Using the Forest Vegetation Simulator (FVS) To Model Fuel Treatments in the Flagstaff Area

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Abstract. Recent stand-destroying crown fires in the Flagstaff, Arizona area have triggered concerned citizens and scientists to form the Greater Flagstaff Forest Partnership (GFFP). This group has focused on restoring sustainable resilient forest landscapes, especially in the wildland-urban interface (WUI). Fire suppression has contributed to the development of very dense ponderosa pine stands in and near the Flagstaff WUI that pose a significant wildfire risk to homes and businesses. One tool forest managers can use to reduce wildfire risk is thinning, which can create ponderosa pine stands that do not carry catastrophic fire as easily. This paper models several thinning regimes defined by residual basal areas ranging from 40 to 120 sq.ft/acre using the Forest Vegetation Simulator with the Fire and Fuels extension and it also examines several thinning frequencies over 60 years. The model produces estimated stand structure results and fire effects such as flame lengths, crowning index, and torching index, for treated and untreated (control) stands. Simulations were run using moderate and extreme fire parameter conditions. Results indicate that moderate thinning conducted just once can substantially reduce fire risk for at least 60 years but that more severe thinnings better control crowning potential. Modelling fuel treatments can assist land managers in a variety of ways to support contemporary forest management decision-making on the ground to reduce the severe risks associated with catastrophic wildfires.

Key words: *Crown fires; Wildland-Urban Interface; Forest Vegetation Simulator (FVS); Fire and Fuels extension (FFE); stand structure; thinning; fire effects; catastrophic wildfires.*

INTRODUCTION

In 1996, several large fires swept through the forests near Flagstaff, AZ. In the aftermath of the 1996 fire season, concerned citizens and scientists formed the Greater Flagstaff Forest Partnership (GFFP) and started to take a hard look at making homes in the wildland urban interface (WUI) more fire safe. One of the early conclusions they came to was that decades of fire exclusion have led to an increased accumulation in all fuel profiles (ground, surface, ladder and canopy) across the landscape. Reducing the risk of unmanageable wildfire is a central goal of the GFFP.

Figure 1: Typical Dense Fire-Excluded ponderosa pine Stand

Before effective fire suppression, lightning and human-caused fires created openings of variable size within a matrix of forest that was more open than forests around Flagstaff today. The historical heterogeneous pattern of our forests has been replaced by a more homogeneous pattern of smaller openings in a matrix of denser forests (Allen et al. 2002, Covington et al. 1997, Figure 1, above courtesy USDA Forest Service). The southwestern ponderosa pine ecosystem has changed over the last century due to a decrease in fire frequency and an increase in fire intensity and severity causing more extensive stand replacing crown fires (Covington et. al 1997). The uniformity of the vertical fuels (ladder to crown fuel densities) due to fire suppression has led to sufficient stocking of an aerial fuel load to initiate and sustain crown fire activity. The forest densities have increased dramatically and there are larger quantities of younger trees in the forest now than historically (Kaufmann et al. 2007). Increasing forest density has led to wildfires recently that are not only very expensive to suppress, but have become larger in size (Mell et al. 2010) and more severe (Poling 2016); increasing fire hazard in the WUI.

The cost of devastating wildfire is greatest in the WUI at the boundary of forests and homes. The WUI is expanding into more fire-prone vegetation, and this increases the risks from wildfire as residential development continues to encroach on forested areas (Mell et al. 2010). High severity wildfires today are more destructive to societal values, life, property and our ecosystem resources as they are negatively changing the landscape. To reduce the risk of devastating wildfire, fuels management and ecological restoration are possible solutions to the increase in fuel loading (Kalies & Yocom Kent 2016).

Altering the dense structure and composition of southwestern ponderosa pine forests (*Pinus ponderosa*) today through different methods of thinning has become an urgent goal among forest managers. Scientists and land managers seek to use every tool, such as models, in their toolbox to try to understand how the risk of wildfires can be reduced. One of these tools is the Forest Vegetation Simulator (FVS) model. FVS is a distance-independent, individual-tree modelling system used widely by the USDA Forest Service and others to predict forest stand dynamics over time (Dixon 2002). The aim of this paper is to examine thinning options through the use of the FVS model to predict the results of intensities and frequencies of thinnings on long-term fire danger in southwestern ponderosa pine forests typical of those near Flagstaff.

Project Overview

The Greater Flagstaff Forest Partnership (GFFP) is a group of concerned citizens and environmental professionals committed to research and development of ecological restoration for sustainable and resilient landscapes in the Flagstaff area. The GFFP formed after the 1996 fire season, during which over 6 million acres burned in the Western U.S (GFFP 2004).

The Arizona Department of Forestry and Fire Management (ADFFM) shares the same desires as the GFFP in planning and implementing restoration of ponderosa pine forest ecosystems. The ADFFM manages funds received by the federal government used for fuel treatments on private lands, similar to fire safe councils in other regions of the western US. The GFFP and ADFFM teamed up in a collaborative effort with Northern Arizona University (NAU) to provide a scientific background for the development of standards and guidelines for fuel treatments. This collaborative project objective is to provide information and scientific data to assist the GFFP and ADFFM with establishing these standards and guidelines. To contribute to this effort, this study will model different thinning treatments in local ponderosa pine stands, and assess changes in stand structure; [trees per acre (TPA), basal area (BA), canopy base height (CBH), and canopy bulk density (CBD)]; and fire variables [(flame length (FL), torching index (TI), and crowning indexes (CI)] immediately after treatment and 60 years post-treatment.

Figure 2: Treated ponderosa pine Stand

The purpose of this study is to utilize stand inventory data to quantify current forest conditions and model pre- and post-treatment fire behavior and the potential fire effects for the Wing Mountain stands. In this paper FVS is used to model results of thinning and to quantify potential fire behavior by thinning from below to specific basal area targets. This research will determine to what degree (ie. reduction in the number of trees by species and size) and at what frequency (one through four treatments) do stands need to be treated to reduce the probability of crown fires. The specific objectives of this work are 1) to assess how the stand structure variables of tree density, canopy base height and canopy bulk density change by intensity and frequency of treatments; and 2) to assess how fire variables of flame length, torching and crowning indices change by intensity and frequency of treatments.

METHODS

Study Area

The study area for this project is located within the Coconino National Forest; Fort Valley Experimental Forest on Wing Mountain which is located approximately seven miles northwest of Flagstaff, Arizona. Fort Valley Experimental Forest has been in place for over 100 years and is part of the Rocky Mountain Research Station Experimental Forests and Ranges. The Wing Mountain area of the Fort Valley Experimental Forest provides an ideal area for this study because it provides excellent forest inventory data from a forest type that is increasingly occupied by residences as the city of Flagstaff extends into the WUI. There are residential properties just across Highway 180 from the study area, making it closely analogous to the Flagstaff WUI. In Figure 3 shows the Wing Mountain study area and its constituent forest stand types, showing the 115 stands chosen of *Pinus ponderosa* (PIPO, or ponderosa pine), and the three sample stands used for modeling (019, 020, 023). DATA: Andrew Stevenson, Silviculturist, Coconino NF, Wing Mountain.

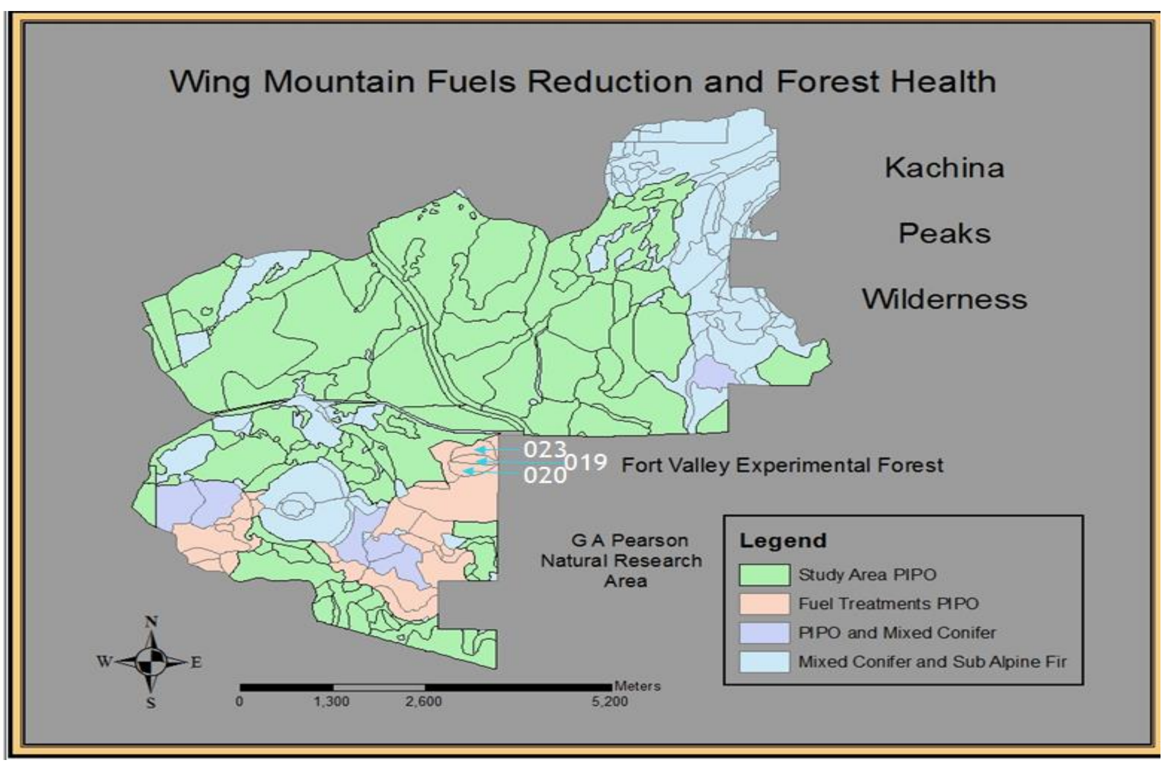

Figure 3: Wing Mountain Study Area

The study area was chosen because it had a recent forest inventory and contained stands of ponderosa pine that had not burned in decades or been thinned or logged. These stands, at the same elevation and with similar fuel loading, are good representatives of the ponderosa pine stands that make up the Flagstaff WUI (GFFP, PFAC. 2004). All 115 stands identified as predominantly ponderosa pine (PIPO in the legend of Figure 1, green and salmon colors) were included in this study. Stands with mixed conifer were not included.

Forest Growth Model

FVS is a family of forest growth simulation models that can simulate a wide range of silvicultural treatments for most major forest tree species, forest types, and stand conditions. FVS has been developed over several decades and continues to be revised as better information becomes available. It is now the most common forest growth and yield model used by natural resource managers and researchers.

FVS is a distance-independent, individual-tree modelling system that uses the forest stand as its basic unit. Stands are the basic unit of management, and projections are dependent on interactions among trees within stands (Crookston and Dixon 2005). It is calibrated for specific geographic areas, and in particular has a regionally specific geographic variant called Central Rockies that covers Arizona and New Mexico as well as several other states (Keyser and Dixon 2015). The model is designed to produce reasonable approximations of forest growth over time using current forest inventory data to describe initial stand conditions and incorporating stand attributes and a list of individual tree information. It models individual tree growth as a function of average stand characteristics (Rebain et al. 2015).

FVS is used here to model stand structures and thinning treatments to test whether those treatments produce results that reduce risks of catastrophic wildfire and assist land managers in their adaptive management prescriptions (Rebain et al. 2015).

FVS Fire and Fuels Extension

The Fire and Fuels Extension to FVS (FFE-FVS) allows for simulations of fires and their fire effects on long-term stand dynamics. FFE-FVS simulates fuel dynamics and potential fire behavior over time, in the context of stand development and management (Reinhardt and

Crookston 2003, Rebain et al 2015). This tool models the effectiveness of proposed fire and fuel management treatments in the context of potential fire behavior and fire effects on short- and long-term stand dynamics. This in turn allows estimates of impacts of the forest management treatment on the severity of fire and the likelihood of a catastrophic fire in the WUI.

