Identifying Mature and Old Forests

IN WESTERN WASHINGTON / SECOND EDITION

by Robert Van Pelt

WASHINGTON STATE DEPT OF NATURAL RESOURCES

Acknowledgements

The need for this guide became apparent after the 2004 Legislature directed DNR to conduct an inventory of old-growth forest stands on state lands as defined by a panel of scientists. The product of that effort, ***Definition and Inventory of Old Growth Forests on DNR-Managed State Lands*** (2005), made it clear that it was important for field personnel to be able to identify with confidence mature and old-growth forests throughout western Washington.

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2ND EDITION: The purpose of this update is to address clarifications and errata that have emerged after extensive field use of the book, as well as updated science on disturbance regimes and stand development. These updates serve to clarify and/or reemphasize the original intent of the text rather than presenting substantive changes. All changes were made and/or approved by the author, in consultation with DNR science staff.

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Washington State Department of Natural Resources

The Washington State 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. Identifying Mature and Old Forests in Western Washington serves as a valuable tool for the department to aid in the identification and protection of these unique forest structures.

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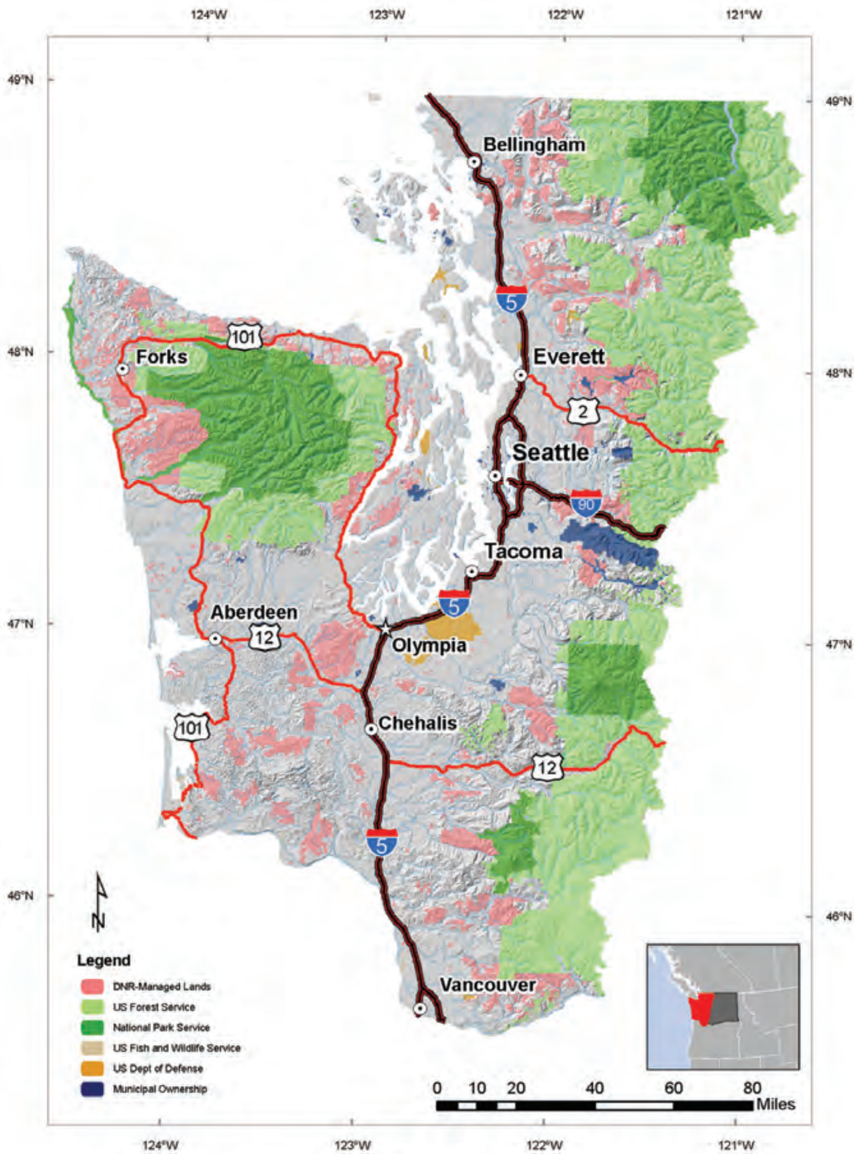
Locator map of Western Washington with major public ownerships.



Map developed by Jeff Rickleffs and Ned Wright, DNR

Introduction

Western Washington is part of the most heavily forested portion of the United States. Within this small region, a great diversity of environments can be found, ranging from the coastal rainforests of the Olympic Peninsula to the gravelly plains of the Puget lowlands and the glacier-clad peaks of the Cascade Mountains. Across this landscape, complex patterns of precipitation have resulted in a variation of fire regimes. Despite this diversity, relatively few species of trees, primarily represented by long-lived conifers, are found within these forests.

Such varied environmental conditions can affect the physiology and appearance of the trees that occupy the region. The purpose of this guide is to help the reader interpret the ecology, disturbance history, and age of a given stand using features of the environment, including the physical characteristics of the trees themselves.

This guide is intended to provide much of the necessary information needed to reconstruct stand history

and discern stand development stages for the major forest types found in western Washington. The great size achieved by many trees coupled with the heart rots common in western Washington makes the use of increment borers impractical in many forests. Assessing the age of a forest without specific knowledge of the ages of the trees contained within is an exercise in gathering and deciphering the relevant pieces of data. A working ecological understanding of the major tree species, the environments where they grow, and the dominant disturbance regimes at play in a given stand is required when making determinations of stand age.

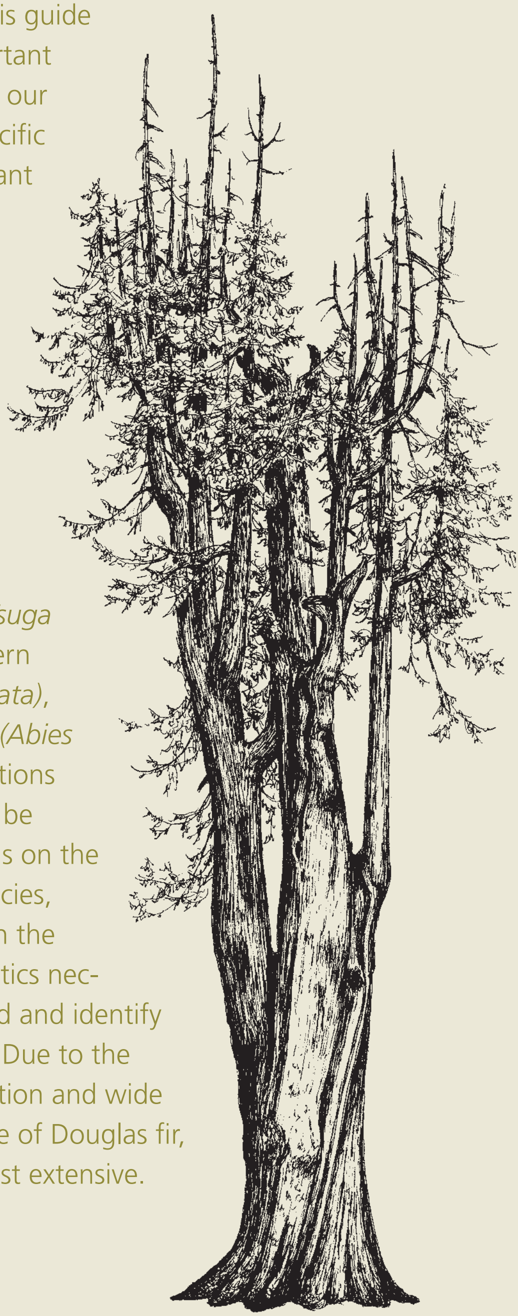
The scope of this guide will be limited to western Washington, while a separate guide covers eastern Washington.

Guide Organization

In order to identify mature and old forests, the great diversity of environments present in western Washington must be acknowledged. In addition, to discern age patterns in forests, one must understand a number of ecological concepts. Finally, the characteristics of the dominant species, important in the identification of mature and old forests, must be clearly understood.

This guide presents the general forces that drive the composition, structure, and the nature of western Washington forests. Physiographic and environmental gradients, fire and wind disturbance patterns, and the ecological characteristics of shade tolerance are discussed. An idealized model of forest stand development is presented in detail, applicable to most forests in western Washington. Variations of the model are also examined.

The latter part of this guide addresses the important individual species in our forests, and the specific characteristics relevant to discussions on forest age and succession. This includes sections on Douglas fir *(Pseudotsuga menziesii)*, Sitka spruce *(Picea sitchensis)*, noble fir *(Abies procera)*, western hemlock *(Tsuga heterophylla)*, western redcedar *(Thuja plicata)*, and Pacific silver fir *(Abies amabilis)*. These sections are not intended to be complete discussions on the ecology of each species, but instead focus on the essential characteristics necessary to understand and identify successional status. Due to the widespread distribution and wide ecological amplitude of Douglas fir, its section is the most extensive.



An understanding of this ecological amplitude is essential to properly understand and discern stand development where Douglas fir occurs.

Several tree species are not specifically treated in this guide, including red alder *(Alnus rubra)*, grand fir *(Abies grandis)*, bigleaf maple *(Acer macrophyllum)*, black cottonwood *(Populus balsamifera ssp. trichocarpa)*, mountain hemlock *(Tsuga mertensiana)*, yellow cedar *(Callitropsis nootkatensis),* and subalpine fir *(Abies lasiocarpa)*. These species are mentioned in the text when appropriate, but a specific section on each was deemed unnecessary. While red alder is abundant at lower elevations in western Washington, and pure stands are not uncommon, it is rare to find specimens older than 100 years of age. Its usefulness in a guide on identifying mature and old forests is therefore limited.

Environmental Setting of Western Washington

Although it is the smallest of the western states (184,824 km^2), Washington is arguably the most diverse, encompassing nearly all of the major biological habitats found in the west. Annual precipitation ranges from 20 cm in the deserts of the Columbia Basin to 600 cm along the western flanks of Mount Olympus on the Olympic Peninsula. The Cascade Mountains divide the state into two regions: western Washington, with a strong maritime climatic influence; and eastern Washington, with a more continental climate. Near the Columbia Gorge, the boundary between eastern and western Washington is defined by the ridge between the Wind and Little White Salmon rivers. Western Washington covers 66,824 km^2.

Western Washington lies on the edge of a large Mediterranean climate zone, centered on California. Mediterranean climates are characterized by warm, mild winters and hot, dry summers. While Washington is neither as hot nor as dry as California, the seasonal patterns are very similar. Throughout the entire region, including the coastal lowland rainforests, the summer months of July-September receive less than 5 percent of the total annual precipitation. South-westerly oceanic storms are the primary source of precipitation for the region.

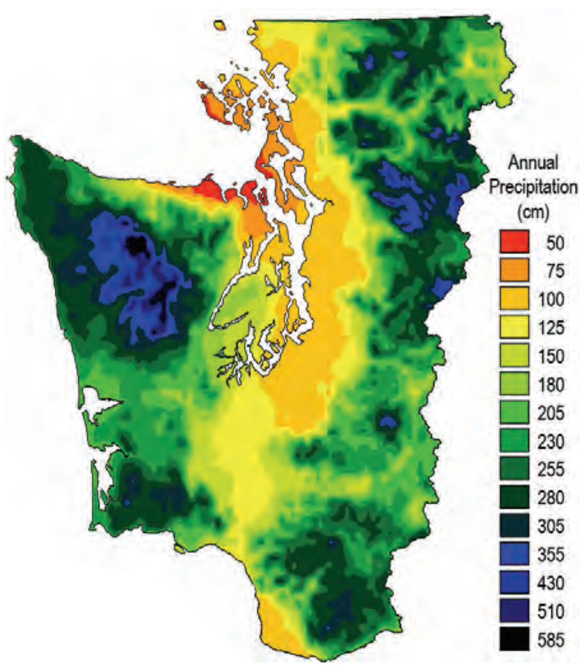


Figure 1. Annual Precipitation for Western Washington.

Western Washington contains a great diversity of habitats, from rainforests to alpine meadows and dry prairies. Along the northeastern, leeward side of the Olympic Mountains for example, a rain shadow is formed, parts of which receive only 43 cm of annual precipitation (Figure 1). Prior to the arrival of Euro-American colonizers in the nineteenth century, all of western Washington was forested with the exception of 8.9 percent of the landscape above the alpine timberline and another 1.4 percent of non-forested prairies or wetlands.

The dominance of evergreen conifers in the Pacific Northwest makes it unique among the temperate regions of the world. In all other temperate regions, including eastern North America, Europe, Asia, Australia, Chile, and New Zealand, conifers are relegated to early successional roles, limited to extreme habitats, or at best share dominance with flowering plants. Here, the opposite is true: flowering plants are relegated to early successional roles, as in the case of alders and cottonwoods, or limited to stressful habitats, as in the case of oaks and madronas. Prior to Euro-American colonization, more than 96 percent of the forests of western Washington were coniferous.

Physiographic regions are often used to divide areas by interrelated geology, physiography, soils, climate, and vegetation. Western Washington is usually divided into six physiographic regions, each with distinct, definable characteristics (Figure 2). The **Olympic Peninsula** is surrounded on three sides by salt water, and contains the massive Olympic Mountains with extensive areas above 1700 meters.

Figure 2. Physiographic Regions in Western Washington.
Background image courtesy of NASA

The **Willapa Hills** are the Washington extension of the Coast Ranges, which continue southward into Oregon. Both the Olympic Peninsula and Willapa Hills are exposed to oceanic storms, and as such, are the Northwest's wettest regions. In the lee of these two regions are the **Puget Trough** and **Cowlitz/Chehalis Valleys**. These two regions are characterized by low elevations and much drier conditions. The Puget Trough occupies the region once covered by several hundred meters of ice from the Cordilleran glaciers of the Pleistocene. To the east of these valleys lie the Cascade Mountains. Within Washington, the Cascade Mountains are broken into two very different sections. The **North Cascades** are steep, dramatic mountains with complex geology. More than fifty glaciers coat the spires, peaks, and ridgelines of this mountainous landscape. In contrast, the **South Cascades** are characterized by low, forested ridges covering much older geologic features.

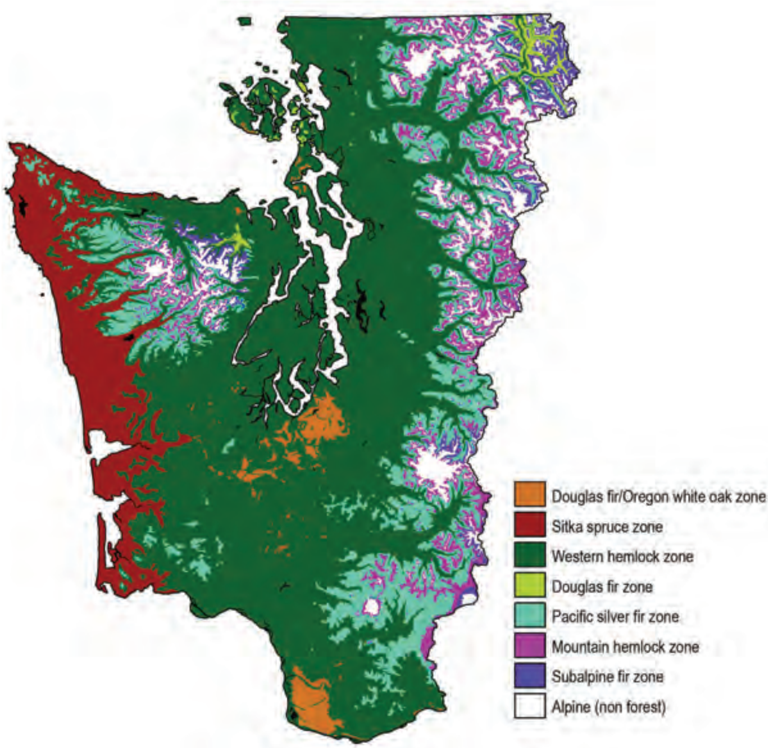


Figure 3. Vegetation Zones in Western Washington

Punctuating this ancient geologic landscape are three huge Quaternary volcanoes: Mount Rainier, Mount Adams, and Mount Saint Helens.

The steep, mountainous topography of western Washington has dramatic effects on precipitation and temperature. Accordingly, tree species have become stratified by their tolerance and competitive abilities. 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 USDA Forest Service and other agencies have further expanded and subdivided the vegetation zones into plant associations. Plant associations are groupings of plant species that recur 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, western Washington can be divided into seven vegetation zones (Figure 3–Table below).

Key[1] to Vegetation Zones in Western Washington.

1.	Subalpine fir ≥10% cover	Subalpine fir zone
	Subalpine fir <10% cover	2
2.	Mountain hemlock ≥10% cover	Mountain hemlock zone
	Mountain hemlock <10% cover	3
3.	Pacific silver fir ≥10% cover	Pacific silver fir zone
	Pacific silver fir <10% cover	4
4.	Sitka spruce ≥10% cover	Sitka spruce zone
	Sitka spruce <10% cover	5
5.	Western hemlock present	Western hemlock zone
	Western hemlock absent	6
6.	Douglas fir and/or Oregon white oak present and below 200 m elevation	7
	Douglas fir present and above 200 m	Douglas fir zone
7.	Oregon ash present	Western hemlock zone
	Oregon ash absent	Douglas fir/Oregon white oak zone

[1]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.

