inland Empire produced from 2 seeds to more than 300 seeds per cone, with a mean production of 226 *(2)*.

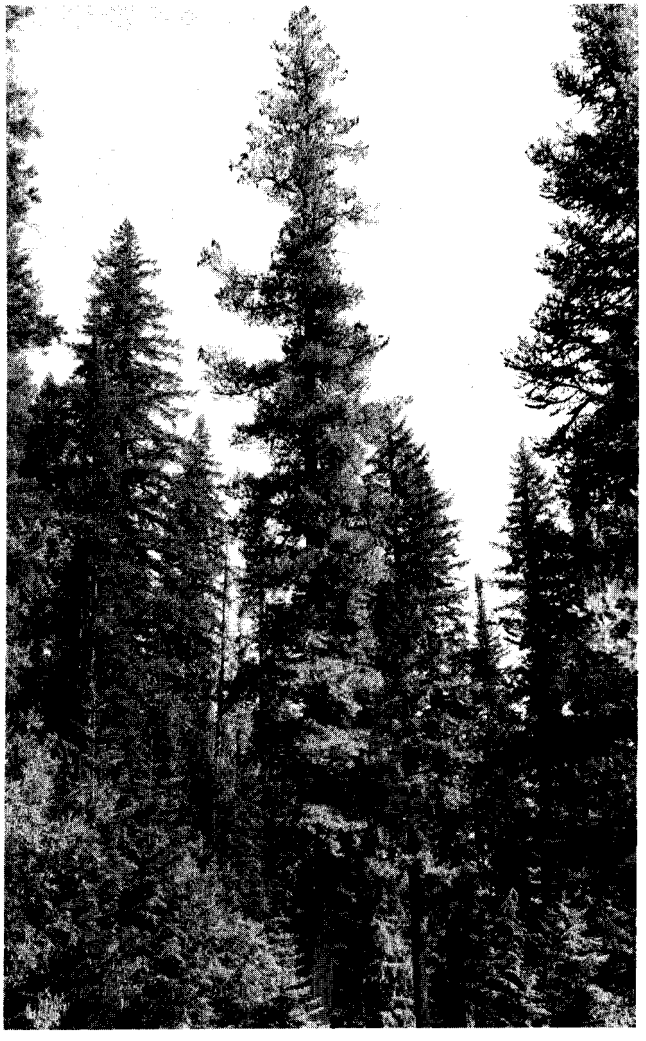

Figure 2—*Western white pine with a good cone crop in the Wenatchee National Forest,* WA.

Western white pines can begin cone production as early as age 7 and become more prolific with age. Not until trees are about age 70 does cone production become both frequent and abundant. It continues to increase with age until trees are about 50 cm (19.7 in) in diameter. After that, seed production depends on individual tree vigor and character of crown or possibly on heritable capacity to set and bear cones *(28)*.

Seed yields for western white pine range from 30,900 to 70,500/kg (14,000 to 32,000/lb) with an average of 59,000/kg (27,000/lb) *(17)*. In the Inland Empire, seed production varies from 41,000 to 457,000/ha (16,600 to 185,000/acre), with average annual seed yields for a 75-year-old stand and an over-

mature stand of 8,600/ha (3,500/acre) and 99,000/ha (40,100/acre), respectively.

Several cone and seed insects and rodents can cause partial to almost complete failures of cone crops in otherwise poor to fair crop years. The cone beetles, ***Conophthorus monticolae*** and ***C. lambertianae,*** and cone moths, ***Dioryctria abietivorella*** and ***Eucosma rescissoriana,*** cause serious seed losses some years ***(12).*** Western white pine seeds are also a favorite food of red squirrels and the deer mouse.

In the Inland Empire, seed dissemination of western white pine begins in early fall; 15 percent of the current crop reaches the ground before September 1, about 85 percent by the end of October, and 15 percent during the late fall and winter (28). Seeds are usually disseminated by wind, but squirrels, mice, and various birds contribute to seed dissemination. Most seeds fall within 120 m (390 ft) of the parent tree, but they have been known to travel over 800 m (2,620 ft) from it (28).

