Identifying Old Trees and Forests

IN EASTERN WASHINGTON

by Robert Van Pelt

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

Acknowledgements

This guide is a companion to *Identifying Mature and Old Forests in Western Washington* (Van Pelt, 2007). It was conceived in response to the work of the Old Growth Definition Committee. The committee was convened at the request of the Washington State Legislature to map and inventory old growth forests on state trust lands managed by DNR. In the course of the committee's work, the need became apparent for field guidance to assist field personnel in identifying individual old trees and forests.

It is essential to acknowledge the people I worked with on the Old Growth Definition Committee: Dr. Jerry F. Franklin, Dr. Miles Hemstrom, Joe Buchanan, Rex Crawford, Steve Curry, Sabra Hull, and Walt Obermeyer, all of whom contributed to the concepts which form the basis of this guide.

Many people reviewed the text during its various iterations, which greatly contributed to improvements in both readability and scientific content:

Richard Bigley
Ron Brightman
Joe Buchanan
Angie Cahill
Chris Earle
Jerry Franklin
Keala Hagman
Miles Hemstrom
Sabra Hull
Arthur Jacobson
Andrew Larson
Jim Lutz
Tami Miketa
Bob Redling
Jeff Ricklefs

The layout and design of this guide was ably and beautifully conducted by Nancy Charbonneau and Jane Chavey of the DNR Communications Group.

Photos, maps, and drawings by author except where indicated otherwise.

Washington State Department of Natural Resources

This guide was produced under contract as part of the ongoing research and application of new information to inform both land management and resource protection goals of Washington's Department of Natural Resources. DNR manages 5 million acres of land—forests, farms, commercial properties and aquatic lands to provide perpetually for both revenue and conservation objectives for the people of Washington State.

Identifiying Old Trees and Forests in Eastern Washington will be a valuable tool for agency forestland managers and others interested in the complexities and ecological relationships that give rise to older forests. This guide will be used by the department to aid in the identification and protection of these unique forest structures.

Suggested Citation

Van Pelt, R. 2008. Identifying Old Trees and Forests in Eastern Washington. Washington State Department of Natural Resources, Olympia, WA. 166 p.

This guide was developed to support management of forested state trust lands.

Washington State
Department of Natural Resources

Land Management Divison
Ecosystem Services Section

September 2008

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Scope and Purpose

This guide is intended to help the reader interpret the ecology, disturbance history, and ages of eastern Washington forests through an examination of environmental conditions and physical characteristics at the stand and individual tree level. The process of recognizing older stands in eastern Washington involves more than simply determining age. The great size achieved by many trees coupled with the heart rot common in old trees in eastern Washington often precludes the use of increment borers. Assessing the age of forested stands and the individual trees contained within is an exercise in gathering and deciphering relevant information, requiring an understanding of the ecology of the major tree species, the environments they grow in, and the dominant disturbance patterns.

Eastern Washington is in many ways a microcosm of western North America. A great diversity of environments can be found within this relatively small area, ranging from rain forests near the Cascade Crest to dry, oak–pine forests of Klickitat County, to barren sand dunes in the Columbia Basin.

Across this landscape, complex patterns of tree species distribution, precipitation, human activity, and fire regimes have resulted in a great diversity of forest types. Such varied environmental conditions affect both tree physiology and appearance. Surprisingly, relatively few species of trees occur—most are long-lived conifer species.

Despite sharing many tree species, the forests of eastern and western Washington differ greatly in stand development and individual tree characteristics. In western Washington, an examination of forest stand-level features usually provides sufficient clues to decipher stand age. In contrast, forest disturbances in eastern Washington often do not kill all trees, and individuals are able to persist from one disturbance to the next. In such cases, the age of individual trees becomes more meaningful than overall stand age. While the stand concept is useful in many areas of eastern Washington, such as in the wet forests along the Cascades or those at high elevations, complex disturbance patterns in the drier forest types of eastern Washington make the task of defining a stand more difficult. In many of these dry or moderately moist forests an individual tree approach is required.

The scope of this guide is limited to eastern Washington—a separate guide has been prepared for western Washington—*Identifying Mature and Old Forests in Western Washington (Van Pelt 2007).*

Guide Organization

The task of identifying mature and old forests and trees in eastern Washington is threefold, requiring an understanding of the diversity of forest environments present, the ecological processes affecting how stands and trees change over time, and the characteristics used to determine age patterns of the dominant tree species. These concepts are discussed in two major sections within this guide.

The first section, **Ecological and Environmental Context,** describes the physiographic and environmental gradients found in eastern Washington. Detailed descriptions of the forested vegetation zones are provided, along with keys used to determine their presence. A discussion of disturbance follows, including fire frequency, severity, and how fire severity patterns have been altered by Euro-American settlement. Insect outbreaks and mistletoe infections are also discussed, as they often provide important clues to stand development. An understanding of stand developmental stages is necessary to determine the age of stands that have developed under high-severity fire regimes. An idealized model of stand development is presented, complete with keys. Lastly, the role of shade tolerance in discerning species interactions and age patterns is presented. In forests that develop under more moderate disturbance regimes, the concept of a stand is difficult to define. Instead, age determination is achieved by an examination of individual trees.

The latter part of this guide, **Individual Species or Species Group Treatments,** addresses the primary tree species found in eastern Washington and their specific characteristics relevant to discussions on forest age and succession. Four species are considered the most important within mid- to lower elevation forests: ponderosa pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), Douglas fir (*Pseudotsuga menziesii*), and grand fir (*Abies grandis*). A discussion of higher elevation forest patterns follows, including descriptions of Engelmann spruce (*Picea engelmannii*) and Rocky Mountain subalpine fir (*Abies bifolia*[1]). A final section discusses several tree species generally considered more important in western Washington—western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), Pacific silver fir (*Abies amabilis*), and mountain hemlock (*Tsuga mertensiana*)—and the differences they exhibit when found in eastern Washington. Each of these sections is intended to focus on the essential characteristics necessary for understanding and identifying successional status of the species, rather than a comprehensive review of their ecology. The sections on ponderosa pine, western larch, and Douglas fir are the most extensive due to these species' widespread distribution, ***ecological amplitude,*** economic importance, and the key role they play in helping to determine the age of forests in which they occur.

The two long-lived upper treeline species—those that occur at the fringe of the highest elevation that trees can grow—alpine larch (*Larix lyallii*) and whitebark pine (*Pinus albicaulis*), are not treated separately in this volume. These species include some of the oldest recorded individual trees in Washington, but live in such extreme treeline habitats that forests or woodlands that are even a few meters tall are often a century or two old. Active forest management does not occur in such severe habitats. Several other common tree species, including western white pine (*Pinus monticola*), lodgepole pine (*Pinus contorta* var. *latifolia*), noble fir (*Abies procera*), yellow cedar (*Cupressus nootkatensis*), Oregon white oak (*Quercus garryana*), quaking aspen (*Populus*

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[1]*A. bifolia and A. lasiocarpa* are closely allied sibling species known to introgress through central British Columbia and northern Washington. *A. bifolia x lasiocarpa* may have morphologic features resembling either species. Pure populations of *A. lasiocarpa* are found in coastal areas of Alaska and British Columbia – see *www.conifers.org* for a more detailed discussion.

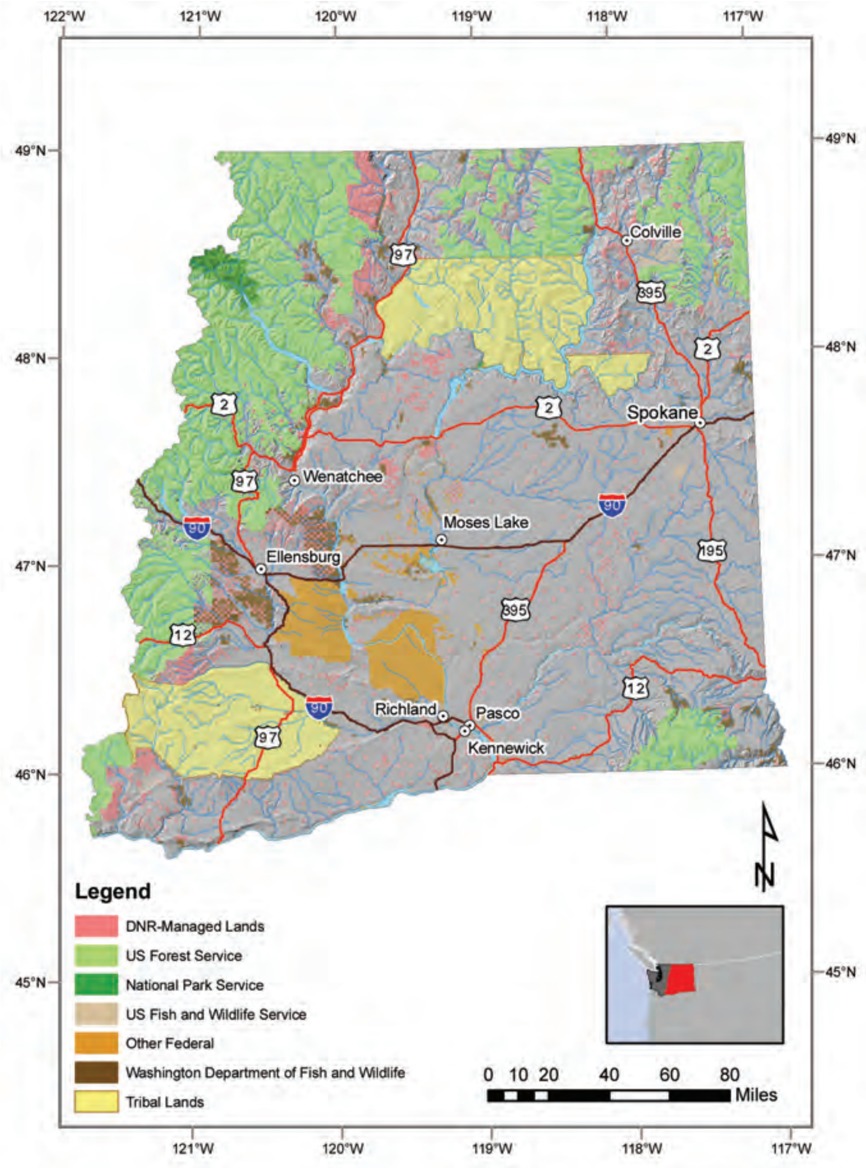
tremuloides), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), and alder species (*Alnus*) were not given their own sections. These species are mentioned in the text where appropriate, but a specific section on each was deemed unnecessary – other species or stand characteristics are sufficient to determine tree or stand age. While alders and cottonwoods are abundant along virtually all watercourses, their short life-spans limit their usefulness in a guide to identifying mature and old forests.

How to Use This Guide

This guide provides the necessary tools to arrive at a reasonable age estimate for a selected tree, grove of trees, or forest stand using a three-step process:

1. Identify the forested vegetation zone.
2. Identify the level of fire-severity to determine if a tree-level or stand-level approach is needed.
3. Determine an approximate age by using either the stand development sequence key or the individual species keys. The remainder of this book provides an explanation of these concepts and includes the necessary keys to accomplish these tasks.

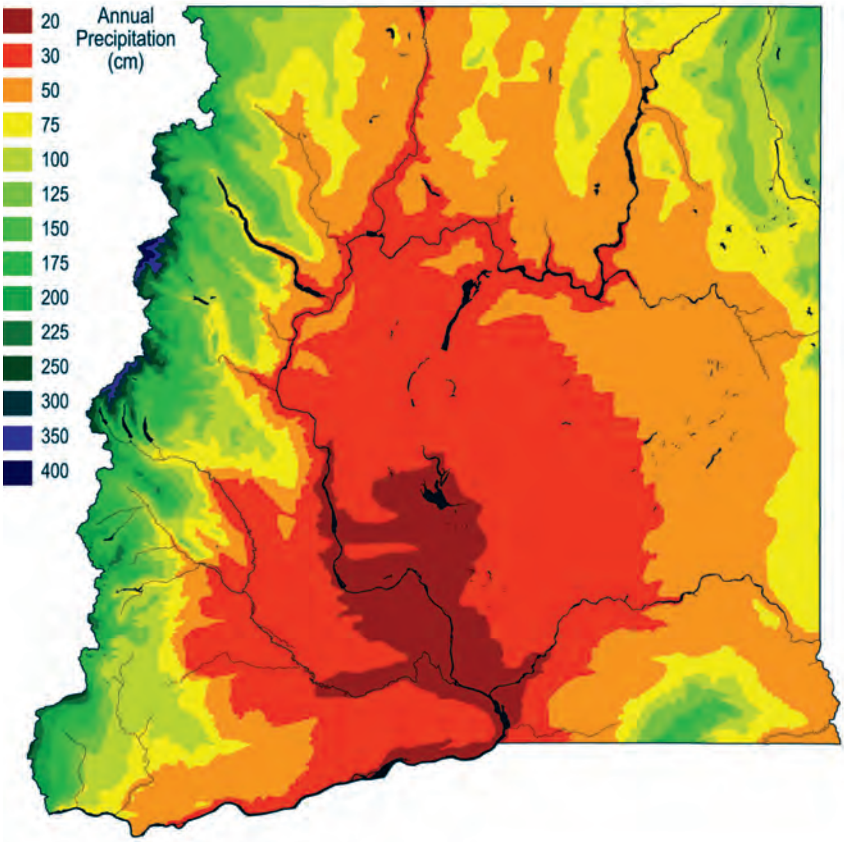
Locator map of Eastern Washington with major public ownerships. Map provided by Ned Wright.



Environmental Setting of Eastern Washington

Although it is the smallest of the western states (184,824 km^2 – 71,361 mi^2), Washington is among the most diverse, encompassing nearly all of the major biological habitats found in the West. Annual precipitation ranges from 20 cm (8 in) in the deserts of the Columbia Basin to 600 cm (236 in) along the western flanks of Mount Olympus on the Olympic Peninsula. The Cascade Mountains divide the state into two regions: western Washington—wet and with a strong maritime climatic influence, and eastern Washington—drier and with continental climatic influences. Eastern Washington, the focus of this guide, measures 118,000 km^2 (45,560 mi^2).

Figure 1. Annual precipitation for eastern Washington.



Eastern Washington lies between two major climatic regimes: a large Mediterranean climate zone centered on California, and the interior continental climate that characterizes much of central North America. Mediterranean climates are coastal in nature, characterized by warm, mild winters and hot, dry summers. In contrast, continental climates are characterized by frigid winters and hot summers. The Columbia Basin, which forms the center of eastern Washington, is protected from these two major climatic regimes by the Cascade Mountains to the west and by the Rocky Mountains to the north and east. While Washington is neither as hot nor as dry as California, the seasonal patterns are similar. Only 5–15 percent of the annual precipitation occurs during the summer months of July to September throughout the entire region, including the more continental areas of far northeastern Washington. Southwesterly oceanic storms are the primary source of precipitation for the region during the other nine months of the year. The presence of the Rocky Mountains, combined with a maritime influence, serves to moderate the continental winter blasts, resulting in a climate far less harsh than areas at the same latitude further east.

Eastern Washington contains a great diversity of habitats, from rain forests to alpine meadows and deserts. The westernmost portion of the region near the Cascade Crest, for example, receives abundant rain and snow where annual precipitation in limited areas exceeds 400 cm (157 in) (Figure 1). While most of the dominant forest types of western Washington may be found in eastern Washington, many are limited to these very wet areas. The bulk of the forested landscapes of eastern Washington consist of mixed conifer forests similar to those found in northern Idaho, western Montana, and southeastern British Columbia—a region defined as the ***Inland Empire.***

The term Inland Empire, coined by a Spokane newspaper in the nineteenth century, was originally used as a marketing phrase to spur colonization. Forests within the region were historically dominated by western white pine and western larch. Prior to 1910, forestry in the richest and wettest portions of this region, centered on the panhandle of northern Idaho, was focused on western white pine. The combination of heavy exploitation by humans, a fairly weak ability to fight off bark beetle attacks, and high susceptibility to an introduced disease—white pine blister rust (*Cronartium ribicola*)—has made white pine more of a memory from the distant past.

Environmental Setting of Eastern Washington

While a single species may dominate in limited areas or during a certain successional state, the forests within eastern Washington are usually a mix of several species. Ponderosa pine, western larch, Douglas fir, grand fir, western white pine, lodgepole pine, Engelmann spruce, subalpine fir, and quaking aspen all can be found growing together in forests throughout the region. Elevation, slope, aspect, topographic position, and disturbance history are the primary determinants in species composition for a given location.

Physiographic regions are often used to divide areas by interrelated geology, physiography, soils, climate, and vegetation. Eastern Washington can be divided into six physiographic regions, each with distinct, definable characteristics (Figure 2).

The **North Cascades** are characterized by steep, glaciated mountains and complex geology. Peaks are commonly more than 2,400 m (7,874 ft). Four surpass 2,800 m

Figure 2. Physiographic regions of eastern Washington. Background image courtesy of NASA.

(9,186 ft), with Bonanza Peak the highest at 2,899 m (9,511 ft). Annual precipitation varies, but is generally high, ranging from a low of 50 cm (20 in) along the Columbia Basin province to more than 400 cm (157 in) near the Cascade Crest.

The **South Cascades** are characterized by high, glaciated ridges that extend eastward from the Cascade Crest. Most of the region is forested, with the exception of Mount Adams (3,742 m – 12,276 ft) and a few peaks in the Goat Rocks (up to 2,494 m – 8,184 ft). The southeastern portion is dominated by the Horse Heaven Hills, a low-gradient plateau dissected by deep canyons. As in the North Cascades, precipitation is highest in the west and decreases sharply to the east.

The **Okanogan Highlands** form a mountainous region of complex geology that was covered by the Cordilleran ice sheet during the Quaternary (ice melting took place 13,000–10,000 years ago). The rolling topography is not as dramatic as either of the Cascade regions. Similar areas are found in southern British Columbia. The climate is dry, as much of the moisture from the Pacific is wrung from the clouds as they pass over the Cascades.

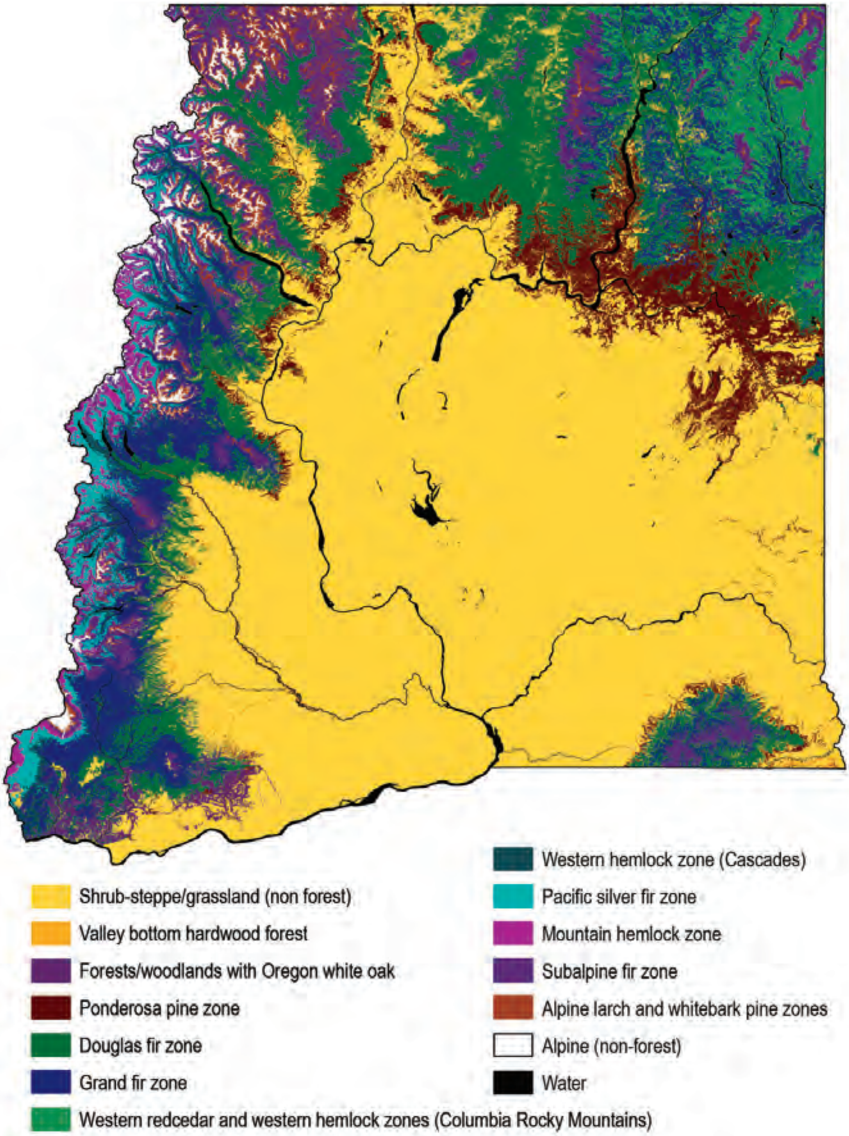
The **Columbia Rocky Mountains** are part of a much larger physiographic region that extends well into British Columbia, northern Idaho, and northwestern Montana. The Selkirk Mountains comprise most of the Washington portion and, like the adjacent Okanogan Highlands, were covered by the Cordilleran ice sheet. The Columbia Rocky Mountains are intermediate in character between the Okanogan Highlands to the east and the remainder of this region outside of Washington, where the mountains are much larger, with broad, low valleys in between.

The **Blue Mountains** are formed from uplifted Columbia basalt deposits, deeply carved by rivers. Most of this region, which has Rocky Mountain affinities, lies to the south in Oregon.

The **Columbia Basin** occupies most of eastern Washington and is dominated by hot, dry environments that support very little forested area. Trees are limited to higher elevations (especially in the northeastern section), and north-facing slopes along the Columbia, Snake, and Spokane Rivers. Small populations of western juniper (*Juniperus occidentalis*) and Rocky Mountain juniper (*Juniperus scopulorum*) are scattered on sand dunes and along cliffs of the Columbia River.

Forested Vegetation Zones
Eastern Washington

Figure 3. Vegetation zones of eastern Washington.



The sharp contrast between the steep mountainous topography of the Cascade Range and the gentle terrain of the Columbia Basin has dramatic effects on precipitation and temperature gradients. Accordingly, tree species have become stratified by their competitive abilities and tolerance to both drought and cold. In *The Natural Vegetation of Oregon and Washington,* Franklin and Dyrness (1973) separate the region into vegetation zones based on the dominant tree species. Subsequent efforts by the Washington State Department of Natural Resources, U.S. Forest Service, and other agencies have further expanded and subdivided the vegetation zones into plant associations. Plant associations are groupings of plant species that reoccur on the landscape with particular environmental tolerances. They can be useful tools for predicting environmental conditions, site productivity, and response to forest management. In the simplest terms, the forested portion of eastern Washington can be divided into 12 vegetation

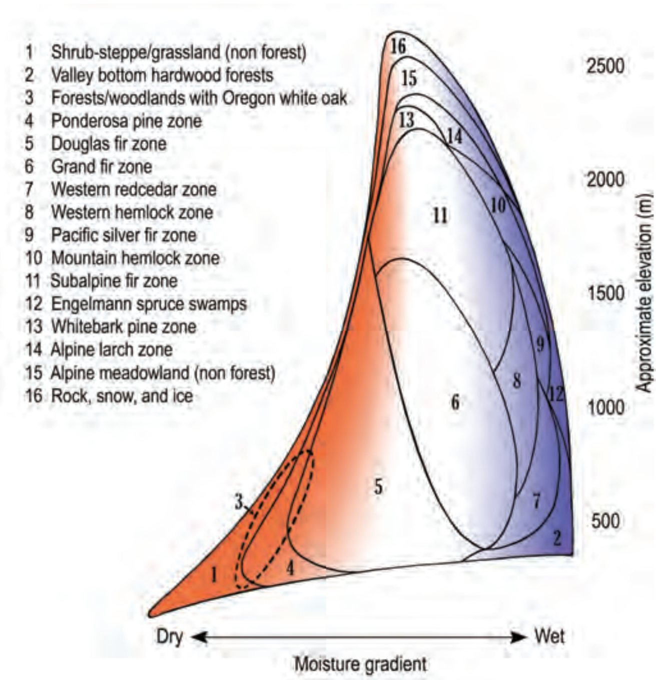


Figure 4. Environmental gradients of eastern Washington vegetation zones. Each of the shapes in the figure represents the environmental space occupied by a given vegetation zone. The species for which the zone is named (e.g. Douglas fir or ponderosa pine) may, in many cases, be able to grow beyond the boundaries of its zone. With the exception of the shrub-steppe/grassland zone, which occupies the bulk of eastern Washington, the size of each polygon is proportional to the area occupied by that forest zone.

zones (Figure 3). Each reflects different temperature and precipitation regimes, within which tree species are stratified by elevation (a surrogate for temperature) and precipitation gradients (Figure 4).

