Effect of Fire Severity on Forest Development in a Mature Douglas-fir Forest in Western Oregon

by

Maxim Seiji Hidzick

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Baccalaureate of Science in Forestry (Forest Restoration & Fire Option)

Presented August 28, 2023
Commencement June 2024

ABSTRACT OF THE THESIS OF

Maxim Seiji Hidzick for the degree of Baccalaureate of Science in Forestry (Forest Restoration & Fire Option) presented on August 28, 2023. Title: Effect of Fire Severity on Forest Development in a Mature Douglas-fir Forest in Western Oregon

Abstract approved:____

Andrew Bluhm

Wildfires can create alternative pathways for forest development, and wildfires have expanded in size, frequency, intensity, and severity across the western United States. The purpose of this paper is to compare forest development of a mature Douglas-fir forest in western Oregon across fire severities. Postburn field measurements were collected in 2022 in the Hagan Research Natural Area (RNA) that burned in the 2020 Holiday Farm Fire. The field data was used to simulate forest development using an array of starting conditions, including unburned (pre-fire data), low, medium, and high fire severity classes. Immediately post-fire, trees per acre, basal area, cubic volume, stand density index, standard deviation of diameter at breast height, crown competition factor, and downed wood volume decreased with increasing fire severity. One hundred years post-fire, with a stand age of 270 years old, all classes, except for the high severity class, had Old Growth Index values approaching that of an old-growth forest lacking the composition of shade tolerant species. In this case study, moderate fire severity in mature Douglas-fir forests may result in a multi-cohort stand only composed of Douglas-fir and thus, large-scale wildfires may result in future forests with lower tree biodiversity than current old-growth forests.

Keywords: Forest Development, Wildfire Ecology, Douglas-fir forests, Pacific Northwest, Fire Severity

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Baccalaureate of Science in Forestry (Forest Restoration & Fire Option) project of Maxim Seiji Hidzick presented on August 28, 2023.

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I understand that my project will become part of the permanent collection of Oregon State University. My signature below authorizes release of my project to any reader upon request.

Maxim Hidzick, Author

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Introduction

In the Pacific Northwest (PNW) of the United States, wildfires serve a variety of ecosystem processes. Stand replacing wildfires reset forest succession and promote the growth of early seral and fire adapted plant species (Franklin et al. 2002). Non-stand replacing wildfires may promote the stand development process, reduce future fire intensities by burning ground fuels, reduce or eliminate fire intolerant plant species, promote the growth of fire adapted species, and create alternative pathways of forest development (Agee 1993). These pathways are highly dependent on the fire severity, the residual tree species that survive the wildfire, what propagules survived the fire in the case of sprouting hardwoods and shrubs, or species that use seed banking strategies. Multiple cohorts can be developed after non-stand replacing wildfires while a single cohort would develop after a stand replacing wildfire.

Understanding stand development of Douglas-fir (*Pseudotsuga menziesii*) forests in the PNW is important for management practices to achieve economic and ecological purposes. Old-growth forests are classified to be around 400 years old. (Franklin et al. 2002) proposed eight stages of stand development: disturbance and legacy creation, cohort establishment, canopy closure, biomass accumulation/competitive exclusion, maturation, vertical diversification, horizontal diversification, and pioneer cohort loss.

Recently, wildfires have expanded in size, frequency, and intensity in the western United States, possibly due to climate change and/or forest management practices. An example of this are the Oregon 2020 Labor Day fires (Evers 2022) which brought high wind speeds and dry air to forests that had elevated fire risk after a few months of the dry season. These types of fires might occur more often in the future. Thus, it is important to understand how a forest could potentially develop after a wildfire. Wildfires can burn at low to high severities (as measured by tree mortality), and thus, they can alter the development or the successional pathway of a forest. Fire severity can alter forest development by the amount, size, and species of the trees killed by the fire (removed). Furthermore, the amount and species regenerating after fire depends on what tree species survived the fire. The goal of this project is to compare forest development of a mature Douglas-fir forest in western Oregon across fire severities and against a preburned condition. Understanding forest development being altered by wildfires is important for plant and animal species that depend on a particular forest structure, biodiversity, and preserving forest ecosystems.

Methods

Study Site

Field data was collected in the Hagan Research Natural Area (44.174°N, -122.4° E), in the Willamette National Forest, west of Blue River, Oregon (Figure 1). The Hagan RNA is 1126 acres. Elevations range from 1600 to 3200 feet across the study area. The Hagan RNA is in the lower western Cascade Mountains which experiences hot and dry summers with cold and rainy winters. The mean annual precipitation is about 70 inches while mean annual temperatures are about 57° F where mean daily minimum temperatures can be 39° F in the winter and daily maximum temperatures 89° F in the summer (DOC 2023). This area is in the *Tsuga heterophylla* zone (Franklin & Dyrness 1988) with the primary tree species found in the Hagan RNA being Douglas-fir, western hemlock (*Tsuga heterophylla*), and bigleaf maple (*Acer macrophyllum*) with smaller amounts of Pacific dogwood (*Cornus nuttalii*). Grand fir (*Abies grandis*) and western redcedar (*Thuja plicata*) were not found on this site. The Hagan RNA originated after wildfires from 1855 and 1895 (USDA 1977), and the stand age is estimated to be around 170 years old which would be in the transition stage from the end of stem exclusion phase to mature stage. The Hagan RNA was burned in the Holiday Farm Fire, which was one of the 2020 Oregon Labor Day fires, that burned approximately 173,500 acres with extreme fire behavior the result of dry, strong, eastern winds and low humidities.

History

Historically, no forest management activities (i.e. no logging or road building) have occurred in this area due to the area being in steep and rugged terrain. Since the 1970s to present day, the Hagan RNA has been a part of the Pacific Northwest Permanent Sample Plot Program (PNW PSP), run by the USFS PNW Research Station and Oregon State University, where they study characteristics of old-growth forest habitat, successional dynamics of upland forests and riparian areas, and tree growth and mortality to provide research for basic and applied ecology (USDA 1997).

Field Data

Ninety-six, systematic, permanent, 0.25 acre (1/10th hectare) circular plots, were established in the Hagan RNA in 1986 by the PNW PSP. Plots are spaced 328 feet (100 meters) apart along transects, with transects 1312 feet (400 meters) apart. The first plot for each transect was 0 to 328 ft from the ridgeline (Kopsch 1986). Live trees within a plot that had a DBH of at least 5 cm were tagged and had their DBH and species recorded. Remeasurements of the plots were made about every five to seven years to measure growth, mortality, and ingrowth. Postburn plot measurements were done July through September of 2022, two years after the Holiday Farm Fire. Post-fire measurements for trees in the plots included survival status (live or dead), DBH of live trees, crown volume scorch, and bark char.

