Colorado Wildfire Risk Reduction Grant Program Monitoring Final Report

April, 2019
CFRI -1903

COLORADO FOREST RESTORATION INSTITUTE

FOREST AND RANGELAND STEWARDSHIP
COLORADO STATE UNIVERSITY

Colorado Forest Restoration Institute

The Colorado Forest Restoration Institute (CFRI) was established in 2005 as an application-oriented, science-based outreach and engagement organization hosted by the Department of Forest and Rangeland Stewardship and the Warner College of Natural Resources at Colorado State University. Along with centers at Northern Arizona University and New Mexico Highlands University, CFRI is one of three Institutes that make up the Southwest Ecological Restoration institutes, which were authorized by Congress through the Southwest Forest Health and Wildfire Prevention Act of 2004. We lead collaborations between researchers, managers, and stakeholders to develop, synthesize, and apply locally-relevant, actionable knowledge to inform forest management strategies and achieve wildfire hazard reduction goals in Colorado and the Interior West. Our work informs forest conditions assessments, management goals and objectives, monitoring plans, and adaptive management processes. We help reduce uncertainties and conflicts between managers and stakeholders, streamline planning processes, and enhance the effectiveness of forest management strategies to restore and enhance the resilience of forest ecosystems to wildfires. We complement and supplement the capacities of forest land managers to draw upon and apply locally-relevant scientific information to enhance the credibility of forest management plans. We are trusted to be rigorous and objective in integrating currently-available scientific information into forest management decision-making. We do this through collaborative partnerships involving researchers, forest land managers, interested and affected stakeholders, and communities.

The Colorado Forest Restoration Institute at Colorado State University receives financial support through the Cooperative and International Programs of the U.S. Forest Service, Department of Agriculture, under the Southwest Forest Health and Wildfire Prevention Act.

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Executive Summary

In 2013, the Colorado General Assembly authorized the Wildfire Risk Reduction Grant (WRRG) Program (SB13-269) to enhance the capacity of local government, community-based organizations, and private property owners to reduce flammable fuels on non-federal lands in and around their communities in order to mitigate the risk of losses from wildfire. The funds were intended for grantees to reduce the density and quantity of flammable vegetation using machinery or crews of people to cut, mulch or chip trees, mow dense brush, and dispose of flammable vegetation offsite. The Colorado Forest Restoration Institute (CFRI) at Colorado State University was tasked by the grant administrator, the Colorado Department of Natural Resources, to design and implement a monitoring strategy to assess the effectiveness of fuel reduction actions of WRRG grantees so that grant administrators and recipients alike could adapt their actions and maximize the impact of public funds.

The monitoring strategy was comprised of field-based measurements of fuel conditions before and after treatment activities, and computer fire simulation modeling to estimate changes in fire hazard metrics, such as the potential for active crown fire. CFRI applied this strategy to a subset of fuel reduction projects funded by the WRRG. Across all monitored sites, we found a general trend of projects successfully reducing fire hazard by changing predicted fire type under severe wildfire conditions from predominately passive crown fire to mostly surface fire. Overall, we found that 80% of projects were predicted to support passive or active crown fire under severe conditions before treatments, and this was reduced to 36% following treatments. Fire hazard was reduced as a result of WRRG treatments for many monitored projects, thereby providing firefighters more opportunities for safe and effective fire response by keeping fire on the ground. In addition to potential fire suppression benefits, promoting forest conditions that burn with a mix of low and moderate intensity surface and passive crown fire may reduce negative ecological impacts such as post-fire erosion that can degrade water quality, increase the chances of survival for existing trees during a wildfire, and restore ecological integrity in ponderosa pine and Douglas-fir forests that historically evolved with frequent fires.

While crown fire reduction is a success story for the WRRG program, the monitoring results also demonstrate that several key principles of fire mitigation, such as increasing tree crown base height and reducing surface fuel loads, were not consistently achieved across the monitored projects. The only treatment method which consistently reduced surface fuels and raised crown base height was prescribed broadcast burning. Fire behavior modeling results suggest that, even with extremely dry fuels and high winds, wildfires that occur in areas previously treated with prescribed fire are more likely to provide opportunities for safe and effective fire response, preserve existing trees, and have reduced soil and water impacts. Hence, reducing the accumulation and continuity of woody surface fuels and reducing ladder fuels are critical aspects of effective fuel reduction and wildfire mitigation.

Limited wood utilization opportunities and limited opportunities to apply prescribed fire on non-federal lands in Colorado can limit land owners' and managers' ability to reduce woody surface fuel loads and raise tree crown base height. One of the key areas where monitoring results supported changes in the WRRG program is to allow funds to be used on prescribed broadcast burns in later grant rounds. In addition to treatment implementation funding, capacity building grants through the WRRG program are a unique mechanism for communities to purchase biomass boilers and other equipment to increase capacity for wood utilization industries in Colorado.

In sum, WRRG program's effectiveness monitoring strategy has yielded information about the quality of acres treated, not just the number of acres, and has contributed to the enhanced on-the-ground adaptive management and effectiveness of fire mitigation actions. By generating quantitative measures of fuel treatment effectiveness, the monitoring strategy can help individuals and agencies working to reduce fire risk on non-federal lands identify measurable objectives and metrics of success. The monitoring results indicate that overall the WRRG program is a success, accomplishing thousands of acres of quality fire mitigation across Colorado, while also localizing science support and increasing our understanding and ability to better implement effective fire mitigation projects across non-federal lands in Colorado.

Introduction: the Wildfire Risk Reduction Grant Program

In the western USA, where federally-managed wildlands interface and intermix with privately-owned developed lands, there is heightened awareness that managing wildland fire risk is a shared responsibility between public and private property owners. During 2012 in Colorado, wildfires in this so-called "wildland-urban interface" (WUI) destroyed over 600 structures resulting in more than $538 million in estimated property losses and caused six fatalities. In response to this devastating fire season, in 2013 the Colorado General Assembly authorized the Wildfire Risk Reduction Grant (WRRG) Program (SB13-269) to enhance the capacity of local government and private property owners to work collectively to reduce flammable fuels on non-federal lands in and around their communities.

From 2013 through 2017, the Colorado Department of Natural Resources administered the WRRG program and, through a multi-stakeholder advisory committee, awarded over $12 million in grants over five granting cycles to 132 projects across 35 counties involving a diversity of organizational types, such as fire protection districts, local governments, and non-profit, non-governmental organizations (Table 1). Due to the 1:1 matching requirement, this resulted in an investment of over $24 million for Colorado non-federal lands fire mitigation through 2017. The size of grants received across the five cycles for any single grantee ranged from $2,400 to over $1.7 million. Grant funds paid for the use of machinery or crews of people to thin trees, mow down dense brush, or haul flammable vegetation offsite to be chipped or burned in safer locations. A portion of funds were also allocated for grantees to purchase equipment to increase current and future capacity for hazardous fuels reduction.

A unique aspect of the WRRG program was the allocation of up to 5% of grant resources for monitoring to examine the effectiveness of fire mitigation activities. Monitoring is widely seen by policy-makers and professionals as a critical step in performing good land management, but is rarely funded, making the WRRG a unique policy and program. The Colorado Forest Restoration Institute (CFRI) at Colorado State University was tasked by the DNR to design and implement a monitoring strategy to measure changes in fuels and fire hazard reduction accomplished through the WRRG program. An initial agreement of $428,600 was allocated to CFRI in September 2013; the agreement was amended by $39,985 in December 2015, and $35,540 in June 2017 to support monitoring on additional projects.

The goal of the monitoring program was to measure the quality of fire mitigation actions to provide information for improving future fire mitigation policy and practices, and to document overall program outcomes and lessons learned per SB16-269 reporting provisions. This was accomplished by collecting and analyzing forest and fuels field measurements before and after fire mitigation activities at a subset of WRRG projects to learn from the range of forest conditions, geographies, and vegetation management techniques being implemented around the state. In addition, CFRI staff performed informational site visits and provided science-based resources for many of the grant recipients, documented project locations, and analyzed grantee self-reported data on project accomplishments as required by the legislation.

Table 1. Wildfire Risk Reduction Grant program application and funding allocation information by organization type, cycles 1-5.

Organization Type	Total applications	Success rate	Percent of funded organizations	Allocated funds	Percent of allocated funds	Average allocation by cycle
Fire Protection District	19	0.51	14%	$1,139,269	9%	$248,332
Homeowner/ Property Association	32	0.67	24%	$1,112,157	9%	$242,422
Municipal/ County Government	35	0.69	26%	$5,706,977	47%	$1,243,977
Non-governmental organization	39	0.78	29%	$2,990,055	25%	$651,756
State Government	3	0.60	2%	$432,949	4%	$94,372
Other	4	0.50	4%	$715,019	6%	$155,856
TOTAL	132	0.66	100%	$12,096,426	100%	$2,636,715

Fuel Treatments for Wildfire Risk Reduction

Much of the non-federal lands in Colorado where human development mixes with wildland vegetation and is at high risk to wildfire is in the foothills and lower elevation forests. This risk has been in the making for over 150 years. Settlement-era grazing and logging, and nearly a century of fire suppression, has led to dramatic increases in tree density in many of these same forests, resulting in significant increases to fuel loading and potential fire behavior. For example, in dry-conifer forests of the upper and lower montane zones, tree densities have doubled and quadrupled, respectively (Battaglia et al., 2018; Brown et al., 2015). Shifts in the horizontal and vertical structure of fuels have contributed, in part, to uncharacteristic fire behavior and effects in the region (Allen et al., 2002).

In addition to increased forest density and fuel loads in some Colorado forests, rapid expansion of human development in Colorado's forested areas has intensified the need to aggressively suppress wildfires before they spread into developments. The fires that do escape initial containment in extreme weather conditions, may spread over tens of thousands of acres with high intensity. Lastly, the increased frequency, duration, and intensity of drought and the increase in average annual temperatures have lengthened the fire season and contributed to more intense fires throughout the western US (Holden et al., 2018; Westerling, 2016). Large, severe wildfires can lead to both diminished ecological integrity and impacts to ecosystem goods and services, such as delayed forest recovery, degraded water quality, erosion and sediment impacts to municipal water supplies, as well as damage to property and loss of life (Chambers, Fornwalt, Malone, & Battaglia, 2016; Fornwalt et al., 2016; Moody & Martin, 2001; Rhoades, Entwistle, & Butler, 2011; Turner, Romme, & Tinker, 2003)

In order to reduce the risk of damaging wildfires, fuel reduction methods such as mechanical thinning and prescribed fire are used to disrupt horizontal and vertical continuity of fuels (Agee & Skinner, 2005; Fulé, Crouse, Roccaforte, & Kalies, 2012). Often, wildfire mitigation treatments also aim to achieve additional ecological objectives such as increasing understory productivity, conserving old trees, and increasing tree age and size class diversity (Addington et al., 2018; Allen et al., 2002). While forest restoration and fuels reduction methods are often complimentary goals in frequent fire forests, Colorado supports diverse forest types across a range of elevations. In some forest types, management activities include goals to mimic effects of the disturbance processes that historically shaped them.

For example, many of Colorado's ponderosa pine forests historically experienced low-to-moderate severity disturbances which generally favored large tree survival, therefore mechanical thinning treatments with a preference for retaining large trees may be used to emulate historical stand conditions. In contrast, subalpine and lodgepole forests typically experienced stand-replacing disturbances, thus creating large openings by clearcutting trees can be used to mimic historical patterns across the landscape. Other silvicultural methods may have no ecological equivalent, such as mastication and chipping, but are used to accomplish specific management objectives by rearranging fuels from tree or shrub canopies to the forest surface. Disrupting the vertical and horizontal continuity of forest fuels discourages the spread of active crown fire and may increase opportunities for fire suppression, though if the goal of the treatment is to promote tree survival following fire, surface fuel loading and crown base height must also be considered (Agee & Skinner, 2005).

Fuel Treatment Effectiveness Monitoring Methods

General Approach

Considering the effort and resources directed towards fuel reduction and forest restoration treatments, policy-makers, managers, and scientists generally agree on the need to better understand the impact these investments have on reducing fire hazard and examine the factors that lead to successful treatments. The monitoring strategy CFRI developed for measuring the WRRG program's effectiveness included multiple components to capture the wide diversity of fire mitigation activities and geographies awarded through program. The WRRG monitoring strategy was organized to answer three questions:

1) *To what extent did hazardous fuel treatments change forest structure and woody surface fuels?*
2) *To what extent did hazardous fuel treatments affect the severity of predicted fire behavior and fire effects?*
3) *What factors contribute to treatments that successfully reduced fire hazard?*

The general approach was to measure changes in fuel loading and arrangement for a subset of 21 projects out of 102 total grantees that carried out fuel reduction activities (30 grants were allocated to grantees to purchase equipment) (Table 2). The selected sites represented a variety of forest types (mixed pinyon pine-Rocky Mountain juniper, ponderosa pine, lodgepole pine, and mixed conifer) and treatment implementation methods (mechanical and hand thinning, clearcutting, mastication, and broadcast burning) across Colorado (Figure 1). At each monitored site, we collected information about woody and non-woody plant species, structure, and composition, and

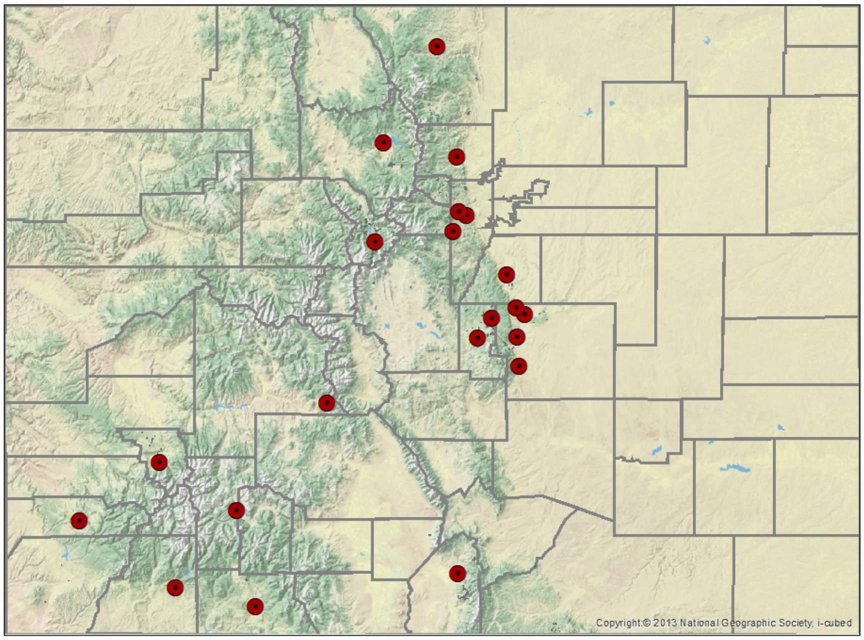

Figure 1: Map of Colorado's WRRG-funded projects monitored by CFRI.

fuel loading. These data were then input into a computer model to estimate changes in fire hazard before and after treatments. Computer models are commonly used to estimate fire hazard and fire behavior under different weather and fuel scenarios, since it is often infeasible and undesirable to set a project ablaze to measure treatment effects.

In addition to conducting quantitative analyses of fuel treatment effectiveness, CFRI also documented program accomplishments per the statute authorizing the WRRG by compiling a database of WRRG project locations, objectives, activities, and accomplishments, such as jobs created and involvement of youth corps. To accomplish these tasks, CFRI staff engaged a majority of grant recipients through phone calls, emails, site visits, and workshops to not only collect information, but also to share lessons learned and deliver localized science support. This engagement essentially served as the WRRG's extension and outreach program, thereby fostering cross-site learning and adaptive management.

Field Sampling

In order to assess the effects of fuel mitigation treatments on wildfire hazard, we used field-based surveys of fuel loading and forest structure before and after mitigation activities to quantitatively monitor changes in fire hazard. Monitoring was initiated in the Fall of 2013, and continued through 2018. Plots were randomly located across each site selected for monitoring. The number and density-per-acre of plots varied with the size of the treatment unit, ranging from 4 to 20 plots per treatment unit, depending on the size and complexity of the project (Figure 2). Post-treatment measurements took place between 1-3 years after the treatment was completed, with a selected number of sites intensively monitored multiple times post-treatment (Table 2). In some cases, we added additional plots on post-treatment sample visits to increase sample depth and better characterize fuel hazard reduction for long term monitoring.

We marked plot locations with Garmin eTrex GPS units and, starting in 2015, we installed permanent plot monuments to aid in the accurate relocation of monitoring plots. To photographically document plot locations and changes in forest conditions, during each plot visit, we took photographs of the forest surface, tree canopy, and two photographs at eye-level facing opposite directions.

CFRI's field measurements of fuel and forest structure complied with widely-accepted science-based standards and techniques, with some modifications to be appropriate for Colorado vegetation types. The CFRI protocols quantified forest structure, composition, and the arrangement of fuel from the forest floor to the tallest vegetation. Sampling protocols were refined and evolved over time to balance sampling efficiency, compatibility with other standard measurement techniques, and to capture critical metrics of fire hazard (Wolk and Hoffman 2013; Wolk and Hoffman 2015a; Wolk and Hoffman 2015b; CFRI 2016a; CFRI 2016b; CFRI 2017).