Tree-dominated vegetation communities in eastern Washington range from sparse savannas and woodlands to dense forests. Upper and lower treelines, some south-facing slopes, and areas of thin soils are naturally sparse. Within this guide, ***forests*** are defined as all habitats in which mature tree crowns cover at least one third of the land area; ***woodlands*** are habitats in which mature tree crowns cover less than one third of the land area. Vegetation zones are defined by their potential ***climax tree species***—the species that may (or could) occur there given sufficient time and lack of disturbance. In many cases, the namesake climax species is absent or present only in small numbers as a result of the current successional state, or the history of disturbance. Generally speaking, the climax species is the most shade-tolerant tree species that can regenerate under a forest canopy. A zone is named for this species only when other more shade-tolerant species are

Figure 5. Timberline environment in the North Cascades. Alpine larch (with fall color) and whitebark pine (on rocks in upper right) are our two highest-dwelling tree species. The alpine larch and whitebark zones consist of sparse woodlands found at elevations higher than the forested subalpine fir zone (visible on the left).

not present. A given species may occur in multiple zones. For example, ponderosa pine is one of the least shade-tolerant conifer species. While ponderosa pine has a zone named for it, the tree also can be dominant or important in other zones, such as in the Douglas fir, grand fir, subalpine fir, Columbia Rocky Mountain western redcedar, or perhaps other zones.

Fires and other stand-replacing disturbances can confound the values in a vegetation key. The key below considers all forested habitats within eastern Washington, including woodlands and very young forests. In these cases, replace the percent cover with the phrase *present and reproducing successfully.* For example,

Key[2] to forested vegetation zones in eastern Washington

1	Alpine larch ≥ 10% cover	Alpine larch zone
	Alpine larch < 10% cover	2
2	Whitebark pine ≥ 10% cover	Whitebark pine zone
	Whitebark pine < 10% cover	3
3	Mountain hemlock ≥ 10% overstory cover or 2% understory cover	Mountain hemlock zone
	Mountain hemlock < 10% overstory cover or 2% understory cover	4
4	Pacific silver fir ≥ 10% overstory cover or 2% understory cover	Pacific silver fir zone
	Pacific silver fir < 10% overstory cover or 2% understory cover	5
5	Western hemlock and/or western redcedar present	6
	Western hemlock and/or western redcedar absent	8
6	Location in the Cascade Mountains	Cascade western hemlock zone
	Location in Columbia Rocky Mountain province	7
7	Western hemlock present	Columbia Rocky Mountain western hemlock zone
	Western hemlock absent	Columbia Rocky Mountain western redcedar zone
8	Subalpine fir ≥ 10% overstory cover or 2% understory cover	Subalpine fir zone
9	Grand fir ≥ 10% overstory cover or 2% understory cover	Grand fir zone
	Grand fir < 10% overstory cover or 2% understory cover	10

in a treeline woodland situation, replace *Whitebark pine with at least 10 percent cover* with *Whitebark pine present and reproducing successfully.* Unless indicated, cover values refer only to the main tree canopy.

All of the upper treeline forests in eastern Washington are in either the **alpine larch** or the **whitebark pine zones.** These treeline communities often consist of sparse woodlands that extend above the lower, denser subalpine fir zone described in Figure 5. Alpine larch has the ability to remain arborescent in situations where other tree species have either dropped out or become ***krummholtz***, a German word for the dwarf, stunted trees often seen in treeline environments.

10	Oregon white oak present	11
	Oregon white oak absent	15
11	Douglas fir and/or ponderosa pine present	12
	Douglas fir and/or ponderosa pine absent	Oregon white oak zone
12	Douglas fir ≥ 10% overstory cover or 2% understory cover	13
	Douglas fir < 10% overstory cover or 2% understory cover	14
13	Regenerating trees dominated by Douglas fir	Douglas fir zone
	Regenerating trees dominated by Oregon white oak	Oregon white oak zone
14	Regenerating trees dominated by ponderosa pine	Ponderosa pine zone
	Regenerating trees dominated by Oregon white oak	Oregon white oak zone
15	Douglas fir present	Douglas fir zone
	Douglas fir absent	16
16	Lodgepole pine dominant	17
	Ponderosa pine dominant	Ponderosa pine zone
17	Subalpine fir present	Subalpine fir zone*
	Douglas fir present	Douglas fir zone*

[2]Each dichotomous key used in this guide consists of a series of paired descriptions, or couplets, describing a given forest stand. Beginning with the first couplet, read each description to determine which most appropriately describes the stand in question. At the end of each description you will find either a number, indicating the next couplet to examine, or a name, indicating the conclusion.

* If at this stage of the key you are still unsuccessful, relax percentage values, and try again or treat as a woodland or early successional stand and try again. A determination of vegetation zone in either case may require expanding the search radius or an examination of adjacent stands.

Figure 6 left. Engelmann spruce is often the dominant tree within the subalpine fir zone. The zone, however, is named for the more shade tolerant subalpine fir. Though the distribution of spruce and fir in eastern Washington are similar, Engelmann spruce may also be found at low elevations along stream corridors and cold air drainages.

Figure 7 below. Mountain hemlock zone in the North Cascades**.** The distribution of the snow-loving mountain hemlock does not stray far from the Cascade Crest, where dry air reduces its competitive abilities.

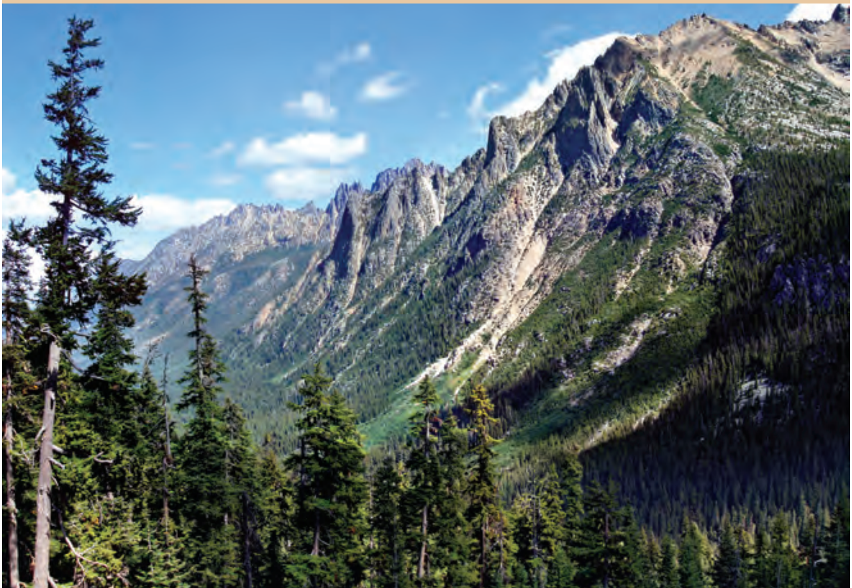


Figure 8. Pacific silver fir zone in the South Cascades. Vegetation zones are compressed near the Cascade Crest, with many Eastside and Westside species growing together. Pacific silver fir reproduces well in the cool, dark, moist understory environment, but will often languish and die in the dry air found in the upper canopy.

The highest forested zone in the region is the **subalpine fir zone.** The most extensive of the subalpine forest communities, the zone is named for the most shade-tolerant species. However, other species, most commonly Engelmann spruce, are often present in greater numbers (Figure 6).

The **mountain hemlock zone** encompasses many very wet and snowy high-elevation forests near the Cascade Crest. Only a small section of this zone occurs in eastern Washington, as the arid environment quickly becomes too hostile for mountain hemlock (Figure 7). Similarly, the **Pacific silver fir** and **western hemlock zones,** common in western Washington, occur in limited areas near the Cascade Crest. Tree species diversity in eastern Washington is highest within these three zones, with sometimes a dozen or more species found growing side by side (Figure 8).

Figure 9. Columbia Rocky Mountain region. Up to 10 conifer species share dominance within the western redcedar and western hemlock vegetation zones found in the mountains of northeast Washington.

Although precipitation in the northeastern corner of the state is sufficient to support both western redcedar and western hemlock forests as well as a high diversity of tree species (Figure 9), the **Columbia Rocky Mountain western redcedar** and **Columbia Rocky Mountain western hemlock zones** differ in many ways from their Cascade counterparts.

Figure 10. Grand fir zone. Many of the best developed examples of western larch (pictured) and ponderosa pine forests are found within the grand fir zone. Historically kept at low numbers by frequent fire, dense stands of grand fir are now common as a result of a century of fire suppression.

The **grand fir zone** is the primary mixed conifer forest belt of eastern Washington (Figure 10). Some of the highest forest productivities in eastern Washington and many of the largest pines, larches, and Douglas firs are found within this zone. As grand fir is a drought-sensitive species, this zone is largely limited to the South Cascades and Columbia Rocky Mountain regions (Figure 2).

Figure 11. Douglas fir zone. Ponderosa pine occurs throughout the Douglas fir zone. On occasion, it is co-dominant with other species (as shown here), but may also form nearly pure stands.

The **Douglas fir zone** is the most extensive forested zone in eastern Washington, consisting of drier areas with annual precipitation between 50 and 80 cm (20 and 31 in) (Figure 11). Generally too dry for grand fir, the primary conifer species present are ponderosa pine and Douglas fir (but limited areas of western larch and lodgepole pine also may be found).

The **ponderosa pine zone** occupies the driest forested environments at the lower fringes of the forested landscape where even Douglas fir cannot survive (Figure 12). The true ponderosa pine zone is not very extensive, even though ponderosa pine is one of the most widespread tree species in eastern Washington.

Oregon white oak becomes a dominant tree or shrub, often growing with ponderosa pine and/or Douglas fir near lower treeline within the South Cascades region, adjacent to the Columbia River (Figure 13). Strictly speaking, pure stands of Oregon white oak contain no conifers and represent a small fraction of the area

Figure 12 left. Ponderosa pine zone. Ponderosa pine is the only conifer that can tolerate the hot, dry conditions at the lower fringes of the forested environment of eastern Washington.

Figure 13 below. Oregon white oak communities. Oregon white oak forms a lower timberline community in the South Cascades along the Klickitat River Canyon. Photo by Andrew Kratz.

mapped as forest/woodlands within the **Oregon white oak zone** in Figure 3. However, these less-than-pure mixed oak stands are distinct enough to warrant inclusion here. Most of the eastern portion of the area depicted is in the ponderosa pine zone, while most of the western portion is in the Douglas fir zone.

In many western states, pure or dominant stands of lodgepole pine are common. In eastern Washington, it is most abundant in the western portion of the Okanogan Highlands, but is present in all forested regions. Nearly always successional to other species in the forests of eastern Washington (Figure 14), lodgepole pine develops extremely dense stands of small trees that are highly susceptible to stand-replacing fire events. For this reason, lodgepole pine does not have its own zone, even though it may appear as the only species capable of growing in certain areas.

Figure 14. Dense stands of lodgepole pine are often encountered at middle to high elevations throughout eastern Washington. These stands are most commonly found where cold air collects in valley bottoms or on poorly drained soils. Lodgepole pine stands are characteristically dense and uniform, with little height differentiation. Such conditions are predisposed to stand-replacing fire events, after which the pine will often recolonize the burned landscape.

Forested Vegetation Zones in Eastern Washington

Table 1 summarizes all of the forested vegetation zones of eastern Washington, the primary tree species that occur in each zone, and whether each species represents a minor (m) or major (M) component of the vegetation.

Vegetation zones

Tree species	Alpine larch	Whitebark pine	Subalpine fir	Mountain hemlock	Pacific silver fir	Cascade western hemlock	Columbia Rocky Mountain western hemlock	Columbia Rocky Mountain western redcedar	Grand fir	Douglas fir	Ponderosa pine	Oregon white oak
Fire Severity	H?	H?	H	H	H	H	H	H M	M H	L M	L	L M
Pacific silver fir			m	M	M							
Subalpine fir		m	M	m								
Grand fir			m			m	m	M	M			
Noble fir				m	m							
Yellow cedar			m	m	m							
Alpine larch	M											
Western larch						m	m	M	M	M		
Engelmann spruce		m	M	m	m	m	m	m	m			
Whitebark pine		M	m									
Lodgepole pine		m	M	m	m				m	m		
Western white pine			m	m	m	m	M	M	m			
Ponderosa pine			m					M	M	M	M	
Douglas fir			m	m	m	M	M	M	M	M		
Western redcedar				m	m	m	M	M	m			
Western hemlock				m	M	M	M					
Mountain hemlock				M	m							
Alders			m	m	m	m	m	m	m	m	m	
Black cottonwood			m	m	m	m	m	m	m	m	m	
Quaking aspen			m	m	m	m	m	m	m	m	m	
Oregon white oak										m	m	M

Table 1. Fire severity and tree species distributions in eastern Washington vegetation zones. Three classes of fire severity are listed: High (H), Mixed (M), or Low (L). More than one fire severity class may be present in a given vegetation zone — in such cases, the dominant class is listed first. Tree species are listed by vegetation zone. A blank indicates the species does not occur; a gray box with a small m indicates the species is a minor component; and a black box with a capital M indicates the species is a major component. The species listed below may not be present at all times — presence will vary with successional stage and disturbance patterns.

Figure 15. The 70,000 hectare (about 173,000 acre) Tripod Fire of 2006 left many areas without a single living tree.

Fire in Eastern Washington Prior to Euro-American Settlement

Prior to the arrival of Euro-American settlers in the nineteenth century, fire was the primary type of disturbance driving forest configuration in the region. After a century of fire suppression, many forests make news only when a wildfire sweeps through an area (Figure 15). While stand-replacing fires were historically an important part of many of the forests in eastern Washington, they certainly were not as extensive as they are today.

Many old photos of the American West show pioneers traveling through park-like stands of ponderosa pine, suggesting that this was representative of forest conditions prior to Euro-American settlement (Figure 16). This is a mistaken view for several reasons. First, pioneers were often faced with primitive conditions with no roads and only a wagon or mule team with which to travel. A dense stand with logs strewn about would not have been their first choice of a travel path—open stands would have been the path of least resistance. Second, the open stands of

Figure 16. Historical photographs often show open, park-like stands of Ponderosa Pine, such as this one from the Blue Mountains. Photo courtesy of Baker County Library, Baker City, Oregon.

ponderosa pines were sunny, attractive, and easy to photograph. People always have felt a connection with the park-like stands of pine, and they still are among our most photogenic forest types. Hence, our historical photographic record is biased towards more attractive stands. From an economic point of view, ponderosa pine is one of the more valuable western trees, so these easily accessed stands were among the first to be logged. Park-like stands of pine still do exist—but they no longer are common (Figure 17). Perhaps this scarcity has further accentuated the allure of the old photographs.

Open pine stands were in fact a common forest type in eastern Washington prior to Euro-American settlement. Ponderosa pine defined the lower treeline throughout the eastside and was often the dominant tree species in the grand fir and Douglas fir zones as well. Fire-return intervals in many of these forests were short, so several to a dozen or more fires might occur in a century. Fuel loads within such a frequent fire regime are low, often present only in the form of branch wood, needle litter, grasses, and a few small trees. Under these ***low-severity fire*** conditions, fires often would creep along the ground and consume the relatively small amount of available fuel. Thick-barked trees like ponderosa pine or western larch often would be unaffected since the fire could not penetrate their bark. Of course, each fire was different and would occasionally jump into the crown and kill or weaken an old tree. These low-severity fires allowed old pine or larch forests to drift through time, seemingly unchanged (Figure 18). Certainly, individual trees would establish, grow, and die, but the overall impression of the stand endured.

Fire scars are often a characteristic of low-severity fire forests, and are an important record for future fire historians. Ground fires often leave charcoal on the outside of thick-barked trees, but this charring usually does not affect the living tissue (i.e., cambium, inner bark) underneath the protective bark. A fire scar, however, is evidence that the fire did kill some of the living tissue underneath. The tree responds to such a wound by converting the sapwood near the exposed area into heartwood. Future wood growth expands into the opening and begins to close over the wound (Figure 19). The juvenile bark on the newly forming edge next to the scar remains thin, however. In the event of another ground fire, the tree is likely to be wounded in the same spot. After centuries of repeated fire, the tree becomes a record of fire frequency within the stand (Figure 20). Fires may be more frequent than represented by the scarring pattern, since an individual tree may not have been affected by *every* low-severity fire that occurred. The record therefore represents a *minimum* for the fire frequency—a complete record requires an examination of many fire-scarred trees within a stand.

Active fire suppression efforts during the late nineteenth and most of the twentieth century have altered natural disturbance patterns in areas formerly governed by low-severity fires, with discernable results. The wide, mushrooming band of

Figure 17. Old-growth stands of ponderosa pine, now scarce, will only persist if actively maintained.

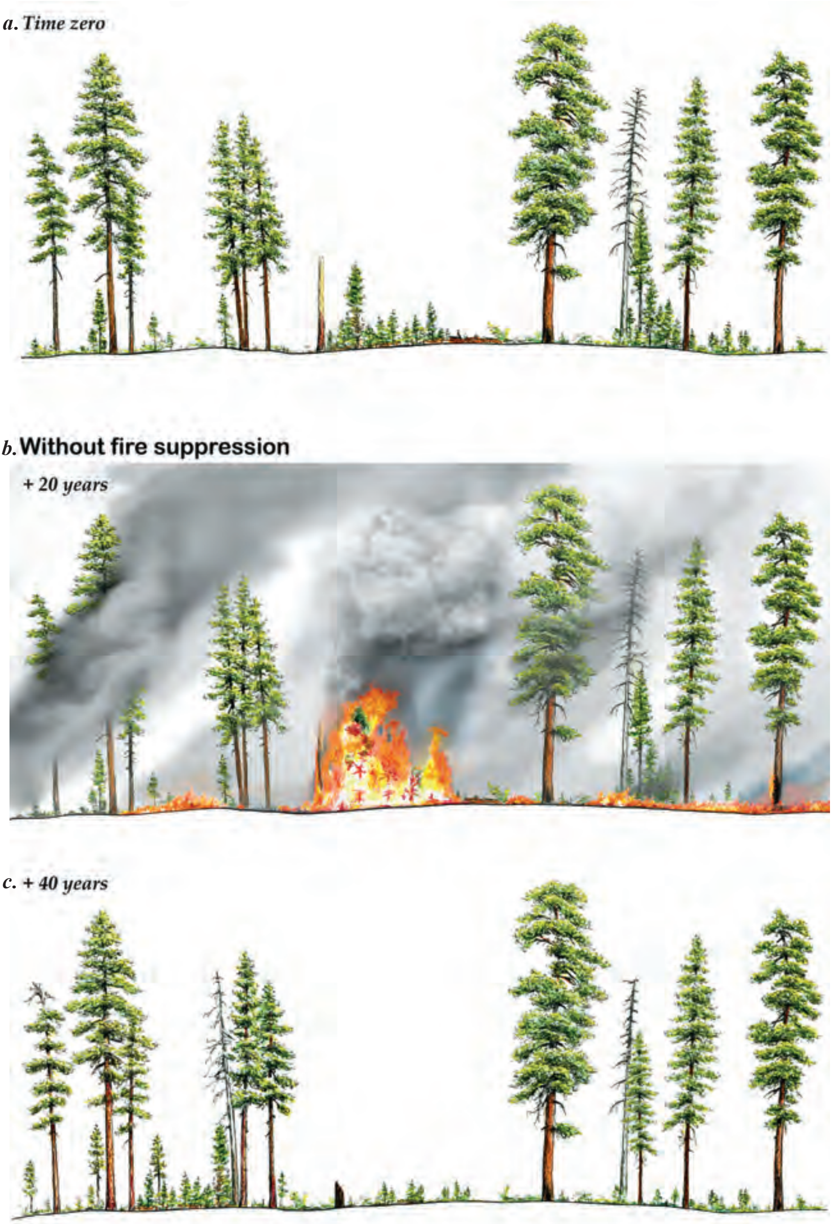
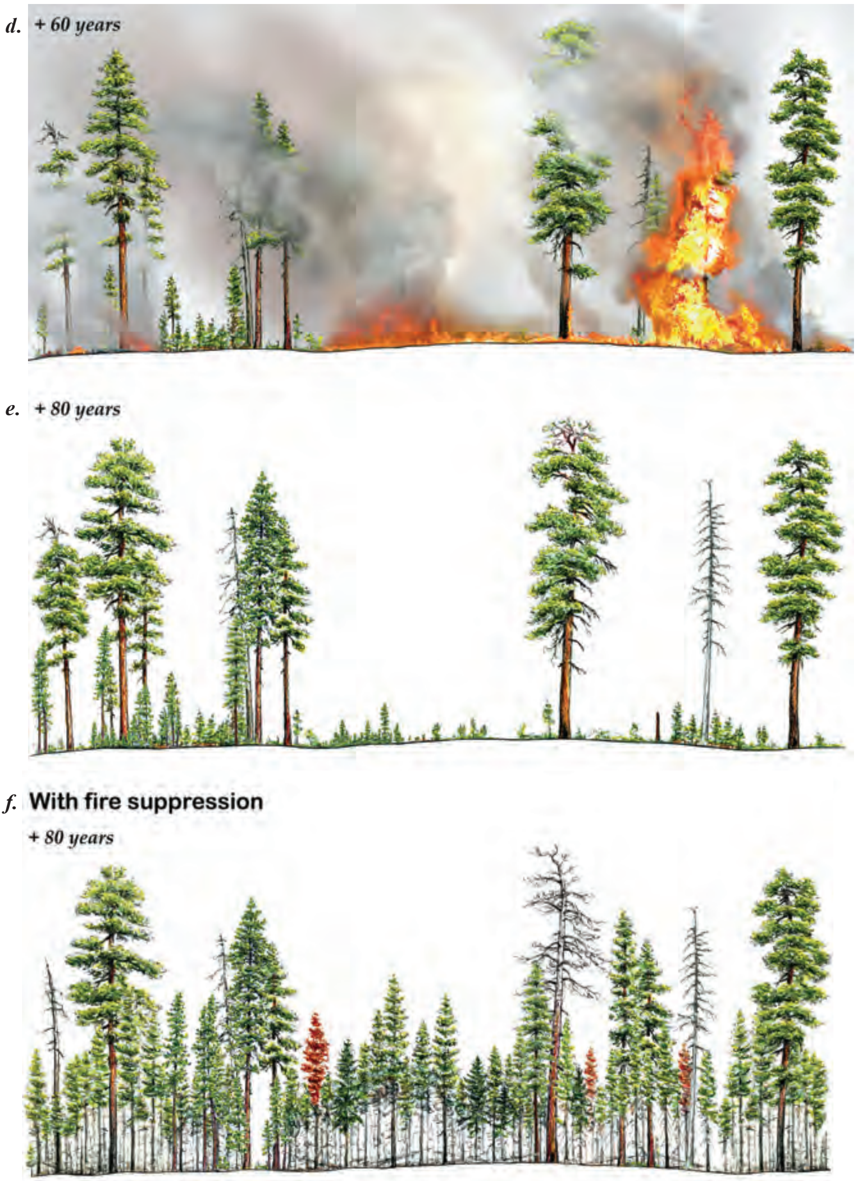


Figure 18. 80 years in an old-growth ponderosa pine forest. Historically, during one century, 2 to 15 ground fires of low to mixed severity would occur in a given stand. Crown fires were uncommon due to reduced fuels from the frequent ground fires. Panel ***a*** shows the profile of a hypothetical



old-growth pine stand. Panels ***b*** to ***e*** illustrate a scenario in which fire maintains the open stand. Although, after 80 years the profile resembles that at time zero, there are significant changes if one follows individual trees. Panel ***f*** illustrates the same forest over the same time period with no fire.

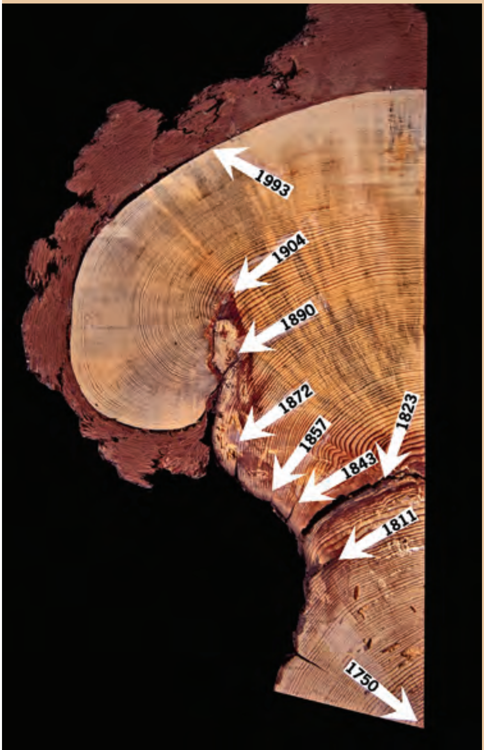


Figure 19 above. Growth pattern following a basal wound often results in a mushroom-shaped base, as this Douglas fir illustrates.

Figure 20 left. Fire scars, characteristic of low-severity events, provide an important record of fire history. Fires may be more frequent than represented by the scarring pattern, since an individual tree may not have been affected by *every* low-severity fire that occurred. The record therefore represents a *minimum* for the fire frequency; a complete record requires an examination of many fire-scarred trees within a stand.

wood visible up against the bark in Figures 19 and 20 has been benignly termed the ***Smoky Bear effect,*** due to its association with fire suppression. Far from aberrant, this mushrooming pattern is nearly universal in dry forest types throughout western North America. Changes at the stand-level are most often reflected in dramatic increases in stand densities (Figure 18f.).