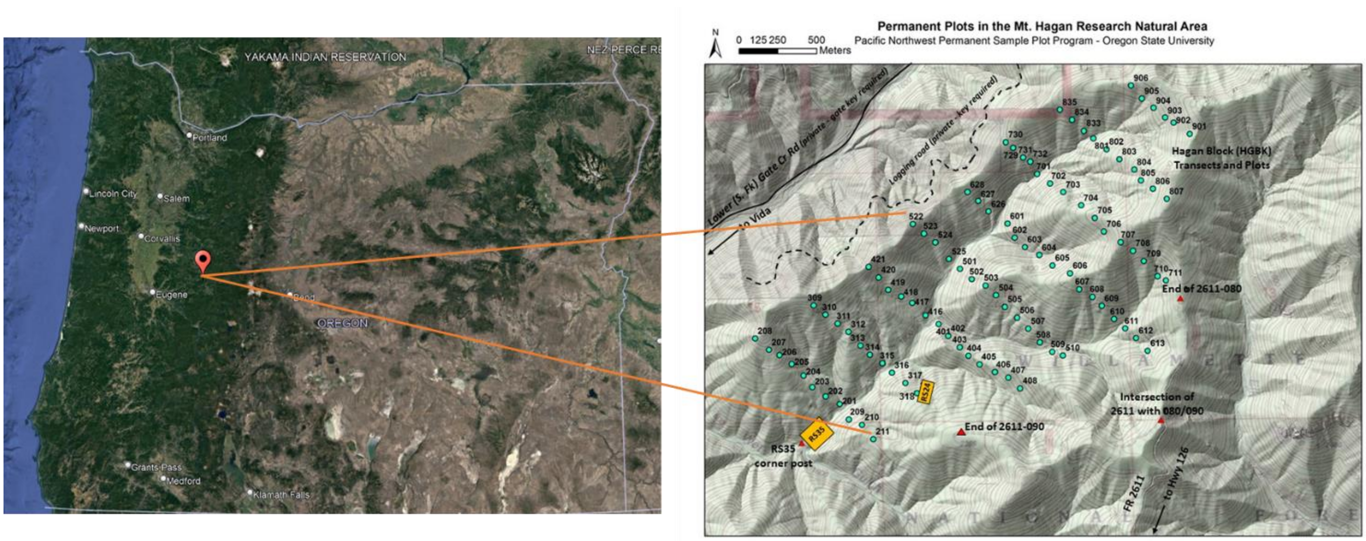

Figure 1. Regional and topographic map of the Hagan Research Natural Area transects

Data Analysis

Field data was analyzed with the Western Cascades variant of the Forest Vegetation Simulator (FVS). Douglas-fir was set as the main site species with a 595 maximum stand density index (SDI). Plots were separated into three fire severity categories based on basal area (BA) mortality: low (BA mortality 1 to 25 percent), moderate (BA mortality 25 to 75 percent), and high (BA mortality greater than 75 percent). Of the 96 total plots, 25 plots were unburned/unaffected by the fire. These 25 plots were excluded from this study. The remaining 71 burned plots were used in the FVS projections, with 27 plots categorized as low severity, 17 plots categorized as moderate severity, and 27 plots categorized as high severity.

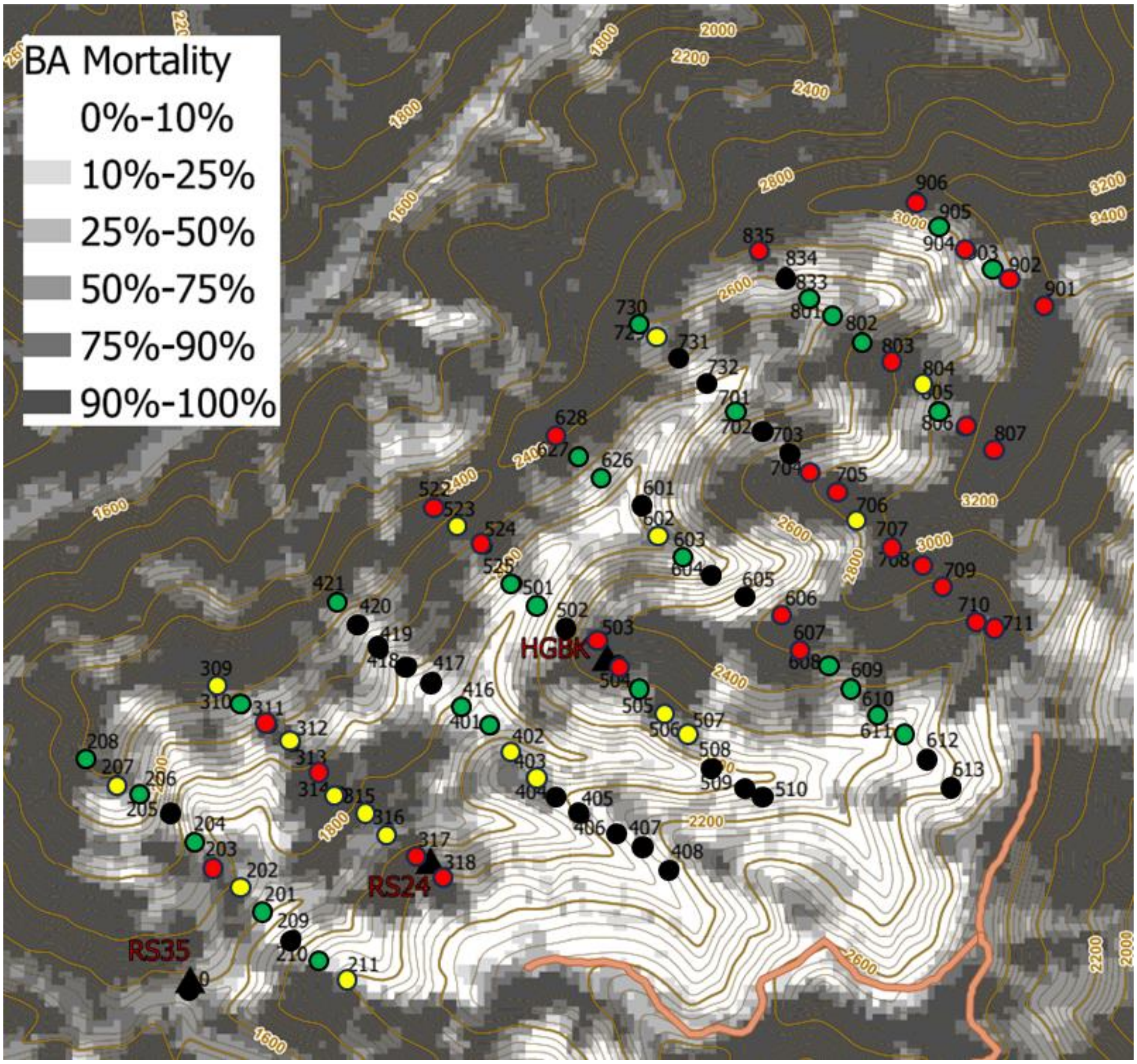

Figure 2. Basal area mortality of the Hagan Block transects after the Holiday Farm fire. Black dots = Plots not considered in this study; Green dots = Low Severity; Yellow dots = Moderate Severity; Red dots = High Severity.

