Elkhorn 4 Prescribed Fire Monitoring Report

COLORADO FOREST
RESTORATION INSTITUTE

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Colorado Forest Restoration Institute

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Authors: Morici, Kat E.[1], Gannon, Benjamin M.[2]

1. Colorado Forest Restoration Institute, Colorado State University, Department of Forest and Rangeland Stewardship, Fort Collins, CO
2. Department of Forest and Rangeland Stewardship, Colorado State University, Fort Collins, CO

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Colorado State University
Colorado Forest Restoration Institute
Department of Forest & Rangeland Stewardship
Mail Delivery 1472
Colorado State University
Fort Collins, Colorado 80523
(970) 491-4685
cfri.colostate.edu

COLORADO STATE UNIVERSITY

Peaks to People Water Fund

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Executive Summary

The Peaks to People Water Fund invests in strategically placed forest restoration and fuel reduction treatments to mitigate wildfire risk to water supplies and other values in the Cache la Poudre and Big Thompson watersheds. This report presents monitoring results from the Ben Delatour Scout Ranch Elkhorn 4 prescribed fire to measure how well site level project goals were met, and to compare field-based outcome measures with modeled landscape data inputs for the Watershed Investment Tool. The overarching goals of the Elkhorn 4 prescribed burn were to minimize the potential for high severity wildfire and reintroduce ecologically appropriate fire into the ponderosa pine ecosystem. One year after the prescribed fire, monitoring results show a reduction in shrubs and small trees, an increase in average tree canopy base height, and minimal mortality of larger trees from the fire. The type of fire predicted to occur under severe conditions was moderated from a majority of plots supporting passive crown fire pre-treatment to a majority burning as surface fire post-treatment. The predicted windspeed needed to initiate crown fire increased from 9mph to 46mph post treatment. The prescribed burn largely met project objectives to reduce risk of severe wildfire and enhance ecologically resilient forest structures. Our field-based monitoring of changes in forest structure indicate that the Watershed Investment Tool is likely underestimating the benefit of prescribed fire for wildfire risk reduction. This is largely a result of mismatches in modeled and measured crown base height and surface fuel model assignments. Continued field monitoring, particularly of prescribed fires, in combination with refinement of the Watershed Investment Tool will provide more accurate measures of treatment outcomes and improve treatment prioritization models, promoting efficient allocation of resources that fosters resilient forests and secures clean water supplies.

Elkhorn 4 Prescribed Burn; Katarina Warnick (CFRI), edited by Andrew Slack (CFRI)

Introduction

The Peaks to People Water Fund provides funding for forest restoration and fuel reduction treatments to reduce wildfire risk to water supplies and other values in the Cache la Poudre and Big Thompson watersheds. The Colorado Forest Restoration Institute (CFRI) partners with Peaks to People Water Fund to develop and apply monitoring tools that measure outcomes of these investments. The aim of this monitoring program is to ensure investments are developed to be strategic and impactful, to measure progress towards achieving project and program goals, and to support continued learning and improvement with Peaks to People stakeholders. CFRI monitors individual projects to characterize their ecological and wildfire risk reduction benefits, and leverages monitoring results to inform progress towards Peaks to People Water Fund program goals using the Watershed Investment Tool. This report presents monitoring results from the Ben Delatour Scout Ranch Elkhorn 4 prescribed fire to measure how well site level project goals were met, and to compare field-based outcome measures with modeled landscape data inputs for the Watershed Investment Tool.

The Elkhorn 4 prescribed fire took place in fall of 2019 with the support of Peaks to People Water Fund as part of the Elkhorn Creek Forest Health initiative. The prescribed fire was planned by The Nature Conservancy and implemented with support from 12 different agencies. The goals of the Elkhorn 4 prescribed fire were to reduce accumulated fuels to minimize the potential for high-severity wildfire, as well as to reintroduce fire into the ponderosa pine ecosystem. To achieve these goals, the following objectives were identified:

- Reduce conifer regeneration (<6" DBH) by at least 20% within 1 year of the burn.
- Reduce 1-, 10- , and 100-hour fuels by 30% immediately post burn.
- Limit mortality of trees greater than 10" DBH to 20% or less.
- Increase native herbaceous vegetative cover by 20% within 2 years of the burn.