Figure 21. Fire severity increases with return interval. As more time passes between fire events, understory fuels accumulate, resulting in hotter fires with increased flame lengths. This large ponderosa pine survived, but fuel loading can eventually allow fires to ascend into the main canopy, killing even large trees.

Conditions become increasingly wet at higher elevations or on north-facing slopes. With wetter conditions, fires are less likely to occur, the fire-return interval lengthens, fuels on the forest floor (logs, dead branches, needle litter, etc.) accumulate, and the number of newly establishing trees increases. These factors combine to increase both the intensity and severity of the next fire event (Figure 21). Higher flame-lengths under such a scenario increase the possibility that the fire will jump into the crowns of main canopy trees, possibly killing them. There is a positive correlation between longer fire-return intervals and the probability of a stand-replacing fire.

Figure 22. Pre-Euro-American settlement fire regimes in eastern Washington.

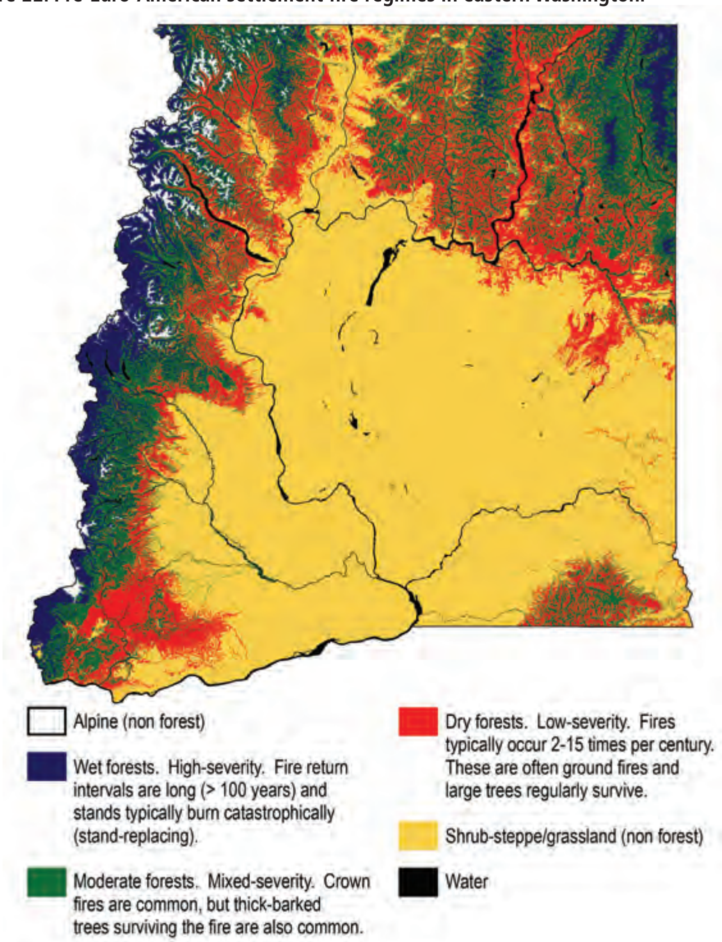
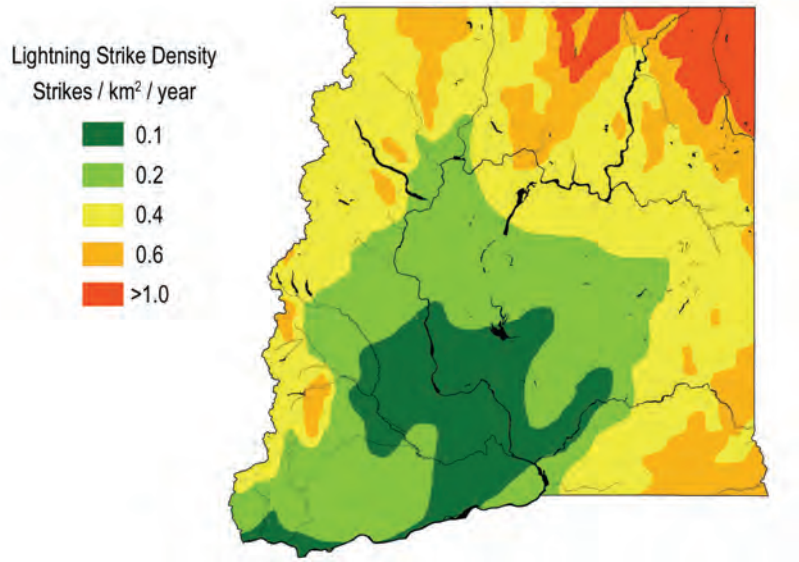


Figure 23. Lightning strike density for eastern Washington. Map derived from U.S. National Lightning Detection Network data.



Since both rain forest and desert conditions exist in eastern Washington, nearly every possible fire scenario is present in the region (Figure 22). Note the similarities between Figure 1 (annual precipitation) and Figure 22 (fire regimes). Precipitation is one of the strongest influences on both vegetation community structure and fire regimes. Other, more subtle patterns also are visible. Slope and aspect also can lead to differences, even in adjacent areas. A dense forest may develop on the cool, north-facing side of a ridge, for example, while the steep, south-facing slope may be too hot or dry to support anything but shrub-steppe vegetation. Sharp contrast also may exist between uplands and the adjoining valley bottoms, where soil moisture is higher from the adjacent stream or river, in addition to the cooler conditions created as cold air drains from the adjacent high mountains.

Ignition sources also are important to consider. Prior to Euro-American settlement, fires were either caused by lightning or intentionally set by Native

Americans. While in retrospect it is often difficult to separate these two (with some exceptions), Native Americans usually set fires for specific reasons in specific places, such as to maintain a desired habitat or vegetation structure for berry picking or hunting. Lightning distribution is more widespread, following a natural pattern as a function of climatic conditions conducive to the formation of cumulonimbus clouds. The frequency of lightning within the Pacific coastal states like Washington is lower than elsewhere in the United States, and as such, they are a poor place to study lightning. That said, there is considerable variation in the frequency of lightning strikes in eastern Washington (Figure 23). Fire probability increases with lightning frequency, all other things being equal. For example, a cedar-hemlock stand growing under the same precipitation regime would be more likely to burn in the Columbia Rocky Mountains than in the Cascades due to more frequent lightning strikes.

In ***mixed-severity fires,*** crown fires may kill portions of the forest while individual trees, patches of trees, or larger areas may only experience ground fires. Fire-tolerant species with thick bark, those located in particular landscape settings such as valley bottoms or ridges, trees with high crown bases, or a combination thereof are the trees most likely to survive (Figure 24). Stand age under low or mixed-severity fire regimes is defined not by the time since the last disturbance, but instead by the ages of trees that survived.

High-severity fires are stand-replacing events discussed in detail in the following section. Unlike low and mixed-severity fires, stand ages under a high-severity fire regime *are* defined by the time since the last disturbance. Survivors of high-severity fires become ***living biological legacies*** in the subsequent stand (Figure 25). A patch of trees missed or only under-burned during a large fire event will behave as a separate stand as the young, surrounding forest grows (Figure 26). The phrase ***legacy trees*** describes this subset of survivors.

Table 1 (page 27) summarizes under which fire severity regime each of the eastern Washington forested vegetation zones fall. Refer to this table to determine whether a stand-based (high-severity) or individual tree (mixed- and low-severity) approach should be used to determine approximate age.

Figure 24 above. Survivors within a burned-over landscape, Entiat River Valley. The open stand condition growing on the thin, rocky soils pictured in the upper left enabled some trees to survive the fire event. The remaining survivors were located in wetter areas associated with stream drainages and valley bottoms.

Figure 25 right. Living biological legacies. Large western larch survived a fire that led to the development of this dense lodgepole pine stand. Note the understory development of subalpine fir beneath the pines.

Figure 26. A patch of larches, spruces, and fir that survived the 85 km^2 (32.8 mi^2) White Mountain Fire of 1988. Survival was likely a result of slightly wetter conditions found near the stream drainage.

Stand Development Following Stand-replacing Wildfire

The stand developmental sequence described in Franklin et al. (2002) provides a useful template for understanding the concept of forest disturbance and succession. This simplified developmental sequence parallels the development of many Pacific Northwest forests following a stand-replacing event, such as a high-severity fire. A more detailed discussion of this developmental sequence as it applies to Douglas fir-western hemlock forests is provided in the companion volume *Identifying Mature and Old Forests in Western Washington* (Van Pelt 2007). While this forest type also occurs in eastern Washington, more species are often present than in the scenario presented for western Washington. Dry forest types, such as many dominated by ponderosa pine, do not follow the typical western Washington developmental sequence. In these forests, a high percentage of trees will survive mixed- and low-severity fire events. Historically, stand-replacing fire events were most common in the Cascade western hemlock, Pacific silver fir, mountain hemlock, Columbia Rocky Mountain western hemlock, and subalpine fir zones. More recently, stand-replacing fires have become common in the grand fir and Columbia Rocky Mountain western redcedar zones as a result of decades of fire suppression and the corresponding increase in stand density and ***fuel loading*** (the amount of combustible material available to feed a fire).

Disturbance and legacy creation

The first stage in a developmental sequence is the disturbance itself. For the purposes of this discussion, disturbances are limited to stand-replacing events that allow a new ***cohort*** of trees to establish—a population of trees of a similar age class that develop together, such as those planted after clearcut logging. In our region, the three primary stand-replacing disturbance events are high-severity wildfires, epidemic insect outbreaks, and logging. While the canopy of the previous stand is removed under each of these scenarios, in most respects these disturbances are very different from each other.

Wildfire can completely kill a stand of trees, but usually consumes only a small proportion of the wood. Landscapes affected by stand-replacement wildfire are often a sea of snags (Figure 27). Epidemic insect outbreaks are occasionally stand-

Figure 27 above. A high-severity portion of the 2001 Thirtymile Fire in the Okanogan Highlands. Six years later, nearly all of the wood remains. Green trees are filled with water and are often not consumed during the initial fire. These snags are likely to burn in a subsequent fire.

Figure 28 left. Very large fires may eliminate seed sources of tree species that would otherwise recolonize the burned area. In such cases, grasses or a shrubfield may persist for decades without human intervention.

Figure 29. Aggressive aspen recolonization following fire. While the fire killed the above-ground aspens, a portion of the underground root system survived. The result is the subsequent development of a dense aspen understory.

replacing events. It is more common, however, for an outbreak to affect only one or a small group of species. As with fire, insect outbreaks leave behind abundant dead wood. Once this remaining wood has dried, forests impacted by either of these situations are vulnerable to subsequent fire events.

Clearcut logging is also a stand-replacing event, but the post-logging situation is very different from those caused by either fire or insects, because dead wood may be nearly absent. Although it is now only one technique among several employed in modern silvicultural management, clearcutting was a major logging technique practiced in Washington for many decades. As such, it constitutes an important part of the disturbance history of many post-Euro-American settlement stands. As traditionally practiced, clearcutting leaves behind very little structure from the previous stand. During the late nineteenth and much of the twentieth century, cleared areas were allowed to reseed themselves naturally from surrounding forested areas. Since the 1950s, clearcuts generally have been replanted within a year or two after logging. Stands resulting from natural reseeding are patchier and it may take longer in some places for these stands to reach the ***canopy closure*** stage (described in a following section).

Cohort establishment

Cohort establishment is the initiation of a new set of trees that forms the basis of a future forest. After a wildfire, conditions for cohort establishment vary tremendously between sites, depending on the extent and severity of the fire in question. Very large fires may leave limited seed sources with which to repopulate the burned area, often allowing shrubs or herbaceous vegetation to persist for a considerable time before trees get re-established (Figure 28). This is not often the case following smaller fires, but even stands subject to very large fires can regenerate quickly if there is a small but diffuse population of surviving trees. In eastern Washington, western larch, lodgepole pine, and aspen are among the quickest to re-establish themselves (Figure 29). Depending on site conditions, however, many other tree species may establish during this initial phase. Large burned areas often are replanted to hasten canopy closure and slow soil erosion (Figure 30).

Figure 30. Cohort establishment. Depending on the availability of seed sources, cohort establishment may take decades.

Repeated disturbances, such as subsequent fires, confound regeneration on several levels:

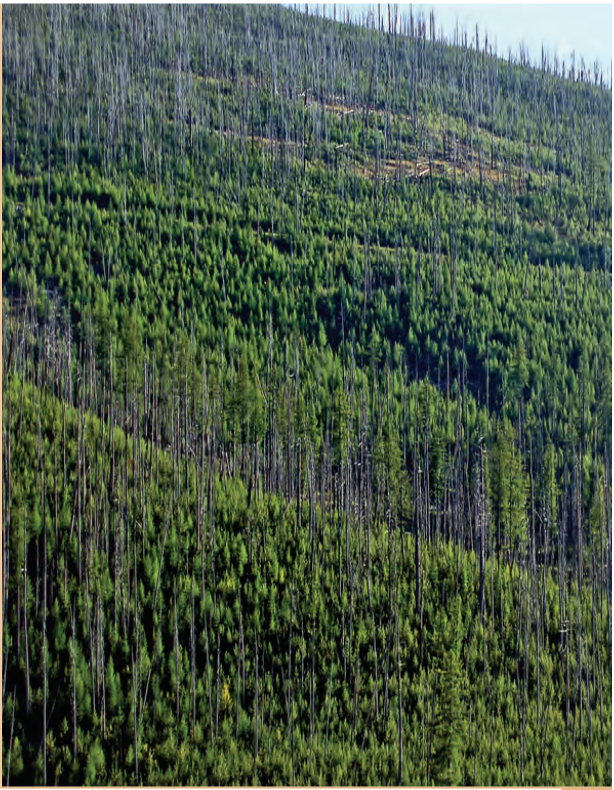
- The few surviving trees that were seed sources may be killed.
- The dense stand of newly regenerating trees most likely will be killed.
- More of the original biological legacies and residual organic matter will be consumed.

All of these processes are common in areas that burn repeatedly. For simplicities' sake, this section will focus on the processes following stand-replacing wildfire.

Canopy closure

Canopy closure between two trees occurs when their crowns begin to touch. While this can take place within a single growing season, at the stand level it may take decades, as determined by the initial spacing of the young trees (Figure 31). Modern planting methods attempt to minimize the time for this process to occur,

Figure 31. Canopy closure after the 1988 White Mountain Fire in the Okanogan Highlands. The developing stand is a result of both natural reseeding and hand planting.



but natural processes are much more irregular. Natural colonization should be random, but often is aggregated according to the distribution of suitable germination sites. In these situations, canopy closure may occur in one spot decades before it occurs only a short distance away. Large piles of woody debris, competition from dense shrub layers, or exposed soils can all create situations that delay tree seedling establishment.

More dramatic environmental changes occur during this stage than in any other. During this relatively brief period, the area is transformed from open to closed canopy—from full sun to deep shade. Near the ground surface, temperature becomes highly moderated, and relative humidity increases. Many plant species, adapted to growing in the high-light environment of the early-colonizing stand, perish in the deep shade imposed by overlapping tree-crowns.

Biomass accumulation/Competitive exclusion

Following canopy closure, the stand will spend several decades in the biomass accumulation/competitive exclusion stage. In eastern Washington, this may continue for 50-60 years on highly productive sites or up to 120 years on poorer sites. At

Figure 32. High-density initial establishment can lead to high density stands. As the average size of trees within a stand increases, the number of trees it can support declines. Density-dependent mortality results from competition for available resources, including light, water, and nutrients.

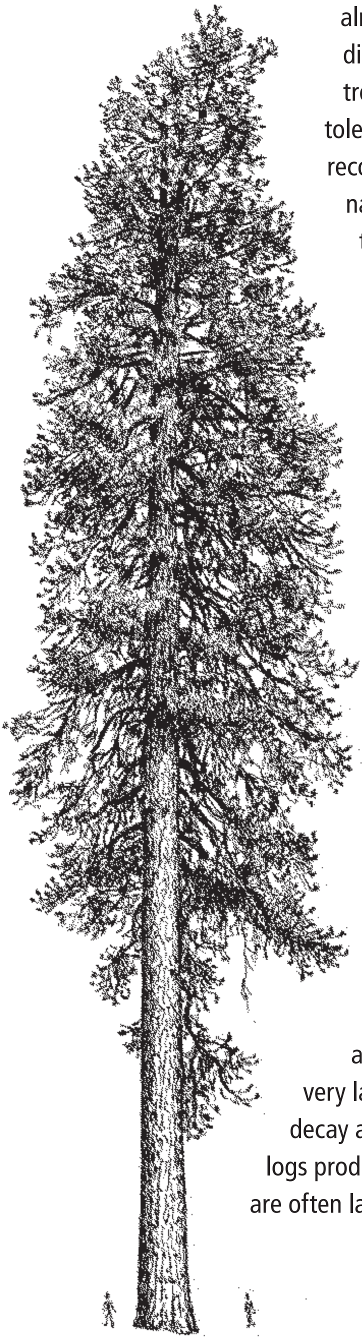
this stage, it is characteristic for a site to be completely dominated by trees. The trees can grow rapidly, converting a shrub field with tiny trees into a tall forest. Standing biomass increases by many orders of magnitude, yet recruitment of new individuals is limited by the deep shade at the forest floor.

Depending on initial stem densities, density-dependant mortality also will be prevalent during this stage (Figure 32). Dead, small-diameter trees are often abundant and appear to be strewn about the forest floor like jackstraws. As the trees grow taller, lower branches on many shade-intolerant tree species, such as lodgepole pine, die in the deep shade cast by branches above them. Crown depths may not change appreciably during these several decades. Crown bases will rise at the same rate as height increases, leaving bare trunks below the living crown as the dead branches fall off. The forest understory is at its most depauperate level during this stage, as the deep shade from a dense, upper canopy is at its most extreme.

Maturation

At maturity, the trees that form the upper canopy have reached 60-90 percent of their ultimate height. Most of the original shade-intolerant cohort that has not

Figure 33. Maturation. Mature forests often have two cohorts – a shade-tolerant understory developing beneath the overlying, maturing stand. Left – subalpine fir beneath a lodgepole pine canopy. Right – western hemlock developing beneath a Douglas fir canopy.



already ascended into the upper canopy will have died. More light reaches the understory as taller tree crowns become isolated, allowing shade-tolerant plants, including various tree species, to recolonize. The rate of understory colonization naturally depends on many factors, including the proximity of seed sources. If the initial disturbance was very extensive, tree seedlings may not colonize for many decades, even if conditions are favorable. Ultimately, the understory is filled in by young, shade-tolerant trees, shrubs, and herbs common to that vegetation zone (Figure 33). The middle canopy will be completely free of foliage and consist only of the trunks of canopy trees. This area, known as the ***bole zone,*** is most dramatic at this stage.

Vertical diversification

Vertical diversification is the first stage of old growth following a stand-replacing event. Shade-tolerant trees are now continuously establishing in the understory and have expanded to occupy the middle canopy (Figure 34). Height growth of the stand proceeds very slowly—most new growth goes into wood production and below-ground processes. Many trees in the shade-intolerant cohort comprising the main canopy become very large during this stage. Mortality continues as decay and other agents kill occasional trees. Snags and logs produced during this stage begin to accumulate and are often large enough to have significance for wildlife.

Stand Development Following Stand-replacing Wildfire

Figure 34 left. Vertical diversification. This early, old-growth forest has a Douglas fir main canopy, with grand fir and western hemlock present in a multitude of sub-canopy sizes. Large gaps and horizontal variability are lacking.

Figure 35 below. Classic old-growth – horizontal diversification. Structural patterns set up during the vertical diversification stage further develop. Large openings, patches of dense trees, and large, old trees transform the homogeneous canopy into a mosaic of very small patches.

Figure 36. Pioneer cohort loss. The Douglas fir cohort established following a previous stand-replacement disturbance will ultimately be replaced by western hemlock and Pacific silver fir, the assumed climax community at this high elevation site.

Horizontal diversification

This stage is considered by many as classic old growth. Some trees within the original cohort of large trees die standing; others fall, often taking one or several smaller neighboring trees down with them. Gaps created by tree mortality increase light levels and nutrient availability in the understory. This pattern of gap formation, followed by infilling from trees in the understory, creates the horizontal diversification indicative of this stage in stand development (Figure 35). In addition, tree mortality is often higher near pre-existing gaps—gap expansion accentuates horizontal variability at the stand level. In eastern Washington, this stage often begins when the stand is between 250 and 350 years old, depending on site location and productivity. Since dominant species such as ponderosa pine, western larch, and Douglas fir easily can live for 500-800 years, this stage may last for several centuries.

Pioneer cohort loss

The final stage of stand development begins when the last of the original cohort dies. At this point, none of the trees in any of the canopy levels are those that originated immediately after the initial disturbance (Figure 36). The structural presence of the original cohort, in the form of snags and logs, extends for a century or more after the last giant pine, larch, or fir dies. The word ***climax*** is often used to describe forests dominated by Engelmann spruce and subalpine fir, or western hemlock and western redcedar, and falsely implies an endpoint to forest succession. The phrase is discouraged by many ecologists, as it represents an idea, not reality. Succession does not really stop when it reaches this point. This final stage of the stand developmental sequence is rarely reached, especially in the disturbance-prone Eastside environments. It is likely that some event will occur to divert a forest from this idealized developmental trajectory. The most common event is an intermediate disturbance, which serves to increase structural heterogeneity and may reset the developmental sequence to an earlier stage.

Other scenarios

The idealized stand-development sequence presented above is not the dominant scenario in eastern Washington. It is limited to wet forests experiencing stand-replacing events, with countless variations. The catastrophic wildfire scenario described above assumes complete mortality for all biological legacies. With such fire-resistant trees as western larch or ponderosa pine, chances are high that a stand-replacing fire will not kill every tree. Even in the hottest and most severe events, such as the Tripod Fire of 2006 or the White Mountain Fire of 1988,

Key to stand development stages following stand-replacement events

The following key may be used for any stand-replacement scenario, including but not limited to development following stand-replacement wildfire, as described above. Throughout this key, the phrase ***original cohort*** refers to the first group of trees established following the stand-replacing event. Excluding legacy trees, this will be the only place that trees with low relative shade tolerance appear in the key. This includes western larch, but also ponderosa pine and Douglas fir when found in a moister vegetation zone, such as the grand fir or western hemlock zone. The phrase ***shade-tolerant cohort*** refers to trees establishing long after the original cohort. It will be useful to determine the vegetation zone (page 18) before using this key. While this key has been widely field tested in eastern Washington, stands may exist that do not key out properly. In these situations, relax the percentage values and retry.

1 Legacy trees present – trees obviously older/larger than the others, or a subset of the largest trees with charcoal on bark 2
No legacy trees 4

2 Legacy trees cover < than 20 % canopy cover . . . . Stand with legacies 4*
Legacy trees have ≥ 20 % canopy cover . . . . Two cohort stand 3

3 Each cohort must be keyed out separately
Older cohort 8
Younger cohort 4

4 Original cohort (live or dead) ≥ 25 % of main canopy stems 5
Original cohort < 25 % of main canopy stems 10

5 Young, planted or naturally reseeded original cohort trees < 10 years old . . . . **Cohort establishment**
Not as above 6

6 Young, planted or naturally reseeded original cohort trees 5-20 years old, abundant shrub cover . . . . **Canopy closure**
Not as above 7

7 Young original cohort trees, not yet overhead, overlapping crowns, shrubs present ≥ 15 % . . . . **Canopy closure**
Not as above 8

8 Original cohort canopy overhead, self pruning, scant understory . . . . **Biomass accumulation/stem exclusion**
Not as above 9

9 Original cohort canopy overhead, self pruning evident, shade-tolerant cohort seedlings present only in understory . . . . **Maturation**
Not as above 10

10 Original cohort upper canopy, shade-tolerant cohort abundant and in several height classes, including main canopy . . . . **Vertical diversification / old-growth**
Not as above 11

11 Original cohort canopy patchy, large canopy gaps present, shade-tolerant cohort abundant in all canopy levels . . . . **Horizontal diversification / old-growth**
All original cohort trees dead (snags or logs), shade-tolerant cohort abundant in all canopy levels . . . . **Pioneer cohort loss – old-growth****

* For legacy trees, refer to the individual sections for the relevant species.
** If the original cohort consisted of shade-tolerant species, the horizontal diversification stage will be equivalent to the pioneer cohort loss stage.

trees survived in ravines and around the edges of the burn. Fire boundaries are sometimes fairly abrupt, the result of a landscape feature capable of stopping a fire, such as a ridgetop or a stream crossing. In most situations, however, the boundaries will be either a gradual change from a burned to unburned area, or a mosaic of patches created by varying burn intensities (Figure 37). In situations where living biological legacies are not present, stand age must be determined by the stand-development sequence.

Figure 37. Mixed-severity fire aftermath. With increased stand densities, mixed-severity fires are now common in areas that previously supported only low-severity events.

Insect Outbreaks

Insects play an important role in structuring the forests of eastern Washington at a variety of scales, ranging from the death of an individual tree, to the elimination of an entire species from a stand, to the near-complete mortality of a forested landscape. With few exceptions, all of the insect species in question are native to eastern Washington and have co-existed with their host tree species for thousands of years.[3] Most damage to forests from insects can be categorized as endemic or epidemic. ***Endemic mortality*** refers to low-level, background mortality that occurs every year with natural variation in the species causing the mortality, population dynamics, and region of impact. ***Epidemic mortality*** refers to rapid, massive, high-mortality outbreaks. While both types of mortality were present in the region prior to Euro-American settlement, epidemic

Figure 38. Engelmann spruce mortality resulting from spruce beetle attack. Such attacks can last for more than a decade.