To measure structure of overstory trees within each plot, we inventoried trees in a variable radius plot using a wedge prism. For each tree that was inventoried in the

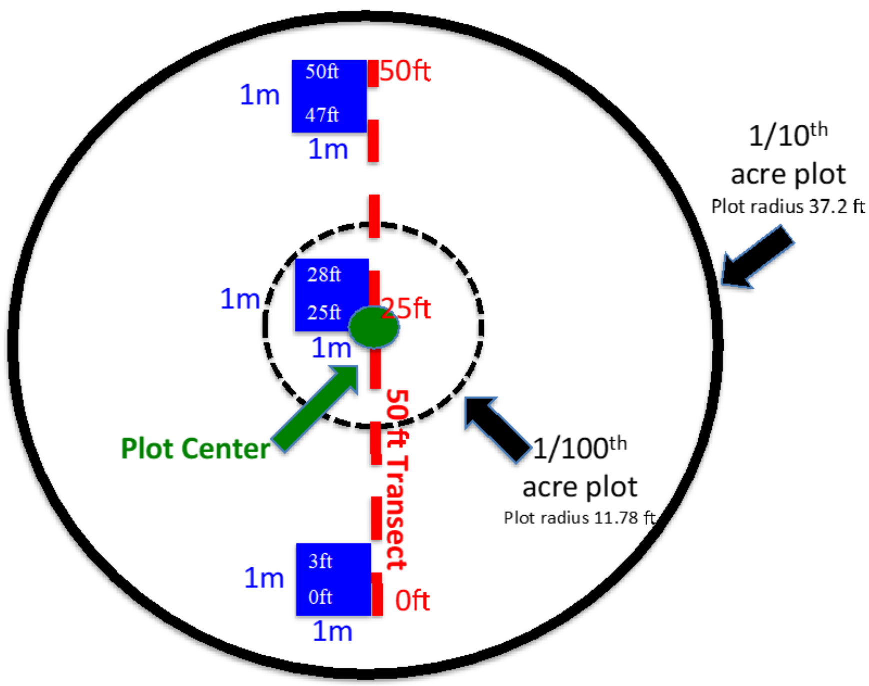

Figure 2: Diagram of the CFRI monitoring plot, not drawn to scale.

Table 2: Description of project sites with CFRI monitoring plots.

Project Site Name	Grantee	Grant Round	Years sampled	Forest Type	Implementation method(s)	County	Elevation (ft)
Ben Delatour Scout Ranch	Coalition for the Poudre River Watershed	4	2016, 2017	ponderosa pine	Mechanical thin, whole tree harvest, broadcast burn	Larimer	7590
Cheyenne Mountain	Coalition for the Upper South Platte	1	2013, 2015	ponderosa pine, Gambel oak	Mastication	El Paso	6163
Costilla County	Costilla County	2	2015, 2015	mixed conifer	Mechanical thin, whole tree harvest	Costilla	9603
Douglas County	Douglas County	1	2014, 2016, 2017	ponderosa pine, Gambel oak	Mastication	Douglas	6957
Fox Run	El Paso County	1 & 2	2013, 2015, 2016, 2017	ponderosa pine	Hand thin, slash chipped or pile burned	El Paso	7425
Genesee Foundation	Genesee Foundation	1	2014	ponderosa pine	Mechanical thin, whole tree harvest	Jefferson	7216
Genesee Mountain Park	City and County of Denver-Parks and Recreation	1	2013, 2015	ponderosa pine	Mastication	Jefferson	7827
Loma Linda	FireWise of southwest Colorado / San Juan Mountains Association	2	2014, 2015	mixed conifer, Gambel oak	Thin, slash used for firewood or masticated	Archuleta	7269
Lone Mesa	Colorado State Parks and Wildlife	5	2017	ponderosa pine, Gambel oak	Broadcast burn, some units masticated prior to WRRG grant	Dolores	7861
Mueller State Park	Coalition for the Upper South Platte	1	2013, 2014	mixed conifer	Mastication	Teller	9546
No Name Creek	Uncompahgre Com, Inc.	2	2014, 2017	lodgepole pine	Clearcut, slash pile burned	Gunnison	9104
Ptarmigan Meadows	Rio Grande Restoration Foundation	2	2014, 2017	mixed conifer, aspen	Mechanical thin, slash pile burned	Hinsdale	9664
Red Rock Canyon	The City of Colorado Springs Parks and Recreation and Cultural Services	1	2013, 2015	pinyon pine	Hand thin, slash chipped	El Paso	6300
Sourdough	Coalition for the Upper South Platte	1	2013, 2015	ponderosa pine	Hand thin, slash chipped and masticated	Teller	8420
Summit County	Summit County and Town of Breckenridge	1	2013, 2015, 2017	lodgepole pine	Clearcut, slash lopped and scattered or removed	Summit	10028
Sunshine Canyon Drive	Sunshine Fire Protection District	2	2014, 2015	ponderosa pine	Thin, slash pile burn	Boulder	6718

Project Site Name	Grantee	Grant Round	Years sampled	Forest Type	Implementation method(s)	County	Elevation (ft)
Timberdale Ranch	FireWise of southwest Colorado / San Juan Mountains Association	2	2014, 2015	ponderosa pine, Gambel oak	Mastication	La Plata	7701
Top of the Pines	West Region Wildfire Council on behalf of Ouray County	1	2013, 2015, 2016	ponderosa pine	Hand thin, slash lopped and scattered	Ouray	8582
West Ranch	Jefferson Conservation District	1	2014, 2015	mixed conifer	Mechanical thin, whole tree harvest	Jefferson	7462
Willow Creek	Northern Colorado Water Conservancy District	1	2013, 2015	lodgepole pine	Clearcut, slash lopped and scattered	Grand	8344
Woodmoor Improvement Association	Woodmoor Improvement Association	2	2014, 2015	ponderosa pine, Gambel oak	Hand thin, whole tree harvest	El Paso	7333

variable radius sample, we recorded species, status (live or dead – and, if dead, recording the stage of decay based on degree of rot), diameter at breast height (DBH), total height, and crown base height (CBH). At some sites, we encountered plots where no trees were cut or otherwise altered. While we acknowledge that tree growth likely occurred between sampling periods, we used the pre-treatment measurements for post-treatment fire modeling in unaltered plots, with the assumption that changes in forest structure over the short sampling period would have minimal to no impact on fire behavior modeling outcomes. Live tree canopy cover was measured in one-foot increments along a 50-foot transect using a GRS Densitometer. Live shrub cover was measured using a line intercept method along a 50-foot transect, and the average maximum shrub height was recorded.

To measure fine woody surface fuel loading, we used the photoload estimation technique with a 1 m^2 quadrat to visually assign a loading for each fuel size class, including 1-hour (<0.25 in diameter), 10-hour (0.25-1 in. diameter), and 100-hour (1-3 in. diameter) fuels (Keane & Dickinson, 2007). Starting in 2016, photoload calibration quadrats were developed by estimating, collecting, drying, and weighing fine woody fuels by size class. To improve the accuracy of visual photoload estimates, we generated calibration curves relating the estimated photoload values to predict the true woody fuel weight as recommended by Tinkham et al. 2016. Separate regressions were generated for each fuel size class, and the regression results were used to calibrate all woody photoload estimates (Morici & Cannon, 2018).

When fine fuel loading was not appropriate to estimate with the photoload sampling technique, such as in masticated fuels (e.g. Mueller State Park), an alternate methodology was adjusted to obtain fuel loadings. Fine woody fuel cover and depth were recorded and quadrats were destructively sampled. We collected fuels from one 0.25 m^2 quadrat per plot, oven dried material for at least 48 hours at 55 degrees C, and weighed masticated fuels. The total weight of the fuel bed was classified into 1-hour, 10-hour, and 100-hour fuel loadings using the corresponding percentage of the masticated fuel bed loading for a similar forest type reported in Battaglia et al. (2010).

We measured lengths and diameters of coarse woody fuel (> 3 inches diameter) in a 0.1 acre circular subplot. The depth of the leaf litter and duff layers were measured in four corners of each quadrat. Average depth of each layer was converted to loading using a bulk density value appropriate for the site's forest type (Battaglia et al., 2010; Brown & See, 1981; Ziegler, 2014).

We increased sampling intensity over the course of the WRRG program to better estimate forest understory components. Saplings (DBH < 5 inches, height > 4.5 feet) were initially counted in a variable radius plot, but were later measured in a 0.01-acre fixed radius plot to better align with U.S. Forest Service monitoring protocols and enhance measurement precision. Initial monitoring protocols (e.g. Wolk and Hoffman 2013) included measurements of tree seedlings (< 4.5 feet tall), herb cover, ground fuel depths, and fine woody fuel loading within a single 1-m^2 quadrat per plot. In later sampling efforts we added two additional quadrats per plot to better capture the spatial variability of fuel and vegetation loading. Tree seedlings were initially tallied in the quadrat(s), and later a supplementary tally by four height size classes within a 0.01 acre fixed radius plot was added to produce more robust estimates of seedling density. We used seedling counts from the quadrat(s) only for consistency during analysis, except at sites where circular plot seedling tallies exist for all visits.

In addition to measuring forest structure and fuel loading pre- and post-fuel treatment, we developed additional protocols to assess vegetation and soil impacts as indicators of burn severity from prescribed broadcast burns conducted at two sites in 2017: Lone Mesa State Park and Ben Delatour Scout Ranch. Burn severity refers to the type and amount of vegetation consumed by a fire and was assessed qualitatively and quantitatively. At each plot, we classified substrate and vegetation burn severity into five categories, from unburned to heavily burned, in ten to twelve 36 in^2 subplots (Table 3; CFRI, 2018; USDI National Park Service, 2003). We calculated percent of substrate burned from 200 observations on eight 25 ft transects. At Lone Mesa State Park, we further quantified substrate burn severity as percent of combined litter and duff depth reduced through consumption using steel nails installed prior to the burn. We installed aluminum number tags on individual overstory trees and saplings to track primary predictors of fire related mortality including percent of crown volume scorched, maximum height of canopy scorch, and the maximum height of char on the trunk (CFRI 2018).

seedlings, woody fuels, and ground fuels were processed by FFE-FVS, which selected up to two of 53 standard fire behavior fuel models for each unit (Anderson, 1982; Scott & Burgan, 2005). At sites with multiple units with different treatment implementation or slash management methods, we analyzed each unit separately.

In most cases, we allowed FVS logic to select a surface fuel model based on the input trees, woody fuels, and ground fuels. However, we identified one incompatibility between our field protocols and FVS in cases with high cover of Gambel oak. FVS considers Gambel oak to be a tree, but its growth form on the Front Range is most often shrub-like, thus field data collection for this species considered Gambel oak to be a shrub. It is not possible to manually input shrub loading into FVS, nor could we convert the cover and height data for Gambel oak into tree density. In these cases, we created custom fuel model selection logic, similar to Scott and Burgan (2005). We used this selection logic to manually assign an appropriate surface fuel model to sites with greater than 20% cover of Gambel oak based on the total shrub cover and average shrub height (Figure 3).

Potential fire behavior and effects were modeled under both severe and moderate fire weather and fuel moisture conditions (Table 4). Severe fire conditions correspond to days with extreme fire danger or 97th percentile weather conditions. Moderate fire conditions represent typical conditions under which prescribed fires may be implemented. We determined that FFE-FVS program values for the Central Rockies variant were congruent with 97th percentile conditions reported from geographically-proximate Remote Automated Weather Stations (RAWs) and thus adequate to characterize severe conditions, with the exceptions of temperature and herbaceous

Table 3: Categories used to quantify soil and vegetation burn severity

	Unburned	Scorched	Lightly Burned	Moderately Burned	Heavily Burned
Substrate	Not burned	Litter partially blackened; duff nearly unchanged; wood/leaf structures unchanged	Litter charred to partially consumed; duff layer not altered over the entire depth; surface appears black; woody debris is partially burned; logs are scorched or blackened but not charred	Litter mostly to entirely consumed, leaving coarse, 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.
Vegetation	Not burned	Foliage scorched and attached to supporting twigs	Foliage and smaller twigs partially to completely consumed; branches mostly intact	Foliage, twigs, and small stems consumed; some branches still present	All plant parts consumed, leaving some or no major stems/trunks; any left are deeply charred

Fire Behavior and Effects Modeling

To understand how changes in forest structure and surface fuels altered fire hazard, we input field data from pre-treatment and post-treatment surveys into the Fuels and Fire Extension to the Forest Vegetation Simulator (FFE-FVS) (E. Reinhardt & Crookston, 2003). All modeling runs used the Central Rockies variant in FVS. Field-collected monitoring data for trees, saplings,

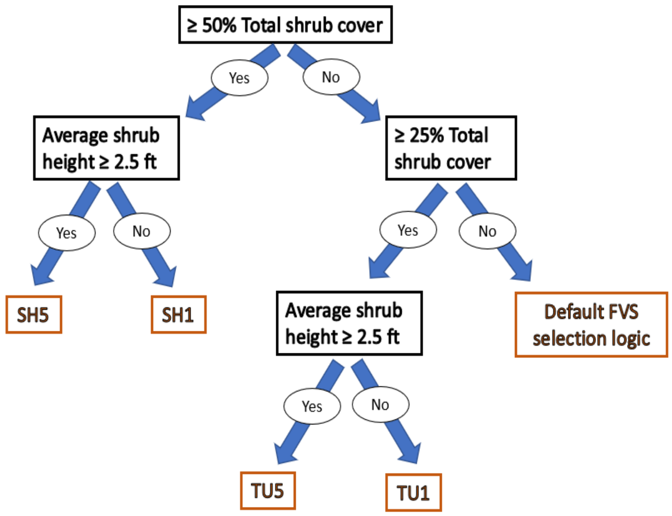

Figure 3: Fuel model selection logic when cover of Gambel oak was equal to or greater than 20%. Selection logic is based on Scott & Burgan (2005).

fuel moisture. To better approximate 97th percentile fire weather conditions observed from RAWs data, we revised the FVS default temperature of 70° F to 90° F, and revised default herbaceous fuel moisture of 120% to 30%. This was done because herbaceous fuel moisture varies throughout the fire season—97th percentile weather conditions can occur when the herbaceous fuel is actively growing and has higher moisture content, or when herbaceous fuel is dormant and cured. We simulated a fire under severe conditions with a cured herbaceous layer, and under moderate conditions with a live herbaceous layer.

Fire simulations for pre-treatment and post-treatment stands were compared to evaluate the change in fire hazard produced by mitigation activities. FFE-FVS modeled fire behavior and fire effects outputs include Torching Index, Crowning Index, fire type, surface flame length, total flame length, and tree mortality. These metrics were compared between pre- and post-treatment stands using paired t-tests. The first three terms are defined below:

- Torching Index is the 20-foot windspeed predicted to initiate crown fire activity, which is influenced by surface fuels, surface fuel moisture, canopy base height, slope steepness, and wind reduction by the canopy.
- Crowning Index is the 20-foot windspeed predicted to maintain active crown fire, and is influenced by canopy bulk density, slope steepness, and surface fuel moisture content. Torching and crowning index were modeled under severe fire conditions. When no trees are present in a unit (such as after a clearcut), we adjusted these values to the highest predicted value within the dataset, which was 282 mph. The improbability of this windspeed is consistent with the impossibility of crown fire activity in the absence of trees.
- Fire type includes surface, passive, and active fires. Surface fire burns on the forest floor and is predicted to occur when the input windspeed is less than both the Torching and Crowning Indexes. Passive crown fire burns individual tree crowns and is predicted when the input windspeed is greater than the Torching Index and less than the Crowning Index. Active crown fire spreads between tree crowns and is predicted when the input windspeed is greater than both the Torching and Crowning Indexes.

FFE-FVS is a widely used platform by fire analysts, fire and fuels managers, and researchers to measure potential fire behavior change following forest fuel reduction treatments (Battaglia et al. 2008; Johnson et al. 2011; Reinhardt et al. 2010). However, there are several limitations to consider when interpreting modeled fire behavior and effects. Cruz & Alexander (2010) found the underlying models and linkages used in FFE-FVS result in a significant underprediction bias for crown fire. Fire modeling runs in FVS take place under constant conditions and do not include changes in fire activity due to variation in weather, topography, or fuels. Additionally, the data collected during monitoring is used to assign one or more pre-set fire behavior fuel models, which are limited in number and do not allow for a continuous spectrum of fire behavior governed directly by the input data. Thus, fine-scale differences in stand conditions may not lead to detectable differences in modeled fire behavior. While FVS accepts detailed tree data, it does not allow for customization of the live herb and shrub layers. FVS predicts herb and shrub loading based on dominant tree species and modeled canopy cover. We discuss some of these limitation in individual project analyses as applicable. Finally, modeled fire behavior in FVS does not account for the impacts of fire suppression actions. Some treatments may facilitate suppression actions, for instance a reduction

Table 4: Weather and fuel moisture values used for fire behavior modelling with FFE-FVS based on fuel moisture and temperature information from RAWS data (Zachariassen et al. 2003)

Fire Conditions	Wind (MPH)	Temp (° F)	Fuel Moisture Conditions (%)						
			1-hr	10-hr	100-hr	1000-hr	Duff	Live Woody	Live Herb
SEVERE	20	90	4	4	5	10	15	70	30
MODERATE	6	77	8	10	12	16	125	120	120

in fire intensity may allow for direct suppression tactics and thinning the tree canopy may increase fire retardant penetration.