To achieve immediate, pre-fire stand/plot characteristics, and to standardize the datasets, the 2018 field data for the 71 plots was grown out four years (to 2022). Then, both the “preburned” (i.e. the pre-fire data for the 71 burned plots) and burned (i.e. immediate post-fire data for the 71 burned plots) datasets were grown to the year 2122 in FVS to get stand conditions 100 years after the fire. To simplify comparisons of stand conditions for both 2022 and 2122, analysis of variance was used to test if the pre-fire stand variables trees per acre (TPA), BA, quadratic mean diameter (QMD), SDI, crown competition factor (CCF), and total cubic foot volume (ft3/acre [VOL]) differed by severity class. Differences by severity class (i.e. treatment) were tested using the GLM (general linear model) procedure in SAS (version 9.4, SAS Institute Inc.). Pairwise comparisons between the severity classes for each response variable were tested using least significant means adjusting the p value to account for the number of pre-planned multiple comparisons. For all six response variables (i.e. stand characteristics) no significant, statistical differences were detected (data not shown). Therefore, the preburned (unburned data) by severity class was collapsed into one preburned/unburned dataset (n=71) for the 2022 and 2122 comparisons.

Stand variables generated by FVS and used in the 2022 and 2122 comparisons are shown in Table 1. The variables TPA, BA, SDI, VOL, height (HT), and the four DBH variables were calculated for both the plot total and by species (Douglas-fir, western hemlock, and “other”). Post-fire tree regeneration is an important factor in stand development and is a required input for FVS projections. However, immediate, post-fire tree regeneration was not measured in this study. Therefore, a search of the literature and personal communication with OSU College of Forestry faculty and PNW Research Station ecologists was used to estimate tree regeneration quantity, rate, and species. For the 71 burned plots, tree regeneration was assumed to be 120 tpa of Douglas-fir establishing over a period of 40 years (Larson & Franklin 2005). 40% of the seedlings would establish in the first decade while 20% of the seedlings would establish each decade for the following three decades (Tepley et al. 2014). These Douglas-fir regeneration quantities and rates were applied across the three fire severity classes since Douglas-fir regeneration rates by fire severity are not well known and to simplify the FVS projections. Western hemlock and other species post-fire regeneration were not considered because: 1) like Douglas-fir, regeneration rates by fire severity for these species, are not well known, 2) the FVS simulation incorrectly suppresses western hemlock regeneration (personal communication, Matthew Powers, OSU College of Forestry 2023), and 3) there is no seed source for non-Douglas-fir within all estimated dispersal ranges/distances.

In addition to the stand variables generated by FVS, Old Growth Index (OGI [Acker et al. 1997]) was calculated for the 2022 and 2122 comparisons across fire severities. This index is useful in evaluating old growth structure or stage of stand development in Douglas-fir stands in the PNW. Old growth index uses four structural variables: standard deviation of tree DBH, density of Douglas-fir trees greater than 100 cm DBH, mean tree DBH, and density of all trees greater than 5 cm. OGI values range from 0 to 100 where 0 is a young stand structure while 100 is an old growth structure.

Table 1. Stand and species Variables that were generated from FVS for 2022 and 2122.

Trees per Acre (TPA)	Basal Area (BA) ft^2 per acre	Volume (VOL) ft^3 per acre
Stand Density Index (SDI)	QMD (in.)	Height (HT)
DBH Standard Deviation (in.)	Minimum DBH (in.)	Maximum DBH (in.)
*Old Growth Index	*Crown Competition Factor (CCF)	*Snags per acre
*Down wood volume (ft^3) per acre		

***Stand Variables Only**

Results/Discussion:

Table 3. Stand Variables in 2022 by Severity Class.

Stand Variable	Preburned	Low Severity	Medium Severity	High Severity
Number of Plots (n)	71	27	17	27
Trees per Acre	97	61	35	1
PSME	83	60	35	1
TSHE	9	0.4	0	0
Other	5	0.7	0	0
Basal Area (ft^2/acre)	280.2	232.2	147.0	8.1
PSME	274.5	230.1	147.0	8.1
TSHE	4.2	1.4	0	0
Other	1.6	0.7	0	0
QMD (in.)	23.4	26.8	29.7	34.0
PSME	25.4	27.1	29.7	34.0
TSHE	8.1	23.2	N/A	N/A
Other	8.2	13.6	N/A	N/A
Stand Density Index	367	289.4	178.1	9.2
PSME	370.5	296.4	178.1	9.2
TSHE	6.4	1.7	0	0
Other	3.7	1.2	0	0
Volume (ft^3/acre)	12522.1	10621.4	6799.1	388.2
PSME	12348.9	10536.9	6799.1	388.2
TSHE	130.6	62.3	0	0
Other	17.6	22.2	0	0
Height (feet)	114	132.5	142.3	154.7
PSME	126.4	133.3	142.3	154.7
TSHE	42.1	123.1	N/A	N/A
Other	44.9	71.2	N/A	N/A
DBH Standard Deviation (in.)	9.6	6.7	5.7	5.9
PSME	7.4	6.5	5.7	5.9
TSHE	3	5.5	N/A	N/A
Other	2.2	4.6	N/A	N/A
Minimum DBH (in.)	2.0	6.3	7.8	26.5
PSME	2.9	8.3	7.8	26.5
TSHE	2.0	20.4	N/A	N/A
Other	2.0	6.3	N/A	N/A
Maximum DBH (in.)	49.7	42.5	50.8	46.5
PSME	49.7	42.5	50.8	46.5
TSHE	28.5	28.2	N/A	N/A
Other	17.5	17.5	N/A	N/A
Old Growth Index	69	59	59	54
Crown Competition Factor (CCF)	297.2	242.6	152.1	8.2
Snags per acre	3	33	73	93
Downwood Volume (ft^3/acre)	4470.5	4073.5	3144.1	1526.8

Preburn, 2022

Preburn stand characteristics of the 71 burned plots are shown in Table 3. The stands are dominated by Douglas-fir where Douglas-fir comprises 85% of the TPA, 98% of the BA, and 99% of the VOL. Stand QMD was 23.4in, SDI was 367, and OGI was 69.