The FFE-FVS was used to model severe and moderate fire conditions for the Wing Mountain area. Moderate fire behavior parameters were provided by Mary Lata, USFS Fire Ecologist, Coconino National Forest while severe fire behavior parameters were derived from data from the 2010 Shultz Fire near Flagstaff (Hall et al. 2011 unpublished; Lata, Mary. "Re: Fuel Conditions COF, (FVS)" personal communication, 10 April 2014 and 12 April 2014). To derive the severe fire conditions, Hall used the 97th percentile for weather conditions. "These conditions were determined by using a Coconino National Forest maintained database of weather observations from the Flagstaff RAWS (Remote Automated Weather Station) over the past eight years, and represent the top three percent of the worst fire weather days" (Hall et al. 2011 unpublished).

The fuel moisture percentages used in modeling moderate and severe fire conditions for default conditions in the model and for the conditions used in this paper are shown in Table 1 (Rebain et al. 2015, see Appendix A and B for details). In addition, the wind speed 20 feet above the ground was set at 23 mph for severe and 9 mph for moderate fire conditions.

Table 1: Fuel Moisture Variables and Fuel Models Used for Modeling in FFE-FVS

Fuels	Fuel Moisture Percent			
	FFE-FVS Default		This Model	
	Severe	Moderate	Severe	Moderate
1-hour fuels	4	8	3 (97th)	7
10-hour fuels	4	10	3 (95th)	10
100-hour fuels	5	12	6 (97th)	13
1,000-hour fuels	10	16	8	16
Live woody fuels	70	120	65	80
Live herbaceous fuels	70	120	30	30
20' Wind Speed	0	0	23 (98th)	9

Live herbaceous fuel much moisture percentage was set at 30 percent for both severe and moderate fire conditions because much of Flagstaff's herbaceous vegetation is only green during monsoonal periods, which is typically the time of least concern from a fire potential standpoint, and during high fire hazard these fuels have very low moisture content (Hall et al. 2011 unpublished).

The fuel models used in this paper were provided by Wes Hall, USFS Resource Specialist, and Andrew Stevenson, Silviculturists; Coconino National Forest (Hall et al. 2011 unpublished; Hall, Wes. "Re: Fuel Models, (FVS)" personal communication, 14 April 2014; Stevenson, Andrew. "Re: Fuel Models, (FVS)" personal communication, 15 April 2014; see Appendix A and B for details).

Table: 2 Fuel Models Used for Modeling in FFE-FVS

	No Treatment Stands	Treatment Stands
Fuel Models	TU5-Timber Understory 5– is a very high load, dry climate timber-shrub understory fuel model	TL5-Timber Litter 5-is the high load conifer litter fuel model
	TL8-Timber Litter 8- is a long-needle timber litter fuel model	

These fuel models chosen and shown in Table 2 to represent the No Treatment stands in FFE-FVS were Timber Understory 5 (TU5), and Timber Litter 8 (TL8), and the fuel model chosen to represent Treated stands was Timber Litter 5 (TL5). TU5 is a very high load, dry climate timber-shrub understory fuel model and TL8 is a long-needle timber litter fuel model. TL5 is the high load conifer litter fuel model. The primary carrier of fire in the TU fuel models is forest litter in combination with herbaceous or shrub fuels. Spread rate and flame length are moderate (Scott and Burgan 2005). The primary carrier of fire in the TL fuel models is dead and down woody fuel. Live fuel, if present, has little effect on fire behavior. Spread rate is moderate, and flame length is low.

Dataset

The Fort Valley Experimental Forest conducted a large forest inventory in 2010 on Wing Mountain. The following data were collected for each stand in the inventory:

- Stand data: BA in sq.ft./acre, Live TPA and Dead TPA (snags), Slope, Aspect, and Elevation.
    - Snags are dead standing trees greater than 3 inches in diameter. If the midpoint of the tree is more than 6 feet above ground for trees encountered in fixed and variable radius plots they are inventoried as "standing live or dead" (Brown 1974),
- Individual tree data: Species, Diameter at Breast Height in inches (DBH), Tree Height in feet, CBH in feet.
- Fuels data: Live and dead woody debris in 1 hour fuels of 0.0"-1/4" in diameter, 10 hour fuels of ¼"-1", 100 hour fuels of 1"-3", and 1000 hour fuels of 3" and greater, depth of litter layer, duff layer, amount of live and dead woody material in the duff layer, and live herbaceous.

Using a Geographic Information System (GIS) layer depicting existing vegetation to select for ponderosa-pine-dominated stands, all stands of ponderosa-pine-dominated forest in basaltic soils (115 total) were selected from the Wing Mountain stand inventory dataset for this study. These 115 stands contain groups of mature trees with dense thickets of smaller diameter ponderosa pine trees and a minor component of Gambel oak (*Quercus gambelii*). The understory vegetation consists mainly of Arizona fescue (*Festuca arizonica*), mountain muhly (*Muhlenbergia montana*), squirreltail (*Sitanion hystrix*), and forbs (Mast et al. 1999).

Out of the 115 stands, three stands were selected to model the results of various levels of thinnings over time. The selection of the stands was determined by the best representation of the stand conditions in the Flagstaff WUI (GFFP, PFAC. 2004), like TPA and BA (sq.ft./acre), and to find three stands from the higher, middle and lower end of these ranges. The selected stands for modeling are stand 800019 (019), stand 800020 (020), and stand 800023 (023).

Stand Structure

Average stand structure of the 115 ponderosa pine stands in the Wing Mountain dataset and the three stands subset selected for modeling treatment are compared by using five variables: TPA, BA (sq.ft./acre), QMD (in), CBD (kg/m3), and stand CBH (ft). Of these variables, TPA, BA, and CBH were measured directly in the field. Individual tree crown base height was measured and averaged from the 2010 data collection at 16.327 feet for all 115 stands and 16.333 feet for the 2010 3-stands. FVS calculates stand CBH by using crown bulk density ranges; therefore, the 2010 data CBH represent measured values and the treatment years of 2014, 2034, 2054, and 2074 are modeled outputs.

The average values for the five variables for the 115-stand population and the three-stand sample are shown below in Table 3. It also shows the results of the FVS model "growing" the stands from the 2010 inventory date to the 2014 treatment initiation date.

These baseline variables show dense stands of mostly small trees. In the four years the stands were "grown" in the FVS model, they lost a few of the smaller trees, gained some growth on remaining trees, but remained very dense and fire-susceptible. The BA for the three-stand sample is very similar to the 115-stand population, though TPA is higher than the average for the 115 stands, indicating that the three-stand sample represents a slightly worse scenario with a smaller QMD and higher stocking.

Table 3: Average of Pre-Treatment Stand Structure for TPA, BA (sq.ft/ac), CBD (kg/m3), CBH (ft), and QMD (in)

	115-stand population		3-stand sample	
Variable	2010 Measured Value	2014 Pre-Treatment Modeled Value	2010 Measured Value	2014 Pre-Treatment Modeled Value
TPA	347	337	407	401
BA (sq.ft/ac)	154	158	151	156
QMD (in)	9.0	9.3	8.2	8.5
CBD (kg/m3)	0.07	0.07	0.06	0.05
CBH (ft)	16	17	16	18

A comparison of the range and standard deviation for BA and TPA between the 3-stand sample and their parent group of 115 stands is shown below (Table 4). It shows that the mean BA of the 3-stands sample is close to the mean for the 115-stand population, but that the 3-stand sample has higher tree density. The 115-stand population has a very wide range for both BA and TPA.

The standard deviation for the 3-stand sample is higher for both BA and TPA likely due to the small sample size.

Table 4: Pre-Treatment Range and Standard Deviation of BA and TPA in 115-Stand Population and 3-Stand Sample in 2014.

	Basal Area (sq. ft./ac)		Trees per Acre	
Values for 2014	115 Stands	3 Stands	115 Stands	3 Stands
Range	76-293	83-237	70-1215	115-611
Standard Deviation	46	77	205	256

Fire Effects

The Wing Mountain dataset provides the data needed for developing the output variables in FFE-FVS that describe probable fire severity. Flame length is dependent on the fuels variables, while torching index and crowning index depend on CBD and CBH as well as the fuel loading.

Treatment Prescriptions

The first research question was to determine what level of thinning intensity would adequately reduce fire hazard in stands, and how fire hazard would change in those stands over a 60-year simulation timescale. At the recommendation of the GFFP and ADFFM, FVS applied a modeled thin from below designed to achieve residual basal area goals of 120, 100, 80, 60, or 40 sq. ft./ac.

The second research question was to determine if a single thinning was sufficient or if multiple thinnings were required to achieve a satisfactory reduction in fire hazard, not only immediately after the thinning, but over time. Therefore, thinnings were applied just once in 2014 or repeated on a 20 or 40-year cycle. These thinnings were compared against the FVS model of stand growth over the same 60 years with no treatment.

The Wing Mountain data were collected in 2010. Individual trees and stands represented in the inventory of the stands were grown in the model to 2014, when this study began. Treatments were applied starting in 2014. The 20-year cycle meant that the same level of thinning conducted in 2014 was modeled again for 2034 and 2054, while the 40-year cycle meant that an additional thinning was conducted only in 2054. All stands were then modeled to grow in FVS to 2074. Appendix A provides the variables used for the model runs that provided the no-treatment results while Appendix B provides the variables used for the model runs that simulated various levels and repetitions of thinnings. Appendix C provides a sample of the FVS stand structure outputs, in this case for a single treatment to a residual BA of 40 (sq.ft./acre), while Appendix D provides the fire model keywords and variables used for the FFE-FVS model. Finally, Appendix E shows a sample of raw output for fire effects for the three stands.

RESULTS

Results of the FVS model runs are reported first for untreated stands, then for stands with one treatment in 2014, then for multiple treatments. All treatment results are shown at the end of the 60-year cycle, although FFE-FVS provided results annually and by decade. All results are restricted to the three-stand sample.

No Treatment

Stand Structure

Average stand structure in 2014 showed dense stands with many small trees. Without treatment and over the 60 years of the simulation, average mortality was 143 trees or 36 percent of the pre-treatment value. Basal area and QMD increased moderately, while CBH increased as the smaller trees died over the 60-year span. The stands at the end of the 60-year modeled growth were still very dense and very fire-prone, as shown in Table 5, below.

Table 5: No Treatment; Stand Structure Outputs Over Time

Year	Basal Area (sq. ft./ac)	Trees per Acre	QMD (in)	CBH (ft)	CBD (kg/m3)
2014	156	401	8.4	18	0.06
2034	168	340	9.5	27	0.06
2054	173	290	10.5	28	0.05
2074	177	258	11.2	31	0.05

Fire Effects

Flame Lengths

Flame lengths needed to initiate a crown fire under moderate and severe conditions over the 60 years of the study without treatment are shown in Table 6 and Figure 4. As modeled by FVS, flame lengths did not vary much over the 60 years of study.

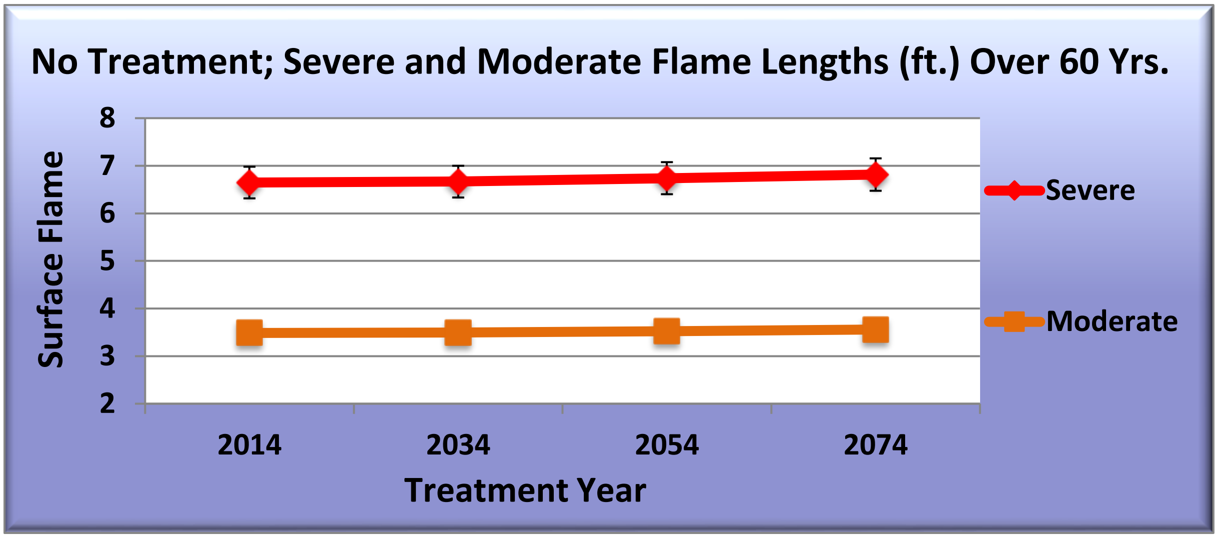

Figure 4: No Treatment, Severe and Moderate Flame Lengths (ft.) over 60 Years

Table 6: No Treatment; Severe and Moderate Flame Lengths (feet) Over 60 Years

Year	Severe	Moderate
2014	6.64	3.48
2034	6.66	3.49
2054	6.73	3.52
2074	6.81	3.55

Crowning and Torching Indices

These two indices are based on the wind velocity required to cause a fire to climb into the crowns of a stand (Torching Index or TI) or to carry a fire in the crowns of a stand (Crowning Index or CI). In general it takes higher wind speeds to push a fire into the crowns (TI) than to sustain that fire in the crowns (CI) once it reaches the canopy. For the no-treatment scenario, the mortality in the stand that gradually increases the CBH in the remaining trees also contributes to a gradual increase in the TI. That same natural mortality is modeled to reduce TPA by 143 trees on average over the 60-year study period (2014-2074), which also slightly increases the wind speed needed to sustain a crown fire. Table 7, below, summarizes change over time for both indices, while Figure 5 shows the change graphically.