The Elkhorn 4 prescribed fire was subdivided into two units to facilitate prescribed fire operations: the northern subunit 4a contains 385 acres and the southern subunit 4b contains 120 acres. CFRI installed 30 monitoring plots in Elkhorn 4a and 9 plots in Elkhorn 4b (Figure 1). Monitoring plots were randomly located with the stipulation that each plot contain a minimum of one tree. This stipulation was added because prescribed fire effects on tree mortality and conifer regeneration were explicit goals of the project. In addition, change in tree canopy base height is a key uncertainty with prescribed fire treatments modeled in the Watershed Investment Tool that we aimed to refine. Field-based plots were measured pre-fire, immediately post-fire, and one year post-fire. Monitoring protocols capture trees, understory vegetation, woody fuels, and fire severity (Colorado Forest Restoration Institute, 2018a, 2018b, 2018c).

The prescribed fire took place October 15-16, 2019. Weather conditions were recorded hourly by the Fire Effects Monitor during prescribed fire operations. Maximum temperatures ranged from 60-70° F

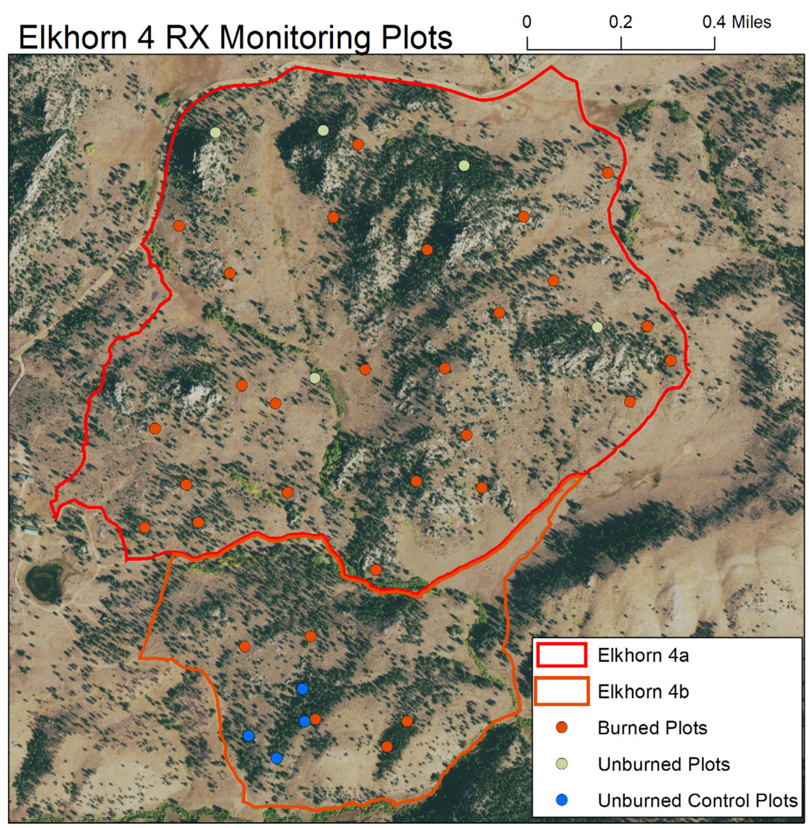

Figure 1. Map of monitoring plot locations within Elkhorn 4. Plot color indicates plots that burned, remained unburned, or were unburned due to ignition operations ceasing.

during the two burn days. The minimum relative humidity was 11-13 percent. Eye-level winds were 2-5 mph with maximum gusts between 13-23 mph. On the second day of burning, the fire escaped from the unit boundaries and prescribed fire operations halted before the entire 4b subunit was ignited. The escaped fire, known as the Elk Fire, caused significant disruption for residents of nearby areas. See the Elkhorn Prescribed Fire Review for more details on the escape (Colorado Department of Public Safety, 2020). Monitoring data is only available inside unit boundaries, and the four plots that did not fall within the prescribed fire extent due to the halting of ignition operations were removed from this analysis (blue plots in Figure 1).

Fire Effects

The prescribed fire burned most of the unit. In Elkhorn 4a, 25 of 30 plots showed signs of fire, along with 5 of 9 plots in Elkhorn 4b. Within each plot, fire effects on the forest floor were classified for 10-12 subplots. Half of the subplots were scorched, which means the litter layer was partially blackened and duff nearly unchanged (Figure 2). Slightly over one-third of the subplots were unburned. No subplots were categorized as heavily burned. This indicates that surface fire severity was very low across much of the area (Figure 3).