[3] The balsam wooly adelgid (*Adelges piceae*), a European species that reached the West Coast in 1929, has been responsible for extensive mortality in all true firs (*Abies*), especially Rocky Mountain subalpine fir (*A. bifolia*) populations in eastern Washington.

outbreaks have increased in size and frequency as a result of fire suppression, forest simplification, landscape-level homogenization of forest stands, and the arrival of non-native insect species.

Most of the damage that occurred during the twentieth century is attributed a relatively small number of species, primarily bark beetles of the genus *Dendroctonus.* Each year, several million cubic meters of timber volume succumb to this genus in the western United States. The most damaging species are the mountain pine beetle (*D. ponderosae*), which attacks the four pine species native to eastern Washington, and the western pine beetle (*D. brevicomis*), which attacks primarily mature and old ponderosa pine. Other notable species include the Douglas fir beetle (*D. pseudotsugae*) and the spruce beetle (*D. rufipennis*). As most of the damage is in the form of endemic mortality, proactive management options are limited. The ecological factors that control insect

Figure 39. Bark beetle galleries. Adult beetles excavate galleries within the inner bark in which to lay their eggs, and the emerging young excavate galleries of their own. In sufficient numbers, the intricate patterns may have a lethal effect on the host tree.

populations are complex and include a combination of climatic conditions and forest stand structure. Periodically, favorable conditions lead to a rapid growth in bark beetle populations and large numbers of trees are killed over a large area. Such outbreaks do not occur frequently—the time interval often is measured in decades. Following an event, the probability of catastrophic wildfire may increase as the extensive mortality greatly increases fuel loading (Figure 38).

An initial attack starts with a pioneering beetle on a random flight. A tree is selected using olfactory cues and the adult bark beetle bores into the bark, excavating galleries in the inner bark in which to lay eggs. Upon hatching, the young larvae mine galleries of their own (Figure 39). If enough beetles are present, the tree becomes girdled and dies. Of course, some tree species are more vulnerable than others. A healthy tree may ***pitch out*** the attacking beetle—the hole in the bark begins a flow of pitch in resinous trees, such as ponderosa pine or

Figure 40. Bark beetle mortality. A large ponderosa pine, already stressed by a near fatal wildfire, became easy prey for marauding bark beetles.

western larch, which may discharge the beetle. Upon successfully establishing itself in a tree, the beetle exudes a powerful pheromone, signaling others nearby that a suitable host tree has been located. This triggers a secondary attack which can consist of several dozen beetles. Trees already under stress from drought or fire damage, or those located near large beetle populations established in other recently dead trees, are most likely to be killed (Figure 40).

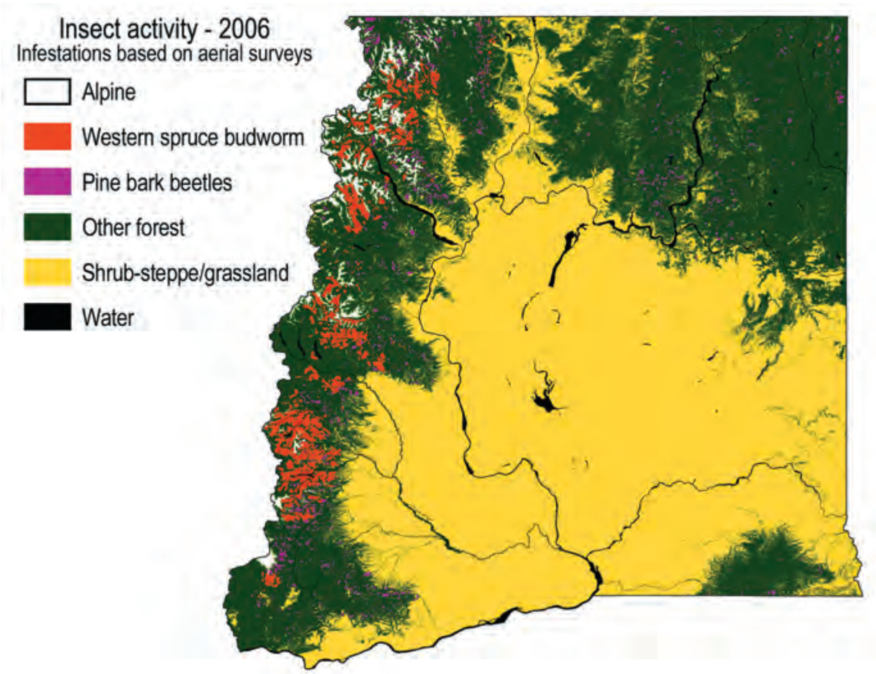
The other primary type of forest insect pests is defoliators. Adult defoliating moths lay their eggs in the buds of trees. The eggs hatch into caterpillars that feed on the emerging new leaves. In sufficient numbers, the caterpillars may eliminate essentially all of a tree's annual production of leaves. Of the many native defoliators in western forests, the two most important in eastern Washington are the western spruce budworm (*Choristoneura occidentalis*) and the Douglas fir

Figure 41. Defoliation by western spruce budworm. An outbreak along the North Cascades highway has taken its toll on the fir and spruce population, leaving the telltale reddish foliage. The few green trees in the photo are pines, which were unaffected.

tussock moth (*Orgyra pseudotsugata*). Both are primarily epidemic species. In eastern Washington, Douglas fir, Engelmann spruce, grand fir, and subalpine fir are the species most susceptible to defoliators (Figure 41). Outbreaks of the Douglas fir tussock moth can be intense, lasting two to four years, before subsiding for many years. Outbreaks of western spruce budworm can last anywhere from a year or two to several decades.

Both bark beetles and defoliators have greatly benefitted from past management practices. Fire suppression and high-grade logging techniques have combined to form forests more susceptible to epidemic insect outbreaks. An excessive number of stems creates stress in all of the trees as they compete for limited below-ground resources—including the main canopy dominants. Both bark beetles and

Figure 42. 2006 map of insect pest activity in eastern Washington. Only those infestations detectable via aerial surveys were mapped. Survey conducted jointly by Washington State DNR and U.S. Forest Service.



defoliators can take advantage of these conditions to mount a successful attack. Forest simplification also contributes to the problem by creating ideal conditions across a wider area. A naturally patchy landscape would have susceptible stands separated from each other by more resistant stands, preventing insect populations from reaching epidemic proportions. Surveys conducted jointly by the Washington State Department of Natural Resources and the U.S. Forest Service indicate that the insect currently causing the most extensive mortality is the western spruce budworm (Figure 42).

Mistletoes

Mistletoes are parasitic plants that grow in the crowns of many tree species found in eastern Washington. Leafy mistletoes, such as members of the genus *Phoradendron*, infect crowns of Oregon white oak. Dwarf mistletoes, in contrast, are small, leafless plants that infect the twigs in the outer crowns of trees (Figure 43). The majority of dwarf mistletoe species are host-specific—that is, they infect only one species or a group of similar species. Most members of the pine family are susceptible to dwarf mistletoes of the genus *Arceuthobium*. Unlike leafy mistletoes, these parasitic plants do little photosynthesis themselves—they get most of their food in the form of sugars from photosynthesis of their host tree. The aerial shoots they produce mostly serve a reproductive function.

Figure 43. Dwarf mistletoe on a subalpine fir. The female plant pictured is covered with ripening seeds, which will be explosively discharged when fully ripe. The sticky seeds can travel as far as 15 m (49 ft), and will occasionally land in the crown of a nearby tree, creating risk of a possible future infection.

Figure 44. Broom formation. Many dwarf mistletoes will form ***brooms*** on the branches of the host tree – dense areas of wood and foliage caused by altering growth hormone concentrations in the vicinity of the infection.

Dwarf mistletoes possess a bizarre seed dispersal mechanism—the seeds are explosively discharged when ripe and coated with a sticky covering that can adhere to the leaves or stems on which they land. Depending on wind conditions and the location of the plant within the tree crown, the seeds can sometimes travel 10-15 m (33-49 ft) away from the parent plant. While impressive, this is a limited distance when compared to other mechanisms of seed dispersal. Gravity limits the upward migration of infections—the heaviest infections typically occur in the lower crowns. Occasional, wider dispersal may occur when the sticky seeds adhere to a bird and are transported to another tree farther away.

Figure 45. Large mistletoe broom in Douglas fir. The brooms of Douglas fir dwarf mistletoe can grow to exceptional size, often severely affecting the growth and health of the tree.

As a parasite, the mistletoe makes use of sugars produced by the host, reducing their availability for tree growth. Hormones produced by the mistletoe also cause excessive, but deformed growth in the vicinity of the infection. These infections often result in ***broom*** formation—dense areas of foliage and branches, which appear as a star-shaped formation easily visible within the crown (Figure 44). Depending on the species, these brooms can grow to be quite large (Figure 45).

Several species of mistletoe infect members of the Pine family in eastern Washington. The size and distribution of these infections can be indirect indicators of tree and stand age. The two most prevalent are the Douglas fir dwarf mistletoe (*A. douglasii* — Figure 46) and the larch dwarf mistletoe (*A. laricis* — Figure 47). Another common species is the lodgepole pine dwarf mistletoe (*A. americanum* — Figure 48). Ponderosa pine is parasitized by the

Figure 46. Extreme Douglas fir dwarf mistletoe infection. In some instances, the dwarf mistletoe will kill all of the non-infected portions of the tree, leaving just the remnants of brooms, as in this heavily infected Douglas fir.

western dwarf mistletoe (*A. campylopodum*), a species that does not readily form brooms, but instead is more common on the main trunks of trees (Figure 49).

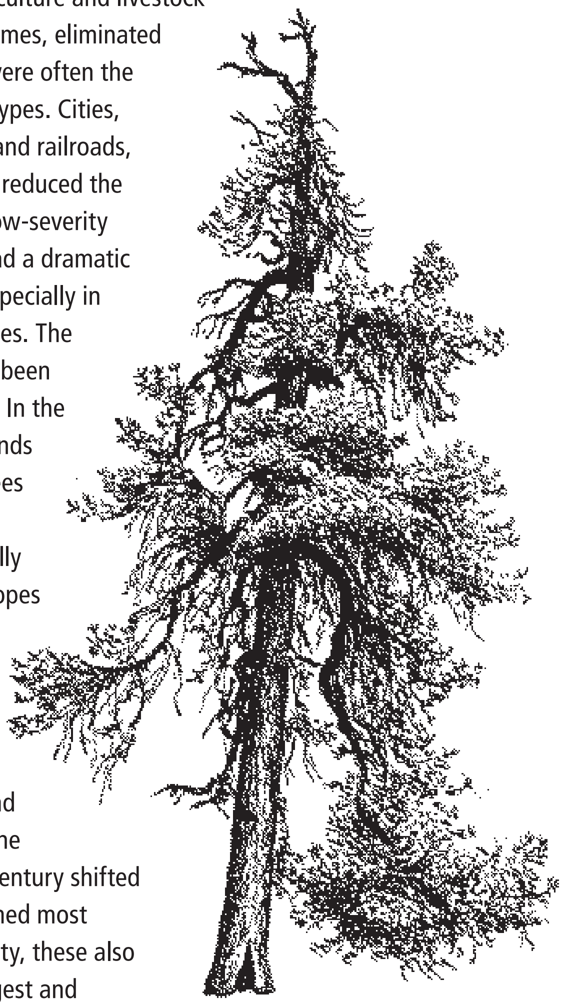
Figure 47. Severe larch dwarf mistletoe infection. All non-infected portions of these two trees are dead. The outlook of such trees is bleak.

Figure 48 above. Lodgepole pine dwarf mistletoe. Ripening seeds of the female plant.

Figure 49 left. Western dwarf mistletoe. The male plant (above) and female plant (below) are both growing out of the main trunk of this young ponderosa pine.

Landscapes, Stands, and Individual Trees

In eastern Washington, fire suppression, logging patterns, and livestock grazing have altered the natural disturbance cycles that originally shaped stand development and the fate of individual trees, leading to forest simplification and homogenization at the landscape level. Beginning in the mid nineteenth century, Euro-American activity began to reduce or eliminate fire from many landscapes. Agriculture and livestock grazing reduced and, sometimes, eliminated the abundant grasses that were often the source of fires in dry forest types. Cities, with their associated roads and railroads, fragmented areas and often reduced the extent and connectivity of low-severity fires. These changes have had a dramatic effect on forest structure, especially in low-elevation, dry forest types. The most significant change has been an increase in stand density. In the absence of frequent fire, stands became thick with young trees and grew to resemble the dense, wetter forests naturally occurring on north-facing slopes or at higher elevations.



Early Euro-American logging used ***highgrading***—the practice of removing only the largest and most valuable trees. While the focus during the twentieth century shifted to the removal of trees deemed most susceptible to beetle mortality, these also tended to be among the largest and oldest trees in a stand. Together, these practices simplified and homogenized forests in our region. Furthermore, excessive grazing by both cattle and sheep eliminated much of the natural grass cover that offered competition to tree seedlings, further contributing to denser stands. Additional grazing impacts include soil compaction, reduced vegetation cover, increased shrub/grass ratio, and increased soil erosion.

Over time, the above practices greatly reduced the differences between the (formerly) low-severity fire regime forests and those that were naturally denser. Large-scale forest simplification has led to forest patch sizes that are larger than those found in pre-Euro-American landscapes. Whether this change is irreversible is still being debated, but the imposed pattern has led to the current situation of large-scale insect epidemics and catastrophic loss due to wildfire, which only serve to exacerbate the problem.

In western Washington, where stand-replacing fires are the norm, the ages of the oldest trees in the stand are usually representative of the age of the stand itself. This is not often the case in the dry mixed-conifer forests of eastern Washington where many of the oldest trees, especially fire-resistant species, will have survived one or more previous fire events. The older the cohort of trees, the more diffuse these old trees will be across the landscape. At such low densities, aging the stand becomes problematic. A series of overlapping, low severity disturbances may lead to the establishment of multiple cohorts. What is the age of the stand in such a scenario? Or perhaps, more appropriately, how does one define the stand? In forests that experience low- and/or mixed-severity fire regimes, the concept of a stand begins to have little relevance in discussions of mature and old forests. Instead, it is the individual tree that determines the presence of old-growth conditions. This cohort of older, scattered legacy trees will serve as the foundation of any restoration plan.

However, in wetter forests that experience infrequent, stand-replacing fires, the stand is still the primary unit of concern—as it is in western Washington. Therefore, depending on the forest type and fire regime under consideration, the landscape, the stand, or the individual tree will be the focus.

Actual and Relative Shade Tolerance

An understanding of shade tolerance and its role in vegetation zones, tree interactions, and successional stage is essential in a guide devoted to determining the age of trees and stands of trees. While shade tolerance may at first seem only marginally related to determining age, it is actually a core concept of vegetation zones and how different tree species interact. Successional status, which will ultimately lead us to tree and stand age, is inseparably linked to an understanding of shade tolerance.

Shade tolerance can be thought of in two ways—actual and relative. ***Actual shade tolerance*** refers to the light level at which a tree can photosynthesize. At low light levels, photosynthesis may be insufficient to balance leaf respiration. With many trees, this balance point, known as the ***compensation point***, occurs at light levels of 2–3 percent of full sunlight (Figure 50). With light levels above this, photosynthesis increases nearly linearly up to a threshold, called the

Figure 50. A generalized view of leaf photosynthesis with increasing light levels. Peak photosynthetic efficiency occurs at the saturation point.

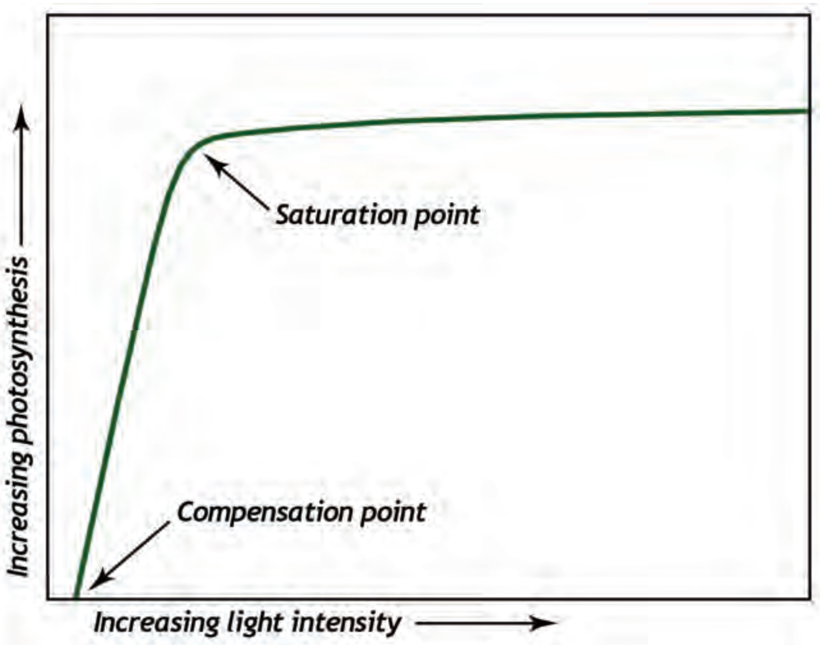


Figure 51. Leaf arrangement in response to light. Left – a fully illuminated shoot from the top of a noble fir tree showing aggregated leaves and self-shading. Below – a shaded shoot from the same stand with minimal self-shading and a high silhouette area ratio (SAR).

saturation point, at which peak photosynthetic efficiency occurs. Leaves cannot use all of the light from a fully illuminated position, so once the photosynthetic apparatus of the leaf is saturated, additional photons are converted to heat. Too much heat can be lethal to the leaf. Although the details will differ among species, the general form of this curve is common to all leaves.

Most trees, including many of the coniferous species, arrange their leaves differently around the stem under contrasting light conditions. For example, noble fir, a shade-intolerant species of subalpine forests in the south Cascades, displays dramatic differences in shoot morphology between branches growing under fully sunlit conditions and those found in the shade (Figure 51). Leaves at the top of the tree receive much more light than they can possibly use and aggregate themselves to provide self-shading. The leaves are oriented in such a way that no individual leaf is fully illuminated. In contrast, leaves in the deep shade exist in lighting conditions well below their saturation point, so aggregation and self-shading would not be beneficial. Instead, heavily shaded leaves are often oriented so that there is maximum exposure to the few photons that do reach them. In other words, these leaves minimize self-shading by orienting themselves perpendicularly to the sun's rays to maximize light interception. In many of our closed-canopy forests, only 1–5 percent of the available light reaches the ground, and most of this arrives in the form of diffuse light. Many of the understory species found in these forests, such as vanilla leaf (*Achlys triphylla*) or vine maple (*Acer circinatum*), orient their leaves parallel to the ground to get maximum exposure to the small amount of diffuse light available.

Each species varies with respect to its ability to aggregate and disperse its leaf orientation. Pines, in general, lack the ability to orient their leaves perpendicularly to the sun's rays or to minimize self shading. As a result, leaves from pines cannot exist in low-light levels. Firs, in contrast, are quite adept in this regard. A common measure of the ability of a shoot to maximize exposure is known as the Silhouette Area Ratio (SAR). SAR is the ratio of the projected area of a shoot to the projected area of all of the leaves individually. Pines typically have low SAR values of 0.3–0.5, indicating a high level of self-shading. The shade shoots of our most shade-tolerant tree species, including western hemlock, Pacific silver fir, western redcedar, grand fir, and Pacific yew (*Taxus brevifolia*), can have very high SAR values (0.95–0.99), indicating almost no self-shading (Figure 52). Shade-tolerant species are thus able to hold foliage lower in their crowns than other trees, often resulting in deeper, denser crowns. As a consequence, the shade cast by shade-tolerant trees is often much darker than that of their shade-intolerant associates.

Relative shade tolerance refers to the shade tolerance of one tree species when compared to its neighbors. Douglas fir, for example, will not grow in the shade of western hemlock or western redcedar. In such cases, its foliage will only exist in areas with high light levels, which in an older forest will be the upper canopy. All of the lower canopy levels, including regenerating trees in the understory, will be occupied by the leaves of shade-tolerant species. Throughout much of the forested parts of eastern Washington, however, where Douglas fir commonly grows with ponderosa pine and western larch, it behaves as a shade-tolerant species. These species of pine and larch have an even lower shade tolerance. In many of these forests, the understory environment is too dark for successful regeneration of the main canopy species. Instead, Douglas fir often is the species that occupies the lower canopy levels and regenerates in the understory. For these reasons, it is important to distinguish between actual and relative shade tolerance when discussing the shade tolerance of tree species.

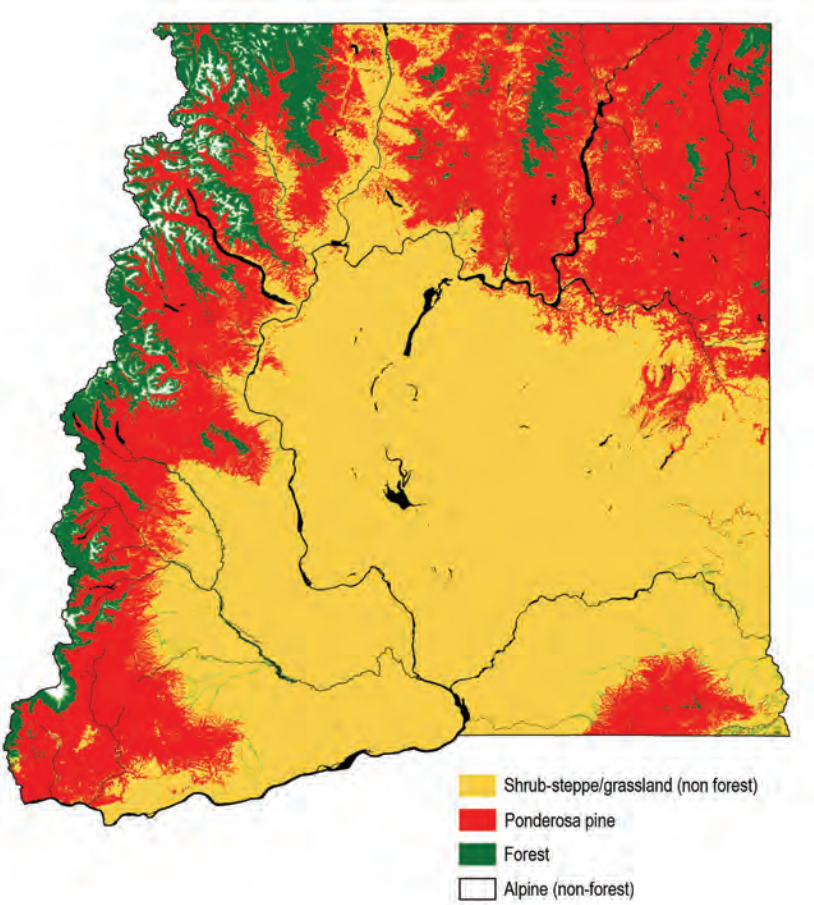
Figure 52. Grand fir has one of the highest known silhouette area ratios (SAR), with values up to 0.99, indicating almost no self-shading of leaves.

Ponderosa Pine (*Pinus ponderosa*)

Throughout most of western North America, ponderosa pine is the first tall tree encountered as one travels up into the mountains. Whether it is from the Great Plains into the Colorado Front Range, from the Nevada deserts into one of the

Figure 53. Ponderosa pine is the first tree encountered as one leaves the Columbia Basin and ascends into the mountains. Scattered trees in woodlands often occur before one reaches the forest.

Figure 54. Range of ponderosa pine in eastern Washington.



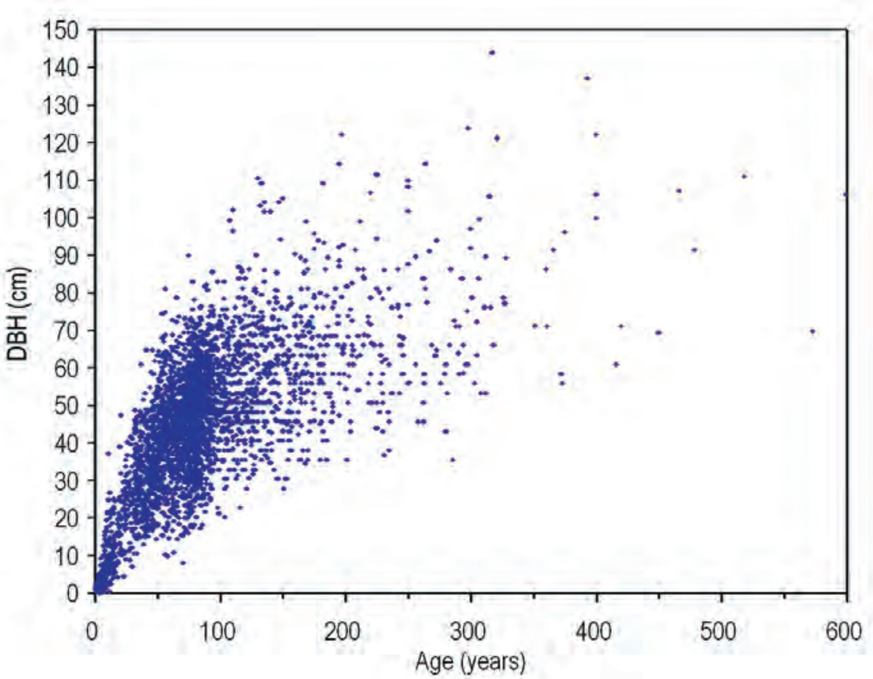
Great Basin ranges, or from the sagebrush steppe of eastern Washington into the Okanogan Mountains, the tall stature and orange-yellow bark of the ponderosa pine is unmistakable (Figure 53). Having a drought tolerance only exceeded by piñons, junipers, and other steppe and desert plants, ponderosas are emblematic of the American west.

