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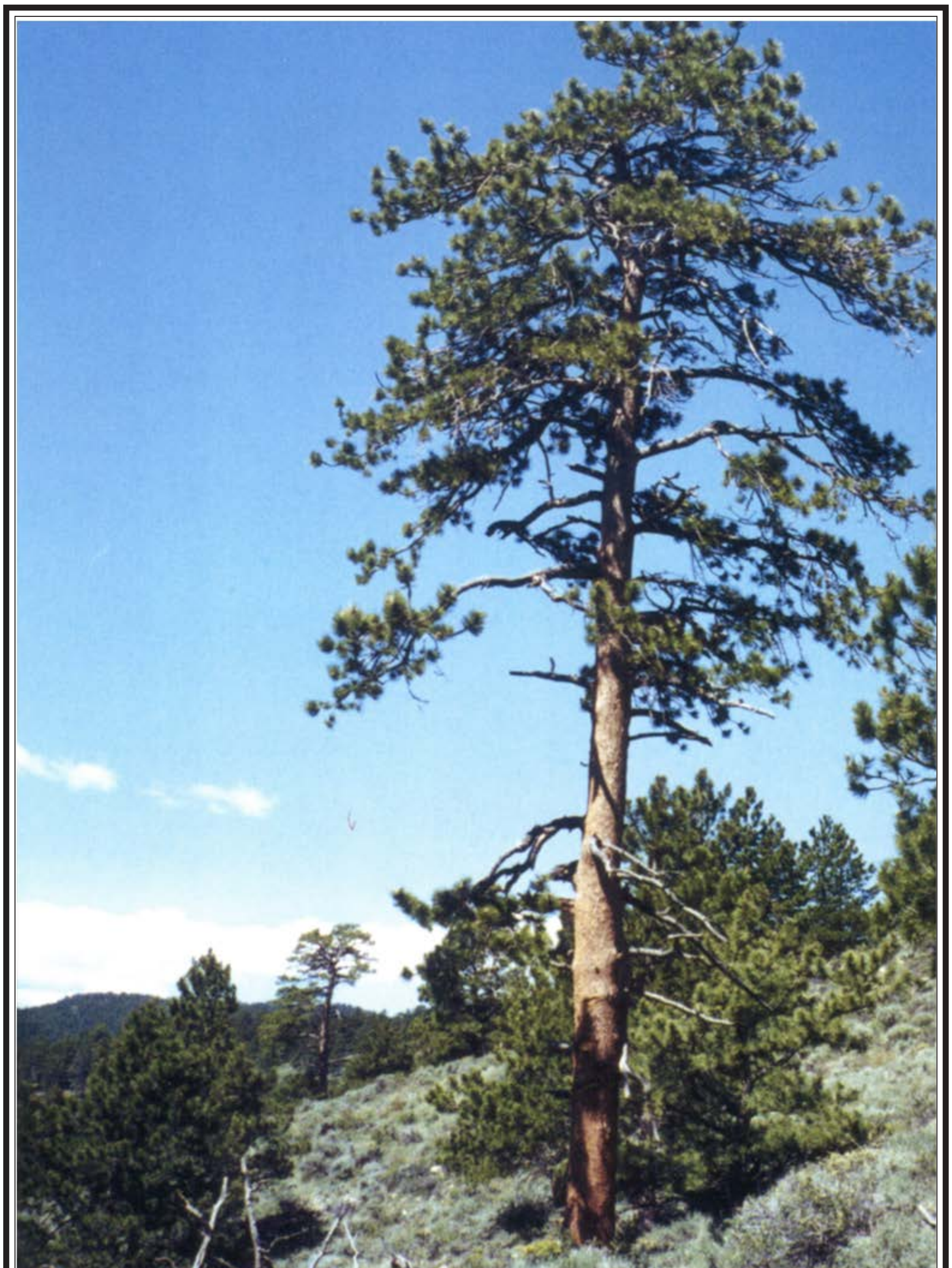
Identification and Ecology of Old Ponderosa Pine Trees in the Colorado Front Range

Laurie Stroh Huckaby, Merrill R. Kaufmann,
Paula J. Fornwalt, Jason M. Stoker, and Chuck Dennis



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Abstract

We describe the distinguishing physical characteristics of old ponderosa pine trees in the Front Range of Colorado, the processes that tend to preserve them, their past and present ecological significance, and their role in ecosystem restoration. Photographs illustrate identifying features of old ponderosa pines and show how to differentiate them from mature and young trees. The publication includes a photographic gallery of old ponderosa pine trees growing on poor, moderate, and good sites. We illustrate trees growing under various forest conditions and with different injuries and histories. We discuss dendrochronological methods of aging old trees and determining their fire history. The companion field guide includes a condensed description of ponderosa pine ecology, distinguishing characteristics of old ponderosa pines, and a photographic gallery illustrating their identifying features.

Keywords: Colorado Front Range, ponderosa pine, old growth, fire ecology

All illustrations and photos by Laurie S. Huckaby, unless otherwise noted.
The trees pictured from Cheesman Lake all burned in the Hayman fire in June 2002.

On the cover: An old ponderosa pine growing on an open, south-facing slope in the Arapaho-Roosevelt National Forest. It is more than 350 years old.

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Identification and Ecology of Old Ponderosa Pine Trees in the Colorado Front Range

Laurie Stroh Huckaby, Merrill R. Kaufmann, Paula J. Fornwalt,
Jason M. Stoker, and Chuck Dennis

Introduction

Old trees were historically a major component of montane forests in the Colorado Front Range. They were an integral part of the spatial and temporal heterogeneity inherent in the ecosystem. Now they are relatively scarce. Many were harvested during the settlement period in the late 19th and early 20th centuries. Century-old stumps of trees that were 400 to 500 years old when cut remain like ghosts amid stands of trees that have established during the last 100 years. Other old trees were destroyed in extensive human-caused fires during the same period. Surviving old trees are now stressed by competition from dense ingrowth of younger trees and are in danger from insect outbreaks and stand-replacing fires (Biondi 1996).

Land managers are now aware that modern forest structure differs from that of the pre-Euro-American settlement landscape, and that change in structure is precipitating a change in disturbance processes such as fire and insect outbreaks. Urban encroachment into the montane zone puts pressure on land managers to mitigate the danger of wildfire. The best way to handle this danger is to restore an ecologically sustainable landscape structure in the montane zone of the Front Range, one that resembles the patterns that existed before Euro-American settlement—patterns that encouraged the survival of old trees. Ecological restoration requires that we understand what the ecosystem was like in the past and what processes regulated and maintained it. Old trees preserve much of this information. The ecosystem records its own history in the form of tree age structure, species distribution, tree ring patterns, and fire scars. Historical accounts from the settlement period, survey records, old photographs, and early research provide a human perspective on the ecosystems of the past.

Restoration of sustainable ecological conditions can be accomplished by management activities that mimic historical structure and processes through mechanical thinning and prescribed burning, guided by scientific studies that reconstruct the structure, composition and processes of the historical landscape (Kaufmann and others 1994, Swetnam and others 1999). Restoration management based on historical ecology can protect and restore old-growth stands. However, unless the old trees are explicitly identified and protected, forest restoration activities could inadvertently damage or destroy many old trees. Old ponderosa pine trees are a legacy of the pre-Euro-American settlement past—a past not so distant in time and hopefully one that it is still possible to recapture. In addition to the historical information contained within their rings, old ponderosa pine trees are resistant to surface fire, provide food and habitat for wildlife, and are a source of genetic continuity for the forest. They are aesthetically attractive, and they are an intrinsic part of the beautiful, dynamic landscape that draws thousands of people to the Front Range every year.

This guide is written to help the reader identify old trees and understand their past and present role as components of forests in the lower montane zone. The Appendix gives additional detail on dendro-chronological methods used for determining ages of trees and fire history. The Glossary defines some of the more technical terminology used in this publication. The Bibliography gives references and further reading on ponderosa pine in the Front Range.

Ecological Zones of the Colorado Front Range

For this publication, we define the Front Range as the area south of the Wyoming border, east of the Continental Divide, west of the Great Plains, and north of Pikes Peak (near Colorado Springs; fig. 1a,b). Two related environmental factors drive ecological processes and the distribution of species in the Front Range: elevation and moisture availability. Going up in elevation has effects similar to going up in latitude.

Figure 1a. Overhead view of the Front Range showing the elevational gradient. Light green designates the plains at around 5000 ft (1540 m). The montane zone is shown as dark green. The subalpine zone is shown as a gradient of tan to redish brown; white areas are above 14,000 ft (4300 m). Sampling sites are denoted by yellow stars. (Map by J. Stoker.)

At higher elevations, the growing season becomes shorter, temperatures are cooler, and precipitation is greater. Fire and other disturbances become less frequent at higher elevations. Changes in vegetation composition along this gradient reflect these environmental changes (fig. 2).

The lowest elevations, where conditions are the warmest and driest, support shortgrass prairie that grades into shrublands in the foothills. Between 5000 and 6000 ft (1540 to 1845 m) elevation, these ecosystems gradually transition into open ponderosa pine forest. The ponderosa pine commonly becomes mixed with Douglas-fir and aspen at higher elevations. The aspect of a slope has an important effect on forest species composition at low and middle elevations. Slopes that face south, west, and southwest are exposed to intense sunlight and dry prevailing winds. These warm, dry slopes support stands dominated by ponderosa pine. Douglas-fir is more common on slopes with a northerly component. Above about 8000 ft (2460 m), these species are accompanied by lodgepole pine and limber pine, forming a transitional mixed conifer forest.

Above 9000 ft (2770 m), where there is usually a persistent winter snowpack, the ponderosa pine and Douglas-fir begin to drop out of the forest mix, and are replaced by lodgepole pine, patches of aspen and limber pine, subalpine fir and Engelmann spruce. Above 10,000 ft (3077 m), the lodgepole pine and aspen become scarcer, and forests are dominated by mixtures of spruce and fir up to treeline at around 11,500 ft. (3540 m). Bristlecone pine and limber pine occur in isolated stands near treeline. Above 11,500 ft (3540 m), the growing season is too short for trees, and the vegetation is composed of low-lying tundra plants similar to those found in the Arctic (Marr 1961).

Our focus is the montane zone, between 6000 and 9000 ft (1845 to 2770 m) elevation, below the level of persistent snowpack. Most of this elevational zone is dominated by forests of ponderosa pine mixed with Douglas-fir, and interspersed with shrubs, grasses and aspen.

1b. Three-dimensional view of the Front Range, looking west from the plains. The montane zone (6000 to 9000 ft [1846 to 2770 m] elevation) is shown in blue. Maps by J. Stoker.

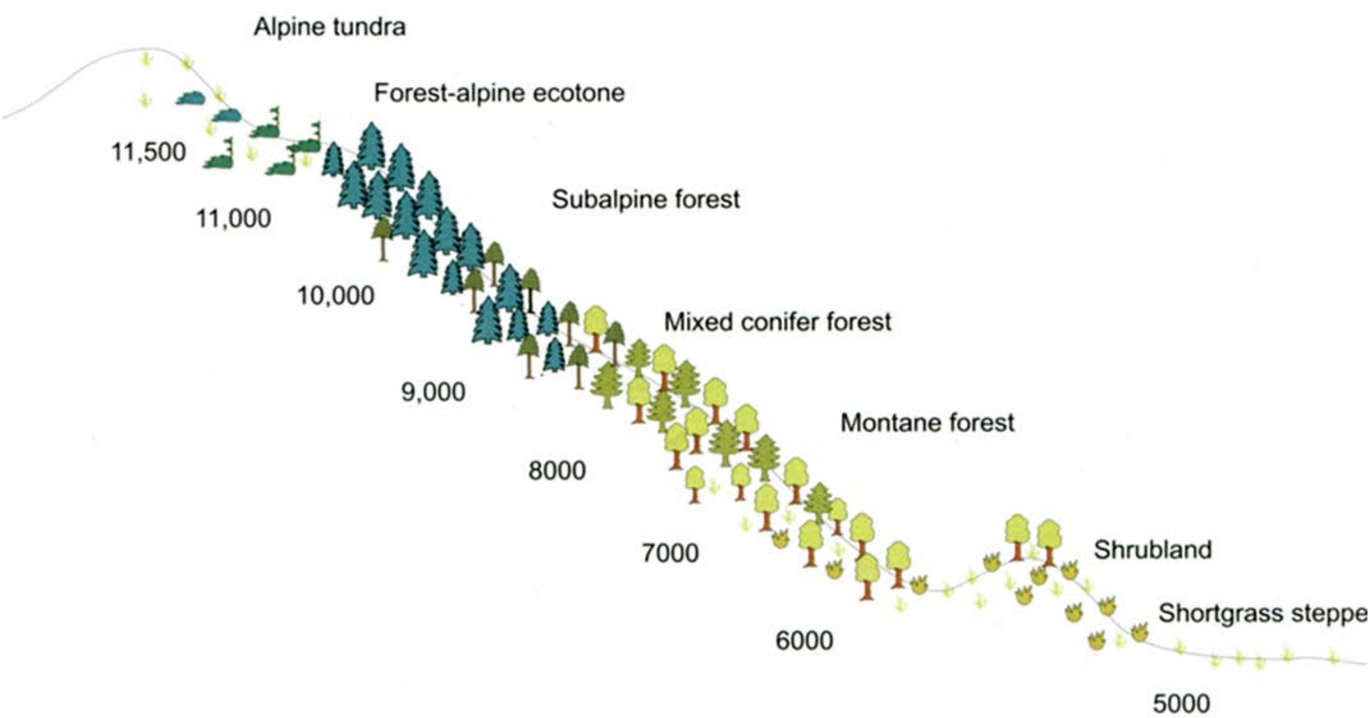


Figure 2. Changing vegetation communities along the elevational gradient of the Front Range, with approximate transitional elevations. Elevation is shown in feet.

Ponderosa Pine and the Montane Zone of the Front Range

Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) is one of the most widespread tree species in the western United States, ranging from northern Mexico into southern Canada, and from California to Nebraska. The Rocky Mountain variety is called *scopulorum*, to distinguish it from the variety found in the Pacific Northwest (Oliver and Ryker 1990) and from the subspecies *arizonica*, found in the Southwest near the Mexican border. In the Colorado Front Range (fig. 1b), ponderosa pine grows from the border of the prairie and the foothills, up to around 9000 ft (2770 m) elevation, depending on topography. It may be found as high as 10,000 ft (3077 m) on warm south-facing slopes. It is the dominant tree in the montane zone (6000 to 9000 ft; 1845 to 2770 m), where it often occurs with Douglas-fir (*Pseudotsuga menziesii*), especially on north-facing slopes (Peet 1991). Ponderosa pine can grow to be very large in other parts of the country, but rarely exceeds 100 ft (30 m) in height in the Front Range. It is tolerant of heat, drought, and fire (Oliver and Ryker 1990).

Ponderosa pine trees have needles in fascicles of two or three. Each tree produces both male and female reproductive structures; the female strobili mature into woody cones. Seeds are moderate in weight for tree seeds, and may be widely dispersed by wind. Ponderosa pine is susceptible to infestation by dwarf mistletoe (*Arceuthobium vaginatum*) and to attack by several insects, most notably the mountain pine beetle (*Dendroctonus ponderosae*) (Oliver and Ryker 1990). Ponderosa pine has long been an important tree for timber, though logging has not been a major industry in the Front Range in recent decades (Veblen and Lorenz 1991).

How Old Is Old?

Ponderosa pine is a long-lived species. The oldest known ponderosa pine trees are more than 700 years old (843 years, Central Utah; 780 years, Mt. Rosa, CO; 742 years, NW Arizona; OLDLIST database). The oldest known ponderosa pine trees in the Front Range are a little over 600 years old (Huckaby and others 2001; C. Woodhouse, J. Lukas, P. Brown, personal communication). However, ponderosa pines of that age are uncommon in the Front Range, whether because of past land use, the frequency of past natural disturbances, or the physiological limits of the species under local conditions. Trees between 300 and 500 years old are widespread though only locally frequent, while trees more than 200 years old are fairly common throughout the Front Range above about 6500 ft (2000 m) elevation.

The Concept of Old Growth and Ponderosa Pine

A single old tree does not make an old forest. Even a scattering of old trees does not necessarily define an old-growth stand. Old growth is a stand condition that develops over time. Old-growth stands have special characteristics that result from long years of growth in the absence of stand-replacing disturbance. Old-growth forest structure varies with forest type, climate, site characteristics, and disturbance regime, but it is distinguished from younger growth by large, physiologically old (for the species and local site conditions) trees as stand dominants, variation in tree size and spacing, accumulations of dead standing and fallen trees relative to younger stands, decay, multiple canopy layers, gaps, and understory patchiness (Kaufmann and others 1992).

A workable definition of old growth cannot be absolute in terms of some minimum age for the trees or some maximum number of canopy layers. The characteristics that constitute old growth vary with the forest type, local site productivity, and the natural disturbance regime. However, in all old-growth stands, competition among dominant trees is minor. Senescence and mortality are important processes, since the oldest cohorts are reaching their natural longevities as determined by site and environment. Physiologically, the old trees have reached their maximum heights for the site conditions and are no longer growing taller. Their crowns are declining, and their respiration equals or exceeds their productivity. They produce secondary metabolic products that may provide some resistance to insects and diseases. In an old stand, net productivity is low, even zero or negative, as newly produced biomass is offset on average by respiration and mortality of trees or tree parts (Kaufmann and others 1992).

Old growth is a temporary condition, as are all stages of forest development. Stand replacement will eventually occur, either by disturbance or as the stand eventually deteriorates so that it no longer functions as old growth, though this may take a very long time. There are multiple pathways by which stands can become old growth, even through disturbance. Species typically considered seral can become old growth if low intensity disturbance maintains their dominance, such as surface fire in ponderosa pine (Moir 1992).

Old growth forest does not necessarily have to be undisturbed, even by human activity, as long as the disturbance does not disrupt the stand structure and function.

How much old growth existed in pre-Euro-American settlement times? How much area did it cover? It is impossible to know for certain, but scientific studies reconstructing historical forests have suggested that old growth historically constituted a significant component of the landscape mosaic in ponderosa pine systems (Arno and others 1995, Fulé and others 1997, Huckaby and others 2001, Veblen and Lorenz 1991). The area occupied by old-growth stands was determined by historical disturbance regimes, and old growth may have been more common in some forest types than others. The proportion of old growth probably varied over time as well. In the current landscape, old-growth stands are usually small, fragmented, and isolated. Scattered individual old trees are more common now than are old-growth stands.

Old-Growth Ponderosa Pine Stands in the Front Range

Old-growth ponderosa pine in the montane zone of the Front Range differs from the usual perception of old-growth forest, which is most commonly derived from subalpine or Pacific Northwest models. Most people think of stands of big trees as old growth, but that is not necessarily true. Young trees on good sites may be very large, and some of the oldest trees exist on poor sites and are relatively small.

Some sources define old growth as any pre-Euro-American settlement forest (Morgan 2000), but we prefer a more physiologically based definition. Ponderosa pine trees begin to change their growth and appearance at around 200 years of age (Kaufmann 1996). Stand structure begins to change around that age, too. By the time the dominant trees are 300 to 400 years old, most stands have developed old-growth characteristics, including coarse woody debris, snags, a variety of tree ages and sizes, dominant trees at the maximum size for the site conditions, and a disturbance equilibrium (Kaufmann and others 1992).

The Front Range montane zone is a dry, unpredictable environment and is relatively unproductive in terms of plant growth and diversity. Trees grow slowly and do not become very large. Disturbance is inherent in ponderosa pine forests. Low- and mixed-severity fires helped maintain open conditions and species composition over time. In the case of ponderosa pine forests, exclusion of disturbance such as fire is itself a disturbance, one that shifts species composition away from ponderosa pine. Historically, disturbances with variable effects created a complex mosaic of stands of different ages across the landscape. Without local stand-replacing disturbance, old stands reached a kind of equilibrium and could persist for centuries (Huckaby and others 2001).

Stands of old-growth ponderosa pine are now relatively rare in the Front Range because of past logging and wildfire. However, individual old trees are not uncommon, and in many locations stands of trees that were too small to be cut during the settlement period are now around 200 years old, poised to become the old growth of the future.

Fire Ecology of the Montane Zone

Historically, fire was the primary regulator of forests in the Front Range. The fire regime of an area is the pattern of fire severity and frequency over a period of time. Fire regimes are influenced by climate, fuels, topography, and ignition sources, which are interrelated. Fire history reconstructions have shown that before Euro-American settlement of the Front Range (beginning with the influx of settlers in the gold rush of 1859), a fire occurred in any given location in the lower montane zone on average every 10 to 20 years (Brown and others 2000, Brown and others 1999, Donnegan and Veblen 2001, Goldblum and Veblen 1992, Veblen and others 2000). Larger fires occurred at longer intervals, on the order of 30 to 60 years (Brown and others 1999). The more frequent but less intense surface fires probably thinned out dense stands of young trees and ingrowth, maintaining an open forest (fig. 3a, b). Occasional mixed-severity fires included a stand-replacing component as well as surface fire. These fires created openings (fig. 4a, b, c) by killing all the trees in patches where the forest was dense or when burning occurred under extreme weather conditions, but they left many survivors. Most pre-Euro-American settlement fires in the montane zone were of low or mixed severity (Brown and others 1999, Heyerdahl and others 1994).

During regionally dry years such as 1851, fires burned many thousands of acres throughout the west (Swetnam and Baisan 1996). Fires with more severe effects may have occurred very infrequently; carbon 14 dating of charcoal layers in an alluvial fan near Buffalo Creek indicates that severe erosion following fires occurred there at approximately 1000-year intervals over the last 2900 years (Elliot and Parker 2001).

Figure 3a. Surface fire in a ponderosa pine stand burns the grass, shrubs, and small trees, but the larger trees are protected by their thick bark and pruned-up crowns. If the fire is hot enough to kill the cambium on one side, mature trees may be scarred. This prescribed fire on the Arapaho-Roosevelt National forest burned in June 2001.