Western white pine seeds remain viable after overwinter storage in duff on the forest floor. Seeds have shown 40 percent viability after one winter's storage, and 25 percent viability after two winters' storage; and less than 1 percent after 3 and 4 years' storage. Western white pine seeds properly stored under artificial conditions of seed moisture content of 5 to 10 percent and temperatures of -18" C (0° F) to -15" C (5" F) remain viable for 20 years ***(17).***

Figure 3—*A western white pine showing rate of growth and branching habit.*

Seedling Development-Western white pine seed requires 30 to 120 days of cold, moist conditions before germination commences ***(17).*** Seed dormancy appears to be controlled by the seed coat, papery seed membrane, and physiological elements of the embryo, gametophyte, or both *(16).* There is a strong genetic component to seed germination with high family heritability. Both fresh seed and stored seed require cold stratification temperatures of 1" C (33" F) to 5° C (41" F) to break dormancy. Germination is epigeal. The seeds of western white pine usually germinate in the spring in soil that was wet to field capacity by melting snow. In the Inland Empire, seed germination at lower elevations begins in late April. At higher elevations and on protected sites, germination may be delayed until early June. Germination can continue on exposed sites until July 1 and on protected sites until August 15. Under full sun, germination begins much earlier and ends much earlier than in partial or fully shaded conditions. Soil temperatures probably control the beginning of germination, and drying out of the topsoil or duff probably stops germination (28). Light appears to have little importance in natural germination of western white pine seed. Mineral surfaces are better germination media than duff even though duff may contain many stored seeds.

During the first growing season, a high percentage of seedlings die, principally because of diseases, but insects, rodents, and birds cause serious seedling losses. ***Fusarium,*** cause of a damping-off disease, and ***Neopeckia coulteri,*** a snow mold, can cause extensive seedling mortality during the first year ***(15).*** Seedlings up to 5 years old are often killed by ***Rhizina undulata,*** a root rot, in patches 0.5 m (1.6 ft) to 1.5 m (5 ft) in diameter. Seedling mortality late in the first growing season is due primarily to temperature and drought. High surface temperature is the most important cause of mortality on exposed sites, and drought is a factor on heavily shaded areas where root penetration is slow and unable to keep pace with receding soil moisture. For the most part, western white pine seedlings have low drought tolerance (20).

All factors considered, western white pine seedling establishment is favored by partial shade on severe to moderately severe sites. On the more sheltered

sites, such as north slopes, little or no shade is best for seedling establishment (28). Once established, western white pine grows best in full sunlight on all sites.

Early root and shoot growth of western white pine seedlings usually is not rapid. The first summer, the primary root grows about 15 cm (6 in) to 30 cm (12 in) in open situations, between 13 cm (5 in) and 23 cm (9 in) under partial shade, and only 5 cm (2 in) to 8 cm (3 in) under full shade. Seedlings planted in soils rich in nutrients, high in organic matter, and with low bulk densities can have first-year root elongation up to 50 cm (20 in). Seedlings usually average between 3 cm (1 in) and 5 cm (2 in) in height by the end of the first growing season. In the Inland Empire, open-grown western white pine seedlings require about 8 years to reach a height of 1.4 m (4.5 ft) (28). Similarly, 20-year-old western white pine (fig. 3) grow about 81 cm (32 in) to 99 cm (39 in) per year on good sites and about 23 cm (9 in) to 46 cm (18 in) on poor sites.

Both height growth and diameter growth of western white pine in the Inland Empire usually begin about the first week of May but may begin as early as April 5 and as late as June 25 depending on elevation, latitude, and aspect (24). Also, in the Inland Empire, leaf buds usually open near May 21 but may open as early as March 27 and as late as June 21. Here, shoot growth usually ends by August 11; reported dates for shoot growth cessation are as early as June 9 and as late as October 21. Winter buds can be formed as early as June 14 and as late as September 30 but are usually formed by August 13. In the Inland Empire, diameter growth normally ceases by the end of August. Old needles usually turn straw yellow between the middle of August and the first week of September and drop soon thereafter. Total needle fall of western white pine is moderate when compared to associated species *(20)*, with needle retention of 3 to 4 years.

Table l-Average size and volume of dominant and codominant western white pine growing in fully stocked stands in the Inland Empire

Item	Site index at base age 50 years		
	12.2 m or 40 ft	18.3 m or 60 ft	24.4 m or 80 ft
Dominants and codominants			
D.b.h., cm	29.5	41.9	56.9
Height, m	26.8	40.2	53.3
Volume, m^3	0.8	2.2	4.9
Cubic volume,[1] m^3/ha	699	976	1,267
Basal area, m^2/ha	70	72	74
Dominants and codominants			
D.b.h., in	11.6	16.5	22.4
Height, ft	88.0	132.0	175.0
Volume, ft^3	27.5	77.0	171.6
Cubic volume, ft^3/acre	9,980	13,950	18,100
Basal area,[1] ft^2/acre	306	314	322

[1] In trees 0.2 cm (0.6 in) and larger in d.b.h.