Figure 4. Mountain hemlock zone. Many picturesque timberline views in western Washington are framed by mountain hemlock—our high-elevation conifer found in the wettest and snowiest locations.

The **subalpine fir** and **mountain hemlock** zones include all of the upper treeline forests in our region. Most of the high-elevation forests in western Washington are very wet and snowy, and fall within the mountain hemlock zone (Figure 4). Only a small section of subalpine fir zone occurs in western Washington, most notably in the northeastern section of the Olympic Mountains where a significant rain shadow exists (Figure 5). The great width of the north Cascades also produces a large rain shadow near the Cascade crest where subalpine fir zone forests also occur.

Together, the **Pacific silver fir**, **Sitka spruce**, and **western hemlock zones** account for the majority of forested land in western Washington. These three zones are the primary focus of this guide. The Pacific silver fir zone occupies the mid- and upper montane zones of the Olympic and Cascade Mountains and the highest elevations of the Willapa Hills; the Sitka spruce zone occupies the outer coastal areas; the western hemlock zone occupies the remainder of the region.

A few exceptions are notable. Western hemlock, Pacific silver fir, and western redcedar are lacking in parts of the Puget Trough and the driest montane areas

Figure 5. Subalpine fir zone. Abundant as the dominant timberline tree in eastern Washington, in western Washington subalpine fir is mostly found where a significant rain shadow exists at high elevations, such as this scene in the northeastern Olympic Mountains.

of the rain shadows (Figure 6). Here, Douglas fir is the primary tree species and is also found uncharacteristically in the understory. These forests are included in the **Douglas fir zone** and are similar to many mid-montane forests in eastern Washington.

A seventh vegetation zone, the **Douglas fir/Oregon white oak zone**, is found in the excessively drained sands and gravels of southern Puget Sound and the Willamette Valley of Oregon. This zone is characterized by the presence of Oregon white oak *(Quercus garryana)*, western Washington's most drought-tolerant tree (Figure 7). Douglas fir and Oregon white oak are found along the perimeter and scattered throughout the native prairies of the Puget lowlands, Chehalis, Cowlitz, and Willamette valleys.

Oregon white oak, with its bimodal ecological distribution, may also be found in wetlands. This key includes the Oregon ash/Oregon white oak wetland forests common in wetlands south of the Puget Sound. As an edaphic type within the larger western hemlock zone, they do not warrant their own zone.

Figure 6. Douglas fir zone. At low and mid elevations in the rain shadow of the Olympic Mountains (see Figure 1), the Douglas fir zone occurs in the absence of western hemlock.

Figure 7. Douglas fir/Oregon white oak zone. Some of western Washington's only native prairies and oak savannas occur in the excessively drained soils of the south Puget Sound region. Limited occurrences of the Douglas fir/Oregon white oak zone are found within and around these prairies.

Fire in Western Washington Prior to Euro-American Colonization

Given the wide range in precipitation for western Washington, there is naturally a wide range in how fire has modified the environment over the millennia. Some areas near the coast or in the wettest spots in the mountains have had no fire for several thousand years. In other areas—particularly lowlands in the rain-shadow of coastal mountains—fire was common, burning through understories or occasionally becoming a stand-replacing event. While the arrival of Euro-Americans in the region during the nineteenth century has had a tremendous impact on the forests of western Washington, Native Americans also modified the landscape with fire—in some areas significantly. Because their presence in the region goes back for thousands of years, however, it is often difficult to distinguish whether a historical fire was due to a lightning or human ignition.

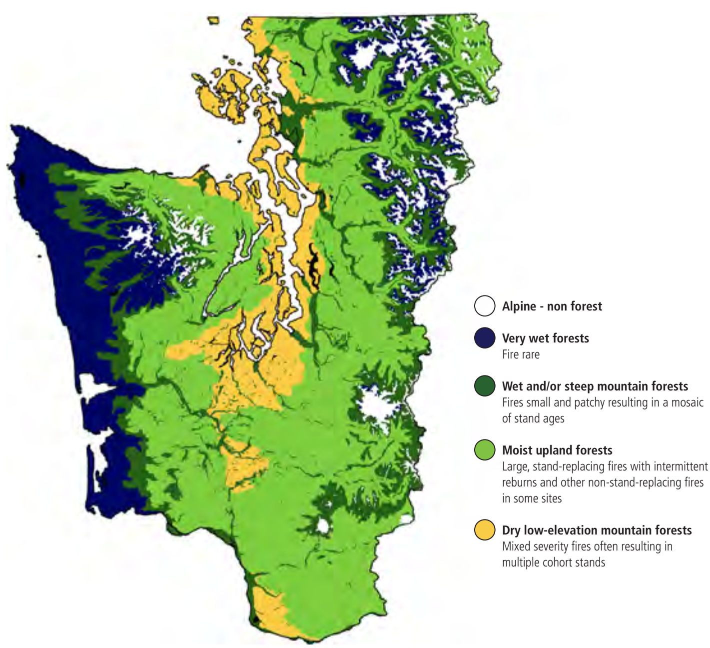


Figure 8. Pre-Euro-American colonization fire regimes in western Washington.

Douglas fir is about the most fire-tolerant tree species in western Washington—its thick bark allows it to easily survive fires of low or moderate intensity. It also has an extremely wide ecological amplitude, meaning it can survive in nearly every environment. Wetlands and high alpine regions are among the only places it will not be found. As a result, Douglas firs are the trees most likely to show evidence of previous fires.

For the period before Euro-American colonization, fire regimes in western Washington can be divided into four broad categories, based on fire frequency and severity (Figure 8). Ancient fire events may be dated by examining radio-isotopes of carbon in the decay-resistant charcoal layers found in the soil. Fire was rare along the coast, as many areas show no evidence of fire for the past several thousand years. Stands located on the broad coastal plains of the Olympic Peninsula and Willapa Hills are composed primarily of western redcedar and western hemlock (Figure 9). Sitka spruce, red alder, and cascara are also common

Figure 9. An ancient forest on the coastal plain in Olympic National Park near Lake Ozette. Western redcedar dominates the entire region of low, swampy soils—with the exceptions being the dark-colored hills, which are dominated by western hemlock.

in places. While western hemlock is typically the most abundant tree species in these stands, it is short-lived in such warm, moist, low-elevation environments. Even before logging, western hemlocks over 200 years old were uncommon, and invariably had rotten centers and did not make it to 300 years. In contrast, western redcedars over 1000 years old were not rare in these coastal plain forests. Many of these ancient trees were not very large, because, unlike the rich and productive soils of the nearby uplands, many areas of the coastal plain have heavily organic soils (muskeg) with low productivity (Figure 10).

A lack of fire has also been detected in many areas within the higher-elevation Pacific silver fir and mountain hemlock zones. These cool, wet forests are composed of shade-tolerant species: mountain hemlock, western hemlock, Pacific silver fir, western redcedar, and yellow cedar. In the most closed sections of these forests, Pacific silver fir is usually the most abundant tree. Mountain hemlock and yellow cedar also become numerous at higher elevations near the upper tree line.

Credit: Steve Curry

Figure 10. The interior of an ancient cedar-hemlock stand near Forks. Even though this stand is many thousands of years old, the largest trees are less than 200 cm diameter.

This super-wet subalpine zone contains the size and age records of several tree species: western hemlock (290 cm dbh, >1,238 years—Figure 11), mountain hemlock (189 cm dbh, >1059 years), Pacific silver fir (233 cm dbh, >900 years), and yellow cedar (416 cm dbh, >1,834 years).

Although rare, fires do occur in these wet forest types. A fire could easily start from a lightning strike along the coast during the drier summer/autumn months. Similarly, a fire burning in a river valley could travel upslope into the mountain hemlock zone during a dry year.

Surrounding these areas are regions that are slightly less wet, with more frequent fire, but which include imbedded wetlands and floodplains (Figure 8). While these regions have fire histories, fires were often infrequent—in many places fire return intervals were >500 years. Fires in this zone were often small and patchy, often spreading from adjacent, more fire-prone areas. The fires were commonly not self-sustaining and soon went out. Even so, they often occurred within the lifespan of a single Douglas fir tree, leaving charcoal on the bark as an indication. However, even within these areas, some of the oldest Douglas firs may not have any charcoal.

The bulk of western Washington is moist uplands, where large patches of stand-replacing fire are a dominant force shaping the landscape. Fires in this zone range from very large wind-driven events with extensive stand-replacing patches, to smaller, less severe events under moderate weather conditions. Virtually all sites experience infrequent, high-severity, stand-replacement fires at some point, with some sites also experiencing more frequent low- to moderate-severity (non-stand-replacing) fires. Reburns are common during the first decades following stand-replacement.

While development of a Douglas fir forest from a single stand-replacing event is not uncommon, there are countless variations. For example, non-stand-replacing fires can impact stand development by removing existing understory shade-tolerant trees and/or creating new regeneration opportunities for them. In some cases, these *intermediate* fires can open the canopy enough for a second Douglas fir cohort to establish, creating a *two-cohort stand*. Additionally, even in stand-replacing fires, it is common for scattered trees to survive in pockets. In the famed **1902 Yacolt Burn**, extensive areas of stand-replacement occurred—

Figure 11. The largest known western hemlocks grow in the cool, moist environments at high elevations with mountain hemlock and Pacific silver fir (pictured in the background). Here, the decay fungi, so aggressive at low elevations, are at a disadvantage.

but in wetter environments, such as the Willapa Hills, western Olympics, or North Cascades, the likelihood increases that a stand-replacing fire will not kill every tree. Even though current belief suggests that wetter forests exist in a stand-replacing fire regime, the chances are high that at least a few trees will survive as living **biological legacies**.

Since forests in the driest portions of the Puget Trough and Cowlitz and Chehalis valleys have largely been replaced or extensively modified by human developments, they are of limited interest in a guide to older forests. Nevertheless, fine examples of old forests still exist in this region, such as at Point Defiance Park in Tacoma (Figure 12), Seward, Schmitz, and O.O. Denny parks in Seattle, Deception Pass State Park on Whidbey Island, and Moran State Park on Orcas Island. In these areas, charcoal is common on the bark of older Douglas fir trees—an indication that they survived at least one previous fire event. Indeed, older stands throughout this lowland zone consistently contain multiple age classes of Douglas fir.

Fire boundaries in these areas are sometimes fairly abrupt, which is often the result of a landscape feature capable of stopping a fire, such as a ridgetop or a stream. Most commonly, however, fire boundaries will be a gradual change from burned to unburned. The edge environment in these situations is termed a feathered edge. As a new cohort of trees develops following this type of disturbance, several different stand structures will be present over a relatively short distance (Figure 13). A feathered edge may define up to five different stand structures: at one end which experienced total stand-replacement fire will be 1) an **even-aged stand**, followed by 2) an **even-aged stand with biological legacies**. In the central portion of the feathered edge will be 3) a **two-cohort stand**, then 4) an **old forest with a minor underburn**, and finally 5) an **old-growth forest**, at the opposite end which experienced no fire.

Much of this lowland zone is located within the rain shadow of the coastal mountain ranges, so stand densities and the proportion of shade-tolerant conifers may be significantly lower. Other sections of this zone have very dry forests resulting from the excessively-drained, gravely and sandy soils left behind by the Puget Lobe of the Cordilleran Ice Sheet, such as near Olympia and Fort Lewis.

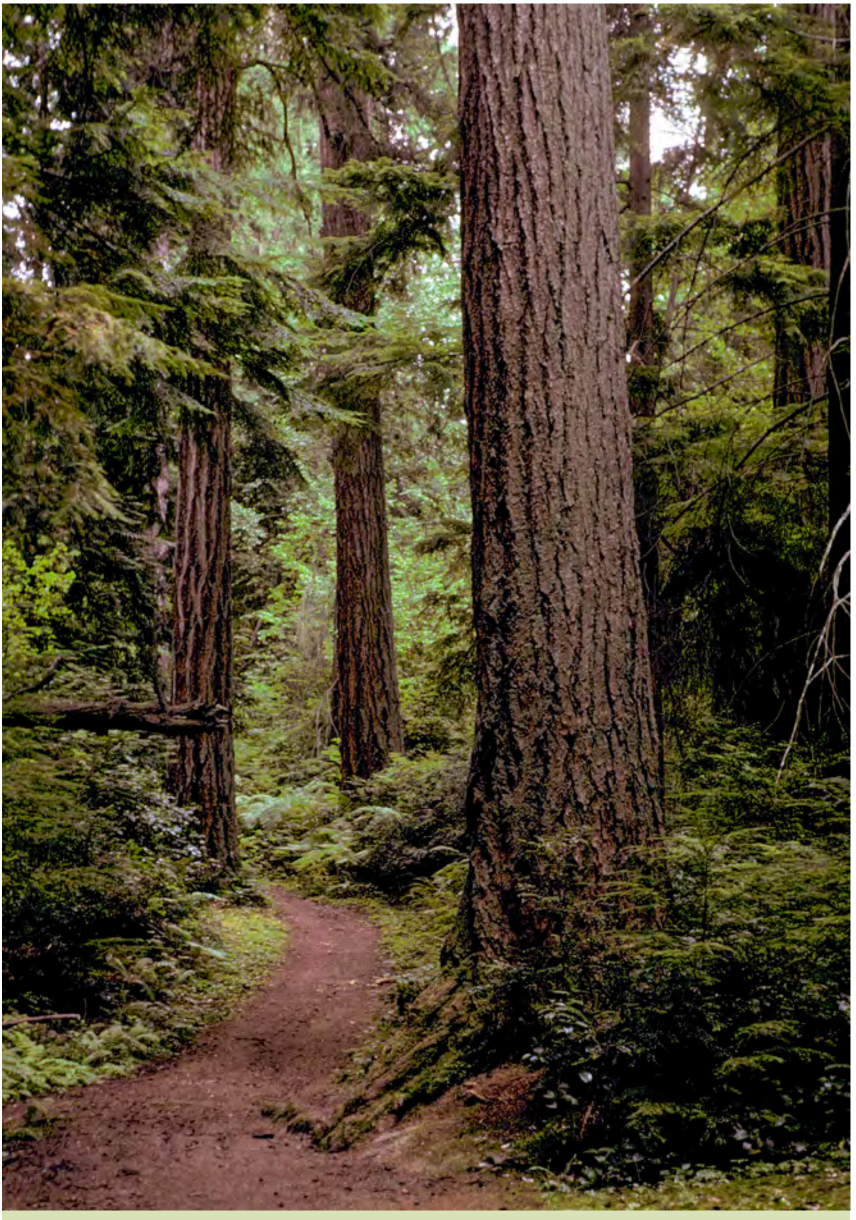


Figure 12. Multiple age classes of Douglas fir trees within the same stand are common in the old forests within the Puget Trough. Point Definance Park in Tacoma has trees up to 240 cm in diameter with charcoal on the bark, yet also has large and old trees with none.

Figure 13. A feathered edge. On the right side is an unburned old-growth forest, and on the left is an 80 year-old stand. The boundary between the two stand types shows various characteristics of both.

Wind Disturbances

Wind is the most prevalent disturbance type in forests close to the ocean. European explorers first reported stand-destroying windstorms along the Washington coast in 1788. Since then, a dozen other hurricane-force storms have hit the coast. The two strongest of these storms were the **21 Blow** of 1921 and the **Columbus Day Storm** of 1962, each with winds recorded in excess of 240 kilometers per hour (150 mph). Both of these began as tropical typhoons that strayed into our region assisted by the jet stream.

Violent winds and fires disturb forests in very different ways. Trees that survive a fire are likely to be among the largest trees in the stand—those with high crowns or thick bark. In contrast, smaller trees have a greater chance of surviving a severe windstorm—understory trees are more prone to be crushed by falling trees than blown over.

On the other hand, taller trees often remain standing in the more common windstorms that coastal forests experience approximately once a year. Because these trees are constantly buffeted by wind, they become wind firm. Thus in common storms, it is often the intermediate canopy trees that blow over. These trees tend to grow in sheltered conditions, and the wind protection they receive from their larger neighbors is usually sufficient for them to remain standing. They are therefore less wind firm than their taller neighbors.

Each tree species responds differently to wind. Forest surveys conducted after historic storms have shown that western hemlock and Pacific silver fir are much more likely to blow over than their larger associates such as Douglas fir. Both western hemlock and Pacific silver fir carry heavy amounts of foliage, making them more susceptible to wind. Ancient western redcedars are the least likely to blow over; their wide bases and often short stature serve to increase their stability.

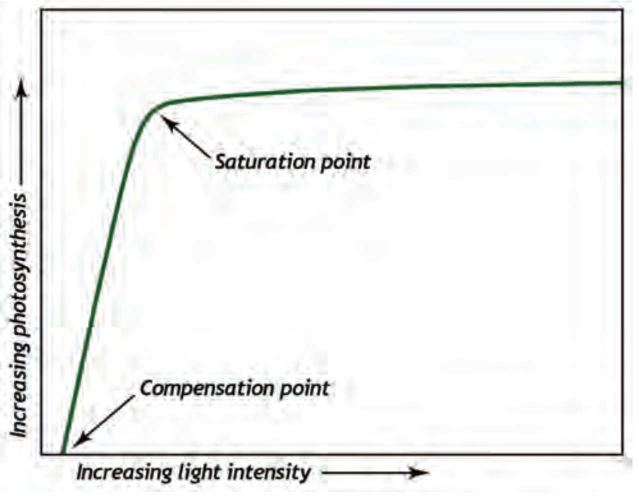
Even though western Washington receives major storms at approximately 20 year intervals, 100 percent canopy removal within a wind-disturbed area is uncommon. Succession after a canopy-removing windstorm proceeds differently than after fire. In most cases, many of the trees that will form the new canopy are already in place in the understory (Figure 14).

