Stand Development in Natural Douglas Fir Forests

The stand developmental sequence as presented in Franklin et al. (2002) provides an introduction to the concept of forest disturbance and succession. This developmental sequence, while simplistic, was the most common in the forests of western Washington prior to Euro-American settlement and provides a useful framework when considering the many divergent scenarios.

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, catastrophic 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.

Figure 16. Aftermath of a catastrophic 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.

Figure 17. Living legacies. Survivors after a catastrophic wildfire are often found in drainages or other moist areas. These surviving trees are the primary seed sources for the next stand.

Figure 18. 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.
Photo: Jerry Franklin

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 destroyed by wildfire are often a sea of snags in a post-fire condition (Figure 16). Individual trees in stream drainages or other wet or protected areas will often survive even

Figure 19. 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 silvicultureal techniques recognize the value of retaining live trees, snags and logs (biological legacies).

severe fire events (Figure 17). 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.***

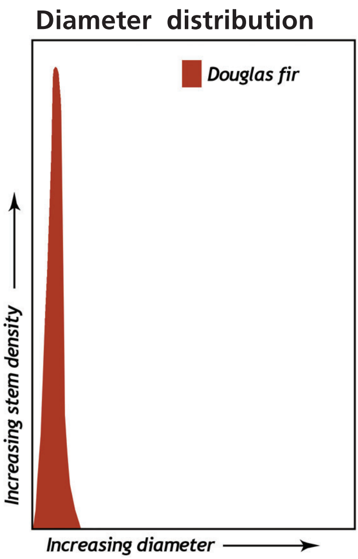
Catastrophic windstorms, in contrast, leave virtually all of the organic matter from the previous forest (Figure 18). This disturbance type tends to work from the top down, blowing over the canopy trees. Survivors from large wind events are often the small understory trees that were not crushed by falling 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.

Figure 20
Cohort Establishment

After Wildfire

After Blowdown

After Clearcutting



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 settlement stands. Traditional clearcutting leaves very little from the previous stand—no live trees and very few, if any, snags. The few logs that remain tend to be heavily decayed or small in diameter (Figure 19). During the late nineteenth and early twentieth centuries, these areas were allowed to reseed themselves naturally from surrounding forested areas. Since the 1960s,

Figure 21. 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.

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.

Cohort establishment

Cohort establishment is the initiation of a new set of trees that forms the basis of a future forest (Figure 20). 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

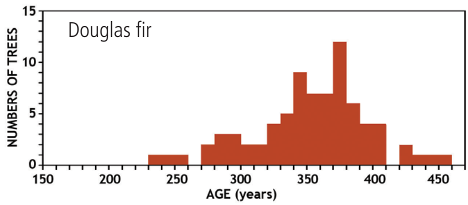
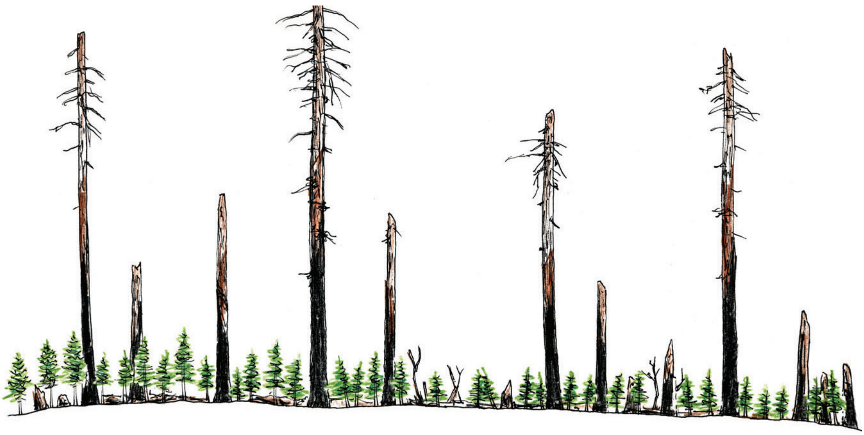


Figure 22. Diameter distribution of trees in the old-growth forest at the Wind River Experimental Forest in the south Cascades. Note the wide age range of the canopy dominants. Modified from Franklin and Waring 1980.