Fire impact on trees varied with tree size. A common measure of fire effects on trees is percent crown volume scorch—the percentage of needles that are

Burn Severity	Unburned	Scorched	Light	Moderate	High
Substrate	Not burned	Litter partially blackened; duff nearly unchanged; wood/leaf structures unchanged	Litter charred to partially consumed; duff layer not altered over entire depth; surface appears black; woody debris is partially burned; logs are scorched or blackened but not charred.	Litter mostly to entirely consumed, leaving course, light colored ash; duff deeply charred, but underlying mineral soil is not visibly altered; woody debris is mostly consumed; logs are deeply charred	Litter and duff completely consumed, leaving fine white ash; mineral soil visibly altered; sound logs are deeply charred, and rotten logs are completely consumed.

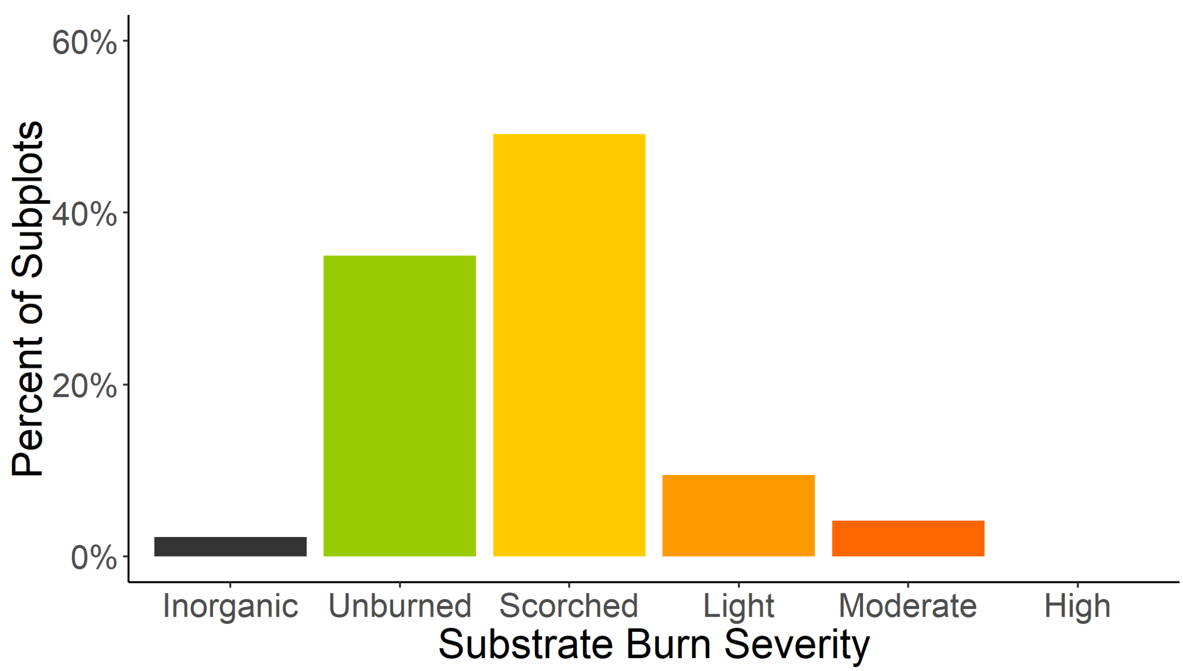

Figure 2. Percent of subplots within each substrate fire severity category. Descriptions of the categories are located above.

Pre-Treatment	Post-Treatment
	
	
	

Figure 3. Pre- and post-treatment photographs within Elkhorn 4. The top right photo was taken immediately post-fire, other post-treatment images are one year post-fire.

visibly red after the fire. To estimate tree mortality from crown scorch measurements, we conservatively assumed that only trees with over 90% crown scorch will die (Fowler et al., 2010). Overall conifer regeneration (defined in the burn plan as trees <6 inches in diameter at breast height) was reduced 45%, meeting the objective to reduce conifer regeneration by at least 20% (CFRI protocols use a 5 inch diameter at breast height cutoff to differentiate trees from saplings). Across all burned plots in Elkhorn 4, average crown volume scorch for trees over 5 inches in diameter was 44%. Our initial estimates are that 28% of the trees within burned plots and 20% of the trees across the entire unit were killed by the fire. The 20% estimated reduction in number of live trees combined with a basal area decline of only 9% indicates that the prescribed fire killed mainly smaller diameter trees (Table 1).