Figure 14. A section of the *21 Blow* with no residual canopy trees. However, the dense hemlock understory quickly responded to the removal of the canopy to form a nearly pure hemlock stand 80 years later.

Important Information on 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, known as the **compensation point** (Figure 15), occurs at light levels of 2–3 percent of full sunlight. With light levels above this, photosynthesis increases nearly linearly up to a threshold, called the **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, the shape of this curve is common to all leaves.

Figure 15. A generalized view of leaf photosynthesis with increasing light levels. Peak photosynthetic efficiency occurs at the saturation point.



Most trees, including our coniferous tree species, arrange their leaves differently around the stem under differing light conditions. For example, noble fir, a shade-intolerant species from subalpine forests of the south Cascades, displays dramatic

Figure 16. Leaf arrangement in response to light. The left photo is of a fully illuminated shoot from the top of a noble fir tree showing aggregated leaves and self-shading. The photo on the opposite page is a shaded shoot from the same stand with little self-shading and a very high SAR value (see page 28).

differences in shoot morphology between those growing under fully sunlit conditions and those found in the shade (Figure 16). Leaves at the top of the tree receive much more light than they can possibly use and aggregate their leaves 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—they minimize self-shading and orient themselves perpendicularly to the sun's rays to maximize light interception. In most of our old-growth forests, only 1–5 percent of light reaches the ground, and most of this arrives in the form of diffuse light. Many of our understory species, such as wood sorrel *(Oxalis oregana)* or vine maple *(Acer circinatum)*, orient their leaves parallel to the ground to maximize exposure to the small amount of diffuse light.

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 red-cedar, grand fir, and Pacific yew *(Taxus brevifolia)*, can have very high SAR values (0.95–0.99), indicating almost no self-shading. Shade-tolerant species are thus able to hold foliage deeper into 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, is not shade tolerant at all when growing with western hemlock and 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 tree species.

In eastern Washington, however, where Douglas fir commonly grows with ponderosa pine *(Pinus ponderosa)* and western larch *(Larix occidentalis)*, it behaves as a shade tolerant species. These species of pine and larch have an even lower shade tolerance than Douglas fir. Thus, in these forests, it is the Douglas fir 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.

Stand Development in Douglas Fir Forests

The stand developmental sequence as presented in Franklin et al. (2002) provides an introduction to the concepts of forest disturbance and succession. This developmental sequence, while simplistic, is common in forests of western Washington. It provides a useful framework when considering the many divergent scenarios, which may include intermediate (partial) disturbances such as wind, pathogens, less-severe fires, cultural burning, and forest management such as thinning. By influencing the mortality, growth, or establishment of tree cohorts, these processes can accelerate, slow, or otherwise alter stand development.

Disturbance and legacy creation

The first stage in a developmental sequence is the disturbance itself. For the purposes of this simplified discussion, disturbances are limited to stand-replacing events that allow a new cohort of trees to establish. In our region, the three primary stand-replacing disturbance events are crown fire, severe blowdown, and timber harvest. 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.

Crown fires will kill the previous stand of trees, but will often only consume a small proportion of the total wood from the previous stand. Landscapes burned by severe wildfire are often a sea of snags in a post-fire condition (Figure 17).

Figure 17. Aftermath of a stand-replacing wildfire. Note that besides killing the trees, the fire did not consume much wood. The trees were alive and thus full of water. Subsequent fires, if they occur, will burn up much of this wood.

Individual trees in stream drainages or other wet or protected areas will often survive even severe fire events (Figure 18). The individuals that manage to survive are typically the larger trees, as the smaller individuals are more susceptible. Individual large trees that have survived the fire, as well as snags and logs on the forest floor, are termed **biological legacies**.

Figure 18. Living legacies. Survivors after a severe wildfire are often found in drainages or other moist areas. Surviving trees are the primary seed sources for the next stand.

Figure 19. Blow-down. All of the organic matter from the killed trees—leaves, branches, stems, and roots—remain on the site. Some of the under-story trees will survive to make up part of the next stand.

In contrast, severe windstorms leave virtually all of the organic matter from the previous forest (Figure 19). This disturbance type tends to work from the top down, blowing over the canopy trees. Survivors from large wind events are often the small understory trees that were not crushed by falling trees. This cohort of surviving understory trees is usually the source of canopy trees for the subsequent stand, which differs from other developmental sequences in that it consists primarily of shade-tolerant species. In western Washington, this disturbance type is most common in coastal areas.

Although it is only one harvest technique of several employed in modern silvicultural management, clearcutting was the dominant harvesting technique practiced in western Washington for many decades. As such, it constitutes an important part of the disturbance history of many post-Euro-American colonization stands. Traditional clearcutting leaves very little from the previous stand—no live trees and very few, if any, snags (Figure 20). The few logs that remain tend to be heavily decayed or small in diameter. During the late nineteenth and early twentieth centuries, these areas were allowed to reseed themselves naturally from surrounding forested areas. Since the mid 20th century, clearcut harvest units have generally been replanted within a year or two after harvest. Stands resulting from natural reseeding are patchier and may take longer (in places) to reach canopy closure.

Figure 20. Clearcutting was the dominant silvicultural technique used through most of western Washington's timber harvest history and is the origin of many of today's stands. Apart from the stumps, foliage, and small branches, little organic matter remains in this large industrial clearcut. Modern silvicultural techniques recognize the value of retaining live trees, snags and logs (biological legacies).

Cohort establishment

Cohort establishment is the initiation of a new set of trees that forms the basis of a future forest (Figure 21). Conditions for cohort establishment following a fire vary tremendously between sites, depending on the extent and severity of the fire. Very large fires may leave limited seed sources with which to repopulate the area. Smaller fires will not usually create this problem. Even stands subject to very large fires can regenerate quickly if there is a small but diffuse population of surviving trees. The 1902 Yacolt Burn, one of the largest recorded fires in western Washington, regenerated very quickly.

Repeat disturbances, such as subsequent fires, confound regeneration:

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

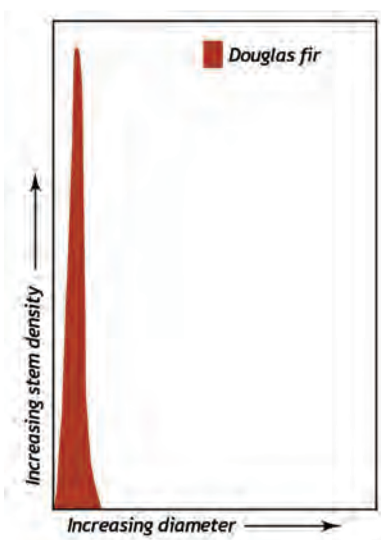
Figure 21, Part A. Cohort establishment after wildfire.

Figure 21, Part B. Cohort establishment after blowdown.

Figure 21, Part C. Cohort establishment after clearcutting.

Indeed, all of these processes will commonly take place in areas that burn repeatedly. For the sake of simplicity, and to develop the concept of stand development, this section will only examine in detail the scenario in which the initiating disturbance is wildfire, as depicted in Figure 21, Part A (After Wildfire).

Figure 21, Part D. Diameter distribution at Cohort establishment.



Large sections of the Yacolt Burn did re-burn. Some areas experienced as many as four fires during the first half of the twentieth century. 100 years later, some of these areas still have not fully regenerated (Figure 22). This scenario was probably not unusual in western Washington prior to Euro-American colonization, particularly in the south Cascades. With witness records of this burn and all of the subsequent fires, we are able to discern the different age classes and their boundaries. As time passes, however, the slight differences in ages between neighboring cohorts become increasingly difficult to distinguish. In addition, as the stand ages, fewer individuals from the original cohort remain. After several centuries, only a small selection of trees remains from the various disturbance and succession events. In the distant future, an examination of trees in stands that originated from multiple fires might only indicate that the dominant canopy trees have a wide age range.

Figure 22. The Yacolt Burn. The view from Lookout Mountain into the headwaters of the East Fork Lewis River shows areas that have burned as many as four times since 1902. Some areas still do not support trees.

This may have been the case in the old-growth forest that was consumed by the Yacolt Burn. An examination of the old forests adjacent to the Yacolt Burn at the Wind River Experimental Forest shows this pattern of a wide variety of age classes in the dominant canopy trees (Figure 23). After several centuries it is difficult to tell whether this pattern was created by multiple fires or by a single, vast fire followed by slow colonization. The nearby situation of the Yacolt Burn may provide important clues. This prolonged version of cohort establishment, referred to as the **early-seral pre-forest stage**, is recognized as an ecologically important pathway, being the only period when the site is dominated by non-tree vegetation and associated organisms. This period can last several decades until tree canopy closure occurs.

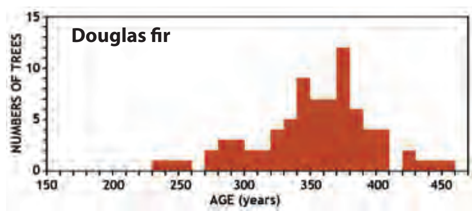


Figure 23. Age distribution of trees in the old-growth forest at the Wind River Experimental Forest in the south Cascades. Note the wide age range of the canopy dominants. Modified from Franklin and Waring 1980.

Canopy closure

Canopy closure between two trees occurs when the two 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 24).

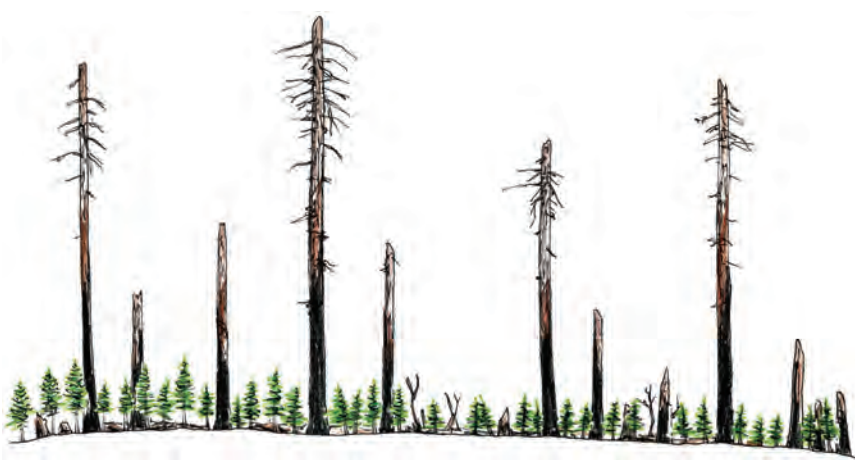
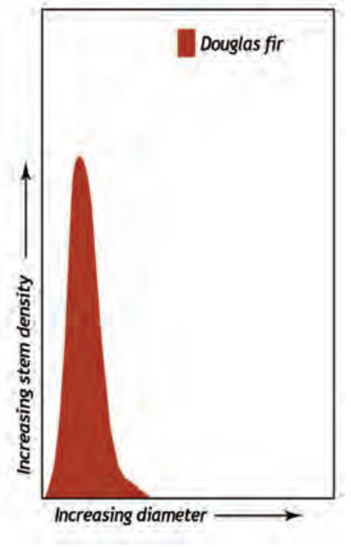


Figure 24, Part A. Canopy closure.

Modern planting methods attempt to minimize the time for this process to occur, but natural processes are much more irregular. Natural colonization is random, and at times aggregated. In these situations, canopy closure may occur in one spot decades before it does only a short distance away. Competition from dense shrub layers (e.g., salmon-berry or vine maple), large piles of woody debris, or certain soil conditions can all substantially delay conifer establishment.

Figure 24, Part B.
Diameter distribution at Canopy closure.



More dramatic environmental changes occur during this stage than in any other. During this relatively brief period, the area goes 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, may perish in the deep shade imposed by the overlapping tree-crowns.

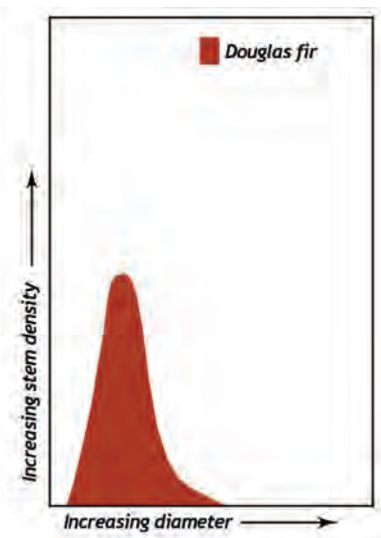
Biomass accumulation / Competitive exclusion

For several decades following canopy closure, until the stand reaches maturity, it will be in the biomass accumulation/competitive exclusion stage (Figure 25). In western Washington, this stage often begins around 25-40 years since the originating disturbance, lasting until age ~60-80 on highly productive sites or age ~120-130 on poorer sites.

At this stage, it is characteristic for a site to be completely dominated by trees. The trees can grow rapidly, converting a shrub field of tiny trees into a tall forest. Standing biomass increases by many orders of magnitude, yet recruitment of new individuals is limited due to the deep shade at the forest floor. Depending on initial stem densities, density-dependent mortality will also be prevalent during this stage.

Figure 25, Part A. Biomass accumulation/Competitive exclusion.

Figure 25, Part B. Diameter distribution at Biomass accumulation/Competitive exclusion.



If the initial stocking of trees was high, many of the thinner/shorter stems will be overtopped and perish. If, however, the initial stocking was low, this type of mortality may be limited. These dead, small-diameter trees can often be quite abundant, depending on initial stocking levels, and appear to be strewn about like jackstraws. Small-diameter logs and snags decay very rapidly and contribute little habitat value to species that require coarse woody debris.

As the trees grow taller, many shade-intolerant tree species (such as Douglas fir) will shed their lower branches as they 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.

The forest understory is at its most depauperate level during this stage. Deep shade is ubiquitous due to a dense, upper canopy layer. It is common for such stands to have only a thin layer of mosses with widely scattered shade-tolerant understory plants.

Maturation I

At this stage of development, commonly occurring at stand age ~60-140 years, trees have typically reached 60-70 percent of their ultimate height. Further height growth proceeds more slowly than it did in the earlier stages of development. Mortality of the slower-growing, overtopped trees continues, as does the height differentiation of the remaining dominant trees (Figure 26). Since taller trees move more in the wind, the crowns of adjacent trees occasionally bump into each other, causing twig breakage at the branch tips. Tree crowns become more individualized to their own space, rather than intermingling with neighboring trees as they did when younger, which is termed **crown shyness**.

All of these factors combine to make the canopy less dense and to allow more light to reach the ground surface. While still very dark, the increased light levels in the understory soon reach the point at which shade-tolerant plants can begin to grow, including tree species such as western hemlock. These shade-tolerant trees occur as a simple, single layer with a narrow height range in this developmental stage. The rates at which new plants colonize the understory will naturally depend on many factors, including the proximity of seed sources. If the initial disturbance was very extensive, or competition from shrubs remains extreme, shade-tolerant seedlings may not colonize for many decades, even if conditions are favorable.

The middle canopy will be completely free of foliage, and will consist only of the trunks of canopy trees (Figure 27). This area, known as the **bole zone**, is most dramatic at this stage.

Figure 26, Part A. Maturation I.

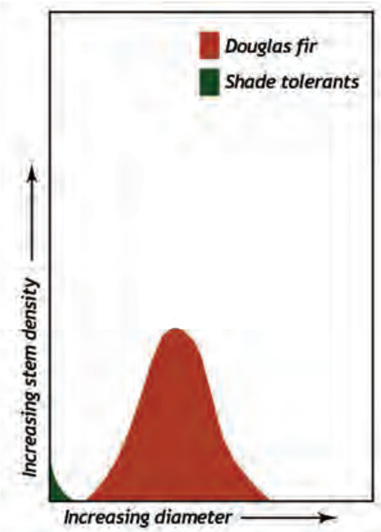


Figure 26, Part B. Diameter distribution at Maturation I.

Figure 27. The Bole Zone. Below the main canopy and above the understory vegetation is a section with no leaves—just the trunks of canopy trees.

Maturation II

Under natural development, Maturation II most often occurs when forests are 120-200 years old, when overstory trees reach approximately 80-90% of their eventual height growth. This is the last stage at which trees exhibit the pointed tops characteristic of juvenile stands (Figure 28, Figure 29). The spatial, competition-based mortality process that was dominant up to this point now shifts to a mortality process driven by fungi, wind, and insects. Of these agents, fungi are the most important in western Washington. Decay from root and stem rots becomes the dominant mortality agent from this stage forward. While wind is an important component of mortality near the coast, many mortality events that may at first appear to be uprooting or stem-snap caused by wind are instead the result of trees already significantly weakened by decay fungi.

At this stage, the understory is often fully recovered and remains so for all subsequent stages. Hemlock and other shade-tolerant tree regeneration, depending on seed source availability, is often quite abundant. Shade-tolerant trees now occupy

Figure 28, Part A. Maturation II.

many height layers, from understory to mid-story (note that individuals originally part of the overstory cohort should be discounted when assessing shade-tolerant recruitment). The amount of woody debris in the stand is at a minimum during this stage: most of the wood left over after the initial disturbance has decayed, and the current stand has yet to produce woody debris of significant diameter.

The bole zone begins to be repopulated with foliage from a new source, epicormic branches (Figure 30). Epicormic branches start from dormant buds on the cambium, not from terminal buds. These often occur at old branch wounds or other places where the bark is very thin. Whereas the original branch died due to low light levels, the surrounding stand continues to grow and change, allowing more light into lower levels of the canopy. An epicormic branch may form and expand into this new light environment. A more detailed discussion of this phenomenon is found in the section on Douglas fir (Page 56).

