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. The total area is 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

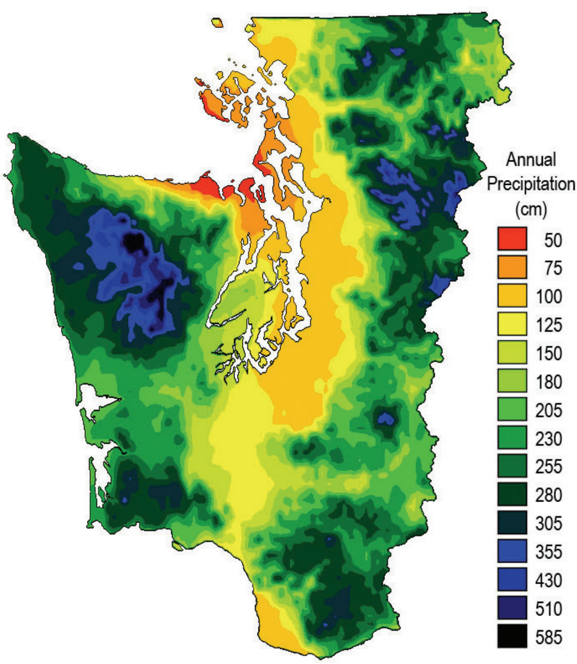


Figure 1. Annual Precipitation for Western Washington.

the total annual precipitation. Southwesterly oceanic storms are the primary source of precipitation for the region.

Western Washington contains a great diversity of habitats, from rain forests 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 settlers 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 settlement, 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

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

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. 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

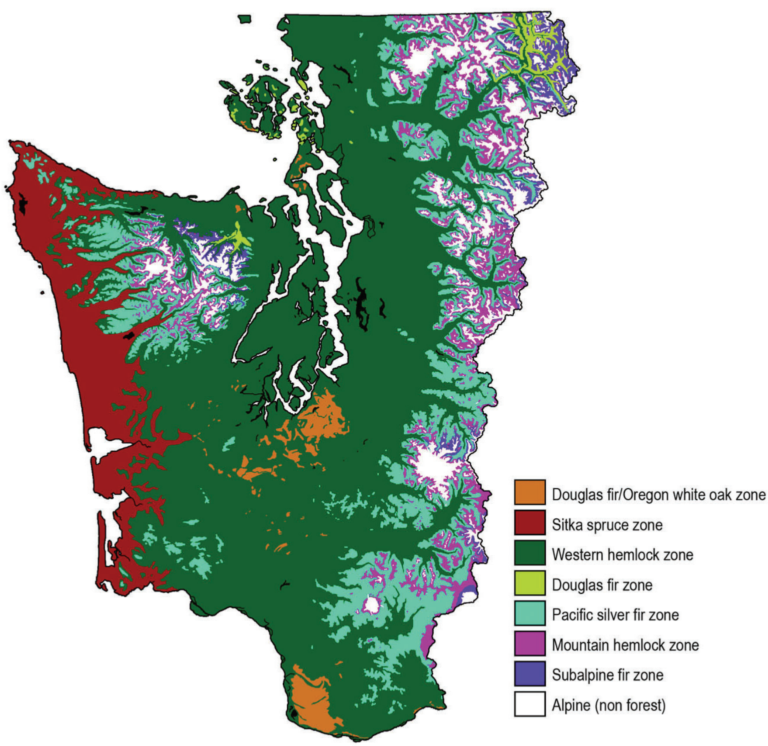


Figure 3. Vegetation Zones in Western Washington

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. 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).

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 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.