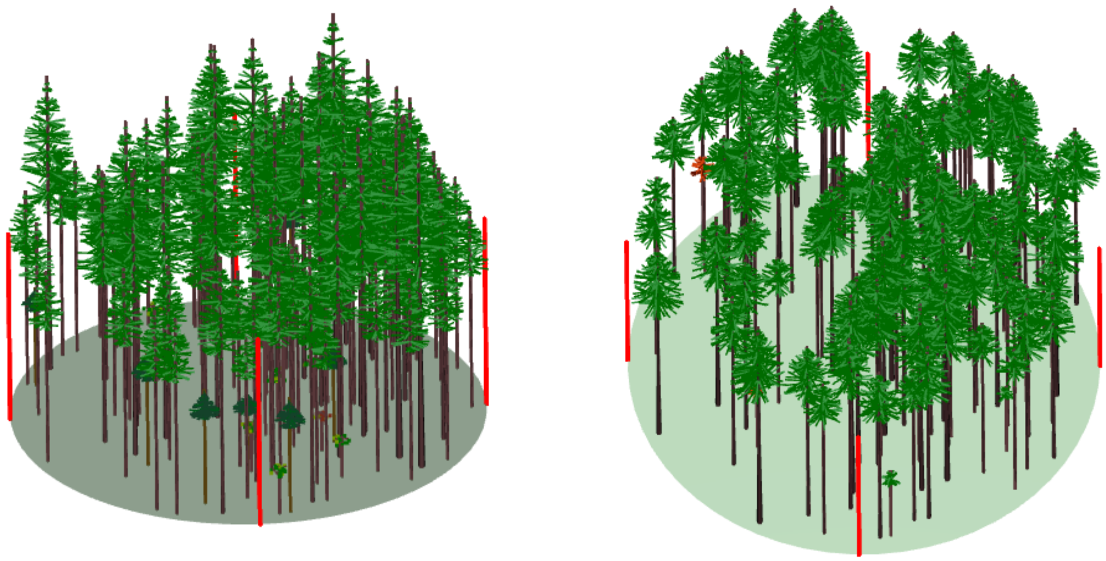

Figure 3. Stand Visualization images produced by FVS of the preburned Hagan plots in 2022. The two examples are from Plots 202 & 507.

Postburn, 2022

Immediately after the fire TPA, BA, VOL, SDI, DBH standard deviation, CCF, and downed wood volume decreased with increasing fire severity. For example, tree mortality was 37%, 64%, and 99% for the low, medium, and high severity classes, respectively. BA and VOL reductions were similar: BA decreased by 17%, 48%, and 97% and VOL decreased by 15%, 46%, and 97% with increasing severity class, respectively. Minimum DBH, HT, QMD, and snags per acre increased with increasing fire severity (Table 3). For instance, QMD increased by 14%, 27%, and 45% with increasing severity class. These patterns indicate that only the largest trees survived in the higher severity classes.

Regarding species composition, Douglas-fir was only the tree species that remained in the medium and high severity class plots- all other tree species experienced 100% mortality. The low severity plots averaged under one tree per acre for western hemlock and other tree species.

Old Growth Index for the preburned plots was 69 and was reduced across all severity classes. OGI decreased because of the reduction of DBH standard deviation and trees greater than 100 cm. The high severity plots had the lowest OGI (51) while the low and moderate severity plots had an OGIs of 54.

The preburned stands in 2022 have not reached early old-growth stage yet since they are below 200 years old, and mean DBH for Douglas-fir, total tree density was lower than the mean DBH of early old-growth forests in the Willamette National Forest (Bagby & Breitenbush) from (Freund et al. 2014). The

OGI of those two sites were 100. The preburned plots had about the same density of western hemlock species but with a smaller mean DBH of western hemlock compared to the Bagby and Breitenbush sites. However, in this study, the preburned plots had a lack of western redcedar.

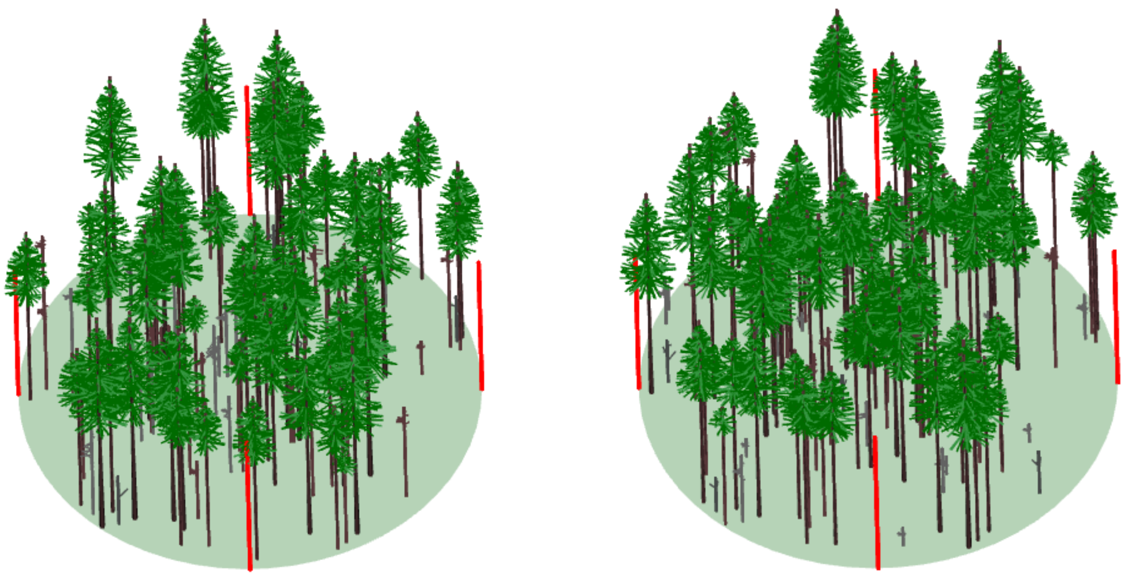

Figure 4. Stand Visualization images produced by FVS of the low severity Hagan plots in 2022. The two examples are from Plots 401 & 805.