Maturation II is among the most widely variable development stages, and arguably the one whose timing is most influenced by prior forest management. While under natural development these stands are often a century-and-a-half old, treatments such as thinning can make key aspects of this stage appear in around half that time—particularly the shift away from density-dependent mortality and development of robust under- and mid-stories. As such, younger stands may classify as Maturation II, as a result of different management histories or site contexts.

Figure 28, Part B. Diameter distribution at Maturation II.

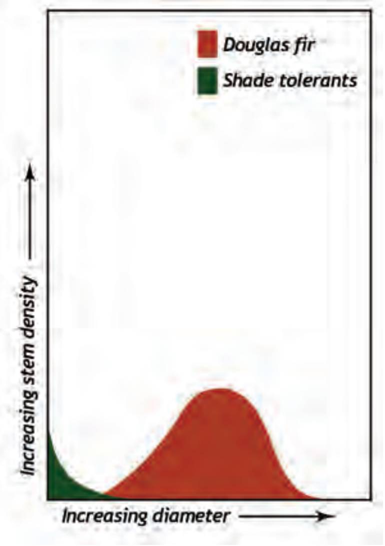


Figure 29. View of the top of the canopy of a 160 year-old stand in the south Cascades. Note the symmetrical tops of a stand still growing in height.

Figure 30. Epicormic branching. Branches can form below the main crown at old branch wounds when light levels increase in that section of the stem.

Vertical diversification

Vertical diversification is the first stage of old-growth, most often appearing in stands ~180-350 years old. The shade-tolerant trees are now continuously establishing in the understory and have expanded to occupy areas below and within the main Douglas fir canopy (Figure 31).

Epicormic branching is found on many of the canopy trees, effectively lowering their crown bases (Figures 31 and 32). This crown deepening permits trees of the main canopy to greatly increase the amount of foliage they carry, thus allowing for increased growth. Height growth, however, proceeds very slowly; most of this new growth goes into wood production and below-ground processes. Many of the Douglas firs in the main canopy become very large during this stage.

Figure 31, Part A. Vertical diversification.

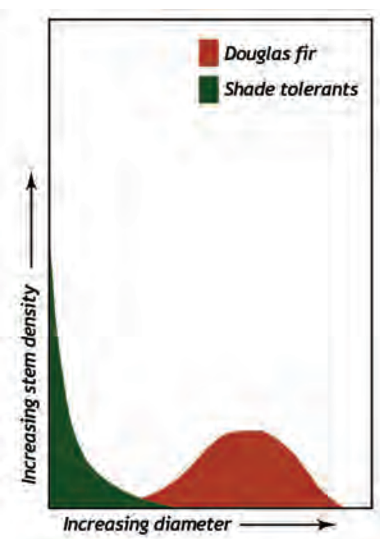


Figure 31, Part B. Diameter distribution at Vertical diversification.

Figure 32. Crown deepening through epicormic branching.

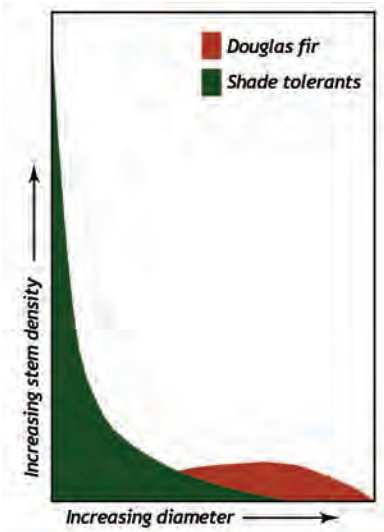
Mortality will continue as decay and other agents occasionally kill trees. The snags and logs produced during this stage, however, are now large enough to have a significant lifespan and begin to accumulate.

Horizontal diversification

Decadence of the Douglas fir canopy continues, with significant mortality events centered on large individual trees. Many of these large trees will die standing; others will fall, often taking one or several smaller neighboring trees down with them. The gaps created by the dead trees open up the understory to higher light levels and increased nutrient availability. This pattern of gap formation, followed by infilling from trees in the understory, creates the horizontal diversification of this stage in stand development (Figure 33). In addition, mortality is higher near pre-existing gaps; gap expansion accentuates this horizontal variability. Sections of the stand are still dominated by large Douglas firs, but they may be few in number and their spacing often highly variable, leaving small sections without any. Older gaps may now be dominated by shade-tolerant trees, from young regeneration to mature individuals. Observing all the variation in this stage takes about 3 tree heights of horizontal distance, which can be 150-250 meters in the largest forests.

Figure 33, Part A. Horizontal diversification.

Figure 33, Part B. Diameter distribution at Horizontal diversification.



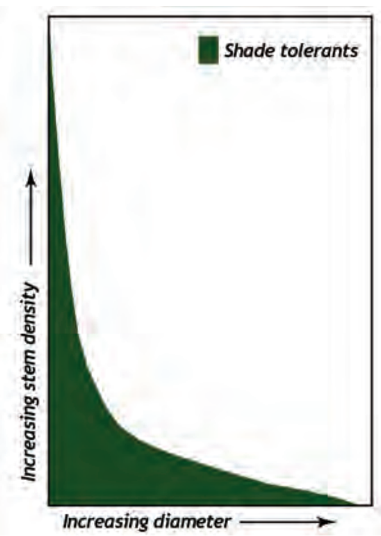
In western Washington, this stage often begins when the stand is between about 300 and 400 years old, depending on site location and productivity. This is the classic stage of old-growth forest that comes to mind for many people: towering Douglas firs with hemlocks present in all size classes, from juveniles to large canopy trees (Figure 33). Since Douglas fir can easily live for 600-800 years, and occasionally 1,000-1,300 years, this stage may last for many centuries.

Pioneer cohort loss

The final stage of stand development begins when all (or nearly all) the Douglas firs have died. At this point, effectively none of the trees in any of the canopy levels originated immediately after the initial disturbance (Figure 34). The structural presence of giant Douglas firs

Figure 34, Part A. Pioneer cohort loss.

Figure 34, Part B. Diameter distribution at Pioneer cohort loss.



extends for several centuries after the last tree dies; snags can last for a century or more, and logs are often still recognizable for several centuries.

The word climax is often used to describe forests dominated by 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 stop when it reaches this point. The term steady-state more aptly describes this condition and implies variation within a final equilibrium (Figure 35). Even this term, however, has short-comings given the long lifespan of some trees (>1000 years). At this time scale, the climate itself is continually changing. A stable condition in one millennium will be different during the next—even if the same species are present.

This final stage of the stand developmental sequence is rarely ever reached. It is likely that some event will occur to divert a forest from this developmental trajectory. The most common is another stand-replacing wildfire, which serves to reset the developmental sequence to the beginning.

Figure 35. In portions of western Washington that are extremely wet, the forest can be older than the oldest pioneer tree. At low elevations, this often results in a pure hemlock forest, as seen here. Closer to the coast, western redcedar is often common—or sometimes dominant. At higher elevations, both hemlock species may be present, along with Pacific silver fir.

Key to Stand Development Stages in western Washington for western hemlock, Sitka spruce, and Pacific silver fir zones following major disturbance (most commonly fire or logging).

Countless variations in stand development pathway can occur due to site context and intermediate (partial) disturbances during the life of a stand—including wind, pathogens, less severe fires, cultural burning, or forest management (e.g., thinning). This key represents a general sequence of archetypal states that reflect the degree of overall structural development, which can be attained through time and/or intermediate disturbance influences.

This key is based on characteristics of live vegetation, mainly conifer tree cohorts. While the key has been tested in a wide variety of stands in western Washington, there may exist stands that do not key out properly. In these situations, relax the percentage values slightly and retry. In borderline cases, select the stage whose overall description best fits the stand. Key the stand interior, not edges.

See footnotes for help interpreting certain steps in the key.

01.	Cut stumps abundant *throughout* stand	Harvest origin 2
	Cut stumps few or absent	Natural disturbance origin 2
02.	Legacy trees—trees considerably older/larger than the main overstory cohort, or a subset of trees with charcoal present on bark[a]	3
	No legacy trees	5
03.	Legacy trees <20% canopy cover	Stand with legacies[b] 5
	Legacy trees ≥20% canopy cover (commonly at least 7 legacy trees/acre)	Two-cohort stand 4
04.	Each cohort must be keyed out separately	
	Older cohort	9
	Younger cohort	5
05.	Douglas fir (live or dead) ≥25% of main canopy stems[c]	6
	Douglas fir <25% of main canopy stems	15
06.	Young Douglas fir trees <10 years old	**Cohort establishment**
	Not as above	7
07.	Douglas fir trees ~5-40 years old, patchy to irregular distribution, crowns mostly isolated or in small clumps, abundant cover/co-dominance of shrubs, herbs, and/or grasses	**Early-seral pre-forest**
	Not as above	8
08.	Douglas fir trees ~5-40 years old, crowns overlapping, crown bases still near ground (not overhead), shrubs usually ≥15% cover	**Canopy closure**
	Not as above	9
09.	Douglas fir canopy fully overhead, self-pruning, conifer understory absent to sparse (<15% cover)	**Biomass accumulation/competitive exclusion**
	Not as above	10

10. Douglas fir overhead, self-pruning, pronounced mid-level bole zone largely free of foliage, epicormic branches absent to sparse (rarely abundant); shade-tolerant conifers[d] with ≥15% cover in understory[e], or in some cases having grown as *single layer*[f] into mid-story level . . . . **Maturation I**
    Not as above 11

11. Douglas fir overhead, bole zone filling from below and (usually) from above. *Above:* epicormic branches abundant (≥15% of trees); *Below:* shade-tolerant conifers abundant in understory plus ≥15% cover in mid-story[e], resulting in wide range of heights[f], but have yet to recruit into the main canopy[c] . . . . **Maturation II**
    Not as above 12

12. As above, *and* with overstory Douglas fir large/old (scoring ≥4; see pg. 66) . . . . . **Maturation II**
    Not as above 13

13. Douglas fir upper canopy; shade-tolerant conifers abundant in many height classes including recruitment into the lower portion of main canopy[c], foliage present from overstory to understory (no consistent bole zone) . . . **Vertical diversification**
    Not as above 14

14. Douglas fir canopy patchy, large canopy gaps present; shade-tolerant conifers recruited into and abundant in all canopy levels . . . . **Horizontal diversification**
    All or nearly all Douglas fir dead (snags or logs); shade-tolerant conifers recruited into and abundant in all canopy levels . . . . **Pioneer cohort loss**

15. Sitka spruce or noble fir ≥25% of main canopy stems
    Use steps 6-14, replacing Douglas fir with Sitka spruce or noble fir
    Sitka spruce or noble fir <25% of main canopy stems
    Use steps 6-14, replacing Douglas fir with western hemlock, western redcedar, and Pacific silver fir collectively[g] *(note that epicormic branching is less common or relevant to the key for these shade-tolerant species)*

a Legacy trees refer to trees that pre-date (survived) the last major stand-initiating disturbance, such as fire, that generated a distinct post-disturbance tree cohort. A common example is two cohorts of Douglas fir, one distinctively older and often fire charred.

b For Douglas fir legacies, see ***Rating system for determining general age of individual Douglas fir trees*** on page 66. For Sitka spruce, western hemlock, or western redcedar legacies, use visual indicators under their individual sections.

c In some cases, shade-tolerant species may have co-established with Douglas fir originally and thus be part of the original (pioneer) overstory cohort. This can often be discerned by a clear size/age gap among the shade-tolerant species. When discernible, this co-established component should be discounted in the later stages of the key. An intent of the key is to assess shade-tolerant layer development arising from understory re-initiation processes. In effect, in these cases apply step 15 (substitution) in a partial manner.

d In these forest zones, the most common shade-tolerant conifers include western hemlock, western redcedar, Pacific silver fir, mountain hemlock, and (rarely) grand fir.

e For conifers, the height demarking the understory from the mid-story varies with overall stand height and other factors, but for keying purposes use approximately 10% of overstory height, which in most mature stands will be ~2.5-5 m (8-16').

f Shade-tolerant sub-canopy trees are considered differentiated into more than a single layer if the mid-story crowns have lifted enough that their crown bases are at or near the tops of the understory trees.

g The horizontal diversification stage in this sequence is equivalent to the pioneer cohort loss stage of the Douglas fir, noble fir, and Sitka spruce sequences.

Figure 36. Classic old-growth. Interior of a 600+ year old stand near Mount Saint Helens showing a diversity of tree sizes and spatial heterogeneity.

Douglas fir *(Pseudotsuga menziesii)*

Douglas fir is the largest and tallest member of the pine family. Living trees have been documented up to 485 cm in diameter, up to 99.5 m tall, and with volumes up to 349 m^3. Even larger and taller trees once existed in western Washington. It 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) and from Colorado to the coast (another 1,600 km). Even in western Washington, it grows in all but the wettest locations—anywhere with a fire history (Figure 37). Throughout much of its native range in the Rocky Mountains, it has high relative shade-tolerance, capable of regenerating in the understory of other tree species (primarily pines). This subspecies is called *Pseudotsuga menziesii glauca.* The coast form, which grows from Vancouver Island south into the Sierra Nevada of California, is subspecies *menziesii*. This subspecies behaves largely as a long-lived pioneer tree, due in part to the tree species with which it is found growing, and the higher productivity and denser forests found along the coast.

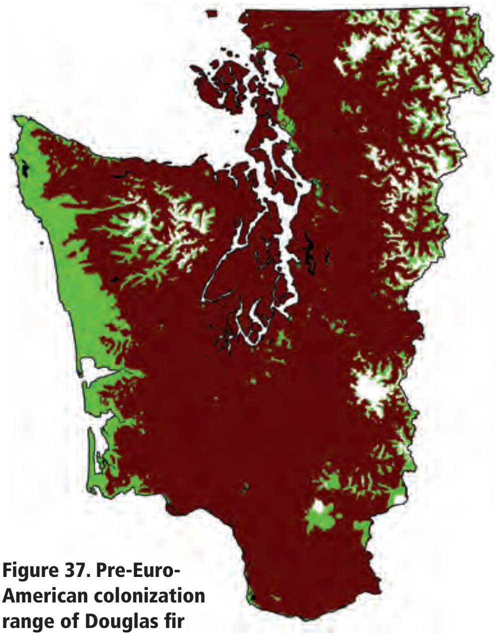


Figure 37. Pre-Euro-American colonization range of Douglas fir in western Washington (red color).

This great adaptability is well displayed in the forests of western Washington. It can be found windswept, growing at 1,500 m elevation along the eastern ridges in Olympic National Park, and just a few kilometers away, windswept again, along the shores of the Straits of Juan de Fuca (Figure 38).

Figure 38. Left: Windswept Douglas fir at 1500 m near timberline on Hurricane Ridge in Olympic National Park. **Right:** Windswept Douglas fir at sea level at Point Wilson near Port Townsend.

A generalist species, Douglas fir grows in a wide range of habitats and assumes a wide range of identities. Like many tree species, size and age are poorly correlated in Douglas fir. It can become a large tree in just a few decades, or grow for centuries and still remain small (Figure 39).

The wood of Douglas fir is considered intermediate in terms of decay resistance. Species such as western redcedar or coast redwood *(Sequoia sempervirens)* are far

Figure 39. Poor correlation between size and age in Douglas fir. Left: 80 year-old tree growing on a productive site in the Willapa Hills is already 130 cm in diameter. Right: 400 year-old trees on a poor site in the south Cascades. Center tree is only 61 cm in diameter.

more decay resistant, while Sitka spruce or western hemlock are far less resistant. Decay resistance helps this species live to great age; trees 600-800 years old are not uncommon in certain parts of its range with long fire return intervals. Trees 1,000 years or older have been recorded from several parts of its range, including several individuals between 1,300 and 1,400 years old.

Certain characteristics of Douglas fir change predictably during its lifespan, including bark characteristics, epicormic branching in the lower crown, and tree shape and crown form. The next sections will examine these in detail.

Bark characteristics

Douglas fir is probably the most fire-resistant of all the trees native to western Washington, due largely to the protective bark that it develops as it ages. Old trees have very coarse and rugged bark, which occasionally can reach a thickness of 35 cm. The thin bark of young trees begins to thicken and develop vertical fissures as trees mature. For the first 100-200 years, the bark is hard and boney, and usually brown to gray (Figure 40). At some locations within western Washington, crustose lichens or mosses may adorn the bark at this stage. This is the most common

Figure 40. Bark of two trees from the south Cascades. Left: 100 years. Right: 150 Years.

condition of many of our second-growth forests, whether they developed naturally or following harvest (Figure 41). Even on productive sites, where Douglas fir trees can become very large at maturity, the characteristic younger bark appearance remains (Figure 42).

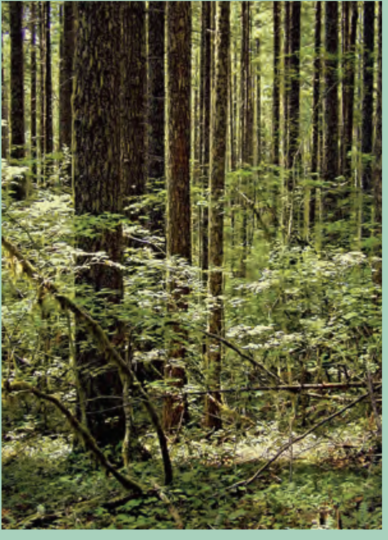


Figure 41. The 1902 Yacolt Burn stand. The hard, boney bark of the densely-stocked stand is evident. Crustose and fruticose lichens adorn the bark.