The burn plan objectives included limiting mortality of trees over 10 inches in diameter to 20% or less, and one year post-treatment we estimate 10% mortality of trees in this size class. Delayed mortality is possible up to approximately 5 years post-fire, but initial monitoring results strongly indicate that the objective to limit mortality of larger trees will be met.

Woody surface fuel loading was low pre-treatment and remained low following the prescribed fire. Fine woody fuels less than 3 inches in diameter, also known as 1-, 10-, and 100-hour fuels, were reduced by 28% immediately post-fire, which is close to the burn plan objective of 30% (Table 2). However, by one year post-treatment, fine fuels accumulated to similar levels as pre-treatment. Measuring small differences in fine woody fuels is difficult with ocular estimation techniques, and this increase may not be ecologically significant given the low baseline fuel loads. Coarse woody fuels, which have a diameter of 3 inches or greater, remained below pre-treatment levels. Coarse fuels were not expected to change significantly between the fire and one year post-treatment visit, so they were not measured immediately post-fire. Over time, the fire killed trees will fall and contribute to the coarse woody fuel load. Litter and duff loads dropped immediate post-burn. During the one year post-treatment visit, deposition from scorched needles increased the litter and duff loads closer to, but still slightly below pre-treatment values.

Shrub cover was reduced across the prescribed burn area. Overall shrub cover changed from 17% to 4% one year after the burn. Average shrub height remained constant at approximately 2.6 feet. The two dominant shrubs both pre- and post-treatment are *Ribes cereum* (wax currant) and *Purshia tridentata* (antelope bitterbrush). These species reproduce mainly by seed, although they are capable of a weak sprouting response following low-intensity fire.

FFE-FVS modeling

Wildfire hazard reduction is a central goal of the Elkhorn 4 prescribed fire. To assess the extent to which fire effects on forest structure and fuels modified expected fire behavior, we input field monitoring data from the pre- and one year post-treatment visits into the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS). A Scott & Burgan fuel model was assigned to each plot in the field or using plot pictures (Scott & Burgan, 2005). Plots were run as individual stands, resulting in a range of fire behavior and effects predictions across the unit. Fire simulations used severe fire weather and fuel moisture conditions, which correspond to

Table 1. Pre- and Post-treatment stand metrics; mean ± one standard deviation.

	Pre-Treatment	Post-Treatment
Live Basal Area (ft^2/ac)	44 (± 28)	40 (± 36)
Live Tree Density (trees/acre)	60 (± 62)	48 (± 70)
Canopy Base Height (ft)	6 (± 4)	11 (± 9)

Table 2. Pre- and Post-treatment woody surface fuels and ground fuels. Coarse woody fuels were not measured immediately post-fire.

	Pre-Treatment	Immediate Post	1 year Post-Treatment
Fine Fuel Loading (tons/acre)	0.78	0.56	0.84
Coarse Fuel Loading (tons/acre)	1.54	-	1.15
Litter/Duff Loading (tons/acre)	5.7	2.0	4.7

days with extreme fire danger or 97th percentile weather conditions (1-hr = 4%, 10-hr = 4%, 100-hr = 5%, herbaceous = 30%, woody = 70%, 20 mph winds, temperature = 90°).

The type of fire predicted to occur under severe conditions changed from a majority of plots supporting passive crown fire pre-treatment to a majority burning as surface fire post-treatment (Figure 4). Surface fire burns on the forest floor, while passive crown fire burns individual and small groups of trees. One plot was predicted to support conditional crown fire throughout both measurement periods, which suggests that it could propagate a crown fire burning into the stand, but it would not support a transition from surface fire to crown fire within the stand. No plots were predicted to support active crown fire under severe conditions. The shift to lower fire intensity predicted across the area indicates the wildfire reduction goals were likely met. The range of conditions present pre- and post-fire, including small amounts of passive and conditional crown fire remaining post-treatment, support ecological restoration objectives to retain a wide range of forest conditions and habitats on the landscape (Addington et al, 2018).

