

Thinning in Mature Douglas-fir Stands in Southwest Oregon: A Case Study

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Mature Douglas-fir-dominated stands are common in interior southwestern Oregon. Many originated after wildfire or timber harvest in the late 19th or early 20th centuries and now range in age from 80 to 150 years old. These stands are important for wildlife habitat, watershed function, recreation, timber production, and a host of other objectives. However, after decades of fire exclusion, many have become very dense and are at considerable risk of loss due to wildfire, drought, and insect attack.

In the past several decades, some mature Douglas-fir stands in the region have been thinned to reduce the fuel hazard, generate commercial timber, and increase tree and stand vigor. Since initial stand densities were often very high, some foresters were concerned that the trees left after the thinning would experience reduced growth, mortality, or windthrow. Additionally, severe drought in recent years has resulted in widespread branch dieback, top kill, and mortality in conifers throughout southwestern Oregon, especially in Douglas-fir on droughty, low-elevation sites. An important management question is to what degree various types of thinning of mature Douglas-fir trees growing in dense stands can improve resistance to drought stress and insect pests.

This case study documents the results of a wide **thinning from below** in two types of mature Douglas-fir stands (90 to 120 years old) on a site in interior southwestern Oregon. We report on stand conditions before thinning and the individual tree and stand-level responses up to 17 years following the thinning.

Key questions addressed include:

- How did individual Douglas-fir trees respond to the style of thinning implemented in this case? Did their growth decrease, stay the same, or increase? What factors affected individual tree growth response?

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Photo: Max Bennett, © Oregon State University
Midslope thinned stand above, unthinned stand below

thinning from below—
A style of thinning in which trees in lower crown classes are removed to favor trees in upper crown classes.

- Was there evidence of shock, windthrow, or increased mortality due to insects or other factors?
- How did growth vary in relation to drought severity in the thinned stands and a nearby unthinned stand?
- What are the lessons learned and implications for management of similar stands in the region?

Stand and Forest Conditions

Local setting

The case study site is situated in the Applegate watershed just south of Medford, Oregon. This area has a Mediterranean climate with cool, moist winters and hot, dry summers. Annual precipitation varies from 20 to 25 inches in the valley bottoms to 50 inches or more on higher peaks. The terrain is mountainous, with steep slopes and a complex mix of soils, including abundant shallow, rocky soils. Compared to moister Douglas-fir forests farther west and north, the case study site has lower productivity, and slower and more variable growth.

History

The forests on the site likely originated after a late 19th-century wildfire or logging or both that occurred in association with mining and early settlement of the Sterling Creek area of southwest Oregon. Before Euro-American settlement in the mid-1800s, forest development in interior southwest Oregon was shaped by frequent, low-to-moderate severity fires, both from lightning and fires set intentionally by Native Americans.

Beginning early in the 20th century, a policy of suppressing all fires was adopted, and fire suppression became increasingly effective over time. As in many other historically frequent-fire forests in the western United States, exclusion of most fires increased forest density and fuel loads, and in some areas, led to higher proportions of more shade-tolerant tree species. These changes have resulted in a landscape that, in recent decades, has become more prone to large-scale, high-severity fire as well as elevated insect-caused mortality.

Stand conditions prior to thinning

The site is roughly 250 acres in size and includes five Douglas-fir stands at elevations of 3,700 to 4,400 feet on northwesterly to southwesterly aspects. Three of the stands are located on ridgelines, and two on midslopes. Each of the three ridgeline stands had similar characteristics, as did the two midslope stands. As a result, we grouped the five stands into two types: ridgeline and midslope.

Prior to thinning, the two stand types were each composed of a dense, even-aged, structurally simple **cohort** of Douglas-fir that appears to have regenerated naturally after wildfire or harvesting or both, with no evidence of subsequent fire, timber harvest, or other disturbance. The stands were dominated by Douglas-fir (95 percent) with scattered ponderosa pine (5 percent). Atypically, only one stand included a small amount of the native

cohort—A grouping of trees of similar age that originated from a single event, such as a wildfire or timber harvest.

hardwoods that are a common component of many stands in southwestern Oregon. There was no significant midstory tree layer, and understory vegetation was sparse due to the dense overstory.