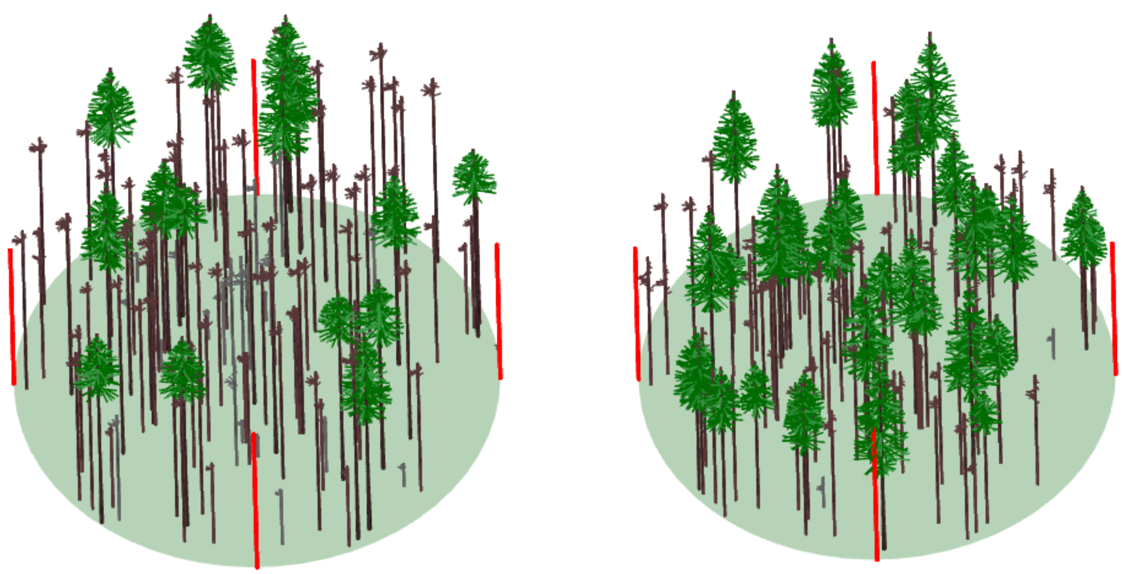

Figure 5. Stand Visualization images produced by FVS of the medium severity Hagan plots in 2022. The two examples are from Plots 314 & 402.

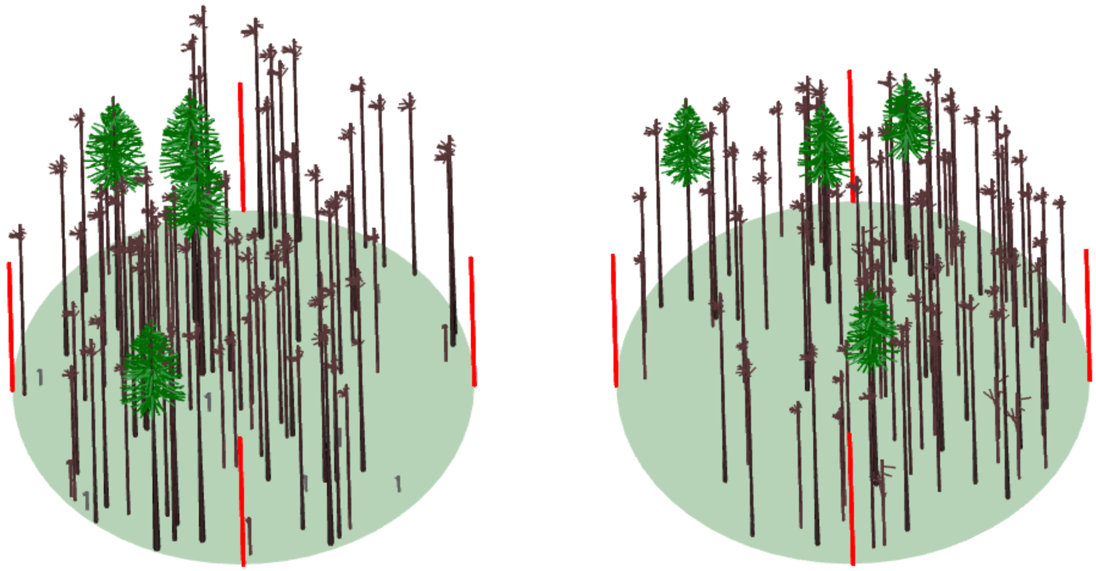

Figure 6. Stand Visualization images produced by FVS of the high severity Hagan plots in 2022. The two examples are from Plots 607 & 628.

100 years Postburn, 2122

The one hundred-year timeframe was used since 1) it is hard to predict future non-stand replacing disturbances that can occur over the longer term and reset successional pathways, and 2) moderate fire severity frequencies of Douglas-fir forests in the western Cascades Range from 50 to 100 years (Dunn et al. 2020).

There was no ingrowth of western hemlock, a shade tolerant species, projected for the 100-year time span in the unburned plots due to the limited number of western hemlock and high canopy closure of the stand (297.2). Since Douglas-fir was essentially the only species remaining in the burned plots, regeneration in the Hagan RNA was going to be Douglas-fir only (Table 4).

After 100 years, FVS predicted a decrease in TPA for the unburned and low severity classes compared to the 2022 densities. This reduction is likely caused by 1) interspecific competition experienced during the stem exclusion period of stand development and reflected in the high values of SDI and CCF both in 2022 and 2122, and 2) no predicted tree regeneration due to these high stand densities and canopy cover. TPA increased substantially in the medium severity class and dramatically in the high severity class, likely due to better seedling survival in the high light and low SDI and CCF environments there.

For the unburned and low severity classes, an increase in QMD was observed due to growth of the canopy dominants, mortality of the smaller canopy trees due to interspecific competition, and the lack of tree regeneration. The opposite effect was seen in the medium and high severity classes where QMD and HT decreased with increasing fire severity likely due to the greater abundance of tree regeneration. TPA were higher while QMD and HT were lower in the high severity class compared to the other classes.

For unburned plots in 2122, mean DBH for Douglas-fir and total tree density was lower than the mean DBH of early old-growth forests of two similar sites in the Willamette National Forest [Bagby & Breitenbush), Freund et al. 2014]. In this study, Western hemlock densities decreased from 2022 and are lower than the Bagby & Breitenbush sites. In 2122, the Hagan RNAs age is 270 years old which corresponds to the start of the early old-growth stage (Franklin et al. 2002).