3b. A stand of large, older trees a few days after a surface fire. The grasses, shrubs, and small trees have burned, opening up the stand, while the larger, older trees are mostly undamaged. The understory vegetation will regenerate within a few years. This area burned as a surface fire in the Bobcat Gulch fire in 2000, but it had also burned in 1993. That fire reduced fuels and made the area less susceptible to crown fire. Photo by M. Kaufmann.

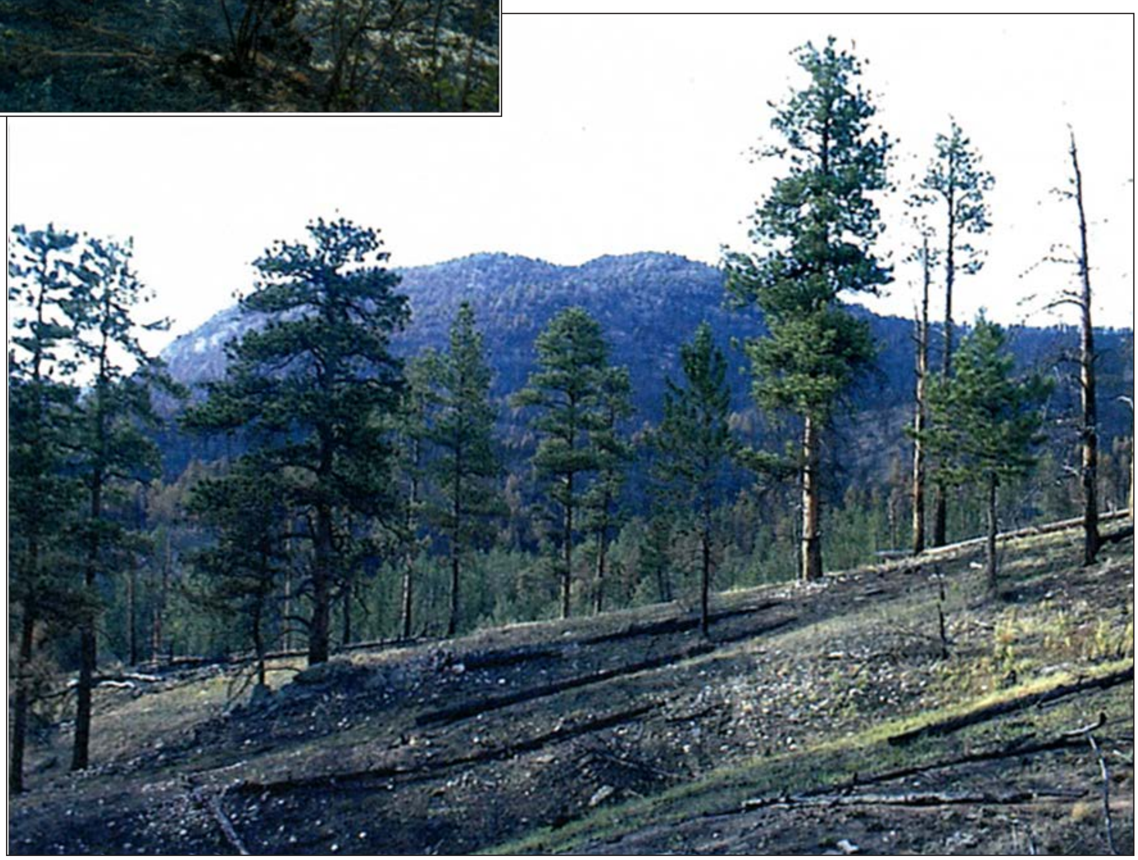


Figure 4. When weather conditions are hot, dry, and windy and fuels are dense, fire in ponderosa pine forests can be intense. Crown fire may kill most of the trees in an area. Dense young stands are susceptible to this kind of fire behavior, and much of the Front Range is now covered by this type of forest. The Schoonover fire **(a)** in May 2002 burned almost 4000 acres (1670 ha) in the South Platte Basin near Trumbull, Colorado. It made a wind-driven run on the afternoon of May 22. The Hayman fire overlapped the area burned by Schoonover two weeks later.

The Bobcat Gulch fire **(b)** in June 2000 burned 10,600 acres (4417 ha), much of it as a crown fire.

(c) A fire at Cheesman Lake in 1851 burned some patches intensely, leaving behind openings that were only beginning to fill in with trees 150 years later when burned in the Hayman fire (**a** by Paula Fornwalt; **c** by M. Kaufmann).

Figure 5a. Fire scar face on an old pine along Highway 7 at Olive Park, CO. Its pith date is 1589.

5b. Fire scars on an old tree above Trumbull, CO, near the South Platte River.

Mature ponderosa pines have thick bark that insulates the cambium from heat. Seedlings and saplings lack this thick bark and are susceptible to fire kill. Many old trees have distinctive scars at the base from past fires that were hot enough to kill the cambium on a portion of the tree's circumference (fig. 5a, b). If the cambium is killed all the way around, the tree will die. If only part of it is killed, the tree often survives and heals in subsequent years by growing wood around the wound. This wood is often soaked with pitch, which the tree secretes to repel insects and fungi from the wound. The pitch is very flammable, so a tree scarred by fire once is likely to scar again. These scars show up as distinctive patterns in the tree rings, which allow dating fires to a precise year, and sometimes to the part of the growing season in which they occurred (fig. 6a, b, c, fig. 7b) (Arno and Sneck 1977, Brown and others 1999, McBride and Laven 1976, Stokes and Smiley 1968). This method of cross-dating fire scars allows reconstruction of historical fire regimes (see the Appendix for details).

Fire behaves differently in different ecosystems. Fire was historically more frequent at lower elevations, especially on the plains and in the adjacent foothills (Mast and others 1998). Fire frequency decreased and severity increased with elevation. Above 9000 ft (2770 m) elevation where lodgepole pine dominates forests, most fires were stand-replacing crown fires that occurred at intervals of 150 to 300 years. Spruce-fir forests usually burned as stand-replacing crown fires within 300 to 500 years or more (Peet 1991). Humans have had much less influence on these longer fire regimes through fire exclusion than on the more frequent montane fire regime. The natural fire regime of ponderosa pine forest in the Front Range also differs from the well-known patterns in ponderosa pine in the Southwest, where more predictable summer rainfall and longer growing seasons allowed the forest to be more productive. There, surface fires were more frequent and more strongly driven by the El Niño climatic cycle, occurring on the order of every three to seven years, and most historical fires did not have a stand-replacing component (Covington and Moore 1994, Woolsey 1911).

Figure 6a. Sampling a fire-scarred stump by cutting a cross-section.

6b. Fire scars can be sampled from living trees by cutting out a partial section through the scar face.

6c. A cross-section of a fire-scarred ponderosa pine. The fire scar face is toward the top of the photo, and the fire scars are marked with black arrows. This tree was cut in a thinning operation near Trumbull in 1999. It has been sanded and cross-dated. The pith date is 1690. The tree was scarred by fires in 1717, 1765, 1820, 1860, and 1880, and it sustained another injury in 1943. The scars in 1717 and 1765 had healed completely before the next fire occurred.

In pre-1860 montane forests, grasses and shrubs in the understory of open woodlands periodically provided continuous fuels that allowed fire to spread across the landscape. Periods of wet weather allowed fuels to accumulate. Subsequent dry weather cured the fuels and made them more flammable. When fuels had built up over time and the conditions were right, larger, more intense fires occurred that usually had mixed effects (Brown and others 1999). Warm, dry periods, periods of high year-to-year variability, and periods of intense El Niño-Southern Oscillation (ENSO) activity encouraged more frequent fires. Cool, wet periods and periods of decreased variability and ENSO activity allowed for longer intervals between fires, greater buildup of fuels, and more intense fires when they did occur (Donnegan and others 2001).

The role of Native Americans in the Front Range fire regime is poorly documented and not well understood. While Native Americans may have ignited fires either intentionally or by accident, the historical fire regime was strongly climate-driven, and it seems unlikely that human ignitions altered the fire regime significantly except on a local scale (Cassells 1983). Most historical fires in the Front Range were probably started by lightning immediately before or during the growing season. Fire frequency increased in many (but not all) montane locations during the settlement period, especially around areas of mining and railroad activity (Brown and others 1999, Donnegan and others 2001, Veblen and others 2000). This was due in part to an increase in human-set fires, but also to a change in climate. The preceding period between 1790 and 1840 was one of less annual variability and decreased ENSO activity, and this change affected fire regimes throughout the Southwest and Southern Rocky Mountains (Donnegan 2001). Fire was less frequent during this period, allowing for a build-up of fuels. After 1840, increasing fire frequency coincided with greater year-to-year variation in precipitation and drought as well as increased human ignitions due to Euro-American settlement.

By the early 1900s, fire frequency in the montane zone dropped dramatically. In some locations, heavy livestock grazing over the preceding decade or two had reduced surface fuels and retarded fire spread. Many areas had been recently logged or burned or both, which had also reduced fuels. However, organized fire suppression became effective during the early 20th century and has continued to the present.

Old Trees in the Landscape

The persistence of old trees is the result of the coincidence and interaction of many factors, including the history of land use at a site, the history of natural disturbance, climate, topography, vegetation, and chance. Because ponderosa pines may live for hundreds of years, they are affected by patterns of climate and disturbance over centuries, as well as by individual events. Each old tree represents a single case, but old trees also have a role in the larger landscape. Entire stands of old trees are unusual, but a few old trees among younger trees in a stand are a common occurrence.

Interactions across multiple scales in space and time create a complex distribution of vegetation communities. Variable frequency and intensity of disturbances interacting with variability in climate over time and with variable topography in space created a temporally shifting mosaic of vegetation across the landscape. Old trees were always present in the landscape, though locations of old stands changed over the period of centuries. When looking at the survival of old trees, one must consider the effects of disturbance at the scale of a single tree, a stand (a group of trees with a more or less uniform history), or a landscape composed of many stands, and the effects of processes across scales in time.

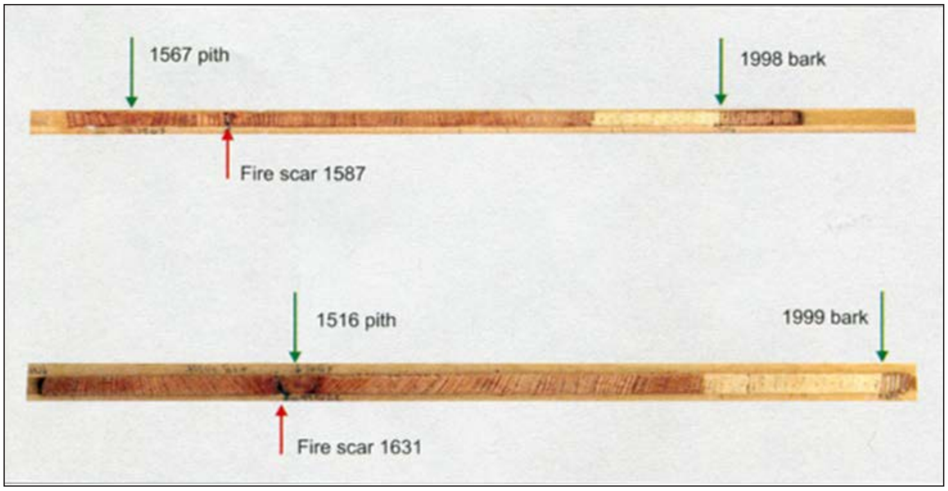
Stand Structure

Stand structure is the distribution of tree sizes, ages, and species in a given area. All of these have changed in the Front Range as the result of human land use, fire exclusion, and possibly climate change. Many of the largest and some of the oldest trees were cut during and after the settlement period. When fire was successfully suppressed, more seedlings survived than would have under a natural fire regime. In the absence of fire over long periods, ponderosa pine may lose dominance in a stand to other, less fire-tolerant species such as Douglas-fir (Oliver and Ryker 1990).

Because ponderosa pine seedlings require mineral soil and full sun, logging and fires create favorable opportunities for regeneration. While ponderosa pines produce cones and seeds most years, not all of the seeds are viable, and few of them are likely to germinate and survive to maturity (W. Shepperd, personal communication). When conditions are favorable, trees produce a huge crop of seeds, increasing the odds that some will survive to maturity. Because groups of trees tend to establish during good conditions, the ages of trees in a forest are usually clumped (Arno and others 1995, Savage and others 1996). It is common to see dense groups of young trees following one of these regeneration events. Before Euro-American settlement, such groups were thinned by fires that killed all but a few of the young trees (fig. 7a,b, c, d). In the absence of fire, most of them survive and create dense forest.

Figure 7a. A clump of young ponderosa pines thinned by surface fire. This group of saplings was killed in an area of surface fire in the Crosier Mountain prescribed burn in 1998. The largest one survived. Note the grass cover under the trees.

7b. Historical fires were sometimes locally cool enough to spare small trees. Core samples from old trees at Cheesman Lake show completely healed fire scars incurred when the trees were very small. The top core is from a tree scarred by a fire in 1587, when the tree was about 2.5 inches in diameter and about 20 years old. The bottom core is from a tree scarred by a fire in 1631, when the tree was only half an inch in diameter and 16 years old. These cores also show how slowly trees can grow in a dry environment.



7c. Even very small trees can survive cool surface fires. This tree will probably survive, but it may be scarred by this prescribed fire, which was intended to reduce dead fuels on the ground.

7d. A group of seedlings that germinated following the Snowtop fire in 1993 was scorched by surface fire during the Bobcat Gulch fire in June 2000. Most of them will probably die. Note the non-native thistles on the left side of the picture that invaded following the fire in 2000.

Figure 8a. An old Douglas-fir dominates a west-facing slope at Cheesman Lake where the young ponderosa pines are infested with dwarf mistletoe.

8b. A young Douglas-fir grows amid a post-Euro-American settlement ponderosa pine forest in Rist Canyon. Young Douglas-fir trees have thin bark and branches that extend all the way to the ground, making them susceptible to burning. Trees like these are common in the understory of ponderosa pine forests in the absence of surface fire.

Grazing by domestic animals removes grasses and allows trees to invade meadows where they had previously been excluded by frequent fire and competition with grasses (Baisan and Swetnam 1997). The warming of global climate may also be contributing to increased seedling survival in recent years. Many of these 20th century trees are now tall enough to create "ladder" fuels—a fire burning along the ground may burn from these small trees with branches close to the ground into the crowns of the larger trees.

Douglas-fir is now more abundant in the Front Range than it was historically (Kaufmann and others 2000a). While Douglas-fir has always shared the montane zone with ponderosa pine (fig. 8a), many more young Douglas-fir survive now than when fire was more frequent. Young Douglas-fir trees have thin bark and a large proportion of live crown to total tree height (live crown ratio) that make them more susceptible to fire (fig. 8b). Old Douglas-firs, however, are quite resistant to fire. They self-prune as ponderosa pines do, and they have very thick bark. Many of the older trees also have fire scars. The species composition of montane forests is now shifting toward dominance by Douglas-fir even in areas where ponderosa pine once existed in nearly pure stands.

Historical Landscape

Before Euro-American settlement, the montane landscape of the Front Range was a varied, shifting mosaic of forest stands of different ages, densities, and species compositions, mixed with grassy openings, shrub fields, and riparian communities. Disturbances had different effects in different stands. A fire might burn quickly and cool through an old, open ponderosa pine stand on a south-facing slope, causing minimal damage, but the same fire might burn much more intensely in a dense young stand of mixed ponderosa pine and Douglas-fir on an adjacent north-facing slope, killing many trees and scarring some of the survivors. Over the centuries, any given location might be occupied by a shrub field in the years following a stand-replacing fire, a dense young stand a century later, or an open old stand that survived fire after fire until a hot, wind-driven fire turned it back into an opening again (Kaufmann and others 2001).

Based on studies done in rare places where there was no logging, it seems that pre-Euro-American settlement forests were much more open and spatially variable than those of the present (Kaufmann et al 2001). They had a larger proportion of old trees and fewer young trees than modern forests, except where the occasional stand-replacing fire had burned. Regular fires maintained open stands—usually less than 30% canopy cover—and created non-forested areas (Kaufmann and others 2001, Fornwalt and others 2002). Competition for light and water was minimal in such stands, and danger of lethal fire to the older trees was small. A few young trees survived to become large enough to resist fire and became the next generation forest.

How common were old trees before Euro-American settlement? There is no way to know for sure, but there are ways to estimate. The few, rare stands that were not logged preserve the historical age structure, though they have also experienced fire exclusion, ingrowth, and mortality. One of the best examples of an unlogged landscape in the Front Range montane zone was the 8645 acre (3500 ha) forest around Cheesman Lake (Kaufmann and others 2001). That area burned severely in the Hayman fire, but studies done in preceding years showed that of trees selected as the five oldest in randomly selected stands, 30% were more than 400 years old, and 40% were between 200 and 400 years old (Huckaby and others 2001).

Even in stands that were logged, evidence remains of the pre-Euro-American settlement age structure. Because the climate of the Front Range is cool and dry, wood rots very slowly. The stumps of many trees cut during logging operations in the late 19th century still exist. Tree-ring dating can determine when these trees died, and how old they were at that time. Historical accounts (such as Jack 1900), government land surveys, early studies, and old photographs (as in Veblen and Lorenz 1991) give glimpses of what the landscape looked like around the time of settlement (fig. 9). Unfortunately, these sources are not quantitative and do not reflect the period much before settlement. Computer models can help visualize what the pre-Euro-American settlement landscape looked like and how disturbances behaved. Models use information on

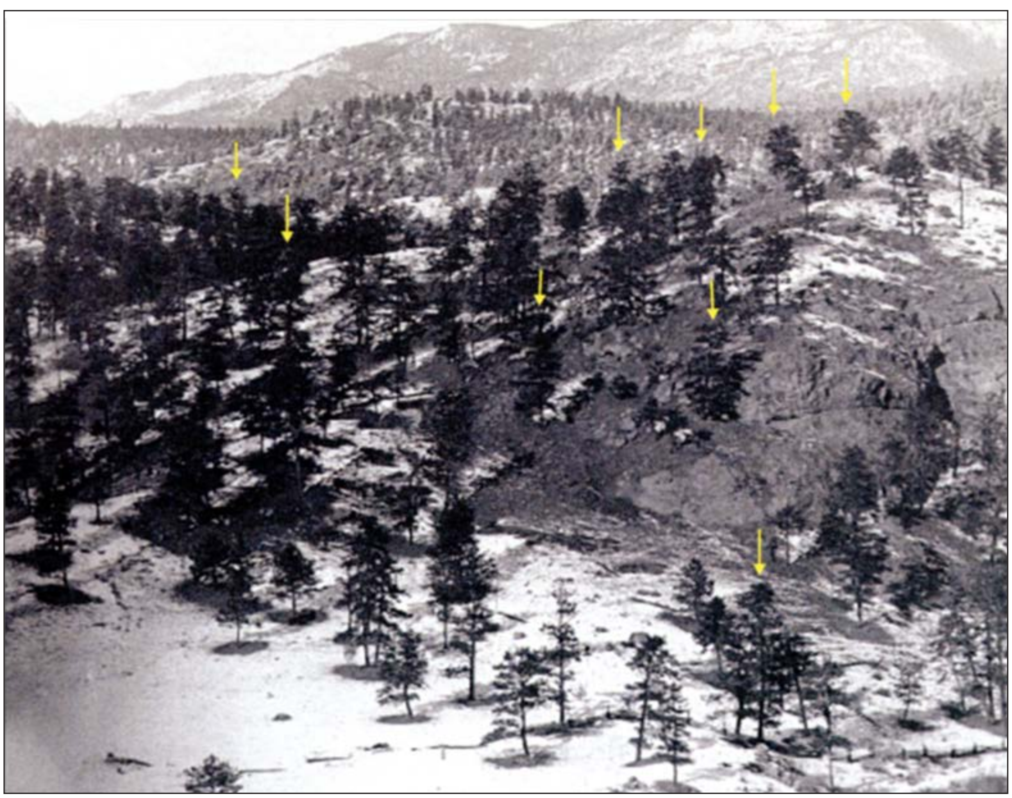


Figure 9. This photograph was taken in December 1896, west of where the Cheesman Lake dam would be in a few years. There is patchy snow on the ground. There had been no logging or settlement in the area before the photograph, but scars on trees recorded a fire in 1880. Note how open the forest is, how many older trees there are (designated by yellow arrows), and how many fallen logs, probably trees killed in the 1880 fire. The foreground is now under water (photo courtesy of Denver Water).

climate, topography, and species characteristics to predict where and how trees grow (Fornwalt and others 2002).

Modern Landscape

Much of the Front Range foothills and montane zone was logged during the settlement period, from the late 1850s through the 1920s. Sporadic logging continued through the 1960s. Many trees were cut during the 1970s and early 1980s in an attempt to control a mountain pine beetle outbreak. Ponderosa pine was the primary tree used in building homesteads, fences, railroads, and mines, and for fuel in settlements and railroads. Larger trees were preferred, particularly those without scars or other damage. In some accessible areas, no old trees remain. The same period saw an increase in fire frequency and intensity, especially around settlements and railroads, because of human-caused ignitions (Veblen and others 2000). Many forests were destroyed in these fires. By the time the US Forest Service was established in 1905, forests in the Front Range had been devastated by human-caused fire, logging, erosion, and overgrazing. The mission of the Forest Service was to stop the abuses, enforce more sensible land use, and put out fires. As Native American tribes were confined on reservations, their influence on fire regimes was removed (Veblen and Lorenz 1991).

Post-settlement land use changed the disturbance regime of the landscape and the scale at which it operated. The effects of human activities homogenized the landscape (fig. 10). Forest regeneration following widespread logging and human-caused fires created large areas where the trees are now about the same age and size. Many trees were planted during the 1930s to combat erosion (Gary and Currie 1977, Pike National Forest archives, Arapaho-Roosevelt National Forest archives). Lack of subsequent disturbance has allowed most of these trees to survive, creating dense, continuous stands. One of the consequences of a homogeneous landscape is that when disturbances do occur, they have relatively homogeneous effects, such as widespread insect epidemics or large fires. What heterogeneity exists in the current landscape is driven largely by variation in topography and land use. Artificial land ownership and management boundaries have imposed land use and management activities that now limit the mosaic from shifting spatially as it once did.