At the time of the thinning, the trees ranged from 85 to 150 years old, with the majority ranging from 90 to 120 years old. Stand density was high, with basal areas of 270 to 430 ft² per acre, a density much greater than the range of 80 to 150 ft² per acre that would typically be recommended for such a site, or would likely have occurred prior to the era of fire exclusion.

While both stand types were dense and similar in age, there were some important differences. Midslope stands were more productive (Douglas-fir 50-year site index of 80 to 85 versus 60 to 65) and lower in **relative density index** (Table 1). They had fewer, larger trees with higher crown ratios, suggesting they would be more vigorous. Ridgeline stands were less productive and higher in relative density index. They had far more trees per acre, and the trees were smaller with lower crown ratios, more ragged crowns, and slower radial growth, indicating lower individual tree vigor. Not surprisingly, given their high densities, some portions of the ridgeline stands had recently experienced mortality.

Thinning implementation

The study site lands are managed by the Medford District, Bureau of Land Management (BLM). From 1998 to 2000, BLM administered the Grubby Sailor timber sale, which included thinning in the stands described previously. The thinning was designed to establish a defensible fuel profile zone (DFPZ) in a strategic ridgeline location. A DFPZ is an area where fuels have been reduced to slow the spread of a fire, reduce its intensity, and facilitate fire suppression. A DFPZ is similar to a shaded fuelbreak but wider (¼ mile or more). In addition to promoting these fire management objectives, the project's other objectives were to improve tree and stand vigor and generate commercial timber.

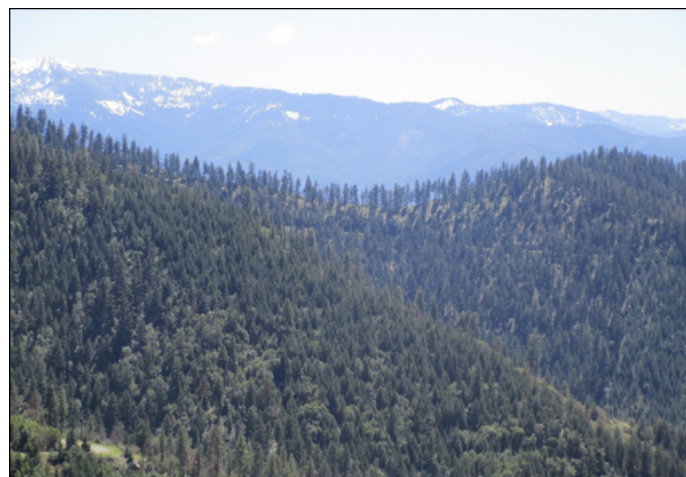


Photo: Max Bennett, © Oregon State University
Defensible fuel profile zone is visible on ridgeline.

relative density index (RDI)—A measure of stocking or stand density based on a percentage of the theoretical maximum stand density index (SDI) for a given species. SDI is calculated from the number of trees per acre and their quadratic mean diameter (diameter of the tree of average basal area).

Table 1. Stand conditions before (1997) and after (2000) thinning

Stand type	Site index ¹	Before thinning					After thinning			
		Trees per acre	Basal area per acre	Relative density index ²	Average diameter	Average crown ratio	Trees per acre	Basal area per acre	Relative density index ²	Average diameter
Midslope stands	80–85	97	286 ft ²	71%	23.3	35%	17	113	24%	34.9
Ridgeline stands	60–65	357	380 ft ²	115%	14.0	25%	42	104	27%	21.3

¹ Site Index for Douglas-fir, 50-year basis

² Relative density for Douglas-fir based on a theoretical maximum stand density index of 530 for Douglas-fir.