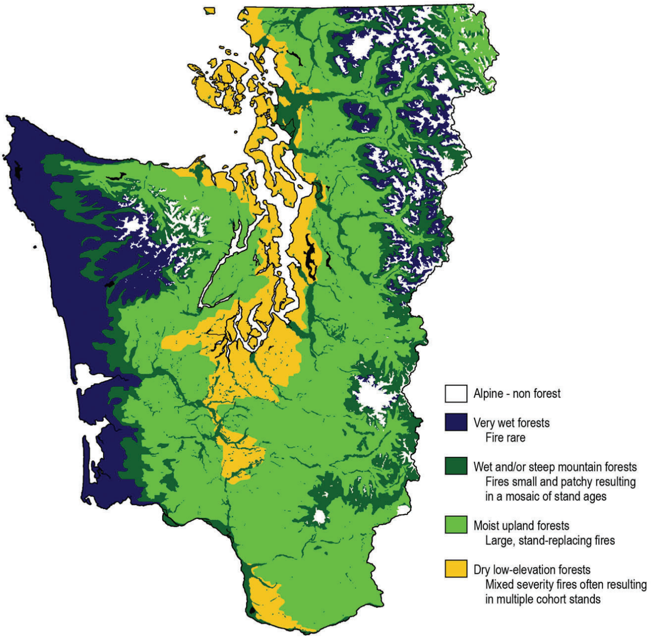


Figure 8. **Pre-Euro-American settlement fire regimes in western Washington.**

Fire in Western Washington Prior to Euro-American Settlement

Given the wide range in precipitation for western Washington, there is naturally a wide range in how fire has modified the environment over the centuries. Some areas near the coast or in the wettest spots in the mountains have had no fire for several thousands years. In other areas fire is common, serving to continually reset the successional clock. 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 to a lesser degree. Because their occupation of the region goes back for thousands of years, however, it is difficult to distinguish between anthropogenic influences on vegetation patterns and the natural background patterns.

Figure 9. Ancient forest on the coastal plain in Olympic National Park near Lake Ozette. Western redcedar dominates the entire region with the exception of the dark-colored hills, which are populated by western hemlock.

For the period before Euro-American settlement, 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 radioisotopes of carbon in the decay-resistant charcoal layers found in the soil. Fire is rare along the coast, as many areas show no evidence of fire for the past several thousand years. The 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 in places. While western hemlock is typically the most abundant tree species in these stands, it is short-lived in such warm, moist environments. Western hemlocks over 200 years old can be found, but invariably they have rotten centers and will not live to 300 years. In contrast, western redcedars over 1000 years old are not rare in these coastal plain forests. Some of these ancient trees are not very large, because, unlike the rich and productive soils of the nearby uplands, many areas of the coastal plain have heavily organic soils and productivity may be low (Figure 10).

Figure 10. Interior of an ancient cedar-hemlock stand near Forks. Even though the stand is ancient, the largest trees are less than 200 cm diameter. Photo: DNR/Steve Curry.

A lack of fire has also been detected in some areas of the 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 the 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. The size and age records for western hemlock (290 cm diameter, > 1,238 years), mountain hemlock (189 cm diameter, > 924 years), Pacific silver fir (233 cm diameter, > 900 years), and yellow cedar (416 cm diameter, > 1,693 years) all come from these locations (Figure 11).

Although rare, fires do occur in these areas from time to time. A fire could easily start from a lightning strike along the coast during the drier summer months. Similarly, a fire burning in a river valley could travel upslope into the mountain hemlock zone during a dry year. Such fires tend to go out quickly or not burn very extensively.

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.

Surrounding these areas are regions that are slightly less wet, including wetlands and floodplains nested within areas of more frequent fire (Figure 8). While these regions do have fire histories, fires are infrequent: fire return intervals are usually > 500 years. Fires in these regions are commonly small and patchy, typically spreading into this zone from adjacent, more fire-prone areas. The fires are commonly not self-sustaining and soon go out. Even so, they occur within the lifespan of Douglas fir. Most of these forests contain either a component of live Douglas fir established after a fire, or snags or logs that indicate a former presence of Douglas fir.