Vegetative Reproduction-Western white pine does not naturally reproduce by sprouting or layering. Cuttings from trees more than 4 to 5 years old are difficult to root *(3)*, although cuttings from 3-year-old seedlings have been rooted with fair success using rooting hormones. Needle bundles from 2-year-old seedlings have produced roots and some have produced shoots successfully.

Western white pine is relatively easy to propagate by grafting at all ages (3). Several types of grafts have been used; early spring grafting before flushing has been most successful. Also, scions, taken from a variety of places in the tree crown, graft with equal success. Grafting conducted under greenhouse conditions is more successful than field grafting. Interspecies grafting on other five-needle rootstocks, such as eastern white pine *(Pinus strobus)*, sugar pine *(P. lambertiana)*, and blue pine *(P. griffithii)*, has been generally successful. Grafting of western white pine on species other than the five-needle white pines has not been accomplished.

Table 2—Mean annual increment of fully stocked stands of western white pine in the Inland Empire

Age	Site index at base age 50 years		
	12.2 m or 40 ft	18.3 m or 60 ft	24.4 m or 80 ft
yr		*m^3/ha*[1]	
20	0.84	1.40	1.89
40	3.29	4.62	5.95
60	4.90	6.86	8.89
80	5.67	7.84	10.29
100	5.88	8.26	10.78
120	5.81	8.12	10.57
140	5.53	7.70	9.94
yr		*fbm/acre*[1]	
20	12	20	27
40	47	66	85
60	70	98	127
80	81	112	147
100	a4	118	154
120	83	116	151
140	79	110	142

[1] In trees 0.2 cm (0.6 in) and larger in d.b.h

Sapling and Pole Stages to Maturity

Growth and Yield-Western white pine trees most often have clean boles with minimum taper and narrow crowns. In the absence of western white pine blister rust ***(Cronartium ribicola)***, the species is long lived; trees are commonly 300 to 400 years old and rarely, up to 500 years old. Overmature trees are often more than 180 cm (71 in) in d.b.h. and 60 m (197 ft) tall.

Tables 1 and 2 show the sizes, net volume, basal areas, and growth rates for western white pine in fully stocked stands in the Inland Empire. Although blister rust modifies stand development, in the absence of the rust, stands develop as shown.

Rooting Habit-The extent of western white pine's root system and the density of its rootlets depend on external conditions *(18)*. Approximately 65 percent of the total root system, exclusive of the central vertical system, occurs in the uppermost 30 cm (12 in) of soil. Mature western white pine systems can spread 8 m (26 ft) laterally from the root collar with verticals descending off the lateral system, as well as in a concentration beneath the root collar. The root systems are tolerant of dense soils and have moderate growth rates. Western white pine trees have approximately 75 percent of their absorbing surface in the upper 60 cm (24 in) of the soil *(28)*. Fine root development of western white pine is favored where vegetative competition is low and available moisture is high.

The fungi that have been reported to form mycorrhizae with western white pine are ***Suillus granulatus, S. subaureus, S. subluteus, Boletellus zelleri, Cenococcum graniforme, Gomphidius ochraceus, G. rutilus, Russula delica, R. xerampelina,*** and *Tricholoma flavovirens*.

Reaction to Competition-Western white pine is almost always a seral species. It is classed as intermediate in shade tolerance when compared to other northwestern tree species. The species attains a dominant position in the stand only following wildfires, even-aged silvicultural systems, or through cultural stand treatments favoring the species.

Western white pine can be regenerated using even-aged silvicultural systems. On favorable sites, clearcut, seed-tree, and shelterwood systems result in adequate and diverse natural regeneration within 5 to 10 years after the regeneration cut. If a natural blister rust-resistant seed source is not present on the site, planting can be used to regenerate the stands.

Western white pine seedlings are well suited for planting. Both bare-root and container-grown western white pine seedlings have excellent survival and growth when properly planted on appropriate sites. Bare-root stock has better survival with spring planting, but containerized stock appears to have excellent survival when planted during either season.

When natural regeneration and the clearcut system are used for establishing conifer mixtures that include western white pine, it is not uncommon to regenerate 11,000 trees per hectare (4,451/acre), of which 1,000/ha (405/acre) are western white pine (4). Similarly, seed-tree cuts can produce 12,000 trees per hectare (4,856/acre) of which 1,500/ha (607/acre) are western white pine. Shelter-wood systems produce more trees, but the proportion that are western white pine is less than for other systems. On southerly aspects, regardless of the cutting system, less regeneration occurs.