Shade-tolerant Douglas-fir and shrubs such as Rocky Mountain juniper (*Juniperus scopulorum*), mountain-mahogany (*Cercocarpus montanus*), Gambel oak (*Quercus gambelii*), and antelope bitterbrush (*Purshia tridentata*) have grown up in the understories of previously open ponderosa pine forests, creating heavy fuel conditions and ladder fuels that can carry fire into the crowns of large trees. Global warming may be contributing to increased tree growth and survivorship over the last 50 years as well. Current dense forest conditions place montane forests at risk of stand-replacing wildfires. Old trees that were well adapted to survive fires in the historical ecosystem are now at risk. The processes that preserved old trees have been altered.

Figure 10. The homogeneous modern landscape in the Front Range. This ponderosa pine forest in the South Platte basin west of Denver is composed of regeneration following logging and fire in the late 1800s. The trees are fairly uniform in size and age, and the forest is dense and continuous over a large area. Photo by M. Kaufmann.

How common are old trees now? Measuring the age structure of forest stands on a large scale is impractical, so there is probably no realistic way to know. It is nearly impossible to differentiate old trees from remotely sensed data like aerial photos and satellite images. The best way to locate old trees is to look for them on the ground. No one has mapped the forests based solely on age, but given the land use history in the Front Range, it is safe to say that old trees are not as common as they once were (fig. 11).

The Urban Interface Problem

The human population of the Front Range montane zone has grown considerably in recent years. Many people have moved into the mountains adjacent to the large urban centers (fig. 12). Roads fragment the landscape, limiting species and processes from moving around as they once did. Fragmented ownership makes management of the land difficult, especially on the scale at which most ecosystem processes operate. Fire is one of the processes disrupted by human settlement.

Since the early 1900s, fire suppression has been very effective. The montane zone now supports forests that are younger, denser, and more continuous than those

Figure 11. Old trees in the modern landscape. This group of old trees (designated by yellow arrows) lives on a bench at the base of a west-facing slope along the Mt. McConnell trail off the Pingree Park road at 7592 ft (2336 m) elevation. This is a better site than the sparse, disturbed slopes above. Young ponderosa pines, Douglas-fir, and juniper are filling in the understory in the absence of surface fire. The old trees have smooth orange bark, small live crown ratios, open crowns with large branches and flattened tops, lightning scars, and fire scars. We cored the tree designated by the orange arrow. Its DBH was 24.9 inches (63 cm). Its pith date is 1642. It had a fire scar in 1707.

Figure 12. Urban development is expanding into the montane forest as the human population of the Front Range grows. This is an area in the foothills west of Denver (photo courtesy of the Colorado State Forest Service).

that occurred historically. Such forests are at risk of burning in large, intense wildfires, endangering human lives and property. Dense continuous stands are also more subject to the spread of disease, insect attacks, and the stress of competition for light and water.

Several recent fires have illustrated the risk of urban interface wildfire. The Buffalo Creek fire in 1996 burned nearly 12,000 acres (5000 ha.) of ponderosa pine forest, most of it as a stand-replacing crown fire. Fortunately it consumed very few homes, but subsequent flooding killed two people, and erosion had significant effects on Denver's water supply. The Bobcat Gulch fire and the Hi Meadow fire in June 2000 each burned about 10,600 acres (4292 ha) and destroyed more than 60 homes. The Hayman fire, the largest in recorded Colorado history, burned almost 138,000 acres (55,870 ha.) and 133 homes in the South Platte basin in 2002. All were human ignitions. Fires of this magnitude were unusual historically, maybe unprecedented. Now, in addition to changing forest structure, such fires endanger many thousands of people who live in the montane zone. Efforts are now being made in the Front Range to thin montane forests and to restore fire in the form of prescribed fires, especially where the risk of wildfire is great (Foster Wheeler Environmental Corporation 1999).

Forest Restoration and Old Trees

The most ecologically sound way to mitigate the risk of intense wildfire is to return the forest to a structure similar to what existed before Euro-American settlement. Because fire was the main regulating process in pre-1860 forests, the logical way to do this is through prescribed fire, but some areas are too heavily populated for prescribed fire to be safe or acceptable to residents. Prescribed fires create smoke and are at risk of escaping containment should the weather change unexpectedly. In some areas, fuels have accumulated to such levels that a prescribed fire would be more intense than desired, killing more trees than intended. In such cases, a combination of mechanical treatment and prescribed fire may be necessary.

Mechanical treatment for restoration purposes involves removing trees based on scientific reconstructions of the historical forest. In general, pre-Euro-American settlement trees are retained as well as some of the larger young trees, to create a prescribed forest density and species composition. Most of the young trees are cut, possibly including some fairly large ones, to restore the forest to a historical density. On a landscape scale, it is desirable to re-create the historical mosaic of forest age and size structure, including sizeable openings. This means clear-cutting or burning intensely in some locations, while leaving open forest in other locations and somewhat denser forest in others. New harvest machines can cut individual trees and remove them with minimal disturbance to the soil. Some of them shred and broadcast the trunks, branches and needles like mulch so they can decay or be burned in a prescribed fire later. Where such activities have been done in the Front Range, there has been a positive response from the grasses and other understory plants, and under non-extreme conditions, a moderation of fire behavior.

Restoring Front Range montane forests to a historical density is controversial. Environmentalists are concerned that restoration will be an excuse to reintroduce unregulated logging. Even in areas where it is clear that thinning would reduce the risk of wildfire, diameter limits have been proposed that would limit the trees that could be cut to those less than some pre-determined size. This method is designed to save older trees, but because the relationship between tree size and age is very poor in the Front Range, it could allow for cutting small old trees, while keeping large young ones that maintain a density greater than the target, and therefore not sufficiently mitigating the risk of stand-replacing fire. There is currently only a limited local market in the Front Range for the small diameter material that will be cut in restoration activities. That makes restoration very costly, as the work must be subsidized by landowners or land management agencies and little or no cost is recouped through sale of the material.

Regardless of how restoration is accomplished, old trees will benefit from a reduction of forest density in the montane zone of the Front Range. Reducing forest density will reduce stress due to competition for water and light and will reduce the risk of insect epidemics and stand-replacing fire. Identifying individual old trees for preservation in restoration activities is essential. Long-term maintenance of restored forest conditions is critical. Unless natural processes such as fire can be reintroduced to the montane zone, the lower density forest will have to be maintained with continued thinning and prescribed fire.

Identification of Old Ponderosa Pine Trees in the Front Range

Appearance of Old Trees (>200 years)

At around 200 years of age, ponderosa pine trees begin to take on distinctive physical characteristics as the result of physiological changes (Kaufmann 1996). Trees acquire these characteristics gradually as they interact with their environment (fig. 13). Trees growing in poor sites or those that are otherwise stressed, as by dwarf mistletoe infestation, may look old earlier.

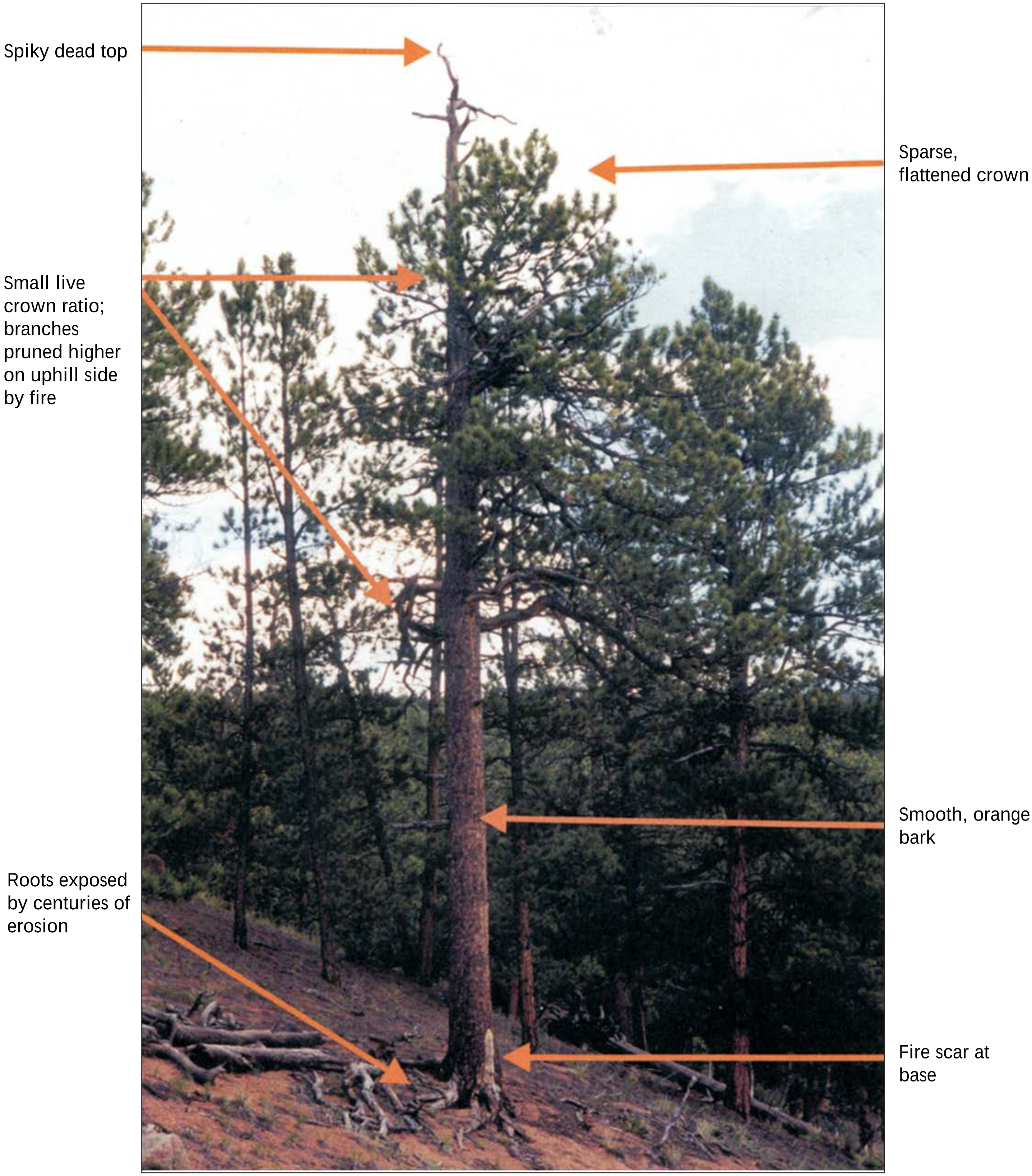


Figure 13. Typical characteristics of old ponderosa pines. This classic old tree lived on a south-facing slope at Cheesman Lake. The inside date on a cross-dated core from this tree was 1455, and that was about an inch from the pith, which was rotten. Most of the other trees on this slope were around 300 years old. They all burned in the Hayman fire in 2002.

Crown shape is determined in part by the site where the tree lives and by its history, but in general, as a tree ages and stops growing taller, the crown appears to flatten out on the top and to acquire a "bonsai" look (fig. 14). This flattening may be more pronounced on poor sites or in older trees. Older trees often have sparse or very open crowns, as branches have died off over the years, leaving a few large branches. Also, the growing tips of the branches are farther from the trunk, and the interior of the crown often has little foliage. The proportion of the live crown to the height of the tree becomes less, both through self-pruning and fire pruning. As a tree gets taller and the crown becomes longer, the lower branches become shaded by the upper branches. When the lower branches cannot get enough light to photosynthesize, they die and eventually fall off. This has the added benefit of removing ladder fuels from the lower part of the trunk, making it less likely that a surface fire will get into the crown. Fires themselves can have the same effect. A surface fire may scorch the lower branches, killing them without killing the tree. This gives the crowns of older trees on slopes or along the edges of old burns a distinctive sloped appearance (fig. 15 a, b).

Old tree trunks become more columnar over time due to differential growth in the upper crown (Kaufmann, unpublished data). As trees become larger, they have a larger surface area over which to spread growth. Old trees are usually not as vigorous as younger trees, so they have less energy for growth. They put on

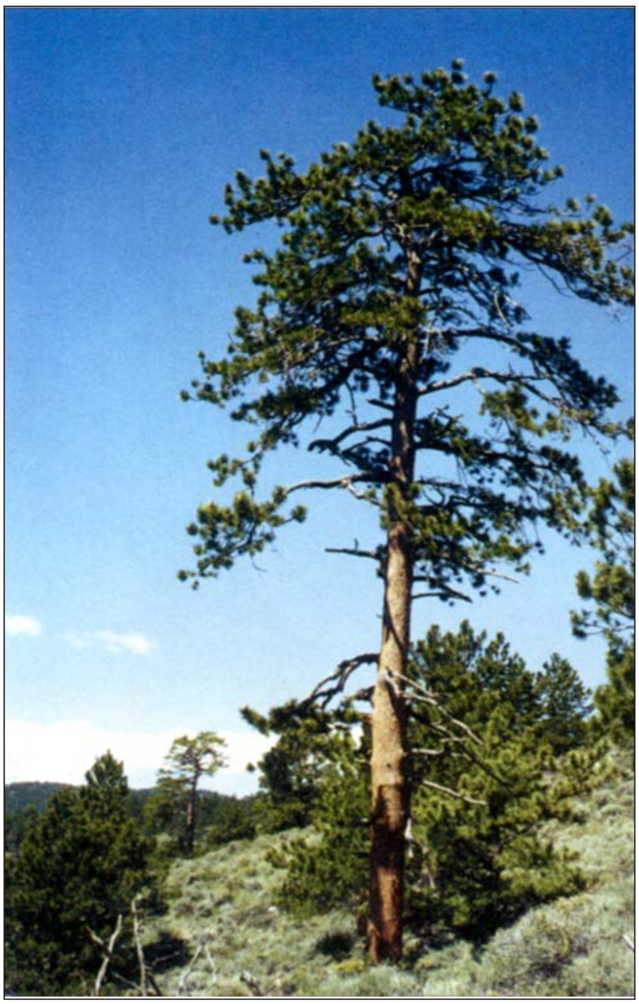


Figure 14. Crown characteristics of old trees. This old tree lives on an open, south-facing slope along the Redfeather-Rustic road at 8349 ft (2569 m) elevation. The shape of its crown is typical of an old, open-grown tree: its top is flattened, it has a sparse, open crown with few large branches, and a small ratio of living branches relative to the tree's total height. The lower branches have died or have been killed by past surface fires. It has a columnar trunk and pale orange bark. Its pith date is 1643, meaning that it germinated more than 350 years ago. It is a moderate-sized tree, with a DBH of 20.3 inches (51.5 cm).

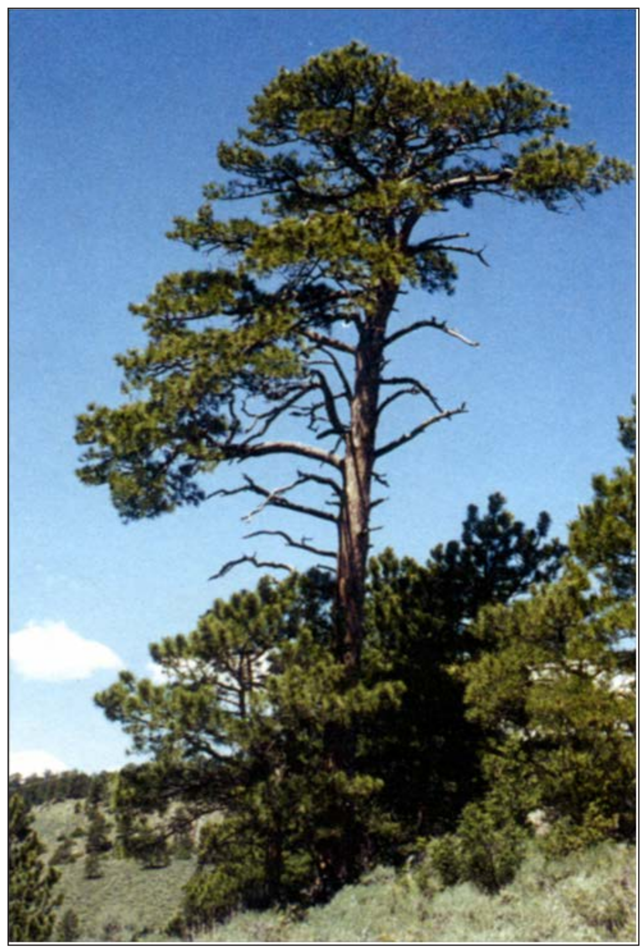


Figure 15a. An old pine on the Redfeather-Rustic road; its pith date is 1550. Its branches have been pruned on the uphill side by past fires, giving its crown a distinctive sloped shape. Recent ingrowth at its base could carry fire into the crown, endangering a tree that has resisted fire for 450 years.

wood in the upper crown first, and if there is any carbohydrate left, they grow wood in the lower part of the trunk. This is one reason why tree-ring samples from old trees are likely to have missing rings in the lower trunk, especially rings formed during stressful years. The tops of old trees are often killed by lightning, fungi, or insects, giving them a spiked appearance. Trees with dead tops are often hollow because the injury allows the entry of fungi.

As ponderosa pine trees age, their bark becomes paler in color, smoother and with smaller flakes. The exact color of the bark varies from location to location, perhaps because of genetics. The old trees we found in the northern Front Range tended to be more gray, while those in the southern Front Range were more orange. Sun exposure may also bleach the bark color. Old tree bark lacks the deep fissures, large flakes and black color of young tree bark (fig. 16 a, b).

15b. A ponderosa pine scorched on the uphill side by surface fire in a prescribed burn. This type of scorching probably explains the lopsided crown shape of some old trees and shows how trees often become scarred on the uphill side. Not only do fuels accumulate there, but fires generally burn uphill unless they are driven by strong winds. Branches already pruned by fire kept flames out of the crown.

Figure 16a. Typical bark on a young tree near Cheesman Lake; it is dark in color, with deep fissures and big flakes.

16b. Typical bark on an old tree near Cheesman Lake; it is mostly pale orange, smooth, with small flakes.

Table 1—Identifying characteristics of ponderosa pine trees at different life stages.

	Crown shape	Live crown ratio	Branches	Trunk shape	Bark	Likely injuries
Old trees (>200 years)	flattened, “bonsai” shape, sparse and open, may be lopsided	small; often fire-pruned	few but large	columnar	smooth, small flakes, pale orange or gray	fire scars, dead tops, broken branches, lightning scars, rot, burls, exposed roots
Transitional trees (150-250 years)	ovoid, flattening on the top, full and rounded	moderate; perhaps half the trunk, beginning to self-prune	fine branches in the interior of the crown dying, longer branches thickening	beginning to lose taper	orange or gray flakes with dark edges, shallow fissures, becoming smoother	relatively few; possibly healed or mostly healed fire scars, lightning scars, mistletoe
Young canopy trees (<150 years)	pointed top, “teardrop” or “Christmas tree” shape, dense foliage	large	many fine branches, dense foliage near the trunk	tapered	large, coarse flakes, deep fissures, dark gray or black with dark orange	very few; possible mistletoe or lightning scars

The longer a tree lives, the more likely it is to be damaged. Dead tops, broken branches, lightning scars, fire scars, rot pockets, and burls are all signs of past injury. A ponderosa pine with an exposed fire scar face is probably at least 150 to 200 years old, since spreading surface fires of the kind that cause such scars ceased in most of the Front Range around 1900 (see fig. 5). See table 1 for a list of identifying characteristics of trees more than 200 years old.

The Transition From Young to Old (Canopy Trees 150 to 250 Years Old)

Ponderosa pine trees around 200 years old are middle-aged and their form begins to change about that time (fig. 17). They are still vigorous, but their upward growth is slowing, so their tops start to flatten out as apical dominance weakens. Lower branches have begun to die off and self-prune, either as they are shaded by upper branches or neighboring trees, or killed by old surface fires. The crown begins to open as dense, small branches on the inside die off close to the trunk. The remaining branches become longer and larger in diameter, and the needles are distributed more toward the outside of the crown. The general shape of the crown becomes round or oval rather than teardrop-shaped with a pointed top, as is common in young trees. The deep fissures in the bark begin to smooth, and the color becomes lighter, more orange or gray than black. Middle-aged trees are old enough to have a fire scar or two, but it has been long enough in most locations since the last surface fire that such scars may have nearly healed and are not readily visible. A healed scar might appear as a deep fissure low on the trunk, rather than the easily recognized “catface.” Trees of this age are often the dominants in present Front Range stands. See table 1 for a list of identifying characteristics of trees 150 to 250 years old.

Appearance of Young Trees (Canopy Trees <150 Years Old)

Ponderosa pine trees less than 150 to 200 years old usually have pointed tops, because they are still growing taller (fig. 18). Strong apical dominance allows young trees to grow fast and to compete for light. Seedlings less than 3 or 4 years old must compete with grasses and forbs, and their survival is always in question. Once seedlings are about six inches tall, they are considered established and are more likely to survive. However, they are still susceptible to many factors in their immediate environment as opposed to larger-scale climatic factors. When they are 3 to 6 ft (1 to 2 m) tall, they begin to interact with the other trees around them, and are more likely to reach the canopy. How long it takes a tree to reach this size varies tremendously. It may take only 20 years or so on a good site, but even tiny trees may be older than they look, especially on poor sites. We have sampled trees that were only three ft. (1 m) tall but were more than 90 years old.