Project Database

To develop a database of WRRG projects, CFRI staff compiled self-reported data from three sources: 1) the initial grant proposals, 2) annual and final performance reports, and 3) direct communication with grant recipients. The data included project accomplishments and geospatial information system (GIS) data. In the cases when grant recipients did not have professional GIS software, CFRI provided guidance and written instructions on how to use Google Earth to create and report spatial data. A minimum of two requests were made for GIS data from each WRRG recipient.

For each project, CFRI compiled and input the following information:

1. Project name
2. Project number (CFRI unique ID)
3. Organization responsible for the project
4. Approximate project boundary
5. Number of acres
6. Management purpose
7. Notes about the project site
8. Treatment activity
9. Slash management practices
10. Canopy treatment type
11. Treatment start date
12. Treatment end date
13. Monitoring data status

The end-date for compiling WRRG grantee self-reported information was December 31, 2018.

Results

Overall Effectiveness of WRRG Fuel Treatments

Over 250 monitoring plots were installed for 21 WRRG projects encompassing 7,591 treated acres. Across all monitored sites, we found a general trend of projects successfully reducing fire hazard by changing predicted fire type under severe conditions from predominately passive crown fire to mostly surface fire (Figure 5). Overall, we found that 80% of projects were predicted to support passive or active crown fire under severe conditions before treatments, and this was reduced to 36% following treatments. Appendix A contains individual summaries for each project, including project description and quantitative measures of changes in fuel conditions and predicted fire hazard. The impact of mitigation depended in part on the dominant tree species or forest type, as we found that treatments were most effective in ponderosa pine forests and had little effect on predicted fire behavior in mixed-conifer forests (Figure 6-A). Different overstory treatment and slash management methods used by WRRG grantees did not differ in their effectiveness at reducing fire hazard (Figure 6-B, Figure 6-C).

Higher windspeeds are predicted to initiate and sustain crown fire in treated stands compared to untreated stands. Torching Index significantly increased from an average of 11 mph prior to treatment to 67 mph following treatment (t_{23}=-3.01, p=0.006). An increase in the Torching Index means a higher windspeed is needed before fire climbs into the canopies of individual trees and groups of trees. Similarly, Crowning Index changed from an average of 50 mph prior to treatment to 90 mph following treatment (t_{23}=-3.01, p=0.006). These results indicate that overall, WRRG treatments reduced crown fire hazard (Figure 4). However, direction and magnitude of the change varied between treatment units.

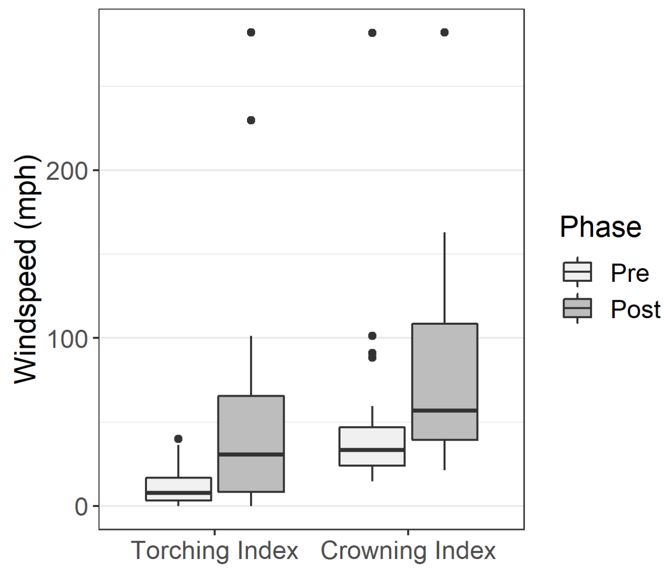

Figure 4: Torching and Crowning Index pre-and post-treatment

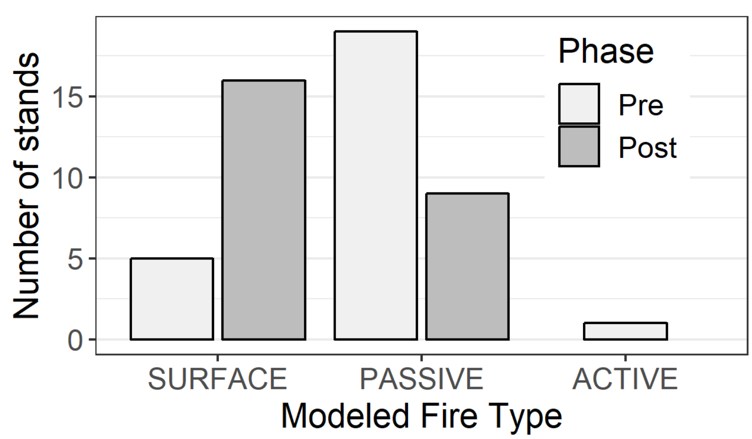

Figure 5: Number of pre- and post-treatment stands for each modeled fire type

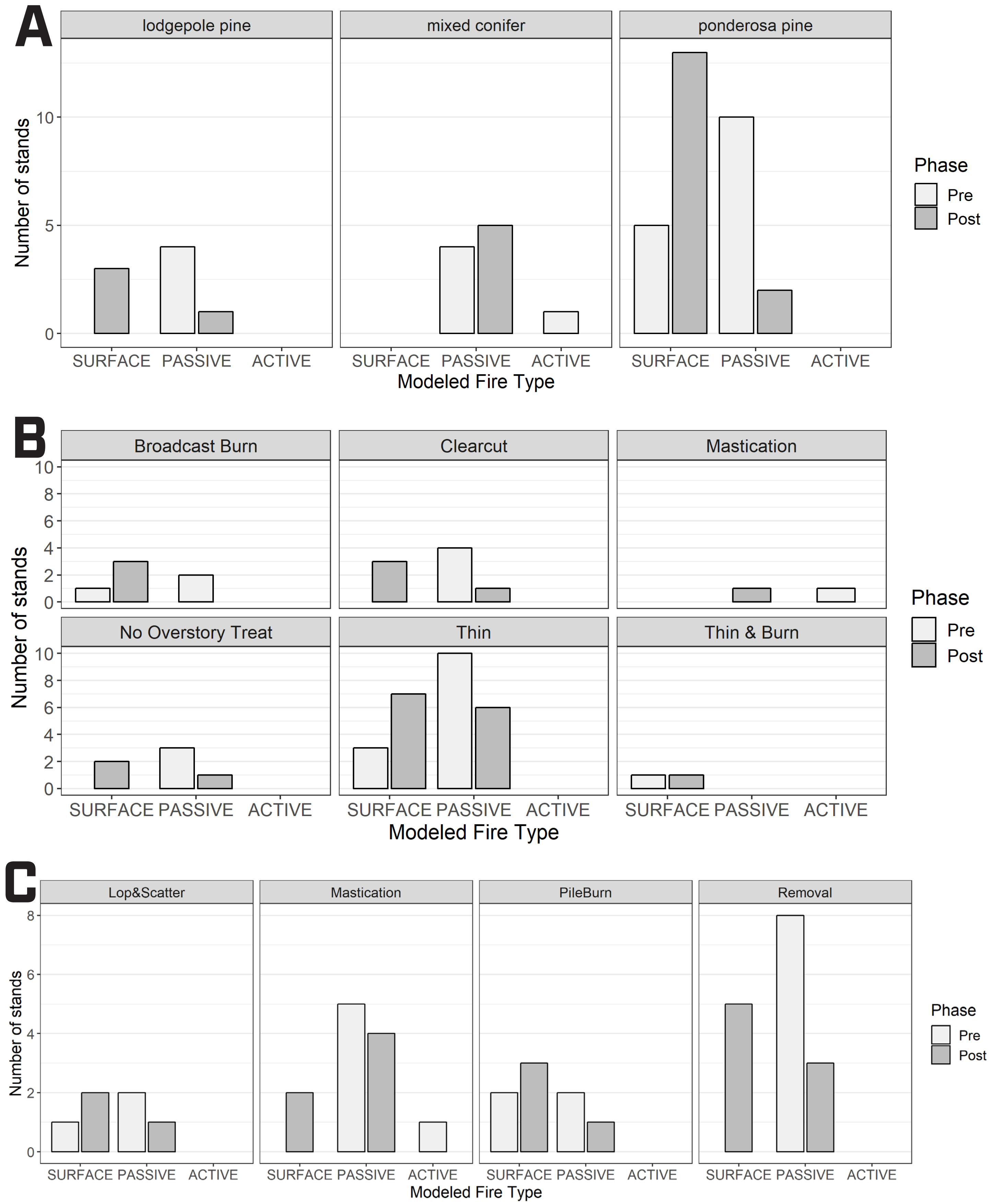

Figure 6: Modeled fire type for pre-treatment and post-treatment stands, predicted in FFE-FVS under severe fire conditions. A) Number of stands in each fire type by forest type. B) Number of stands in each fire type by overstory treatment method. C) Number of stands in each fire type by primary slash management method.

The fire behavior modeling results demonstrate that forest type is an important factor in the success of fuel reduction treatments. Following mitigation, ponderosa pine stands experienced the greatest reduction in predicted fire hazard under severe conditions. Of the ten ponderosa pine stands included in our study that were expected to support passive crown fire, all but two stands converted from passive crown fire to surface fire following mitigation treatments. Mitigation in mixed conifer stands showed a slight reduction in fire hazard metrics at most sites, but none of the five monitored sites were predicted to drop fire from the tree canopies to the surface. The sole pinyon pine stand receiving monitoring analysis did not show any change in predicted fire type due to treatment, although, given its singularity, treatment effectiveness can't be generalized. All fuel reduction activity in lodgepole pine involved clearcutting, which removed most of the tree overstory and therefore eliminated the potential for crown fire. The only exception occurred in Willow Creek, where a handful of trees remaining in one plot following treatment led to the prediction of passive crown fire. However, surface fire would reasonably be expected across most of Willow Creek, as no other plots had trees remaining to carry crown fire following treatment.

The wide array of combinations in treatment implementation methods and slash management methods led to a small number of stands represented by each group (Table 5). As a result, we cannot directly attribute overall treatment effectiveness to a particular implementation method, aside from complete tree removal effectively eliminating crown fire hazard in the case of clearcuts in lodgepole pine. Four of the ten thinned units that were predicted to support passive crown fire under severe conditions prior to treatment shifted to surface fire following treatment. Prescribed fire was applied to four units, and in all cases dramatically reduced the potential for active crown fire to occur. Overstory tree mastication only occurred at one site, where predicted fire type under severe conditions shifted from active crown fire to passive crown fire. Our inference on implementation method effectiveness is constrained by the limited sample sizes for treatment combinations.

Fuel reduction activities may change the distribution of woody fuels from the canopy to the forest floor, depending on how residual slash is treated. Sites where slash was removed or pile burned shifted towards supporting surface fire under severe conditions, with six of the ten sites initially predicted to support passive crown fire converting to surface fire after treatment. Mastication of slash or small trees and shrubs resulted in four of five sites continuing to support passive crown fire following treatment. The greatest increases in fine woody fuels took place in masticated areas and sites that were clearcut with slash lopped and scattered. Sites with the largest decreases in fine woody fuels were thinned or clearcut with slash either removed or piled and burned. Most treatments had little impact on the loading of coarse woody fuels. Interestingly, two of the three sites that substantially increased coarse woody fuel loading listed pile burning as the planned slash management activity. One of the sites had not yet burned the piles by the post-treatment monitoring visit. At the other site, most piles were incompletely burned, perhaps due to poor pile construction and/or lack of maintenance during burning, such as moving unburned ends into the center of the burning pile to facilitate more complete consumption.

To begin examining treatment longevity, we collected repeated post-treatment measurements at six units across four sites in ponderosa pine and lodgepole pine forests. Sites were measured two to four times following treatment, and usually took place at one-year intervals. In keeping with the overall program-wide results, predicted fire type under severe conditions shifted from passive crown fire to surface fire following treatment at most of the re-measured sites. However, measurements at most sites were within 3 years post-treatment, and the shift of fire type showed variable trends over time depending on the vegetation type. The Douglas County projects that were monitored returned to passive crown fire within two growing seasons after the Gambel oak mastication treatment. Cover of Gambel oak three years post-treatment equaled pre-treatment Gambel oak cover, although the average height was one foot shorter. At Fox Run, tree basal area and density noticeably increased in the 1-4 years following thinning. Both the Chip and Pile Burn units remained in surface fire condition during that period.

Table 5: Number of stands in each overstory treatment- slash management combination

Slash Management	Overstory Treatment					
	Broadcast Burn	Clearcut	Mastication	None	Thin	Thin & Burn
Lop and Scatter	0	2	0	0	1	0
Mastication	0	0	1	3	2	0
Pile Burn	0	1	0	0	3	0
Removal	0	1	0	0	7	1
NA	3	0	0	0	0	0

The lodgepole clearcut in Summit county was effective at removing crown fire hazard, aside from one sapling that grew into the Rac Jac unit and returned the stand to a prediction of passive crown fire. No saplings emerged in the Prospector unit, and surface fire would reasonably be expected to dominate both units since no other trees remained. As expected in lodgepole forests, tree regeneration is high in both the minimum and full utilization units, though the density was highly variable and average seedling height 3 years post-treatment was less than one foot. Future monitoring can illuminate how long this shift will last before additional treatments are needed and will yield new knowledge about treatment longevity.

Effectiveness of Prescribed Fire: Two Case Studies

Monitoring plots at Lone Mesa State Park and Ben Delatour Scout Ranch captured prescribed fire effects immediately following the broadcast burns in order to characterize fire severity. Each site contained two units, one that recently received fuel hazard reduction treatments through mastication or thinning, as well as one that had not recently been managed for fuel. At both sites, fire effects on substrate and vegetation were less severe in thinned or masticated stands compared to unmanaged (burn only) stands (Table 6). The prescribed fire at Lone Mesa spread across the entire project area, with all plots showing signs of being burnt. The fire reduced combined litter and duff depths by about 50% in each stand, though masticated stands started with slightly greater depths and displayed more variable consumption. Substrate burn severity ranged from unburned to heavily burned in both masticated and unmasticated areas, with two-third of observations being scorched or lightly burned in each case. However, 25% of vegetation observations in unmasticated stands were moderately to heavily burned compared to 5% in masticated areas.

Thinned stands at Ben Delatour Scout Ranch were largely unimpacted by the prescribed fire. In the 30% of severity subplots visibly impacted by fire, 73% of soil and 90% of vegetation observations were either scorched or lightly burned. This is in contrast to the burn only stand, where all subplots were visibly impacted by fire and 25% of soil observations and 85% of vegetation observations were either moderately or heavily burned. Damage incurred to trees during the prescribed fires followed similar trends, with increased damage in unthinned or unmasticated stands. The forest density at Ben Delatour Scout Ranch was similar in both units prior to treatment, though the unmasticated unit at Lone Mesa State Park had extremely low tree density prior to treatment, well below density in the masticated stand. On average, crown volume scorch was approximately 70% higher in unmasticated or unthinned stands compared to masticated or thinned stands at each respective site (Table 6). Average stem char height in unmasticated stands was 25 ft to 45 ft greater in previously unmanaged stands compared to those that received mastication or thinning, respectively Saplings were largely absent from plots at each site, with just one captured at Ben Delatour Scout Ranch. While fire-related tree mortality is best assessed 3-5 years following a burn, our preliminary results one year post-burn reveal no trees in the thinned or masticated stands were killed by the prescribed fire. The prescribed fire in the unmasticated stand at Lone Mesa State Park reduced live tree density from 3 to 2 trees per acre. In contrast, burning in unthinned stands at Ben Delatour Scout Ranch reduced live tree density from 104 to 65 trees per acre and basal area from 70 to 36 square feet per acre, which was comparable to the reduction by thinning alone. Additional tree mortality may occur over the next several years due to high crown volume scorch in the burn only stand.