In eastern Washington, the distribution of ponderosa pine defines the lower treeline on all sides of the Columbia Basin (Figure 54). The few exceptions include woodlands of Oregon white oak or western juniper in the South Cascades and the sparse stringers of valley bottom hardwoods that occasionally stray further into the shrub-steppe or grasslands. The ability to tolerate harsh conditions, including drought, heat, and surface fire, allows ponderosa pine to occupy most habitats (Figure 55)—the species is a component in most forest types in eastern Washington, including some at fairly high elevations. Its competitive ability is limited primarily by its low relative shade tolerance. The presence of Douglas fir or grand fir in the main canopy, or any closed canopy situation, prevents young pine seedlings from thriving.

As with many tree species with wide distributions and ***ecological amplitudes,*** age and size of ponderosa pine are not closely correlated. Because ponderosa pine can grow in most of the vegetation zones in eastern Washington, from rocky cliffs to riparian zones, the size of a tree reveals little about its age (Figure 56)—an 80 cm (31 in) diameter tree in eastern Washington could be 60 years old or 600.

Figure 55. The remarkable adaptability of ponderosa pine will occasionally allow a tree on a rocky cliff to live for centuries, such as this tree in the South Cascades.

Figure 56. Poor correlation between size and age for ponderosa pine. Data are all from eastern Washington and include data from the Washington State DNR, the U.S. Forest Service, and the author.



Ponderosa pine is one of the ***hard pines*** (subgenus *Pinus*), characterized by heavy (ponderous), somewhat decay-resistant, resinous wood. Abundant resins in healthy trees help defend against attacks by the mountain or western pine beetle. Ponderosa pine has been a very important timber tree. The wood of old trees is strong, often clear, and has been used to produce products ranging from lumber to much higher-quality finished products such as moldings.

The sapwood of ponderosa pine is thicker than any of its associated trees (Figure 57). In many species, sapwood is often weak and prone to decay and contrasts sharply with heartwood. Sapwood comprises a large portion of young ponderosas as well as trees close to maturity, dramatically decreasing their market value. In addition, the wood of young-to-mature trees is knotty, containing the embedded remains of lower branches. These young trees are often called ***bull*** or ***blackjack*** pines, a reference to their poor lumber value. Therefore, the difference in timber value between an old and a young pine is substantial.

Figure 57 above. Thick sapwood is a characteristic of ponderosa pine. Young trees, which consist of nearly all sapwood, have little commercial value.

Figure 58 right. The strange and lovely puzzle-piece bark of ponderosa pine.

Bark characteristics

The orange-yellow bark, comprised of a myriad of small, puzzle-piece flakes, is characteristic of older ponderosa pines (Figure 58). When warmed by the sun, the bark has an aroma of vanilla, butterscotch, pineapples, or even cream soda, caused by the presence of terpenes – complex hydrocarbons that are the source of scent for many herbs, spices, and perfumes.

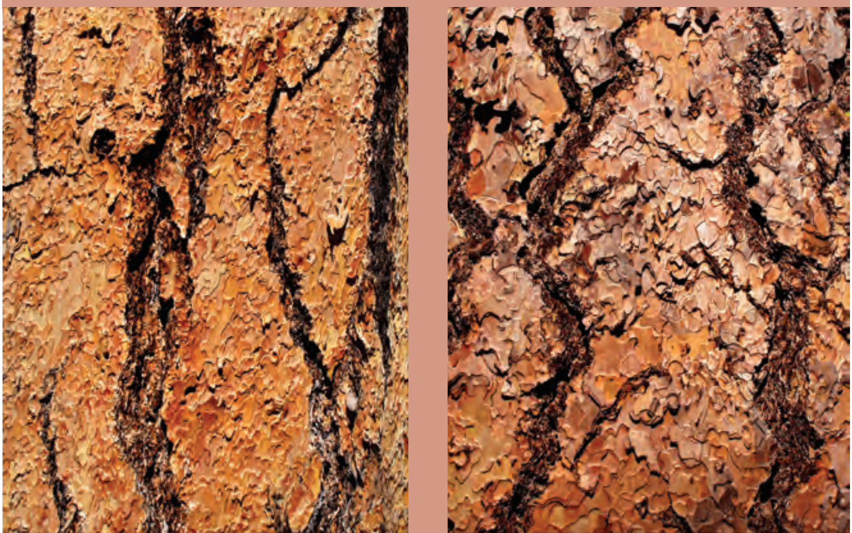
The thick bark of ponderosa pine is key to its ability to survive fire. For the first century, the bark is dark brown to nearly black and begins to break up into thick, vertical fissures. During the second century, the outer layers of the bark ridges begin to flake off, revealing the reddish brown color characteristic of mature trees (Figure 59). As the tree ages, the outermost bark continues to flake off, causing the colorful plates of outer bark to get wider, while the width of the dark fissures

Figure 59. A maturing pine is just beginning to develop color in the outer bark.

in between remain relatively constant (Figure 60). By the third century, the bark plates have become substantially wider than the fissures, a sign of old age (Figure 61). Foresters often affectionately refer to these old, valuable trees as ***yellow-bellies***. Unlike trunk diameter, maximum plate width is well correlated with tree age—a feature we will use to help us in aging trees (Figure 62).

134 years 164 years 227 years

Figure 60. Bark patterns on mature ponderosa pine. Note residual charcoal in the center photo.



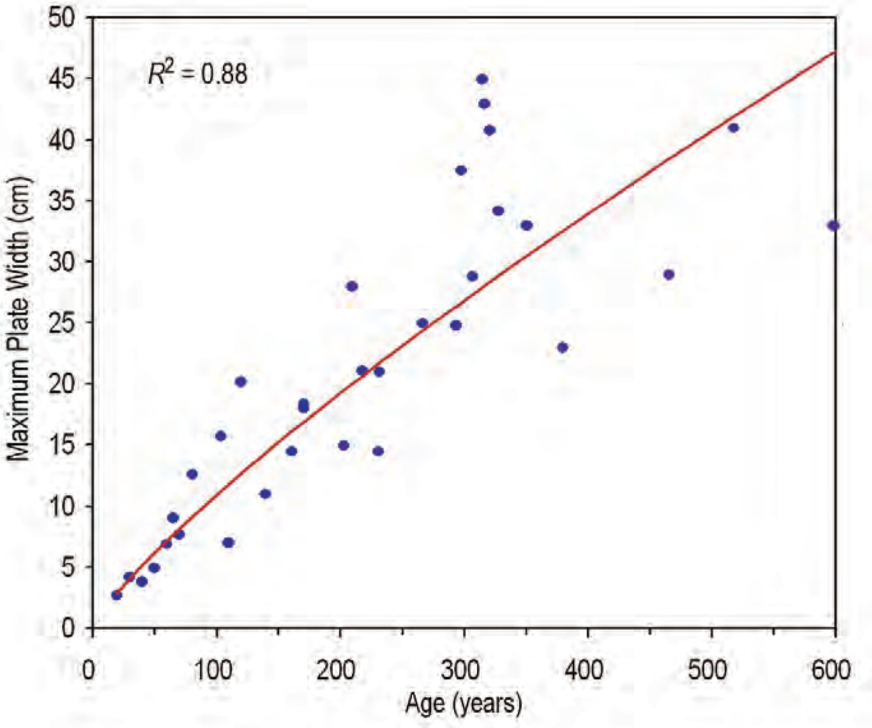
271 years 304 years

Figure 61. Bark patterns on old ponderosa pine. The colorful bark plates are generally more than three times wider than the darker fissures that separate them.

Lower crown characteristics

Ponderosa pine growth is ***whorl-based,*** like many members of the pine family. Whorl-based growth starts at the end of the growing season, when the terminal leader produces several buds at the tip. One of these buds will be the new terminal leader for the next growing season, while the remaining buds will become

Figure 62. Bark plate width is a better predictor of tree age than tree size.



branches. Each branch grows away from the others as it radiates out from the tree. Both the leader and the branches grow and elongate after the spring bud break, depending on the growing conditions. In most pine, fir, and spruce species, four to six branches are produced each year. This pattern repeats every year, so that over time the tree will consist of a series of branch whorls, separated by short sections of trunk. Each of these short sections of trunk represents the amount the leader grew in the year when that section was the top of the tree (Figure 63).

Over time, branches in the lower crown die due to shading and the lower crown lifts as the tree grows taller (Figure 64). Dead branches are usually present in the lower crown of 100 year old trees, but eventually fall off, leaving tell-tale signs of where the branches once were (Figure 65). As the tree grows, the bark begins to cover up the locations of these former branches—however, residual evidence may be visible on trees older than 200 years (Figure 66). Only in old age (trees greater than 250 years) are the scars of original branches completely covered (Figure 67).

Figure 63. Whorl-based branch growth on a young ponderosa pine.

Figure 64 left. The whorl-based branch growth is clearly visible below the receding crown of this ponderosa pine.

Figure 65. Old branch whorls are still visible decades after the branches have fallen off.

In part due to the open nature of pine forests, ponderosas do not fill in their lower crowns with ***epicormic branches*** as do the more shade-tolerant associates Douglas fir and grand fir. As a result, the original branches are persistent and mature in much the same manner as the main trunk, especially in open-grown conditions (Figure 68).

Crown form and tree vigor

The appearance of a tree of a given age is affected by a number of factors, including site productivity and overall tree vigor. In general, differences become accentuated with age. To aid in their identification, a series of crown profiles of

Figure 66 left. A century may pass before bark growth completely obscures old branch locations.

Figure 67 right. The rough and deeply furrowed bark of old trees shows no indication of where the original branches were located when the tree was younger.

trees has been prepared that represent trees of different ages and degrees of vigor (Figure 69). These were inspired by the profiles developed by Keen (1943), who designed similar drawings for rating resistance to insect attack. While his profiles of ponderosa pines were amazing in their simplicity and utility, the different objectives of this book prompted the creation of a set of new profiles. Although Keen depicted four age classes in his diagram, the youngest is omitted here as this guide is primarily focused on mature and old trees. For a given age, an intermediate vigor class may represent a weak tree on a good site, or a healthy tree on a poor site. Therefore, more than one tree is depicted for intermediate and low vigor categories.

Ponderosa Pine

Figure 68. The thick, colorful bark of old trees is found not only on the trunk, but also extends to the old, original branches.

Figure 69. Ponderosa pine crown form and tree vigor in eastern Washington. Idealized forms represent three age and four vigor classes (A-high vigor to D-low vigor). Vigor is a function of site productivity and response to disturbance and environmental stress. More than one individual is shown for vigor classes B-D to illustrate possible variations. Competition-based mortality usually ensures that most trees in vigor classes C and D do not survive to the next age class. The trees depicted are the same scale in the first image, and at differing scales on the following pages.

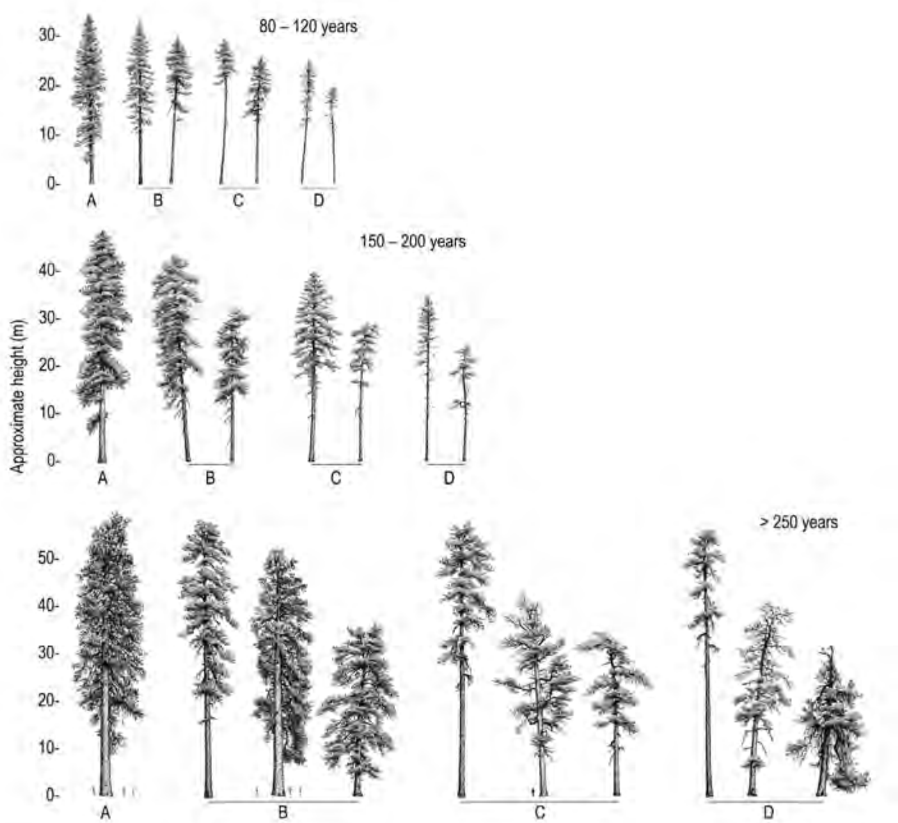
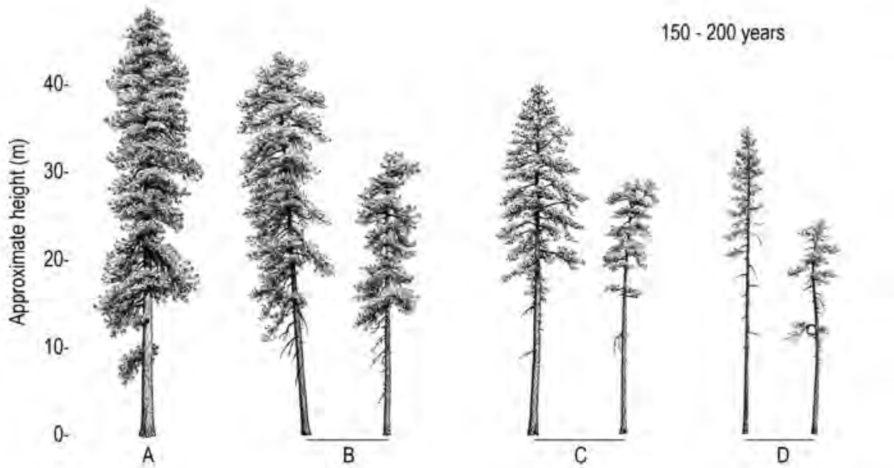


Figure 69 Continued



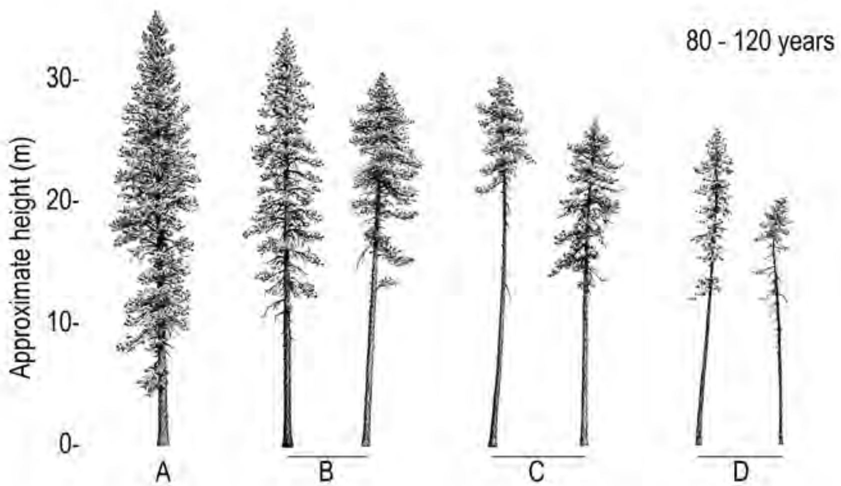
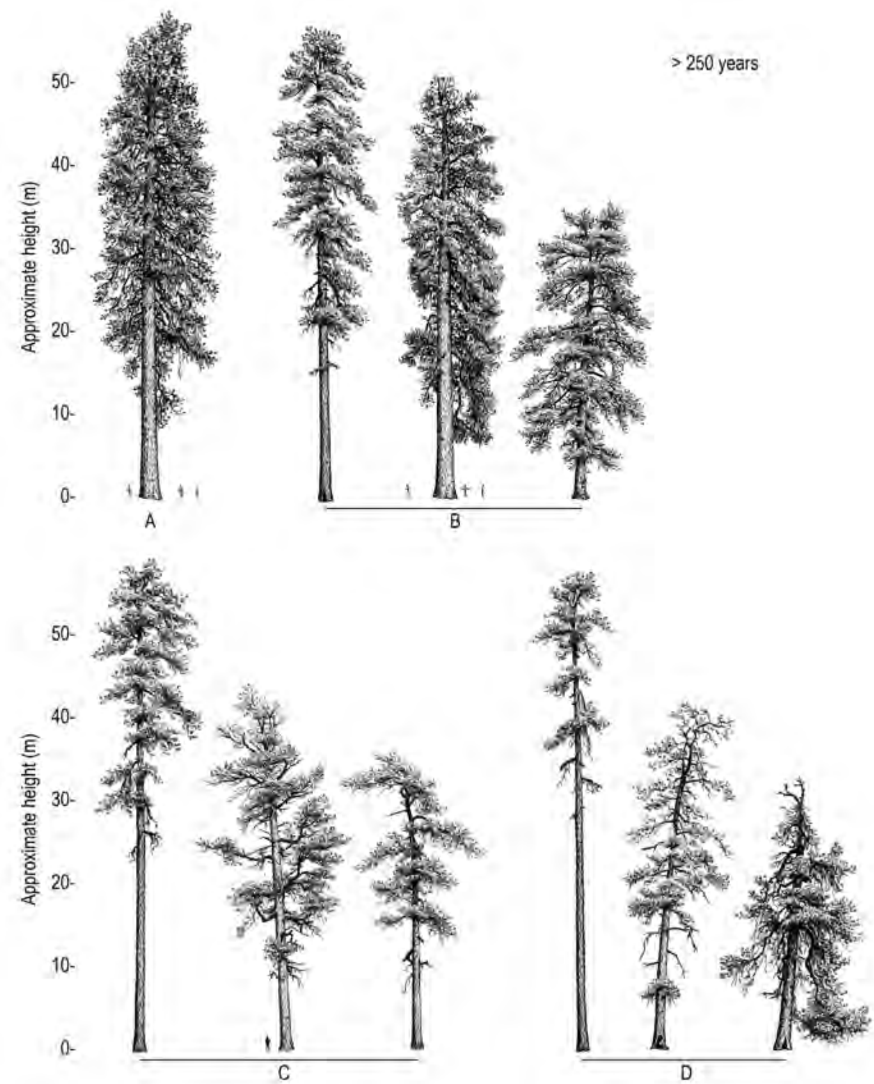


Figure 69 Continued



Rating system for determining the general age of ponderosa pine trees

(Choose one score from each category and sum scores to determine developmental stage)

Lower trunk bark condition	Score
Dark bark with small fissures	0
Outermost bark ridge flakes reddish, fissures small	1
Colorful plates, width about equal to fissure widths	2
Maximum fissure to fissure plate width ≥ 15 cm (6 in) and <25cm (10 in)	3
Maximum fissure to fissure plate width ≥ 25 cm (10 in)	5
Knot indicators on main trunk below crown	
Dead branches below main crown, whorl indicators extending nearly to tree base	0
Old knot/whorl indicators visible below main crown	1
No knot/whorl indicators visible	3
Crown form (refer to Figure 69)	
Similar to a tree in top row	0
Similar to a tree in middle row	3
Similar to a tree in bottom row	5

Scoring Key

< 2	Young tree
2–5	Mature tree < 150 years
6–10	Mature tree ≥ 150 years
> 10	Old tree ≥ 250 years

Longevity and death

How long can ponderosa pines live? A few individuals of the Rocky Mountain form (ssp. *scopulorum*) have been recorded over 900 years old, including a 1,047 year-old tree in Southwestern Colorado. The record for ssp. *ponderosa*, the type we have in eastern Washington, was discovered while carrying out research for this book—a living tree with a ring-count of 907 growing in the Wenatchee National Forest (Figure 70).

The development of spiral grain, uncommon in young trees, often becomes more prominent with age. An examination of old logs or snags reveals little if any spiraling when the trees were younger (the wood nearer the center of the tree). While not limited to ponderosa pine, this character is most often expressed in old trees of this species. A close examination of old conifers, either on rich or poor sites, shows that spiral grain is not rare. Old trees on harsh or rocky sites typically show spiral

Figure 70. Pristine, old-growth pine stand in the South Cascades. Many pines here are 300-600 years old – one tree has been measured at more than 900 years. The steepness of surrounding cliffs has isolated this stand and prevented cattle from ever reaching it.

Figure 71. On harsh sites, spiral grain allows the roots to reach all of the tree's branches. The spiral grain visible in the main trunk can also extend to the branches, giving them a structural advantage in snowy environments.

grain patterns with greater frequency than those on higher productivity sites. But if one looks at old conifers, either on rich or poor sites, it is obvious that spiral grain is not rare. Old trees of many species growing on harsh or rocky sites typically show spiral grain patterns with greater frequency than those on more productive sites. This is evidence of the adaptive advantage the growth pattern affords—the growth pattern results in increased connectivity of roots to all of the branches on a tree, not just the ones in line with the path of the wood cells (Figure 71). The phenomenon probably does not occur any more often in the seedlings of trees on these stressed sites. Instead, it may be that the few trees that survive to become old trees represent the small proportion of the population that developed this

Figure 72. The spiral grain of old trees is often not visible until the bark is removed. In this ponderosa pine log, the tight spiral of the outer wood gives way to progressively weaker spirals towards the center of the log.

character and were consequently more likely to survive (Figure 72). In addition, the crown is not only able to deal with moisture stress better, but the trunk itself is stronger because of the spiral grain. Since bark does not grow in the same manner as wood, it often hides the spiral grain beneath. Lighting scars can reveal a spiral pattern in the underlying wood (Figure 73), evident in both logs and snags.

Very few trees live to old age because of the many mortality agents they face. Drought, fires, insects, disease, competition, logging, and development represent continual threats to living trees. A tree stressed by one of these factors, if not killed outright, will be more vulnerable to bark beetles or disease.

Figure 73. Spiral grain in wood is sometimes masked by the bark, as revealed by this lightning scar on a pine.

Western Larch (*Larix occidentalis*)

Western larch signals its presence within the dense conifer forests that blanket the slopes of eastern Washington with bright yellow foliage each autumn (Figure 74) and a verdant flush of new growth each spring (Figure 75). Deciduous conifers are unusual and include only a few members of the Cupressaceae family (*Glypto-strobus, Metasequoia,* and *Taxodium*).

Figure 74. The golden glow of a western larch in autumn is unmistak-able – and unforget-table.

Figure 75 above. The bright green of the new flush of larch foliage is a welcome sign of spring, and a nice contrast to the darker greens of the neighboring pines and firs.

Figure 76 left. The photosynthetically efficient foliage (with cones) of western larch. Shed each year, the soft foliage contains none of the lignins and toxins present in the perennial evergreen needles of other species. Interestingly, larch is also is relatively free of insect pests.