This was a very wide thinning from below, with retention of the most vigorous dominant and co-dominant trees, which tended to be the largest and oldest trees in the stands. The treatment removed 60 to 73 percent of the pre-treatment basal area and 83 to 88 percent of the trees per acre in the midslope and ridgeline stands, respectively (Table 1, page 3). Relative density index was reduced substantially, especially in the ridgeline stands. Canopy closure went from “lights out” (87 to 92 percent) to much more open conditions (46 to 58 percent). Residual basal areas ranged from 100 to 113 ft² per acre. After thinning, the trees were fairly evenly spaced, with no clumping or large canopy gaps.

The stands were logged using a combination of cable systems on steeper ground (slopes greater than 35 percent) and ground-based systems on more gentle terrain. Logging slash was hand-piled and burned. The understory was subsequently seeded with grass, and some areas were underplanted with Douglas-fir and ponderosa pine.

Individual Tree Response

Basal area growth

After thinning, **basal area growth** rates increased for 96 percent of the trees, with only 4 percent of surviving trees showing slower post-treatment growth. On a stand-average basis, basal area growth rates for individual trees were 2 times higher than before in the midslope stands and 2.75 times higher in ridgeline stands (growth ratio, Table 2). In short, almost all of the trees **released** following thinning and sustained faster growth during the 17-year measurement period. In effect, the thinning reduced competition and redistributed the growth potential of the site on fewer trees, so faster individual tree growth might be expected. However, some foresters had questioned the ability of the leave trees to respond, given the high pre-thin densities, poor appearance of the trees in each stand, evidence of insect-related mortality in a portion of the ridgeline stand type, and what appeared to be a very “aggressive” thinning that removed a high percentage of the basal area in a single entry.

Large differences were observed between the midslope and ridgeline stands in both pre- and post-treatment individual tree growth. Before thinning, the average basal area growth of individual trees in the midslope stands was nearly 2.5 times greater than in the ridgeline stands (Table 2). The midslope stands were more productive, less dense, and had larger trees on average, so faster individual tree growth and more rapid stand differentiation in this stand were not surprising. After thinning, trees in the midslope stands continued to grow faster than those in the ridgeline stand, but the relative difference between the stands was less. In effect, trees in the ridgeline stands showed a greater degree of release after thinning, perhaps because the magnitude of density reduction in these stands was greater.

basal area growth—Basal area is the cross-sectional area of the tree, measured in square feet, at 4.5 feet above the ground. To evaluate how individual trees responded to thinning, we converted diameter measurements into basal area and calculated the increase in basal area (basal area growth) for each tree over time. See Appendix 1 (page 11) for more information.

release—Refers to faster tree growth after an event or treatment, such as a thinning.

Table 2. Basal area growth (BAG) before and after thinning, individual tree averages

Average annual basal area growth per tree (ft ²)			
Stand type	1987–1997	2000–2017	Basal area growth ratio ¹
Midslope	0.05	0.09	1.97
Ridgeline	0.02	0.05	2.75

¹ See Appendix 1 (page 11) for definition and calculation of growth ratio. Figures in table are averages for individual trees in each of two midslope stands and three ridgeline stands.

Height growth

While trees increased substantially in diameter and basal area after thinning, height growth was minimal, with trees growing an average of fewer than 6 inches per year in both the midslope and ridgeline stands. Evidently, the trees had nearly reached their maximum heights. Trees that are larger in diameter for a given height have greater taper and tend to be more windfirm. As a result, the ratio of height to diameter is often used as a measure of tree stability and windfirmness. A ratio of 80 to 1 has been used as a threshold; trees with higher ratios are considered increasingly susceptible to wind damage and snow breakage.

In 2000, the average height-to-diameter ratio of trees selected for retention in the thinning was 45.6 in midslope stands and 50.1 in ridgeline stands, suggesting that they would be stable following thinning. It should be noted these were dominant and co-dominant trees, the largest and “best” in the stands. Many other trees in the stands prior to thinning were smaller in diameter and had much greater height-to-diameter ratios with correspondingly reduced stability.