Table 7: No Treatment; Torching and Crowning Index Over 60 Years

No Treatment Year	TI (mph)	CI (mph)
2014	52	36
2034	80	37
2054	78	40
2074	84	45

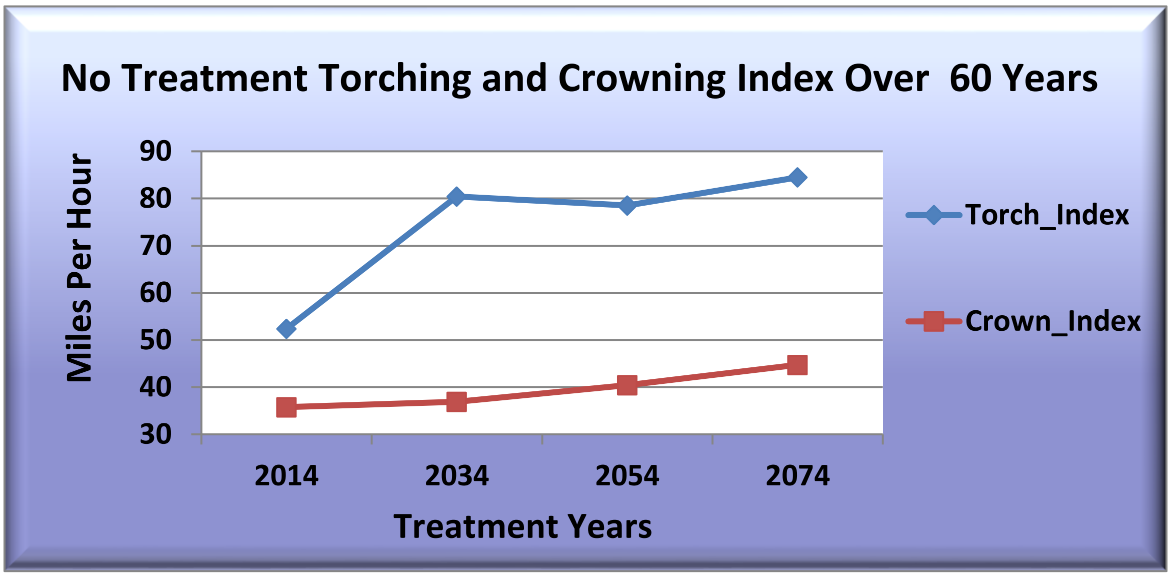

Figure 5: No Treatment Torching and Crowning Indices Over 60 Years

Single Thinning in 2014

Stand Structure

The single thinning conducted in 2014 was programmed to reduce targeted residual basal area to 120, 100, 80, 60, or 40 sq. ft. /acre. However, FVS was unable to model the densest residual basal areas and reduced stands to 108 square feet instead of 120, and 94 square feet instead of 100. This is due to the thin from below modeled treatment. FVS had to remove one more tree to reach its target but the last removal surpassed the actual target. Thus the actual residual basal area was 108, 94, 80, 60, and 40 sq. ft. /acre.

Table 8: 2014 Stand Structure Outputs After Single Thinning, by BA (sq. ft./ac) Targets

Basal Area (sq. ft./ac)		TPA	QMD (in)	CBH (ft)	CBD (kg/m3)
Target	2014 Modeled				
40	40	24	15.6	50	0.02
60	60	48	15.1	46	0.02
80	80	71	14.4	40	0.03
100	94	96	13.4	35	0.03
120	108	129	12.4	33	0.04
No treatment	156	401	8.4	18	0.06

Stand structure outputs 60 years after the single treatment show stands with fewer TPA but greater BA and larger QMD, as seen in Table 9, below.

Table 9: 2014 Single Treatment of BA (sq. ft./ac) Targets Stand Structure Outputs-Compared to 2074 Stand Structure Over 60 Years

Basal Area (sq. ft./ac)		TPA	QMD (in)	CBH (ft)	CBD (kg/m3)
2014 Target	2074 Modeled				
40	60	24	21.4	55	0.01
60	86	33	21.9	54	0.01
80	106	44	21.0	53	0.02
100	126	62	19.3	50	0.02
120	144	92	16.9	47	0.03
No Treatment	177	258	11.2	31	0.05

Fire Effects

Flame lengths

The reductions in surface flame lengths immediately after a single treatment are shown below in Table 10 and Figure 6. The sharp drop in flame lengths for both severe and moderate fire scenarios is likely due to the mechanical thinning from below and an the change in fuel models from fuel model TU5 (very high load, dry climate) and TL8 (high load conifer litter) to the Treatment fuel model of TL5 (High load conifer litter). The TU 5 model is a very high load, dry climate timber-shrub understory fuel model, which represents conditions pre-treatment. Because the modeled treatment reduced the timber understory to nearly zero by thinning from below, the fuel model was shifted to TL5 after treatments (see Appendix A and B for details).

Table 10: 2014 Single Treatments of Severe and Moderate Surface Flame Lengths in feet

Basal Area (sq. ft./ac)	Single Treatment, 2014 Results	
	Severe	Moderate
40	3.78	1.62
60	3.30	1.44
80	3.01	1.33
100	2.87	1.28
120	2.73	1.23
No Treatment	6.65	3.49

The no treatment severe surface flame length is less than 7 feet and the moderate surface flame lengths are between 3 and 4 feet. The least severe thinning, as modeled, reduces the flame lengths by over half under both severe and moderate conditions and appears to reduce flame lengths slightly better than the more severe thinnings.

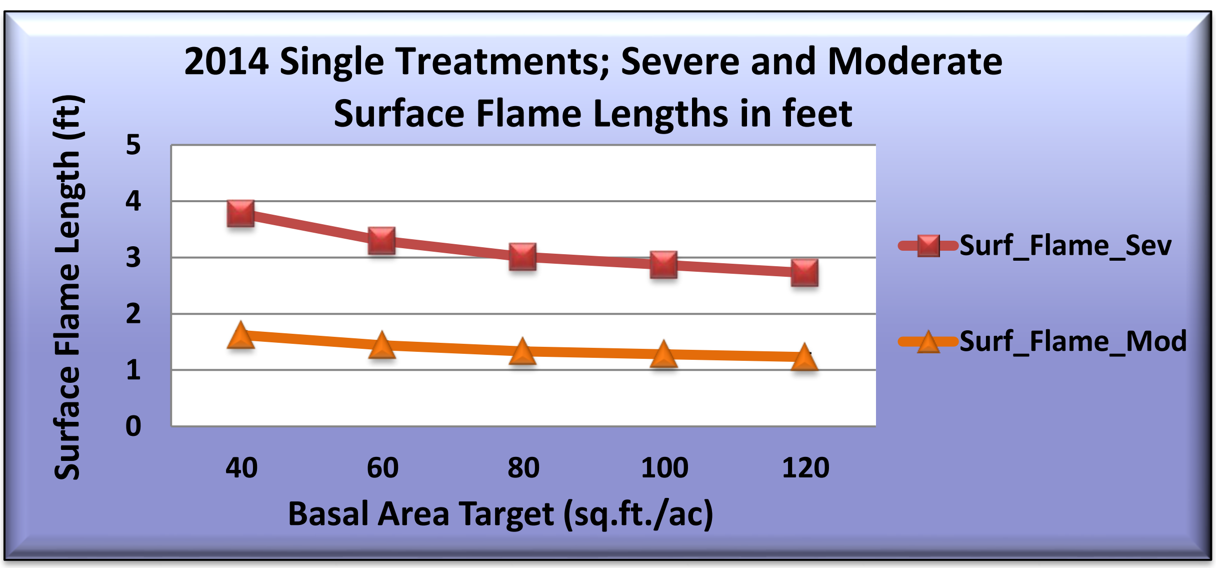

Figure 6: 2014 Single Basal Area (sq. ft./ac) Treatments; Severe and Moderate Flame Lengths in feet

After 60 years the single treatment stands showed closely similar results to those shown immediately after thinning, with the best results continuing to be shown in the lowest thinning intensity (Table 11 and Figure 7).

Table 11: 2074 Severe and Moderate Surface Flame Lengths in feet After 2014 Single Basal Area (sq. ft./ac) Treatments.

Basal Area (sq. ft./ac)	2074 Flame Length in feet Results-Single Treatment in 2014	
	Severe Conditions	Moderate Conditions
40	3.55	1.53
60	3.12	1.37
80	2.95	1.31
100	2.78	1.25
120	2.64	1.20
No Treatment	6.82	3.56

The various levels of treatment made no significant difference in reduction in flame length under either moderate or severe fire conditions. The lightest thinning, to a residual BA of 120, did better than the heaviest thinning to a residual BA of 40. Any treatment reduced flame lengths by about half. This reduction in flame length is seen immediately after treatment and is sustained over the 60 years of model runs, showing a slight reduction in flame lengths after 60 years even in the lightest thinning scenario.

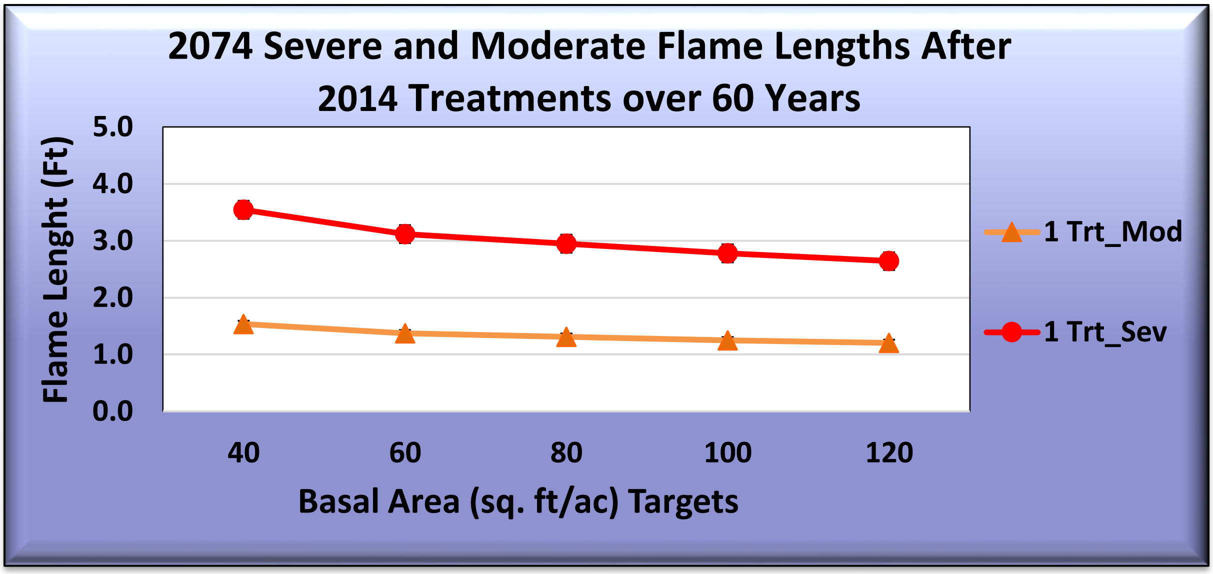

Figure 7: 2074 Severe and Moderate Flame Lengths After 2014 Treatments over 60 Years

Torching Index

Changes in the probable wind speeds in miles per hour (mph) of torching by no treatment with fuel models TL8 and TU5 are shown in Table 12 and Figure 8, below. For the 2014 one-time basal area treatment of 40, 60, 80, 100, and 120 the fuel model used is TL5. The increase in wind speed to torch is due to the combination of the fuel model used and the lack of ladder fuels after thinning from below, resulting in modeled wind speeds in excess of any recorded or likely future winds.