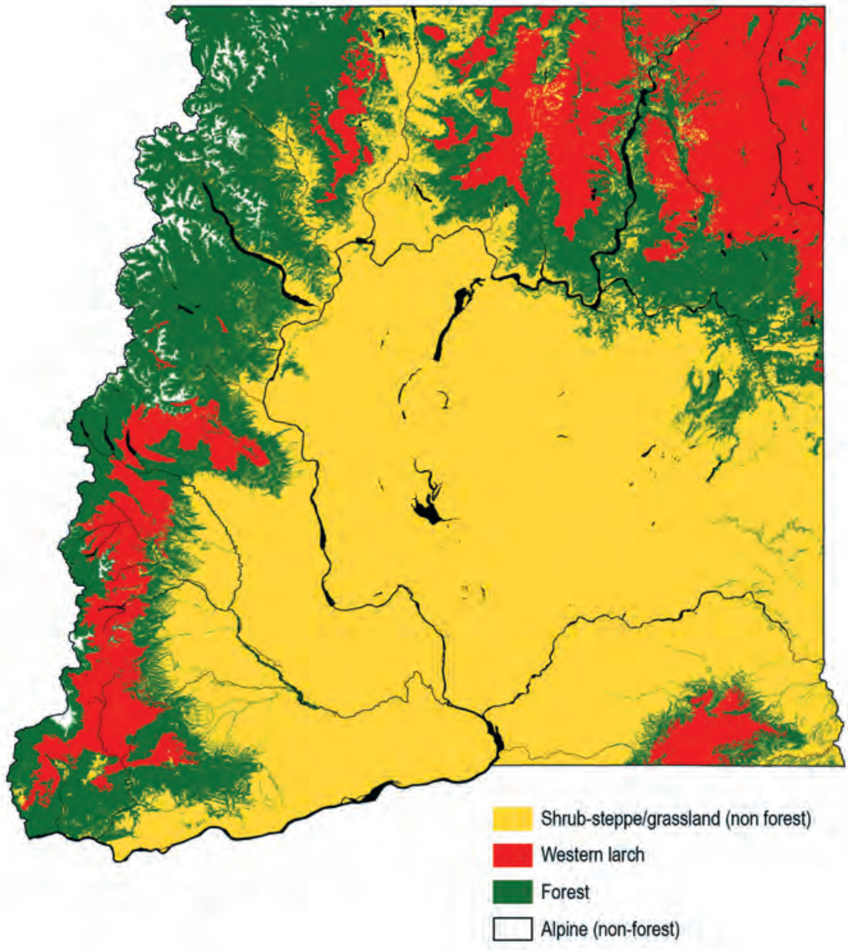
Plant physiologists have long puzzled over the advantages and disadvantages of evergreen and deciduous foliage, and leaf size and shape. The extreme environments of very high latitudes or altitudes tend to favor evergreen species. Foliage represents a considerable investment of the tree's resources, and the ability to retain foliage for many years, even decades, is advantageous in the cold environments where growing seasons are short. Substantial carbon and nutrient savings can be realized by dedicating only a small percentage of the carbon and nutrient budget to the annual production of leaves. Despite these advantages, the fact that the 11 species of larch persist in and even dominate many arctic and alpine environments in the Northern Hemisphere has led scientists to conclude that other advantages allow larches to compete in these harsh environments. Given that their crown shape and leaf size are similar to many of the evergreen conifers with which they grow, there must be something different with their leaf anatomy that gives larches an additional advantage.

Deciduous leaves are easier to produce than evergreen leaves. The lignins that enable evergreen leaves to persist for many years, and the toxins that reduce herbivory come at a high metabolic cost. In addition, the photosynthetic efficiency in larch may be twice that of neighboring evergreen associates (Figure 76). It is not necessary for the leaves of deciduous trees to be especially tough or durable, since leaf lifespan is so short. The penalty for this, of course, is that larches must replace *all* of their leaves annually. While evergreen conifers can grow during the part of the year when deciduous trees are bare, this advantage is reduced at high latitudes or altitudes by winters that are too harsh or light levels too low for efficient photosynthesis. Larches are highly efficient at translocating nitrogen prior to leaf drop, an important characteristic in the nitrogen-limited arctic and alpine environments. Western larch has a few other adaptations it uses to compete in an evergreen-dominated world. It has one of the fastest seedling growth rates among associated conifers, enabling the species to rise above neighboring trees where its low shade tolerance is no longer a limiting factor.

Western larch distribution coincides with the boundaries of the Inland Empire, defined to the east as the portion of the Rocky Mountains drained by the Columbia River Basin. While the center of distribution is located in northwestern Montana, many of the largest and tallest specimens are found in the mixed forests of the South Cascades region (Figure 77). In eastern Washington, an anomalous gap

Figure 77. Some of the largest and tallest western larches in eastern Washington are found in the western hemlock zone in the South Cascades. While often a minor component of these diverse forests, the larch's successional status often indicates that they are among the oldest trees present.

Figure 78. Range of western larch in eastern Washington.



occurs in the North Cascades region, where conditions may be too dry for the larch to be competitive (Figure 78). Within its range, however, western larch grows in a wide variety of habitats, including near-alpine conditions within the subalpine fir zone (Figure 79). In some ways, western larch fills the niche occupied by ponderosa pine in environments too cold for the pine to tolerate, although there is considerable overlap in their distributions. Old, but slender trees can be found rising above canopies of Engelmann spruce and subalpine fir at the upper elevations of its dominance (Figure 80). Elsewhere, under more favorable conditions, the

Figure 79 above. Dwarf form of western larch in the Wenatchee Mountains. The remarkable adaptability of western larch allows it to grow in unexpected places. As a result, size and age are not well correlated in this species.

Figure 80 left. A 400+ year spruce-fir stand with emergent larch in the Okanogan Highlands. In such cold and dry forests, many of the larches have narrow crowns and small diameters; few trees exceed 60 cm (23.6 in) in diameter. Photo by Steve Curry, Washington DNR.

Figure 81. Within the grand fir zone, whole stands of western larch can live to great age. The thick bark, decay resistance, and longevity of the species occasionally allow such remarkable stands as this to develop.

larch can dominate forest stands with subordinate mixtures of grand fir, lodgepole pine, and Douglas fir (Figure 81).

Bark characteristics

Like its fire-resistant associates, western larch develops very thick bark with age, enabling it to survive frequent fire. Even young trees quickly develop bark thick enough to allow survival after light-to-moderate ground fires. Bark on mature and old trees can mimic that of Douglas fir or ponderosa pine, both of which are fire-resistant species often found growing alongside larch. Mature trees, between 100 and 250 years, often have the rugged, grayish-brown bark of a Douglas fir (Figure 82). Old trees, greater than 250 years, often develop the richly colored bark of a ponderosa pine (Figure 83). In old, mixed stands, it may be necessary to look to the crown to verify species identification. Very old larches can develop bark thicker than any of their associates—up to 35 cm thick (14 in) (Figure 84). The bark transformation from young to mature to old is not as consistent, nor

Figure 82 above. Mature western larch (left) will often have bark that is difficult to distinguish from Douglas fir (right).

Figure 83 below. The bark of very old western larches (left) is often a mimic for ponderosa pine bark (right).

Figure 84 left. Bark thicker than 30 cm (1 ft) is not uncommon on very old western larch trees.

Figure 85 right. The bright yellow wood visible beneath the bark in this fire-scarred larch is filled with resin, making it very decay resistant.

as predictable, as that of ponderosa pine. Ultimately, bark characteristics must be used with crown form, lower crown characteristics, charcoal and fire scars, and relationships to other trees in the stand in order to develop enough clues to determine approximate tree age.

Historic fires often left charcoal on the bark of mature larch trees, but actual wounding was much less common. Fire scars that do form cause heartwood formation in the vicinity of the wound to ***compartmentalize*** decay. Compartmentalization refers to the deposit of defense compounds in wood adjacent to the decay. In a healthy tree, this compartmentalization effectively isolates the decay and prohibits it from spreading to other parts of the tree. Fire-scarred larches often deposit excessive amounts of resin in the wood adjacent to a fire scar, which can greatly slow decay (Figure 85). As a result, larch stumps can be an excellent source of firewood—the resin-filled section within is the last to decay (Figure 86).

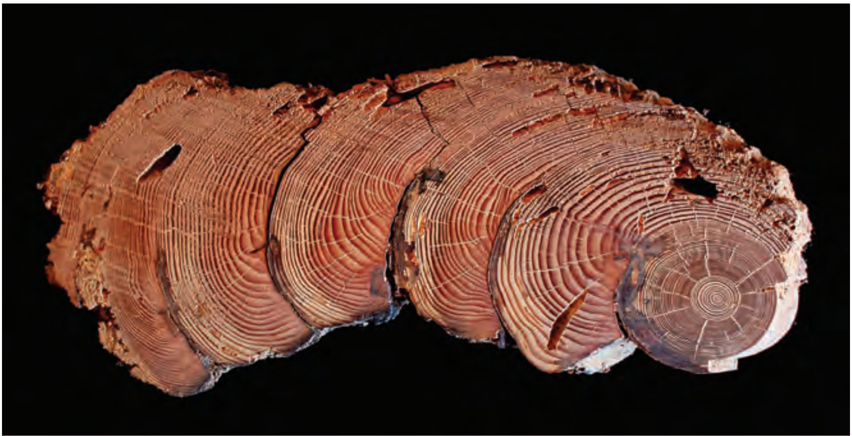


Figure 86 above. Nearly all that is left of this old western larch stump is the resin-filled wood near the fire scar. The wood was collected and polished – the remainder of the stump has long-since rotted away.

Figure 87 left. While not a whorl-based conifer like many other members of the pine family, western larch nonetheless grows tiers of branches in a predictable manner.

Figure 88. Epicormic branches developing below the main crown in a maturing western larch.

Lower crown characteristics

As with other rapidly growing pioneer trees, western larch often will form dense stands. While larches are one of the few groups within the pine family that do not grow in a whorl-based manner, young trees still develop tiers of original branches, just as the whorl-based pines and firs do (Figure 87). As the stand develops, lower branches are shed as they become shaded. Depending on the stand's density, the crown base often will recede at a rate comparable to the height growth of the stand. As the maturing stand thins, light is able to penetrate below the living crown. Larches often respond by producing ***epicormic branches*** below the base of the live crown. Epicormic branches, which start from the cambium and not from terminal buds, often occur at the axils of branches and twigs, the sites of old branch wounds, or other locations where the bark is thin (Figure 88). The crowns of mature western larches are often a combination of

Figure 89. Mature western larch. The graceful crown consists of original branches and an unmistakable radiating fan of epicormic branches adorning the base of the crown.

Figure 90. A very dense stand of grand fir and Engelmann spruce has developed around this western larch, threatening its survival. Note the spiral scar – the result of an old lightning strike, indicating spiral grain in the wood beneath.

original and epicormic branches, a pattern that becomes accentuated as trees age. Because epicormic branches form on the outside of the trunk, they can grow in any direction, even tangential to the trunk. Original branches, in contrast, always form perpendicular (radially oriented) to the trunk. If many epicormic branches start from a common locus, a fan-shaped system of branches will result (Figure 89).

Susceptibility to high-severity fire dramatically increased in many of the forests of eastern Washington during the twentieth century as a result of increased stand density (Figure 90). The seeding and early growth habits of western larch on productive sites are adapted to maturing dense stands. Epicormic branching, combined with a deciduous growth form, provides western larch with a strong defense against crown scorch. As western larch produces new foliage each year, it is less impacted by foliage loss from late-season severe fire events than other evergreen conifers (Figure 91). Even if the crown scorch occurs earlier in the year, the larch's prolific ability to produce epicormic branches may be enough to enable the tree to survive.

Figure 91. The White Mountain Fire of 1988, Okanogan Highlands. The late-season crown fire killed dozens of square kilometers of forest. The fire occurred as the larches were beginning to shut down for the year, and as result, many were able to grow a new crop of leaves the following year.

Figure 92. Large limbs with mature bark are a sign of an old tree. In this case, the twisted shape resulted from an old mistletoe infection.

Crown form and tree vigor

Crown complexity, arising from damage due to prolonged mistletoe infections or physical events, can assist in determining tree age (Figure 92). In a manner similar to the production of epicormic branches, larches have the ability to produce ***reiterated trunks*** following crown damage (Figure 93). Reiterated trunks have the appearance of small trees within the crowns of larger trees. While typically a response to the loss of the tree top, they also can spontaneously arise in structurally complex crowns.

A series of profiles have been prepared to illustrate the crown structures that can occur in western larch during its lifetime, including the variations imposed by site productivity and elevation (Figure 94).

Figure 93. Reiterated trunk formation in western larch. Old trees can recover from crown damage by producing secondary trunks, as illustrated here.

Figure 94. Western larch crown form and tree vigor in eastern Washington. Idealized forms represent three age and four vigor classes (A-high vigor to D-low vigor). Vigor is a function of site productivity and response to disturbance and environmental stress. More than one individual is shown for vigor classes B-D to illustrate possible variations. Competition-based mortality usually ensures that most trees in vigor classes C and D do not survive to the next age class. The trees depicted are the same scale in the first image, and at differing scales on the following pages.

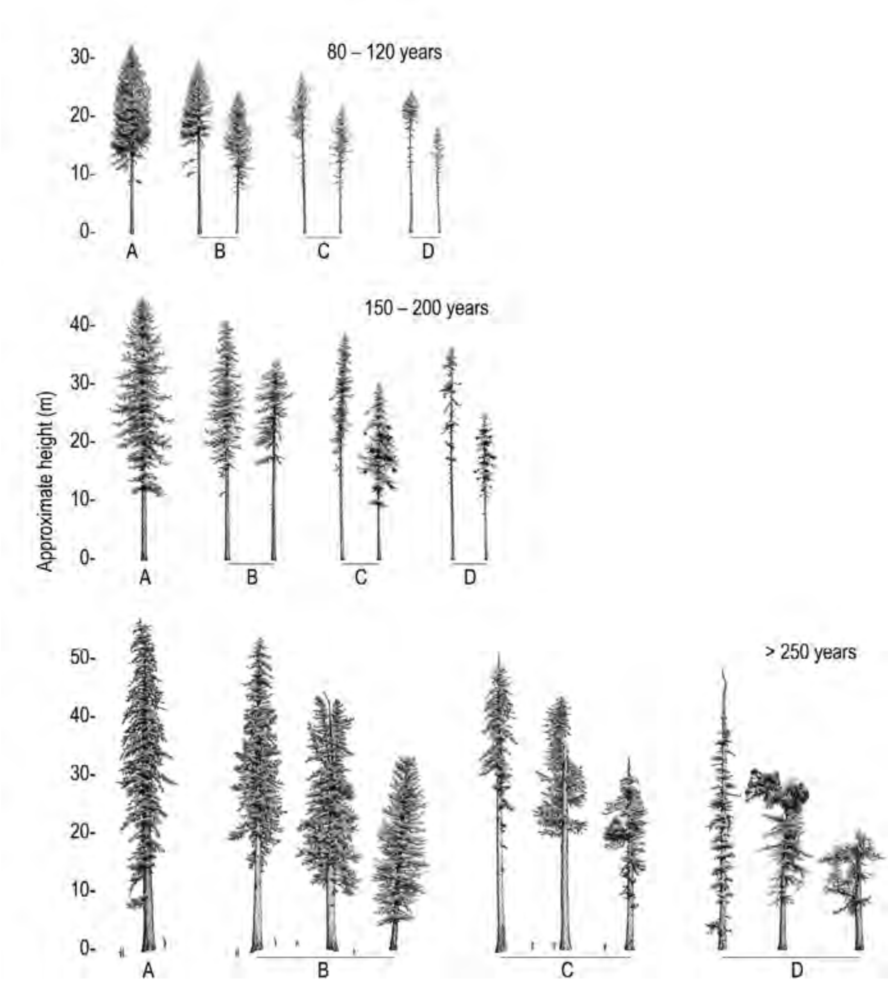
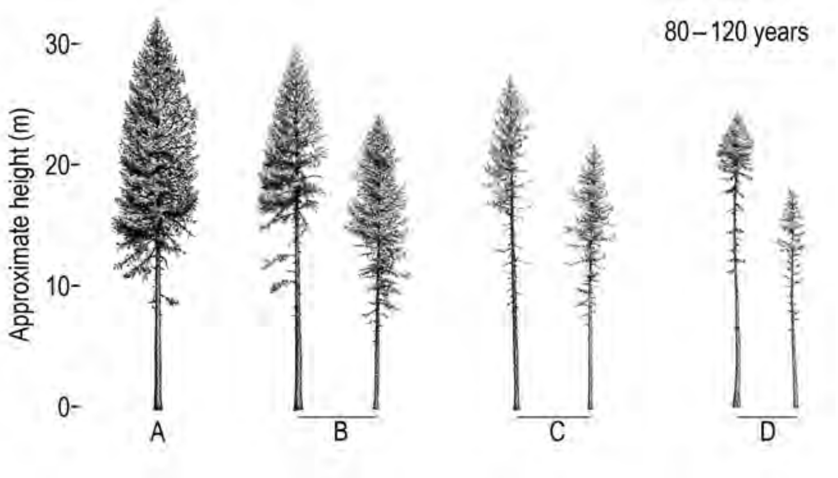
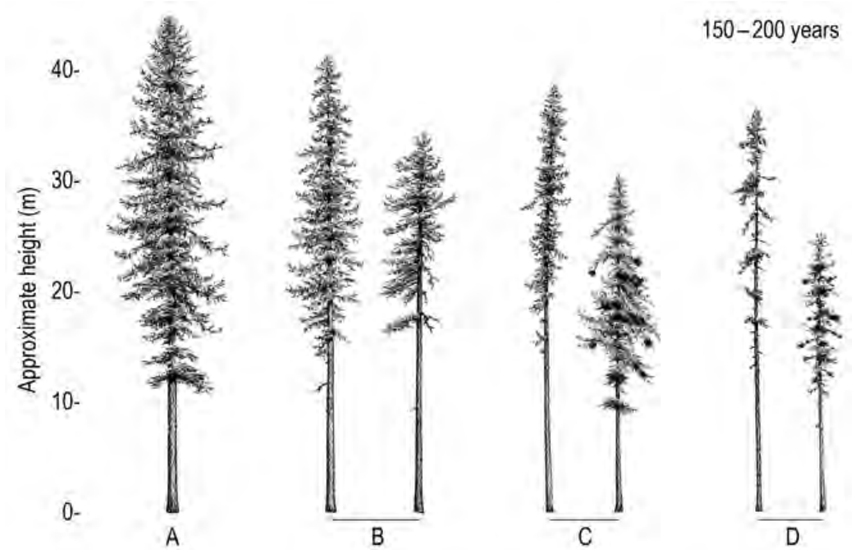


Figure 94. Continued





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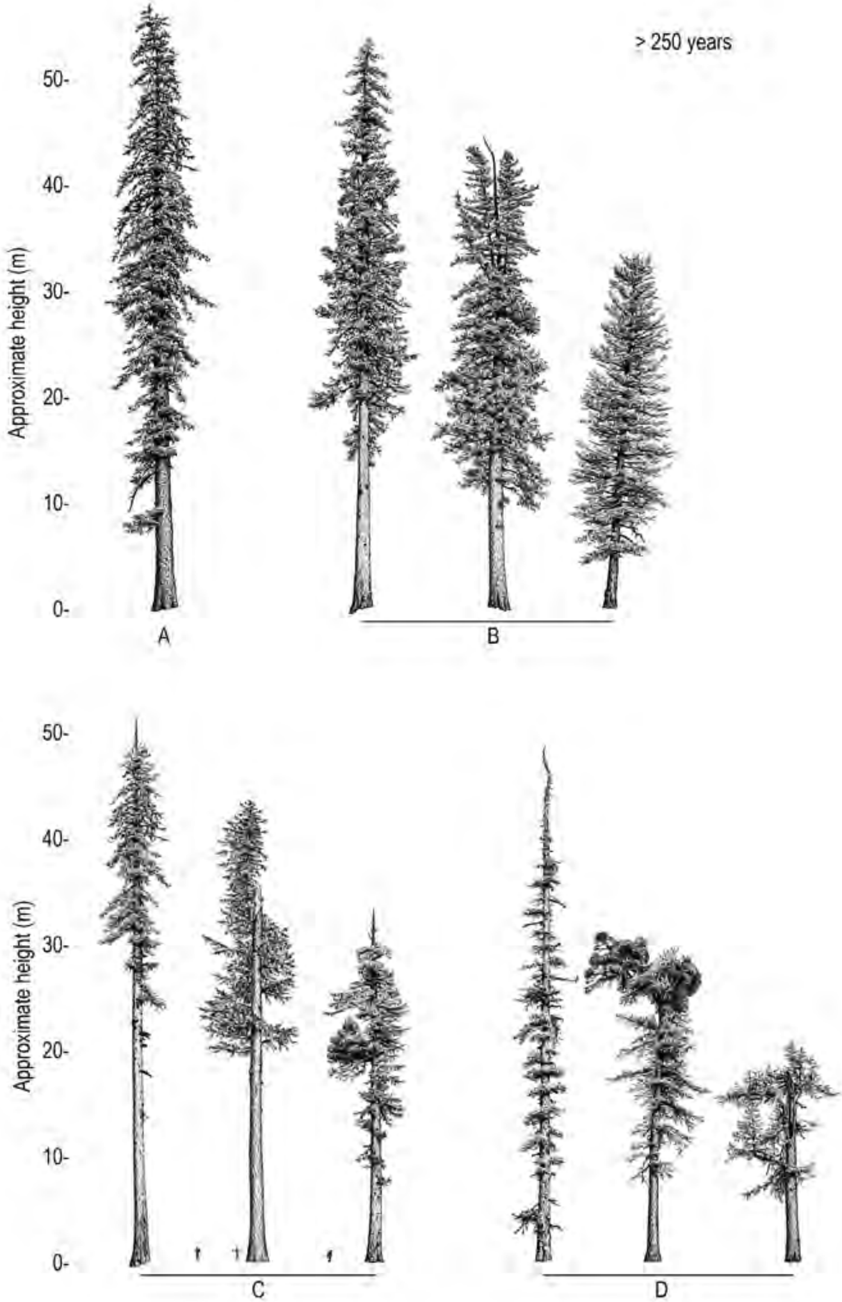


Rating system for determining the general age of western larch trees

(Choose one score from each category and sum scores to determine developmental stage)

Bark condition, tree base	Score
Hard, bony bark with small fissures	0
Hard bark with moderately deep fissures (4-10 cm – 2-4 in)	1
Deep fissures present (> 10 cm – 4 in)	3
Maximum fissure to fissure plate width ≥ 15 cm (6 in)	3
Knot indicators, lower one-third of tree	
Branch stubs present.	0
Old knot/whorl indicators visible	1
No knot/whorl indicators visible	2
Lower crown indicators	
No epicormic branches	0
Small epicormic branches present	1
Large and/or gnarly epicormic branches present	2
Crown form (refer to Figure 95)	
Similar to a tree in top row	0
Similar to a tree in middle row	3
Similar to a tree in bottom row	5

Scoring Key

< 3	Young tree
3–6	Mature tree < 150 years
7–10	Mature tree ≥ 150 years
> 10	Old tree ≥ 250 years

Longevity and death

Several factors contribute to the longevity of western larch, including thick, fire-resistant bark, very resinous wood, and high, deciduous crowns with the ability to regenerate both trunks and branches. Even in the face of increased fire severity caused by fire suppression and overgrazing, old larches would still be a common feature of our eastern Washington landscapes if it were not for their valuable wood. This is the primary reason old larches, as depicted on these pages, are so difficult to find (Figure 95). Old larches are commonly 400 to 600 years old, with occasional trees in excess of 900 years.

Ultimately, decay from either velvet-top fungus (*Phaeolus schweinitzii*) or the quinine conk (*Fomitopsis officinalis*) will lead to death of old larches. A large, swollen base is often a sign of infection by the velvet-top fungus (Figure 96), which infects the roots and lower stems of trees, but may take centuries before it weakens the stem enough to cause structural failure (Figure 97). Decay from the quinine conk often manifests itself in the middle or upper trunks of trees. On occasion, however, the hoof-like conks of this fungus occur on the lower trunk (Figure 98). Once infected, larches can live on for decades or even centuries, until the resin-filled tree base finally decays to the point where it can no longer support the weight of the crown (Figure 99).

Figure 95. An old-growth stand of western larch. As a consequence of the valuable lumber, stands such as this have become extremely rare.

Figure 96. The swollen base of an old western larch often indicates decay.

Figure 97. The classic barber chair stump of an old western larch – the tell-tale sign of the velvet top fungus.

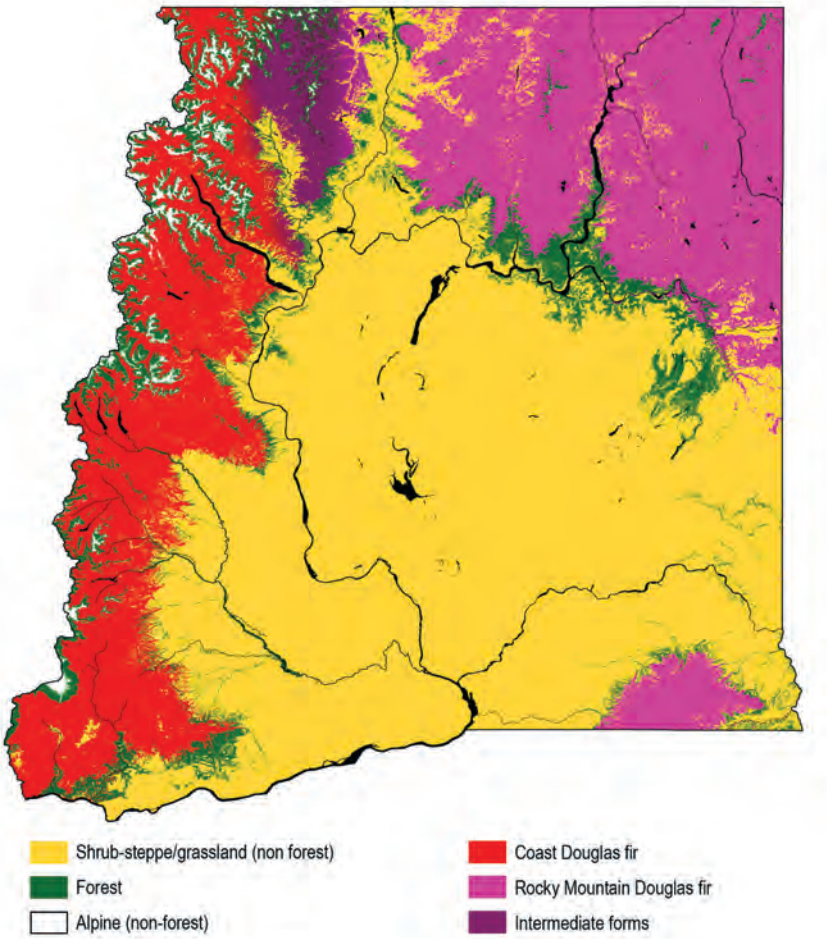
Figure 98. Quinine conk on the stem of an old western larch. Such rotten trees can live for decades or even centuries, resting on the strength of the resin-filled wood in the lower stems.