By 2017, average height-to-diameter values had decreased to 43.3 in midslope stands and 45.6 in ridgeline stands, suggesting that average tree taper and windfirmness had increased after thinning. Over the 17-year post-treatment period, no trees were lost to windthrow in the measurement plots, and there was no evidence of windthrow in the surrounding thinned stands, even those located on exposed ridgelines.

Crown ratio

On average, crown ratios did not increase between 2000 and 2017, or increased by only a few percent; this is not surprising since the trees grew little in height, so there was little opportunity for crowns to lengthen significantly. However, **epicormic branching** was noted in some trees, especially in parts of the ridgeline stands. Also, many of the crowns appeared to be dense and vigorous, suggesting that leaf area and overall tree vigor may have increased even if the measured crown ratios didn't.

Mortality

While growth is important, drought-associated mortality levels are also of great interest. Between 2000 and 2017, trees in one measurement plot were lost to fire. Aside from that, only three trees died during the 17-year period, for an annual mortality rate of 0.23 percent. The trees are suspected to have succumbed to a combination of drought stress and flatheaded fir borer attack, although one of the trees also had fire damage. When the plots were re-measured in 2017, some mortality was visible within the thinned stands but outside of the measurement plots, mostly occurring at edges where the stands bordered lower-productivity sites with shallow soils. This edge pattern is very consistent with flatheaded fir borer mortality observed elsewhere in southwest Oregon.

epicormic branching—Epicormic branches are new branches that arise from dormant buds on the boles of trees, usually after exposure to increased light levels. Douglas-fir produces epicormic branches; ponderosa pine does not.



Photo: Max Bennett, © Oregon State University
Flatheaded fir borer (FFB) mortality is often found on stand edges.

Growth of trees in the thinned stands compared to a nearby unthinned stand

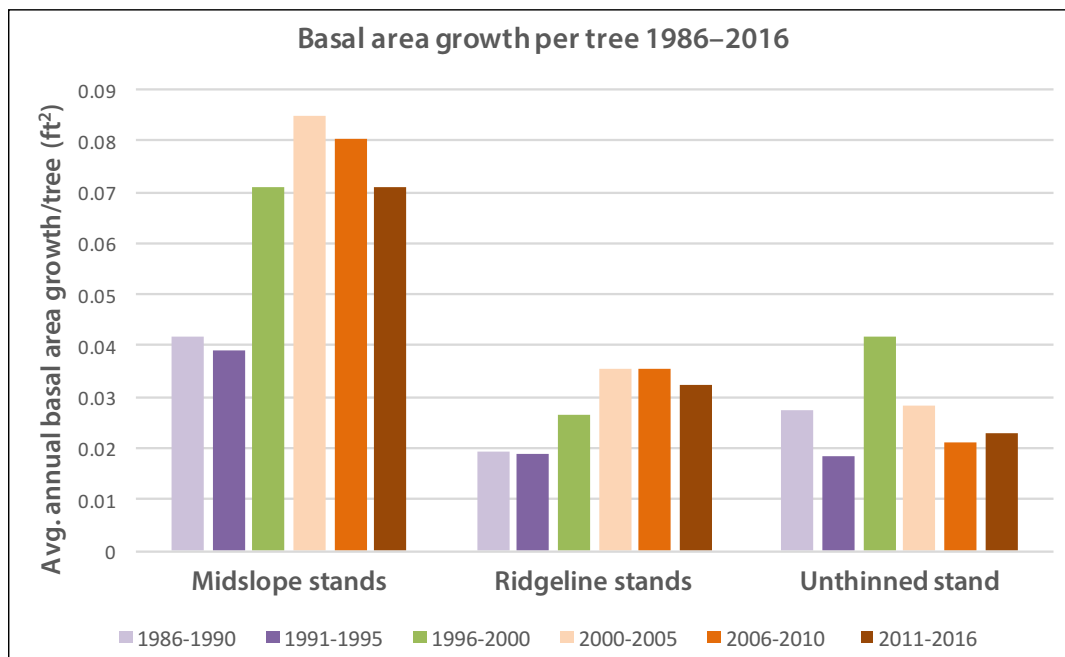
We also compared radial and basal area growth of a subsample of trees in the thinned stands with otherwise similar dominant and co-dominant trees in a nearby unthinned stand. The unthinned stand was immediately below and adjacent to one of the midslope stands and was dense, with point estimates of basal area ranging from 290 to 390 ft² per acre, similar to the pre-treatment densities of the thinned stands. Productivity in the unthinned stand was not measured but appeared to be intermediate between the midslope and ridgeline stands.