Figure 42. A 170 year-old stand in the Hoh Rain Forest. Trees are very large for their age, but still have the hard bark of a mature stand. Mosses, rather than lichens, grow on the bark.

It is often difficult to assess the ages of trees in late maturity and in the vertical diversification phase. At the stand level, all of the characteristics of an old-growth forest may be present, including large trees, logs, snags, and a diversity of canopy heights within the western hemlock community (Figures 43 and 44). With the exception of the forest floor bryophytes, all of the green in Figure 43 is hemlock foliage, even though the view of trunks is completely dominated by Douglas fir. These trees are 55-70 m tall, and they have very little foliage below 30 m. Even these large Douglas firs share many characteristics with younger trees, including crown characteristics and youthful bark. The colorful, flakey bark of older trees begins to appear near the tree base, which is what people see when walking

Figure 43. A 280 year-old stand at Mount Rainier National Park. The bark is becoming more colorful and flaky near the base of the tree, but branch wounds are still evident.

Figure 44. A 330 year-old stand in the south Cascades. Colorful, flaky bark extends up the stem; branch wounds no longer evident. Tree in front center is a western hemlock.

around in such a forest. An inspection of the tree bole, however, reveals that the harder bark of a younger tree is still present for most of the height of the tree.

Bark grows outward from the cambium; wood is formed on the inside of the cambium. As the tree grows, new bark forms underneath older bark, forcing it outward. The bark develops fissures in some trees as it expands, since the outer layers of bark were formed when the tree diameter was smaller. On trees with thick bark, the outermost bark is the oldest (Figure 45). Thin barked trees either do not make very much bark each year (alders) or have bark that exfoliates regularly (spruces). Douglas fir produces large amounts of bark which it retains it for a long time. This is characteristic of many fire-resistant tree species. Many older Douglas firs in the Puget Trough have charcoal on their outer bark, an indication that they survived a previous bout with fire (Figure 46).

The final stage of bark development in Douglas fir is characterized by the development of the colorful papery bark of an ancient tree (Figure 36, Page 50).

Figure 45. Close up of a 250+ year-old tree in the Puget Trough. Note thick bark but the color is still the brownish-gray of youth. On a few of the outermost bark flakes, the smooth, juvenile bark has yet to be shed.

Figure 46. A 300+ year-old tree in the Puget Trough. The hard, boney bark of youth is now completely vanished and colorful flakey bark is beginning to appear. Also note the charcoal—which often indicates the presence of more than one age class of Douglas fir.

At this stage the bark can take on many different appearances, depending on exposure, lean, and neighboring trees. Since it is soft and papery, it can easily come off in sheets, as illustrated by the bark on a leaning tree. Over the centuries, small branches, leaves, and other small bits of debris are continually shed from the canopy during storms or other events. On a leaning tree, the upper surface of the bark is exposed to this constant rain of debris, gradually sloughing off the outermost ridges of bark and creating a smooth surface (Figure 47). The tree is not damaged by this process—only the outermost ridges of bark, produced centuries earlier, are removed. The hard bark of youth is not always shed when the softer, papery bark is produced. On protected locations, such as on the underside of a leaning tree, the bark can remain very thick (Figures 47 and 48).

Lower crown characteristics

The growth of Douglas fir is whorl-based, like that of many conifers. Whorl-based growth occurs at the end of the growing season when the terminal leader

Figure 47. Leaning 600+ year-old tree displays the two major bark types on old Douglas firs. The protected side has very thick bark from centuries of accumulation. The exposed side is smooth. It still has plenty of thickness to protect the tree, it has just lost the outermost ridges.

Figure 48. The protected side of a very large tree showing the 30+ cm bark thickness that they can occasionally obtain.

produces several buds at the tip. One of these buds will be the new terminal leader for the next growing season; the remainder will be branches. Pines, firs, spruces, and Douglas firs all share this pattern (Figure 49). Since the original branches are formed at the terminal leader, their pith is directly connected to the pith of the trunk. The trunk has virtually no diameter when this occurs; hence original branches remain perpendicular to the trunk, even as the trunk gets larger. Since this pattern repeats every year, the distance between whorls corresponds to one year of tree growth. Trees that maintain this morphology are termed **model conforming**, since they are following their architectural model of growth.

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 typical bark (Figure 50; Figure 39, Page 52—left). If shading occurs rapidly and many branches die at once, these stubs may be visible in groups for many years, radiating around the stem (Figure 51). Ultimately, these will also drop off and their presence will be masked years later by the continually expanding bark. The complete masking of these patterns, however, may take anywhere from 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 occur, such as the opening up of the canopy during maturation, epicormic branches may begin to form at some of these old wounds.

Since epicormic branches start from dormant buds located on the cambium on the outside of the trunk,

Figure 49. Whorl-based growth. Easily visible behind Karl are whorls of 4-6 branches coming out of the tree at the same height. This pattern is repeated every 80 cm or so in this tree, which was the annual height growth of the tree when these were formed.

Figure 50. Whorls of branch wounds still visible below the main crown in this 150+ year-old tree.

Figure 51. Stubs from dead branches being retained below the main crown in this 200+ year-old tree.

their growth is not restricted to be perpendicular to the bole. Indeed, since these new branches are responding to increased light levels, they will often grow every which way, and may be completely tangential to the trunk (Figure 52). As light conditions in the lower crown improve due to further canopy openings, more and more epicormic branches may be produced. Trees at late maturity or in the vertical diversification phase are often composed of an upper crown of original branches and a lower crown composed of the stubs of dead original branches surrounded by many younger epicormic branches (Figure 53).

Figure 52. Epicormic branches in the lower crown of a 250+ year old tree showing the haphazard and often tangential direction they take upon leaving the trunk.

Figure 53. Lower crown of a 200+ year-old tree showing large original branches at the top of the picture and epicormic branches at the crown base.

Since it is uncommon for very old trees to grow appreciably in height, they do not produce any more original branches. Instead, existing branches, either original or epicormic, are maintained through the process of within-branch epicormic shoot production. This process occurs at the branch level, not the tree level. The individual branches can reach massive proportions in these old trees (Figure 54), often producing secondary trunks of their own (Figure 55).

Figure 54. A massive, radiating epicormic branch system on a giant tree.

Figure 55. A small secondary trunk emerging from a large epicormic branch system.

Crown form and tree vigor

As a Douglas fir tree ages, it transforms itself from a simple, whorl-based growth form, to a highly individualistic shape. The individuality is due in part to the long lifespan of the species. As time proceeds, 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 unique.

In homage to the ponderosa pine crown classes developed by Keen (1943), crown profiles of Douglas fir at four ages (1–4) and four vigor classes (A–D) for western Washington forests are presented in Figure 56. Trees depicted at the left of the drawings (A classes) are the most vigorous, with decreasing vigor proceeding to the right. These are presented to a unified scale in Figure 56, and on the following pages are at different scales with approximate heights and ages for the four series. Not all of the trees in one series will make it to the next series. For example, competition-based mortality will ensure that most of trees in classes 1C and 1D do not make it to the next stage.

Vigor can be thought of as how much leaf mass there is compared to how much respiring tissue the tree has. Class A trees all have large amounts of leaf mass and

Figure 56. Crown form and tree vigor. The Douglas firs depicted are idealized forms representing four age classes (1-4) and four vigor classes (A-D) in western Washington. The 28 trees are all at the same scale. On the following pages the four age classes are presented individually, with scales added.

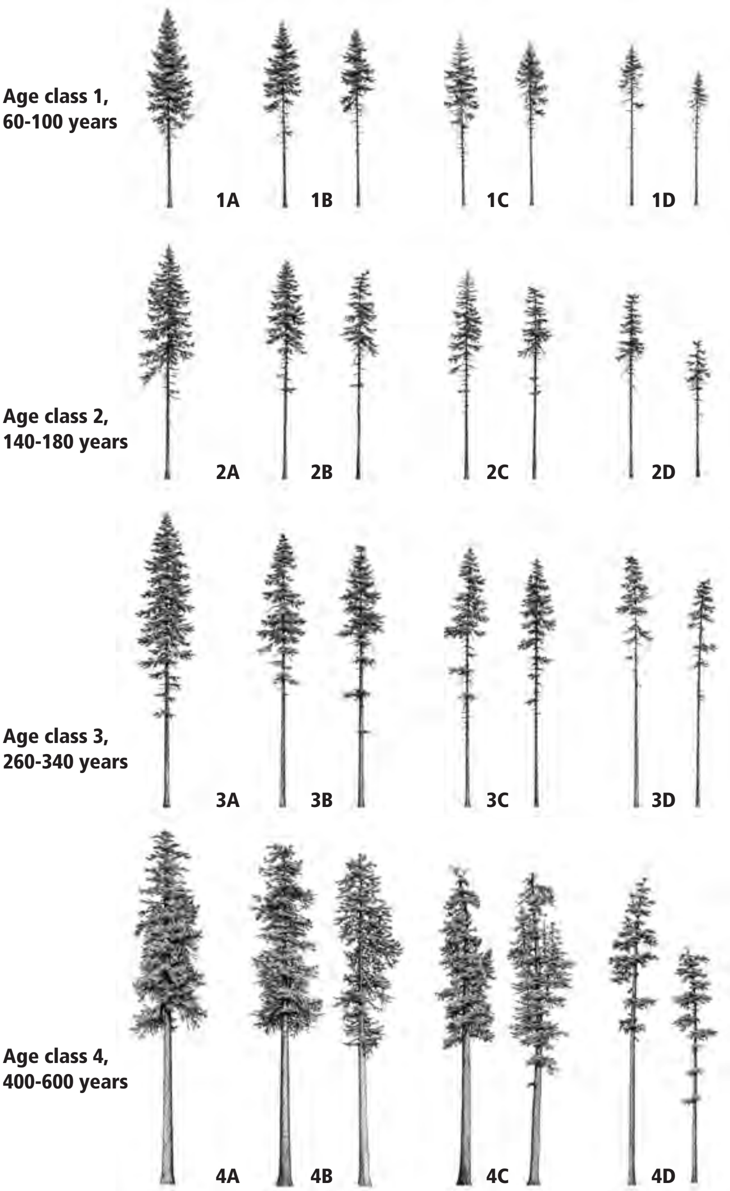
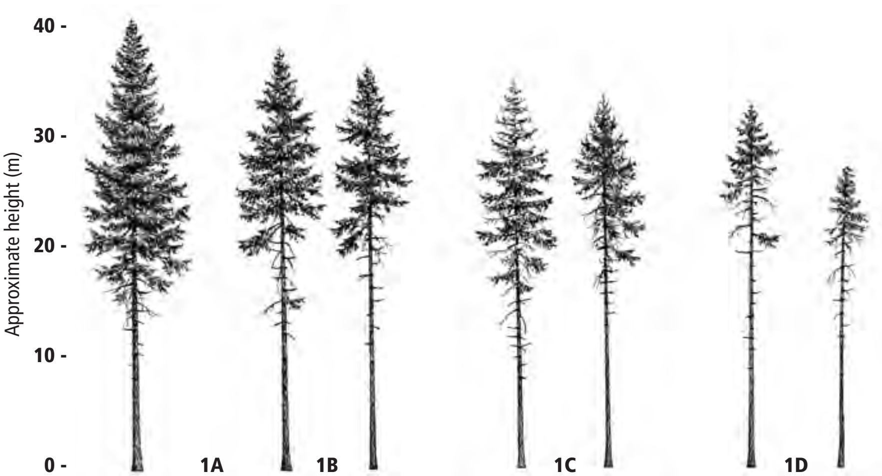
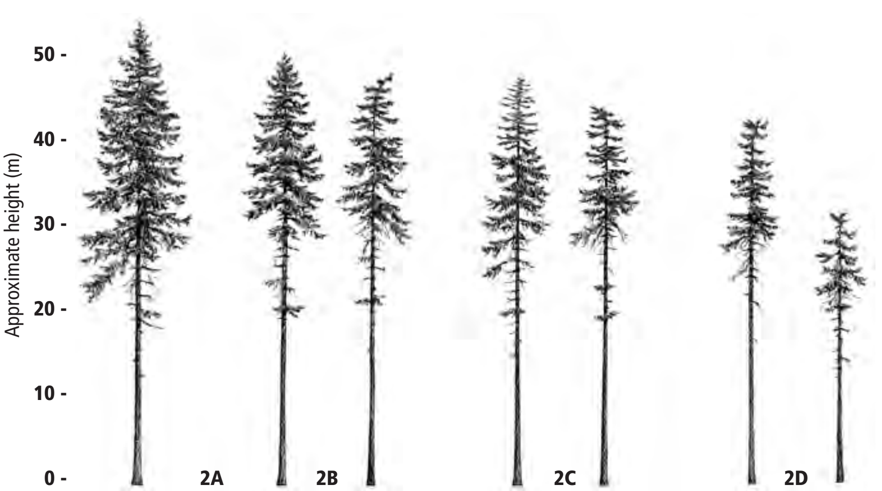


Figure 56 (continued).

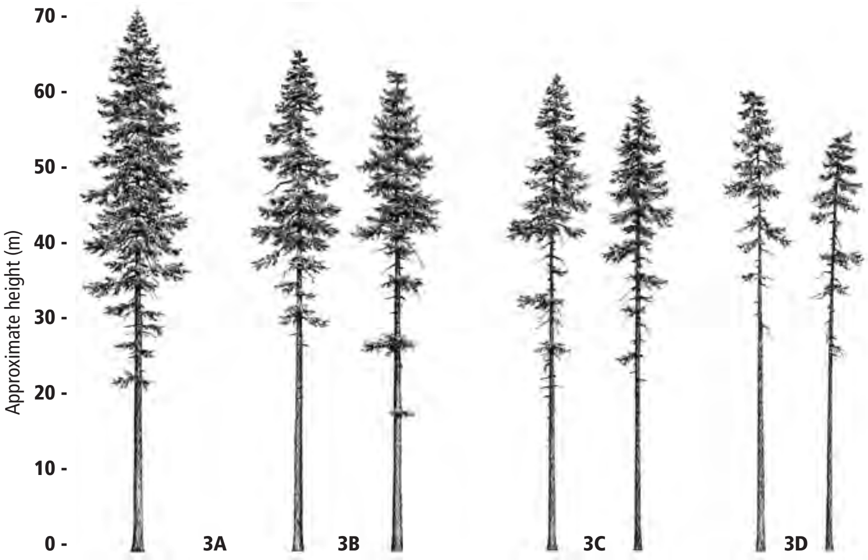
Age class 1, 60-100 years



Age class 2, 140-180 years



Age class 3, 260-340 years



Age class 4, 400-600 years

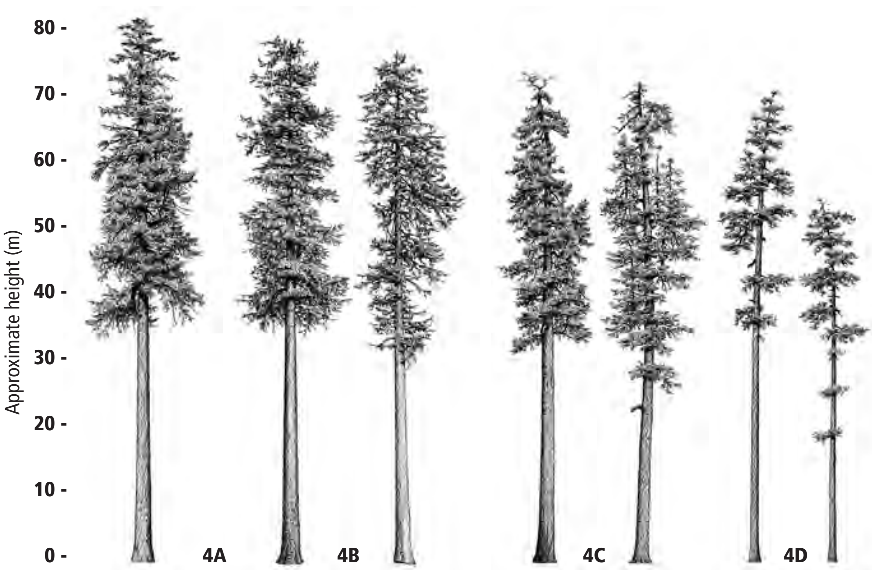
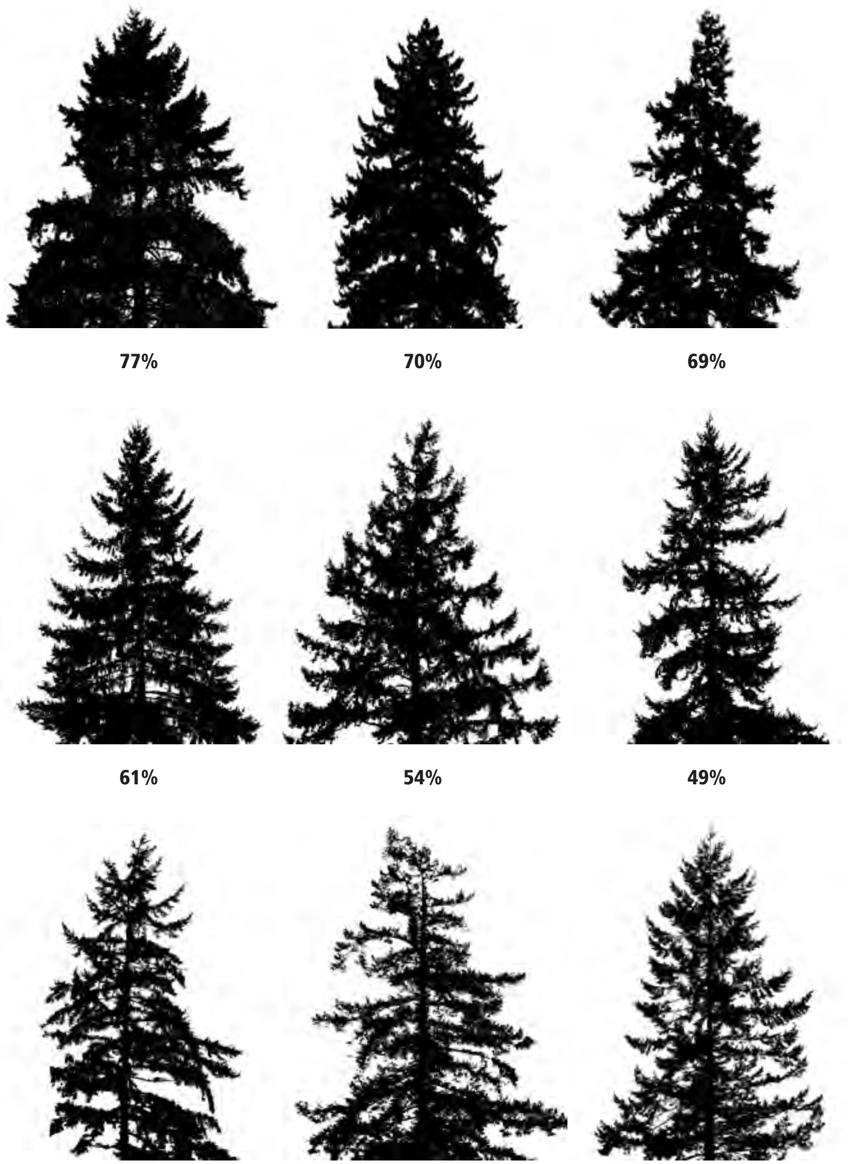


Figure 57. Crown opacity. An indirect measure of tree vigor.
Numbers represent the percentage of sky that is blocked by the crown silhouette.
Low numbers represent trees in decline that will probably not last long.