Figure 99. A broken stem of an old larch indicating advanced decay from the quinine fungus.

Douglas Fir (*Pseudotsuga menziesii*)

Douglas fir is something of an enigma—it is one of six or seven species of *Pseudotsuga,* the others of which are relatively small trees that play minor roles in forests within their limited ranges in eastern Asia, Mexico, and southern California. Douglas fir is the largest and tallest member of the pine family. Living trees have been documented up to 485 cm (191 in) in diameter, up to 99.4 m (326 ft) tall, and with volumes up to 349 m^3 (12,320 ft^3). Even larger and taller trees once existed

Figure 100. Range of Douglas fir in eastern Washington.



in western Washington. Douglas fir is also the most widespread of all western trees. It can be found growing from southern Mexico to central British Columbia (a distance of 5,000 km – 3,100 mi) and from Colorado to the coast (another 1,600 km – 1,000 mi).

Two distinct varieties are found in eastern Washington—the Rocky Mountain form (*Pseudotsuga menziesii* var. *glauca*) and a coastal form (*P. menziesii* var. *menziesii*). The Rocky Mountain Douglas fir has high relative shade-tolerance, capable of regenerating in the understory of other tree species (primarily pines) throughout much of its native range in the Rocky Mountains. The Coast Douglas fir, which grows from Vancouver Island south into the Sierra Nevada of California, behaves largely as a long-lived pioneer tree, due in part to the tree species with which it grows and the higher productivity and denser forests found along the coast. Both varieties are present in Eastern Washington, with a transition zone occurring between the Methow and Okanogan Valleys (Figure 100). The two varieties are visually distinguished largely by their cones. Those of the Rocky Mountain form tend to be smaller, often with recurved bracts (Figure 101). Foliage

Figure 101. Contrasting branch and foliage sprays from the two Douglas fir varieties. On the left is the coast form, var. *menziesii*, and on the right is the Rocky Mountain form, var. *glauca*. The Rocky Mountain form often has smaller cones and bluer foliage.

Figure 102. The many faces of Douglas fir allow it to behave as a long-lived pioneer, a shade-tolerant understory tree, and to grow in almost any eastern Washington forest type.

of this variety tends to be bluer, as a result of *stomata* on both upper and lower surfaces of the leaves.

Douglas fir might be considered the 'Jack-of-all-trades' among native trees, as it grows in a wide range of habitats and assumes a wide range of identities (Figure 102). This species shares many features with ponderosa pine and western larch; namely, very thick bark at maturity and the ability to withstand moderate to high-intensity fires. It also has moderately hard wood that is decay resistant and very resinous. This resinous feature helps to defend against bark beetle attacks and compartmentalize wood decay, much as its large associates do. Such qualities enable these species to live to great ages—as both Douglas fir varieties, as well as the pine and the larch, have all been recorded to live to the millennium mark in remote mountain lairs.

Douglas fir also has many of the qualities of its other cousins, the true firs (*Abies*). Throughout the Northern Hemisphere, firs are often among the most shade-tolerant trees within their particular forests. In western Washington, three of the world's most shade-tolerant trees (western hemlock, western redcedar, and Pacific silver fir) dominate the understory of nearly every forest type. In this context, Douglas fir is relegated to the status of a long-lived pioneer. In eastern Washington, however, these three shade-tolerant species are restricted to the wettest areas up against the Cascade Crest or in far northeastern Washington. In the remaining forest zones of eastern Washington, the most shade-tolerant understory tree is often either grand fir or Douglas fir. While more shade-tolerant than Douglas fir, grand fir is also less drought-tolerant. Therefore, the climax species in most ponderosa pine forests of eastern Washington is Douglas fir.

Figure 103. Cross-section of a Douglas fir understory tree within a ponderosa pine stand. The small disk of wood has 103 rings.

With shade-tolerant understory trees such as grand fir or Douglas fir, size and age are even more poorly correlated than they are for ponderosa pine or western larch. Since a Douglas fir seedling can linger in the understory of a pine forest for decades (Figure 103), ***functional age*** is often a more useful concept than actual age. For shade-tolerant canopy trees, the functional age is the age since ***release***— the point at which unrestricted conditions allow for rapid growth. A change in environmental conditions, forest structure, or community composition may allow a small understory tree that was suppressed and barely growing for decades to ascend into the main canopy. For example, a canopy gap may form when one or more large, overtopping neighbors die from fungi, insects, or wind. As a result, increased light reaches the understory. Many shade-tolerant species undergo a series of suppression and release episodes before reaching the canopy. In closed-canopy forests, it is rare for a seedling to grow uninterrupted into the main canopy.

Bark characteristics

Old Douglas firs are very fire-resistant, due largely to the protective bark that develops with age. In contrast, the thin bark of young trees offers little protection, even from low-intensity fires. The thin bark begins to thicken and develop vertical fissures as trees mature. For the first 100 to 200 years, the bark is hard and bony, and usually brown to gray (Figure 104). Old trees have very coarse and rugged

Figure 104. The hard, bony bark of mature trees. Depending on environmental conditions, Douglas fir bark is either brown or gray. In this case the gray is caused by lichens.

Figure 105. The characteristic colorful and flaky bark of old Douglas firs in western Washington is present in eastern Washington only in the wettest forests.

bark, which occasionally can reach a thickness of 35 cm (14 in).

Bark development in Douglas fir reflects the wide range of conditions in eastern Washington. The companion guide, *Identifying Mature and Old Forests in Western Washington* (Van Pelt 2007), describes the predictable pattern of bark development, from hard, bony bark to soft, papery bark, in detail. This same pattern is visible in eastern Washington, but is limited to wet forests near the Cascade Crest (Figure 105)—please consult this Westside guide when working in wet Cascade forests in eastern Washington. In the drier parts of the region, particularly within the grand fir and Douglas fir vegetation zones, the appearance of old trees can be quite different (Figure 106). As a general rule, bark thickness in eastern Washington Douglas fir is a more consistent feature than either the color of the bark on old trees or the development of the papery sheets of outer bark.

Lower crown characteristics

Douglas fir growth is whorl-based, like that of ponderosa pine. In Douglas fir, the lower crown begins to recede once a stand has achieved canopy closure. The lower branches die when they become too heavily shaded. Once dead, they often rot at their base and drop off the tree, leaving just a small scar in the otherwise unblemished bark (Figure 107). Ultimately, branch scars are hidden by the continually expanding trunk after a period of several decades to more than a century.

During that interval, the bark will be thinner at these spots than in the surrounding areas. If changes in the surrounding forest occur, such as the opening up of the canopy or the death of a neighboring tree, epicormic branches may begin to form at some of these old wounds. Old Douglas fir trees often have an upper crown of original branches and a lower crown composed of the dead remnants of original branches surrounded by younger epicormic branches and fan-shaped epicormic systems (Figure 108).

Figure 106. Hard, but thick bark is common on old Douglas firs in the drier parts of its range in eastern Washington.

Crown form and tree vigor

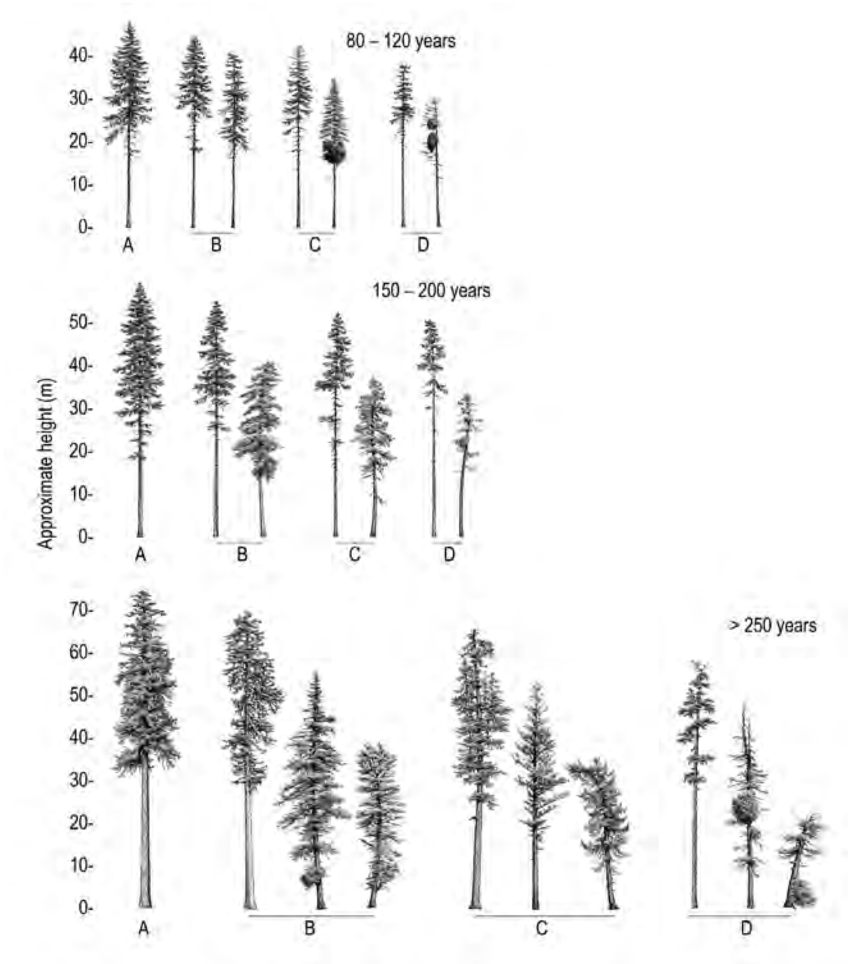
As a Douglas fir tree ages, it transforms from a simple, whorl-based, conical crown form to a highly individualistic shape. The individuality is in part due to the long lifespan of the species. Over time, shading from neighbors, damage from storms or falling trees, the effects of decay, and differences in their specific growth environments all combine to make each tree structurally unique.

Crown profiles of Douglas fir at three age classes and four vigor classes (A-D) are presented in Figure 109. As with ponderosa pine and western larch, variation in crown structure is a function of age, productivity, and crown damage. Naturally, not all of the trees in one series will advance to the next. For example, competition-based mortality will ensure that most of the trees in classes 1C and 1D do not make it to the next stage.

Figure 107. Branch scars on a mature Douglas fir. The locations of original branches that have since died and fallen off are still evident. One original live branch and some epicormic branches are visible in this photograph.

Figure 108. Epicormic branches. A fan of epicormic branches (visible at the base of this Douglas fir crown) often indicates a tree in late maturity.

Figure 109. Douglas fir crown form and tree vigor in eastern Washington. Idealized forms represent three age and four vigor classes (A-high vigor to D-low vigor) in eastern Washington. Vigor is a function of site productivity and response to disturbance and environmental stress. More than one individual is shown for vigor classes B-D to illustrate possible variations. Competition-based mortality usually ensures that most trees in vigor classes C and D do not survive to the next age class. The trees depicted are the same scale in the first image, and at differing scales on the following pages.



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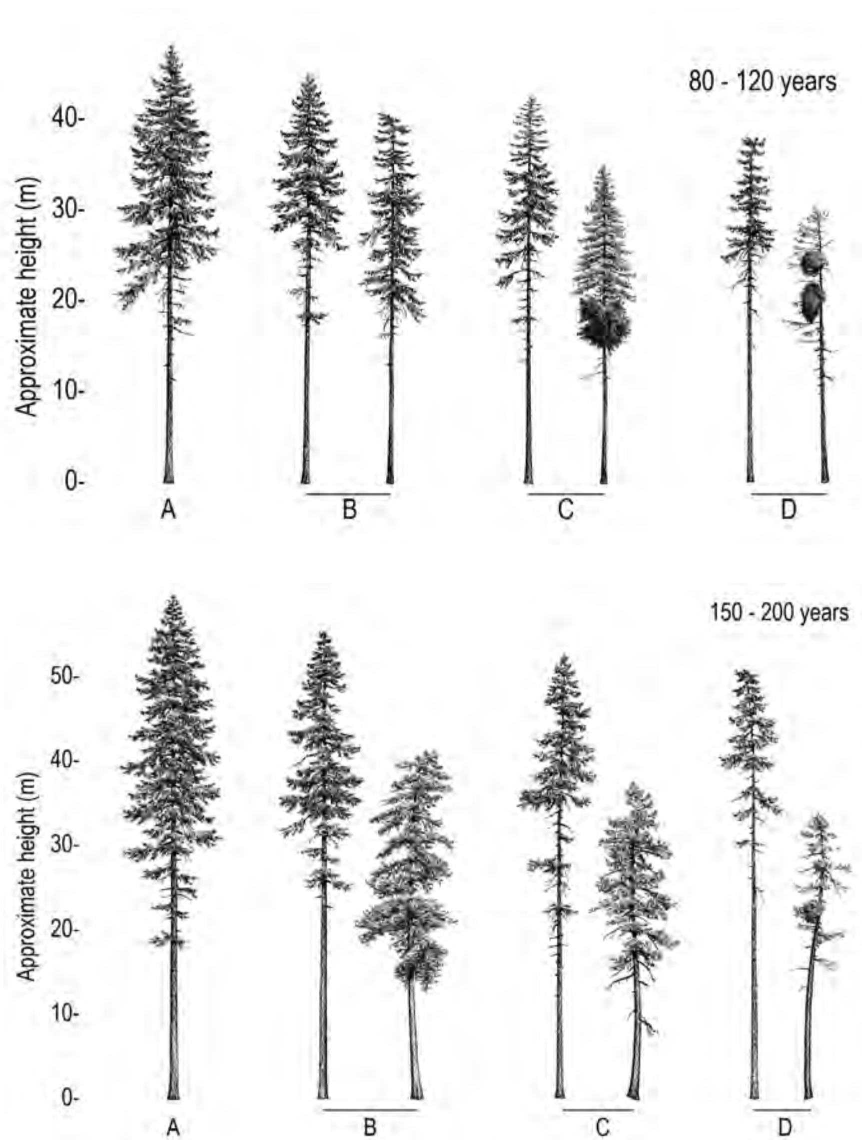

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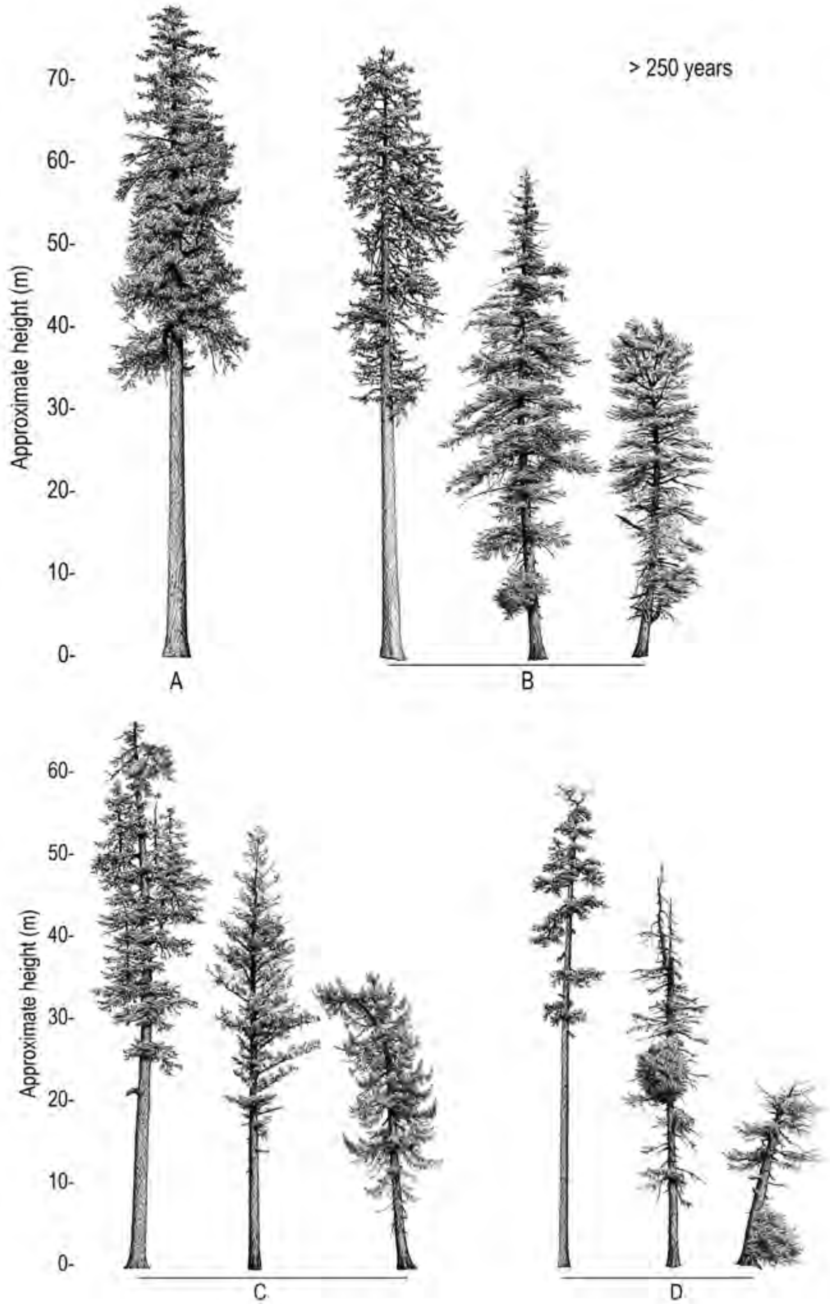


Rating system for determining the general age of Douglas fir trees

(Choose one score from each category and sum scores to determine developmental stage)

	Score
Bark condition, lower one-third of tree	
Hard, bony bark with small fissures	0
Hard bark with moderately deep fissures (4-10 cm – 2-4 in)	1
Deep fissures present (> 10 cm – 4 in)	3
Knot indicators, lower one-third of tree	
Branch stubs present.	0
Old knot/whorl indicators visible	1
No knot/whorl indicators visible	3
Lower crown indicators	
No epicormic branches	0
Small epicormic branches present	1
Large and/or gnarly epicormic branches present	3
Crown form (refer to Figure 109)	
Similar to a tree in top row	0
Similar to a tree in middle row	3
Similar to a tree in bottom row	5

Scoring Key

< 3	Young tree
3–6	Mature tree < 150 years
7–10	Mature tree ≥ 150 years
> 11	Old tree ≥ 250 years

Longevity and death

Moderate decay-resistance and resinous wood helps Douglas firs occasionally live to great ages—trees 600 to 800 years old are not uncommon in many parts of its range. Trees 1,000 years or older have also been recorded, including some in dry montane areas similar to eastern Washington. For a Douglas fir tree that has survived to become a canopy tree in an old-growth forest, a delicate balance exists between photosynthesis and respiration. Stresses from fire or competition within dense stands can create vulnerability to bark beetle attacks. Similarly, beetle populations increase following fire, blowdown, or logging as a supply of inner bark becomes more available (Figure 110). An upper age limit for Douglas fir in most eastern Washington forests is determined by the velvet-top fungus. This slow-growing fungus can often take 200 to 400 years before it makes its presence known, and may require several more centuries to cause tree death. This

Figure 110. Douglas fir killed as a result of beetle attack. Beetle populations increase following fire, blowdown, or harvest as a supply of inner bark becomes more available. Under such circumstances, beetle populations can increase to the point where otherwise healthy trees can be killed.

fungus causes decay in the upper roots and lower stems of old trees, weakening them. The sapwood of the tree is unaffected—many infected trees appear healthy and vigorous. Structurally, the base of the tree is compromised and will ultimately fail. Tip-ups with small root plates or snapped boles near the base often indicate death by velvet top fungus (Figure 111).

Figure 111. Death by velvet top fungus often takes the form of short, broken stumps on old trees.

Grand Fir (*Abies grandis*)

Grand fir is a lovely, graceful, montane tree that is maligned by many due to its vigorous regeneration on some sites. It is one of the world's tallest trees, with living trees recorded to 81.4 m (267 ft) (Figure 112). With one of the fastest growth rates among native conifers in eastern Washington, it can surpass Douglas fir in both height and wood volume on productive sites (Figure 113). On an alluvial site in western Washington, a 38 year-old tree was 40.2 m (132 ft) tall, and early growth rates in plantations have been recorded up to 1.22 m (4 ft) per year.

Figure 112. The classic form of a mature grand fir.

Foresters may dislike grand firs for stealing growing space from more valuable pine and larch species. Unplanted and often unwanted, grand fir regenerates in great numbers, requiring considerable investment in time and resources for vegetation management (Figure 114). Unchecked growth of grand fir can lead to future problems. The wood is soft, weak, prone to decay, and carries a lower stumpage price than associated trees. Losses from decay fungi are significant—it is not uncommon for mature stands of grand fir to

Figure 113. Grand fir may exhibit extremely rapid growth on alluvial soils. Under ideal conditions, grand fir may grow faster than nearly any other of our native trees, including Douglas fir.

Figure 114. An old-growth larch stand being replaced by grand fir. Nearly all of the green foliage pictured here is that of grand fir – most from trees less than 100 years old. The new foliage has yet to emerge on the larch in this early spring photograph.

Figure 115. After a century of fire suppression in many ponderosa pine forests, grand fir seedlings are often the only tree species able to reproduce.

Figure 116. Fire-scarred grand fir. Thin bark and a susceptibility to low-intensity fires are characteristic of the species – scarred individuals can occasionally survive for a short while. Photo by Keala Hagmann.

Figure 117. A pure stand of grand fir. While uncommon, pure stands can occur in limited areas. This stand is located within an old-growth western larch forest.

have lost 30 to 50 percent of their merchantable wood volume. It makes good pulp, however.

Grand fir was largely ignored during early logging operations in favor of neighboring ponderosa pine and western larch, the wood of which is far more valuable. For this reason, the proportion of grand fir has greatly increased in these stands. In low- and mixed-severity fire regimes, the thin-barked grand fir was naturally kept in low numbers. Decades of fire suppression, however, have allowed abundant

Figure 118. High-severity fire fueled by a dense fir stand. The giant pine was severely weakened by the fire and later succumbed to a bark beetle attack.

regeneration of grand fir and precluded the recruitment of shade-intolerant pine and larch seedlings (Figure 115). As a result, grand fir now flourishes in forest types where it was once a minor component. While lacking the thick-bark of its more fire resistant associates, a mature grand fir will occasionally survive a ground fire (Figure 116). Any wounding of the bark can spell doom for grand firs, as subsequent decay is inevitable and swift.

The grand fir glut resulting from highgrade-logging practices and fire suppres-

Figure 119. A riparian larch stand being invaded by grand fir and Engelmann spruce. All but the larch are less than 100-years old. The larches are being killed by below-ground competition and bark beetles.

sion has additional consequences. Dense stands of grand fir (and Douglas fir on some sites) cause stress on mature and old pines and larches as they compete for below-ground resources, such as water and nutrients (Figure 117). Under stress, the normally resistant pine and larch are vulnerable to bark beetle attack. As the pine and larch of the upper canopy begin to die, they are replaced by firs in the understory. The resulting dense stands of grand fir, now commonplace, are themselves vulnerable to a variety of defoliators, including the western spruce

Figure 120. Grand fir grows best in flood-plains. In such locations it can successfully compete with Douglas fir in height growth. High levels of available moisture also allow it to compete with more shade-tolerant species such as western redcedar and western hemlock.

budworm and Douglas fir tussock moth. Large areas of weakened, dead, and dying trees increase the chance of catastrophic wildfire (Figure 118).

For the general public, the success of grand fir has resulted in a transformation of once open pine stands. Gone are favored picnic spots. A grassy glade near a stream, now unrecognizable, has been replaced by dense thickets of small and medium-sized firs, while the pines overhead gradually die from competition-induced stresses (Figure 119).

Tree characteristics

Grand fir is a ***site sensitive*** species—under favorable conditions, it grows and competes extremely well yet performs poorly in dry, cold, or otherwise harsh conditions. Less shade-tolerant than western hemlock or Pacific silver fir, it is either absent from stands containing these species or present only in the main canopy. Moist upland forests, too dry for western hemlock, are its primary habitat. River floodplains are an exception, however. Their slightly open nature and rich soils allow grand fir to grow and compete well alongside western redcedar, western hemlock, and other species (Figure 120).

Figure 121. Bark on two mature grand firs shows the smooth, vertical bark plates typical of this age. Note the pattern of branch whorls still visible in the bark.