Stand susceptibility to passive or active crown fire can also be quantified on a continuous scale using the Torching and Crowning Indexes. The Torching Index is the predicted windspeed required to initiate crown fire activity, or passive crown fire. The Crowning Index is the predicted windspeed required to maintain an active crown fire. The fuel moisture conditions match the severe weather scenario described previously. Top windspeeds projected by FFE-FVS reached unrealistically high values for some plots, therefore the maximum value was changed to 200 mph. The Elkhorn 4 prescribed fire resulted in a considerable increase in the Torching Index, but only a slight rise in the Crowning Index (Figure 5). The median Torching Index rose from 9 mph to 46 mph, which was largely driven by the increase in tree canopy base height. Other factors that influence the Torching Index include surface fuels, slope steepness, and wind reduction by the canopy, none of which were heavily impacted by the prescribed fire. Median Crowning Index increased from 47 to 52 mph. The small change is indicative of the prescribed fire's minimal effect on canopy bulk density, as it primarily killed smaller trees.

WIT Comparison

One goal of the Peaks to People monitoring program is to improve how forest management effects are represented in the Watershed Investment Tool (WIT). Earlier monitoring of thinning, burning, and combined thinning and burning treatments at the Scout Ranch revealed several discrepancies

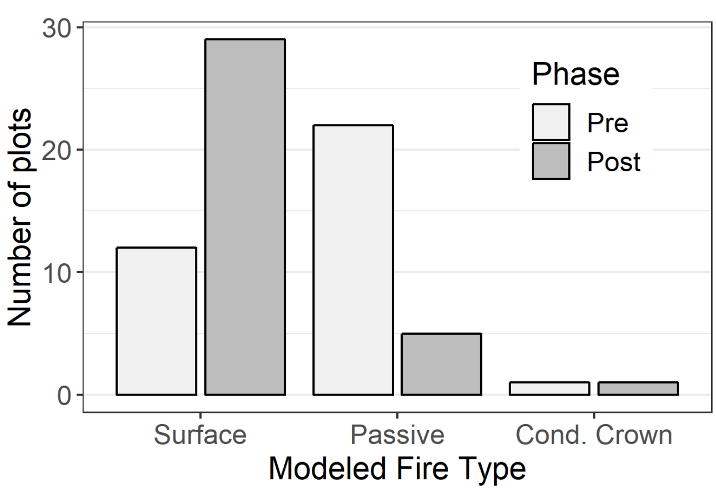

Figure 4. Number of pre- and post-treatment plots predicted to support surface, passive crown, and conditional crown fire in FFE-FVS under severe fire weather and fuel moisture conditions.

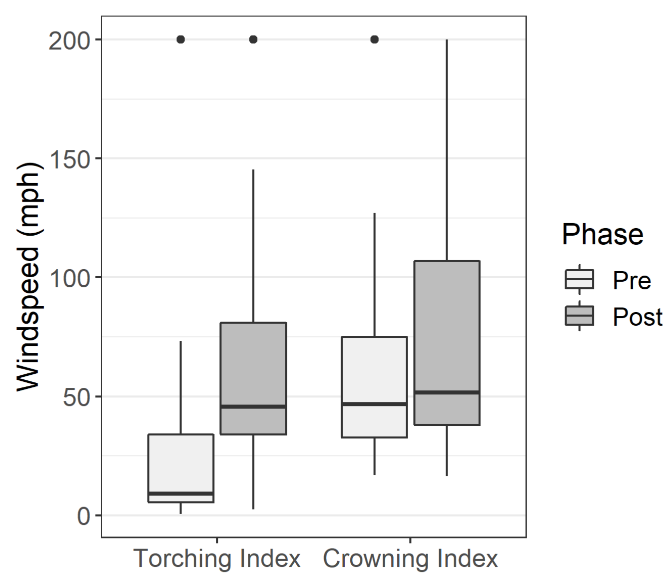

Figure 5. Boxplots showing the range of windspeeds predicted to support torching (Torching Index) and active crown fire (Crowning Index) within Elkhorn 4 pre- and post-treatment.

in fuels and fire behavior between the WIT and field-based monitoring of site conditions (Morici et al. 2019). In particular, pre-treatment canopy base heights were much higher in the field than predicted by LANDFIRE (2016); higher canopy base heights translate to lower crown fire hazard. However, an exciting result from the earlier monitoring was that the burn-only treatment increased canopy base height far more than predicted in the WIT, which translates to more effective crown fire hazard reduction. The Elkhorn 4 prescribed fire presents an opportunity to evaluate the consistency of these effects and whether modifications to effects modeling in the WIT are warranted.