WRRG Grantee Self-Reported Accomplishments

As Table 7 shows, grantee self-reporting varied widely

Table 6: Observed mean and standard deviation of prescribed fire severity measurements at Lone Mesa State Park and the Ben Delatour Scout Ranch

	Lone Mesa State Park		**Ben Delatour Scout Ranch**	
	Masticated and burned	*Burn only*	*Thinned and burned*	*Burn only*
Percent Surface Burned	60.7 ± 9.2	56.3 ± 6.1	23.0 ± 27.0	39.3 ± 18.1
Litter/Duff Consumption	50.4 ± 37.1	54.4 ± 21.4	Not Measured	
Overstory Crown Volume Scorch (%)	11.1 ± 16.0	80.4 ± 21.0	18.9 ± 37.1	94.4 ± 10.4
Overstory Stem Char Height (ft)	9.8 ± 7.2	36.3 ± 18.0	4.6 ± 9.6	51.0 ± 22.4

Table 7: Summary of WRRG grantees' self-reported accomplishments for award amount, actual acres treated vs proposed acres to be treated, cost per acre treated, biomass removed, revenue generated, and jobs provided, FY13-17 reporting periods

Accomplishment	No. of grantees reporting	Total amount	Average	Std. deviation	Range
Amount awarded	132	$12,096,426	$89,137	$141,309	$2,400 - $1 million
Proposed acres to be treated	89	23,769 acres	423 acres	413 acres	5 – 2,830 acres
Actual acres treated	89	16,806 acres	191 acres	414 acres	6 – 2,551 acres
Cost per acre[1]	94	n/a	$1,486	$1,907	$10 - $7,500
Biomass removed (in cubic yards)	42	255,602 yds^3	6,086 yds^3	16,091 yds^3	3 – 80,000 yds^3
Biomass removed (in tons)	32	35,798 tons	1,119 tons	2,145 tons	14 – 10,575 tons
Revenue generated	20	$497,734	$26,197	$40,638	$200 - $150,000
Jobs provided	61	666.75	11 persons	9.5 persons	0.25 – 29 persons

[1] Cost per acre ($1,486) x total actual acres (16,806) = $24,973716, approximating the 1:1 cost match for the WRRG program, with 92% (94 out of 102) WRRG grantees conducting fuel treatments reporting.

across the variables CFRI set out to compile per the WRRG's enable statute, SB16-269. Across all granting rounds, from July 2013 to December 2018, 89 grantees reported completing 16,806 acres of fuel reduction treatments out of 23,769 acres proposed for treatment (approx. 71%) (Table 7). The average project treatment size was 414 acres and ranged in size for a single project from six to 2,551 acres. Ninety-four grantees reported that the average cost per acre treated as $1,486 and ranged in cost for a single project from $10 to $7,500 per acre. Grantees were given the option to report the amount of flammable fuel removed by either volume (cubic yards) or weight (tons) of biomass. Forty-two grantees reported 255,602 cubic yards and 32 grantees reported 35,798 tons of woody biomass were removed from WRRG project sites. The volume of 255,602 cubic yards is the equivalent of a football field stacked to a depth of 5'4" of woody biomass. The weight of 35,798 tons is the equivalent of about 2,386 full-size (but empty) school buses. Twenty grantees reported a total of $497,734 in revenue generated from WRRG projects through the sale of woody materials; the materials ranged from firewood to landscaping mulch to sawlogs. The average revenue generated for the 20 grantees was $26,197 and revenue from a single project ranged from $200 to $150,000. Sixty-one grantees reported that the WRRG provided for a total of 666.75 jobs across 79 distinct private enterprises, non-profit organizations, and state or local government agencies across Colorado (see Appendix A for comprehensive list of contractors). The average number of jobs was 11 per project and ranged in number for a single project from 0.25 to 29 persons. Many of these jobs were part-time, corresponding to the seasonality and episodic time frame of the field work associated with fuel reduction.

As of December 2018, CFRI was able to collect spatial data associated with 59 projects, totaling 7,856 acres (Table 8).

Discussion and Lessons Learned

The Wildfire Risk Reduction Grant Program (WRRG) provided funding for hazardous fuels reduction projects on private land throughout the state of Colorado, with the aim of reducing wildfire hazard to critical infrastructure and property. CFRI collected and analyzed field monitoring data at a subset of WRRG projects to assess the effectiveness of WRRG grantees' activities and to incorporate adaptive management into the program. Fire modeling results from FFE-FVS across all monitored sites broadly reveal a reduction in most fire hazard metrics following treatment. However, treatments in mixed conifer stands remained densely forested or had high fuel loading and as a result showed little change in fire hazard following treatment. Monitoring more sites, especially in forest types other than ponderosa pine, would increase our confidence in these results. Long-term monitoring is also recommended to assess treatment lifespan and schedule repeated treatments.

Removal of small-diameter trees led to an increase in Crowning Index, the windspeed required to sustain active crown fire. Crowning Index increased by at least 5

Table 8: Summary of WRRG project acreage reported in Final Reports and calculated from spatial database

	Total projects awarded	Completed projects with final reports	Total implementation projects (projects that note acres treated in final report)	Total Projects in GIS	Polygons	Acres (in GIS)	Acres reported in final report	Missing from GIS (Reported acres – acres in GIS)
Round 1	25	22	18	20	581	3840	3,564.27	-275.73
Round 2	27	25	21	19	1672	2547	2,893.46	346.46
Round 3	*37*	*29*	*25*	*11*	*103*	*701*	*5,107.79*	4,406.79
Round 4	*26*	*20*	*18*	*7*	*48*	*534*	*2,900.89*	2,366.89
Round 5	*17*	*8*	*5*	*2*	*3*	*234*	*401*	167.00
TOTAL	*132*	*104*	*87*	*59*	*2407*	*7856*	*14867*	7011

mph at 72% of the monitored sites following treatment. Torching Index, or windspeed required to initiate crown fire, increased by at least 5 mph at 64% of the monitored sites. We found treatments with the largest reductions in wildfire hazard usually decreased surface fuels and raised average tree crown base height. ***The only treatment that consistently achieved these changes was prescribed broadcast burning.*** Several challenges with treatment implementation also came to light, such as the increase in woody surface fuels counteracting the expected reduction in fire behavior from tree removal, and tree removal decreasing wind reduction by the canopy causing higher below-canopy winds that can increase tree torching potential.

Treatment effectiveness is the result of many factors, some of which are unique to each site, such as forest type and tree size distribution prior to treatment. Starting forest type and structure conditions determines what remains following mitigation, thus affecting treatment success. An analysis of factors affecting high-severity fire found that live fuel was the dominant factor in the Southern Rockies ecoregion (Parks et al., 2018). Along these lines, our results indicate that forest type is a primary determiner of treatment success. This finding is contrary to a meta-analysis by Fulé et al. (2012)with co-occurring species, are adapted to a disturbance regime of frequent surface fires, but extended fire exclusion and other factors have led to historically uncharacteristically dense stands and high fuel loadings, supporting high-severity fires. Treatments to begin to reverse these changes and reduce fuel hazards have been tested experimentally and observations of wildfire behavior in treated stands have also been reported. Using a systematic review methodology, we found 54 studies with quantitative data suitable for meta-analysis. Combined treatments (thinning + burning, in which fuels treatment effectiveness was not found to be influenced by forest type, though the majority of studies used in the meta-analysis were from the Southwest and the West Coast of the US.

In the WRRG program, treatments occurring in ***ponderosa pine and lodgepole pine forests showed the highest rate of conversion from passive crown fire to surface fire under severe weather and fuel moisture conditions***. Ponderosa pine is a fire-tolerant species, especially when thinned to select for large trees and low overall tree densities (Pollet & Omi, 2002). Lodgepole pine treatments achieved the passive-to-surface fire type transition by clearcutting all trees, thus eliminating crown fire potential. ***None of the treatments monitored in mixed conifer or pinyon pine converted from crown fire to surface fire***. Mixed conifer forests support shade-tolerant species capable of growing underneath the dominant canopy, resulting high tree densities and ladder fuels that create vertical continuity between the forest surface and tree canopy. Pinyon pine forests tend to have low average crown base height, which allows surface fire to ignite tree crowns, even under moderate fire weather and fuel moisture conditions. However, the number of monitored treatment units was greater for ponderosa pine than any other forest type, given that the majority of WRRG grant applications came from wildland-urban interface areas of the Colorado Front Range and southwestern Colorado; additional monitoring of hazardous fuels treatments in other forest types would be beneficial to solidify the significance of forest type to treatment effectiveness.

Fire hazard reduction also depends on the specific treatment implemented and slash management activities. The wide variety of treatment methods and intensities included in this program prevents us from drawing overarching conclusions about best treatment practices across the state, as few examples of most treatment combinations are represented (Table 5). However, our results are in agreement with a multitude of studies that observed ***mitigation treatments that increase woody surface fuels may increase fire behavior and negate the fire hazard reduction expected*** from mitigation (Omi & Martinson, 2010; Prichard, Susan J, Peterson, David L., & Jacobson, Kyle, 2010; Raymond & Peterson, 2005). Removing or burning woody surface fuels is critical to treatment success immediately after implementation. However, the addition of fine woody fuels appears to be temporary, as several sites with multiple post-treatment monitoring visits found fine fuels were reduced within several years. Coarse woody fuels, on the other hand, persist for a longer time period. Few sites were monitored long term, and research on the persistence of fine woody fuels is generally lacking for Colorado. Further monitoring is necessary to verify this finding.

We re-visited three sites to track changes in understory, forest structure, and woody fuels over several years following treatment, and our results indicate that ***forest type and treatment method impact fuel treatment longevity***. At Douglas County, we found that Gambel oak re-sprouts rapidly following treatment, and ***mastication of Gambel oak may be ineffective at reducing fire hazard beyond two growing seasons following treatment***. In addition, we tracked tree regeneration as it is known to diminish treatment longevity (Tinkham et al. 2016). Over 10,000 lodgepole seedlings per acre were present three years after clearcutting in Summit County, though average height was less than one foot. As the new lodgepole cohort develops, additional entries will be needed to maintain effectiveness of the firebreak. At Fox Run Regional Park, density of ponderosa pine seedlings increased following treatment, though the vast majority of seedlings were between 0-4 inches tall and may be susceptible to heavy mortality during periods of drought. Since ponderosa pine regeneration is episodic and varies based on climate and cyclical cone production years, a longer study period is needed to inform the length of time treatments are effective at maintaining low fire hazard conditions.

Case Studies

Because the results from CFRI's fuel treatment effectiveness assessment are complex and contain a lot of site-specific nuances, we offer an exploration of seven WRRG projects as case studies to illustrate four general trends we identified in our assessment. These trends are: 1) stands predicted to have moderate fire hazard prior to treatment and low fire hazard following treatment, 2) stands predicted to have low fire hazard before and after treatment, 3) stands predicted to have moderate fire hazard that changed little following treatments, and 4) stands displaying modeling results that were difficult to reconcile with forest structural changes observed in the field.

1) *Stands predicted shift from moderate fire hazard to low fire hazard following treatment*

Summit County and Lone Mesa State Park both contained two monitored units that were predicted to shift from passive crown fire to surface fire following treatment. At Summit County, dense beetle-killed lodgepole pine stands were clearcut. Thus, no trees remained to support crown fire. Prescribed fire at Lone Mesa State Park dramatically lowered modeled fire hazard by raising tree crown base height and reducing cover of Gambel oak in the understory. However, Gambel oak is known to re-sprout vigorously following disturbance so frequent treatments may be required to maintain low fire hazard.

2) *Stands predicted to have low fire hazard before and after treatment*

Ben Delatour Scout Ranch thinning units and Top of the Pines were predicted to have relatively low fire hazard prior to treatment and thus this low hazard could not be substantially reduced by restoration treatments. Surface fire was predicted throughout the study period at each of these sites under severe conditions, though Torching Index decreased and Crowning Index increased after thinning. Both sites are dominated by ponderosa pine and started with comparatively low tree density of less than 100 trees per acre, as well as low fine woody surface fuel loading of around 1 ton per acre. In general, fire hazard is low in sparse forests made up mostly of fire-tolerant tree species with little woody surface fuel loading.

3) *Stands predicted to have moderate fire hazard that changed little following treatments*

Costilla County and Red Rock Canyon were predicted to have moderate fire hazard prior to treatment, and this prediction remained unchanged following treatment, likely due to limited changes in components of forest structure such as ladder fuel density and canopy base height. Costilla County treated a roadside corridor within a mixed conifer forest, comprised of white fir, Douglas-fir, and aspen. The stand remained dense following treatment, bearing over 500 saplings per acre. Saplings of shade-tolerant species are considered ladder fuels, which bring fire from the forest surface to the tree crowns. At Red Rock Canyon, the Pine unit contained sparse pinyon pine trees with very low average crown base heights. As a result, a surface fire with 3-foot flame lengths was expected to ignite the crowns of the trees even under moderate fire weather and fuel moisture conditions. The mitigation project reduced tree density but added fine woody fuels and did not change crown base height, thus passive crown fire was predicted under severe and moderate conditions before and after treatment.

4) *Stands displaying modeling results that were difficult to reconcile with forest structural changes observed in the field*

While most sites displayed reasonable modeling results given the input data, results at a few sites were more ambiguous and fire behavior modeling results were difficult to reconcile with field observations of forest structure. Our FVS modeling predicted that the treatment at Cheyenne Mountain dramatically reduced fire hazard. However, field-based surveys indicated that tree density was low to start and reduced very little (from 14 to 8 trees per acre) and measured shrub cover, along with photographs, show minimal reduction of shrubs across the area. Nevertheless, our modeling methods selected different pre- and post-treatment surface fuel models as the change in shrub cover narrowly missed the thresholds to manually assign a fuel model following mitigation (Figure 3). Cover of Gambel oak changed from 23% before treatment to 19% following mastication. Consequently, we assigned a shrub fuel model to the pre-treatment stand, resulting in high fire hazard; whereas post-treatment fuel models were assigned using the FVS default fuel model selection process and resulted in low-hazard timber litter fuel models. Realistically, a 4% reduction in Gambel oak cover would not produce an enormous reduction in fire behavior. However, running both pre- and post- treatment stands through FVS's default fuel model selection process also resulted in a dramatic reduction of predicted fire hazard following treatment. Thresholds such as this are difficult to avoid, as most fire modeling platforms use logic-based assignment of fuels. We expect that post-treatment fire behavior likely resembles pre-treatment fire behavior at Cheyenne Mountain.

Effectiveness Monitoring Program Lessons Learned

The WRRG effectiveness monitoring program was a novel aspect of wildfire mitigation grant programs for both Colorado and nationally. As such, it afforded an opportunity for learning, reflection, and continuous improvement. Below, we discuss both positive directions and challenges we experienced over the past five years.

Positive directions

- ***CFRI's monitoring program was cost-efficient:*** Monitoring is widely seen by policy-makers and professionals as a critical step in performing good land management, but is rarely funded, making the WRRG a unique policy and program. One of our intentions was to demonstrate that effectiveness monitoring could be conducted at a reasonable cost relative to overall program costs. Between July 2013 and December 2018, with the $504,125 in state funds allocated to CFRI, we established over 250 plots covering 7,591 acres over 21 WRRG fuel reduction projects (20% of WRRG fuel reduction projects). In addition to the field measurements, CFRI staff also organized and conducted analysis of spatial and non-spatial data, including complex fire behavior modeling. With the cost totaling $504,125 over 5 years, CFRI's monitoring program cost $66.41 per acre when including only projects where forestry and fuels monitoring occurred. Including the services CFRI provided to the advisory committee on overall program direction and information shared with all grant recipients through presentation of results at several workshops and providing localized science support to dozens of additional grantees, the total monitoring program cost was $21 per acre over all proposed treatment acres. The total costs for CFRI's monitoring program represents 4.2% of the WRRG program total cost and 4% of the per-acre cost for treatments.

- ***Monitoring results facilitated learning and adaptive management, not evaluation and judgment:*** CFRI structured the monitoring program to embody Colorado State University's land mission of advancing knowledge to benefit society via education, research, and outreach. We presented monitoring results to the WRRG advisory committee and to grantees in a non-judgmental, constructive manner intended to foster learning; for many, it was the first time they had seen quantitative fire hazard metrics associated with wildfire mitigation. Providing quantitative metrics for the effects of wildfire mitigation treatments can inform the WRRG program in identifying measurable objectives for which future grant proposals to aim, and best practices for grantees to utilize to attain those objectives. Indeed, WRRG grant program requirements changed after initial monitoring results showed elevated fire hazard due to increases in surface fuel loading; the new requirements specified greater detail in grant proposals for removing surface fuel. Monitoring results were also used by several grantees in their outreach and education to property owners and the broader community about the effects of their work. This, in turn, helped build local understanding and support for continued wildfire mitigation efforts. In the end, grantees who were able to adapt and learn from monitoring data were better able to justify future funding requests and earn public trust.

- ***The monitoring program served as an outreach about, and feedback mechanism for, the WRRG program:*** CFRI not only carried out intensive field monitoring on 21 projects, but also performed informational site visits and provided science-based technical informational resources for many of the grant recipients. This extension service complemented information from the Colorado State Forest Service and other sources. Through the monitoring, CFRI served an outreach/extension role for the WRRG program. In turn, CFRI also brought feedback from grantees back to the Colorado DNR and the WRRG advisory committee about program administration and grantee performance. In this way, CFRI served as the program's eyes and ears in the field.

- ***The WRRG monitoring program created a demand for effectiveness monitoring for other wildfire mitigation programs in Colorado:*** The overall approach and specific monitoring protocols CFRI developed for the WRRG have been adopted by several other wildfire mitigation projects in Colorado, including: the Colorado-Big Thompson Headwaters Partnership, Denver Water-US Forest Service's Forest-To-Faucets, the Northern Colorado Fireshed Network, the Peaks-to-People Water Fund, the San Juan Headwaters Forest Health Partnership, and the Upper South Platte Partnership. In effect, the WRRG program created the demand for effectiveness monitoring for wildfire mitigation fuel treatments; as such, Colorado is viewed as a leader nationally with the extensive effectiveness monitoring being conducted.