Figure 23

Canopy Closure



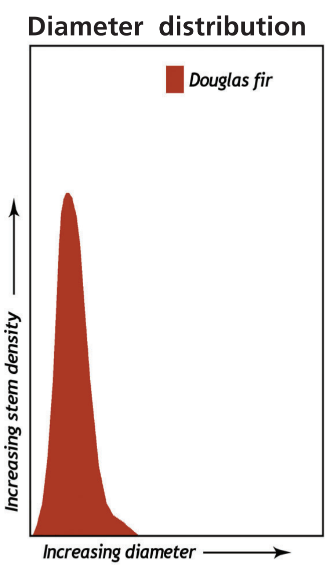
trees. The 1902 Yacolt Burn, one of the largest recorded fires in western Washington, regenerated very quickly.

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

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.

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 the upper panel of figure 20.

Large sections of the Yacolt Burn did re-burn. Indeed, 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 21). This scenario was probably not unusual in western Washington prior to Euro-American settlement, 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.



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

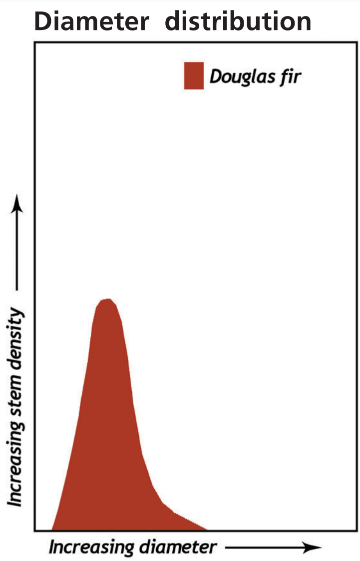
Figure 24
Biomass Accumulation/Competitive Exclusion

Forest shows this pattern of a wide variety of age classes in the dominant canopy trees (Figure 22). 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.

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 23). 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. Large piles of woody debris, competition from dense shrub layers, or exposed soils can all create situations that delay tree seedling establishment.

More dramatic environmental changes occur during this stage than in any other. During this relatively brief period, the area 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 24). In western Washington, this may take 30-40 years on highly productive sites such as in the Willapa Hills, or nearly 100 years on poorer sites in the Cascades.

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-dependant mortality will also be prevalent during this stage. 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.

Figure 25
Maturation I: Pre-Euro-American settlement

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: Forests originating after Euro-American settlement

At maturity, trees have 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 25). 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.

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

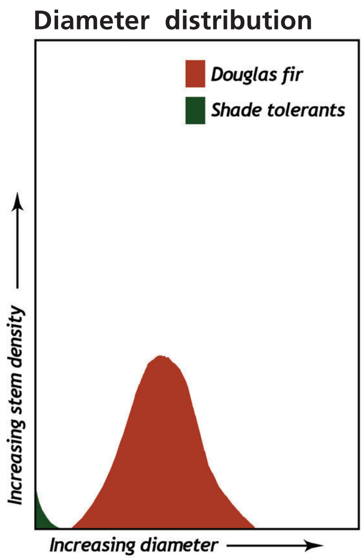


Figure 26. The Bole Zone. Below the main canopy and above the understory vegetation is a section with no leaves — just the trunks of canopy trees.

in the understory soon reach the point at which shade-tolerant plants can begin to grow, including tree species such as western hemlock. 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, hemlock 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 26). This area, known as the ***bole zone,*** is most dramatic at this stage.

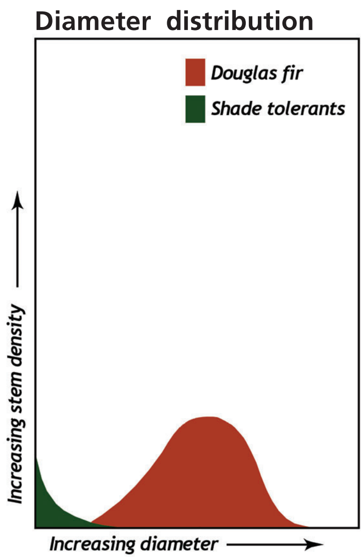
Maturation II: Forests originating before Euro-American settlement

Approximately 80-90 percent of the height growth of the stand is completed by this stage. This is the last stage at which trees exhibit the pointed tops characteristic of juvenile stands (Figure 27, Figure 28). 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 more important in western Washington. Decay from root and stem rots becomes

Figure 27

Maturation II: Pre-Euro-American settlement

Figure 28. View of the top of the canopy of a 160 year-old stand in the south Cascades. Note the model-conforming tops of a stand still growing in height.