The bulk of western Washington is moist uplands, where large-scale, stand-replacing fires are the dominant force shaping the landscape (Figure 8). The forests created by stand-replacing fire events are the most widespread and most relevant to forestry in western Washington. This is detailed in a following section entitled *Stand development in natural Douglas fir forests.*

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 of one sort or another, they are of limited interest in a guide to older forests. Nevertheless, fine examples of old forests still exist in these regions, 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 they survived a previous fire event. Indeed, older stands throughout this zone consistently contain multiple age classes of Douglas fir.

Sections of this zone are much drier, located within the rain shadow of the coastal mountain ranges. As a result, stand densities, and the proportion of western hemlock and western redcedar is lower. Other sections of this zone have very dry forests resulting from the excessively-drained, gravely and sandy soils left behind by glaciers. Douglas fir is one of the most fire-tolerant trees in western Washington; with its thick bark it can often survive fires of low or moderate intensity.

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 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.

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. 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 usually 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. 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 13).

Figure 14. A generalized view of leaf photosynthesis with increasing light levels. Peak photosynthetic efficiency occurs at the saturation point.

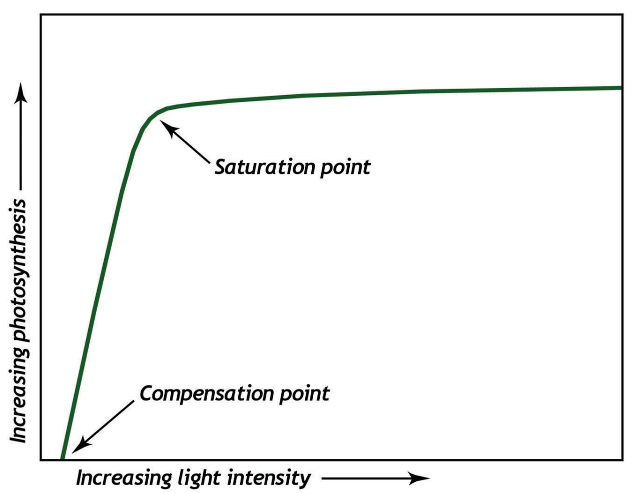


Figure 15. Leaf arrangement in response to light. The left photo is of a fully illuminated shoot from the top of a noble fir tree showing aggregated leaves and self-shading. The photo on the opposite page is a shaded shoot from the same stand with little self-shading and a very high SAR value (see page 26).

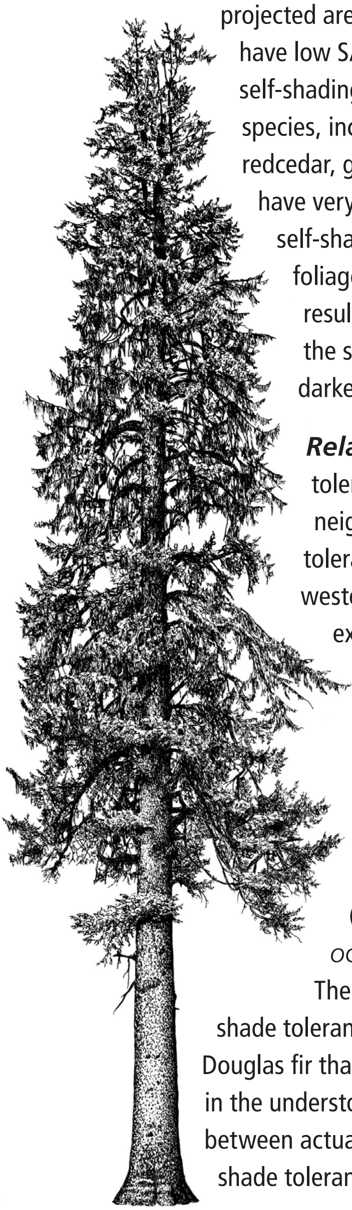
Important Information on Shade Tolerance

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 14), 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.

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 differences in shoot morphology between those growing under fully sunlit

conditions and those found in the shade (Figure 15). 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 redcedar, 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.