The individual tree selection system cannot be used to manage western white pine successfully because it tends to favor the more shade-tolerant species, such as western redcedar and western hemlock, but group selection may have limited application.

Where reproduction has become established under partial cuttings, the density of overstory and time until removal greatly affect development. Western white pine growth can be inhibited even by the shade of a light shelterwood. Sixteen-year-old western white pine growing under an overwood density of 6 m^2/ha (27 ft^2/acre) were 2.0 m (6.6 ft) tall compared to trees 0.5 m (1.6 ft) tall growing under an overwood density of 21 m^2/ha (91 ft^2/acre) (28).

The composition of a western white pine stand is determined during the first 30 years of the stand's life *(13)*. Lodgepole pine and western larch can grow one and one-half times as fast in height as western white pine during this period. Western larch can usually maintain its superiority in height growth through maturity, but lodgepole pine's growth superiority seldom lasts past age 50. Similarly, grand fir can equal western white pine height growth for the first 30 years and Douglas-fir is about equal in height growth. On northerly aspects and in shaded conditions, western hemlock height growth can equal that of western white pine *(8)*.

Dominant western white pine over age 30 responds to release, but not aggressively. In the Inland Empire, in 55- to 65-year-old stands, half of the basal area must be removed to gain lasting improvement *(10)*. The effectiveness of light to moderate thinnings in 55- to 65-year-old stands of western white pine is short-lived. Therefore, during the first 30 years,

species composition is relatively plastic and can be modified materially by changing the density of residual overwood and by weeding or thinning. Beyond age 30, treatments are less effective and must be drastic to be long lasting.

Damaging Agents-At one time or another, fire has left its mark on practically every part of the western white pine forest (28). Western white pine depends on fire or timber harvesting to remove competing conifers and allow it to become established as an early seral species. Its relatively thin bark and moderately flammable foliage make it intermediate in fire resistance among its conifer associates *(20)*. As a result of fire protection and the lack of major fires, plus blister rust infection, the proportion of western white pine regeneration (planted and natural) in northern Idaho, eastern Washington, and western Montana decreased from 44 percent in 1941 to 5 percent in 1979.

Western white pine when dormant is tolerant of cold and along with lodgepole pine is one of the more frost-tolerant northwestern species. Needle desiccation can occur when cold, drying winds cause excessive loss of moisture that cannot be replaced fast enough because of cold or frozen soil or tree trunks. Also, western white pine is more tolerant of heat than most of its more shade-tolerant associates.

The species is sensitive to both sulfur dioxide and fluoride smelter fumes, which cause the foliage to yellow and drop prematurely *(15,20)*. Depending on the site, western white pine is relatively windfirm, but considerable damage can occur from windthrow. Snow often causes breakage in young pole stands.

Western white pine is beset by many serious diseases *(15)*. By far the most prominent disease of western white pine is blister rust. In northern Idaho and contiguous parts of Montana and Washington, a combination of climate, abundant alternate host plants (species of *Ribes*), and susceptible pines contribute to heavy losses. But, through selection of naturally rust resistant trees for seed sources for natural regeneration and planting of rust resistant nursery stock, damage to western white pine stands from blister rust in the future should be minimal. Other stem diseases, such as dwarf mistletoe, *Arceuthobium laricis,* and *A. tsugense,* occur on western white pine; however, they are of little consequence.

In prolonged periods of drought, pole blight, a physiological disorder, can occur in stands of the 40- to 100-year class, causing yellow foliage and dead resinous areas on the trunk. Later the top dies and, in a few years, the tree. The disease does not appear to be caused by a primary pathogen but results from rootlet deterioration in certain soils restricting the uptake of water. The disease, a consequence of a drought from 1916 to 1940 *(19)*, caused serious mortality to western white pine from 1935 to 1960. At present, the disease is not a major cause of mortality in western white pine stands. In conjunction with pole blight studies, root lesions caused by *Leptographium* spp. were isolated; these could have a role in the decline caused by pole blight.

A needle blight, caused by *Lecanosticta* spp., often leads to shedding of foliage more than 1 year old. Another foliage disease that attacks mainly the upper and middle crown is needle cast caused by *Lophodermella arcuata.* Two other needle cast fungi, *Bifusella linearis* and *Lophodermium nitens*, attack isolated trees.