As fire severity increased, BA, SDI, VOL, QMD, HT, and CCF decreased. For example, BA was 87%, 58%, and 34% that of the unburned projection (by increasing severity class, respectively). The medium severity class had the lowest TPA and greatest OGI out of all three burned plots. This is due to the medium severity class having a combination of Douglas-fir greater than 100 cm and a high DBH standard deviation resulting from large residual trees and small regenerating trees. The low severity class had more Douglas-fir greater than 100 cm than the medium severity class, but tree regeneration was not able to establish post-fire in the competitive environment of the low severity class (CCF=297). The high severity class did not have many residual trees post-fire and was mainly composed of Douglas-fir regeneration, therefore OGI was slightly less in 2122 (51) compared to 2022 (54). The unburned class had the highest OGI (92). However, this value was only slightly greater than the OGI of the low and medium severity classes (86 and 87, respectively).

One hundred years post-fire, with a stand age of 270 years old, all classes, except for the high severity class, have OGI values approaching that of an old-growth forest. However, all classes will not have the presence of shade tolerant tree species- a characteristic of an old-growth forest. Even beyond 2122, the forest will be primarily dominated by Douglas-fir because of the (almost) complete elimination of shade tolerant species both in the watershed and in the surrounding landscape and thus, slow dispersal/colonization of non-Douglas-fir tree species.

According to Tepley's (2013) criteria, the 2022 Holiday Farm Fire in the Hagan RNA was an episodic fire (fires occurring every 100-200 years) with the low and moderate fire severity classes experiencing non-stand replacing conditions while the high severity class was essentially a stand replacing event. The Hagan RNA is unlikely to follow Tepley's proposed pathways due to the lack of shade tolerant tree species surviving the fire. After the fire, the unburned, low, and high severity classes had only one cohort. The unburned and low severity classes had the remnant cohort of Douglas-fir trees that are around 270 years old while the high severity class had the single post-fire cohort of Douglas-fir trees that range from 60-100 years old. The moderate severity class had both cohorts: the pre-fire, remnant cohort and the regenerating post-fire cohort.

When a wildfire occurs during a stand's development phase (i.e. age) is critical in determining if shade tolerant trees would reestablish in the future stand. For example, if a low or moderate severity fire occurs when the stand is at an age before a significant amount of shade tolerant tree species are present, these stands would likely be reestablished by only Douglas-fir (or other shade-intolerant species). Conversely, an old-growth forest stand that has a high density of shade tolerant tree species present and survive a non-stand replacing fire would likely have a larger component of shade tolerant tree species post-fire. In addition to the timing of a fire just discussed, there's another critical factor and that's the size of the fire and the heterogeneity of severity. Small fires would have shorter dispersal distances for shade tolerant seeds and a heterogenous fire would allow shade tolerant species to persist and disperse into the burned areas (i.e. the 25 plots in the Hagan that didn't burn).

Table 4. Average Stand Variables by Severity Class in 2122.

Stand Variable	Preburned	Low Severity	Medium Severity	High Severity
Number of Plots (n)	71	27	17	27
Trees per Acre	78	56	52	98
PSME	70	55	52	98
TSHE	5	0.4	0	0
Other	3	0.6	0	0
Basal Area (ft^2/acre)	335.6	291.0	194.9	113.1
PSME	327.6	288.6	194.9	113.1
TSHE	6.4	1.8	0	0
Other	1.5	0.9	0	0
QMD (in.)	28.6	31.1	26.7	14.6
PSME	29.6	31.8	26.7	14.6
TSHE	11.8	27.1	N/A	N/A
Other	10.2	15.4	N/A	N/A
Stand Density Index	407.4	341.4	239.7	178.7
PSME	400.8	352.2	239.7	178.7
TSHE	6.4	2.0	0	0
Other	2.7	1.2	0	0
Volume (ft^3/acre)	14491.2	12689.9	8336.0	3048.9
PSME	14208.0	12594.9	8336.0	3048.9
TSHE	240.0	77.9	0	0
Other	43.2	28.7	0	0
Height (feet)	111.8	134.6	114.4	71.6
PSME	126.4	135.7	114.4	71.6
TSHE	26.7	124.1	N/A	N/A
Other	19.6	79.8	N/A	N/A
DBH Standard Deviation (in.)	10.0	8.3	10.1	4.4
PSME	8.4	8.2	10.1	4.4
TSHE	3.4	7.7	N/A	N/A
Other	2.8	9.2	N/A	N/A
Minimum DBH (in.)	2.3	2.9	3	8
PSME	4.1	2.9	3	8
TSHE	2.8	22.9	N/A	N/A
Other	2.3	7.4	N/A	N/A
Maximum DBH (in.)	56.3	54	58.6	51.1
PSME	56.3	54	58.6	51.1
TSHE	33.7	32.5	N/A	N/A
Other	24.9	19.5	N/A	N/A
Old Growth Index	92	86	87	51
Crown Competition Factor (CCF)	344.2	295.2	200.2	136.5
Snags per acre	6	28	39	19
Downwood Volume (ft^3/acre)	2892.7	2812.6	5060.9	7206.9

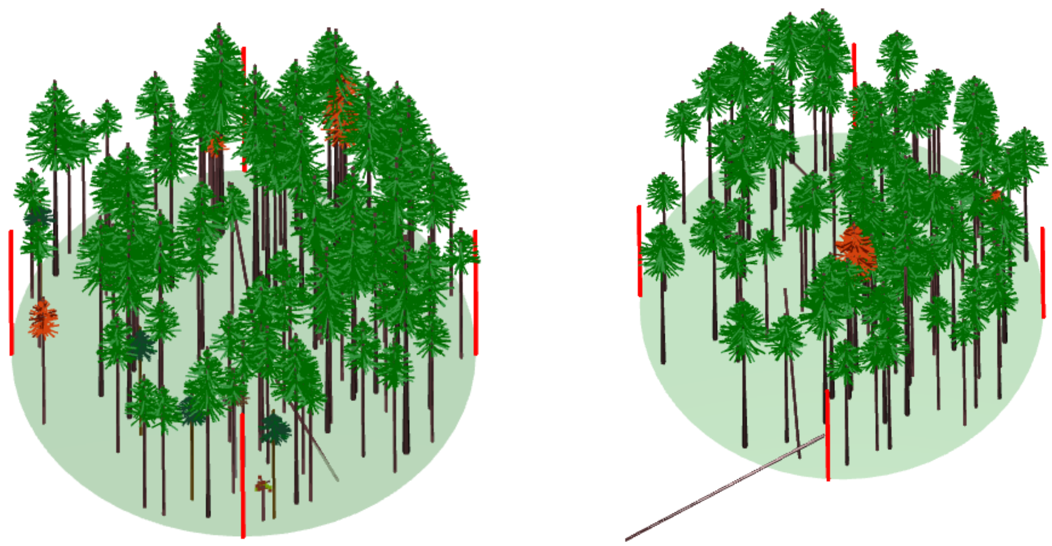

Figure 7. Stand Visualization images produced by FVS of the preburned Hagan plots in 2122. The two examples are from Plots 202 & 507.