Challenges

- ***Managing a tension between efficiency and rigor:*** Any monitoring program faces a tension between being cost-efficient and producing rigorous results upon which adaptive management decisions can be made with a high degree of scientific confidence. For the WRRG program, the tension emerged between the need to monitor many projects and the intensity of sampling and measuring fuels data. To quickly put in place a monitoring system at the outset of the WRRG program, we elected to extensively sample across many projects in order to capture as much variability as possible. Hence, the number and density of plots, and the intensity of measurements within plots, were intentionally insufficient to produce results with a high degree of scientific confidence for any one site. As the program advanced, we adapted the measurements to capture the variation in fuel loading and we also re-measured sites over time. The trends in fire hazard over time-since-treatment when coupled with more rigorous scientific research on fuel treatment effectiveness, will be meaningful for continued learning and improvement.

- ***Compiling and verifying spatial data proved challenging:*** WRRG grantees were required to submit final accomplishment reports, but were not required to submit spatial data on precise treatment boundaries. Spatial data is an indispensable way to monument WRRG fuel treatment projects to benefit continued understanding about fuel treatment effectiveness; it is a form of institutional memory that can endure long after the primary principals of projects have moved on. CFRI had to solicit this data through individual contacts of grant recipients. CFRI was unable to develop a complete spatial dataset of DNR WRRG funded treatments, capturing only 56% of projects and 52% of total treatment acres. The reasons for these challenges are manifold:

    - There were no protocols for spatial data collection efforts.
    - Many grant recipients were small organizations without the ability to map projects and submit spatial data.
    - Staff turnover among grant recipients made it difficult to request data from listed contacts.
    - Grant recipients were not aware they needed to collect spatial data.
    - The transition of WRRG administration from the Department of Natural Resources to the Colorado State Forest Service made it difficult for grant recipients to know who was responsible for certifying completion, issuing payment, and tracking spatial data.

In some cases, acres reported on final report did not match total acres as calculated from spatial data submitted by the grant recipient. Sometimes the difference was slight and attributable to rounding errors or variability in GPS tracking. In other cases, the difference was more substantial and may resulted from a change in the project scope, imprecise GIS data, entire parcels being reported rather than treatment boundaries, or a grant recipient combining multiple funding sources to accomplish a single project. In the future, wildfire risk grant programs may wish to require the submission of spatial data as part of the initial agreement between the granting agency and grant recipient. This could take several forms: requiring the submission of a standardized shapefile by the grant recipient before payment is issued or tasking the spatial data could be collected by the agency in charge of program administration.

In conclusion, the results generated by CFRI's effectiveness monitoring program indicate that the WRRG program is a success, accomplishing thousands of acres of quality fire mitigation across Colorado, while also localizing science support and increasing our understanding and ability to better implement effective fire mitigation projects across non-federal lands in Colorado.

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APPENDIX A: List of Contractors

Below is a comprehensive list of contractors that performed services for WRRG grantees, as reported by 89 grantees in final performance reports.

Contractor Name	Type	Location
AC Trees	Private enterprise	Monument
Adam's Tree Service	Private enterprise	Estes Park
AJ Construction	Private enterprise	Durango
Alpine Tree Services	Private enterprise	Silverthorne
Anderson Tree and Stump Removal	Private enterprise	Colorado Springs
Angry Squirrel Tree Service	Private enterprise	Palmer Lake
Arborilogical West	Private enterprise	Pagosa Springs
Asplundh	Private enterprise	Golden
Beloved Earth	Private enterprise	Colorado Springs
Classic Gardens Landscape Contractor	Private enterprise	Colorado Springs
Coalition for the Upper South Platte	Non-profit	Lake George
Colorado Tree and Lawn Specialists	Private enterprise	Denver metro
Colorado TreeScapes	Private enterprise	Denver metro
Complete Tree Services	Private enterprise	Colorado Springs
Costilla County	County government	Costilla County
Dolores Tree Service	Private enterprise	Dolores
Dove Creek Enterprises	Private enterprise	Elizabeth
Enviro Land Management	Private enterprise	Whitewater
EZ Forestry	Private enterprise	Jefferson County
Fire Smart	Private enterprise	Durango
Forest Scapes Tree Services	Private enterprise	Durango
Fox Trail Landworks, LLC	Private enterprise	n/a
Front Range Arborists	Private enterprise	Colorado Springs
Gilbert's Tree Service	Private enterprise	Fountain
Golden Eagle Tree Services	Private enterprise	Durango
Golden West Pine Sawmill	Private enterprise	Ault
H&H Forestry	Private enterprise	La Veta
Higher Ground Forestry and Land Management	Private enterprise	Woodland Park
Highland Contracting	Private enterprise	Colorado Springs
Hortus Tree and Landscaping Services	Private enterprise	Colorado Springs
John Noard Enterprises	Private enterprise	n/a
K & K Tree Service	Private enterprise	Woodland Park
Laramie Landscuplting	Private enterprise	Laramie, WY
Larimer County Emergency Services	County government	Fort Collins
Lind Tree Service	Private enterprise	Colorado Springs
Local residents	Private citizens	Costilla County
Mark-It Forestry	Private enterprise	Colorado Springs
Matt's Maintenance Tree Service	Private enterprise	Parker
Mile High Youth Corps	Non-profit	Colorado Springs

Morgan Timber Products	Private enterprise	Laporte
Mountain High Tree Care and Consulting	Private enterprise	Colorado Springs
MP Forestry	Private enterprise	Trinidad
Mr. Stump Tree Service	Private enterprise	Colorado Springs
Noble Tree Specialists	Private enterprise	Pagosa Springs
Oaklands Ranch Sawmill	Private enterprise	Sedalia
Offering Moore Landscaping and Trees	Private enterprise	Colorado Springs
P & A Tree Service	Private enterprise	Alma
Pagosa Springs Tree Service	Private enterprise	Pagosa Springs
Pathfinder Construction of SW Colorado	Private enterprise	Pagosa Springs
Ranch Creek, Ltd.	Private enterprise	Granby
RMRP Enterprises	Private enterprise	Louisville
San Juan Fencing	Private enterprise	Pagosa Springs
Scebbi Tree Services	Private enterprise	Wellington
Seedmasters	Private enterprise	Colorado Springs
SilvaPro	Private enterprise	Leadville
Southwest Colorado Conservation Corps	Non-profit	Durango
Splintered Forest	Private enterprise	Denver metro
State Wildland Inmate Fire Team, CO Dept. of Corrections	State government	Statewide
Summit Forestry	Private enterprise	Fort Collins
Swift Creek Brush Cutters	Private enterprise	Mancos
T-Rox, LLC	Private enterprise	Pueblo
Tall Timbers Tree and Shrub	Private enterprise	Colorado Springs
TC Tree Service	Private enterprise	Monte Vista
Terra Firma Forestry	Private enterprise	Salida
Tree Beavers	Private enterprise	Black Forest
Tree Masters	Private enterprise	Monument
Tree Musketeers	Private enterprise	Black Hawk
Treeman Tree Services	Private enterprise	Palmer Lake
Uprooted Artistry	Private enterprise	Loveland
West Range Reclamation	Private enterprise	Montrose
Western Timber Management	Private enterprise	Glenwood Springs
Wildfire Planning International	Private enterprise	Colorado-wide
Wildfire Protection Professionals	Private enterprise	Franktown
Wildland Restoration Volunteers	Non-profit	Fort Collins
Willis Timberworks	Private enterprise	Colorado Springs
Willow Creek Logging	Private enterprise	Granby
Wise Wildfire, Inc.	Private enterprise	Mancos
Woodchuck Tree Service	Private enterprise	Durango
Yellow Pine Consulting	Private enterprise	Gunnison

Source: WRRG grantee final performance reports

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Monitoring Summary

Ben Delatour Scout Ranch—Burn Only

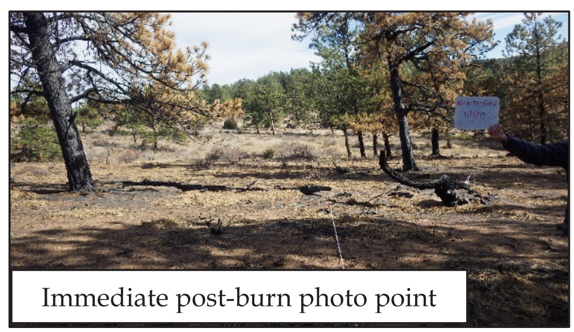
Wildfire Mitigation Strategy: Prescribed fire was applied to a ponderosa pine stand in a collaboratively funded demonstration project designed to promote forest resilience to wildfire and protect water supply and infrastructure.

Project Highlights: Prescribed fire reduced modeled fire hazard, achieving similar fire mitigation benefits as an adjacent unit that was mechanically thinned before prescribed burning. The fire reduced tree density and basal area, though some large ponderosa pine trees were killed in addition to smaller trees regularly targeted by fuels treatments. Crown base height of the remaining live trees raised substantially and surface fuels were reduced following the prescribed burn, which increased the stand's resistance to crown fire.

Project Information

Implementation Agency	The Nature Conservancy
Funding	The Nature Conservancy, Peaks to People Water Fund
Location	Larimer County, CO
Year Completed	2017
Area Monitored	5 acres
Forest Type	Ponderosa pine
Implementation Method	Broadcast burn
Slash Treatment	Broadcast burn

Pre-treatment photo point



Immediate post-burn photo point

1 yr post-burn photo point

Forest and Fuels Inventory

Summary	Pre-treatment	Post-treatment
Year sampled	2017	2017
Live basal area* (ft^2/ac)	70 ± 40	36 ± 30
Live tree density (trees per acre)	104 ± 75	65 ± 70
Canopy cover (%)	37 ± 25	22 ± 25
Canopy base height (ft)	7 ± 4	33 ± 10
Fine Woody Fuel Loading (tons/acre)	0.68	0.37

*Basal area is the cross-sectional area of tree stems at breast height (4.5 ft.) for a given area.

Prescribed fire severity assessment

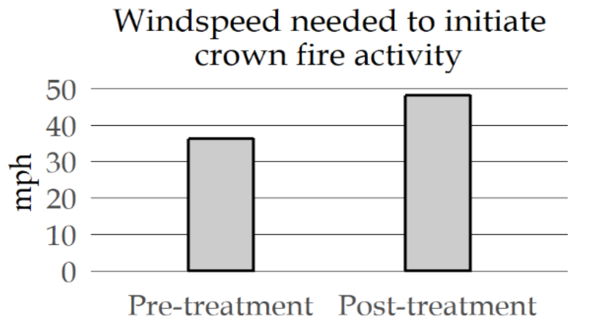
All five plots showed signs of fire, with 39% of plot ground surface visibly burned.

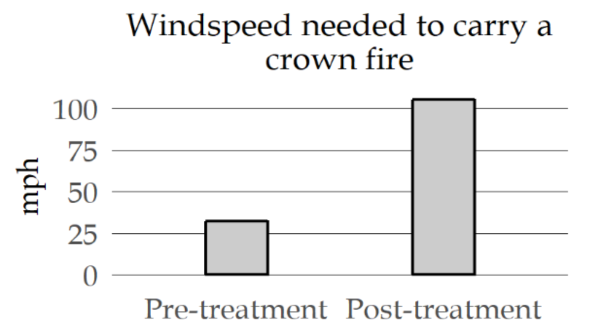
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 5 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

Modeled Fire Behavior

	Pre-treatment		**Post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Surface	Surface	Surface	Surface
Total flame length (ft)	2.8	1.2	6.2	0.2
Surviving tree basal area (ft^2/ac)	48 (68%)	56 (80%)	18 (50%)	28 (77%)





Pre-treatment

Post-treatment

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Full methods and details described in the WRRG Monitoring Report, available at https://cfri.colostate.edu. Summary prepared March 2019.

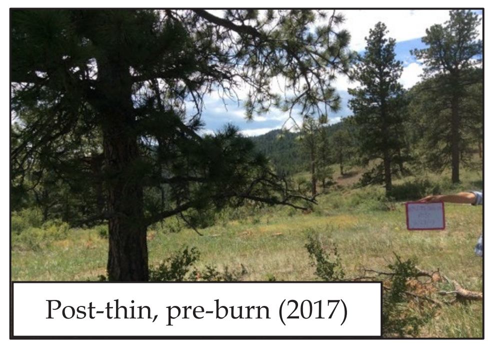
Monitoring Summary

Ben Delatour Scout Ranch—Thin and Burn

Wildfire Mitigation Strategy: Mechanical thinning followed by a prescribed broadcast burn was applied to a ponderosa pine stand in a collaboratively funded demonstration project designed to promote forest resilience to wildfire and protect water supply and infrastructure.

Project Highlights: Fire hazard was relatively low before mitigation and was further reduced following the combined thin and burn treatment. Removing slash off site during mechanical thinning, and the subsequent prescribed burn, minimized surface fuel accumulations and raised average tree crown base height, improving resistance to torching and minimizing potential for active crown fire.

Pre-treatment photo point (2016)



Post-thin, pre-burn (2017)

Post-thin, post-burn (2017)

1-year post thin, post burn (2018)

Project Information

Implementation Agency	Coalition for the Poudre River Watershed, The Nature Conservancy
Funding	The Nature Conservancy, Peaks to People Water Fund, Coalition for the Poudre River Watershed
Location	Larimer County, CO
Year Completed	2017
Area Monitored	24 acres
Forest Type	Ponderosa pine
Implementation Method	Mechanical thin, broadcast burn
Slash Treatment	Removal, broadcast burn

Forest and Fuels Inventory

Summary	Pre-treatment	Post-thin, pre-burn	Post-thin, post-burn
Year sampled	2016	2017	2018
Live basal area* (ft^2/ac)	69 ± 34	30 ± 25	31 ± 25
Live tree density (trees per acre)	97 ± 63	39 ± 47	39 ± 47
Canopy cover (%)	38 ± 20	26 ± 22	26 ± 19
Canopy base height (ft)	12 ± 7	9 ± 5	14 ± 10
Fine Woody Fuel Loading (tons/acre)	1.22	1.19	1.17

*Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

Prescribed fire severity assessment

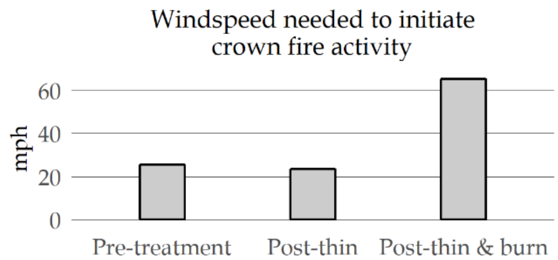
The prescribed fire was extensive but patchy, with eight of thirteen plots showing signs of fire, but only 23% of ground surface visibly burned.

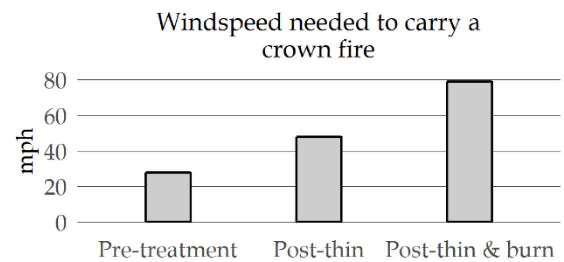
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 13 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

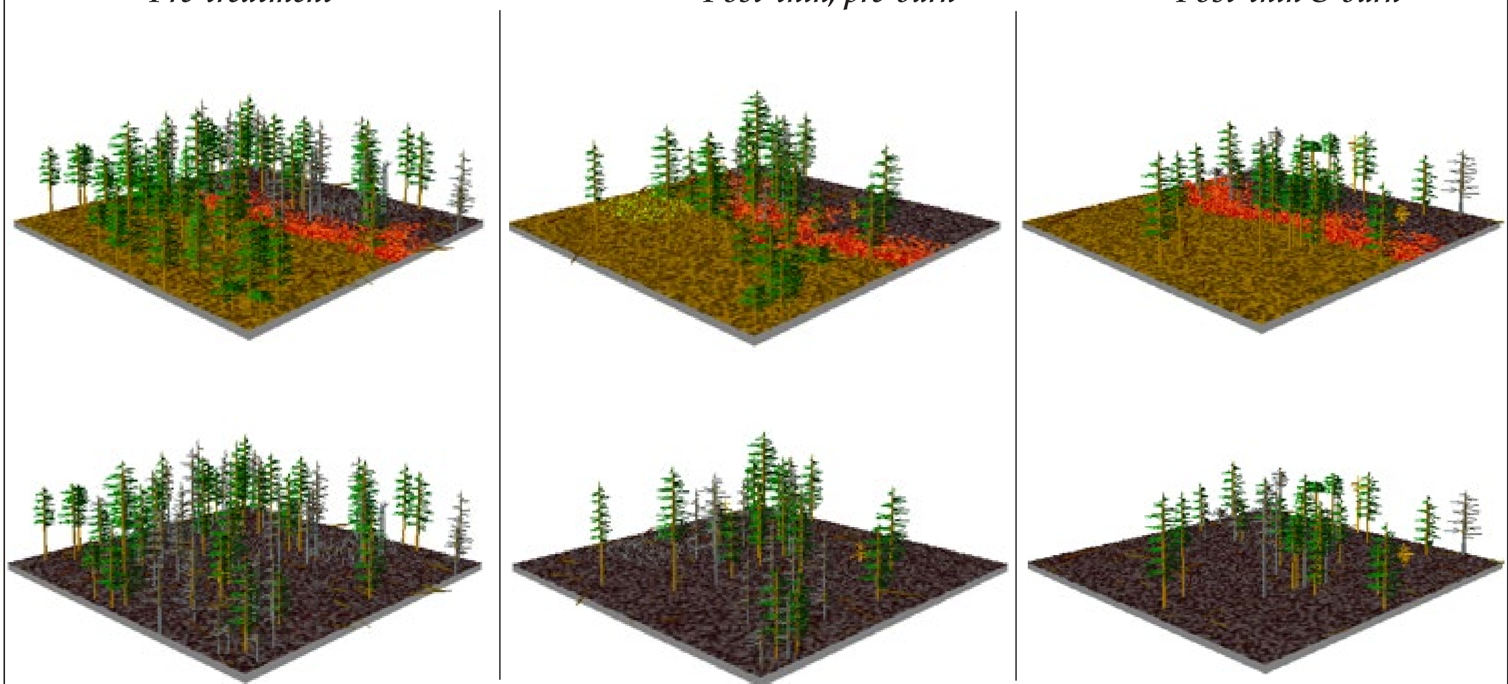
Modeled Fire Behavior

	Pre-treatment		**Post-thin**		**Post-burn**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Surface	Surface	Surface	Surface	Surface	Surface
Total flame length (ft)	3.8	1.6	3.7	1.4	3.6	1.4
Surviving tree basal area (ft^2/ac)	39 (56%)	56 (81%)	21 (70%)	25 (82%)	24 (77%)	26 (83%)





Pre-treatment | ***Post-thin, pre-burn*** | ***Post-thin & burn***



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Full methods and details described in the WRRG Monitoring Report, available at https://cfri.colostate.edu. Summary prepared March 2019.