Photo: Max Bennett, © Oregon State University
Unthinned stand

Radial growth of the sampled trees was measured with increment cores from 1986 to 2016. Basal area growth was then calculated from the radial growth data (see Figure 1). Basal area growth was examined for six successive growth periods: two prior to thinning (1986 to 1990, 1991 to 1995), one encompassing the time of thinning (1996 to 2000), and three after thinning (2000 to 2005, 2006 to 2010, and 2011 to 2016).

Individual tree basal area growth increased in the midslope and ridgeline stands after the thinning, while declining after 2000 in the unthinned stand. As will be discussed later in more detail, the uptick in growth from 1996 to 2000 evident in both thinned stands as well as the unthinned stand (green bar) is coincident with a period of above-average precipitation and low drought stress. The superior growth of trees in the midslope stands



Graphic: Max Bennett, © Oregon State University

Figure 1. Average annual basal area growth of trees in thinned and unthinned stands, 1986–2016

compared to the ridgeline stands is also very apparent; the average basal area growth of midslope trees was more than double that of ridgeline trees for all growth periods.

Response to drought stress

Recent droughts in parts of the western United States, as well as predictions of more summer drought resulting from climate change, have increased the need to understand how trees and stands respond to drought stress. Not only does drought reduce tree growth and increase the likelihood and severity of fire, but prolonged or severe moisture stress can also increase the susceptibility of trees to insects and pathogens.

In southwest Oregon, the flatheaded fir borer (FFB) is the main agent of insect-related mortality of Douglas-fir trees. FFB-related mortality typically increases with or just after severe drought years. In 2016, following drought and elevated temperatures in 2013 to 2015, FFB-related mortality in southwest Oregon skyrocketed, with more than 120,000 trees killed in the region. One of the epicenters of FFB-related mortality was the Applegate watershed, which encompasses the study site, although most of the mortality was at lower elevations than the study site.

To understand how trees in the study site responded to drought, we compared the radial growth of the sampled trees in the thinned and unthinned stands from 1986 to 2016 against the Palmer Drought Severity Index (PDSI). The PDSI is a frequently used measure of drought severity that takes into account both precipitation and temperature.

PDSI values are positive or negative numbers, with negative 2 regarded as moderate drought, negative 3 as severe drought, and negative 4 as extreme drought. PDSI can be calculated for a short-term (3-month) or long-term (12-month) period; we used the long-term value. Between 1986 and 2016, the PDSI for the local area had many ups and downs, with severe drought measured in 1992, 1994, and 2001, and nearly reached in 2013 to 2015. All other factors being equal, radial growth would be expected to increase in periods when the PDSI was positive and decrease when it was negative.

Radial growth of trees in both the thinned and unthinned stands shows similar patterns prior to thinning (Figure 2, page 8). For example, from 1995 to 1999, a period when the PDSI was strongly positive, radial growth increased in both stand types. However, the pattern was different after thinning. From 2001 to 2003, when the PDSI was strongly negative, radial growth in the unthinned stand decreased substantially while remaining steady in the thinned stands. Positive PDSIs in 2005 to 2006 and 2010 to 2012 were associated with strong upticks in radial growth of trees in the midslope stands, relatively steady growth in the ridgeline stands, and steady



Photo: Max Bennett, © Oregon State University

The midslope stands had higher productivity and larger trees. Note the grass in the understory.