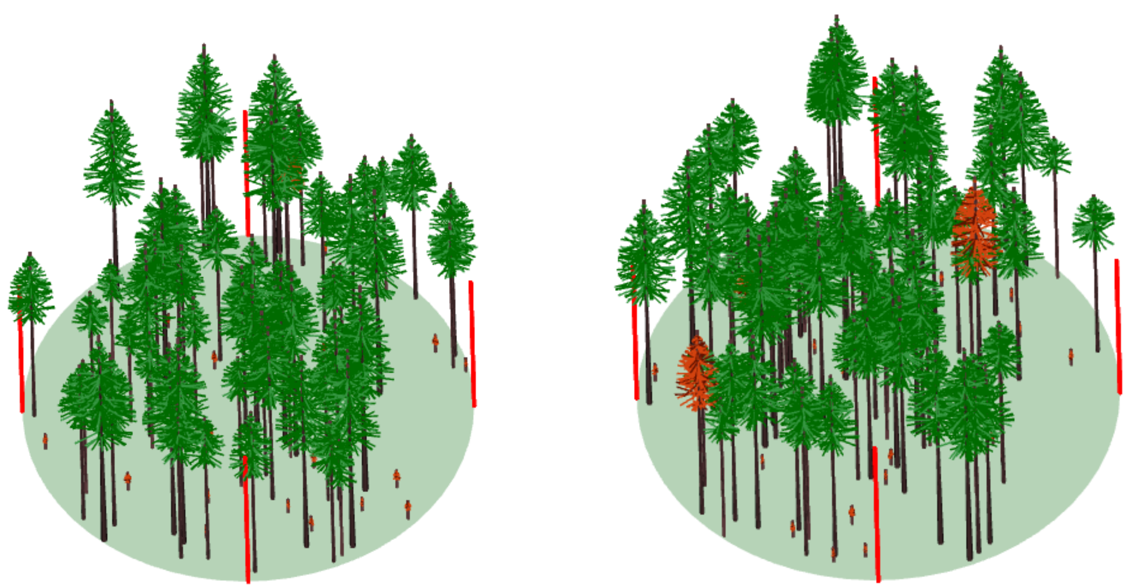

Figure 8. Stand Visualization images produced by FVS of the low severity Hagan plots in 2122. The two examples are from Plots 401 & 805.

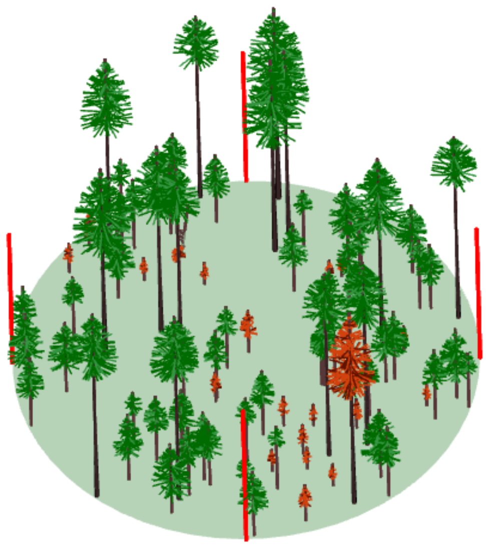

Figure 9. Stand Visualization images produced by FVS of the medium severity Hagan plots in 2122. The two examples are from Plots 314 & 402.

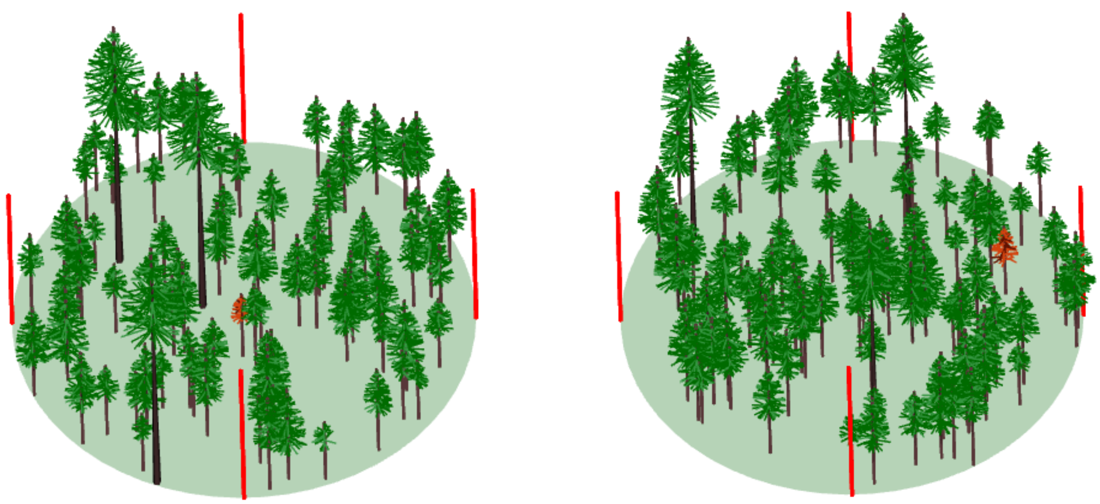

Figure 10. Stand Visualization images produced by FVS of the high severity Hagan plots in 2122. The two examples are from Plots 607 & 628.

Implications

This paper is a case study of what Douglas-fir stand development in the PNW could look like with larger scale wildfires like the Oregon 2020 Labor Day Fires being more common in the future. These results show a potential loss of shade tolerant species, resulting in stands being dominated only by Douglas-fir for extended periods of time before shade tolerant tree species can (re)establish. In this case, moderate fire severity in mature Douglas-fir forests removed shade tolerant tree species while promoting residual Douglas-fir. This resulted in a multi-cohort stand composed only of Douglas-fir and thus, large-scale wildfires may result in future forests with lower tree biodiversity than current old-growth forests. This might have potential negative effects on future forest ecosystem functions. Depending on severity, fires can accelerate forest development to the old-growth stage. If desired, shade tolerant tree species can be planted on sites that were burned under low to moderate severity fires with little to no residual shade tolerant species to promote species-rich development of old-growth Douglas-fir forests. Moderate severity fires or small-scale disturbances may be a tool used to accelerate stand development.