The trunks of young trees are usually tapered. Branches grow relatively low on the trunk and have usually not begun to self-prune. The bark of young ponderosa pine trees is dark gray or dark orange and black, with deep

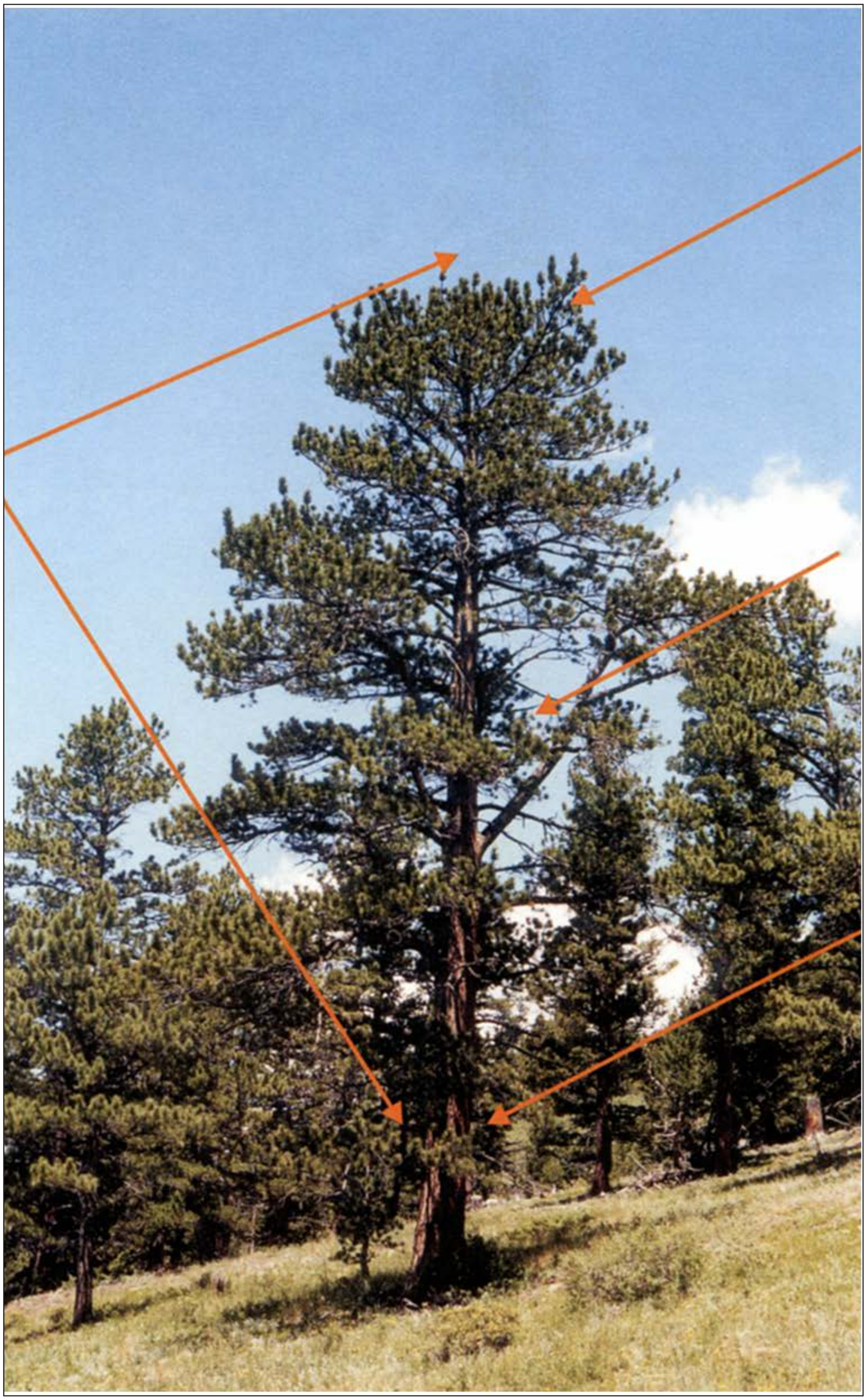


Figure 17. A middle-aged tree showing the transition in appearance to old tree characteristics. This tree, growing on a gentle south-facing slope above Lily Lake in Rocky Mountain National Park, is around 200 years old. It is beginning to take on old tree characteristics: its crown is still full but beginning to open up as fine branches die, and its top is ovoid and beginning to flatten. Its branches are beginning to self-prune. Its bark is becoming smooth and orange, losing its deep fissures.

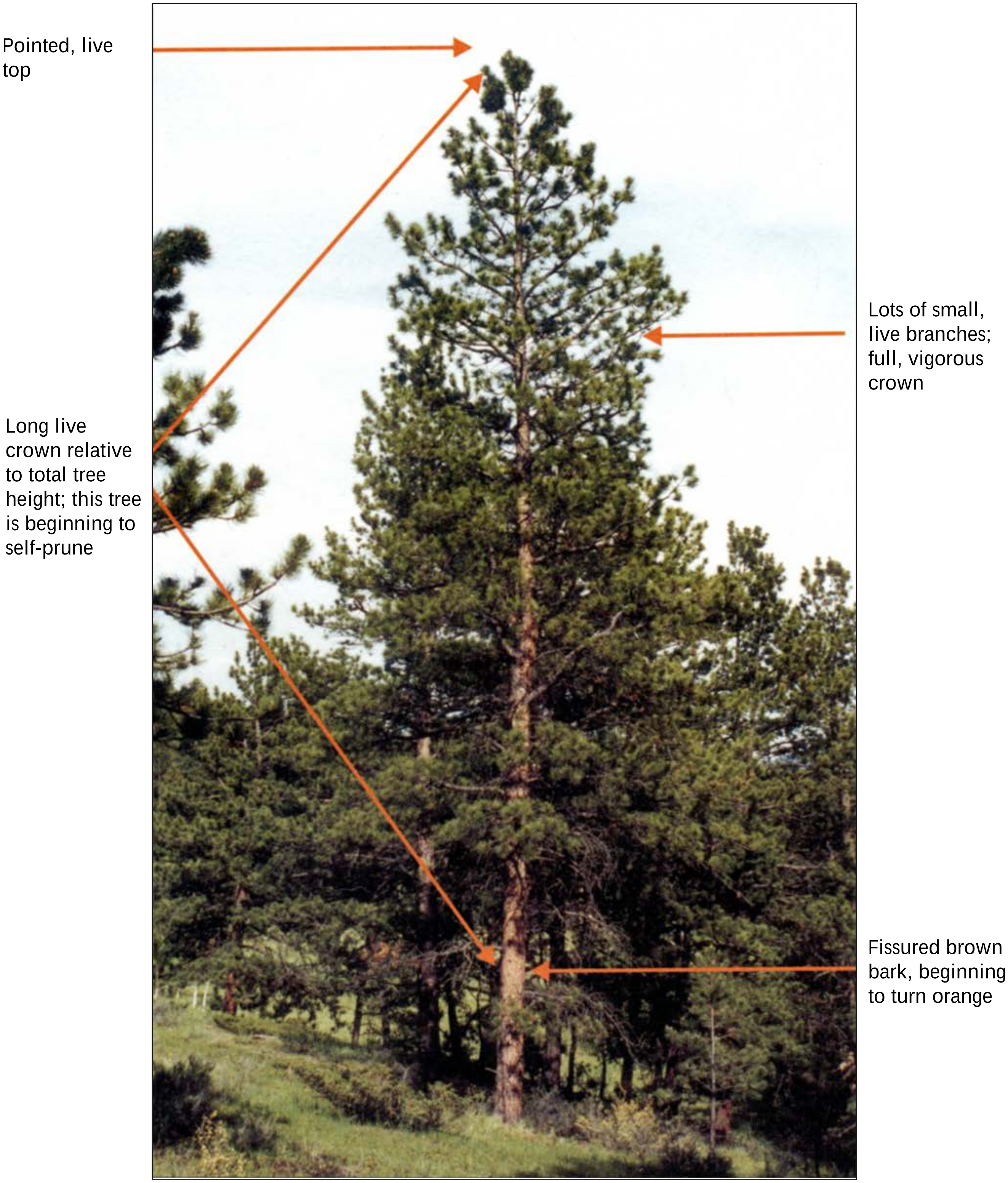


Figure 18. Typical characteristics of young ponderosa pines. This vigorous young tree grew on a west-facing slope at Cheesman Lake. There were many other young trees in this stand, regeneration following a stand-replacing fire in 1851.

fissures and thick, flaky layers. On some small trees the bark appears almost all black; these slender youngsters are called "blackjacks." Most young trees do not have fire scars. They may have mistletoe, but if trees are infected while young, the mistletoe will be distributed throughout the crown and may distort the shape of the branches. Young trees on good sites may be very large, but they usually have a distinctive pointed top and a full crown that extends most of the length of the trunk. Crowns of healthy young trees have many dense, small-diameter branches, most of which bear live needles, so the crown looks full and thick. They usually have few dead branches. Dense forests are more likely to be composed of young trees. See table 1 for a list of identifying characteristics of canopy trees less than 150 years old. Figure 19 shows an old tree and a young tree side by side on a poor site.

Tree Size

Not all old trees are large, and not all large trees are old. However, if a tree is by far the largest or tallest tree in the stand, it is probably older than its neighbors (fig. 20). Ponderosa pines in the Colorado Front Range are usually limited by the availability of water. Trees grow more quickly on sites where water is readily available. Such sites include those along streams, even intermittent streams where water may not flow on the surface year around; flat, grassy areas where water soaks into the soil; and at the base of rock outcroppings, where water collects off the rocks. A 150-year-old tree on a good site may be 30 inches (80 cm) in diameter.

Where water is less readily available, trees grow more slowly. Steep slopes, slopes that face south and

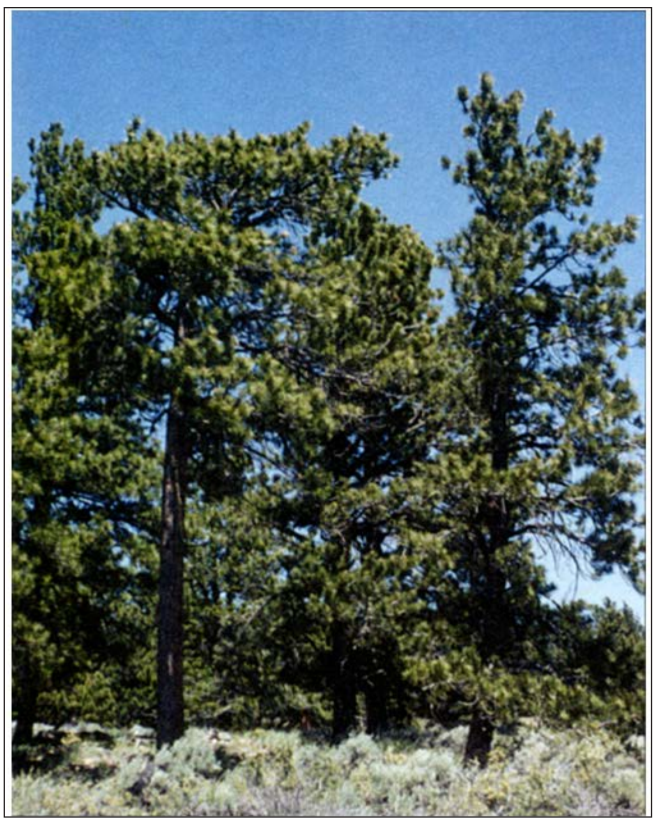


Figure 19. An old tree and a young tree side by side. These two trees live on a dry south-facing slope near the top of a ridge along the Redfeather-Rustic road at 8453 ft. (2601 m.) elevation. They are close to the same size, but the tree on the left is 128 years older. Its pith date is 1761. Its DBH is 13.2 inches (34 cm). Its crown has been pruned up to about a third of the length of the trunk, and its bark is pale and smooth. The tree on the right has a pith date of 1889. Its DBH is 12.4 inches (32 cm). Its crown is sparse, but still pointed at the top, and its live crown occupies more than two-thirds of its trunk. Its bark is nearly black.

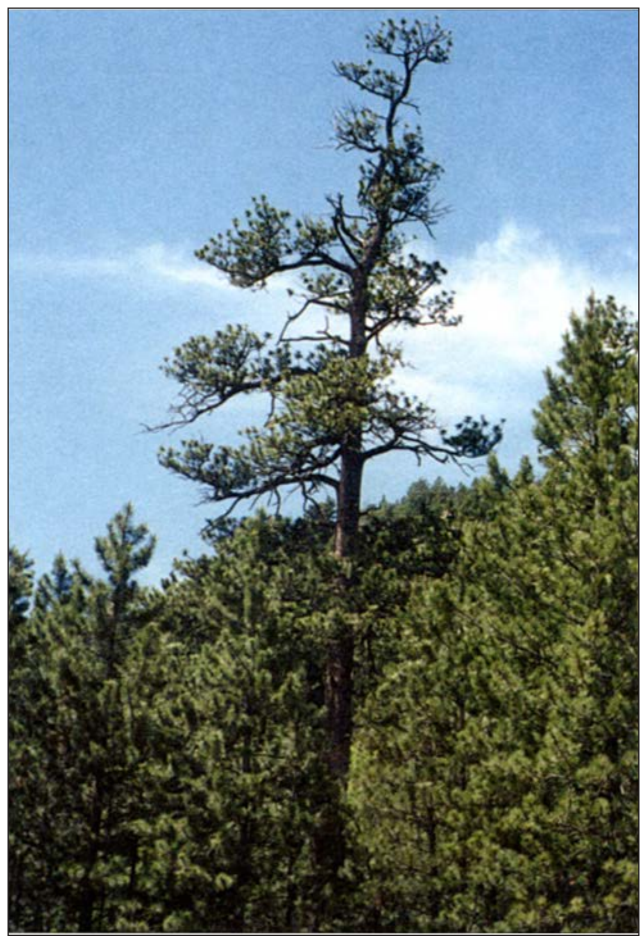


Figure 20. A case in which size does indicate an older tree: this old tree towers above more recent ingrowth at the base of a slope along the Pingree Park Road. Its pith date is 1672 and it has a fire scar in 1846. The old tree has the sparse, pruned crown and smooth orange bark typical of old trees. Its smaller neighbors have full, pointed crowns and dark, fissured bark.

west and are exposed to sun and wind, ridgetops, rocks, and places where the soil is very shallow or well-drained do not hold water. Trees on these sites must depend on brief pulses of water from rain or snow events. Small, old trees are likely on such sites. A 400-year-old tree might be as little as 12 inches (30 cm) in diameter. On such sites, trees are usually less subject to competition and to the spread of parasites and diseases. The lack of water means that understory species like grasses and shrubs are sparse, providing little fuel for fires. Fires burning there are not likely to be intense, so old tree survival is enhanced.

Open-Grown Versus Forest-Grown

Trees that have grown in the open tend to have a different appearance from those that have grown in a forest. Open-grown trees tend to have fuller, more rounded crowns and a few long, large-diameter branches (fig. 21 a). Trees that have grown in a more closed environment will be relatively slimmer, with shorter, thinner branches (fig. 21 b). Old trees can be found in closed forest environments, but the oldest trees are usually open-grown, possibly because they lack competition, or because they are less likely to be destroyed in a fire.

Ponderosa pines require full sunlight to grow well, and when stands are dense and trees shade one another, the shaded trees grow slowly, often develop poor form, and may ultimately die. However, such suppressed trees may be relatively old despite their small size (fig. 21 c). They can persist for hundreds of years under the shade of other trees. If the neighboring trees are eliminated (by fire or logging, for example), suppressed trees may be released and start growing faster. This is evident in the width of their annual rings (fig. 22 a, b, c). Douglas-fir does not suffer as much from shading as ponderosa pine. Young Douglas-fir trees benefit from shaded conditions where the soil surface does not get as hot as in the open.

Types of Injuries

Fire scars are common injuries found on old pines, but trees accumulate scars from other sources as well. Old trees often have distinctive scars from lightning strikes (fig. 23 a). Lightning scars are usually long and narrow and often spiral around the trunk. They usually start in the crown, and they may or may not reach the ground. Sometimes lightning kills the top part of the tree. It may blow off branches or even split the trunk, but trees can survive this kind of damage.

Porcupines often feed on the cambium of ponderosa pines, and scars left by their gnawing are easily mistaken for fire scars (fig. 23 b). However, porcupine scars are generally irregular in shape and usually do not reach the ground. Porcupines may sit on a branch higher in the crown and gnaw a patch of the trunk above the branch. Other injuries can create similar-looking scars, including abrasion damage from logging, road-building, and neighbor trees falling against the trunk. These scars are usually irregular in shape.

Native Americans harvested the cambium of ponderosa pine for food and medicine, and their activity left detectable scars (Kaye and Swetnam 1999, Martorano 1981, Swetnam 1984). Various tribes did

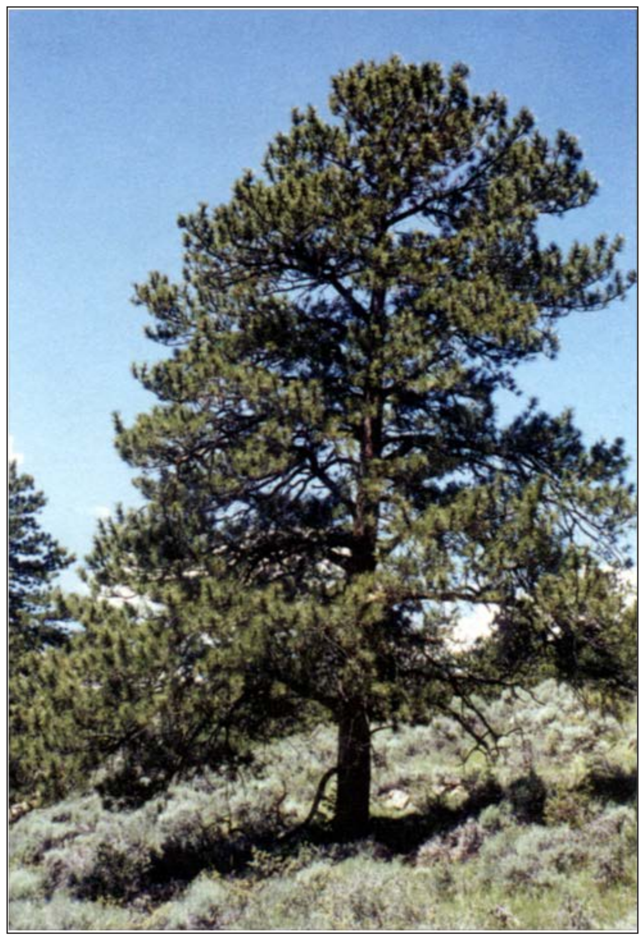
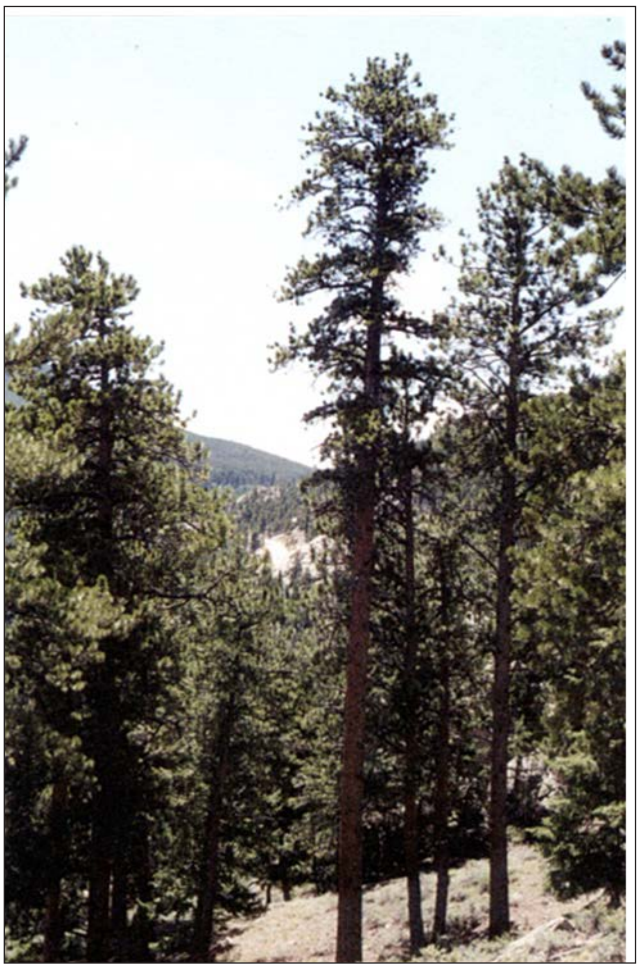


Figure 21a. Open-grown tree: This middle-aged tree lives in a sage meadow near a south-facing ridgetop along the Redfeather-Rustic road at 8453 ft (2601 m) elevation. It is beginning to develop old-tree characteristics as well as open-grown characteristics. Note the full, rounded crown and long heavy branches. Its top is beginning to flatten out, but the lack of surface fire during the 20th century has allowed it to keep its lower branches. Its pith date is 1811; its DBH is 21 inches (53.3 cm). The core revealed a healed fire scar near the pith and relatively rapid growth.

this "peeling" throughout the range of ponderosa pine. The Utes were known to practice the technique in the Front Range until the late 19th century. Women used a sharp instrument to cut into the bark from as high as they could reach, down to about knee level. Then they peeled off the bark and cambium in a strip a few inches to a foot wide. Scars caused by peeling can be mistaken for lightning scars or fire scars. They usually occur on large, older trees, often in groups. The scars usually occur at mid-trunk and do not reach the ground.

Many old trees have dead tops, caused by lightning strikes, porcupine damage, or infestation by fungi. On steep slopes or on the edges of washes, tree roots may be exposed by centuries of erosion. Along streams and washes, debris washing downstream during flash floods can damage the cambium and cause scars that look somewhat like fire scars. It is possible to date flood events using these scars, which usually occur on the upstream side of the trunk. Old trees may be infested with dwarf mistletoe, a common parasite (fig. 23 c, d), though young trees are also susceptible. Old trees may survive for decades with mistletoe, with slower than normal growth. Young trees are likely to be killed or fatally weakened by an infestation. Mistletoe infestation



21b. Forest-grown tree: This tree grows in relatively dense ponderosa pine forest on an east-facing slope along Highway 7 at 8671 ft (2668 m) elevation. It is a dominant forest-grown tree. Note its tall, straight trunk and narrow crown with short lower branches. Its bark is beginning to look smooth and pale. Its pith date is 1762; its DBH is 22.2 inches (56.4 cm).