Wildfire Risk Reduction Grant Monitoring Summary:
Cheyenne Mountain State Park

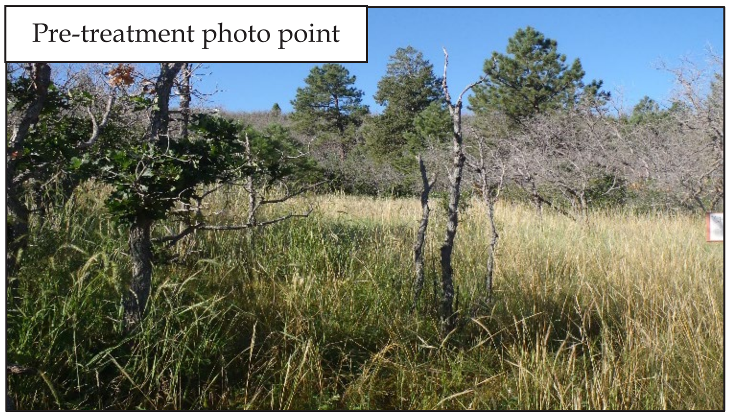
Wildfire Mitigation Strategy: Gambel oak was masticated in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard within a sparse ponderosa pine stand.

Project Highlights: Crown fire hazard was predicted to be reduced immediately following mastication of Gambel oak, despite minimal change tree structure and shrub cover. Cover of Gambel oak was only slightly reduced (23% to 19%) and will likely soon return to pre-treatment levels due to re-sprouting. Although mulching of oak increased woody fuels, the primary objective of this project was to remove standing oak. Oak management also reduced average Gambel oak height from 7.6 ft to 4.9 ft, which may facilitate opportunities for less invasive treatments such as repeated prescribed fire, additional mechanical removal and/or follow up hand removal to maintain initial fire mitigation benefits.

Project Information

Grant Recipient	Coalition for the Upper South Platte
Award Date	August 2013
Location	Teller County, CO
Year Completed	2015
Area Monitored	30 acres
Forest Type	Ponderosa pine/Gambel oak
Implementation Method	No overstory treatment
Slash Treatment	Mastication of understory

Pre-treatment photo point



Forest and Fuels Inventory

Summary	Pre-treatment	1 yr post-treatment
Year sampled	2013	2015
Live basal area* (ft^2/ac)	11 ± 12	8 ± 7
Live tree density (trees per acre)	14 ± 28	8 ± 10
Canopy cover (%)	18 ± 25	12 ± 19
Canopy base height (ft)	9 ± 6	11 ± 7
Gambel oak cover (%)	23 ± 14	19 ± 24
Gambel oak height (ft)	7.6 ± 4.6	4.9 ± 2.1
Fine Woody Fuel Loading (tons/acre)	1.02	2.61

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

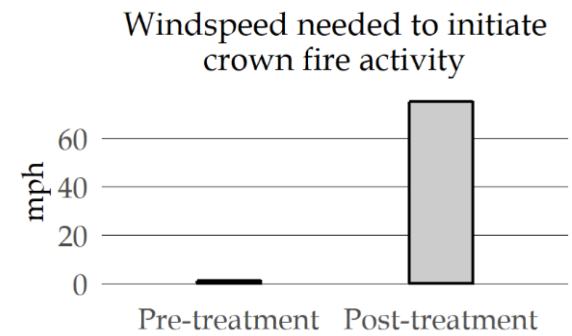
1 yr post-treatment photo point

Fire Hazard Analysis

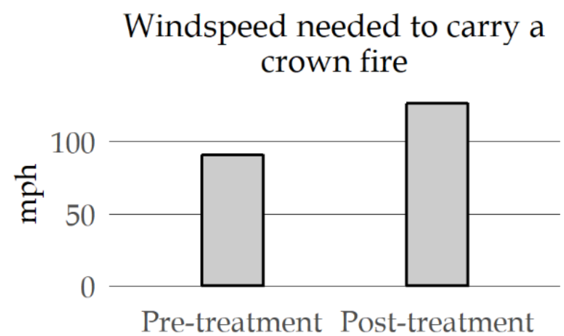
We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 12 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

Modeled Fire Behavior

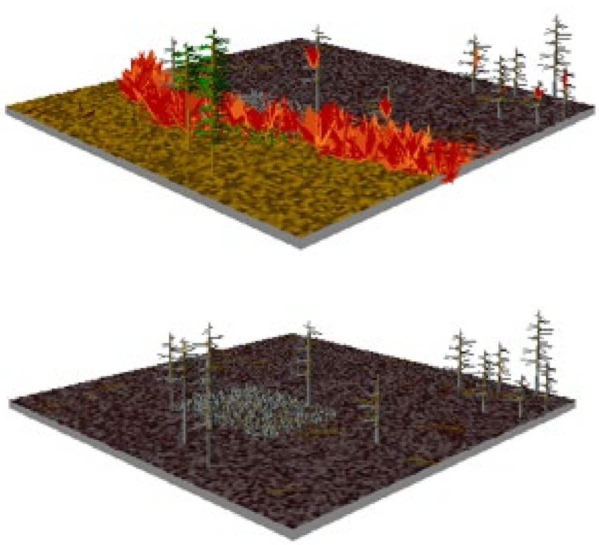
	Pre-treatment		1 yr post-treatment	
Fire weather and fuel conditions	*Severe*	*Moderate*	*Severe*	*Moderate*
Fire type	Surface	Surface	Surface	Surface
Total flame length (ft)	12.0	5.0	4.7	1.8
Surviving tree basal area (ft²/ac)	0 (3%)	2 (20%)	6 (74%)	7 (87%)



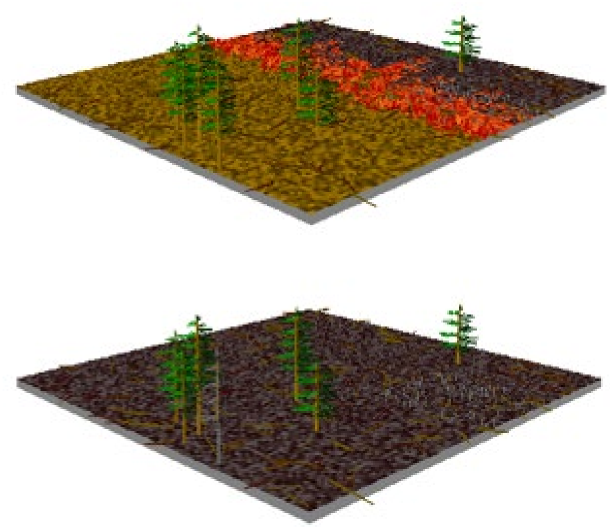
**Results driven by Gambel oak cover change from 23% to 19% cover.



Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary: *Costilla County*

Wildfire Mitigation Strategy: The Costilla County roadside thinning treatment, funded by the Wildfire Risk Reduction Grant program, involved hand crews clearing the road right-of-way. The project was designed to improve ingress/egress safety and supply wood for a biomass boiler to heat the Costilla County Road and Bridge Department shop.

Project Highlights: The biomass boiler provided an excellent wood utilization opportunity. Reduced tree density following mitigation improved resistance to active crown fire, which may enhance opportunities for fire suppression. However, passive crown fire was predicted in the stand under both moderate and severe fire conditions, consequently tree mortality remained unchanged. Additional tree removal concentrating on small trees, trees with low crown base height, and fire intolerant species—such as white fir—would improve ingress and egress route safety.

Project Information

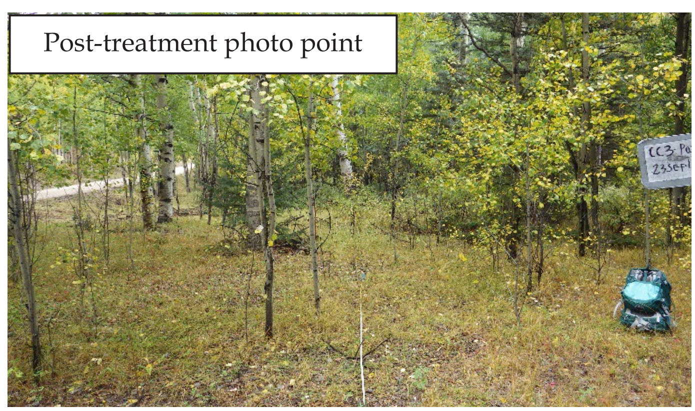
Grant Recipient	Costilla County
Award Date	May 2014
Location	Costilla County, CO
Year Completed	2014
Area Monitored	8 acres
Forest Type	Mixed conifer
Implementation Method	Thin
Slash Treatment	Removal and chip


Pre-treatment photo point

Forest and Fuels Inventory

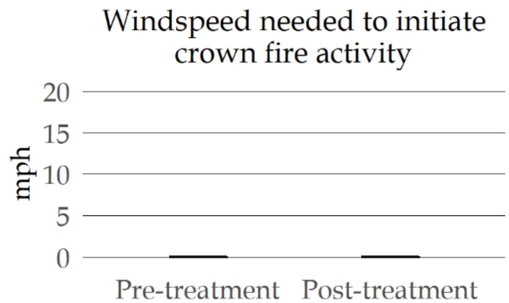
Summary	Pre-treatment	Post-treatment
Year sampled	2015	2015
Live basal area* (ft²/ac)	116 ± 94	75 ± 47
Live tree density (trees per acre)	998 ± 522	737 ± 473
Canopy cover (%)	65 ± 25	58 ± 29
Canopy base height (ft)	8 ± 7	9 ± 7
Fine Woody Fuel Loading (tons/acre)	1.71	1.83

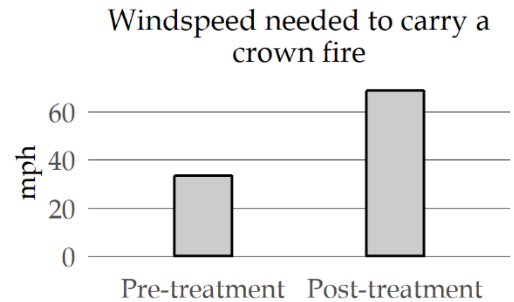
* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.


Post-treatment photo point

Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 11 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The figures show changes in modeled fire behavior under severe conditions.





Costilla County: Capacity Building and Utilization

Total Project Cost: $40,886	DNR funds used: $20,443

Biomass boiler (top right) installed at Costilla County Road and Bridge shop, San Luis, Colorado. Wood (top left) from roadside fire mitigation was used to heat county buildings.

The Costilla County road and bridge department shop (left) was heated using wood from fire mitigation work on county right of way, replacing propane as a heat source.

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Wildfire Risk Reduction Grant Monitoring Summary

Douglas County

Wildfire Mitigation Strategy: Gambel oak was masticated in a Wildfire Risk Reduction Grant project designed to reduce wildfire hazard in a ponderosa pine stand.

Project Highlights: Gambel oak cover was greatly reduced immediately following mastication, but due to prolific re-sprouting and growth, fire mitigation effectiveness diminished over time. Within 2 growing seasons, the site returned to high crown fire hazard and potential conifer mortality. The oak mitigation creates a window of opportunity in which less invasive follow-up treatments such as repeated prescribed fire, mechanical removal, and/or hand removal can be more feasibly applied to maintain initial fire mitigation benefits.

Pre-treatment photo point (2014)

Immediate post-treatment photo point (2015)

2 yr post-treatment photo point (2016)

3 yr post-treatment photo point (2017)

Project Information

Grant Recipient	Douglas County
Award Date	August 2013
Location	Douglas County, CO
Year Completed	2014
Area Monitored	33 acres
Forest Type	Ponderosa pine/ Gambel oak
Implementation Method	Thin
Slash Treatment	Mastication

Forest and Fuels Inventory

Summary	**Pre-treatment**	**3 yr post-treatment**
Year sampled	2014	2017
Live basal area* (ft^2/ac)	36 ± 22	32 ± 18
Live tree density (trees per acre)	136 ± 304	96 ± 234
Canopy cover (%)	26 ± 26	17 ± 31
Canopy base height (ft)	13 ± 9	10 ± 7
Gambel oak cover (%)	42 ± 18	42 ± 24
Fine Woody Fuel Loading (tons/acre)	0.91	0.98

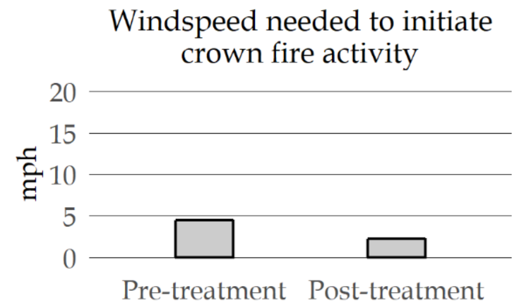
* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

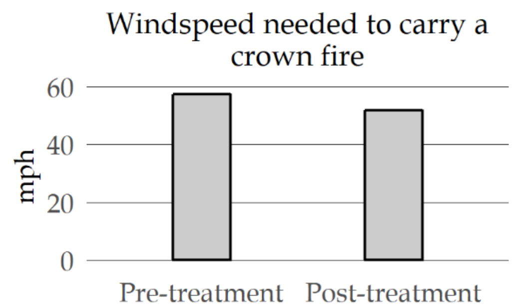
Fire Hazard Analysis

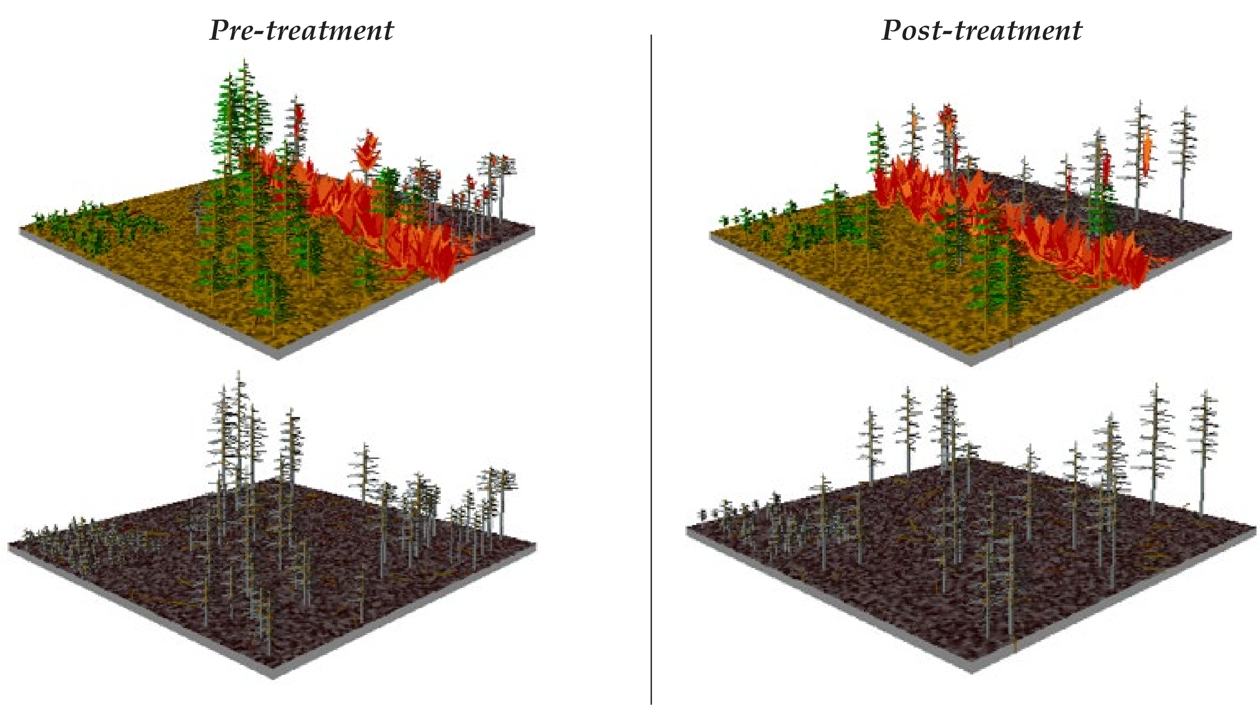
We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 11 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

Modeled Fire Behavior

	Pre-treatment		3 yr post-treatment	
Fire weather and fuel conditions	*Severe*	*Moderate*	*Severe*	*Moderate*
Fire type	Passive	Surface	Passive	Passive
Total flame length (ft)	20.0	4.0	19.4	4.1
Surviving tree basal area (ft^2/ac)	1 (3%)	17 (48%)	1 (3%)	15 (46%)







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Wildfire Risk Reduction Grant Monitoring Summary:
Fox Run Regional Park—Chip Unit

Wildfire Mitigation Strategy: Mechanical thinning was applied to a ponderosa pine stand, with chipping of residual slash, in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard.