Over the 60-year timespan of the study, the model predicts torching index to rise even further, even without treatment, likely due to mortality being modeled from below and a substantial reduction in smaller TPA over time. It is also possible that FVS does not properly model the fuel loading resulting from that mortality. With a single treatment, wind speeds for torching are modeled to be much higher than any likely future attainable winds, indicating that the model assumes that these stands are very unlikely to carry fire into the crown. This may be due in part to the change in fuel model from TL8/TU5 for untreated and TL5 for the treated stands.

Table 12: 2014 Single Basal Area (sq. ft./ac) Treatment Torching Index compared to 2074 Potential Fire Behavior after 60 Years.

Basal Area (sq. ft./ac)	Torching Index (mph)	
	2014	2074
40	252	321
60	291	380
80	290	415
100	270	435
120	287	449
No Treatment	52	84

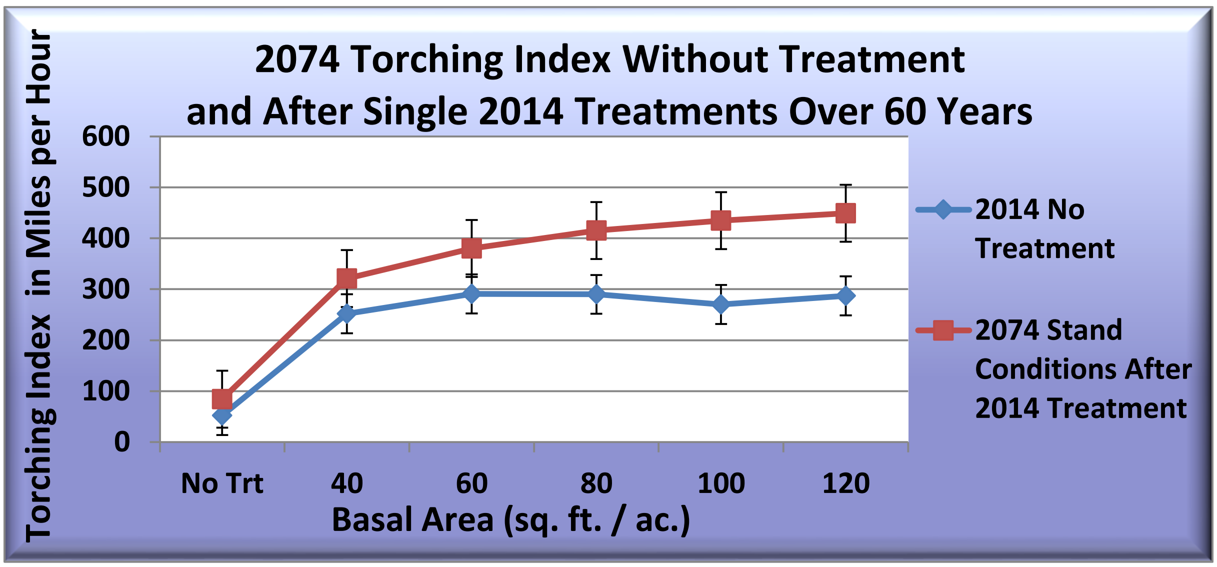

Figure 8: 2074 Torching Index over Basal Area Without Treatment and After Single 2014 Treatments After 60 Years

Crowning Index

Crowning Index is an indicator of the wind speed needed to sustain a crown fire once the fire has reached the crowns. The more severe thinnings show a substantially higher crowning index than the lesser thinnings because there are so few trees remaining in the stand to carry the fire. In the 40 BA residual stands, for example, there are only 24 trees per acre remaining in the model in 2014. CI is the only output variable that shows a greater response to increasing intensities of treatment, as seen in Table 13 and Figure 9, below.

Table 13: 2014 Single Basal Area (sq. ft./ac) Treatment Crowning Index compared to 2074 Potential Fire Behavior after 60 Years.

BA Target	Crowning Index (mph)	
	2014	2074
40	80	101
60	60	84
80	51	71
100	48	60
120	46	54
No Treatment	52	84

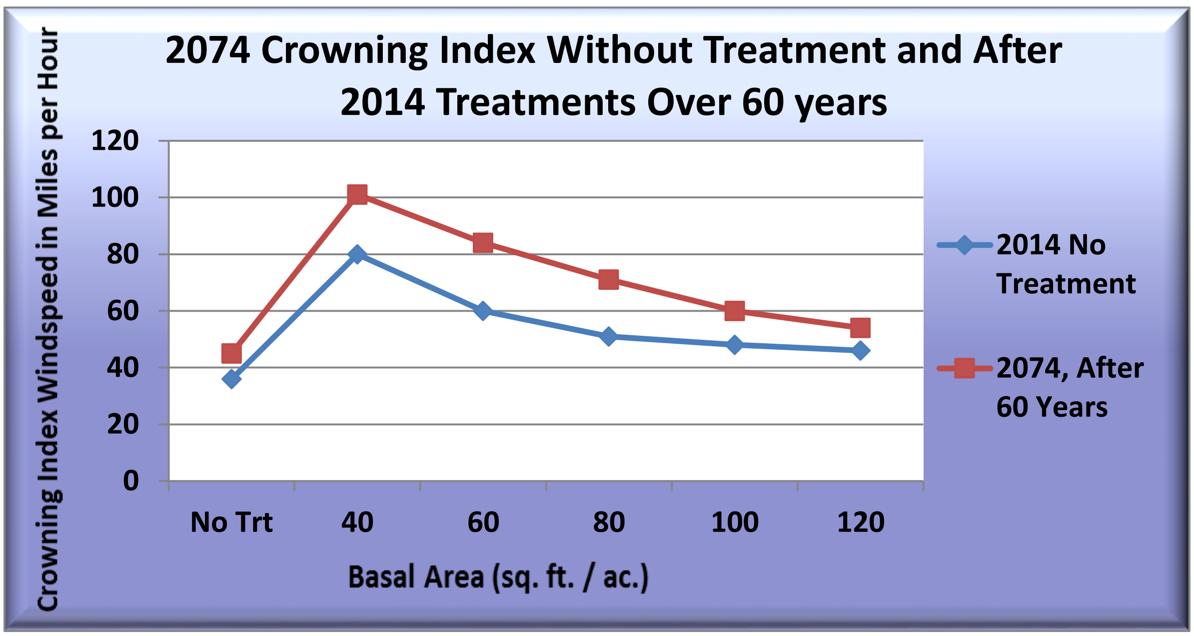

Figure 9: 2074 Crowning Index Over Basal Area 2014 Without Treatment and After 2014 Single Treatments Over 60 Years

Two Treatments and Four Treatments

Stand Structure

Stand structure output data for pre and post treatments to target residual basal areas of 40, 60, 80, 100, and 120 ft² per acre over 60 years is shown in Table 14. Treatment years were:

- Single treatment: 2014
- Two treatments: 2014 and 2054
- Four treatments: 2014, 2034, 2054, and 2074.

FVS outputs show that the additional thinnings will reduce stand density further over time as indicated by reduced TPA. The thinnings to BA targets of 40, 60, and 80 leave fewer than 40 TPA, probably too severe for most landowners. Even the least severe thinning leaves fewer than 50 TPA after 60 years.

Fire Effects

Fire effects output data for pre- and post- treatments to target residual basal areas of 40, 60, 80, 100, and 120 sq.ft./ac over 60 years are shown in Table 14. Treatment years were:

- Single treatment: 2014
- Two treatments: 2014 and 2054
- Four treatments: 2014, 2034, 2054, and 2074.

FVS variables displayed are severe and moderate flame length (FL), crowning index (CI), and torching index (TI). While additional thinnings do reduce fire risks and hazards, they do so only to a small extent when compared with a single treatment in 2014 (Table 15). For example, a single treatment in the 120 sq.ft./ac BA target stands results in a CI of 46.21 mph immediately after treatment and a CI of 54.23 after 60 years. The two-treatment scenario increases crowning index to 64.55 mph at 60 years, but that is well within the range of historic wind speeds during fires. By contrast, the more severe 40 sq.ft/ac BA target single treatment results in a CI of 80.16 mph after one treatment in 2014 and a CI of 101.43 mph after 60 years, while the two-treatment scenario increases CI to 126.15 mph after 60 years, still within the historic range of wind speeds in the Flagstaff area. Four treatments to the 40 sq.ft/ac BA target result in a CI of 130.41 mph after 60 years. While this is an improvement over the modeled CI of 101.43 mph with just one treatment, it is still within the historic range of wind probabilities in Flagstaff. According to the FVS-FFE model, any of the treatments results in stands that may sustain a crown fire under very severe wind conditions.

Table 14: Stand Structure Output Data for All Treatments

	40 BA				60 BA				80 BA				100 BA				120 BA			
YEAR	TPA	BA	CBH	CBD	TPA	BA	CBH	CBD	TPA	BA	CBH	CBD	TPA	BA	CBH	CBD	TPA	BA	CBH	CBD
No Treatment																				
2010	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06
2014	400.67	156.00	18.00	0.06	400.67	156.00	18.00	0.06	400.67	156.00	18.00	0.06	400.67	156.00	18.00	0.06	400.67	156.00	18.00	0.06
2034	340.00	167.67	27.67	0.06	340.00	167.67	27.67	0.06	340.00	167.67	27.67	0.06	340.00	167.67	27.67	0.06	340.00	167.67	27.67	0.06
2054	289.67	172.67	28.33	0.05	289.67	172.67	28.33	0.05	289.67	172.67	28.33	0.05	289.67	172.67	28.33	0.05	289.67	172.67	28.33	0.05
2074	257.67	177.00	31.00	0.05	257.67	177.00	31.00	0.05	257.67	177.00	31.00	0.05	257.67	177.00	31.00	0.05	257.67	177.00	31.00	0.05
1 Treatment																				
2010	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06
2014	24.00	40.00	49.67	0.02	48.00	60.00	46.33	0.02	71.33	80.00	40.33	0.03	96.33	94.33	34.67	0.03	129.00	107.67	33.33	0.04
2034	21.00	50.00	52.67	0.01	36.33	72.33	51.33	0.02	55.67	93.00	49.00	0.02	77.00	109.33	42.00	0.03	110.33	124.67	40.33	0.03
2054	22.67	56.33	55.00	0.01	34.33	81.00	52.00	0.02	49.33	101.00	51.00	0.02	68.33	120.33	47.67	0.03	99.67	137.00	43.67	0.03
2074	24.00	60.33	55.67	0.01	32.67	85.67	53.67	0.01	44.00	106.33	53.00	0.02	61.67	126.33	50.00	0.02	91.67	144.33	47.33	0.03
2 Treatment																				
2010	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06
2014	24.00	40.00	49.67	0.02	42.00	60.00	46.33	0.02	65.33	80.00	40.33	0.03	90.33	94.33	34.67	0.03	124.67	107.67	33.33	0.04
2034	21.00	50.00	52.67	0.01	36.33	72.33	51.33	0.02	55.67	93.00	49.00	0.02	77.00	109.33	42.00	0.03	110.33	124.67	40.33	0.03
2054	12.00	40.00	56.00	0.01	20.67	60.00	52.33	0.01	35.33	80.00	51.33	0.02	47.67	94.67	50.33	0.02	61.00	108.00	47.33	0.03
2074	14.33	43.33	55.33	0.01	20.33	64.33	56.67	0.01	31.00	84.00	48.00	0.02	41.67	99.33	53.33	0.02	54.67	114.33	51.00	0.02
4 Treatment																				
2010	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06	406.67	151.33	16.33	0.06
2014	24.00	40.00	49.67	0.02	42.00	60.00	46.33	0.02	65.33	80.00	40.33	0.03	90.33	94.33	34.67	0.03	124.67	107.67	33.33	0.04
2034	15.67	40.00	53.67	0.01	27.67	60.00	51.00	0.01	44.67	80.00	49.67	0.02	63.33	95.67	46.00	0.03	81.00	109.00	42.33	0.03
2054	11.67	40.00	55.00	0.01	20.67	60.00	52.67	0.01	34.00	79.00	51.00	0.02	53.67	94.67	50.67	0.02	60.00	108.00	48.00	0.03
2074	10.67	39.00	56.67	0.01	16.67	59.33	56.00	0.01	31.00	84.00	54.33	0.01	37.00	91.67	53.33	0.02	46.33	105.00	52.33	0.02