Bark on grand fir never develops the thickness of its fire-tolerant associates. The smooth bark of young trees gives way to finely-dissected fissures, isolating the smooth, outer bark plates as tidy, vertical ridges (Figure 121). The transformation that many trees experience from young gray bark to increasingly more colorful mature bark does not occur with grand fir. Instead, the even pattern of gray bark plates remains in maturity (Figure 122). Even in giant old trees, bark characteristics reveal little about age (Figure 123).

Like Douglas fir and western larch, grand fir is an opportunist, using epicormic branch formation to fill in crowns as conditions permit. As the stand matures and conditions change around a tree, light penetration may allow new branches to grow where they had been previously lost (Figure 124). The increased shade tolerance of grand fir relative to pine, larch, and even Douglas fir allows deeper crowns to form. Rapid growth on productive sites can lead to very tall trees in a century or less. Coupled with relatively weak wood, these factors inevitably result in windthrow or crown damage from wind storms. As with western larch, the ability to produce epicormic branches in combination with the capacity to produce reiterated trunks can re-build damaged portions of the crown. Many old grand firs have forked or otherwise reiterated tops, indicating recovery from earlier crown damage (Figure 125).

Since grand fir is rarely a pioneer tree, it often is of little use in identifying stand age. Instead, the shade-intolerant trees under which it is growing should be the focus of attention. However, in forests established in the wake of a stand-replacing event, the grand fir cohort can help determine the stage of stand development, which in turn can reveal stand age.

Longevity and death

The 'live fast, die young' philosophy has its price. Grand fir has the shortest

Figure 122. Mature bark patterns. The thick, colorful, and rugged bark of a Douglas fir (behind) contrasts nicely with a grand fir of the same age.

Figure 123. Bark on a giant grand fir. Other than size, there is little about the bark that alludes to age in this 2 m (6.6 ft) diameter tree.

lifespan of all of our native conifers. A functional age of 300 years has yet to be recorded, although functional ages of 250 years are not uncommon. To be fair, since it has high relative shade tolerance in many vegetation types, it can survive as a suppressed understory tree for a century or more before release. A grand fir with an actual age of 472 years was recorded in the Blue Mountains, but more than a third of the growth rings occurred in the first few centimeters, indicating growth suppression when the tree was young. This species does not invest in the physiologically expensive compounds that many tree species develop to protect

Figure 124. Epicormic branches are just beginning to develop at the crown base of this maturing tree. Note that fissures are beginning to develop in the bark and that several dead branches have already fallen off.

their wood from decay. Grand fir heartwood and sapwood are basically the same, apart from the role that sapwood plays in water and nutrient transport. Wood-decay fungi readily colonize wounds on mature grand fir. The most aggressive is the Indian paint fungus (*Echinodontium tinctorium*), which enters through old-branch wounds or other openings into the tree and destroys both cellulose and lignin within the heartwood. The hard, woody, nearly black conk announces the presence of an infection center that may extend several meters in both directions (Figure 126).

Figure 125. Upper crowns of several old grand firs reveal various patterns of trunk reiteration and epicormic branching in an effort to maintain a full crown.

Figure 126. Indian paint fungus on grand fir. The distinctive, nearly black hoof-like conk (circled) indicates extensive heart rot. The bright brick red interior of the conk was often used as a pigment by Native Americans.

Engelmann Spruce (*Picea engelmannii*)-Subalpine Fir (*Abies bifolia*) Forests

Spruce-fir forests are common throughout the Northern Hemisphere at high latitudes or high altitudes. Many of the world's 34 species of spruce and 50 species of fir grow together in various combinations somewhere amidst their ranges. In North America, the combination of Engelmann spruce and subalpine fir is the most extensive, and can be found in the Rocky Mountains from the Yukon Territory to New Mexico, and in the Coast Ranges and Cascades from British Columbia to California (Figure 127). Countless mountain landscapes are richly decorated with these two species—often providing the frame for photographs of mountain scenery. They even bring distinctive color to the compositions, as their cones are often as colorful as the flowers with which they grow (Figure 128). Even though there are differences in the ecologies of these two species, it is amazing how similar their ranges are. Of course, there are plenty of places where one species will occur without the other, especially at the edges of the ranges.

Figure 127. Engelmann spruce–subalpine fir forest. The combination of Engelmann spruce and subalpine fir is the most extensive spruce–fir forest type found in North America. It occupies much of the subalpine forest in eastern Washington.

Figure 128. Maturing cones of subalpine fir (left) and Engelmann spruce (right) often add lively color to an otherwise evergreen forest.

In eastern Washington, it is difficult to find one species without the other. Even if such a place is located, the other species will no doubt be nearby. Spruce-fir forests dominate all but the wettest subalpine forests in our region (Figure 3, Figure 4). The vegetation zone is named for subalpine fir, the more shade-tolerant of the pair, but the spruce is also shade tolerant and can regenerate in the understory of all but the darkest forests within its range.

Engelmann spruce and subalpine fir do not tolerate warm temperatures very well, but they can endure temperatures as low as –50° C (–58° F). As a result, they form extensive forests in the high, cold mountains throughout western North America (Figure 129). They also are tolerant of very wet conditions, including riparian areas and the swampy ground near beaver ponds or other wetland features (Figure 130). The wet conditions near streams allow these species to descend to elevations where it would otherwise be too hot or dry. In steep mountain topography, stream drainages are often drainages for cold air as well, allowing cold mountain air to pour down into the lowlands. The largest specimens of the two

Figure 129. A spruce–fir landscape near the Stuart Range in the Wenatchee Mountains is just one of many mountain vistas framed by either one (or both) of these species.

Figure 130. Englemann spruce and subalpine fir can reach great sizes on moist soils. A swamp encircling a beaver pond along Icicle Creek supported former record specimens of both species.

species are found within the cool and moist conditions of these lower elevation sites, where snowfall is lower and growing seasons are much longer (Figures 131 and 132). Many other species find these conditions optimal as well, and such stands often contain ten or more tree species.

Living in snowy environments forces trees to adapt their architecture to deal with the physical stresses of being covered by wet, heavy snow. Many of our high-elevation pines, such as whitebark pine or limber pine (*Pinus flexilis*), develop

Figure 131. Subalpine firs do well in a variety of cold and wet conditions. This record-sized speciman is enjoying these conditions in the cold air drainage of a valley bottom, where the smaller snowpack allows for an extended growing season.

flexible, rubbery twigs that simply flop over to dump any accumulated snow. The crowns of spruces and firs often form tall spires that naturally shed snow with their short branches. Subalpine fir is one of the world's most extreme examples of this characteristic, with mature tree crowns often being only a few meters wide (Figure 133). Harsh environmental conditions near treeline restrict arborescent growth forms and many species are reduced to krummholtz. Both spruce and fir branches in contact with the ground are able to take root. This strategy, called ***layering*** is quite useful in alpine environments where seedling survival is limited

Figure 132. Record-sized specimens of Engelmann spruce occur where cold air drainages allow them to grow at elevations normally below their ranges.

(Figure 134). During the long winters at this elevation, trees are subject to constant physical stress from strong winds, desiccating air, and abrasion by ice crystals. The protective blanket of winter snowpack is often their only refuge—any twigs emerging above soon fall victim to the extreme exposure. To cope with such conditions, trees can use their own structures to protect the growing portion of the plant. Individual plants can live for centuries by growing downwind through layering, using older parts of the plant to take the brunt of the harsh winds (Figure 135).

Figure 133. Alpine woodlands in the Pacific Northwest receive some of the highest snowfalls recorded on Earth. The spire-like crown form of subalpine fir is perfectly shaped to shed this potentially burdensome load.

Disturbance in these wet and cold environments is most commonly a stand-replacing event, and often provides the only opportunity for shade-intolerant trees to enter the developmental sequence. Stand development is predictable, and thus the developmental stage is correlated with stand age. Growth rates in pure spruce-fir forests are universally slow—height growth normally averages just a few centimeters per year. Trees 10–20 cm (4–8 in) in diameter are frequently 50 to 150 years old, and trees over 30 m (98 ft) tall are often 250 to 350 years old

Figure 134. Layering of subalpine fir allows the species to proliferate in some our harshest mountain landscapes.

Figure 135. Downwind movement of a krummholtz Engelmann spruce allows the actively growing portion of the plant to receive protection by the older parts of the plant. Note the dead wood to the right indicates the position of the plant centuries earlier. Prevailing winds are from right to left.

Figure 136. An old subalpine fir. Even on moderately productive sites, 200 years or more are required for tall trees such as this to develop.

Figure 137. A great diversity of height and diameter classes of the shade-tolerant subalpine fir indicates an old-growth forest, even if the tallest specimens are only 15–20 m (49-66 ft) tall.

(Figure 136). Both spruce and fir can survive for decades, even centuries, as suppressed understory trees—alive, but with extremely little annual growth.

Many mature and old spruce-fir forests contain a residual component of the original cohort of pioneer trees. These residual pioneer trees, usually western larch or lodgepole pine, are often more than a century older than the shade-tolerant cohort of spruce and fir underneath. In any case, by the time spruce-fir forests develop a rich diversity of sizes within the shade-tolerant cohort (vertical diversification), they are very old, regardless of tree size (Figure 137).

Westside Species

Cascade regions

Rainforest conditions may be found in limited areas near the Cascade Crest in eastern Washington. Here, annual precipitation may reach 4 m (13 ft), most of which falls as snow. Most of these wet, mountain forests occur in three primary vegetation zones: the mountain hemlock, Pacific silver fir, and Cascade western hemlock zones—all of which are more abundant in western Washington (Figure 138). The dominant patterns of the trees and forests in these zones are similar to those west of the crest. Refer to the companion guide, *Identifying Mature and Old Forests in Western Washington* (Van Pelt 2007), for more information on these stand types.

Figure 138. Rainforests of western hemlock and Pacific silver fir near the Cascade Crest behave very similarly, whether east or west of the divide.

The strength of these three zones weakens dramatically as one moves down the valleys and into the drier, montane environment more typical of eastern Washington. Thus, the zones are compressed into relatively small spaces in some of these high, Cascade valleys (Figure 3). The eastern Cascade distribution of mountain hemlock, Pacific silver fir, western hemlock, western redcedar, yellow cedar, and noble fir (noble fir is found only in the South Cascades region) is limited to these zones.

These common Westside species react differently to the conditions east of the Cascade Crest. Pacific silver fir is the most shade-tolerant, but also the most sensitive to dry air. In many forested areas just east of the Cascade Crest, Pacific silver fir is abundant in the understory yet uncommon in the canopy. Pacific silver fir reproduces well in the cool, dark, moist understory environment, but grows extremely slowly (Figure 139). Individuals may reach the main canopy, but often cannot survive the desiccating conditions. Mountain hemlock is more tolerant of desiccating air, growing as an alpine tree in many parts of its range. As such, it persists in the main canopy, often at lower elevations than Pacific silver fir, even though the fir is still present in the understory. Western hemlock can also persist in the understory to high elevations. All three species are commonly present in many of these Eastside Cascade forests. Western red-cedar is also common, often extending down river valleys further than its shade-tolerant associates.

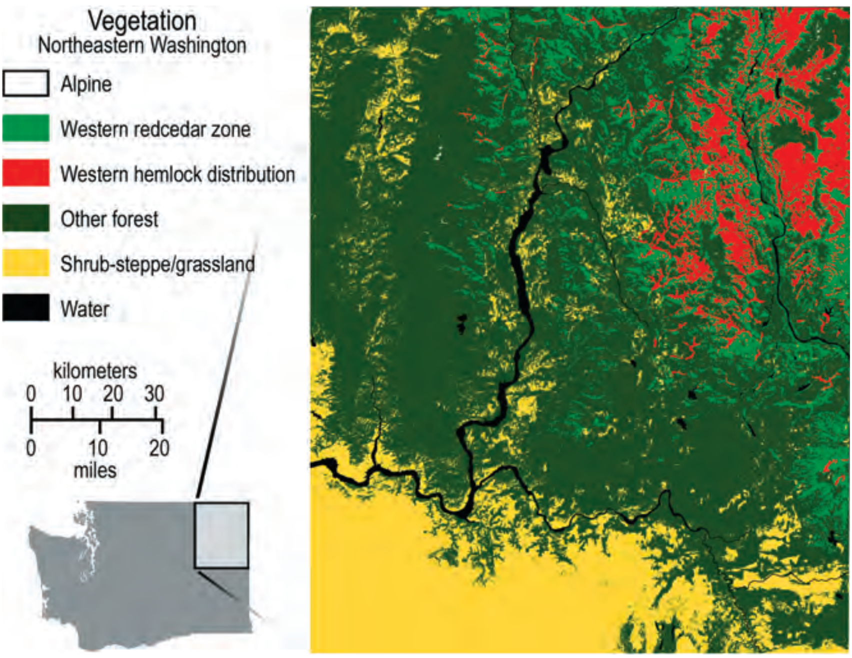
Figure 139. Short, flat-topped Pacific silver fir trees growing slowly in the understory of rain forests near the Cascade Crest can easily be 100–200 years old.

Another difference between these Eastside Cascade forests and their Westside counterparts is the addition of the common montane species from eastern Washington. In these steep mountain valleys just east of the Cascade Crest it is not uncommon to see eight or more species of conifers, from both east and west, all sharing dominance (Figure 8).

Columbia Rocky Mountain region

Far northeastern Washington receives more precipitation than the Okanogan Highlands of north central Washington, and western hemlock, western redcedar, and mountain hemlock reappear in Inland Empire forests. However, fire regimes are different than in similar sites in the Cascades, due to increased lightning frequency and the adjacency of other stand types. The result is a higher likelihood of other, more fire-adapted species being present with the hemlocks and redcedars. In addition, precipitation patterns are not quite as dramatic as they are in the Cascades (Figure 1). As a result, the distributions of western hemlock and western redcedar are quite different from each other, warranting the formation of a separate vegetation zone (Figure 140). Western redcedar/grand fir forests extend well beyond the western hemlock forests throughout this region (Figure 141). Even though redcedar is tolerant of wet and

Figure 140. Forested vegetation in the Columbia Rocky Mountain province. Western hemlock occupies only a small portion of the Columbia Rocky Mountain western redcedar zone.



sometimes saturated soils, it can also tolerate drier soils than western hemlock. The roots of western redcedar penetrate soils to a deeper extent than western hemlock, and similar-sized trees have greater root mass.

More frequent fire regimes allow ponderosa pine and western larch to play a larger role in these vegetation zones than in similar forests in the Cascades. In many cases, an overstory remnant of ponderosa pine, western larch, or Douglas fir will be present to help determine the age of a forest rather than relying on the shade-tolerant component. In situations where only the shade-tolerant component remains, the patterns of development will be similar to those of Cascade forests.

Figure 141. Extensive areas of grand fir–western redcedar forest exist within the Columbia Rocky Mountain western redcedar zone, well beyond the range of western hemlock.

Patterns in mature and old forests

Wildfires in the Columbia Rocky Mountain Region are often high-severity, stand-replacing events due to fuel accumulations and relatively long fire return intervals. To age such stands, use the key to stand development stages following stand-replacement events, presented on page 52. Use any combination of western hemlock, western redcedar, Pacific silver fir, or mountain hemlock as the shade-tolerant cohort. Old-growth forests are any that key to the vertical diversification stage or older. Because of the cool to cold environment of the Pacific silver fir and mountain hemlock vegetation zones, forest growth is slow and stands that key to the maturation stage will often be more than 200 years old.

Conclusion

The great diversity and ages of forests found in eastern Washington makes the task of creating a comprehensive guide difficult. There will be occasional forests that do not fit the keys properly and others where the ages are difficult to discern. Each stand is unique and presents its own set of challenges. There are sure to be cases when informed judgment will substitute for certainty. The ecological information contained in this guide is intended to narrow the range of possibilities and give the user increased confidence when making age determinations in the forests of eastern Washington.

English Equivalents

When you know:	Multiply by	To find
Centimeters (cm)	.39	Inches (in)
Meters (m)	3.28	Feet (ft)
Kilometers (km)	.62	Miles (mi)
Square kilometers (km^2)	.386	Square miles (mi^2)
Square kilometers (km^2)	247.1	Acres (ac)
Hectares (Ha)	2.47	Acres
Cubic meters (m^3)	35.3	Cubic feet (ft^3)

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Glossary

Biological legacy – structures left behind after a disturbance. After a stand-replacing event like a wildfire, the snags and logs are biological legacies. ***Legacy trees*** are a type of ***living biological legacy*** – trees that survived a major disturbance.

Cambium – in trees, the cambium is responsible for the secondary growth of stems and roots. It consists of a layer of actively dividing cells located between the bark and wood. Layers of sapwood (xylem) are produced to the inside of the cambium, and layers of bark (phloem) are produced to the outside of the cambium. The innermost bark is living tissue and responsible for the transport of sugars to all of the non-photosynthetic parts of the tree, such as the roots.

Canopy – the collective unit describing all of the photosynthetically active portions of an ecosystem. A forest ecosystem can be divided into three main components: the forest soil, the forest floor, and the forest canopy. A forest canopy can be further divided into other useful categories, such as the understory canopy, upper tree canopy, even a shrub canopy. However, the term is typically used in its narrow sense, referring to the tree canopy.

Climax – a theoretical term for the endpoint of forest succession. In reality, no such conditions actually exist, because of the ever-changing background conditions (climate, soils, geology, disturbance regime). In the Pacific Northwest, climax forests are thought of as those where all of the canopy layers are composed of shade-tolerant trees, such as western hemlock or Pacific silver fir.

Cohort – a generation of trees, or a group of trees with similar functional ages. The most common cohort is the generation of trees planted after clearcutting, or the generation of trees that seed in after a wildfire. Both of these examples are often referred to as the ***original cohort*** or ***pioneer cohort.***

Crown – the collective term for the space occupied by all of the leaves on a tree. Thus the crown includes not only all of the leaves, but also the twigs, branches, limbs, and trunks occupying that space.

Disturbance – any perturbation that causes changes in a vegetation community. In forests, disturbances are frequently caused by external factors, such as wildfires, floods, windstorms, logging, or insect outbreaks. Disturbances can be small, such the death of a canopy tree, or large, such as a volcanic eruption.

Ecological amplitude – the boundaries of environmental conditions at which an organism can live and function. Species with low ecological amplitudes are often rare or live in specialized habitats.

Epicormic branch – any branch that develops from the cambium. In model-conforming conifers, these would include all branches that are not produced by the leader of the main trunk. As such, the pith of an epicormic branch will not extend all the way to the pith of its trunk of origin. Since these are forming from the cambium, their orientation is often tangential to the main trunk, in contrast to the radial orientation of original branches.

Fire regime – the level of fire severity. Severity levels are often related to the percentage of trees that are killed. A low-severity fire kills 20% or less of the basal area of a stand; a high-severity fire kills at least 70% of the basal area; and a mixed-severity fire kills between 20% and 70% of the basal area.

Fire-return interval – the time between fire events within a stand, often calculated from fire-scarred trees. Naturally, the fire regime is closely related to the fire return-interval. Fire return-intervals for ***low-severity*** fire regimes are often defined as anything 25 years or less, fire return-intervals for ***mixed-severity*** fire regimes are often defined as anything between 25 and 100 years, and fire return-intervals for ***high-severity*** fire regimes are often defined as anything at least 100 years.

Fuel loading – the availability of combustible materials to feed a fire. Higher fuel loads generally mean higher temperatures and greater flame lengths. The amount of available fuels is related to the severity of a subsequent fire.

Functional age – the age since release. Many shade-tolerant trees are able to survive in the forest understory for decades or even centuries. If conditions change, such as the opening up of the canopy, many of these trees can dramatically increase their growth rates and ascend into the main canopy. In some situations such as after logging, surviving understory trees may form a new cohort along with seedlings. These trees will all have the same functional age, yet their actual ages may vary by a century or more.

Heartwood – the inner, dead portion of wood that no longer actively transports water and nutrients (see sapwood). The heartwood in many tree species is richly colored, such as in redwood (*Sequoia sempervirens*) or black walnut (*Juglans nigra*). Since sapwood of all trees is pale in color, it is the heartwood that gives value to the lumber for woodworking. Many tree species deposit complex compounds in the heartwood that make it resistant to decay. Decay-resistant heartwood is the primary reason so many conifer species can live past the millennium mark.

Highgrading – a logging practice in which only the most valuable trees are removed. This practice is common in areas where many species are present within a forest, such as mixed-conifer forests or tropical rain forests.

Krummholtz – dwarfed, stunted, and often deformed trees growing in arctic or alpine situations. From a German word meaning ***twisted wood,*** krummholtz forms when conditions are too severe for normal tree growth. In the Pacific Northwest, it is common to see treeline krummholtz of whitebark pine, subalpine fir, or Engelmann spruce, although many other species can also form krummholtz.

Layering – a means of vegetative propagation in which an aerial shoot comes in contact with the soil and develops roots of its own. If later separated from the parent plant, shoots that have layered can often survive. Layering is common in alpine environments where plants are small and often spend months under a blanket of snow.

Old-growth – a term often used to describe structurally complex forests that have individual trees older than approximately 200 years. In forests that originated through a stand-replacing event, old-growth occurs when the stand has reached the vertical diversification stage of stand development (page 48).. Other terms that are sometimes used as synonyms include virgin, ancient, primary, overmature, decadent, or primeval. Ecologists tend to favor the term old-growth since it refers to a process and has less emotional bias.

Original branch – any branch whose initial bud was produced by the terminal leader of a trunk and thus has a pith that reaches the pith of the trunk.

Pioneer – in ecology, pioneer refers to the plants that are the first to arrive after a stand-replacing event such as wildfire, clearcutting, floods, volcanic eruptions, or even glacial retreat. In the Pacific Northwest, many weedy species of herbaceous plants often are pioneers following fire or logging. Pioneer tree species are frequently intolerant of shade and grow rapidly in full sun, such as western larch or lodgepole pine.

Reiterated trunk – any trunk on a tree other than the main trunk. The term 'reiterate' means 'to repeat,' hence a reiterated trunk is a secondary trunk that repeats the primary architectural model of tree growth within a tree crown. In many conifers, reiterated trunks retain the appearance of young trees growing within the crown of a larger tree.

Release – the dramatic increases in growth that follow when a suppressed tree is relieved of the factors that were suppressing it. For understory trees in forests, release usually comes in the form of the removal of some canopy trees, which lets more light into the understory, allowing increased growth. Suppressed trees are naturally walking a fine line between life and death, and the shock of increased light levels could kill them. However, release is what happens if a suppressed tree is able to respond positively to increases in light.

Sapwood – the outer portion of wood in a tree that conducts water and nutrients from the roots to the other living portions of the tree. All wood starts out as sapwood but is eventually converted to heartwood when no longer needed. The amount of sapwood needed by a tree is species specific, but is related to how many leaves the tree carries—healthy trees with full crowns of a given species will have more sapwood than suppressed trees with small crowns.

Stand – a patch of vegetation that represents a homogeneous unit with respect to its surroundings. Stand boundaries are often where forests of different ages are adjacent—ridgelines, streams, species changes, changes in soil characteristics, or changes in vegetation type can all demarcate a stand boundary. Stands can be smaller than a hectare to many hundreds of hectares.

Succession – the changes to a vegetation community following disturbance. The disturbance can be as small as the death of a single tree to as large as an entire landscape being consumed in wildfire. In forests, many aspects of succession follow predictable patterns, based on shade tolerance and the ecologies of the species involved.

Suppression – extremely slow growth in trees, which can be caused by any number of factors. In forests, the most common form of suppression is due to lack of light. The forest understory can be very dark, and few trees can tolerate these conditions without dying. Many shade-tolerant trees, however, can persist in low light levels for decades or even centuries with very little growth. Growth consists of producing a few leaves and root hairs each year, but height growth may cease and even the deposition of wood may or may not occur in suppressed trees. In old-growth forests of the Pacific Northwest, it is not difficult to find understory trees of western hemlock, Pacific silver fir, or mountain hemlock 100–200 years old and only a few centimeters in diameter.

Trunk – in most conifers, any vertically-growing appendage. The main trunk is the primary stem that emerges from the ground, and reiterated trunks are those whose origin is a limb or other trunk within the crown.

Whorl-based – a growth form common in many conifers in which the terminal shoot produces several buds at the tip, one of which retains the role of terminal shoot, and the remaining all become branches. Conifers exhibiting whorl-based growth include *Abies, Picea, Pinus,* and *Pseudotsuga*. Other conifers, like *Larix* and *Tsuga,* produce branches more or less continuously from the terminal shoot.

Windthrow – a term often used when a tree is blown over and a portion of the root system remains attached to the trunk and is tipped over as well. Depending on the species, the size of the root plate can indicate the presence of root decay.

About the author

Robert Van Pelt is a research ecologist at the University of Washington in Seattle, where he received both his Ms and PhD. A native of the Midwest, he has lived in Seattle for more than 20 years. He has extensively studied old-growth forests across North America, particularly in California and the Pacific Northwest.

Currently, he is involved in canopy research on the structure and physiology of the world's tallest trees—coast redwood, Douglas fir, Sitka spruce, giant sequoia, and mountain ash in Australia. Always fascinated with facts and figures, his passion for trees led him to start the Washington Big Tree Program in 1987, which keeps records on the largest of each species of tree in the state. This ultimately led Robert to write *Forest Giants of the Pacific Coast (2001),* which chronicles in detail the largest trees in western North America.

Author, Robert Van Pelt 52m (170') up in a pine tree.
Photo: Will Blozan

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