Project Highlights: A reduction in tree density and basal area led to a reduction in fire hazard, though the effects are diminishing with time. The wind speed predicted to sustain active crown fire increased post-treatment, yet it began to drop back down in the second post-treatment measurement, 3-5 years post-treatment, as tree density and basal area started rebounding. The wind speed predicted to initiate tree torching exhibited the opposite behavior—it increased over time. The addition of fine woody surface fuels in the chipping units appeared to be temporary, wood chips either decayed or were buried in litter by the final measurement.

Project Information

Grant Recipient	El Paso County
Award Date	August 2013 & May 2014
Location	El Paso County, CO
Year Completed	2014
Area Monitored	42 acres
Forest Type	Ponderosa pine
Implementation Method	Hand thin
Slash Treatment	Chip and removal

Pre-treatment photo point

Post-treatment photo point (2016)

Forest and Fuels Inventory

Summary	Pre-treatment	Post-treatment	Post-treatment 2
Year sampled	2013, 2014	2013, 2014, 2016	2017
Live basal area* (ft^2/ac)	130 ± 46	95 ± 36	104 ± 37
Live tree density (trees per acre)	395 ± 325	175 ± 113	198 ± 102
Canopy base height (ft)	22 ± 10	23 ± 10	22 ± 10
Fine Woody Fuel Loading (tons/acre)	1.53	2.02	1.36

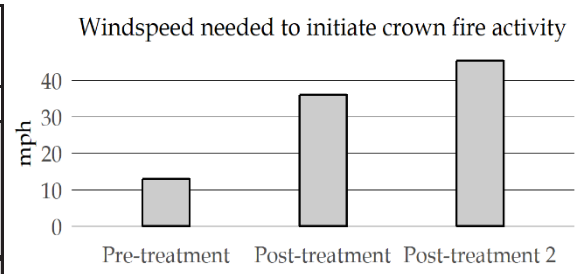
* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

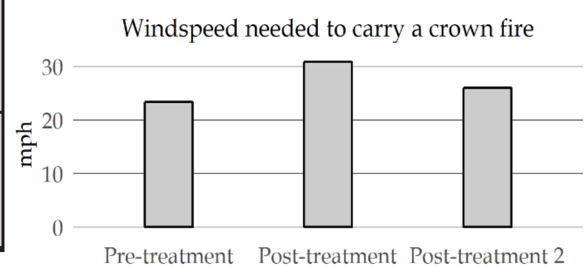
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 16 field plots pre-treatment, 17 plots post-treatment, and 19 plots in the second post-treatment visit. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

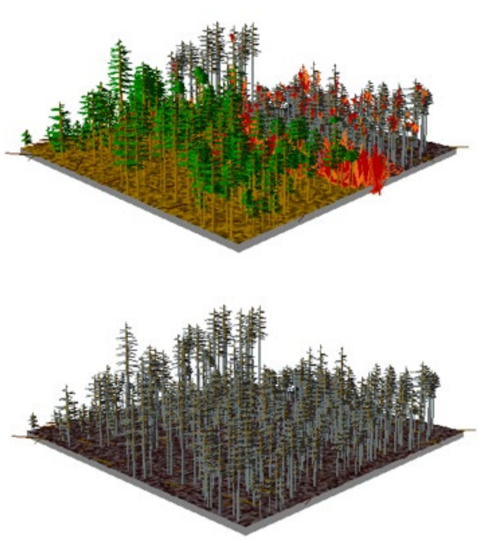
Modeled Fire Behavior

	Pre-treatment		Post-treatment		Post-treatment 2	
Fire weather and fuel conditions	*Severe*	*Moderate*	*Severe*	*Moderate*	*Severe*	*Moderate*
Fire type	Passive	Surface	Surface	Surface	Surface	Surface
Total flame length (ft)	24.2	0.5	4.1	1.8	3.2	1.4
Surviving tree basal area (ft^2/ac)	1 (1%)	92 (71%)	49 (52%)	73 (77%)	72 (69%)	78 (75%)

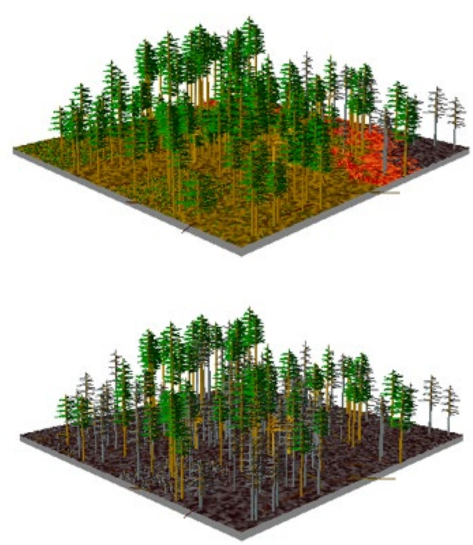




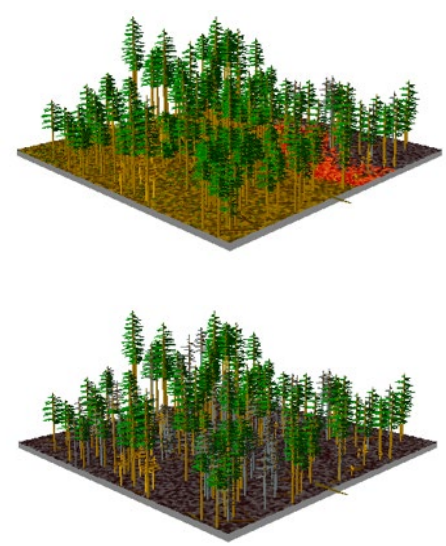
Pre-treatment



Post-treatment



Post-treatment 2



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Wildfire Risk Reduction Grant Monitoring Summary:
Fox Run Regional Park—Pile Burn Unit

Wildfire Mitigation Strategy: Mechanical thinning was applied to a ponderosa pine stand, with residual slash pile burned, in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard.

Project Highlights: Tree density and basal area were substantially reduced following treatment. As a result, the windspeed predicted to sustain active crown fire increased, though it had begun to drop back down in the second post-treatment measurement. The windspeed predicted to initiate tree torching exhibited the opposite behavior—it did not change immediately following treatment but increased over time. Thus, predicted fire-caused tree mortality was lowest in the final measurement year. The pile burn unit had no notable change in fine fuel loading throughout the course of the monitoring.

Project Information

Grant Recipient	El Paso County
Award Date	September 2014
Location	El Paso County, CO
Year Completed	2015
Area Monitored	14 acres
Forest Type	Ponderosa pine
Implementation Method	Hand thin
Slash Treatment	Pile burn & chip

Pre-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	1 yr post-treatment	2 yr post-treatment
Year sampled	2015	2016	2017
Live basal area* (ft^2/ac)	157 ± 70	96 ± 34	101 ± 30
Live tree density (trees per acre)	472 ± 353	199 ± 129	209 ± 119
Canopy base height (ft)	23 ± 9	25 ± 9	24 ± 9
Fine Woody Fuel Loading (tons/acre)	1.17	1.26	1.22

1 yr post-treatment photo point

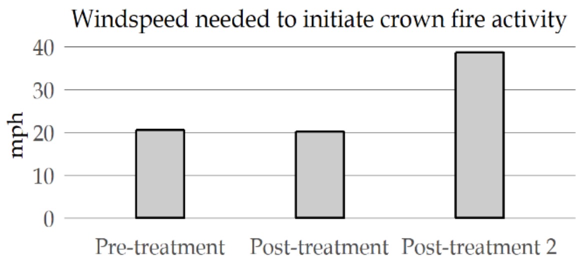
* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

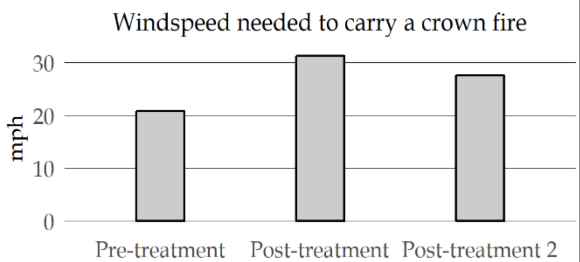
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 8 field plots pre-treatment and 1 year post-treatment and 7 plots 2 years post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

Modeled Fire Behavior

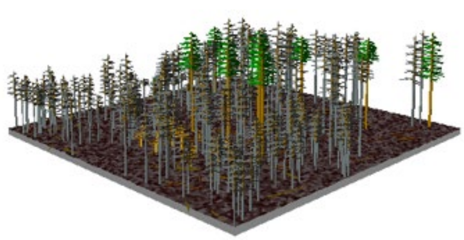
	Pre-treatment		**1 yr post-treatment**		**2 yr post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Surface	Surface	Surface	Surface	Surface	Surface
Total flame length (ft)	4.9	0.7	7.5	0.4	4.6	0.4
Surviving tree basal area (ft^2/ac)	28 (18%)	108 (69%)	2 (2%)	72 (75%)	37 (37%)	76 (75%)



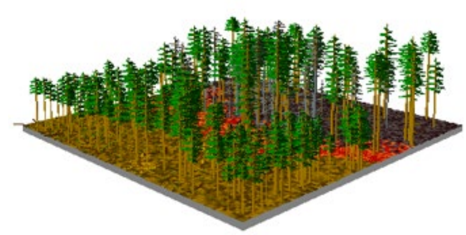


Pre-treatment

1 yr post-treatment



2 yr post-treatment



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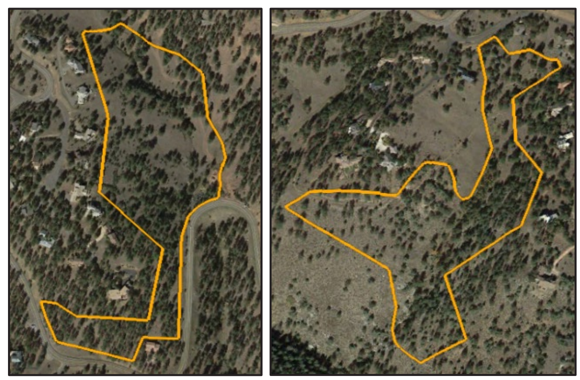
Wildfire Risk Reduction Grant Monitoring Summary:
Genesee Foundation

Wildfire Mitigation Strategy: The Genesee Foundation implemented a mechanical thinning project with a whole tree harvest, funded by the Wildfire Risk Reduction Grant program for wildfire hazard reduction.

Project Highlights: Passive crown fire was predicted under severe conditions prior to mitigation, and surface fire was predicted following mitigation. Resistance to active crown fire increased following mitigation, although the wind speed predicted to initiate crown fire activity remained relatively low. While the treatment overall resulted in a moderate reduction in the stand's fire hazard, there was only a slight reduction in predicted tree mortality. Additional follow-up treatments, such as prescribed broadcast burning, could increase tree crown base height and may improve tree survival under severe fire conditions.

Project Information

Grant Recipient	Genesee Foundation
Award Date	August 2013
Location	Jefferson County, CO
Year Completed	2014
Area Monitored	28 acres
Forest Type	Ponderosa pine
Implementation Method	Thin
Slash Treatment	Removal



Pre-treatment aerial imagery (2013)

Forest and Fuels Inventory

Summary	Pre-treatment	Post-treatment
Year sampled	2014	2014
Live basal area* (ft²/ac)	57 ± 34	54 ± 32
Live tree density (trees per acre)	87 ± 77	54 ± 31
Canopy cover (%)	38 ± 25	29 ± 20
Canopy base height (ft)	13 ± 9	12 ± 8
Fine Woody Fuel Loading (tons/acre)	0.87	0.71

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

Post-treatment aerial imagery (2017)

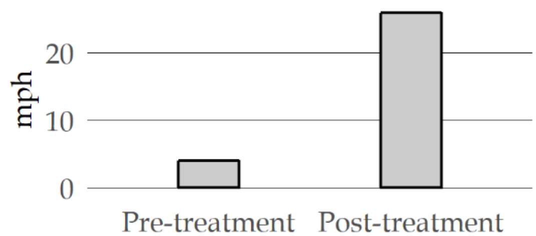
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 7 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

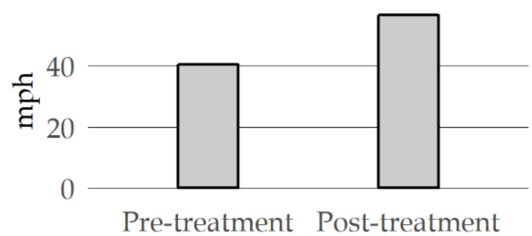
Modeled Fire Behavior

	Pre-treatment		**Post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Surface	Surface	Surface
Total flame length (ft)	14.5	0.5	5.7	0.4
Surviving tree basal area (ft²/ac)	2 (3%)	46 (80%)	8 (14%)	45 (84%)

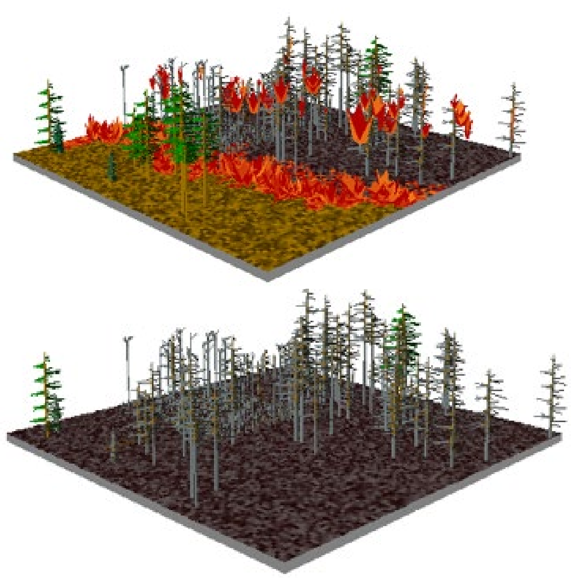
Windspeed needed to initiate crown fire activity



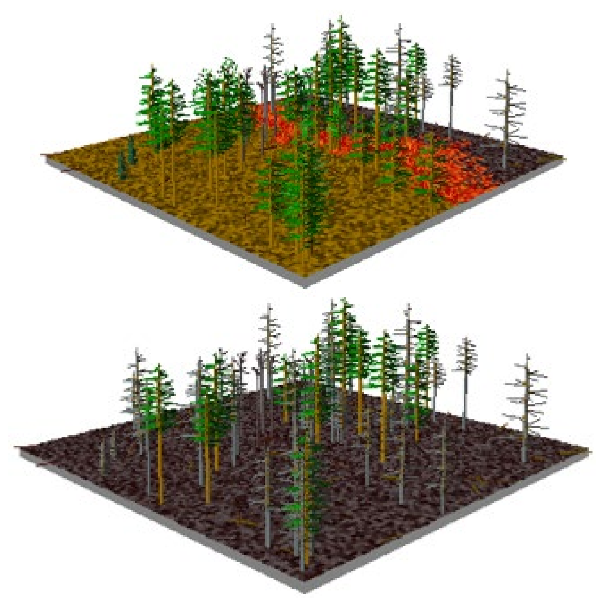
Windspeed needed to carry a crown fire



Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary:
Genesee Mountain Park

Wildfire Mitigation Strategy: The understory mastication treatment at Genesee Mountain Park focused on removal of small trees in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard within a ponderosa pine stand.

Project Highlights: Understory mastication resulted in a slight reduction in basal area and moderate reduction in tree density. However, both fine and coarse woody fuels increased following mastication. Woody surface fuels will decay over time, but the short-term increase likely canceled any change in predicted fire behavior or effects due to treatment. Passive crown fire is predicted in the stand under severe fire conditions both before and after mastication.