The WIT uses crown fire activity (or "fire type") modeled with the Scott and Reinhardt (2001) method in FlamMap (Finney et al. 2015) as a proxy for burn severity by associating surface, passive crown, and active crown fire with low, moderate, and high severity burning, respectively. Fire behavior is modeled for extreme fuel moisture and winds (1-hr = 2%, 10-hr = 3%, 100-hr = 6%, herbaceous = 30%, woody = 63%, 20 mph winds at 20 ft blowing uphill) to reflect that most area burns under similar extreme conditions in the Colorado Front Range. This scenario provides a conservative test of treatment effectiveness under the most extreme conditions—fuel treatments tend to perform better in low to moderate fire weather (Kalies and Kent 2016). In our previous monitoring at the Scout Ranch, the WIT predicted mostly surface fire behavior in the burn-only unit before treatment and very little change in crown fire activity after the prescribed fire. The field monitoring confirmed that most of the burn-only unit was predicted to burn as surface fire. Like the previous burn-only unit, most of the Elkhorn Unit 4 cover is grass, shrub, or open woodland (Figure 1), and as such, FlamMap predicts mostly surface fire with a healthy dose of passive crown fire, but very little active crown fire (Table 3). The WIT predicted that the prescribed fire treatment would shift a small portion of the passive and active crown fire areas to less intense fire types (Table 3).

There are three reasons for the minor changes in crown fire activity predicted by FlamMap. The first two reasons are related: first, the pre-treatment canopy base heights from LANDFIRE (2019) are quite low, and second, prescribed fire is currently parameterized in the WIT to have small effects on canopy fuels. Thus, it is rare that the canopy base height is raised enough to avoid crown fire. The third reason for the minor differences is that most of the unit is already predicted to burn as surface fire. An area in surface fire condition cannot be improved in the WIT except through conversion to a non-burnable cover type, which would conflict with ecological objectives. In the pre-treatment project evaluation phase, the project partners discussed that the unit was not far departed from ideal conditions, so large changes in potential fire behavior were not expected.

Table 3. Percent and acres of the Elkhorn Unit 4 area predicted by FlamMap to support each fire type before and after a simulated prescribed fire.

Pre-Treatment						
Unit	**Surface**		**Passive**		**Active**	
	%	acres	%	acres	%	acres
Elkhorn 4a	58%	221.7	40%	154.8	2%	8.7
Elkhorn 4b	50%	59.6	47%	56.0	4%	4.2
Total	*56%*	*281.3*	*42%*	*210.8*	*3%*	*12.9*
Post-Treatment						
Unit	**Surface**		**Passive**		**Active**	
	%	acres	%	acres	%	acres
Elkhorn 4a	62%	239.5	36%	139.2	2%	6.4
Elkhorn 4b	62%	74.1	36%	42.7	3%	3.1
Total	*62%*	*313.6*	*36%*	*181.9*	*2%*	*9.6*

The treatment focus on introducing low severity fire to the landscape and reducing small diameter ladder fuels should be viewed as maintenance to keep the unit in a resilient mosaic of grass, shrub, woodland, and forest states.

The field monitoring plots were prioritized in areas of the unit with forest cover. To compare the WIT and field-based fire behavior predictions, we extracted predicted fire behavior from FlamMap for each pixel (representing an area of 900 meters^2 or 0.22 acres) that contained a field monitoring plot. The percent of plots predicted to support each fire type are presented in Table 4 for the pre- and post-treatment conditions. FlamMap predicted more pre-treatment surface fire than the field-based predictions because more of the FlamMap plots fell in areas mapped as non-forest vegetation types. Field plots were intentionally located in areas to capture a minimum of one tree—in other words, open areas devoid of trees were excluded from field measurements, but included in FlamMap fire predictions. In addition, the 900 meter^2 pixels represent an area slightly more than twice the size of a field monitoring plot. Minor differences may also be due to imperfect GPS data placing the sample plot in an adjacent pixel. FVS-FFE predicted that more of the plots would transition to a less intense fire type – primarily by moving from passive crown fire to surface fire. FVS-FFE also predicts a "conditional crown fire" fire type, in which surface fire is not predicted to be intense enough to initiate crown fire, but the canopy fuels are dense enough to support crown fire spreading into the plot.

Differences between modeled fire types can be attributed to differences between the modeled and field-measured fuel conditions as well as minor disagreements in the assigned fire behavior fuel models.

Similar to the 2017 burn-only unit (Morici et al, 2019), we found that field-measured canopy base height was higher than modeled in the LANDFIRE dataset pre-treatment, and the prescribed fire nearly doubled canopy base height (Table 5). This means that most

Table 4. Percent of the 35 plots predicted to support each fire type with the WIT versus the field-based data collection and FFE-FVS modeling.