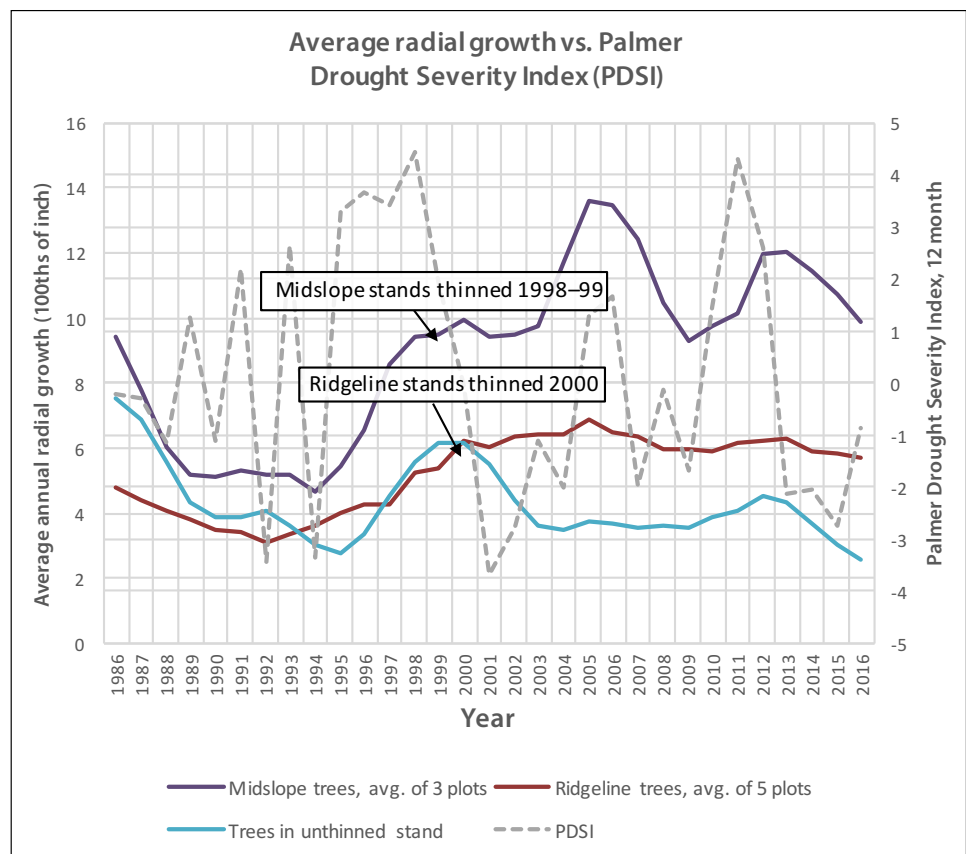
growth with a small increase in 2012 in the unthinned stand. In summary, periods with positive PDSI values appear to be associated with increased radial growth of trees in both thinned and unthinned stands, but radial growth of trees in the thinned stands was much greater after thinning and seemed to be less negatively affected by drought.

Initial tree vigor and post-treatment growth

Crown ratio and radial growth are common measures of tree vigor that are used in evaluating the suitability of trees for retention in thinning. We found that pre-treatment crown ratio and 10-year radial growth were positively associated with post-treatment growth. When all trees in the thinned stands were lumped together, trees with pre-treatment crown ratios of greater than 40 percent grew, on average, about twice as fast in diameter after thinning as trees with pre-treatment crown ratios of less than 30 percent. Similarly, trees with pre-treatment radial growth of greater than 0.7 inches per decade grew more than twice as fast on average after thinning as trees with pre-treatment radial growth of less than 0.4 inches per decade.

Lessons Learned

- **In this case study, 90- to 120-year-old Douglas-fir trees growing in very dense stands responded well to wide thinning from below.** Despite initial concerns that the trees would “shock,” die, or blow down following a heavy thinning, nearly all the trees responded with significantly increased growth. We suspect this was due in part to careful selection of the most vigorous dominant and co-codominant leaf trees available by an experienced crew. While the stands were heavily overstocked prior to thinning, most leaf trees still had “acceptable” crown ratios (30 percent or greater) and low height-to-diameter ratios, making them quite windfirm. Had the available leaf trees been less vigorous and windfirm, the results would likely have been very different. Poor response following thinning of dense, mature Douglas-fir stands in southern Oregon has been observed in other cases, generally in stagnant stands with low-vigor leaf trees.