Douglas fir

68%

66%

48%

47%

30%

16%

represent rapidly growing trees. In contrast, class D trees have low amounts of foliage and thus will probably not be able to sustain the amount of respiring tissue of all of their leaves, roots, and cambium.

Leaf mass is difficult to quantify, but it is related to the amount of sapwood area in the trunk, since this is the main transport of water and nutrients up from the soil. The density of the crown is also correlated with the amount of foliage. Crown opacity is a measure of the amount of sky that is blocked by the silhouette of a crown, and is another measure of tree vigor (Figure 57, previous pages).

Rating system for determining general age of individual Douglas fir trees

Choose one score from each category and sum scores to estimate tree age.
Key was designed for legacy trees specifically, but may also be useful in estimating approximate age range of main overstory cohorts.

Bark condition of lower stem, tree base within ~6 m (20 feet) of ground	**Score**
Hard, boney bark with small fissures	0
Hard bark with deep fissures	1
Hard bark with charcoal present	2
Soft, flaky bark with deep fissures	2
Flaky bark with charcoal present	3
Knot indicators, main stem below live crown	
Branch stubs present along majority of trunk	0
Old knot/whorl indicators visible (branch stubs may still be present immediately below live crown)	1
No knot/whorl indicators visible (branch stubs may still be present immediately below live crown)	2
Lower crown indicators	
No epicormic branches	0
Small epicormic branches present	1
Large and/or gnarly epicormic branches present	2

Scoring Key

<2	~35–80 years
2–3	~70–160 years
4–5	~140–240 years
>5	~210+ years

Age ranges are approximate. Note that age ranges are wide since growth can vary depending on factors such as site productivity, elevation, stand structure, or disturbance history.

Longevity and death

A Douglas fir tree that has survived the myriad agents of mortality (root disease, stem rot, bark beetles, etc.) to become a canopy tree in an old-growth forest must still contend with the velvet top fungus *(Phaeolus schweinitzii)*. This slow-growing fungus is often overlooked by many foresters, because it can often take 250-300 years before it makes its presence known (Figure 58). For stands of this age or older, it is the primary cause of Douglas fir mortality. This fungus causes decay in the upper roots and lower stem of old trees, weakening them. The sapwood of the tree is unaffected; many infected trees appear healthy and vigorous. Structurally, however, they have been compromised and a minor windstorm is often the final blow. Tip-ups with small root plates or snapped boles near the base indicate death caused by velvet top fungus (Figure 59).

Figure 58. Conks of the velvet top fungus.

Figure 59. Death by velvet top fungus. Top: The tip-up of a 361 cm diameter Douglas fir with a very small root wad—a sign of root rot. Lower images are of trees shattering near the base due to heart rot. The lower left is of a 323 cm diameter tree, near Lake Crescent and to the right is a 408 cm diameter tree at Quinault Lake—both on the Olympic Peninsula. Both show the classic **barber chair** stump—healthy sapwood splintering around the decayed heartwood.

Sitka spruce *(Picea sitchensis)*

Sitka spruce is a maritime species, growing along the outer coast from Cape Mendocino in northern California to the Aleutian Island chain of Alaska. Within this range it seldom strays very far from salt water (Figure 60). A tolerance for salt spray combined with a wood that has among the highest known strength/weight ratios allows it to thrive in the outer coastal environment (Figure 61, next page). The species achieves its best growth in western Washington, where it is found further from the sea than anywhere else in its range.

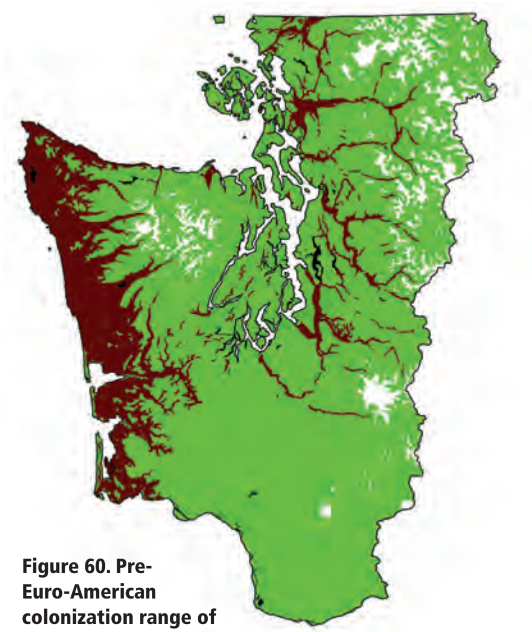


Figure 60. Pre-Euro-American colonization range of Sitka spruce in western Washington (red color).

Of the major tree species found in western Washington, Sitka spruce is the one most restricted to low elevations. It can be found away from the coastal environment only along the floodplains of large, ocean-flowing rivers (Figure 62). The combination of medium shade tolerance and its preference for well watered, productive soils allows it to grow only as far as 80 km from saltwater. Forests within the Sitka spruce zone have some of the highest forest productivities reported for the planet (Figure 63). It is so restricted to these productive, coastal sites that its presence is the basis for identifying one of our major forest zones (Figure 3). As a site-sensitive species, Sitka spruce is unable to establish in poor or dry environments—as illustrated by its absence from the slope forests adjacent to the river floodplains of the Cascade and Olympic Mountains.

Figure 61. Left: Windswept Sitka spruce trees adorn the outer coast from northern California to the Aleutian Islands of Alaska. **Right: Trees along the ocean front often develop strange forms** as a result of nearly constant exposure to high winds, even inside the protection of a forest.

Figure 62. Large floodplains in western Washington provide ideal conditions for Sitka spruce to dominate, such as on the South Fork Hoh River on the Olympic Peninsula.

Figure 63. Rainforests dominated by Sitka spruce and western hemlock have some of the highest growth rates known—often producing record-sized trees in just two or three centuries.

Along with Douglas fir, Sitka spruce is the other giant member of the pine family. The tallest and largest known living trees are nearly the same size for both species (Douglas fir: 99.5 m, 349 m^3; Sitka spruce: 100.2 m, 337 m^3) The largest known diameter Sitka spruce (539 cm) is the largest recorded for any member of the pine family. It is odd that Sitka spruce and Douglas fir can be so similar in so many ways, yet could not be more different in others.

Early growth patterns

Perhaps the greatest difference between these two species is their seeding characteristics. While of similar size, the seed requirements of each species are completely different. The mineral soil of sand or ash preferred by Douglas fir is a poor seed bed for spruce. It instead prefers elevated organic substrates such as logs or stumps. In the moist, coastal environments where it grows, the forest floor is often a dense carpet of bryophytes and other plants. The thickness and competition these provide presents a difficult obstacle for the tiny seed to overcome. A log, however, especially one freshly fallen, provides a wonderful organic substrate that is (at least temporarily) free from this competition (Figure 64). Lines of trees are often visible in some of these coastal forests where competition on the forest floor is high (Figure 65). As the trees mature they form what is known as a **forest colonnade** (Figure 66).

Figure 64. Several groups of spruce seedlings can be seen colonizing wood in this grassy glade in the rainforest.

Figure 65. Young Sitka spruce trees growing in lines reveal that they started their lives on a log.

Figure 66. A forest colonnade. Mature trees in a row with interwoven roots is sometimes the only evidence of the former location of a nurse-log.

Life is precarious for a seedling that starts on an elevated substrate. The bark of a decaying log may slough off, taking the young plants with it. If the log decays quickly, the young seedling might not be able to get roots into the ground in time to support its own weight. To survive, the tree must ultimately be able to support its own weight, and the roots that were in the log will become stems when the log disappears (Figure 67). If the log or stump on which the young spruce started its life was very large, huge buttresses may be the only evidence centuries later of the tree's origin (Figure 68).

Since Sitka spruce is a site sensitive species, variation in growth rates between trees is far less pronounced than for Douglas fir. Consequently, size and age are more closely correlated for Sitka spruce. This relationship holds true only for height and total volume, however, not for the diameter at breast height (DBH). Buttresses are highly variable and exhibit a considerable influence on DBH, depending on the size of the stump or log on which the spruce germinated. In older stands, measuring the DBH of a Sitka spruce amounts to nothing more than measuring buttress roots, a measurement with limited usefulness. As an extreme example, how do you measure the DBH on the Quinault Lake Spruce (Figure 69)?

Figure 67. If a spruce started on a very large log, the resulting tree can often have a bizarrely shaped root system.

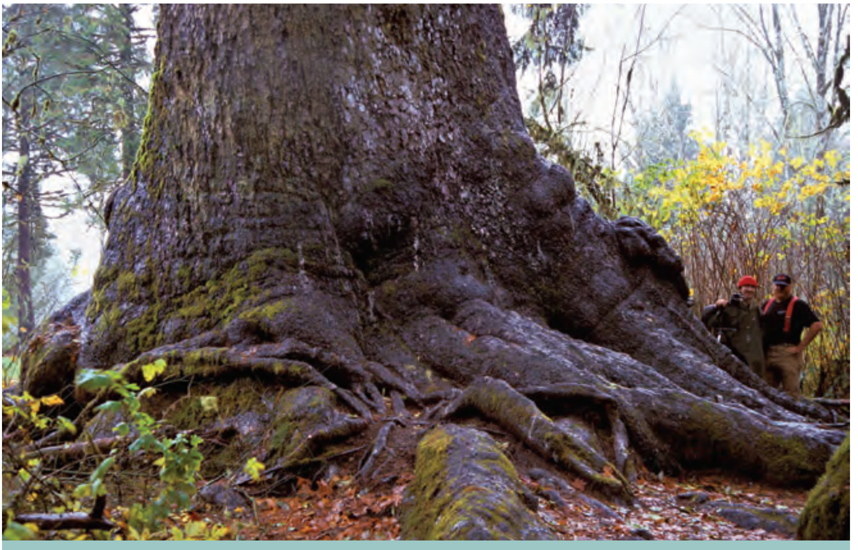


Figure 68. The Lake Quinault Spruce. The huge buttresses found on trees such as this indicate that they started life on a very large stump or log.

Figure 69. The Lake Quinault Spruce. The red line indicates where DBH would be measured. How useful is such a measurement?

Patterns in mature trees

Many of the clues used to determine the age or successional stage of a Douglas fir do not apply to Sitka spruce. The textural patterns of the bark, for example, do not change much over time. The bark flakes that develop on trees during their first century of life continue, relatively unchanged, throughout the remainder of their life (Figure 70).

The pattern of epicormic branching in mature trees is also not as consistent as for Douglas fir. While Sitka spruce is every bit as capable as Douglas fir in producing epicormic branches, it often

Figure 70. Bark characteristics do not change much with Sitka spruce. The left photo shows small trees near the coast that have similar bark flakes to the 450 cm tree in the right photo.

does not need to. Two primary reasons account for this: Sitka spruce is slightly more shade-tolerant than Douglas fir; and often grows in less dense stands. The loss of original branches and the lifting of the crown during the biomass accumulation/competitive exclusion phase is a major pattern in densely-stocked Douglas fir stands—such a pattern is often less of a factor in many Sitka spruce stands. This is particularly true in the floodplain forests where spruce is often growing up through an alder canopy, rather than a dense stand of other spruces. Since alders are leafless for half of the year, some of the spruces will keep many of their original branches and thus maintain deeper crowns (Figure 71).

Even in the older Sitka spruce/western hemlock stands growing on floodplains, stand densities are much lower than their Douglas fir/western hemlock counterparts. This may be due in part to a shared dominance with bigleaf maple, and to a lesser degree, alder and cottonwood. Moreover, heavy grazing by deer and elk is common in many spruce floodplain forests and influences understory vegetation and seedling recruitment. Chronic, small-scale disturbances created by wind and/or flooding are common, as are the shorter life-spans of most of the tree species.

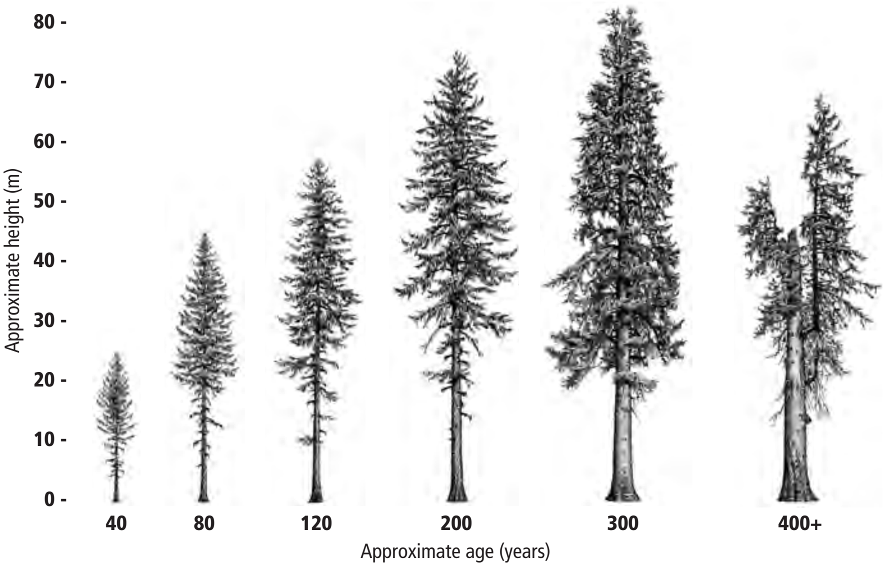


Figure 71. Changes in crown form in Sitka spruce over time. Note that despite a few epicormic branches in the lower crown, trees retain a simple architecture for the first two centuries. Decay puts an upper limit on longevity.

Figure 72. Upper canopy of a 250+ year-old spruce stand in Olympic National Park. Many of the trees still retain the branch structures of young trees.

The strength of Sitka spruce wood makes it common for trees to live well into their third century with the simple architecture of their youth (Figure 72). By then, most of their height growth has been completed. Wind, decay, and the exposure to the elements begin to take their toll, creating the individuality seen in old spruce crowns (Figure 73).

Longevity and death

The pattern of slowed height growth in older stands is common to both Sitka spruce and Douglas fir. While the ultimate height and size of Sitka spruce and Douglas fir are similar, Sitka spruce achieves these dimensions in about half the time. This is advantageous for the spruce, since its lifespan is about half that of Douglas fir. On productive sites, a Sitka spruce has never been successfully aged to over 400 years, making it one of the shortest-lived of all western conifers. This may seem strange considering it is one of the largest trees in North America. Individual trees, such as the Quinault Lake Spruce, certainly live slightly beyond this but they cannot be aged by non-destructive methods. Even if cut, their centers would likely be rotten and hollow. Sitka spruce, like Douglas fir, is susceptible to velvet top fungus. Giant spruces are frequently killed by this disease after only 250-350 years (Figure 74). Trees that have their tops broken during storm events will also begin to decay from the top down, often breaking off in sections (Figure 75).

Figure 73. Upper crown profiles of several 300+ year-old spruces. The simple growth pattern of youth is still detectable in a few trees, but their individuality and idiosyncrasies become apparent.

Figure 74. Death by velvet top fungus. The two classic cases are the fallen trunk, full of rot, with a small root wad (left), or the splintered stump, with sapwood still intact (right).

Figure 75. The rotten top of a 400+ year-old spruce snapped off in a violent winter storm, only to impale itself in the ground a full 20 m away from its base.