	WIT (FlamMap)		Field-based (FVS-FFE)	
Fire Type	**Pre**	**Post**	**Pre**	**Post**
Surface	40%	51%	23%	83%
Passive	51%	43%	74%	14%
Active	9%	6%	0%	0%
Conditional crown	0%	0%	3%	3%

Table 5. Comparison of canopy base height and canopy cover. Note that canopy base height was only calculated for forested pixels in the WIT summary because non-forested pixels are assigned a value of zero.

Canopy base height (feet) *Only calculated for forested pixels

	WIT (LANDFIRE)		Field-based (meas.)	
Statistic	**Pre**	**Post**	**Pre**	**Post**
Minimum	1.0	1.1	0.0	1.5
Mean	2.2	2.5	5.4	11.7
Maximum	6.9	7.5	13.5	32.7

Canopy cover

	WIT (LANDFIRE)		Field-based (meas.)	
Statistic	**Pre**	**Post**	**Pre**	**Post**
Minimum	0	0	0	0
Mean	17	16	24	21
Maximum	55	52	92	94

treed areas of the unit started in a condition that is less prone to crown fire than predicted by the WIT and the realized effects made the plots far less prone to crown fire. Average canopy cover was close for both the WIT and field-based measurements, but the field-based measurements were more variable. This is likely a scale issue due to the larger size of the LANDFIRE pixels compared to the area measured within field plots.

The field crew assigned most of the post-treatment fire behavior fuel models to "Low Load Dry Climate Timber-Grass-Shrub" (#161), whereas the WIT transitioned more plots to "Short, Sparse Dry Climate Grass" (#101) and "Low Load, Dry Climate Grass-Shrub" (#121) in the Scott and Burgan (2005) classification (Table 6). These are all low load grass or shrub fuel models that grade between each other at the site. The "Low Load Dry Climate Timber-Grass-Shrub" model preferred by the field crew has lower flame lengths than the "Low Load, Dry Climate Grass-Shrub" model (Figure 6), which partially explains the larger shift towards surface fire behavior using the field data. Differences in fuel model assignment in the field compared to LANDFIRE data could be attributed to the bias in areas selected for field monitoring plots, as plots were required to contain at least one tree. In areas without trees, the WIT post-treatment fuel model assignments are reasonable with our observations of the unit.

Table 6. Plot count by fire behavior fuel model from the WIT (LANDFIRE 2019) and the field-based observations. See Scott and Burgan (2005) for detailed descriptions of the fuel models.

		WIT (FlamMap)		Field-based (crew obs.)	
FBFM	**FBFM Description**	**Pre**	**Post**	**Pre**	**Post**
101	Grass 1	4	13	0	3
102	Grass 2	9	0	0	4
121	Grass-Shrub 1	0	15	2	0
122	Grass-Shrub 2	15	0	18	2
141	Shrub 1	0	0	1	0
161	Timber-Understory 1	0	6	13	24
165	Timber-Understory 5	6	0	0	0
181	Timber-Litter 1	0	1	1	2
188	Timber-Litter 8	1	0	0	0