21c. Suppressed tree: This tree inhabits a small, rocky ridge in a relatively dense forest along Highway 7 near Olive Park at 8349 ft (2569 m). It is rotten at the center, but the inside date on the core was 1671, and narrow rings indicated very slow growth. Its DBH is only 10.2 inches (25.9 cm). It is small, with twisted branches, a sparse crown and a flattened, deformed top.

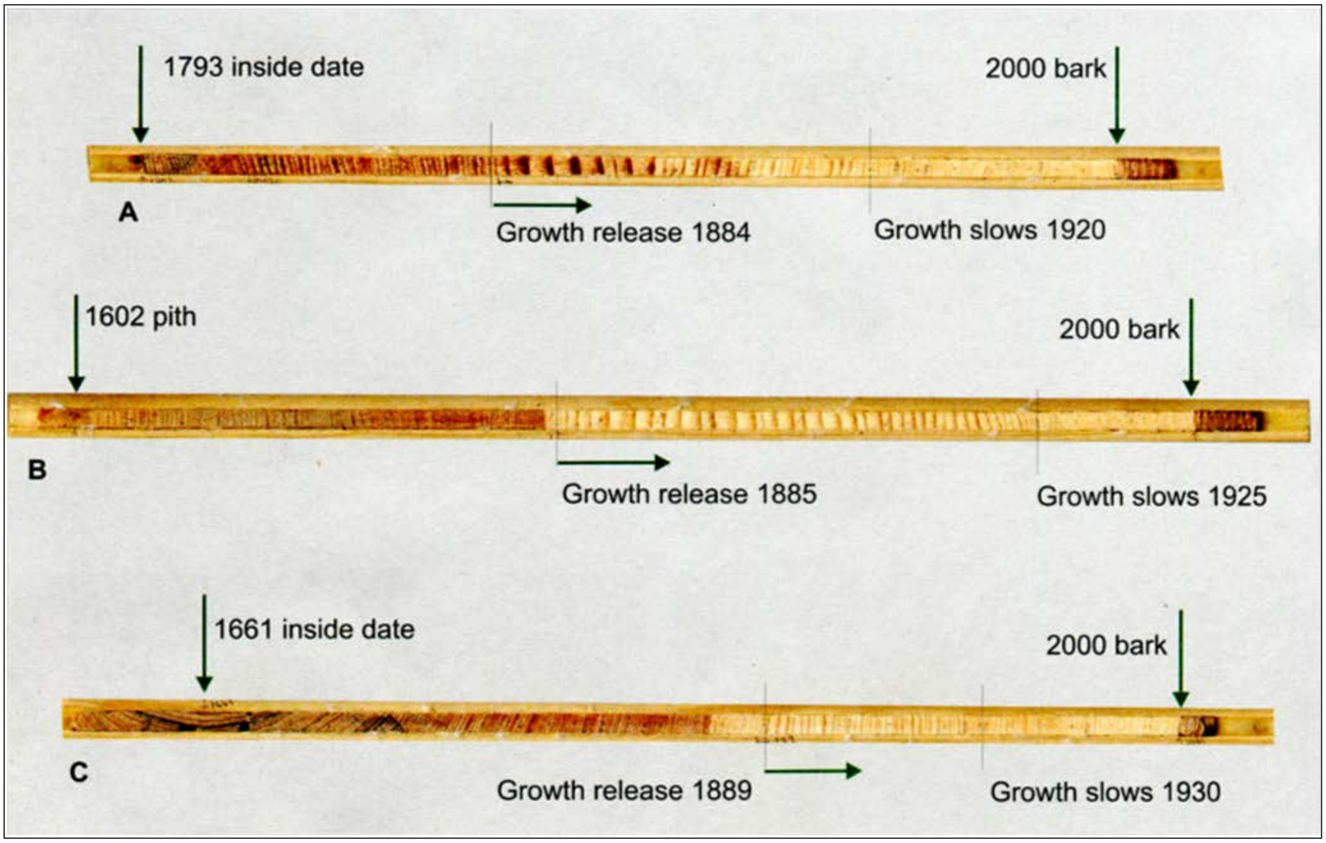


Figure 22. These core samples show growth releases in trees following logging at Saloon Gulch along the South Platte River. These cross-dated core samples come from old living trees that were probably too small to interest the loggers in the 1880s. The bark is on the right side of the picture; the pith or inside of the sample is to the left. Each sample is from a different tree. The growth releases are indicated by the sudden increase in the width of the annual rings, which look like vertical stripes on the samples. The area was logged in the mid-1880s. When their neighbors were cut, reducing competition for light and water, the remaining trees responded within a few seasons by growing more quickly for the next 40 years or so. Their growth rate began to slow again in the 1920s and 1930s as regeneration again closed up the stand.

can create old-growth crown characteristics in younger trees (Hawksworth and Weins 1972, Hawksworth and Geils 1990). Mistletoe infestation was locally common prior to Euro-American settlement, but may have been limited spatially by frequent fire as infected trees tend to be more flammable than healthy ones.

Common Locations of Old Trees

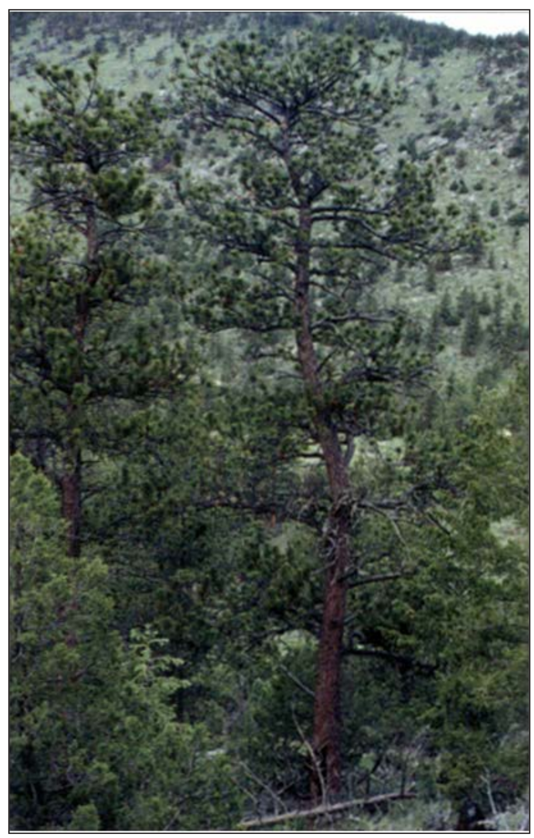
Despite disruptions to the montane ecosystem in the last 150 years, old trees are widespread in the Front Range. Trees in inaccessible locations and on poor sites often were not cut when logging was easier elsewhere. Rock outcroppings, steep slopes, ridgetops (fig. 24 a), and higher elevations (fig. 24 b) that were historically less accessible by road, less populated, and less susceptible to fire provided havens for old trees. Rock outcrops in meadows and the edges of meadows are also havens for old trees, as they were protected from intense fires.

We found relatively few old ponderosa pine trees below about 6500 ft (2000 m) elevation. Whether this is because trees at lower elevations were more accessible from settlements and were cut, or because there were just fewer trees there originally is unclear. Frequent fires and drought at low elevations probably confined trees to ridgetops, watercourses and rock outcrops, and historical photos bear this out (fig. 25). The lower foothills are now covered with ponderosa pine up to 120 years old, established since the beginning of fire exclusion. Above 6500 ft (2000 m), old ponderosa pine trees become more common. The higher elevations were historically less accessible by road and were less heavily populated, and fire may have

Figure 23a. A lightning scar on an old tree at Cheesman Lake. Lightning scars can sometimes look like fire scars, but they are usually long and narrow, extending down from the crown but sometimes not to the ground, and often spiraling around the trunk.

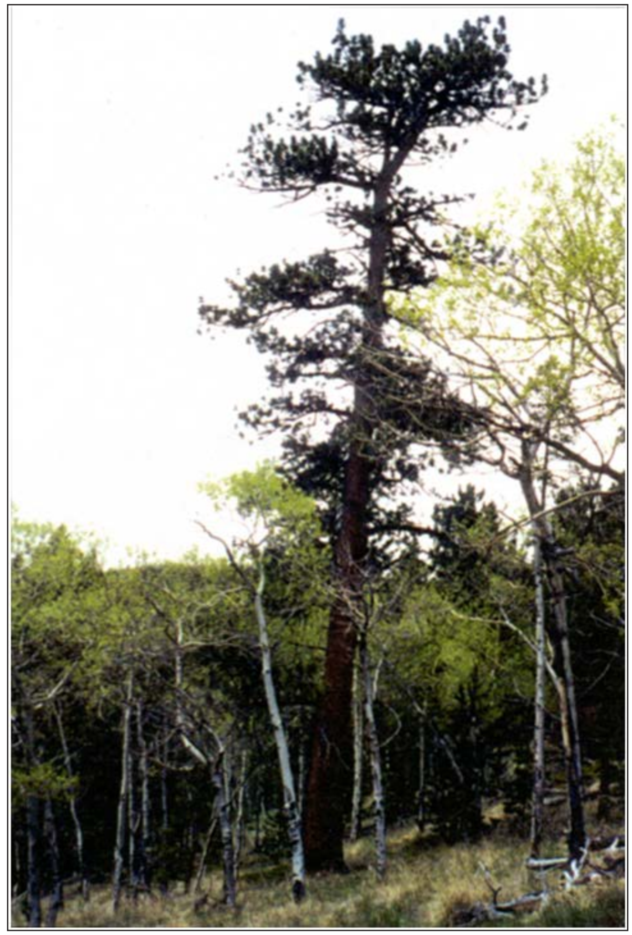
23b. Porcupine damage on a ponderosa pine. Porcupine scars can look like fire scars, but they are usually more irregular in shape and usually do not extend to the ground. The aspen behind it was damaged by elk.

23c. Dwarf mistletoe causes characteristic swellings on the branches and may create tangled “witches’ brooms” in the crown.



23d. Dwarf mistletoe infesting a ponderosa pine. This parasite deforms tree crowns and may give a younger tree an old tree crown shape prematurely.

Figure 24a. This old tree lives on a dry, rocky ridge along Highway 7. It is small, deformed, and rotten at the center, but it is more than 350 years old. It has a healed fire scar and a lightning scar, smooth gray bark, a flattened top, and a sparse open crown. Many of its neighbors are of similar age and are stunted by the harshness of the site.



24b. Though ponderosa pine forests are most common at lower elevations, older ponderosas can be found on sunny, south-facing slopes above their usual range. They may be relicts from a past climate or fire regime. This lone, old ponderosa pine lives on a south-facing slope at 10,000 ft (3077 m) elevation along the Old Flowers Road trail. Note the clone of young aspen around the old pine.

been less frequent. Rock outcrops in meadows and the edges of meadows are often havens for old trees in high valleys like Estes Park. Warm south-facing slopes as high as 10,000 feet elevation support old ponderosa pine trees, and older ponderosas are common in the mixed conifer zone, where they occur with lodgepole pine, limber pine, Douglas-fir, and aspen.

Old trees are often found on south- and west-facing slopes (fig. 26 a, b), on and around rock outcrops, at the edges of high meadows (fig. 27), and on the upper third of slopes. Even in areas that were logged and now support young forest, individuals with twisted or scarred trunks, rot, large limbs, and dead tops were often passed over by loggers. Old trees often occur in small groups, but it is unusual to find a stand in which all the trees are old. Old-growth stands are usually multi-aged. Of course, none of these suggestions is a rule. We found old ponderosa pine trees alone, on north-facing slopes, near rivers, in fairly dense stands, and right beside houses and campgrounds. Across a vista, groups of old trees are apparent as taller, rough-looking, browner areas amid the smoother, greener, more uniform-looking young forest.

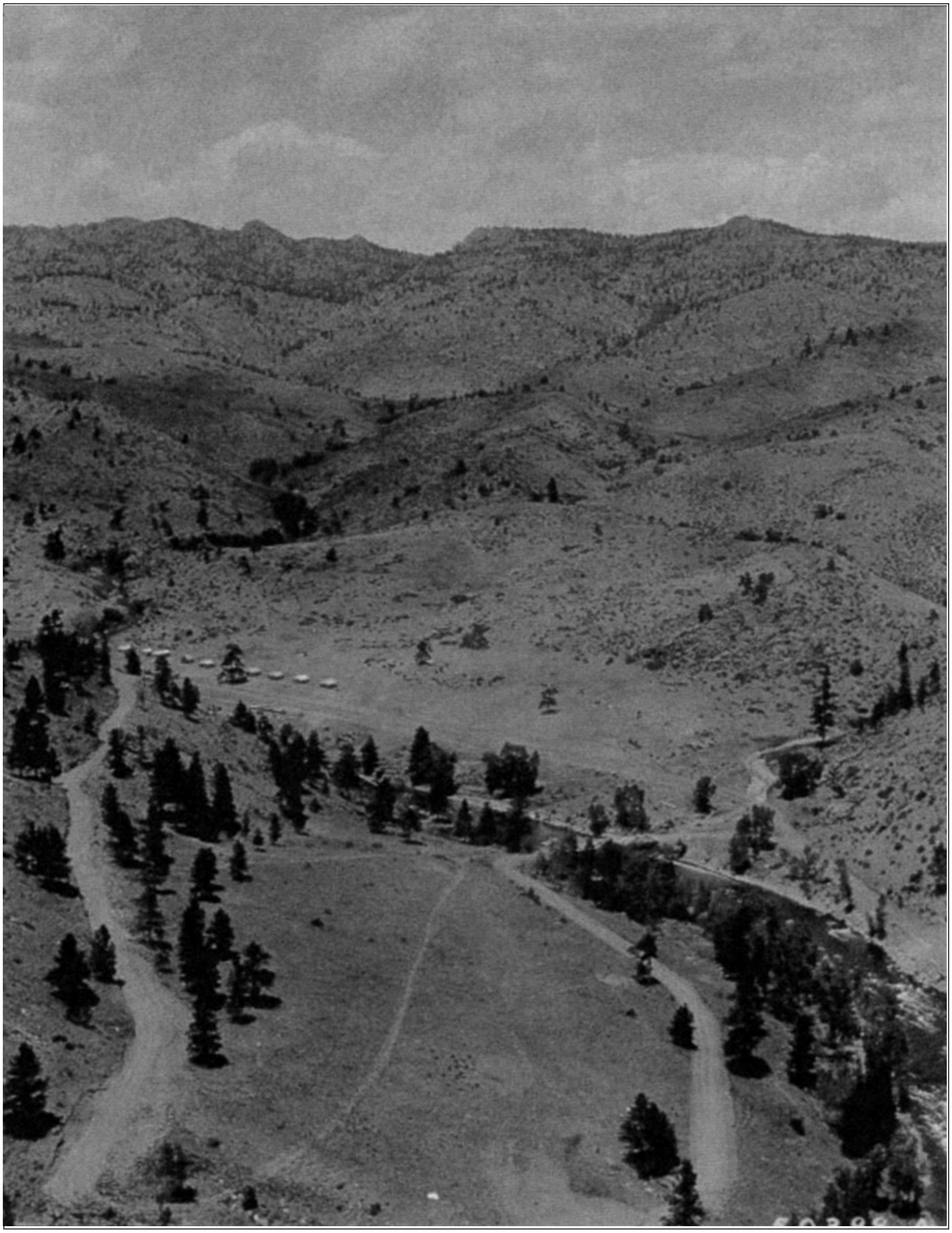


Figure 25. The lower Cache la Poudre River canyon in 1920. This picture was taken from Inspiration Point, looking northwest across the river from the new Bennetts Creek auto road (now the Pingree Park Road) into the area beyond Eggers. The road construction camp is in the left center. Most of the view ranges in elevation between 6000 and 7000 ft (1846 to 2154 m). Note how few trees were growing at this elevation. Most of the trees were along the river and other drainages (photo by W.I. Hutchinson, courtesy of Arapaho-Roosevelt National Forest archives).

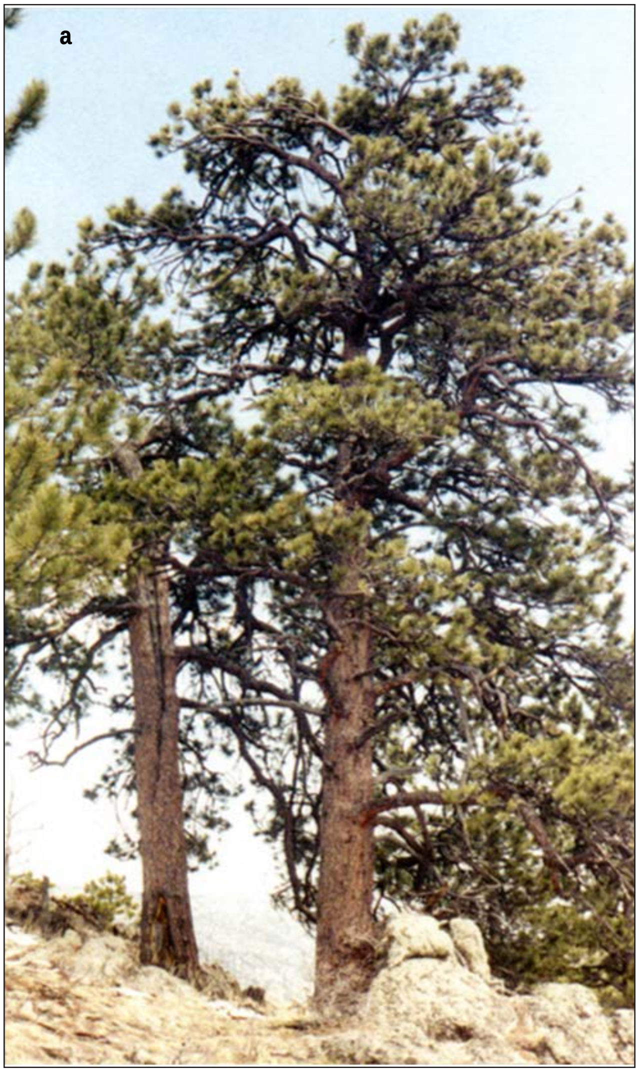


Figure 26a. Old trees growing on steep, rocky south- and west-facing slopes. These two old trees live on a rocky west-facing slope along the Crosier Mountain trail at around 7500 ft (2300 m) elevation. Both have smooth, gray-orange bark, gnarled branches, live crowns pruned up above the ground, and fire scars. The tree on the left also has a lightning scar, and its top is dead, probably killed by lightning. **b.** Old trees on open, grassy south- and west-facing slopes. This old tree lived on a barren, grassy-shrubby, south-facing slope at Cheesman Lake at 7066 ft (2174 m) elevation; its center was rotten, but its inside date was 1720, and its estimated pith date was 1550. It was typically open-grown, with a flattened top, large, gnarled branches, and pale orange smooth bark. It had a visible fire scar face with several scars.

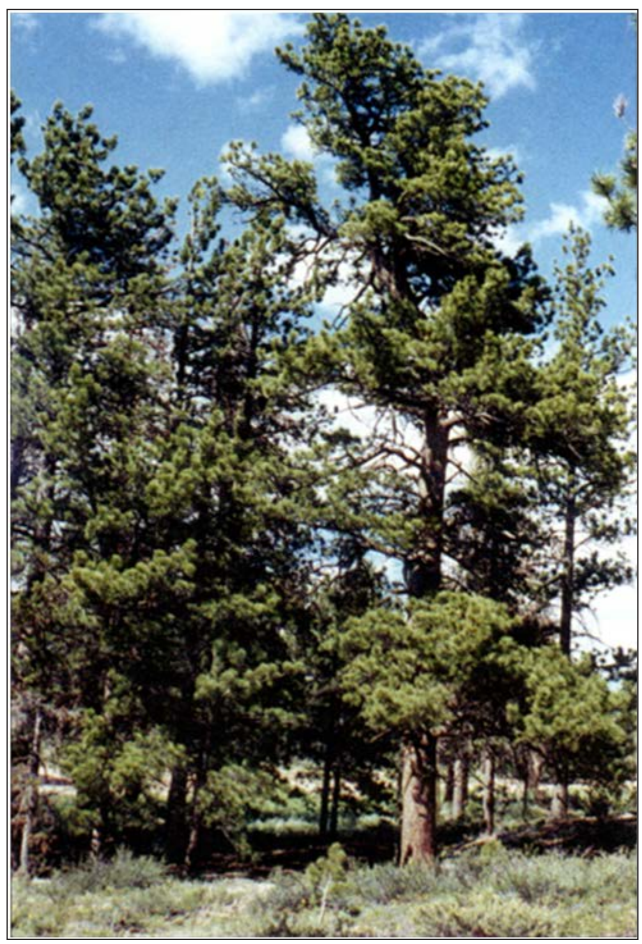


Figure 27. A classic old tree along the Redfeather-Rustic road at 8320 ft (2560 m) elevation; its pith date is 1569, its DBH is 24.4 inches (62.1 cm). It lives on the west edge of a rock outcrop in the midst of a meadow and has the typical flattened top, smooth orange-gray bark, and a fire scar.

Gallery of Old Tree Photos

How We Found Trees for This Publication

We searched for old trees along a north-south transect of the Front Range to capture changes in soils and weather conditions that vary along this latitudinal gradient. We took four excursions, each with multiple sampling locations: one along the dirt road from Rustic in the Poudre Canyon to Redfeather Lakes; one along the Pingree Park and Crown Point roads above the Poudre Canyon; one along the Glen Haven road from Drake to Estes Park (which is full of old trees that are all on private land), and then south along Highway 7 from Estes Park to Allenspark; and one in the Cheesman Lake property in the South Platte basin, which is owned by Denver Water. Based on other research from the Cheesman Lake property, we knew old trees were common there because much of that area was never logged. Except for Cheesman Lake, we did all our sampling on U.S. Forest Service land. We deliberately avoided canyons, that are historical and modern travel corridors, and where fire probably behaved differently. Our sampling locations are marked by yellow tree shapes in figure 1.