Table 15: Fire Effects Indices Output for All Treatment Levels

	40 BA				60 BA				80 BA				100 BA				120 BA			
YEAR	FL SEV	FL MOD	TI	CI	FL SEV	FL MOD	TI	CI	FL SEV	FL MOD	TI	CI	FL SEV	FL MOD	TI	CI	FL SEV	FL MOD	TI	CI
No Treatment																				
2010	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49
2014	6.65	3.49	52.39	35.78	6.65	3.49	52.39	35.78	6.65	3.49	52.39	35.78	6.65	3.49	52.39	35.78	6.65	3.49	52.39	35.78
2034	6.67	3.50	80.43	36.88	6.67	3.50	80.43	36.88	6.67	3.50	80.43	36.88	6.67	3.50	80.43	36.88	6.67	3.50	80.43	36.88
2054	6.74	3.53	78.49	40.42	6.74	3.53	78.49	40.42	6.74	3.53	78.49	40.42	6.74	3.53	78.49	40.42	6.74	3.53	78.49	40.42
2074	6.82	3.56	84.47	44.74	6.82	3.56	84.47	44.74	6.82	3.56	84.47	44.74	6.82	3.56	84.47	44.74	6.82	3.56	84.47	44.74
1 Treatment																				
2010	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49
2014	3.78	1.62	252.03	80.16	3.30	1.44	290.84	59.98	3.01	1.33	289.97	50.53	2.87	1.28	270.06	47.82	2.40	1.12	286.53	46.21
2034	3.62	1.56	289.36	97.00	3.18	1.40	347.77	78.64	2.96	1.32	372.16	60.87	2.81	1.26	348.01	54.09	2.73	1.23	370.58	49.17
2054	3.55	1.54	315.62	111.45	3.12	1.37	365.59	80.28	2.95	1.31	395.08	65.01	2.78	1.25	408.91	56.82	2.66	1.21	410.13	50.10
2074	3.55	1.53	321.25	101.43	3.12	1.37	379.92	83.86	2.95	1.31	414.53	70.69	2.78	1.25	435.29	60.33	2.64	1.20	448.54	54.23
2 Treatment																				
2010	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49
2014	3.78	1.62	252.03	80.16	3.30	1.44	290.84	59.98	3.01	1.33	289.97	50.53	2.87	1.28	270.06	47.82	2.40	1.12	286.53	46.21
2034	3.62	1.56	289.36	120.92	3.18	1.40	347.77	78.64	2.96	1.32	372.16	60.87	2.81	1.26	348.01	54.09	2.73	1.23	370.58	49.17
2054	3.94	1.68	269.77	133.63	3.44	1.49	311.82	92.70	3.11	1.37	360.70	72.60	2.99	1.33	378.78	60.30	2.66	1.21	381.61	52.14
2074	3.92	1.67	268.95	126.15	3.42	1.49	343.69	108.06	3.13	1.44	386.47	72.99	2.99	1.33	405.81	73.64	2.87	1.28	419.86	64.55
4 Treatment																				
2010	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49	6.67	3.50	46.90	35.49
2014	3.78	1.62	252.03	80.16	3.30	1.44	290.84	59.98	3.01	1.33	289.97	50.53	2.87	1.28	270.06	47.82	2.40	1.12	286.53	46.21
2034	3.88	1.66	264.30	134.07	3.37	1.47	312.36	89.21	3.08	1.36	353.87	64.82	2.93	1.30	355.33	55.86	2.73	1.23	351.10	50.60
2054	3.94	1.69	264.26	119.47	3.44	1.50	313.93	97.63	3.12	1.38	355.86	81.33	2.99	1.33	381.21	64.76	2.81	1.26	387.57	55.99
2074	4.02	1.71	264.75	130.41	3.54	1.53	321.75	107.35	3.17	1.39	372.01	87.37	3.05	1.35	391.03	79.72	2.87	1.28	410.31	65.01

Flame Length

Results show that there is no significant difference among frequency of thinnings, such that one thinning in 2014, regardless of intensity, dramatically reduces flame length (Table 16 and Figure 10). The model shows this reduction persisting through time even without further treatment, and shows no important differences among thinning intensities. This is likely due to the FVS removal of all small trees during any of its mechanical thinnings from below, raising stand CBD even with one thinning.

Table 16: Flame Lengths 60 Years after Two and Four Thinning Treatments

Target BA (sq. ft./ac)	Two Treatments, 2074 Results		Four Treatments, 2074 Results	
	Moderate Conditions	Severe Conditions	Moderate Conditions	Severe Conditions
40	1.67	3.92	1.71	4.02
60	1.37	3.11	1.53	3.54
80	1.48	3.42	1.39	3.17
100	1.32	2.99	1.35	3.05
120	1.28	2.87	1.28	2.87
no treat	3.56	6.82	3.56	6.82

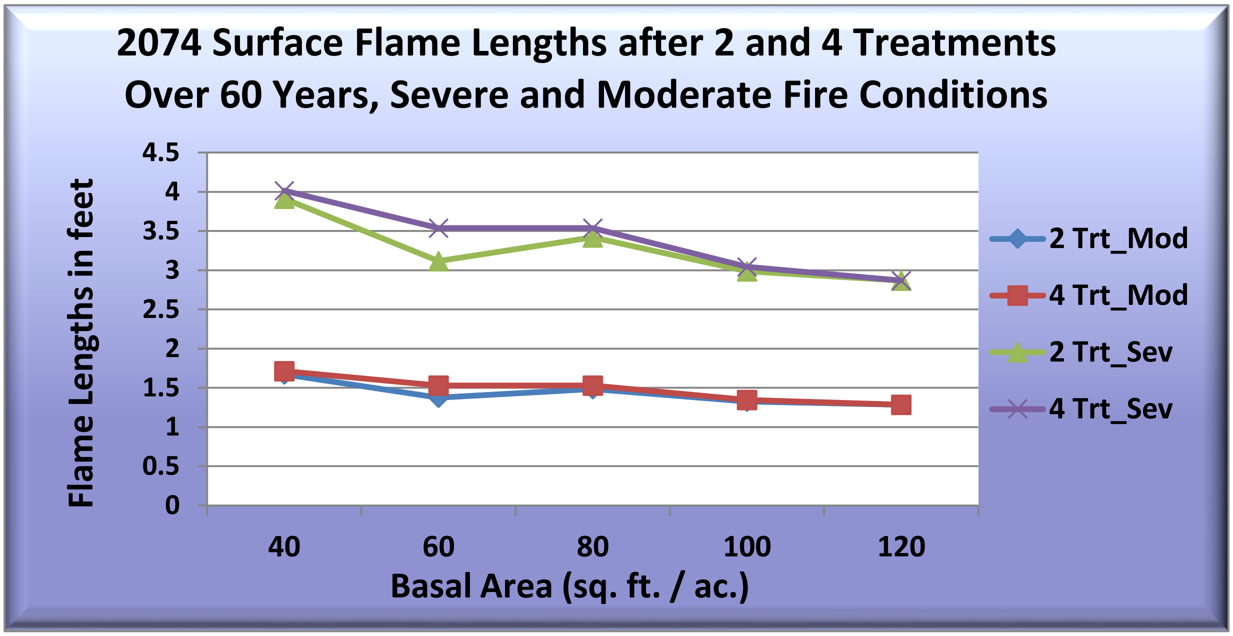

Figure 10: 2074 Surface Flame Lengths, Severe and Moderate Fire Conditions, Two and Four Treatments, after 60 years

Torching Index

Even a single treatment shows huge increases in wind speeds needed to create torching conditions (Table 17 and Figure 11), much above any recorded or likely future wind speeds under a forest canopy in the Flagstaff area. After 60 years, the two-and four-treatment model runs show *decreases* in the wind speed necessary for a fire to reach into the crowns, a paradoxical result likely explained by how the model treats surface fuels in the more severe thinnings. However, the wind speed results from the model at all treatment levels are still much higher than historically recorded windspeeds under the canopy in the Flagstaff area.

Table 17: 2074 Torching Index for Two and Four Treatments with TPA

BA Target (sq. ft./ac.)	2074 Torching Index (mph)		TPA	
	Two Treatments	Four Treatments	Two Treatments	Four Treatments
40	269	265	14	11
60	344	322	20	17
80	386	372	31	31
100	406	391	42	37
120	420	410	55	46
No Treatment	84	84	84	84

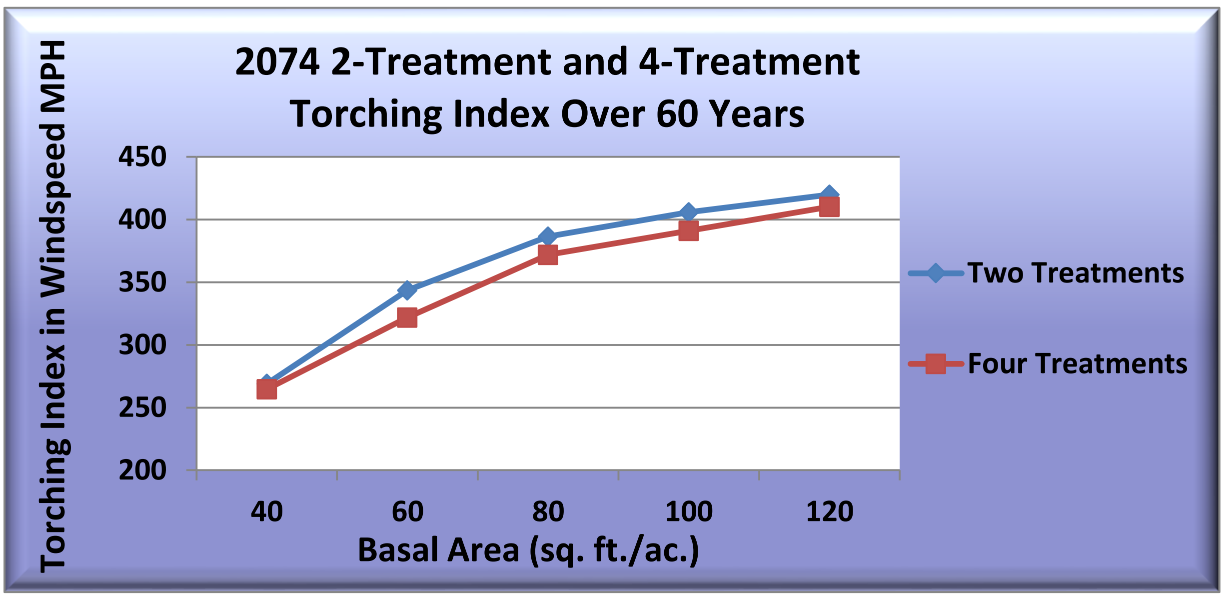

Figure 11: 2074 Torching Index for Two and Four Treatments Over 60 Years

Crowning Index

The results for two and four treatments are very similar to those for a single treatment, again because TPA is so dramatically reduced for the most severe thinnings at the first treatment that high wind speeds would be needed to carry a fire. Table 18 and Figure 12 show the resultant wind speeds needed to maintain a crown fire in 2074, 60 years after initial treatment. The spacing from the thin from below cut left a residual TPA of 14 with two treatments and 11 for four treatments for the 40 sq.ft/ac BA target. These low TPA values result in low CBD values, which drive the model's assumptions about the wind speed needed to carry fire from crown to crown.