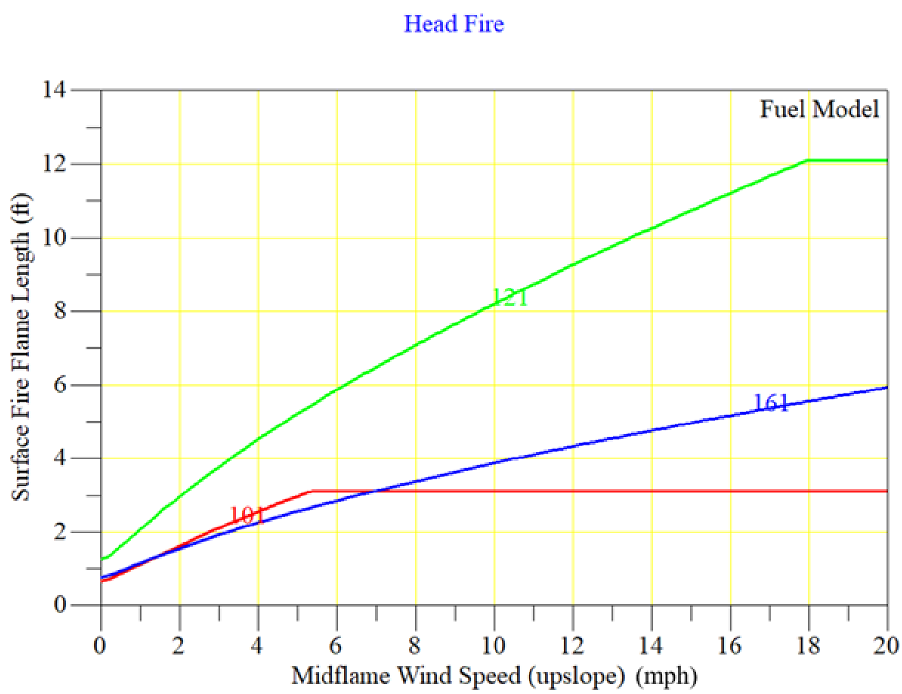

Figure 6. Comparison of predicted flame lengths for the most common post-treatment fire behavior fuel models using Behave 6.0 (Heinsch et al. 2010) with the same fuel moisture conditions as the WIT. Fuel models include "Low Load Dry Climate Timber-Grass-Shrub" (#161), "Short, Sparse Dry Climate Grass" (#101) and "Low Load, Dry Climate Grass-Shrub" (#121).

Discussion

Ponderosa pine forests in the Colorado Front Range have historically supported low- to mixed-severity fire. After a century of fire suppression, the reintroduction of prescribed fire is expected to increase forest resilience and support many valued ecosystem services. Small trees and shrubs serve as ladder fuels for fire to climb into the canopy of mature trees, and these long-lived woody plants will expand in the absence of disturbance. The Elkhorn 4 prescribed fire post-treatment monitoring results show a reduction in shrubs and small trees along with an increase in average tree canopy base height. Together, these factors will reduce how readily fire climbs from the forest floor into the crowns of trees and maintain a mosaic of grass, forbs, shrubs, and trees.

The Elkhorn 4 prescribed fire largely met the specific objectives laid out prior to treatment:

- Reduce conifer regeneration (<6” DBH) by at least 20% within 1 year of the burn. Although conifer regeneration was sparse across the unit, trees <6 inches in diameter were reduced by 45%.
- Reduce 1-, 10-, and 100-hour fuels by 30% immediately post burn. Fine woody fuels were reduced by 29% immediately post-burn, but within one year of the burn accumulated to similar levels as pre-treatment. Fine fuel loading for all time periods was low at less than 1 ton/acre. While woody fuel contributes to fire behavior, the dominant fuel influencing fire spread at this site is the grass component.
- Limit mortality of trees greater than 10” DBH to 20% or less. One year post-fire the expected mortality of trees greater than 10 inches in diameter is 9%.
- Increase native herbaceous vegetative cover by 20% within 2 years of the burn. We were unable to evaluate this objective during the one year post-treatment visit. Understory vegetation was surveyed in Elkhorn 4b, so it would be possible to evaluate this objective 3 years post-treatment if time and funding allow.

The overarching goals of the Elkhorn 4 prescribed burn were to minimize the potential for high severity wildfire and reintroduce fire into the ponderosa pine ecosystem. While the record-breaking 2020 Cameron Peak Fire perimeter reached within two miles of the prescribed burn area, it did not burn through the prescribed fire area to provide a real-world test of treatment effects on wildfire severity. To estimate treatment effectiveness, we used data from field monitoring plots to simulate a wildfire burning under severe conditions in FFE-FVS. Model results indicate that the treatment achieved the desired reduction in fire severity. Prior to the prescribed fire, a majority of the plots were predicted to support passive crown fire whereas most plots were predicted to support surface fire after treatment.

We compared field monitoring plots and FFE-FVS analyses to the forest conditions and fire effects predicted by the Watershed Investment Tool. The results contributed to a growing body of evidence that canopy base height in the field is higher than LANDFIRE suggests, and prescribed fire has much larger effects than are found in studies outside the Southern Rockies. One area that warrants further exploration is the discrepancy in fire behavior fuel models between field monitoring plots and LANDFIRE data. There is a scale mis-match between LANDFIRE pixels and field data, and an intentional bias in field plot locations towards forested areas could contribute to the difference in fuel models. Continued field monitoring, particularly of prescribed fires, in combination with refinement of the Watershed Investment Tool will provide more accurate measures of treatment outcomes and improve treatment prioritization models. Improving the models, in turn, will promote efficient allocation of resources to create and maintain resilient forests and secure clean water supplies.

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