Old trees usually occurred in small groups. We selected trees from which we felt we could get a good picture and increment core, photographed them, and cored them with an increment borer to determine their ages. Coring usually does not damage the tree. We selected trees in a variety of growing conditions, from harsh to moderate to good sites. We were probably biased by taking pictures of trees in relatively open conditions, where it was easier to get a good picture. However, old trees seem more likely to occur in open conditions.

We grouped portraits of old trees by the site conditions on which they occurred, because site condition, as well as age, affect a tree's appearance (fig. 28). We chose trees on various slope positions and aspects and in both open and closed forest (though more in open forest) to represent the range of conditions under which old trees may be found. We also included a few portraits of younger trees under different site conditions for comparison. With each tree portrait, we report the tree's diameter at breast height (DBH; standardized to 4.5 ft [1.4 m]) above the ground). This is a general measure of a tree's size and is included to indicate their relative size under different conditions. We did not measure the heights of the trees.

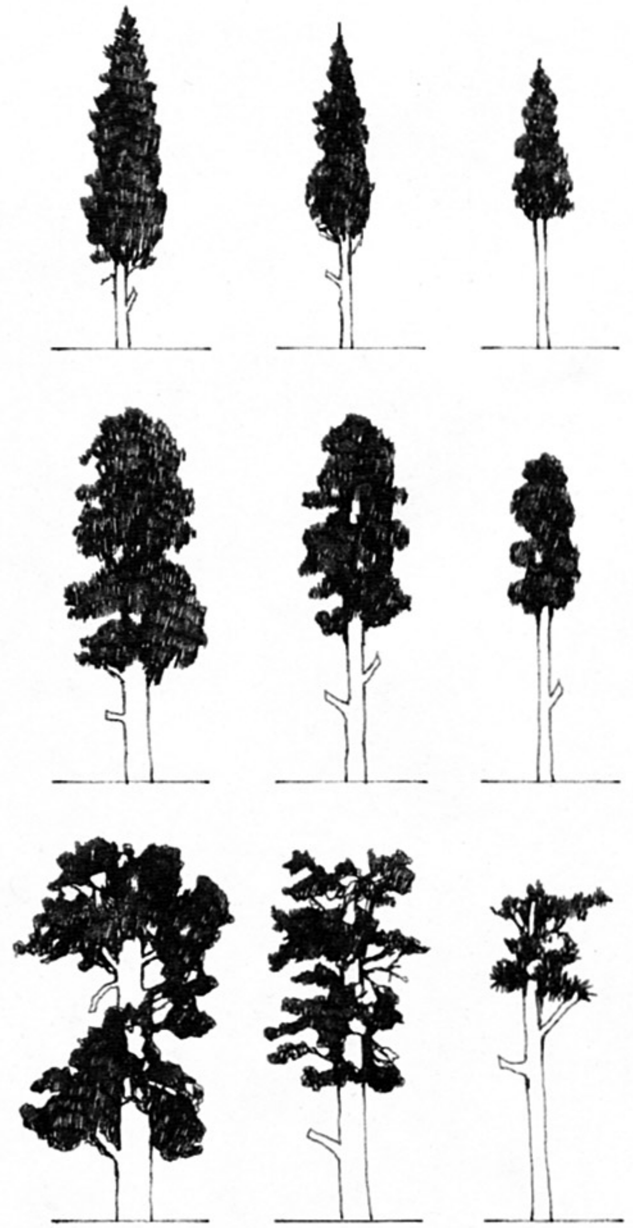


Figure 28. Idealized silhouettes of ponderosa pines of various ages and on various site conditions in the Front Range of Colorado (in the style of the Keen [1955] tree vigor classification for ponderosa pine in Oregon). The horizontal rows represent three age classes: top, the youngest, less than 150 years; middle, transitional trees 150 to 250 years old; and bottom, the oldest, trees more than 250 years old. The three site classes are represented by the vertical columns: left, good sites such as meadow edges and riparian areas; middle, moderate sites such as east-facing slopes or gentle slopes; and right, poor sites such as steep south-facing slopes or ridgetops (drawing by Joyce Vandewater).

We also report the tree's age, which we derived by cross-dating cores taken low on the trunk. We cross-dated the cores by matching ring-width patterns in the samples with composite chronologies from the area. When trees were rotten, we estimated their ages by estimating the number of rings that would fill out the remaining length of the tree radius and using a negative exponential curve to take into account age-related growth trends (see the Appendix for details). Most of the trees pictured are between 400 and 500 years old.

Old trees on poor sites (fig. 29 a, b, c, d, e, f)

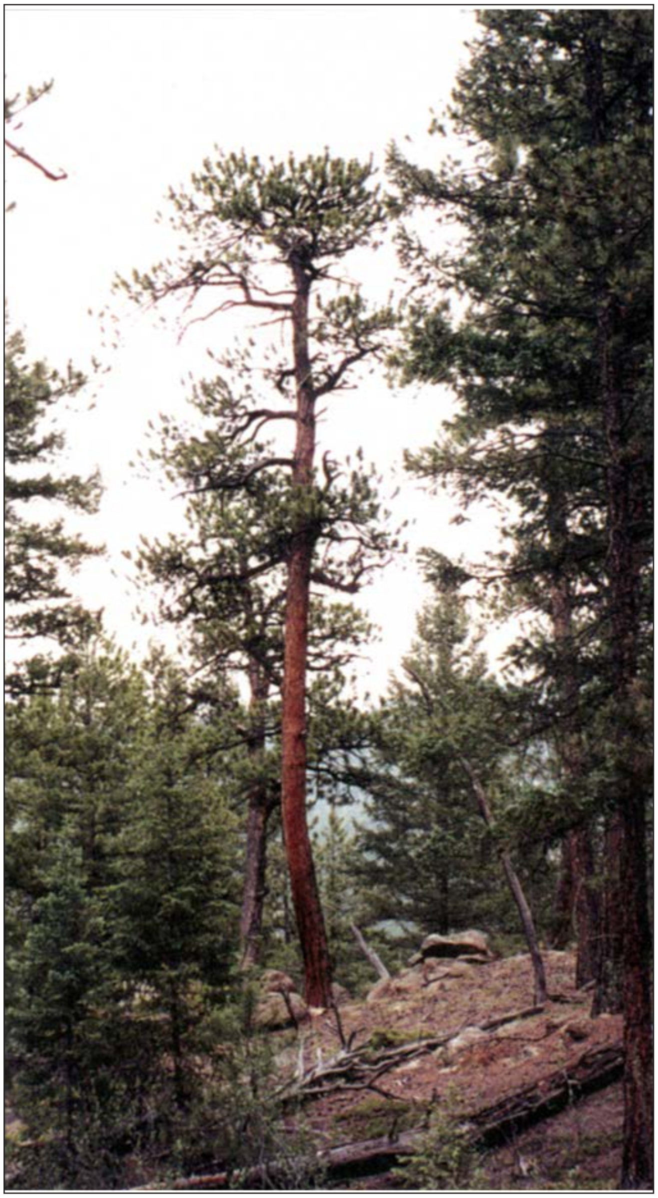
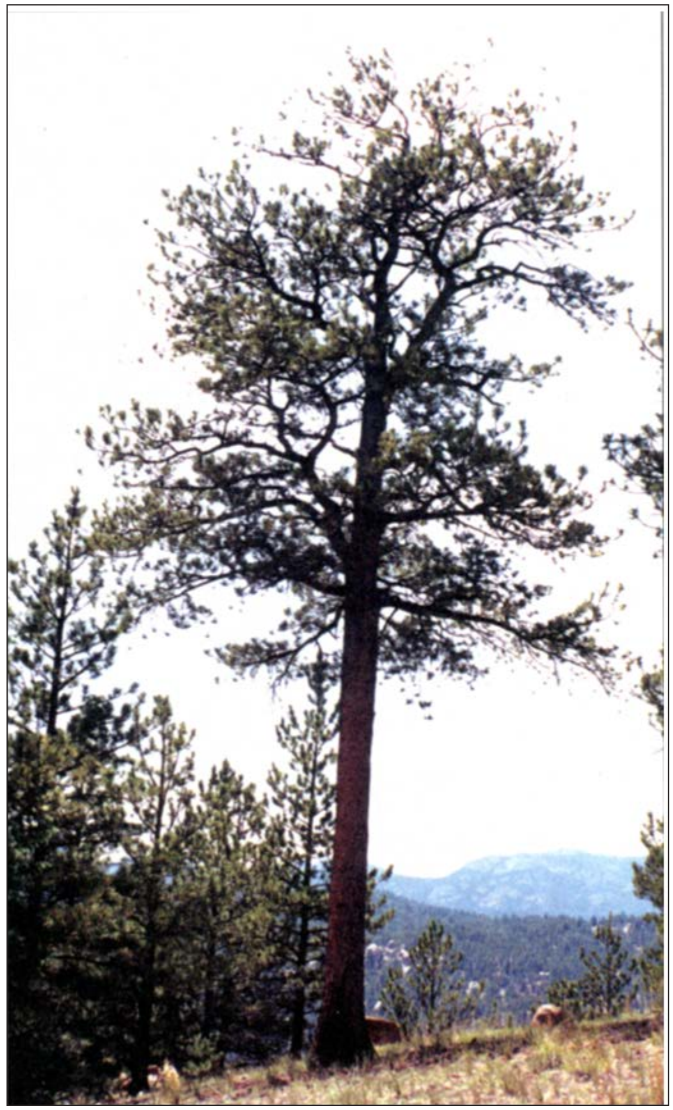
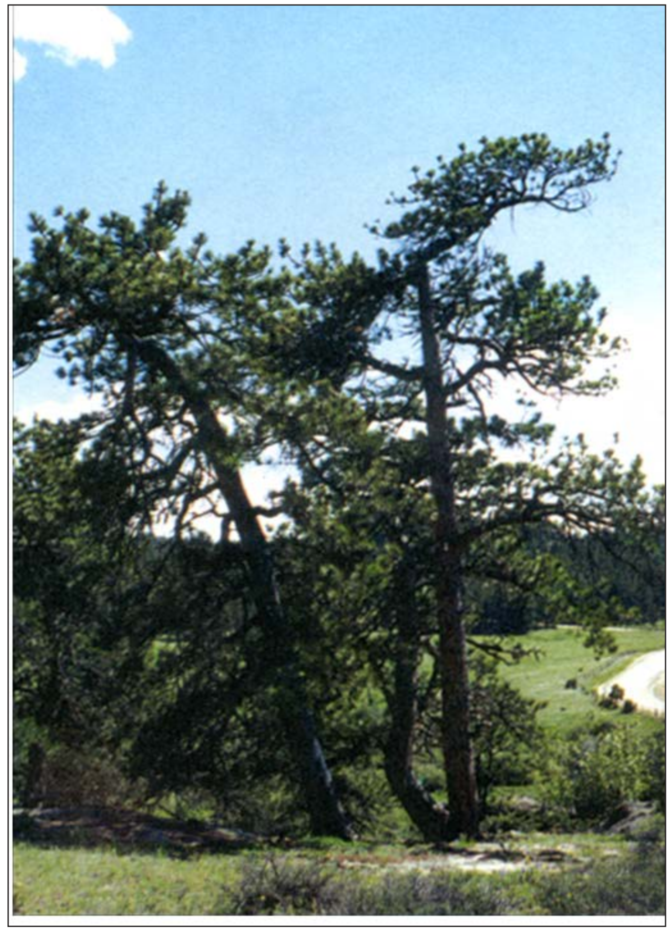


Figure 29a. DBH=18.4 inches (46.7 cm), pith date 1545. This was a typically scraggly looking old tree on a poor, rocky site. Its flattened, very sparse crown, small live crown ratio, and smooth orange bark were exaggerated by the harshness of the site. At 7319 ft (2252 m) elevation, this mostly east-facing ridge on the Cheesman Lake property is relatively low and dry, but young Douglas-fir populated the understory.

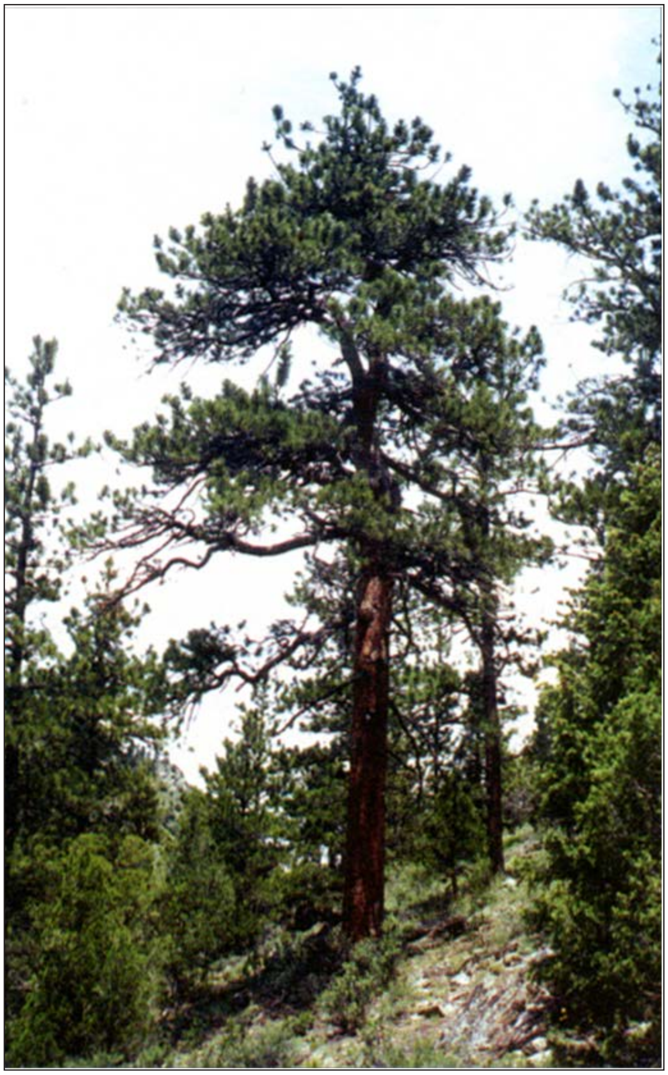


29b. DBH=20.8 inches (52.9 cm), pith date 1574. This tree lived in a common location for old pines: an open, south-facing slope just below a ridgetop at 7000 ft (2154 m) elevation on the Cheesman Lake property. It had a scar face with several fire scars, small live crown ratio, a sparse, slightly flattened, open-grown crown, and smooth orange bark.

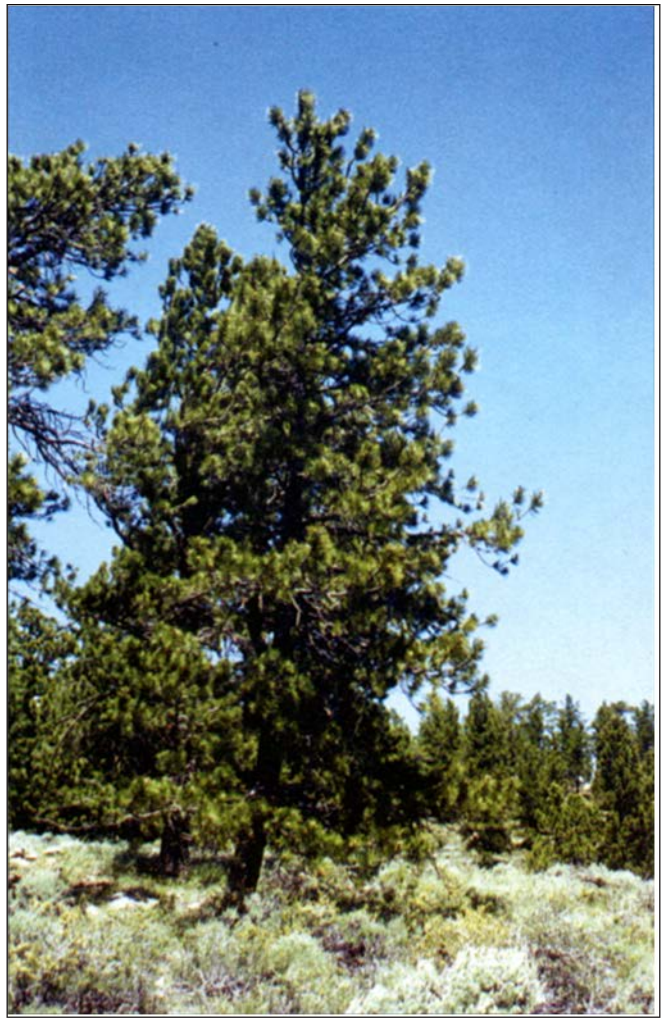
29c. DBH=18.8 inches (47.7 cm), pith date 1605. This small old tree grows on a poor, rocky site at 8778 ft (2701 m) elevation, relatively high for ponderosa pine. It has been encroached by aspen and lodgepole pine. It has a somewhat flattened top, a very sparse crown and tiny live crown ratio, smooth orange-gray bark, and four fire scars. It lives along Highway 7 at Meeker Park.



29d. DBH=15.2 inches (38.5 cm), pith date 1560. This group of old trees lives on a rock outcrop in the middle of a meadow along the Redfeather-Rustic road at 8307 ft (2556 m) elevation. We cored the tree on the left. The flattened tops, deformed crowns, small live crown ratios and smooth orange-gray bark identify them as both old and stressed.



29e. DBH=21.4 inches (54.3 cm) inside date 1663, est. pith date 1521. This tree lives near seven other old trees on a steep, rocky, west-facing slope at 7592 ft. (2336 m.) elevation along the Mt. McConnell trail. Evidence of local disturbance includes many fallen trees. It and its neighbors are infested with dwarf mistletoe. Nearby trees have fire scars from 1851, 1707, and 1700. This tree has typical smooth orange-gray bark, a flattened top, twisted and pruned branches, and a big burl (caused by an injury) beside a fire scar. It is rotten in the center.



29f. DBH=12.5 inches (31.7 cm), pith date 1889. This younger tree lives on a south-facing slope near ridgetop at 8453 ft (2601 m) elevation along the Redfeather-Rustic road. Its pointed crown, long live crown ratio, and darker bark indicate that it is younger than some of its neighbors, though its small size attests to the harshness of the site.

Old trees on moderate sites (fig. 30 a, b, c, d, e, f)

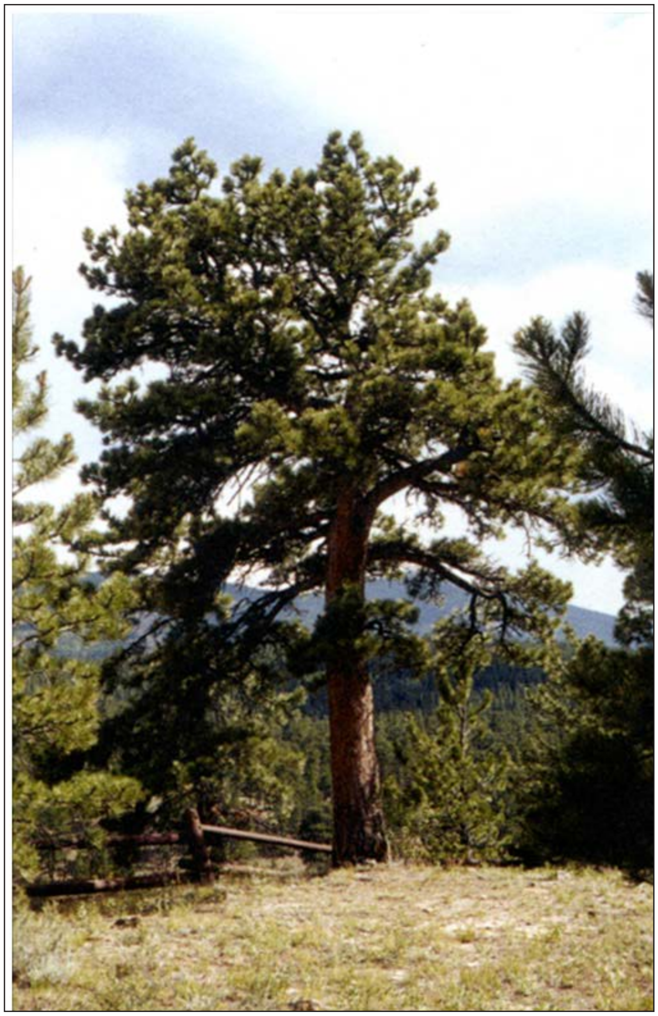
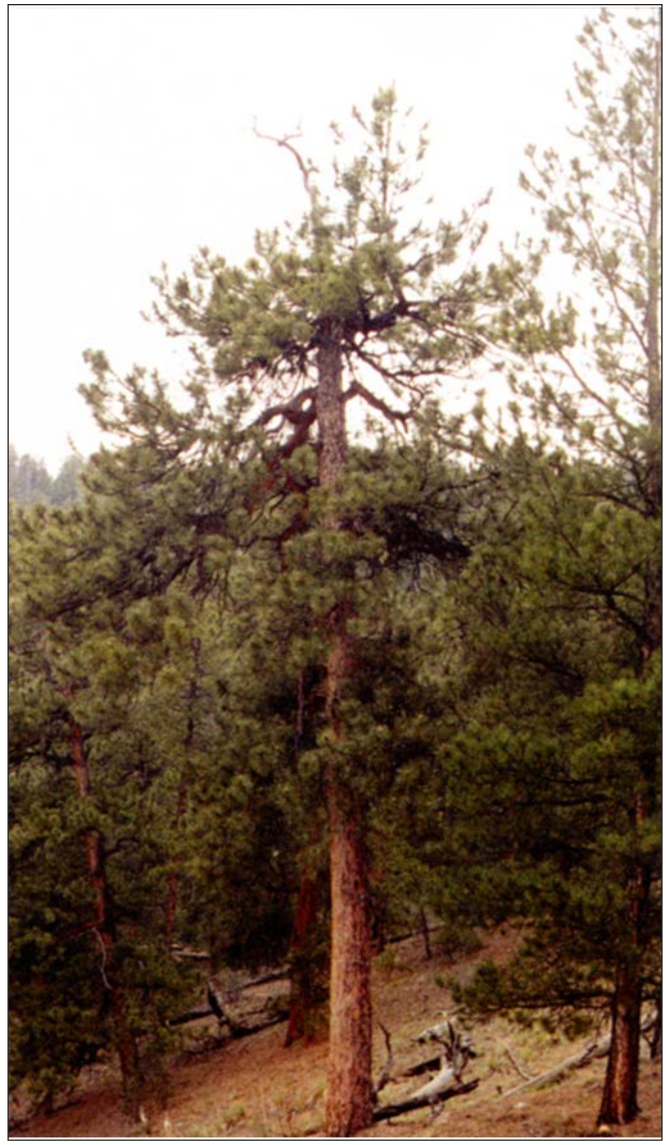
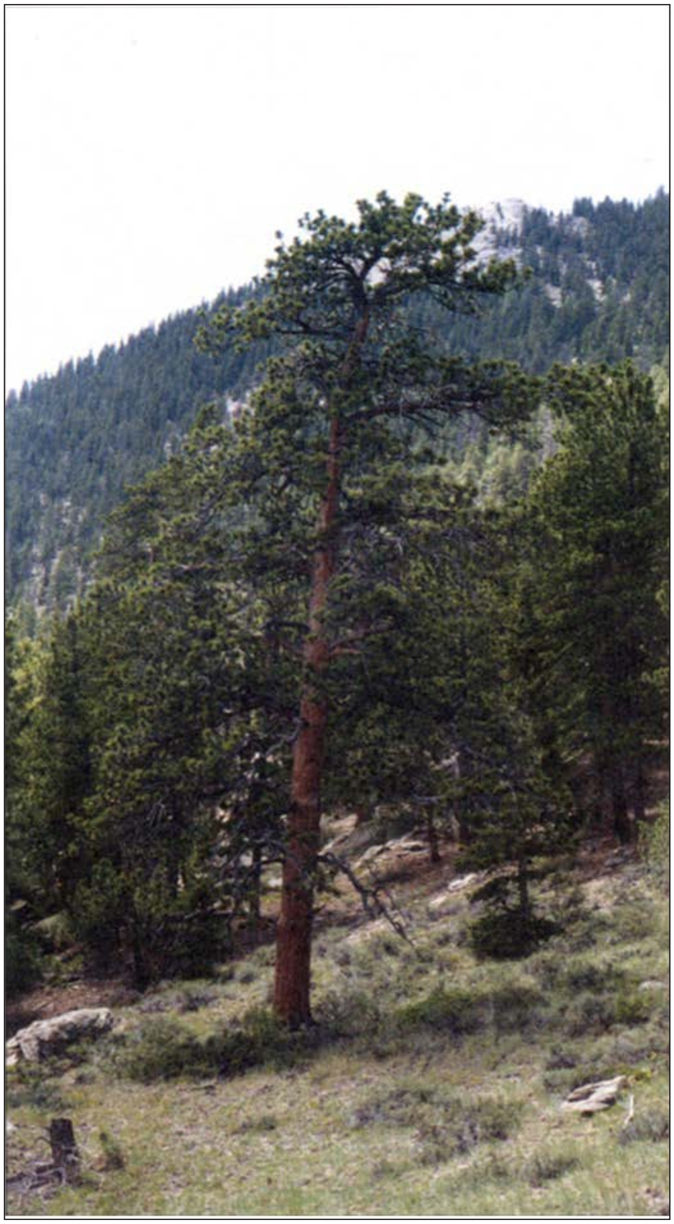