Noble Fir *(Abies procera)*

Within western Washington, noble fir is a subalpine species largely restricted to the south Cascades (Figure 76). A disjunct population also occurs at the higher elevations of the Willapa Hills.

Noble fir is a very popular ornamental tree throughout the Pacific Northwest and is considered a premiere Christmas tree. Some of its beauty is attributed to the color of the foliage (Figure 16, left), which is derived from stomatal bands on both the upper and lower surfaces of the needles. Noble fir is the tallest (89.9 m tall) and largest (290 cm diameter, 161 m^3 volume) recorded member of the true firs (genus *Abies*). It also can form pure, incredibly dense stands that can rival Douglas fir stands in total volume (Figure 77).

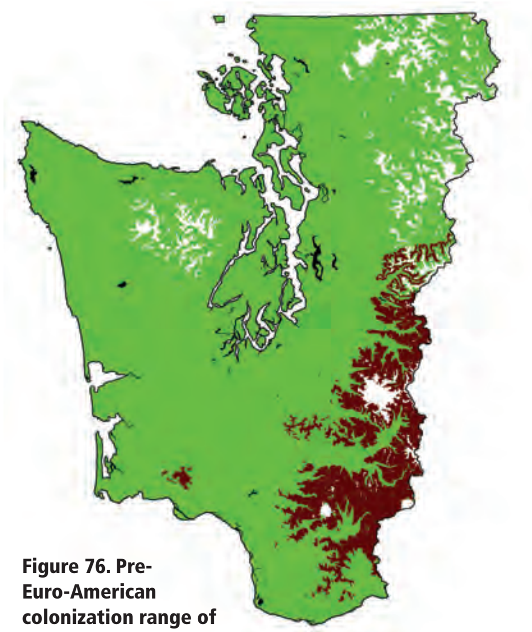


Figure 76. Pre-Euro-American colonization range of noble fir in western Washington (red color).

In many ecological aspects, noble fir shares more in common with Douglas fir than other members of its own genus. Unlike most western true firs, noble fir is a shade-intolerant, pioneer tree that can regenerate abundantly after a severe disturbance. An important physical adaptation is its large cones, which are sparsely produced at the top of trees at maturity (Figure 78, Figure 16, left). These cones contain very large seeds, which can provide a young sprout with nutrients for up to a year while its roots are trying to find a favorable spot to grow.

Figure 77. One of the densest forests in the Pacific Northwest is, surprisingly, *not* a Douglas fir forest, but this noble fir forest at the Mount Saint Helens National Volcanic Monument. This forest contained 3126 m^3/ha of wood volume—64% of which was noble fir.

Figure 78. Noble fir cones, while not prolific, are produced near the top of the tree, providing the best opportunity for seed dispersal. Each large seed stands a better chance of survival than the multitude of tiny seed produced by a tree such as western hemlock.

Figure 79. A stunted old noble fir growing at 1500 m timberline in the south Cascades. Mount Saint Helens is visible in the distance.

Like many other true firs, the young seedlings can be very stiff and sturdy, not needing an elevated surface on which to grow. This characteristic allows noble firs to be very successful in areas with deep winter snowpacks (Figure 79). Four to five months of debris can accumulate atop the snowpack found in high elevation forests, smothering or crushing the small seedlings of species such as Douglas fir during spring snowmelt. Noble fir seedlings, even young ones, will often survive such abuse. While large seeds commonly limit seed dispersal distances, the snowy and icy environment of high-elevations can allow seeds to blow around to sometimes great distances (Figure 80).

Like Douglas fir, noble fir can regenerate quite abundantly after a severe fire (Figure 81). This quality, combined with the ability to withstand a deep snowpack, makes noble fir ideal for high-elevation forestry applications. Noble fir is the tree of choice wherever the replanting of Douglas fir is limited by snowpack. The wood of true firs is generally considered soft and weak, lacking the strength and decay resistance of Douglas fir or western larch.

Figure 80. A small noble fir seedling in the middle of the pumice plain on the northeast section of Mount Saint Helens. The nearest mature noble fir to this tree is more than 5 km distant.

As such, the wood is often used for low-grade lumber products or pulp. Noble fir, however, produces a stronger and more durable wood, with a very high strength-to-weight ratio. For this reason, noble fir along with Sitka spruce was used for airplane and ladder construction. When early foresters discovered that noble fir did not have the poor quality wood associated with true firs, they called it larch, so that people would buy the wood. Both Oregon and Washington have a Larch Mountain, which was named for the noble fir growing atop them.

Like many other true firs, noble fir maintains a very symmetrical shape to its crown well into its second century. It also rigidly adheres to a whorl-based architecture. Young trees often appear perfectly symmetrical. Over time, exposure to wind and elements transforms the symmetrical crowns into the more individualistic crowns typical of older forests (Figure 82). Many members of the pine family, most notably Douglas fir, continually replace their foliage through epicormic branching. Minor crown damage, from a windstorm for example, is quickly replaced by new foliage. The ability of noble fir to produce epicormic shoots or branches appears to be extremely limited; wind-damaged trees rarely recover. This, combined with susceptibility to root rots, ultimately limits the longevity of noble fir. Noble fir is abundant in old growth forests with ages up to 300, after which there is a rapid decline. A 400 year-old forest will have very few noble firs remaining, most of which will be declining.

Figure 81. Two views of pure noble fir stands. The upper photo shows a pure stand of noble fir (bluish crowns in upper left of photo), that came in very densely after the 1902 Yacolt Burn. Note the scattered noble fir trees in the bottom right of the photo, which is an unburned section of older forrest. The bottom photo is the interior of a stand during the height of the biomass accumulation/competitive exclusion phase of stand development—note the lack of vegetation in the understory. Also note the white, lichen-covered trunks are just beginning to develop the cracks that lead to bark appearance of mature trees.

Credit: Jerry Franklin

Figure 82. Mature crowns of Noble fir begin to loose their symmetrical, model-conforming crowns of youth.

Western hemlock *(Tsuga heterophylla)*

As one of our most shade-tolerant tree species, western hemlock is abundant in nearly all old forests in western Washington (Figure 83). Although it is often overlooked when growing with its much larger associates—Douglas fir, Sitka spruce, or western redcedar—western hemlock can occasionally reach impressive dimensions. It has been recorded to 83.3 m tall, 290 cm in diameter, and with a volume of 121 m^3 (Figure 11). Even though it only represents a fraction of the wood volume in old-growth forests, it nearly always represents more than half of the foliage (Figure 84). Accordingly, western hemlock controls the understory light environment in these old stands. A mature hemlock tree casts a very dense shade, only allowing shade-tolerant plants to persist.

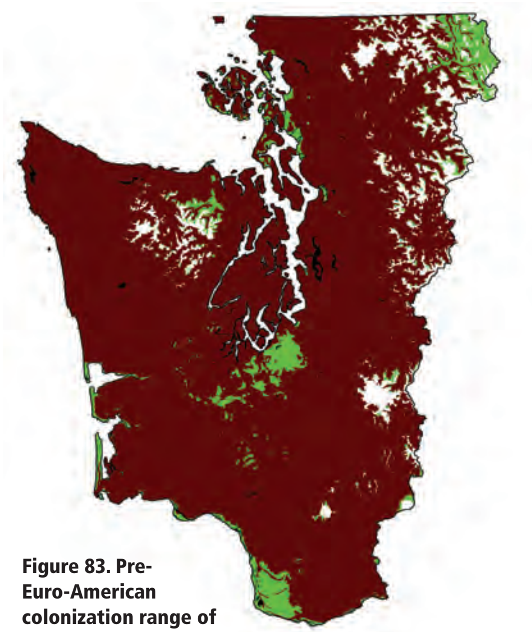


Figure 83. Pre-Euro-American colonization range of western hemlock in western Washington (red color).

Like Sitka spruce, western hemlock seedlings are mostly limited to elevated woody substrates (Figure 85). Large logs can present the same problems for a young hemlock seedling as for spruce, and successful seedlings can form similar rows of trees as they grow along the length of a log (Figure 86).

Besides stumps and logs, a third woody substrate exists that Sitka spruce does not typically exploit. Large Douglas fir trees often have a wide skirt of bark that forms at their base (Figure 87). Douglas firs produce large amounts of bark during their lifetime, which accumulates at the base of the tree as it sloughs off.

Figure 84. An old-growth Douglas fir/western hemlock stand at Mount Rainier National Park. Apart from some moss on the branches and a few ferns on the forest floor, all of the green in the photo is western hemlock foliage.

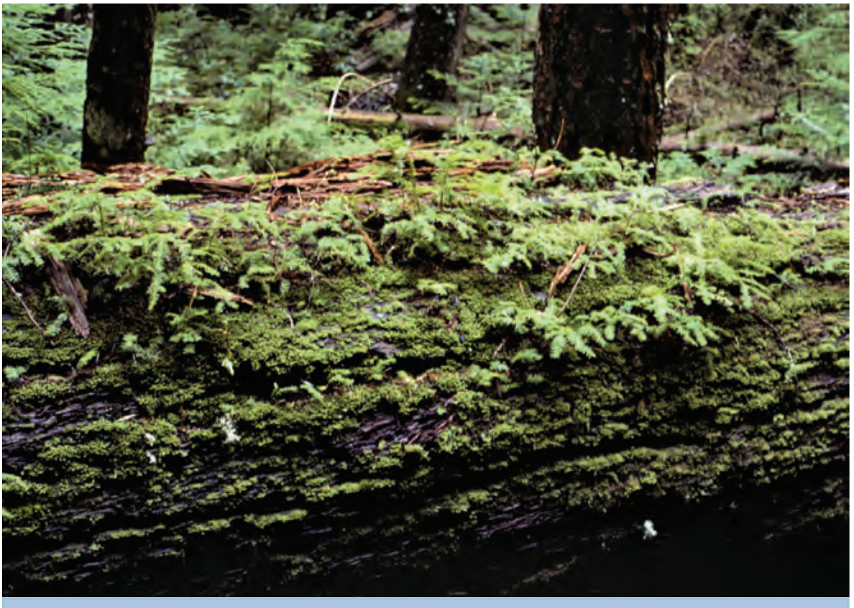


Figure 85. A Douglas fir log covered with moss and abundant western hemlock seedlings.

Figure 86. Western hemlock seedlings colonizing an open area with the help of a nurse log.

Figure 87. The common sight of a large skirt of bark at the base of an old Douglas fir tree. Note hemlock seedlings using bark as a growing substrate.

Because it is elevated and continually accumulating, it has reduced competition from other plants and roots. Bark decays very slowly, so this skirt of organic substrate makes the perfect growing medium for a young hemlock seedling. In old-growth Douglas fir forests it is common to see a big old tree with its **minion**—groups of small hemlocks clustered around the tree base (Figure 88).

Even though western hemlock is one of our most shade-tolerant tree species, it still needs a gap or other opening to ascend into the canopy. Like most shade-tolerant tree species, western hemlocks can

Figure 88. Douglas fir *minion.* Western hemlock seedlings growing on shed bark accumulated at the base of the tree.

persist in dark forest understories for decades, even centuries, without growing much (Figure 89). These small, **suppressed** trees often develop an umbrella shape, in an attempt to capture as much light as possible. In many cases, these suppressed trees are often nearly the same age as large hemlocks growing nearby that had better opportunities when younger. If an opening in the canopy occurs, such as when a large tree falls over, the small tree may be able to **release**, responding by increasing its growth in the new light environment. Usually, however, the light gap will be closed by neighboring trees or other trees present in the understory. In most old-growth forests, upper canopy western hemlocks have experienced repeated periods of suppression and release.

Figure 89. A 210 year-old hemlock that is scarcely 2 m tall in the south Cascades. Such suppressed trees form an umbrella shape—producing only a few leaves each year.

Figure 90. A 300 year-old hemlock in a 400+ year-old Douglas fir/western hemlock forest in the south Cascades. The extreme shade-tolerance of this species allows it to maintain its original branches close to the ground.

Many of the clues that reveal the age of Douglas fir trees, such as bark characteristics or epicormic branches, are often absent in western hemlock. Since old western hemlock trees often have bark similar to much younger trees, the bark appearance gives few clues to tree age. Due to western hemlock's high shade tolerance, the branch-pruning seen in Douglas fir may not occur. Epicormic branches are often not present, even in trees several centuries old (Figure 90). Branch size, however, does change predictably through time. Hemlock trees less than 150 years old typically have very small, but numerous, branches (Figure 91). The presence of large-diameter (>10 cm) branches on a western hemlock is usually an indication of an older tree (Figures 90 and 92).

Figure 91. Post-Euro-American colonization hemlocks rarely have branches >10 cm, regardless of trunk size. Wood production is devoted to height growth and trunk enlargement, well into the second century.

Figure 92. Branches >10 cm in diameter usually indicate an older hemlock, regardless of the trunk size.

Hemlocks often do not appear in a stand until the second century, as outlined in the ideal stand development scenario presented earlier. Even at 200 years in many stands, depending on disturbance intensity and proximity to seed sources, hemlocks have yet to grow into the upper canopy. The presence of hemlocks of different sizes in a Douglas fir forest, including canopy trees, is therefore an excellent indication of an old-growth forest.

Even in coastal forests—where western hemlocks can sometimes be the oldest trees—a mixed structure stand will still take considerable time to develop. For example, a coastal stand that is blown over, burned, or clearcut, can come back to a pure hemlock canopy (Figure 14). The same patterns of stand development will occur under the idealized scenario presented earlier, substituting western hemlock for Douglas fir. Vertical diversification will still take time to develop.

Hemlock dwarf mistletoe

A distinctive characteristic—mostly unique to western hemlock in western Washington—are mistletoe infections. Mistletoes are parasitic plants that grow in the canopy of many tree species. The leafy mistletoe popular at Christmastime is a member of the genus *Viscum* found on hardwood trees in Europe. Crowns of our native oak, (*Quercus garryana*), become infected with another leafy mistletoe of the genus *Phoradendron.* In contrast, dwarf mistletoes are small, leafless mistletoes that often infect the twigs in the outer crowns of trees (Figure 93). Many members of the *Pinaceae,* including Douglas fir, western larch, and several of our pine and fir species become infected with dwarf mistletoes of the genus *Arceuthobium.* In western Washington only one species is common: *Arceuthobium tsugense,* which is mostly limited to western hemlock crowns.

Figure 93. A male hemlock dwarf mistletoe plant infecting a branch at 50 m above the ground. Female plants explosively discharge seeds which can occasionally fly 10 m or more away from the parent tree.

These parasitic plants possess a unique 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 10-12 m away from the parent plant. While impressive, this is a limited distance when compared to other mechanisms of seed dispersal. Occasionally the sticky seeds will adhere to a bird and be transported much farther away.

As a parasite, the mistletoe makes use of sugars produced by the host tree, reducing their availability for tree growth. Hormones produced by the mistletoe cause excessive, but deformed growth of the tree in the vicinity of the infection. This often results in broom formation—dense areas of foliage and branches which appear as star-shaped formations on branches (Figure 94).

Because of the relatively slow manner in which this species propagates itself, hemlock dwarf mistletoe is, with some exceptions, generally only found in older forests. The most common exception to this general rule is when infected hemlocks are the residual trees in a developing stand. The mistletoe is in a perfect position to rain down seeds onto the new cohort of trees. This scenario is most common along the coast, in areas where wind was the disturbance agent. After a severe wildfire, the few surviving hemlock trees will not usually persist long enough to infect the next generation of hemlocks, which may not establish for a century or more under the new Douglas fir canopy.

Longevity and death

Throughout much of its range in western Washington, western hemlock will be susceptible to decay fungi and will likely die before reaching 300 years of age. This is true in nearly all forests below 1,000 m in elevation. The tree does not produce decay-resistance extractives in its heartwood, and the warmth and moisture of these low elevation sites is ideal for fungal growth.

Both Douglas fir and western hemlock are subject to a wide array of different decay fungi, several of which will attack one species and not the other. Particularly on poor sites, one will occasionally encounter sections of an old-growth Douglas fir/western hemlock forest in which all of the Douglas firs have died. In these situations, a limited area of pure hemlock forest might be found (Figure 95).

Figure 94. A mistletoe broom. Hormones within the mistletoe cause excessive growth in the hemlock in the vicinity of the infection. Such dramatic infections are usually only found in old forests.

Figure 95. A section of pure western hemlock within a 400+ year-old Douglas fir/ western hemlock forest. Such sights are usually the result of the Douglas fir being killed off by disease.

Because fungi are limited in their effectiveness at high elevations, such as the upper Pacific silver fir or mountain hemlock zones, western hemlock in these locations routinely reaches ages of 800+ years, even up to 1,200 years (Figure 96, Figure 11).

Extremely old western hemlock forests, such as those on the coast or in the North Cascades, are also susceptible to one of our only outbreak insects—the hemlock looper (*Lambdina fiscellaria*). This moth has been known to defoliate small sections of pure hemlock stands from time to time. Given that most old hemlock stands are already infected with hemlock dwarf mistletoe, the results of a looper infestation can be particularly unsightly (Figure 97).

Figure 96. A section of forest that is several thousand years-old near Glacier Peak in the north Cascades. If the frequent avalanches do not kill the trees, many can survive for more than 1000 years.

Figure 97. A pure hemlock stand in the north Cascades killed by the hemlock looper. The added stress of these dramatic mistletoe infections probably made the trees more susceptible to the defoliation.