Graphic: Max Bennett, © Oregon State University

Figure 2. Radial growth of trees in thinned and unthinned stands in relation to drought stress

- **The timing of the treatment in relation to recent weather conditions may have influenced the result.** Coincidentally, the stands were thinned following several years of above-average rainfall and low drought stress, at a time when radial growth in both stands, as well as in the nearby unthinned stand, was increasing; hence, the trees were starting from a point of relatively high vigor compared to the recent past. If the thinning had occurred during a severe drought year and then been followed by several drier-than-normal years, the results may have been quite different.



Photo: Max Bennett, © Oregon State University
Increment cores showing increased growth after thinning

- **The results are consistent with previous research demonstrating that Douglas-fir can respond positively to thinning even at advanced ages.** Douglas-fir is well known for its longevity and sustained growth. A previous study by Latham and Tappeneir showed that old growth Douglas-fir trees in southwestern Oregon grew faster after density reduction, but there was generally a lag period of several years before a response was noted, and the growth increase peaked at 25 to 45 years after thinning. The trees in this study were younger; their growth remained steady after treatment, while growth of trees in the unthinned stand declined, suggesting that the trees in the thinned stand responded quickly to treatment.
- **Thinning improved drought resistance.** While trees in the unthinned stand grew more slowly in periods of drought stress, tree growth in the thinned stands was less negatively affected by drought, rebounded more quickly following dry periods, and showed little evidence of drought or insect-related mortality. As summer droughts become more pronounced with climate change, thinning may serve as an important tool to buffer stands from the effects of drought stress.
- **Thinning may have improved resistance to flatheaded fir borer (FFB) infestation.** As noted previously, FFB is the primary insect agent of mortality of Douglas-fir in interior southwest Oregon. FFB-related mortality typically increases during and following drought years, and trees on harsh, low-elevation sites are particularly affected. FFB-related mortality has been observed in both thinned and unthinned stands in the Applegate, and some local observers have argued that thinning increases the risk of infestation. In one ridgeline stand on the site, insect-related mortality, probably due to the FFB, had occurred just prior to the initial treatment, suggesting that a similar scenario was imminent in nearby ridgeline stands. After the thinning, though, there was little beetle-related mortality in any of the stands, while other areas in the Applegate watershed experienced substantial FFB-related mortality. However, the stands in this case study were located above 3,500 feet in elevation, while most FFB-related mortality has occurred below this elevation; therefore, it's not clear if the lack of mortality is a result of the thinning, elevation-related factors (such as decreased moisture stress), or some other explanation.

- **On average, trees in the midslope stands grew faster before and after thinning, but trees in the ridgeline stands showed a greater degree of release.** Although their post-thinning basal areas were nearly identical, the more productive midslope stands had fewer and much larger trees than the ridgeline stands, so they would be expected to experience greater absolute individual tree basal area growth after thinning. In contrast, trees in the less productive ridgeline stands were smaller and growing more slowly before thinning. After thinning, however, they experienced a greater relative increase in individual tree basal area growth, perhaps because the magnitude of the density reduction in the ridgeline stands was greater.
- **The midslope and ridgeline stands have different management potentials.** Thinning in the more productive midslope stands accelerated the growth of large trees for potential future timber production, older forest habitat, or other objectives. Thinning in the less productive ridgeline stands was probably more urgent in order to reduce density and insect-related mortality and to maintain the fire-management benefits of the defensible fuel profile zone. Historically, these types of overstocked, low-productivity ridgeline sites have been thought to be unable to respond favorably to treatment, but this was not the case here.
- **Understory development after thinning varied, with implication for fire management.** The stands in this case study were at moderate elevations (3,500 to 4,500 feet) and heavily dominated by Douglas-fir, with minor hardwood components. While such stands are fairly abundant in the Applegate, many other stands in the region have much higher proportions of Pacific madrone. The presence of stump-sprouting madrone and other shrubs typically means more in-growth of ladder fuels and a greater need for fuels maintenance over time. In the majority of both the midslope and ridgeline stands, overstory density seemed low enough to allow for regeneration of understory trees and shrubs, including madrone, but the lack of an existing madrone seed source in the overstory and the heavy seeding of grass following thinning seem to have minimized this. By contrast, in one of the ridgeline stands, substantial regrowth of madrone and deerbrush ceanothus was visible in 2017. Expensive maintenance will be needed in this type of stand to ensure long-term fire-management benefits, and to maintain growth and vigor of the retained overstory trees.