Table 18: Crowning Index after 60 Years for Two and Four Treatments

BA Target (sq.ft./ac.)	Crowning Index (CI) mph		Trees per Acre (TPA)	
	Two Treatments	Four Treatments	Two Treatments	Four Treatments
40	126	130	14	11
60	108	107	20	17
80	73	87	31	31
100	60	80	42	37
120	65	65	55	46
No Treatment	45	45	84	84

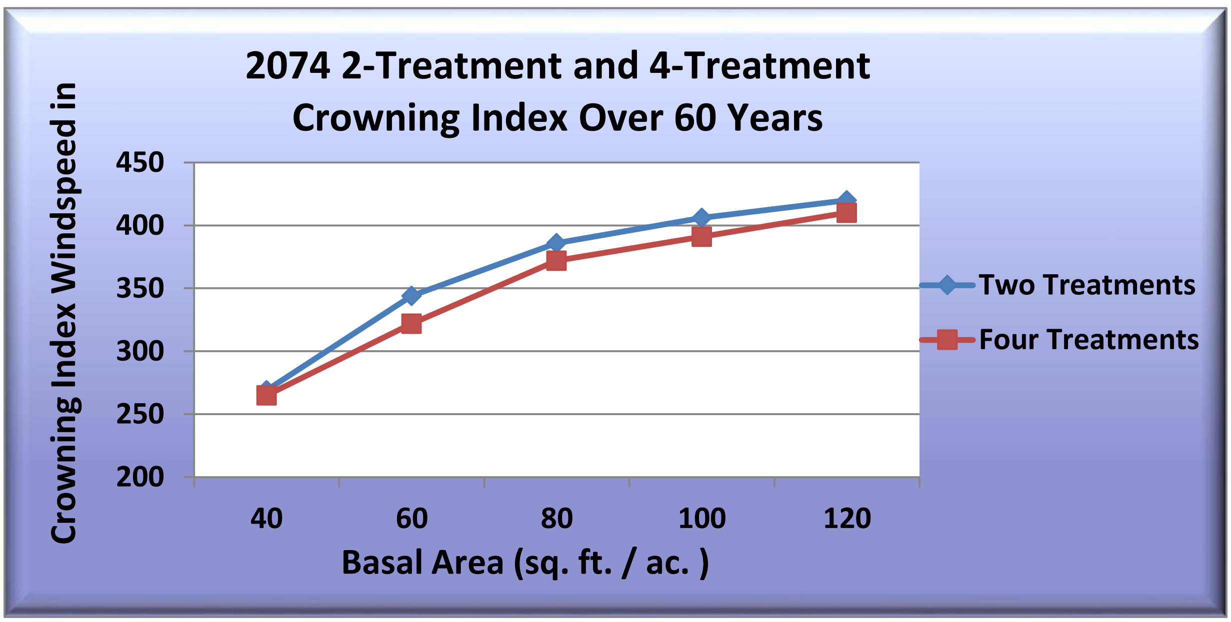

Figure 12: 2074 Crowning Index for Two and Four Treatments after 60 Years

DISCUSSION

The goal of this study was to provide recommendations to the GFFP and the ADFFM for the development of standards and guidelines that can help reduce fire risks and hazards in the Flagstaff WUI. The specific objectives of this work were:

1. To assess how FVS models stand structure changes in ponderosa pine stands similar to those found in the Flagstaff WUI in TPA, BA, CBH and CBD based on intensity and frequency of thinnings; and
2. To assess how fire variables of flame length (FL), torching index (TI), and crowning index (CI), change by intensity and frequency of thinnings.

In all basal area treatments except the initial 40 sq.ft./ac BA treatment, the model shows a reduction of trees per acre over time after the initial thinning. The FVS model shows that CBH rises from around 18 to about 50 feet for all the intensities of thinnings, and the CBD is reduced from 0.06 kg/m^3 to less than 0.04 kg/m^3 for all intensities and frequencies of treatment. This is likely due to the model's mechanical removal of all small trees during the thinning from below. FVS calculates stand CBH by using CBD ranges which in turn depends on TPA values. The model may therefore reduce CBD unrealistically. Fuel models are important inputs in FFE-FVS because much of the fire behavior in FVS will be driven by the changes in the fuel models.

Flame Lengths

The model appears to provide a likely future scenario for stand structure based on the treatments applied, provided that the thinnings are conducted as modeled. Based on these modeled stand structure changes, the FFE-FVS model reported results for flame lengths, torching index, and crowning index. The model shows flame lengths under severe and moderate fire weather conditions to be cut in half through the initial basal area ft^2 per acre treatment for all intensities of thinnings. This could be due in part to the FVS removal of all small trees during any of its mechanical thinnings from below, raising stand CBH by 17 to 23 feet even with one thinning. It could also be due to the change in fuel model between no treatment and treatment runs, and the resultant underestimation of residual understory fuels. Future research may indicate a better choice of post-treatment fuel models to more realistically model stand responses to treatments.

Torching Index

Torching indices, providing an estimate of likelihood of a fire reaching into the crowns of a stand, are modeled to rise from around 50 mph (a likely wind speed during a fire in the Flagstaff area) to over 250 mph after any of the treatments. The model thus indicates that the likelihood of torching drops to near zero after any thinning. This result could be due to the model's underestimation of fuel loading in the understory after thinning. Fire behavior simulations around the Flagstaff area have in the past underestimated crown fire behavior.

Crowning Index

The crowning index, providing an estimate of the likelihood of a crown fire being sustained in the stand, is modeled to increase to 100+ miles per hour (a likely wind speed during a fire in the Flagstaff area) for the 40 basal area ft^2 per acre treatment but the 120 basal area ft^2 per acre treatment has barely increased over the untreated stands to a wind speed of 65 mph (a likely wind speed during a fire in the Flagstaff area). Since these wind speeds could occur in the Flagstaff area it could mean that if a crown fire were to enter the lightest-thinned stands, it could be sustained.

Model Limitations

The FFE-FVS model as run conducted a mechanical thinning from below, choosing stems only by diameter, until a specified BA was achieved. The use of just three stands reduced the flexibility of the model to thin correctly. In future efforts it is recommended to use more sample stands and to consider allowing FVS to use tree "tripling" to allow for more accurate thinning and better results.

FFE contains no climatologic data and will not estimate site-specific moistures. FFE-FVS uses information about surface fuel and stand structure to predict whether a fire is likely to crown. Both torching and crowning index depend in part on surface fuel moisture; therefore these conditions must be specified. When flame lengths are dependent on surface fuel loading each treatment will have different residual fuel loads that should directly affect the flame lengths (Rebain et al. 2015). This will depend on the fuel models chosen for pre and post-treatment. In addition, the FFE-FVS simulations may underestimate severe fire behavior and resultant crown fire risk (Cruz and Alexander 2010).

Flame lengths under severe and moderate fire weather conditions were not modeled to change much after the first initial treatment. We would expect the flame lengths to reduce after any treatment but they increase slightly in 2-treatment years and 4-treatment years. This could be due to the assumption in FFE that all harvested boles are removed from the stand, and the associated crown material is left in the stand, unless the user enters a specific keyword in the model run. When thinning or harvesting, users can optionally control what is removed and what is left in the stand as slash through the YARDLOSS keyword. The YARDLOSS keyword allows users to specify a proportion of “removed” live trees to be left in the stand, and whether these stems are left as standing snags or felled. This keyword and its control of slash remaining were not applied for this study. Future studies should consider adding the YARDLOSS variable to better control for forest floor fuel loading after thinnings.

Decomposition rates in most variants are not sensitive to aspect, elevation or potential vegetation. Fire conditions (fuel moisture, wind speed, and temperature) must be selected by the user. Many of these limitations can be eliminated by the use of keywords in the model and the quality of the data to receive the best, most realistic results. These limitations suggest opportunities for further research and model development (Rebain et al. 2015).

RECOMMENDATIONS

Advanced analytical tools like FFE/FVS that can predict changes in stand structure based on thinning treatments are important for developing guidelines for landowners in the WUI. Use of these tools requires expertise in fire modeling and thinning treatments to answer questions about how forest vegetation will change in response to natural succession, disturbances, and proposed management actions.

It would be interesting to look at another FFE-FVS run that did not select only three stands but used all 115 stands from the Fort Valley Experimental Forest on Wing Mountain and also removed all slash after thinning to determine whether the fire hazards would further decline under more intensive thinnings. Likewise it would be important to explicitly control the model's buildup of forest floor fuels over time to see if the fire hazards would rise decades after a single thinning.

The best possible stand treatment recommendation for landowners in the Flagstaff area will vary based on desired objectives and must take into account pre-treatment stand conditions as well as landowner preferences. The least severe thinning modeled, resulting in residual BA of 108 sq.ft./ac, shows satisfactory increases in flame length and wind speed needed to achieve torching, thus reducing fire danger. However, the crowning index is still well within the historically recorded wind speeds for Flagstaff area with the least severe thinning (54 mph). The FVS model indicates that more severe thinnings will somewhat increase the wind speed needed to achieve a crown fire, but even the most severe thinning, which leaves only 24 TPA after 60 years, still shows a CI within measured wind speeds (101 mph). Any recommendations to landowners would need to reflect that a crown fire could not be ruled out at any thinning level, but that thinnings to lower BA targets of 100 or 80 sq.ft./ac. will reduce crown fire danger further than that of the 120 sq.ft./ac BA target thinning. The model results indicate that two or four treatments do not produce substantially improved results and would likely not be cost-effective at any target BA level.

The fuel model (FL-5) selected for the post-treatment evaluations of fire effects does not model well the buildup of forest floor fuels over time. While thinning is an important first step, aggressive management of forest floor fuels over time is likely to be essential to maintain a reduced fire hazard over time. Landowners should be encouraged to deal with surface fuel buildup from needles, branches, and small tree mortality to reduce fire hazard.

Even the more severe thinnings from below are unlikely to create enough income to cover the expense of the thinning. Intensive mechanical treatment of slash followed by periodic aggressive surface fuel management might further raise costs and could make the recommendations less palatable in the absence of some incentive or subsidy. The GFFP might advocate for a reduction in fire insurance rates for landowners who sensibly manage the surrounding forest, possibly resulting in sufficient incentive, or help landowners to find grant funding to assist them in completing the thinning and slash treatments.

It would also be interesting to look at prescribed fire, including periodic broadcast burns, as additional tools to reduce fire hazard after a thinning and maintain desired stand conditions with very limited buildup of hazardous ladder fuels over time. Well-managed prescribed burns are likely to be less expensive than hand removal of surface fuels. Efforts to restore southwestern ponderosa pine forests could require extensive projects employing varying combinations of young-tree thinning and reintroduction of low-intensity fires (Allen 2002).

A resilient ponderosa pine forest ecosystem will require a thorough consideration of the forest structure and composition that will persist under the array of disturbance factors. More research is needed to better model fuel treatments through thinning and/or periodic broadcast burns that would allow homeowners to keep properties of their stands they desire without causing high fire risk.

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APPENDIX A: No Treatment (Pre- Treatment)

Time Scale

- 2010-2014

Management Actions

- Plant & Natural Regeneration -> Sprouting off -> 2014 -> Species ponderosa pine kcp file from Dr. Kristen Waring; NAU; School of Forestry Associate Professor
- Fuel Treatments -> None

Outputs

- Database Extension -> Specify Output Database -> results
- Base FVS Reports -> Build Summary Statistics Table in Database
- FFE -> Reports -> Select Fire and Fuels Extension Reports -> Output the Potential Fire and Fuels Report -> Both (Uncheck the rest)
- Event Monitor [EM] Compute Variables -> Build Compute Table in Database

Post Processors

- Main Output File

Modifiers (Severe-Shultz Fire/Moderate-Hall et al)

- Modify Potential Fire Conditions -> Set fuel moistures for potential fires -> Severe
    - Moisture value for 1-hour fuel [0-0.25"] -> 3% (97th percentile) Mary Lata
    - Moisture value for 10-hour fuel [0.25-1"] -> 3% (95th percentile) Mary Lata
    - Moisture value for 100-hour fuel [1-3"] -> 6% (97th percentile) Mary Lata
    - Moisture value for 3+ fuels -> 8% (Wes Hall)
    - Moisture value for duff fuels -> 15% (Default)
    - Moisture value for live woody fuels -> 65% (Wes Hall)
    - Moisture value for live herb fuels -> 30% (Wes Hall)
- Modify Potential Fire Conditions -> Set fuel moistures for potential fires -> Moderate
    - Percent moisture for 1-hour fuel [0-0.25"] -> 7% (Wes Hall)
    - Percent moisture for 10-hour fuel [0.25-1"] -> 10% (Wes Hall)
    - Percent moisture for 100-hour fuel [1-3"] -> 13% (Wes Hall)
    - Percent moisture for 3"+ fuel -> 16% (Wes Hall)
    - Percent moisture for duff -> 125% (Default)
    - Percent moisture for live woody fuels -> 80% (Wes Hall)
    - Percent moisture for live herb fuels -> 30% (Wes Hall)
    - Modify Potential Fire Conditions -> Set wind speed for potential fires ->
    - 20-foot wind speed for severe fires -> 23 mph (98th percentile) Mary Lata
    - 20-foot wind speed for moderate fires -> 9 mph (Wes Hall)
- Modify Potential Fire Conditions -> Set temperature for potential fires ->
    - Temperature for severe fires ->77 degrees F -> (50th percentile) Mary Lata
    - Temperature for moderate fires -> 60 degrees F -> (Wes Hall)
- Fire Behavior -> Set fuel model(s) ->
    - 165 = TU5 Very high load dry climate
    - 188 = TL8 High load conifer litter