Western redcedar *(Thuja plicata)*

Western redcedar might be considered the long distance runner of our native trees. It persists in small numbers for the first several hundred years and only shows its stamina with great age. Like western hemlock, redcedar is very shade tolerant and often does not appear in Douglas fir forests until maturity. Western redcedar is the largest tree in the Pacific Northwest, with living individuals recorded up to 599 cm in diameter and 500 m^3 of volume. With the exception of yellow cedar, western red-cedar is the longest lived tree species in western Washington. Trees over 1,500 years of age have been recorded. Older trees probably exist, but are impossible to date due to their large sizes and often hollow centers. Western redcedar has a very wide ecological amplitude, tolerating a wide range of soil conditions, and grows from sea level to tree line (Figure 98).

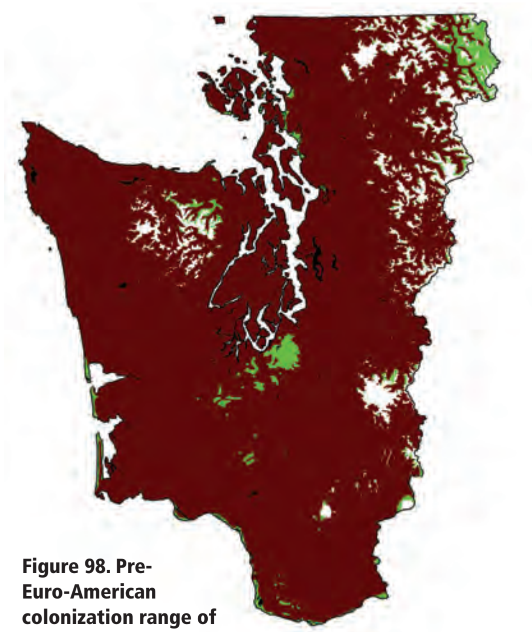


Figure 98. Pre-Euro-American colonization range of western redcedar in western Washington (red color).

Most coniferous trees found in western Washington are members of the pine family. Western redcedar, in contrast, is a member of the cypress family, (*Cupressaceae*). Studies have shown the soils underneath an ancient redcedar are different than those under members of the pine family and influence seedling regeneration though a higher pH. In forests where western hemlock and western redcedar co-occur, seedlings of each species are more abundant under trees of their own species, than under trees of the other. Since western redcedar is such a long-lived species, one would expect its numbers to gradually increase over time.

Figure 99. Away from the coast, pure groves of redcedar are limited to forested wetlands or sections of alluvial forest in the north Cascades, such as this stand from a swamp in the south Cascades.

Figure 100. Extensive stands of nearly pure western redcedar are only found along the coasts of Washington and British Columbia.

This is indeed what happens. Throughout most of western Washington, however, and particularly in the Puget Sound or Cascade provinces, forests over 500 years-old are uncommon. With the exception of some swampy areas, western redcedar is a minor component throughout this entire region (Figure 99).

Extensive forests dominated by western redcedar are found only along the coast (Figure 100, Figure 9). The dominance of redcedar in many coastal forests is only partly due to the moisture; it is also due to the great ages of the forests there. There are (or were) extensive forested areas along the coast where 1,000 years or more has passed since the last major fire event (Figure 101). In some of these coastal forests, several thousand years have passed without fire, meaning the stand could be much older than the oldest trees present. No individual trees are that old. Had all of western Washington been kept free of fire for the last 1,500 years, western redcedar would be the dominant tree throughout the region.

Young redcedars' preference for soils already occupied by redcedar is evident in some second-growth forests. Redcedar-dominated second-growth stands are only found on coastal sites that were previously ancient redcedar forests (Figure 102).

Redcedar is also different from members of the pine family in the decay-resistance of its wood. As with other cypress family trees such as coast redwood and yellow cedar, western redcedar has highly decay-resistant wood. It is thus unlike its common associates Sitka spruce or western hemlock, in that it can survive major crown damage. When the top of a spruce or hemlock is blown out, the tree will often be unable to outgrow the incipient decay. A redcedar, in contrast, will resprout new leaders and continue on.

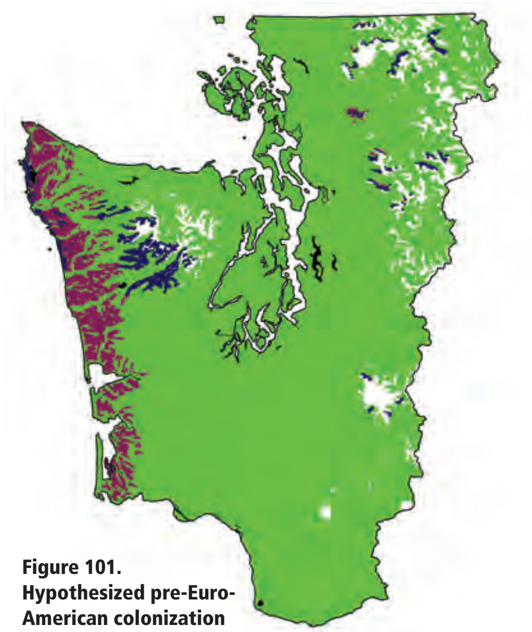


Figure 101. Hypothesized pre-Euro-American colonization locations of 1000+ year-old forests (purple and blue colors). Blue denotes areas where such forests remain intact.

Top die-back is common on redcedar in particularly hot, dry summers. After the die-back, a new leader (or leaders) will develop from an existing branch (or branches) below the dead top. The dead leader often will remain on the tree after this recovery, so that after many centuries of this process, many of these dead tops will be present—giving rise to the term **candelabra top** (Figure 103). In many other tree species, top dieback followed by reiteration from a side branch also occurs, but with different results. In a hemlock or a spruce, for example, the dead top will rot and fall away, so that after several decades the only evidence of the disturbance will be a slight kink in the trunk at the location of the resprout. The redcedar preserves its history of die-back and resprouting, so an ancient tree is a living record of its past.

Figure 102. A young, pure stand of western redcedar that regenerated after a cedar stand was logged.

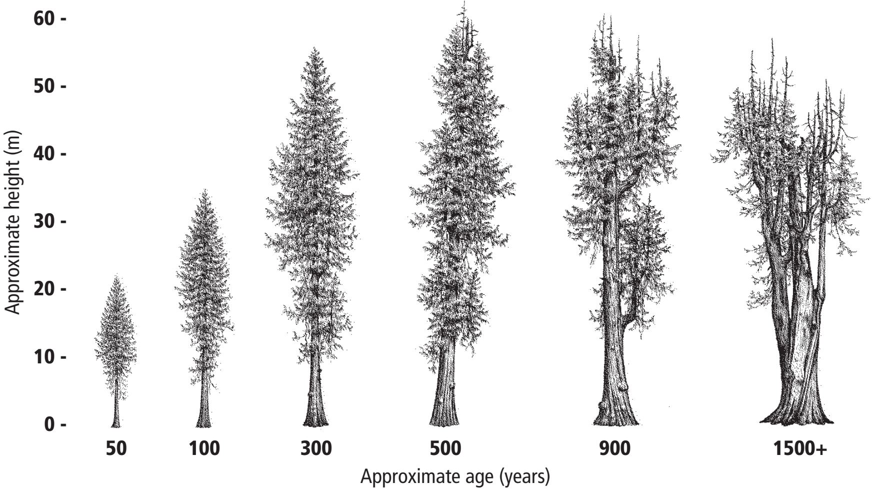


Figure 103. Changes in crown form of western redcedar over time. Note that trees remain relatively simple for the first several centuries—it is only in great age that the individual character and candelabra tops often seen in ancient stands emerge.

Pacific silver fir *(Abies amabilis)*

Like western hemlock, Pacific silver fir is extremely shade-tolerant and is often represented in a variety of size classes in old-growth forests. However, it is less tolerant of warm temperatures and drought, and is more typically restricted to the cooler environments found at higher elevations than western hemlock. An exception is near the coast, where it is commonly found at low elevations (Figure 104). The largest recorded Pacific silver fir grew at only 283 m elevation on the coastal plain of the Olympic Peninsula (237 cm diameter, 63.4 m tall, and 74 m^3 volume).

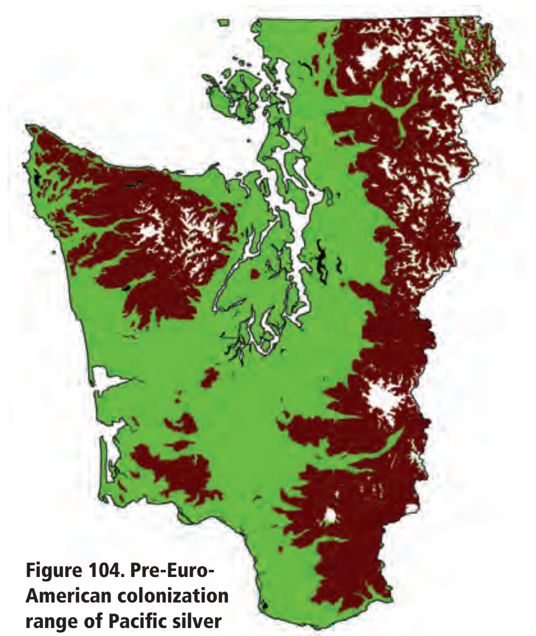


Figure 104. Pre-Euro-American colonization range of Pacific silver fir in western Washington (red color).

The microclimate in the understory of an old-growth forest is heavily moderated by the canopy, being much cooler and moister in the summer and warmer in the winter. Because of this, it is not uncommon to see understory silver firs in portions of the western hemlock zone—places where it is absent or cannot survive in the upper canopy (Figure 105). Many of these understory trees, like their western hemlock associates, can exist for decades or centuries as small, umbrella-shaped trees.

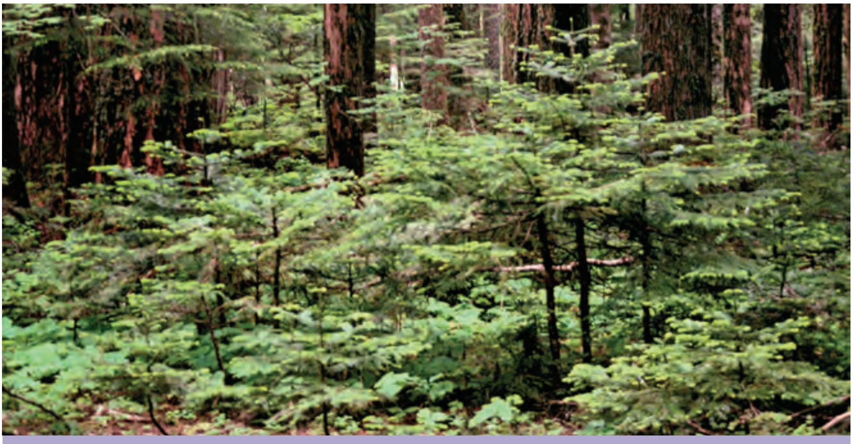


Figure 105. Small patch of understory Pacific silver fir in a Douglas fir/western hemlock forest in the south Cascades. Many of these small trees are up to 170 years old, yet are still less than 2 m tall.

Unlike its shade-tolerant associate western hemlock, Pacific silver fir does not prefer logs as a seedbed. The seeds of Pacific silver fir are very large, and can provide sustenance for young seedlings for a year or so while they get their small roots established. In addition, the young sprouts of Pacific silver fir are extremely stiff, and are often able to withstand the debris that small understory plants are subject to—the same debris that often smothers young hemlock seedlings. These factors combine to allow seedlings of Pacific silver fir to do well on many forest floor substrates.

While usually neither the largest or most conspicuous tree in the forests within the Pacific silver fir zone, Pacific silver fir is often the most numerous tree in mature and old forests (Figure 11). Young to mature trees maintain a relatively smooth bark that is often coated with one or several species of white, crustose lichens (Figure 11). Since silver firs are not decay-resistant, and few trees live more than a couple hundred years in low-elevation forests, these white-barked trees are all that many people ever see. In the cooler and moister parts of its range, however, silver firs can live to great ages. Older trees develop a flakier, sometimes purplish bark reminiscent of Sitka spruce (Figure 106).

Figure 106. A very old forest of Pacific silver fir and western hemlock in the Olympic Mountains. Old individuals of silver fir can often be 600-800 years old and develop the flakey bark more characteristic of spruce.

In most situations, silver firs will only be a part of the upper canopy in the later stages of succession—just as western hemlock was in the stand development sequence presented earlier. Exceptions to this can occur if the forest blows over, leaving a hemlock and silver fir understory to become the new canopy. A similar situation occurred after the 1980 eruption of Mount Saint Helens. A Pacific silver fir understory was present beneath a dense snowpack in May when the eruption occurred. The overstory was killed by the intense heat, leaving only these small understory trees to start the new forest (Figure 107).

Figure 107. Survivorship at Mount Saint Helens. A deep snowpack allowed a group of Pacific silver fir understory trees to become the new cohort when the remaining canopy was killed by the blast from the 1980 eruption, as shown in this 1989 photo.

With very shade-tolerant trees such as western hemlock or Pacific silver fir, it is often useful to think of **functional ages**. In the example of the volcanic eruption, or in the example of the 21 Blow windstorm, understory trees grew as unconstrained seedlings as if they had been recently planted. Even though the trees may have been 100-200 years old, their functional age, such as the trees in Figure 14, will date from the time of the canopy removal.

Conclusion

The great diversity and ages of forests found in western Washington make 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 presents its own set of mysteries, and there are sure to be cases when professional judgment will have to substitute for certainty. Ultimately, however, it is to be hoped that the ecological knowledge contained in this guide can be used to narrow the range of possibilities and give the user increased confidence in making age determinations in older forests.

English Equivalents

When you know:	*Multiply by*	*To find*
Centimeters (cm)	0.39	Inches (in)
Meters (m)	3.28	Feet (ft)
Kilometers (km)	0.62	Miles (mi)
Square kilometers (km^2)	0.386	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)
Cubic meters (m^3)	177	Approx.* Board feet (bf)

**Based on* ft^3 *x 5*

Citations

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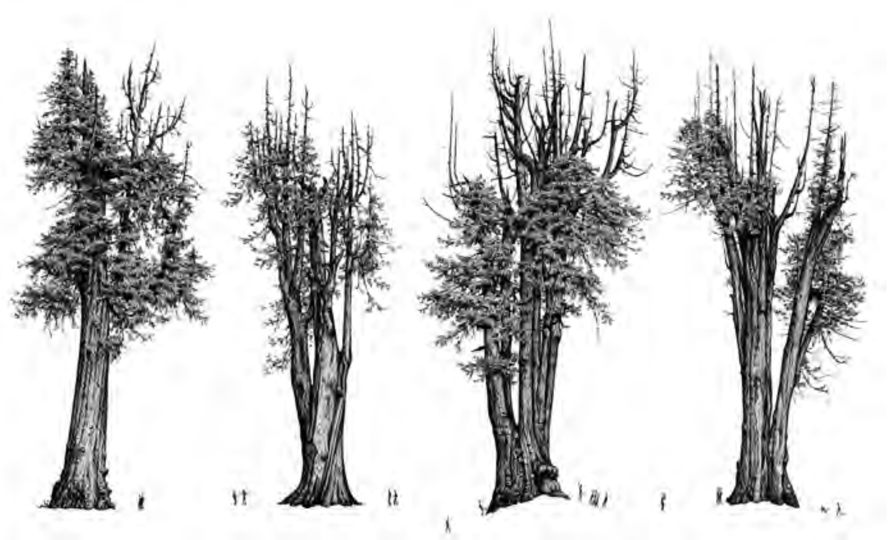

Appendix

Crosswalk between stand development terms used in this guide and terms used in other DNR publications.

OG Guide	DNR Glossary	Essential ecological process, elements, and other notes
Cohort establishment phase	Ecosystem initiation	Establishment of cohort individuals
Canopy closure	Competitive exclusion: sapling exclusion	Canopy closes
Late canopy closure and early Biomass accumulation/ competitive exclusion	Competitive exclusion: pole exclusion	Inter-tree competition is the dominant ecological process. Live trees compete with each other for resources (light, water, nutrients). Loss of stems <2" dbh due to shading; self pruning begins.
Biomass accumulation/ competitive exclusion and early Maturation I	Competitive exclusion: large tree exclusion	Inter-tree competition is the dominate ecological process. Live trees compete with each other for resources (light, water, nutrients). Loss of stems <5" dbh due to shading.
Maturation I	Understory delevoment	A shift of the dominate mortality processes occurrs from inter-tree competition to stochastic events (disease, wind, fire, pests) resulting in stem loss of larger trees (dominant and co-dominant) and a loss of shade. Openings in the canopy appear, allowing regeneration of shade tolerant species. High rate of biomass accumulation is maintained. In later stages, rate of live biomass accumulation begins to decrease. Continued understory development and stochastic stem loss. Stages generally lacking large down woody debris and large snags.
Maturation II	Botanically diverse	Development of additional species in lower and mid canopy. Large down woody material and large snags are generally absent or at low levels.
Vertical diversification	Niche diversification	Development of additional species in lower and mid canopy to abundant additional species at all canopy levels and increasing levels of large down woody debris and large snags.
Horizontal diversification	Fully functional	More stochastic stem losses create larger gaps. High accumulation of large woody debris, large snags.

Development stages used in this guide from Franklin et al 2002. DNR stages adapted from Carey et al 1996 and Franklin et al 2002.

Notes

About the author

Robert Van Pelt is an Affiliate Professor 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 since the mid 1980s. He has studied old-growth forests extensively 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 redwoods, 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.

Robert Van Pelt (author) 170' up in a pine tree. Credit: Will Blozan

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