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. 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 a significant diameter.

The bole zone begins to be repopulated with foliage from a new source, epicormic branches (Figure 29). 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 45).

Vertical diversification

Vertical diversification is the first stage of old-growth. The shade-tolerant trees are now continuously establishing in the understory and have expanded to occupy the areas below the crowns of the main Douglas fir canopy (Figure 30).

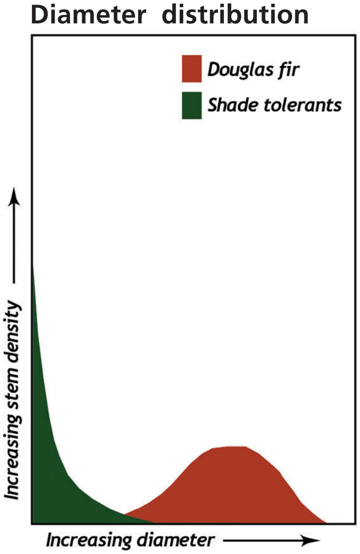
Epicormic branching is found on many of the canopy trees, effectively lowering their crown bases (Figure 31). This crown deepening permits trees of the main canopy to greatly increase the amount of foliage they carry, thus allowing for

Figure 29. Epicormic branching. Branches can form below the main crown at old branch wounds when light levels increase in that section of the stem.

Figure 30

Vertical Diversification

Figure 31. Crown deepening through epicormic branching.



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.

Mortality will continue as decay and other agents kill occasional 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 32). 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, and older gaps may now contain dense regions of hemlock regeneration.

In western Washington, this stage often begins when the stand is between about

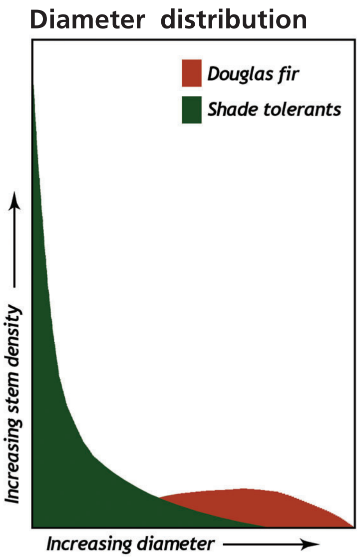
Figure 32
Horizontal Diversification

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 the last of the Douglas firs dies. At this point, none of the trees in any of the canopy levels originated immediately after the initial disturbance (Figure 34). The structural presence of the giant Douglas firs 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. 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.

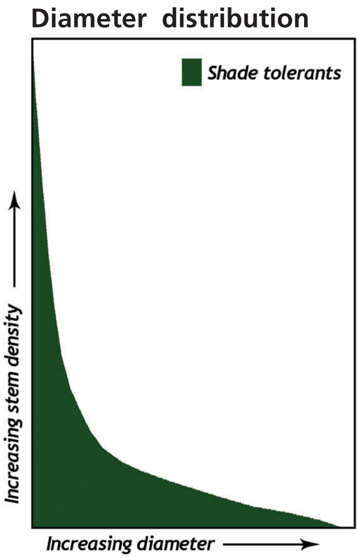
This final stage of the stand developmental sequence is rarely ever reached. It is likely that some event will occur to divert a forest from this developmental trajectory. The most common is another catastrophic wildfire, which serves to reset the developmental sequence to the beginning.

Figure 34
Pioneer Cohort Loss

Other scenarios

The idealized situation presented above, while not uncommon, has countless variations. For example, the catastrophic wildfire scenario assumes that all of the biological legacies are dead. Even in the Yacolt Burn, trees survived in ravines and around the edges of the burn. 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 *some* trees will survive as living biological legacies.