APPENDIX B: FVS Input Variables for Post- Treatment Stands

Time Scale

- 2014-2074 –> 20 year cycle

Management Actions

- Plant & Natural Regeneration -> Sprouting off -> 2014 -> Species ponderosa pine kcp file from Dr. Kristen Waring; NAU; School of Forestry Associate Professor
- Fuel Treatments -> Thin from below -> basal area target -> 40, 60, 80, 100, & 120

Outputs

- Database Extension -> Specify Output Database -> results for each BA treatment
- Base FVS Reports -> Build Summary Statistics Table in Database
- FFE -> Reports -> Select Fire and Fuels Extension Reports -> Output the Potential Fire and Fuels Report -> Both (Uncheck the rest)
- Event Monitor [EM] Compute Variables -> Build Compute Table in Database
- Post Processors
- Main Output File

Modifiers (Severe-Shultz Fire/Moderate-Default)

- Modify Potential Fire Conditions -> Set fuel moistures for potential fires -> Severe
    - Moisture value for 1-hour fuel [0-0.25"] -> 3% (97th percentile) Mary Lata
    - Moisture value for 10-hour fuel [0.25-1"] -> 3% (95th percentile) Mary Lata
    - Moisture value for 100-hour fuel [1-3"] -> 6% (97th percentile) Mary Lata
    - Moisture value for 3+ fuels -> 8% (Wes Hall)
    - Moisture value for duff fuels -> 15% (Default)
    - Moisture value for live woody fuels -> 65% (Wes Hall)
    - Moisture value for live herb fuels -> 30% (Wes Hall)
- Modify Potential Fire Conditions -> Set fuel moistures for potential fires -> Moderate
    - Percent moisture for 1-hour fuel [0-0.25"] -> 7% (Wes Hall)
    - Percent moisture for 10-hour fuel [0.25-1"] -> 10% (Wes Hall)
    - Percent moisture for 100-hour fuel [1-3"] -> 13% (Wes Hall)
    - Percent moisture for 3"+ fuel -> 16% (Wes Hall)
    - Percent moisture for duff -> 125% (Default)
    - Percent moisture for live woody fuels -> 80% (Wes Hall)
    - Percent moisture for live herb fuels -> 30% (WH)
- Modify Potential Fire Conditions -> Set wind speed for potential fires ->
    - 20-foot wind speed for severe fires -> 23 mph (98th percentile) ML
    - 20-foot wind speed for moderate fires -> 9 mph (WH)
- Modify Potential Fire Conditions -> Set temperature for potential fires ->
    - Temperature for severe fires ->77 degrees F -> (50th percentile) ML
    - Temperature for moderate fires -> 60 degrees F -> (WH)
    - Fire Behavior -> Set fuel model(s) ->
        - 185 = TL5 High load conifer litter

APPENDIX C: Summary Statistics for Three Sample Stands

STAND 80019

SUMMARY STATISTICS (PER ACRE OR STAND BASED ON TOTAL STAND AREA)

		START OF SIMULATION PERIOD									REMOVALS				AFTER TREATMENT					GROWTH THIS PERIOD			MAI		
YEAR	AGE	NO OF TREES	BA	SDI	CCF	TOP HT	QMD	TOTAL CU FT	MERCH CU FT	MERCH BD FT	NO OF TREES	TOTAL CU FT	MERCH CU FT	MERCH BD FT	BA	SDI	CCF	TOP HT	RES QMD	PERIOD YEARS	ACCRE PER	MORT YEAR	MERCH CU FT	FOR TYP	SS ZT
2010	0	487	230	434	186	86	9.3	5300	4481	19286	0	0	0	0	230	434	186	86	9.3	4	98	14	0.0	221	11
2014	4	476	237	443	191	84	9.6	5639	4850	21234	454	4359	3671	14809	40	58	28	88	18.4	20	41	2	0.0	221	11
2034	24	21	58	77	39	97	22.4	2053	2033	11688	0	0	0	0	58	77	39	97	22.4	20	37	4	0.0	221	14
2054	44	24	71	93	46	89	23.3	2721	2799	16923	0	0	0	0	71	93	46	89	23.3	20	36	5	0.0	221	14
2074	64	26	83	108	53	86	24.3	3356	3525	22288	0	0	0	0	83	108	53	86	24.3	20	30	5	0.0	221	13

STAND 80020

SUMMARY STATISTICS (PER ACRE OR STAND BASED ON TOTAL STAND AREA)

		START OF SIMULATION PERIOD									REMOVALS				AFTER TREATMENT					GROWTH THIS PERIOD			MAI		
YEAR	AGE	NO OF TREES	BA	SDI	CCF	TOP HT	QMD	TOTAL CU FT	MERCH CU FT	MERCH BD FT	NO OF TREES	TOTAL CU FT	MERCH CU FT	MERCH BD FT	BA	SDI	CCF	TOP HT	RES QMD	PERIOD YEARS	ACCRE PER	MORT YEAR	MERCH CU FT	FOR TYP	SS ZT
2010	0	120	81	142	67	58	11.1	1585	1324	5745	0	0	0	0	81	142	67	58	11.1	4	56	23	0.0	221	13
2014	4	115	83	144	68	61	11.6	1717	1460	6477	78	822	675	2688	40	64	31	61	14.2	20	32	12	0.0	221	13
2034	24	29	47	69	34	71	17.2	1301	1189	6054	0	0	0	0	47	69	34	71	17.2	20	29	19	0.0	221	14
2054	44	26	47	68	32	68	18.3	1494	1431	8071	0	0	0	0	47	68	32	68	18.3	20	22	24	0.0	221	14
2074	64	24	42	62	28	61	17.9	1465	1474	8614	0	0	0	0	42	62	28	61	17.9	20	18	23	0.0	221	14

STAND 80023

SUMMARY STATISTICS (PER ACRE OR STAND BASED ON TOTAL STAND AREA) **stand 23**

		START OF SIMULATION PERIOD									REMOVALS				AFTER TREATMENT					GROWTH THIS PERIOD			MAI		
YEAR	AGE	NO OF TREES	BA	SDI	CCF	TOP HT	QMD	TOTAL CU FT	MERCH CU FT	MERCH BD FT	NO OF TREES	TOTAL CU FT	MERCH CU FT	MERCH BD FT	BA	SDI	CCF	TOP HT	RES QMD	PERIOD YEARS	ACCRE PER	MORT YEAR	MERCH CU FT	FOR TYP	SS ZT
2010	0	613	143	310	118	70	6.5	3010	2439	11082	0	0	0	0	143	310	118	70	6.5	4	41	1	0.0	221	12
2014	4	611	148	318	122	72	6.7	3167	2574	11689	598	1962	1392	4983	40	52	27	83	23.7	20	17	2	0.0	221	12
2034	24	13	45	57	29	88	25.1	1492	1514	8893	0	0	0	0	45	57	29	88	25.1	20	17	3	0.0	221	14
2054	44	18	51	67	32	68	22.9	1771	1835	11221	0	0	0	0	51	67	32	68	22.9	20	15	3	0.0	221	14
2074	64	22	56	75	35	59	21.7	2014	2112	13310	0	0	0	0	56	75	35	59	21.7	20	12	3	0.0	221	14

APPENDIX D: Fire Model Keywords Used

```
FMIN       FIRE MODEL KEYWORDS:

POTFMOIS   FIRE MOISTURE CONDITIONS FOR CALCULATING SEVERE POTENTIAL FLAME LENGTHS
ARE:
           % MOISTURE FOR 0-.25"=   3.; 0.25-1"=   3.; 1-3"=   6.; 3+"=   8.; DUFF=
0.; LIVE WOODY = 65.; LIVE HERB = 30.

POTFMOIS   FIRE MOISTURE CONDITIONS FOR CALCULATING MODERATE POTENTIAL FLAME
LENGTHS ARE:
           % MOISTURE FOR 0-.25"=   7.; 0.25-1"=  10.; 1-3"=  13.; 3+"=  16.; DUFF=
0.; LIVE WOODY = 80.; LIVE HERB = 30.

POTFWIND   FIRE WIND SPEEDS USED FOR CALCULATING POTENTIAL FLAME LENGTHS ARE
           FOR SEVERE FIRE:   23. AND FOR MODERATE FIRE:    9. MPH

POTFTEMP   FIRE TEMPERATURES USED FOR CALCULATING POTENTIAL FLAME LENGTHS ARE
           FOR SEVERE FIRE:   77. AND FOR MODERATE FIRE:   60. DEGREES F

FUELMODL   IN DATE/CYCLE    0 THE FUEL MODELS AND WEIGHTS THAT WILL BE USED ARE:
           MODEL 185:  100.0%

END        END OF FIRE MODEL OPTIONS.
```

APPENDIX E: FFE-FVS Model Outputs for Fire Effects, No Treatment-Three Sample Stands

****** FIRE MODEL VERSION 1.0 ******
POTENTIAL FIRE REPORT
MGMT ID: NONE

STAND ID: 0304020000800019

FIRE CONDITION	WIND (MPH)	TEMP (F)	FUEL MOISTURE CONDITIONS (PERCENT) 0-0.25"	0.25-1"	1-3"	3"+	DUFF	LIVE WOODY	LIVE HERB
SEVERE	23.0	77	3.	3.	6.	8.	0.	65.	30.
MODERATE	9.0	60	7.	10.	13.	16.	0.	80.	30.

YEAR	FLAME LENGTH (FT) SURFACE SEV	SURFACE MOD	TOTAL SEV	TOTAL MOD	FIRE TYPE S	FIRE TYPE M	PROB OF TORCHING SEV	PROB OF TORCHING MOD	TORCH INDEX SEVERE MI/HR	CROWN INDEX SEVERE MI/HR	CNPY BASE HT FT	CANPY BULK DENSTY KG/M3	POTENTIAL MORTALITY SEV. %BA	MOD. %BA	SEV. (TOT CU VOL)	MOD. (TOT CU VOL)	POTEN. SMOKE SEV. (T/A <2.5)	MOD. (T/A <2.5)	FUEL MODELS MOD	%WT	MOD	%WT	MOD	%WT	MOD	%WT
2010	5.9	3.2	6	3	S	S	0.72	0.02	99.1	23.8	27	0.087	34	21	1484	987	0.11	0.10	165	50	188	50				
2011	5.9	3.2	6	3	S	S	0.78	0.03	99.1	23.8	27	0.087	34	21	1484	987	0.12	0.10	165	50	188	50				
2012	5.9	3.2	6	3	S	S	0.66	0.02	99.1	23.8	27	0.087	34	21	1484	987	0.12	0.11	165	50	188	50				
2013	5.9	3.2	6	3	S	S	0.63	0.02	99.1	23.8	27	0.087	34	21	1484	987	0.12	0.11	165	50	188	50				
2014	5.9	3.2	6	3	S	S	0.57	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.12	0.11	165	50	188	50				
2015	5.9	3.2	6	3	S	S	0.57	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.12	0.11	165	50	188	50				
2016	5.9	3.2	6	3	S	S	0.51	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.12	0.11	165	50	188	50				
2017	5.9	3.2	6	3	S	S	0.62	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.12	0.11	165	50	188	50				
2018	5.9	3.2	6	3	S	S	0.71	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.12	0.11	165	50	188	50				
2019	5.9	3.2	6	3	S	S	0.74	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.12	0.11	165	50	188	50				
2020	5.9	3.2	6	3	S	S	0.60	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.12	0.11	165	50	188	50				
2021	5.9	3.2	6	3	S	S	0.61	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.12	0.12	165	50	188	50				
2022	5.9	3.2	6	3	S	S	0.62	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2023	5.9	3.2	6	3	S	S	0.51	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2024	5.9	3.2	6	3	S	S	0.57	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2025	5.9	3.2	6	3	S	S	0.57	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2026	5.9	3.2	6	3	S	S	0.51	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2027	5.9	3.2	6	3	S	S	0.62	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2028	5.9	3.2	6	3	S	S	0.71	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2029	5.9	3.2	6	3	S	S	0.74	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2030	5.9	3.2	6	3	S	S	0.60	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2031	5.9	3.2	6	3	S	S	0.61	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2032	5.9	3.2	6	3	S	S	0.62	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2033	5.9	3.2	6	3	S	S	0.51	0.01	104.9	23.7	28	0.088	31	21	1426	1012	0.13	0.12	165	50	188	50				
2034	5.9	3.2	6	3	S	S	0.47	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.13	0.12	165	50	188	50				
2035	5.9	3.2	6	3	S	S	0.41	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.13	0.13	165	50	188	50				
2036	5.9	3.2	6	3	S	S	0.39	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.14	0.13	165	50	188	50				
2037	5.9	3.2	6	3	S	S	0.42	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.14	0.13	165	50	188	50				
2038	5.9	3.2	6	3	S	S	0.42	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.14	0.14	165	50	188	50				
2039	5.9	3.2	6	3	S	S	0.42	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.15	0.14	165	50	188	50				
2040	5.9	3.2	6	3	S	S	0.48	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.15	0.14	165	50	188	50				
2041	5.9	3.2	6	3	S	S	0.41	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.15	0.15	165	50	188	50				
2042	5.9	3.2	6	3	S	S	0.46	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.15	0.15	165	50	188	50				
2043	5.9	3.2	6	3	S	S	0.45	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.16	0.15	165	50	188	50				
2044	5.9	3.2	6	3	S	S	0.47	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.16	0.15	165	50	188	50				
2045	5.9	3.2	6	3	S	S	0.41	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.16	0.16	165	50	188	50				
2046	5.9	3.2	6	3	S	S	0.39	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.16	0.16	165	50	188	50				
2047	5.9	3.2	6	3	S	S	0.42	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.17	0.16	165	50	188	50				
2048	5.9	3.2	6	3	S	S	0.42	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.17	0.16	165	50	188	50				
2049	5.9	3.2	6	3	S	S	0.42	0.00	111.5	23.7	30	0.088	24	17	1267	975	0.17	0.16	165	50	188	50				