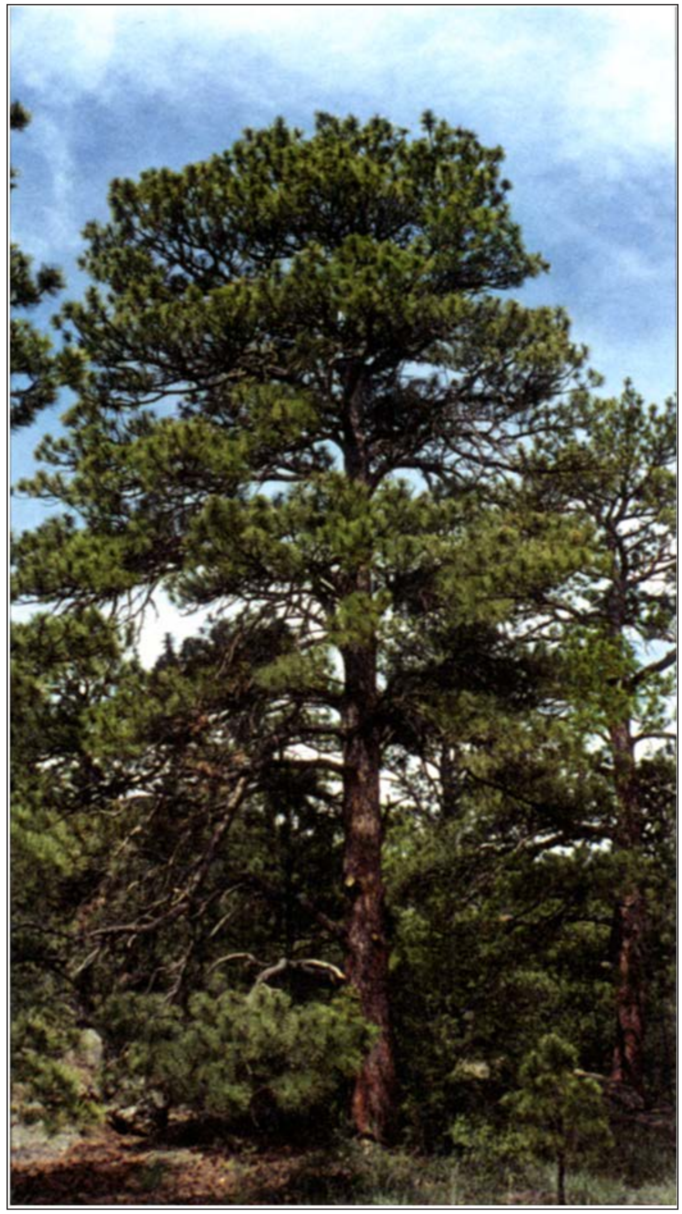
Figure 30a. DBH=19 inches (48.4 cm), pith date 1589. This tree grows on the edge of a north-facing ridge at 8307 ft (2557m) elevation along Highway 7 at Olive Park. It is open-grown but not very tall. It has a flattened top, smooth orange bark, large branches, and fire scars on the north side.



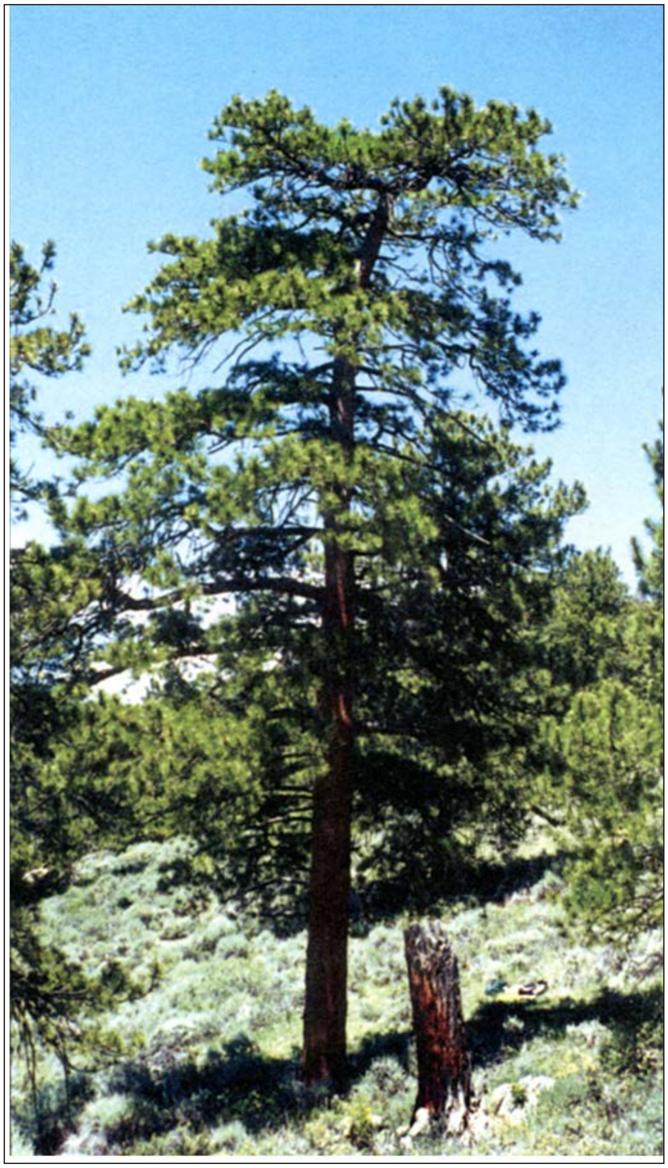
30b. DBH=20.6 inches (52.3 cm), inside date 1744, est. pith date 1626. This tree lived on an open east-facing slope just below a ridge on the Cheesman Lake property at 7319 ft (2252 m) elevation. The entire stand was old; there were many fallen trees, perhaps killed by a past fire. The tree was rotten in center, possibly because of its dead top. It had very smooth, pale bark and a sparse, open-grown crown.



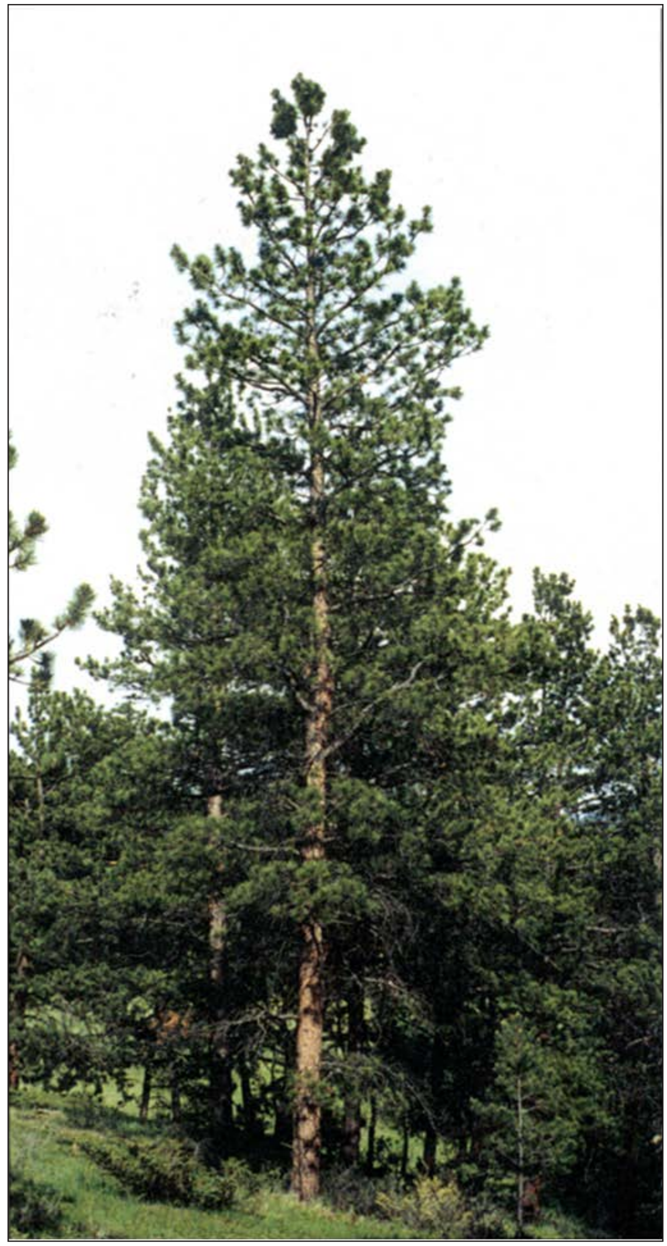
30c. DBH=25.3 inches (64.2 cm), pith date 1595. This open-grown tree lives in an east-facing meadow at 8710 ft (2680 m) elevation along Highway 7. It has classic old-tree characteristics: the flattened, “bonsai” open crown and the smooth orange bark. Though it lacks visible fire scars on the trunk, its lower branches are charred from past surface fires.



30d. DBH= 23.4 inches (59.5 cm), pith date 1769. This middle-aged tree lives on a flat, rocky ridgetop along the Pingree Park Road at 7293 ft (2244 m) elevation, in a location that sees heavy recreation use and has much ingrowth of Rocky Mountain juniper. It has a full, open-grown crown that is beginning to flatten at the top, fire scars, wounds from bear scratches, and bark beginning to shift from dark gray to orange.



30e. DBH=24.4 inches (62 cm), pith date 1527. This tree inhabits a gentle, open, south-facing slope near the hilltop along the Redfeather-Rustic road at 8453 ft (2601 m) elevation. It has a typical flattened top and smooth orange bark. Because it is on a moderate site, it has a fuller crown than trees of similar age on poor sites. A core revealed a rot pocket from a healed fire scar—perhaps from the same fire that killed the short snag beside it?



30f. DBH=15.7 inches (40 cm), pith date 1887. This tree lives on a gentle east-facing slope at the edge of a meadow along the Crown Point road at 8425 ft (2500 m) elevation. It has the typical pointed top of a rapidly growing tree, no visible scars, and a long, full crown. Its bark is fissured, beginning to turn orange, and lower branches are starting to self-prune.

Old trees on <u>good</u> sites (fig. 31 a, b, c, d, e, f)

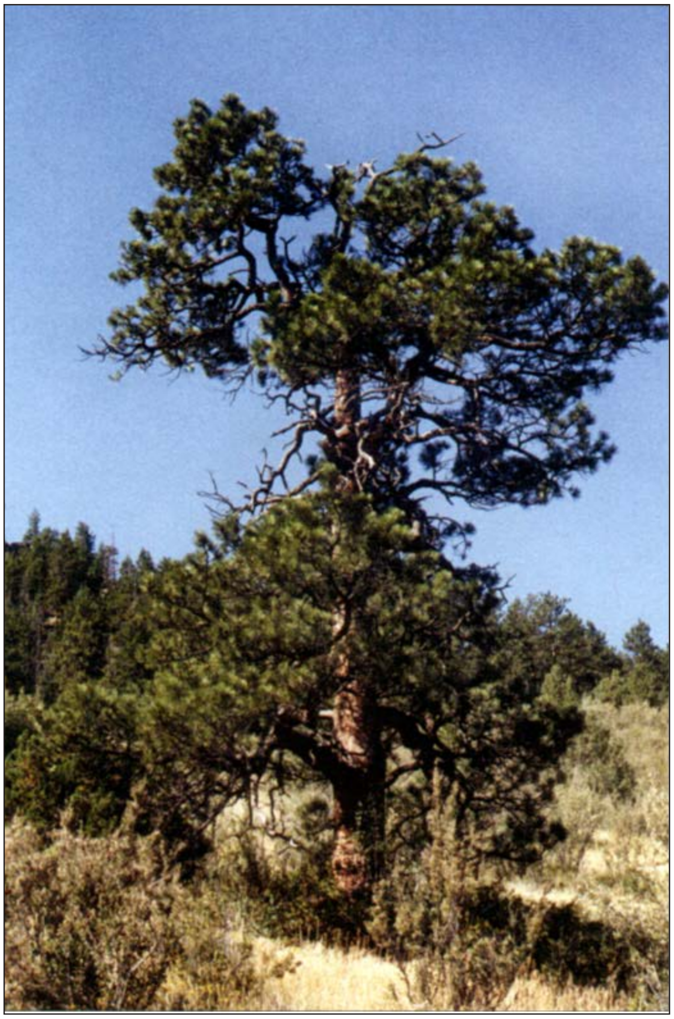
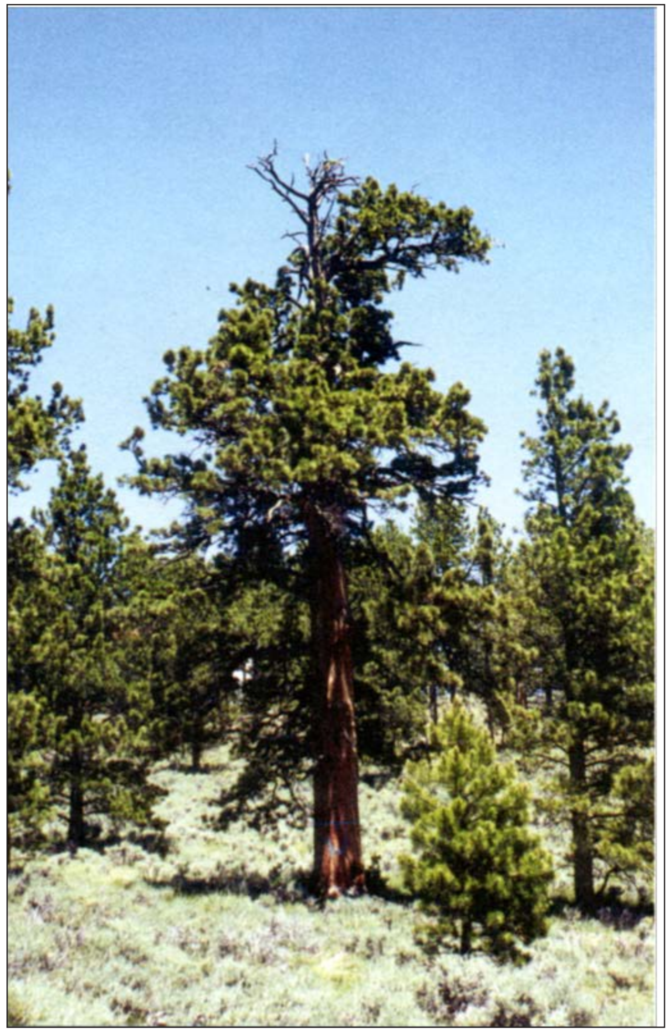
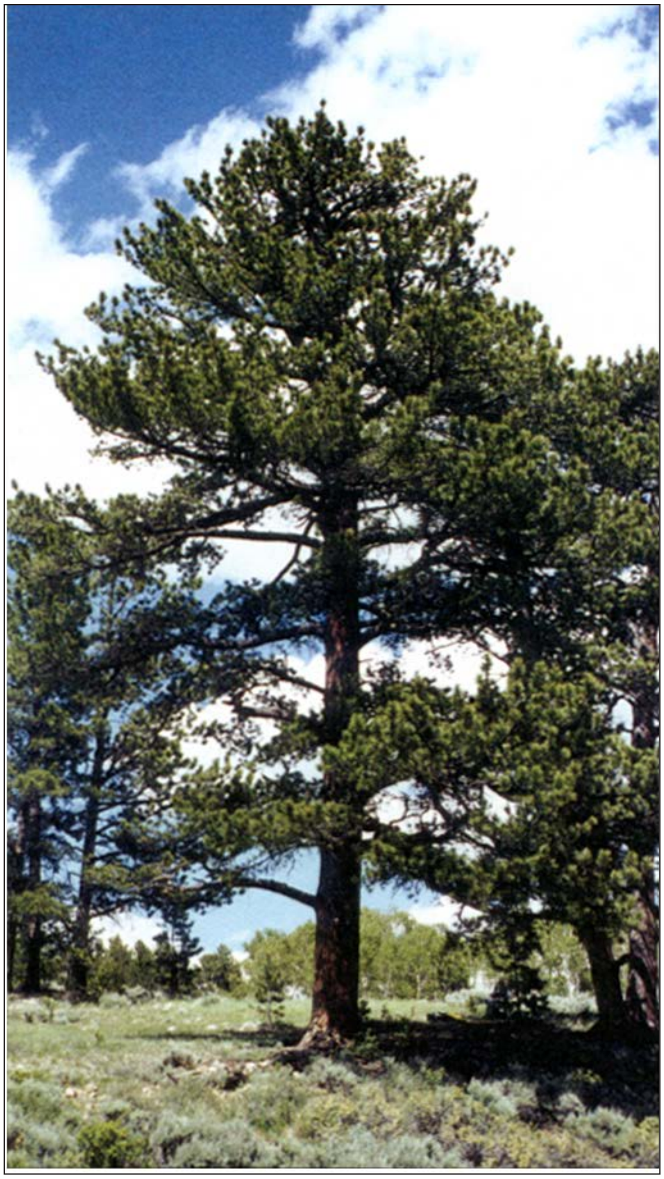


Figure 31a. DBH=27 in (68.5 cm), inside date 1718; est. pith date 1581. This large tree lives on a grassy, shrubby, gentle north-facing slope at 6409 ft (1972 m) elevation above a river valley along the Glen Haven road. Its center is rotten, probably because of its dead top. It is open-grown, with large heavy branches, a dead top, smooth orange bark, a sparse crown, and a large burl near the base.