The foremost root disease of western white pine is *Armillaria* spp., causing fading foliage, growth reduction, root-collar exudation of resin, dead and rotten roots, and black rhizomorphs. *Heterobasidion annosum* and *Phellinus weiri* also cause some mortality of individuals and groups. The most important butt-rot fungi are *Phellinus pini, Heterobasidion annosum,* and *Phaeolus schweinitzii.* Many other fungi are capable of causing decay in injured or overmature trees, and rot often becomes excessive in trees over 120 years of age.

The bark beetles are the most important group of insects that attack western white pine. The mountain pine beetle *(Dendroctonus ponderosae)* kills groups of trees, primarily in mature forests. Trees weakened by blister rust are often attacked by the mountain pine beetle. Likewise, weakened trees are sometimes attacked by the red turpentine beetle *(Dendroctonus valens)*. Usually, this beetle is not aggressive and does not become epidemic, but through repeated attacks it can kill trees. More often, it just weakens them, leading to fatal attack by other bark beetles *(12)*.

Attack of western white pine by mountain pine beetle sometimes results in attack on the bole by emarginate ips *(Ips emarginatus)*. Likewise, the ips beetle *(Ips montanus)* attacks weakened western white pine, its principal host, in association with other bark beetles. The *Pityogenes fossifrons* beetle breeds principally in western white pine, but its attacks are seldom primary. The beetle is capable, however, of attacking western white pine reproduction. Many other bark beetles and insects attack western white pine, but, for the most part, they do not cause extensive damage.

Special Uses

Because western white pine wood is nonresinous, it is highly desired for the manufacture of moldings

and trim. Also, western white pine is used for pattern stock, in cabinet shops, and for home handicraft because of its softness and workability. The clear grades of lumber are used for patterns in the foundry industry, mainly because of the high degree of dimensional stability. Decorative plywood is manufactured by slicing, and a limited amount of rotary-cut veneer is manufactured for industrial use.

Western white pine grows in some of the finest western outdoor recreation areas and has considerable esthetic value. In addition, the long, distinctive cones are collected in considerable numbers for novelties or souvenirs.

Genetics

Population Differences

Western white pine is different in genetic variation from most other conifers that have been intensively studied *(26)*. Within northern Idaho, western white pine genetic variation is high, and most of this variation is among trees within a stand. Differences among stands and elevational zones occur, but the proportion of the variance attributable to these sources is usually smaller than that for trees within stands. Evidence indicates little geographic or ecologic differentiation of populations for western white pine. The adaptation of western white pine to different geographic, climatic, topographic, and edaphic conditions is governed more by phenotypic plasticity than by selective differentiation (22). Also, it appears that there is little difference among populations from coastal Washington and western British Columbia and northern Idaho populations (27). There appear to be genetic differences, however, between California populations and Idaho populations (23). Because of the small genetic variation detected in populations of western white pine in northern Idaho, seeds can be transferred without regard to elevation, latitude, longitude, or habitat type.

Races

Several single recessive genes are recognized in western white pine (3). Albino genes, chlorophyll deficient genes, a curly foliage gene, and a dwarfing gene have been found. Monoterpenes also appear to be under strong genetic control. Height growth gains of 4 to 12 percent are possible according to estimates from progeny testing and selections.

Work on inheritance of blister rust resistance in western white pine began in 1950. This early work indicated considerable heritability of blister rust resistance. Most foliar resistance is governed by genes reducing the frequency of secondary needle infections and causing slow fungus growth in secondary needles (3). In the stem, genetic resistance is governed primarily by genes controlling a fungicidal reaction and causing slow growth of the fungus. Other resistance mechanisms include lowered frequency of needle lesions, premature shedding of needles, and fungicidal reaction in the short shoot. Nursery and field tests of rust resistant seedlings after two cycles of selections indicate rust resistance of 66 and 88 percent, respectively.

Hybrids

Western white pine can be easily crossed with other five-needle white pines *(3)*. It hybridizes successfully with Balkan pine *(Pinus peuce)*, blue pine *(P. griffithii)*, eastern white pine *(P. strobus)*, Japanese white pine *(P. parviflora)*, southwestern white pine *(I? strobiformis)*, and limber pine (I? *flexilis)*. Hybridization with Swiss stone pine *(P. cembra)*, Korean pine *(P. koraiensis)*, and whitebark pine *(P. albicaulis)* has not been as successful.

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