Cont. APPENDIX E: FFE-FVS Model Outputs for Fire Effects, No Treatment-Three Sample Stands

POTENTIAL FIRE REPORT

STAND ID: 0304020000800020 MGMT ID: NONE

FIRE CONDITION	WIND (MPH)	TEMP (F)	FUEL MOISTURE CONDITIONS (PERCENT) 0-0.25"	0.25-1"	1-3"	3"+	DUFF	LIVE WOODY	LIVE HERB
SEVERE	23.0	77	3.	3.	6.	8.	0.	65.	30.
MODERATE	9.0	60	7.	10.	13.	16.	0.	80.	30.

YEAR	FLAME LENGTH (FT) SURFACE SEV	SURFACE MOD	TOTAL SEV	TOTAL MOD	FIRE TYPE S	FIRE TYPE M	PROB OF TORCHING SEV	PROB OF TORCHING MOD	TORCH INDEX SEVERE MI/HR	CROWN INDEX SEVERE MI/HR	CNPY BASE HT FT	CANPY BULK DENSTY KG/M3	POTENTIAL MORTALITY SEV. %BA	MOD. %BA	SEV. (TOT CU VOL)	MOD.	POTEN. SMOKE SEV. (T/A	MOD. <2.5)	FUEL MODELS MOD	%WT	MOD	%WT	MOD	%WT	MOD	%WT
2010	7.5	3.8	7	4	S	S	0.79	0.10	34.4	46.2	17	0.035	91	23	1432	347	0.07	0.06	165	50	188	50				
2011	7.5	3.8	7	4	S	S	0.67	0.10	34.4	46.2	17	0.035	91	23	1432	347	0.07	0.06	165	50	188	50				
2012	7.5	3.8	7	4	S	S	0.76	0.11	34.4	46.2	17	0.035	91	23	1432	347	0.07	0.06	165	50	188	50				
2013	7.5	3.8	7	4	S	S	0.82	0.11	34.4	46.2	17	0.035	91	23	1432	347	0.07	0.06	165	50	188	50				
2014	7.5	3.8	8	4	S	S	0.63	0.03	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2015	7.5	3.8	8	4	S	S	0.80	0.03	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2016	7.5	3.8	8	4	S	S	0.70	0.03	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2017	7.5	3.8	8	4	S	S	0.80	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2018	7.5	3.8	8	4	S	S	0.80	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2019	7.5	3.8	8	4	S	S	0.71	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2020	7.5	3.8	8	4	S	S	0.69	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2021	7.5	3.8	8	4	S	S	0.69	0.03	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2022	7.5	3.8	8	4	S	S	0.82	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2023	7.5	3.8	8	4	S	S	0.68	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2024	7.5	3.8	8	4	S	S	0.63	0.03	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2025	7.5	3.8	8	4	S	S	0.80	0.03	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2026	7.5	3.8	8	4	S	S	0.70	0.03	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2027	7.5	3.8	8	4	S	S	0.80	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2028	7.5	3.8	8	4	S	S	0.80	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2029	7.5	3.8	8	4	S	S	0.71	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2030	7.5	3.8	8	4	S	S	0.69	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.07	0.06	165	50	188	50				
2031	7.5	3.8	8	4	S	S	0.69	0.03	41.9	46.8	20	0.034	86	20	1452	330	0.08	0.06	165	50	188	50				
2032	7.5	3.8	8	4	S	S	0.82	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.08	0.06	165	50	188	50				
2033	7.5	3.8	8	4	S	S	0.68	0.04	41.9	46.8	20	0.034	86	20	1452	330	0.08	0.06	165	50	188	50				
2034	7.7	3.9	8	4	S	S	0.47	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.07	0.06	165	50	188	50				
2035	7.7	3.9	8	4	S	S	0.41	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.08	0.07	165	50	188	50				
2036	7.7	3.9	8	4	S	S	0.33	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.08	0.07	165	50	188	50				
2037	7.7	3.9	8	4	S	S	0.38	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.08	0.07	165	50	188	50				
2038	7.7	3.9	8	4	S	S	0.35	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.08	0.07	165	50	188	50				
2039	7.7	3.9	8	4	S	S	0.40	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.08	0.08	165	50	188	50				
2040	7.7	3.9	8	4	S	S	0.47	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.09	0.08	165	50	188	50				
2041	7.7	3.9	8	4	S	S	0.33	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.09	0.08	165	50	188	50				
2042	7.7	3.9	8	4	S	S	0.41	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.09	0.08	165	50	188	50				
2043	7.7	3.9	8	4	S	S	0.41	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.09	0.08	165	50	188	50				
2044	7.7	3.9	8	4	S	S	0.47	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.09	0.08	165	50	188	50				
2045	7.7	3.9	8	4	S	S	0.41	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.09	0.08	165	50	188	50				
2046	7.7	3.9	8	4	S	S	0.33	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.09	0.09	165	50	188	50				
2047	7.7	3.9	8	4	S	S	0.38	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.10	0.09	165	50	188	50				
2048	7.7	3.9	8	4	S	S	0.35	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.10	0.09	165	50	188	50				
2049	7.7	3.9	8	4	S	S	0.40	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.10	0.09	165	50	188	50				
2050	7.7	3.9	8	4	S	S	0.47	0.00	77.5	52.1	35	0.029	61	13	1269	278	0.10	0.09	165	50	188	50				

Cont. APPENDIX E: FFE-FVS Model Outputs for Fire Effects, No Treatment-Three Sample Stands

STAND ID: 0304020000800023

POTENTIAL FIRE REPORT
MGMT ID: NONE

FIRE CONDITION	WIND (MPH)	TEMP (F)	FUEL MOISTURE CONDITIONS (PERCENT) 0-0.25"	0.25-1"	1-3"	3"+	DUFF	LIVE WOODY	LIVE HERB
SEVERE	23.0	77	3.	3.	6.	8.	0.	65.	30.
MODERATE	9.0	60	7.	10.	13.	16.	0.	80.	30.

YEAR	FLAME LENGTH (FT) SURFACE SEV	SURFACE MOD	TOTAL SEV	TOTAL MOD	FIRE TYPE S	FIRE TYPE M	PROB OF TORCHING SEV	PROB OF TORCHING MOD	TORCH INDEX SEVERE MI/HR	CROWN INDEX SEVERE MI/HR	CNPY BASE HT FT	CANPY BULK DENSTY KG/M3	POTENTIAL MORTALITY SEV. %BA	MOD. %BA	SEV. (TOT CU VOL)	MOD.	POTEN. SMOKE SEV. (T/A	MOD. <2.5)	FUEL MODELS MOD	%WT	MOD	%WT	MOD	%WT	MOD	%WT
2010	6.6	3.5	24	3	P	S	0.87	0.00	7.2	36.5	5	0.048	98	27	2944	603	0.10	0.08	165	50	188	50				
2011	6.6	3.5	24	3	P	S	0.87	0.00	7.2	36.5	5	0.048	98	27	2944	603	0.10	0.08	165	50	188	50				
2012	6.6	3.5	24	3	P	S	0.87	0.00	7.2	36.5	5	0.048	98	27	2944	603	0.10	0.08	165	50	188	50				
2013	6.6	3.5	24	3	P	S	0.87	0.00	7.2	36.5	5	0.048	98	27	2944	603	0.10	0.08	165	50	188	50				
2014	6.6	3.4	21	3	P	S	0.93	0.46	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2015	6.6	3.4	21	3	P	S	0.93	0.44	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2016	6.6	3.4	21	3	P	S	0.92	0.35	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2017	6.6	3.4	21	3	P	S	0.92	0.40	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2018	6.6	3.4	21	3	P	S	0.94	0.48	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2019	6.6	3.4	21	3	P	S	0.93	0.46	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2020	6.6	3.4	21	3	P	S	0.92	0.34	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2021	6.6	3.4	21	3	P	S	0.94	0.50	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2022	6.6	3.4	21	3	P	S	0.92	0.34	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2023	6.6	3.4	21	3	P	S	0.93	0.43	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2024	6.6	3.4	21	3	P	S	0.93	0.46	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2025	6.6	3.4	21	3	P	S	0.93	0.44	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2026	6.6	3.4	21	3	P	S	0.92	0.35	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2027	6.6	3.4	21	3	P	S	0.92	0.40	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2028	6.6	3.4	21	3	P	S	0.94	0.48	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2029	6.6	3.4	21	3	P	S	0.93	0.46	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2030	6.6	3.4	21	3	P	S	0.92	0.34	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2031	6.6	3.4	21	3	P	S	0.94	0.50	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2032	6.6	3.4	21	3	P	S	0.92	0.34	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2033	6.6	3.4	21	3	P	S	0.93	0.43	10.3	36.9	6	0.048	98	26	3091	630	0.10	0.08	165	50	188	50				
2034	6.3	3.4	6	3	S	S	0.82	0.23	52.3	34.8	18	0.051	38	26	1043	758	0.09	0.08	165	50	188	50				
2035	6.3	3.4	6	3	S	S	0.88	0.30	52.3	34.8	18	0.051	38	26	1043	758	0.09	0.08	165	50	188	50				
2036	6.3	3.4	6	3	S	S	0.87	0.30	52.3	34.8	18	0.051	38	26	1043	758	0.09	0.08	165	50	188	50				
2037	6.3	3.4	6	3	S	S	0.88	0.33	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.08	165	50	188	50				
2038	6.3	3.4	6	3	S	S	0.88	0.34	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.08	165	50	188	50				
2039	6.3	3.4	6	3	S	S	0.86	0.27	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.08	165	50	188	50				
2040	6.3	3.4	6	3	S	S	0.81	0.20	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				
2041	6.3	3.4	6	3	S	S	0.84	0.25	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				
2042	6.3	3.4	6	3	S	S	0.84	0.22	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				
2043	6.3	3.4	6	3	S	S	0.89	0.27	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				
2044	6.3	3.4	6	3	S	S	0.82	0.23	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				
2045	6.3	3.4	6	3	S	S	0.88	0.30	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				
2046	6.3	3.4	6	3	S	S	0.87	0.30	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				
2047	6.3	3.4	6	3	S	S	0.88	0.33	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				
2048	6.3	3.4	6	3	S	S	0.88	0.34	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				
2049	6.3	3.4	6	3	S	S	0.86	0.27	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				
2050	6.3	3.4	6	3	S	S	0.81	0.20	52.3	34.8	18	0.051	38	26	1043	758	0.10	0.09	165	50	188	50				