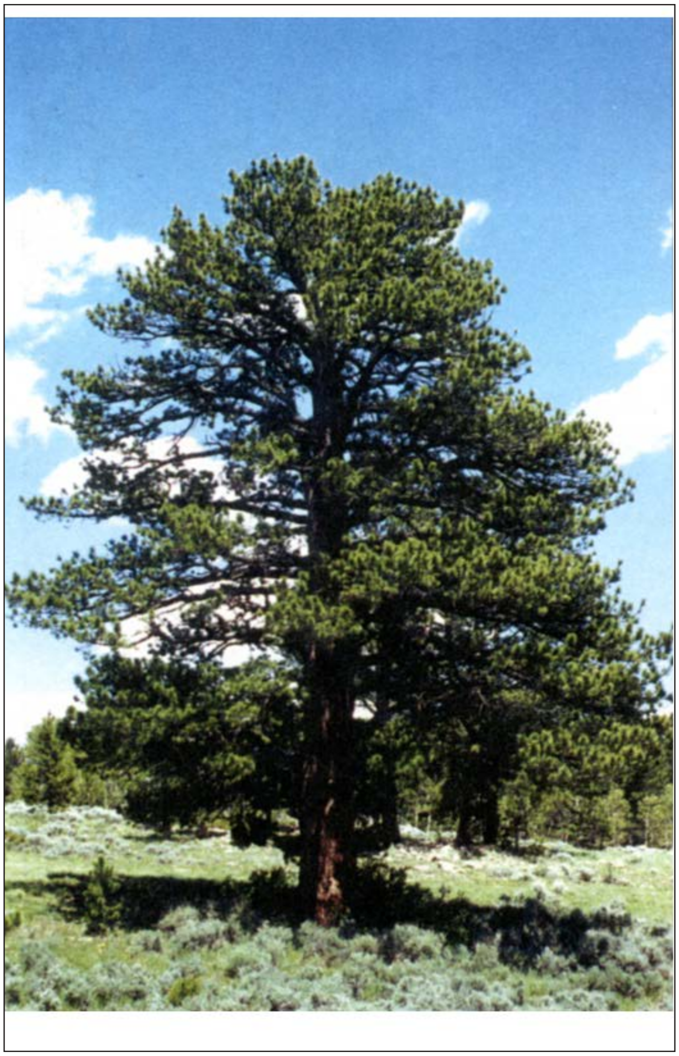


31b. DBH=40.8 inches (103.8 cm), inside date 1729; est. pith date 1486. This ancient tree grows on a flat bench above a southeast-facing slope, just below the ridge at 8453 ft. (2601 m.) elevation, along the Redfeather-Rustic road. It is the oldest and largest tree in the vicinity. It has a dead top, smooth red-orange bark, small live crown ratio, and large, heavy branches. No fire scars showed on the trunk, but it had an axe scar from long ago. It has been marked by the U.S. Forest Service for preservation as a wildlife habitat tree. It was rotten in the center. This was the second-largest and second-oldest tree we found.

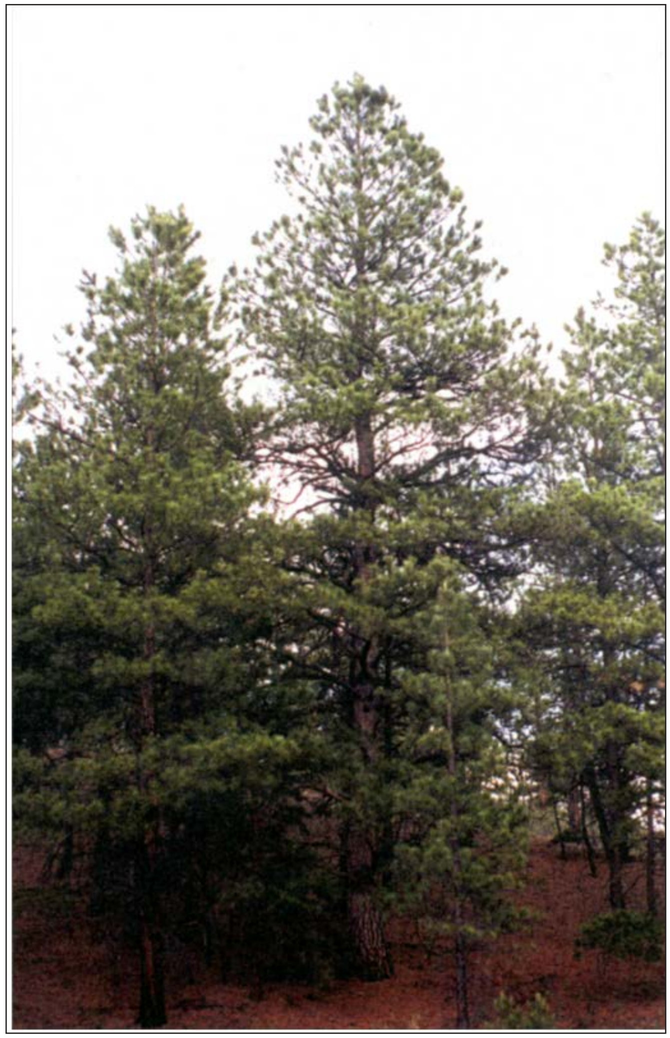


31c. DBH=31 inches (79.1 cm) inside date=1586; est. pith date 1539. This tree lives in a flat sage meadow at the abandoned townsite of Manhattan, 300 ft (100 m) above a stream at 8460 ft (2603 m) elevation along the Redfeather-Rustic road. The center was rotten. It is typically open-grown and has smooth orange bark, but because it is on a good site, its old tree crown characters are subtle; the crown is more rounded and full than a tree of similar age on a poor site.

31d. DBH=25.4 inches (64.6 cm), inside date 1600, est. pith date 1462. This old tree, surrounded by a cluster of younger ones, lives at 8125 ft (2500 m) elevation along the Crown Point Road at the base of a gentle, east-facing slope near the edge of a meadow. It was rotten in the center. It has a deformed, dying top, a lopsided crown with lower branches scorched on the underside, and a scar on the uphill side. If the estimate of age is correct, this is the oldest tree that we sampled.



31e. DBH=42.5 inches (108 cm) inside date=1710, est. pith date 1614. This tree also lives in the flat sage meadow at the abandoned townsite of Manhattan, 300 ft (100 m) above a stream at 8460 ft (2603 m) elevation along the Redfeather-Rustic road. The tree was so large our borer could not quite reach the center, so we estimated its pith date. It is the largest tree we sampled. It is typically open-grown, and has smooth orange bark, but because it is on a good site, its old tree crown characters are subtle.



31f. DBH=31.9 inches (81.2 cm) pith date 1879. This large, open-grown young tree was being encroached by younger ingrowth of ponderosa pine and Douglas-fir. Its growth rate was tremendous. It lived on the Cheesman Lake property on a gentle west-facing slope not far from a perennial stream at 7157 ft (2202 m) elevation. It had dark, fissured bark, a long live crown, pointed top, and no scars. It was one of the largest trees we sampled.

Conclusion

The pre-Euro-American settlement history of the Front Range is not recorded in the form of ruins or artifacts, but in the living monuments of old trees. Ecological restoration efforts intended to reconstruct the landscape as it was before Euro-American influence must conserve old trees, which were an integral part of the landscape. To do that, workers must be able to identify old trees, define treatment prescriptions that preserve them, and create conditions that will allow them to persist. Existing trees that are 200 years old or more will form the basis for future old growth stands.

Why Keep Old Trees?

• *Restoration to a more historical and ecologically sustainable state.* We know that old trees were more common in the Front Range before Euro-American settlement than they are now. They contributed to the operation of natural processes that sustained the ecosystem. A sustainable montane ecosystem must contain old trees.
• *History.* Old trees preserve the history of climate and fire in their rings, and they continue to record this history as they grow. Older stands give us a better idea of what the area looked like before settlement and how natural processes operated in the absence of intensive human influence.
• *Wildlife benefit.* Old trees provide habitat for wildlife in their dead branches and hollow trunks. They produce seeds that are food for wildlife. Old, open stands support diverse vegetation and provide suitable cover for deer and elk. Rotting wood harbors fungi and insects that provide food for bears and other animals.
• *Fire resistance*. Old trees are fire-resistant. They survived many fires before settlement, and if the forest is thinned to reduce ladder fuels, they will likely survive many more. Surface fires can burn through older stands with historical densities without killing all the trees.
• *Aesthetics*. Many people find old trees to be beautiful. Their shapes are graceful and interesting. Older stands, with open, grassy understories and large, shapely old pines are very attractive, much more so than a dense jungle of adolescent Douglas-fir. Beautiful scenery is part of what draws tourists to Colorado.

Old ponderosa pine trees are living embodiments of the history of the Front Range. Despite dramatic changes in human land use, stand structure, climate, and disturbance regimes during their lifetimes, many old trees survive, even adjacent to urban development. The individual ponderosa pine trees pictured in this book were part of the historical landscape. Some were here when Coronado led his band of explorers into Kansas in 1541; all of them had been here for centuries before Major Long's expedition first sighted Long's Peak in 1820. These trees persisted through the gold rush and intensive land use of the 19th century. The end of the 20th century has left them in an environment unlike any they have experienced, where the danger of wildfire, competition, and disease is greater than ever before.

As we move into a new century with a new, developing philosophy regarding our relationship to our environment, old trees can assist in shaping the future of the landscape with lessons from the past. Because landscape-altering activity by humans is relatively recent in the Front Range, land managers have a better chance here than in most locations to understand and recapture the structure and function of the landscape before it was dramatically altered by human activity. To create a sustainable landscape where humans, old trees, and the other elements of a healthy forest can coexist, we must preserve the old trees as we restore the ecosystem to a more sustainable and historical state.

Postscript

As of this writing (September 2002), the Hayman fire, which started on June 8, burned almost 138,000 acres (55,870 ha) over much of the montane zone of the South Platte basin, destroying homes and businesses—and old trees. The trees from Cheesman Lake pictured in the Gallery are all dead (fig. 32). A thousand-year-old log on the south end of the property, which survived 17 fires as a living tree and more after it was dead, is largely consumed. The Hayman fire was human-caused, driven by high winds, extreme drought, and dense, continuous fuels. The fire season of 2002 started early and burned more acreage in Colorado than in the last 10 years combined. The combination of altered stand structure, the worst drought in decades, and an increased human population have created an unprecedented situation. Hopefully restoration work in the montane forests of the Front Range will protect remaining old trees.

Acknowledgments

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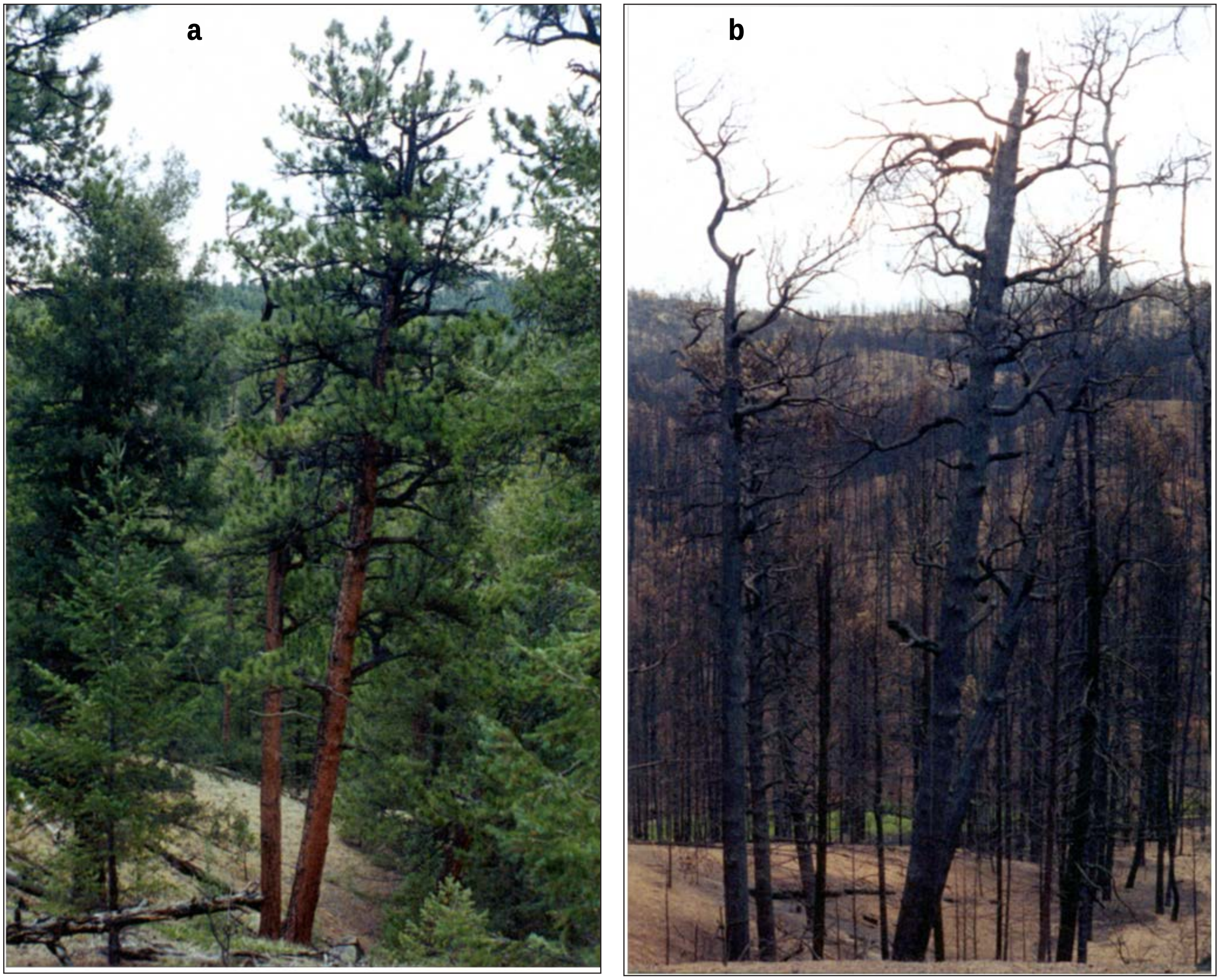

Figure 32. Before and after the Hayman fire, 2002. **a.** This old tree grew on a small east-facing ridge on the south end of the Cheesman lake property. We cored the tree on the right; its pith date was 1635. Though there were a number of old trees in this stand, note how dense it was, particularly with ingrowth of young Douglas-fir. **b.** The same old tree in late July 2002, about a month after the Hayman fire burned intensely through the area. Note that all of the sparse grass, shrubs, small trees and nearly all of the coarse woody debris on the ground have been consumed. The needles and small branches in the tree crowns were also consumed. Sprouting willows in the riparian area to the east are the only evidence of life in the photo. The riparian area and the hills beyond are not visible in photo a because of dense forest, evident in photo b by the charred skeletons of small trees. The smaller tree to the immediate left of the tree we cored has fallen to the right. It may be many years before trees will regenerate in this landscape, and many centuries before there is an old-growth stand on this ridge again.

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Appendix

Dendrochronology

Dendrochronology is the science of using tree rings dated to the exact year of their formation to analyze temporal and spatial patterns of processes. It works because in temperate regions, woody plants add a distinct layer of growth every season. The width of each annual growth ring (the wood produced in that year) is constrained by limiting factors in the plant's environment. In semiarid environments like the ponderosa pine zone of the Front Range, the variation in ring width is usually caused by variation in water availability, especially early in the growing season (Woodhouse and Brown 2001). At higher elevations, temperature is usually more limiting to tree growth.

The fundamental principle of dendrochronology is crossdating—matching the patterns of ring width with other tree ring series of known date in order to assign an exact calendar year to each ring (Stokes and Smiley 1968). Crossdating allows dendrochronologists to positively date pieces of wood for which the year of death or the pith date are not known. Without crossdating, we could only count the rings, not be sure of their year of formation. By analyzing multiple samples from an area, we can minimize the noise created by the growing conditions experienced by individual trees and statistically filter out all but the effects of interest (such as climate or disturbance).

This is important in places such as the Front Range where growing conditions are harsh and samples are likely to have false rings or missing rings. In some years a tree may be unable to produce any wood at all in the part of the stem that was sampled, and this condition shows up as a missing ring in the sequence. Some of the samples used in this publication were missing as many as 20 rings. During some years water is available in the spring but conditions become very dry in the middle of summer. The growth process slows and the tree produces cells that look like the small, thick-walled latewood cells typical of the end of the growing season. If water becomes available again in the late summer, the tree may begin to grow normally again, and a false ring is formed.

Dendrochronologists select trees growing on sites that are sensitive to some limiting environmental quantity. For example, sampling a tree growing along a riverbank will not provide information about rainfall patterns because the tree already has as much water as it needs and its growth will not respond much to variation in precipitation. Trees are usually sampled with an increment borer, a hollow instrument like an auger that removes a pencil-sized sample of wood (see fig. 7 b; 22 a, b, c). This does not usually damage the tree. Cores are glued to a strip of stronger wood and sanded with fine sandpaper so the cells within the rings can be seen under a stereomicroscope. Samples can then be cross-dated visually. The widths of the rings can be measured using a computer-based instrument and these measurements can be statistically analyzed or combined with others to create a chronology.

The principles of dendrochronology can be applied to many fields of study. Tree rings can be used to date the construction of archaeological ruins (Douglass 1929), to reconstruct past climate using the relationship between tree ring width and instrumental temperature and precipitation data (Fritts 1976), to reconstruct the history of global climate events such as the El Niño-Southern Oscillation (Woodhouse 1993), to detect the effects of pollution (Cogbill 1977), and to detect and date forest disturbances that affect tree growth (Veblen and others 1991) including insect outbreaks (Swetnam and Lynch 1993) and fires (Brown et al 1999).

Dendrochronology can be used to reconstruct fire regimes by dating fire scars and determining forest age structure. Samples are taken from fire-scarred faces on living trees and remnant wood by cutting a partial or complete section with a chainsaw. The wood is sanded finely and cross-dated just as cores are. The fire scars are localized within cross-dated rings on each sample. Fire scar dates collected from the same geographic area can then be statistically analyzed.

The mean fire interval (MFI) is the average number of years between fire dates. It can be computed for a single sample or for all samples from a site combined. Because it is possible to have a minimum number of years in an interval (1), but not necessarily a maximum interval, the data are often positively skewed. For that reason, the Weibull Median Probability Interval (WMPI) is sometimes used to express the average time between fire events because it does not assume normal distribution of the data as the MFI does. The minimum and maximum intervals between fires at a given location are also important, as they give an idea of the range of times between fires (Grissino-Mayer 2001).

Fire scar sampling gives a conservative estimate of the number of fires that occurred in a location. Not every tree is scarred by every fire that it experiences, and two adjacent trees might record different fire dates, or none at all, even though fires occurred there. Also, fire scars only occur on trees that survived fires, which occurs when the fire at that location was a surface fire. This can occur around the edges of a crown fire, as well. The effects of stand-replacing fires are determined by sampling the age structure of a forest. If most of the oldest trees in a stand germinated around the same time following a fire date confirmed by fire scars, it is likely that the fire was stand-replacing in that location. Death dates from logs that retain their outer rings under bark can also confirm the date of a stand-replacing fire.

For excellent information on all aspects of dendrochronology, go to the Ultimate Tree-ring Web Pages, http://web.utk.edu/~grissino/.

Glossary of Terminology

Canopy cover—a measure of forest density. For a given area, it is the percentage of the ground that is covered by tree crowns. This is most often measured from aerial photographs.

Cambium—the growing tissue of a tree immediately under the bark; every growing season, the cambium produces a layer of wood.

Community—an assembly of organisms that tends to occur together under similar environmental conditions; usually considered to be a smaller spatial scale than an ecosystem.

Cross-dating—the dendrochronological method of assigning a calendar year to a tree ring by matching patterns of ring width to patterns in a composite chronology of known dates.

Crown—the leaves and live branches of a tree.

Crown fire—an intense fire that consumes the crowns of the trees. Active crown fire burns from tree crown to tree crown, killing most of the trees. Passive crown fire involves torching of individual trees. Crown fires occur naturally in some ecosystems on an infrequent basis (about every 150 to 300 years in lodgepole pine, for example); it usually occurs under conditions of dense fuels, high winds, and severe drought.

DBH—(diameter at breast height) a measure of tree size; the diameter of the trunk at 4.5 ft (1.4 m) above the ground.

Dendrochronology—the science of precisely dating tree rings based on patterns of annual ring width; see Appendix for details.

Disturbance—a process that changes the structure of a population; in ponderosa pine forests, this includes fires of varying intensities, insect outbreaks, logging, grazing, windthrow, etc.

El Niño-Southern Oscillation (ENSO)—a climatic phenomenon characterized by weakening of trade winds and sea surface warming in the eastern and central equatorial Pacific Ocean which occurs ever 2 to 7 years and affects weather around the world. In the American Southwest and West, El Niño conditions are usually warmer and wetter than normal. Anomalously cold sea surface temperatures in the equatorial Pacific causes La Niña conditions, which are usually cool and dry in western North America. The Southern Oscillation Index (SOI) is the change in the difference in tropical sea level pressure between the eastern and western hemispheres that accompanies El Niño conditions. High SOI (large pressure difference) is associated with strong trade winds and La Niña conditions; low SOI (small pressure difference) is associated with weaker than normal trade winds and El Niño conditions.

Front Range of Colorado—generally described as the mountains and foothills of northern Colorado, bounded on the west by the Continental Divide, on the east by the Great Plains, on the north by the Wyoming border, and on the south by Pikes Peak.

Fire intensity—the heat output from a fire.

Fire regime—the pattern of fire frequency and intensity in a given area over time.

Fire severity—the ecological effects of a fire.

Gradient—A gradual change in a quantity that occurs with the change in a given variable; for example, temperature declines with increasing elevation.

Live crown ratio—the percentage of the tree trunk that supports living branches; a tree with 100% live crown ratio has branches all the way to the ground.

Montane—refers to middle-elevations; in the Front Range, between about 6000 and 9000 ft (1845 to 2770 m) in elevation, below the line of persistent winter snowpack. This zone is dominated by coniferous forests of ponderosa pine and Douglas-fir, with patches of aspen and openings that may be shrubby or grassy or both.

Mixed severity fire—a fire event that has mixed effects, burning as a surface fire in some locations and as a crown fire in others depending on fuel and weather conditions.

Old growth—a forest defined by well-developed structures and often complex living interrelationships; dominance by late successional species (which can be disturbance-dependent species in the case of frequent low-intensity disturbance); and only minor competition among dominant trees. The age of the dominant trees defines old growth, and it varies from species to species and ecosystem to ecosystem.

Pith, pith date—the pith is the center of the tree; in a core sample or a cross section, it represents the earliest year of growth for the sample. If the pith is not present on a sample because of rot or an off-center core, it is possible to estimate the number of rings to the pith if the diameter of the tree is known.

Prescribed fire—a fire deliberately set by humans to accomplish some planned alteration in community structure, usually under specific, low-risk conditions.

Surface fire—a fire that burns primarily along the ground, consuming grasses, shrubs and small trees, but usually causing minimal damage to larger trees; historically this was the common type of fire in Southwestern ponderosa pine.

Succession—the gradual change in the species composition of an ecosystem over time in the absence of major disturbance or other environmental change; for example, Douglas-fir will gradually dominate upper montane forests in the absence of fire, supplanting much of the ponderosa pine.

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