At the drier end of the spectrum, such as sections of the Puget Trough located within a rain shadow, the chances that individual trees will survive a fire are also high. Low stand densities combined with the presence of thin and dry soils allows some trees to survive with only minimal charring. A newly developing stand containing a few surviving trees from the previous stand would be described as an even-aged stand with surviving biological legacies. If enough trees survive, the subsequent stand would be termed a two-cohort stand. Fire boundaries are sometimes fairly abrupt, the result of a landscape feature capable of stopping a



fire, such as a ridgetop or a stream crossing. In most situations, however, the boundaries will be a gradual change from a burned to an unburned area. 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 35). At one end of a feathered edge will be an even-aged stand, followed by an even-aged stand with biological legacies. In the central portion of the feathered edge will be a two-cohort stand, then an old forest with a minor underburn, and finally an unburned forest.

Figure 35. 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 is very irregular.

Key to Stand Development Stages in Western Washington for Western hemlock, Sitka spruce, and Pacific silver fir zones.

While this 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.

1. Cut stumps present throughout stand 2
   No cut stumps. . . . . Natural forest*. 3

2. Stumps cut by chain saw (short stumps – planted seedlings). 3
   Stumps cut by hand saw (tall stumps, springboard notches – naturally reseeded) 3

3. Legacy trees – trees considerably older/larger than the others, or a subset of trees with charcoal on bark present. 4
   No legacy trees 6

4. Legacy trees < than 20 % canopy cover. . . . . Stand with legacies 6**
   Legacy trees ≥ 20 % canopy cover . . . . Two cohort stand 5

5. Each cohort must be keyed out separately
   Older cohort 10
   Younger cohort 6

6. Douglas fir (live or dead) ≥ 25 % of main canopy stems 7
   Douglas fir < 25 % of main canopy stems 15

7. Young, planted Douglas fir trees < 10 years old. **Cohort establishment phase**
   Not as above 8

8. Young, planted Douglas fir trees 5-20 years old, abundant shrub cover . . . . **Canopy closure**
   Not as above 9

9. Douglas fir trees, not yet overhead, overlapping crowns, shrubs present ≥ 15 % . . . . **Canopy closure**
   Not as above 10

10. Douglas fir canopy overhead, self pruning, scant understory . . . . **Biomass accumulation/stem exclusion**
    Not as above 11

11. Douglas fir overhead, self pruning; western hemlock, western redcedar, or Pacific silver fir present only in understory . . . .
Maturation I—Forests originating after Euro-American settlement***
Not as above 12

12. Douglas fir overhead, epicormic branches present, western hemlock, western redcedar, or Pacific silver fir seedlings, saplings, or small poles present, yet no main canopy trees . . . .
Maturation II — Forests originating before Euro-American settlement***
Not as above 13

13. Douglas fir upper canopy, western hemlock, western redcedar, or Pacific silver fir abundant and in many height classes, including main canopy . . . .
. . . . **Vertical diversification**
Not as above 14

14. Douglas fir canopy patchy, large canopy gaps present, western hemlock, western redcedar, or Pacific silver fir abundant in all canopy levels . . . .
. . . .**Horizontal diversification**
All Douglas fir trees dead (snags or logs), western hemlock, western redcedar, or Pacific silver fir abundant in all canopy levels. . . . . . . **Pioneer cohort loss**

15. Sitka spruce, noble fir, or red alder ≥ 25 % of main canopy stems . . . . . .
. . . . **use steps 7-14, replacing Douglas fir with Sitka spruce, noble fir, or red alder**
Sitka spruce, noble fir, or red alder < 25 % of main canopy stems . . . . . .
. . . . **use steps 7-14, replacing Douglas fir for western hemlock, western redcedar, and Pacific silver fir collectively******

* Certain areas in the Puget Basin were cleared of stumps during the early days of Euro–American settlement. While very few of these cleared areas have been reconverted to forests, the occasional stand may be encountered.

** For Douglas fir legacies, see the Rating System for Aging Legacy Trees on page 64. For Sitka spruce, western hemlock, or western redcedar legacies, use visual indicators under their individual sections.

*** Key was written in 2007. While stands keying out to Maturation I and II will be valid in any year, their relation to Euro-American settlement will not.

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

Figure 33. Classic old-growth. Interior of a 600+ year old stand near Mount Saint Helens showing a diversity of tree sizes and spatial heterogeneity.