Limitations

There were some limitations in the field data that affected the accuracy/reliability of the FVS projections. Trees less than 5cm DBH were not measured. Delayed mortality from the fire (which can alter structure by bringing more light to the understory to promote additional seedlings, snags, and down wood), was also not accounted for in the modelling. Down wood volume and the presence of snags was also not measured in the field.

When projecting stand development to 2122, subsequent disturbance outbreaks (such as drought, bark beetles, pathogens, or future wildfires which can significantly alter stand development and begin a new cohort of shade tolerant tree species) were also not considered/modeled. Mortality from FVS was based on density dependent factors rather than density independent factors. And, likely most important for projecting future stand conditions, FVS could not automatically simulate ingrowth, and ingrowth seedlings could not be regenerated in the unburned FVS run since those seedlings were suppressed and thus killed off by the model. Regeneration of resprouting hardwood species (e.g. Pacific dogwood, red alder, and bigleaf maple), was also not factored into the modelling. The topography of the plots was not considered on how it would affect stand development. Trees would have difficulty establishing on steeper slopes, and steeper slopes can wash away water and nutrients and deposit them on flatter sites. Aspect also impacts stand development. Southern aspects receive more sunlight, and it might be too hot and dry for seedlings to establish while northern aspects have more shade and moisture which would allow for more seedlings to establish (Agee 1993)

References

Acker, S. A., Sabin, T. E., Ganio, L. M., & McKee, W. A. (1998). Development of old-growth structure and timber volume growth trends in maturing Douglas-fir stands. *Forest Ecology and* Management, 104(1), 265–280. https://doi.org/10.1016/S0378-1127(97)00249-1

Agee, J. (1993). Fire Ecology of Pacific Northwest forests. *Island Press, Washington, D.C., USA*.

Dunn, C. J., Johnston, J. D., Reilly, M. J., Bailey, J. D., & Miller, R. A. (2020). How does tree regeneration respond to mixed-severity fire in the western Oregon Cascades, USA? *Ecosphere (Washington, D.C)*, *11*(1). https://doi.org/10.1002/ecs2.3003

Evers, C., Holz, A., Busby, S., & Nielsen-Pincus, M. 2022. Extreme winds alter influence of fuels and topography on megafire burn severity in seasonal temperate rainforests under record fuel aridity. Fire, 5(41). https://doi.org/10.3390/fire5020041

Franklin, J. F. & Dyrness, C. T. (1988). Natural vegetation of Oregon and Washington ([Rev. & enl. ed.].). *Oregon State University Press*.

Franklin, J. F., Spies, T. A., Pelt, R. V., Carey, A. B., Thornburgh, D. A., Berg, D. R., Lindenmayer, D. B., Harmon, M. E., Keeton, W. S., Shaw, D. C., Bible, K., & Chen, J. (2002). Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management*, *155*(1), 399–423. https://doi.org/10.1016/S0378-1127(01)00575-8

Franklin, J.; Bell, D.; Remillard, S.; Powers, M. 2023. Long-term growth, mortality and regeneration of trees in permanent vegetation plots in the Pacific Northwest, 1910 to present. Long-Term Ecological Research. Forest Science Data Bank, Corvallis, OR. [Database]. Available: http://andlter.forestry.oregonstate.edu/data/abstract.aspx?dbcode=TV010. https://doi.org/10.6073/pasta/5835a1fadb7fd65842f90256edae999c. Accessed 2023-08-28.

Freund, J. A., Franklin, J. F., & Lutz, J. A. (2015). Structure of early old-growth Douglas-fir forests in the Pacific Northwest. *Forest Ecology and Management 335*, 11–25. https://doi.org/10.1016/j.foreco.2014.08.023

FVS Staff. 2008. (revised December 22, 2022). Westside Cascades (WC) Variant Overview – Forest Vegetation Simulator. *Internal Rep. Fort Collins, CO: U. S. Department of Agriculture*, *Forest Service*, *Forest Management Service Center.* 85p.

Google Earth. (2015). Hagan Transects 44°13’22.32” N, 120°42’33.40”W, elevation 3836 ft. *Google*.

Klopsch, M. W. (1986). Structure of mature Douglas-fir stands in a western Oregon watershed and implications for interpretation of disturbance history and succession. *Oregon State* University. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/6t053m55c

Larson, A. J., & Franklin, J. F. (2005). Patterns of conifer tree regeneration following an autumn wildfire event in the western Oregon Cascade Range, USA. *Forest Ecology and Management*, *218*(1), 25–36. https://doi.org/10.1016/j.foreco.2005.07.015

Powers, M. (2023). Personal Communication. *Oregon State University College of Forestry*.

Reilly, M. J. & Spies, T. A. (2015). Regional variation in stand structure and development in forests of Oregon, Washington, and inland Northern California. *Ecosphere (Washington, D.C), 6*(10), art192–27. https://doi.org/10.1890/ES14-00469.1

SAS Institute. (2023). Analytics Software (version 9.4) [Computer software]. *SAS Institute Inc*.

Tepley, A. J., Swanson, F. J., & Spies, T. A. (2013). Fire-mediated pathways of stand development in Douglas-fir/western hemlock forests of the Pacific Northwest, USA. *Ecology (Durham)*, *94*(8), 1729–1743. https://doi.org/10.1890/12-1506.1

Tepley, A. J., Swanson, F. J., & Spies, T. A. (2014). Post-fire tree establishment and early cohort development in conifer forests of the western Cascades of Oregon, USA. *Ecosphere (Washington, D.C)*, *5*(7), art80–23. https://doi.org/10.1890/ES14-00112.1

U.S Department of Agriculture. (1997). Establishment Record for Hagan Research Natural Area. *U.S Department of Agriculture, Forest Service.*

U.S Department of Agriculture. (2023). Forest Vegetation Simulator (2023.2) [Computer software]. *U.S Department of Agriculture*, *Forest Service*.

U.S Department of Commerce. (2023). 1991-2020 Climate Summary of Monthly Normals Cougar Dam, OR US USC00351914 Elev: 1260 ft. Lat: 44.1308° N Lon: -122.2419° W. *U.S Department of Commerce*, *National Oceanic & Atmospheric Administration*, *National Environmental* Satellite, Data*, and Information Service*.