Photo: Max Bennett, © Oregon State University

In contrast to the other stands, substantial madrone and shrub regeneration was observed in one of the ridgeline stands.

- **An “aggressive” (i.e., wide) thinning accelerated development of large Douglas-firs, potentially extending tree longevity, reducing the risk of loss to drought and other stressors, and encouraging development of older forest habitat.** The forest structure that developed as a result of the thinning was relatively simple, featuring large, uniformly spaced trees

with few snags and downed logs and minimal understory development. While not suitable habitat for wildlife species requiring complex, multistory late seral forest, it could help meet the need for open late seral forest, which is actually much less abundant than closed late seral forest in the Rogue Basin. Future thinnings in these stands could be designed to promote increased spatial variability.

- **The stands on this study site initiated after the era of frequent, low-severity fire and grew for many decades without thinning, fire, or other disturbances.** The question, then, was if such dense, long-undisturbed stands could develop characteristics similar to contemporary, old-growth stands that had formed in much more open stand conditions with frequent fire. In this case, the study-site trees did respond to thinning and appear to be developing older-forest characteristics.

Appendix 1. Data Collection and Analysis

In 1997, prior to thinning, we installed three permanent plots in each of two midslope and three ridgeline stands, for a total of 15 measurement plots. Each plot included a variable radius point sample for trees over 8 inches DBH (diameter at breast height), using a 20 BAF (basal area factor), and two nested fixed area plots for trees 0 to 4 inches and 4 to 8 inches. This is the sampling protocol used for collecting data for the Organon growth and yield model. Baseline data were collected on tree and stand conditions, including species, diameter, sapwood width and years, height, crown ratio, and 10-year radial growth.

The 15 plots were re-measured in 2000 shortly after thinning, and again in 2017. This allowed for a comparison between individual-tree and stand growth for 10 years prior to thinning and for up to 17 years after thinning. Trees in one of the ridgeline plots were killed in a fire; these were dropped from subsequent analysis.

Basal area growth was determined for each tree for the 10-year period prior to thinning (1988 to 1997) and for the 17-year period following thinning (2000 to 2017) and converted to an annual value. The basal area growth ratio was then calculated for each tree as the ratio of the average annual growth after thinning to the average annual growth before thinning. Average annual per-tree basal area growth and growth ratio values were then calculated for each stand. These data were used to produce tables 1 and 2.

For an individual tree, a basal area growth ratio of less than 1.0 indicates that the tree grew more slowly after treatment than before treatment, while a value greater than 1.0 indicates the tree grew faster after treatment—that is, it “released.”

Basal area growth is an absolute measure of growth while growth ratio is a relative measure, and these measures can be independent of each other. For example, a large tree that was growing rapidly (i.e., a high absolute value) but at the same rate before and after thinning would have a growth ratio of 1.0, whereas another tree that was growing slowly before thinning and showed increased growth after treatment would have a growth ratio of greater than 1.0, even if it had a lower absolute basal area growth rate than the first tree.

In 2016, trees in eight of the measurement plots were cored back to 1985, providing a 40-year record of radial growth for each sampled tree. This record included data from trees in three plots in the midslope stand (17 trees total) and five plots in the ridgeline stands (26 trees total). Dominant and co-dominant trees in an adjacent unthinned stand of similar composition, density, and age were also cored to provide a comparison (13 trees total). These data were used to produce figures 1 and 2.

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