Project Information

Grant Recipient	City and County of Denver-Parks and Recreation
Award Date	August 2013
Location	Jefferson County, CO
Year Completed	2015
Area Monitored	99 acres
Forest Type	Ponderosa pine
Implementation Method	No overstory treatment of large trees
Slash Treatment	Mastication

Pre-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	1 yr post-treatment
Year sampled	2013, 2014	2015
Live basal area* (ft²/ac)	53 ± 34	46 ± 27
Live tree density (trees per acre)	89 ± 121	50 ± 42
Canopy cover (%)	26 ± 22	28 ± 25
Canopy base height (ft)	13 ± 9	11 ± 7
Fine Woody Fuel Loading (tons/acre)	0.87	1.56

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

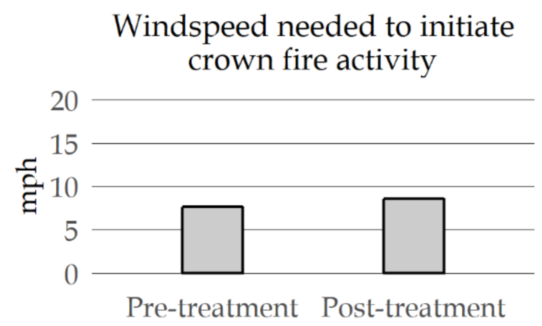

1 yr post-treatment photo point

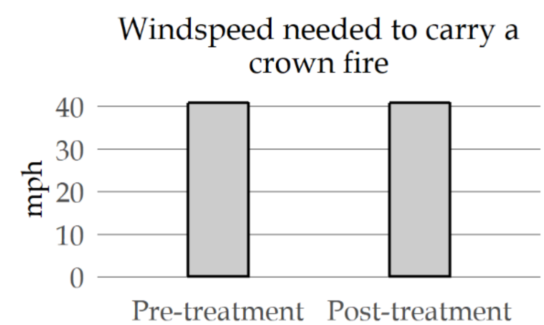
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 15 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

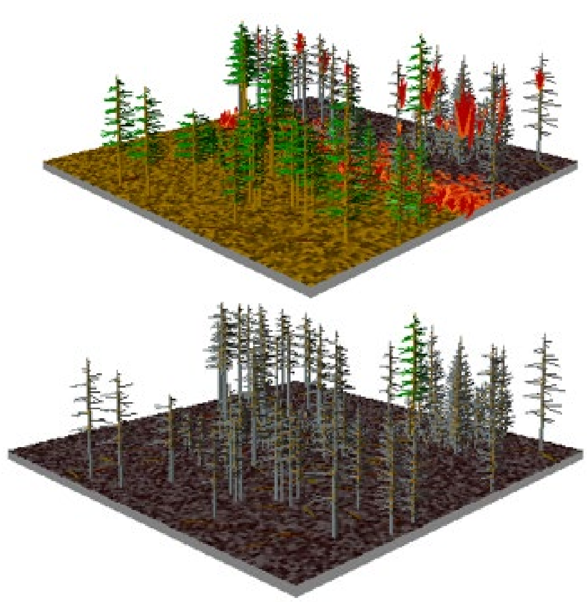
Modeled Fire Behavior

	Pre-treatment		1 yr post-treatment	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Surface	Passive	Surface
Total flame length (ft)	9.6	0.4	11.5	2.8
Surviving tree basal area (ft^2/ac)	2 (3%)	43 (82%)	1 (3%)	35 (76%)

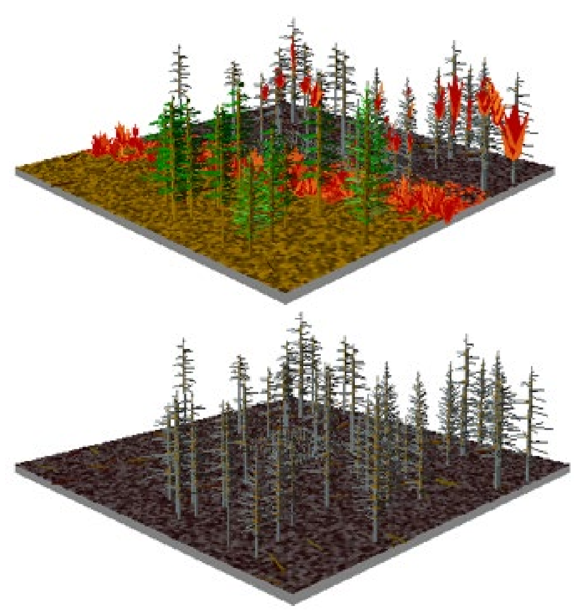




Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary

Loma Linda

Wildfire Mitigation Strategy: A mixed conifer stand was thinned with shrubs and slash masticated in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard.

Project Highlights: Thinning and mastication reduced fire hazard under moderate fire conditions, but was less effective to change fire hazard under severe burning conditions. Under moderate fire conditions, the modeled fire type was reduced from passive crown fire to surface fire and post fire tree mortality decreased following mitigation. Under severe fire conditions, the wind speed expected to initiate crown fire activity remained very low. However, lower tree density after treatment increased the wind speed required to maintain active crown fire from 35 to 52 mph and reduced predicted flame lengths. Mastication greatly increased woody surface fuel loading and the hazard for an intense surface fire. Follow-up monitoring of shrub re-sprouting and change in woody surface fuel loading and maintenance with broadcast prescribed burning would enhance fire mitigation benefits.

Project Information

Grant Recipient	FireWise of southwest Colorado/San Juan Mountains Association
Award Date	May 2014
Location	Archuleta County, CO
Year Completed	2015
Area Monitored	15 acres
Forest Type	Mixed conifer/Gambel oak
Implementation Method	Thin
Slash Treatment	Mastication/Removal

Pre-treatment photo point

1 yr post-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	1 yr post-treatment
Year sampled	2014	2015
Live basal area* (ft²/ac)	87 ± 39	68 ± 20
Live tree density (trees per acre)	320 ± 536	163 ± 342
Canopy cover (%)	58 ± 17	56 ± 21
Canopy base height (ft)	31 ± 17	30 ± 13
Gambel oak cover (%)	22 ± 12	6 ± 7
Gambel oak height (ft)	6.6 ± 5	1.0 ± 0.7
Fine Woody Fuel Loading (tons/acre)	0.97	2.61

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

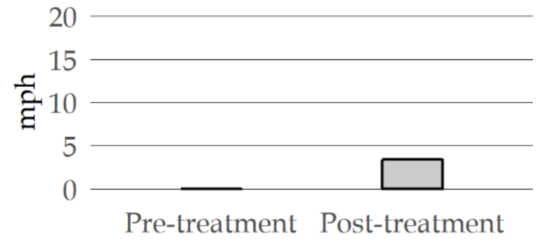
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 7 field plots pre-treatment and 11 post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

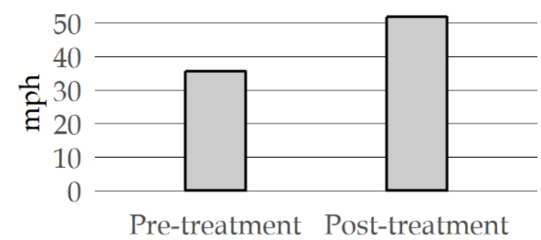
Modeled Fire Behavior

	Pre-treatment		**1 yr post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Passive	Passive	Surface
Total flame length (ft)	29.0	3.9	12.9	3.5
Surviving tree basal area (ft^2/ac)	2 (2%)	62 (71%)	3 (4%)	58 (85%)

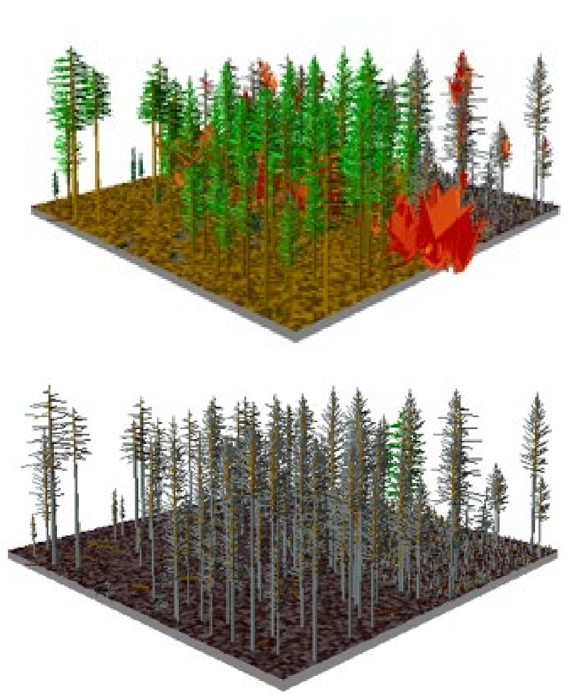
Windspeed needed to initiate crown fire activity



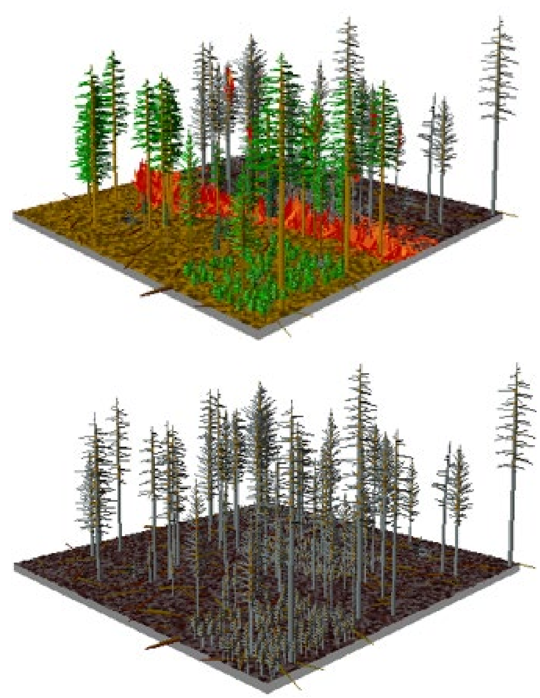
Windspeed needed to carry a crown fire



Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary

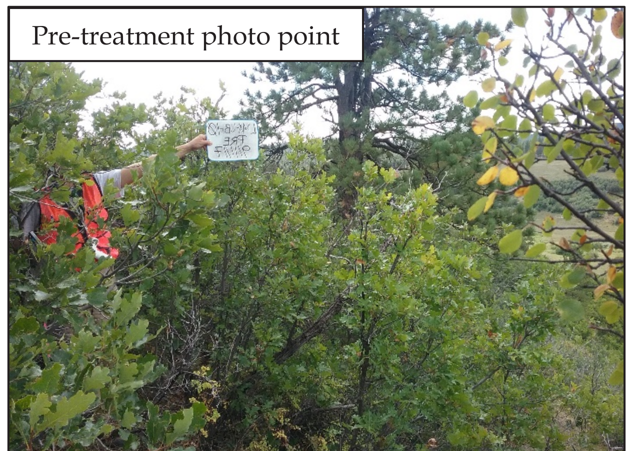
Lone Mesa State Park—Burn Only Unit

Wildfire Mitigation Strategy: Prescribed broadcast fire was applied to reduce Gamble oak cover in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard and enhance wildlife habitat.

Project Highlights: The prescribed burn generally reduced fire hazard and achieved wildlife habitat objectives to top kill oak and encourage re-sprouting. The prescribed burn reduced modeled flame lengths and fire intensity, especially under severe burning conditions, while reducing cover of Gambel oak by about two-thirds one year post burn. Pre-burn management of oak and repeated treatments may help mitigate negative impacts to conifers, manage oak abundance and maintain wildlife habitat. This burn helped state agencies build partnerships and capacity for conducting prescribed fire.

Project Information

Grant Recipient	Colorado Parks and Wildlife
Award Date	October 2016
Location	Dolores County, CO
Year Completed	2017
Area Monitored	19 acres
Forest Type	Ponderosa pine/Gambel oak
Implementation Method	Broadcast burn



Pre-treatment photo point

1 yr post-treatment photo point

Forest and Fuels Inventory

Summary	**Pre-treatment**	**1 yr post-treatment**
Year sampled	2017	2018
Live basal area* (ft²/ac)	7 ± 9	5 ± 10
Live tree density (trees per acre)	3 ± 6	2 ± 6
Canopy cover (%)	0 ± 1	0 ± 1
Canopy base height (ft)	11 ± 4	36 ± 13
Gambel oak cover (%)	60 ± 11	22 ± 15
Average shrub height (ft)	7.9 ± 0.3	9.3 ± 1.0
Fine Woody Fuel Loading (tons/acre)	1.01	1.12

*Basal area is the cross-sectional area of tree stems at breast height (4.5 ft.) for a given area.

Prescribed fire severity assessment

The burn was extensive throughout the unit and all plots showed signs of fire, with 56% of the ground visibly burned. The average 80% of overstory conifer tree canopy volume scorched in the burn was over four times greater than in adjacent masticated and prescribed burned units with higher conifer tree density. Average maximum height of char on the tree trunks was 36 ft, over three times greater than in masticated and burned stands.

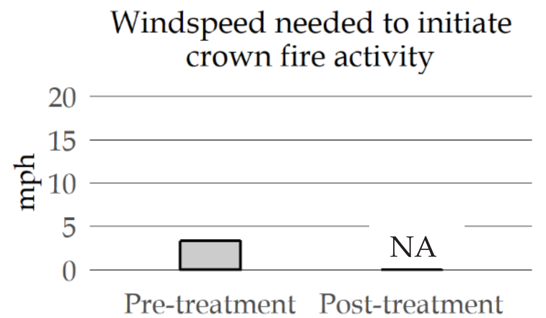
Fire Hazard Analysis

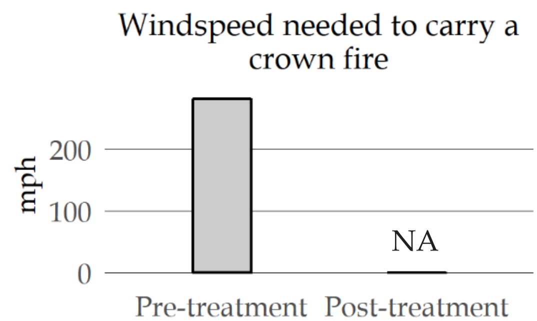
We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 11 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

*NA indicates not enough trees were present to model fire behavior.

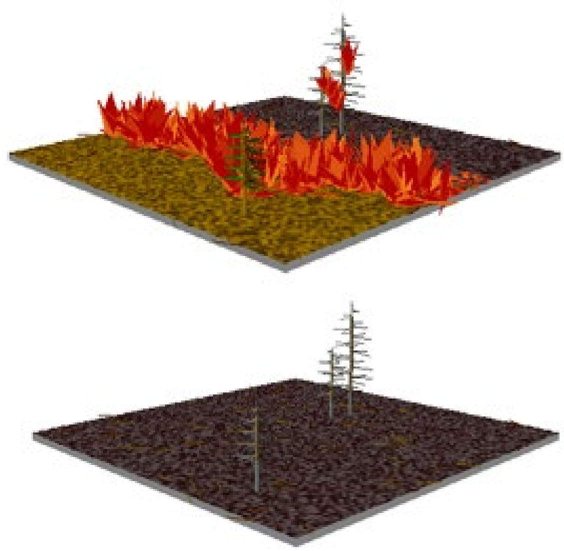
Modeled Fire Behavior

	Pre-treatment		1 yr post-treatment	
Fire weather and fuel conditions	*Severe*	*Moderate*	*Severe*	*Moderate*
Fire type	Passive	Surface	Surface	Surface
Total flame length (ft)	24.9	9.0	12.3	4.9
Surviving tree basal area (ft^2/ac)	1 (8%)	1 (9%)	0 (9%)	4 (83%)

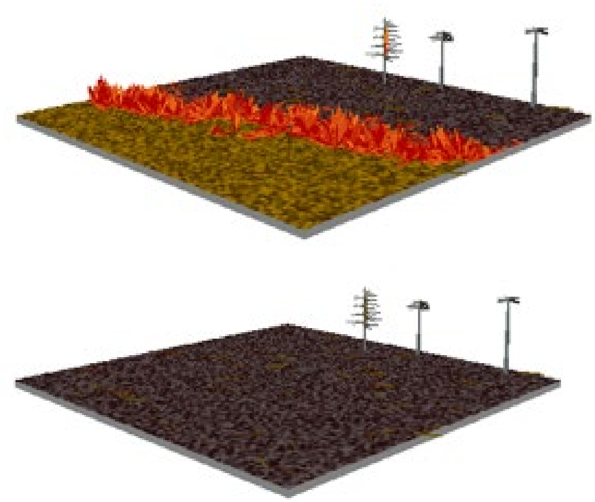




Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary

Lone Mesa State Park—Masticated + Burned Units

Wildfire Mitigation Strategy: Prescribed broadcast fire was applied to a ponderosa pine stand with an understory of Gambel oak, which was previously masticated in 2013, in a Wildfire Risk Reduction Grant funded project to reduce wildfire hazard and enhance wildlife habitat.

Project Highlights: Resistance to crown fire and future post-fire tree mortality increased dramatically as a result of the burn. The fire did not kill any trees by one year post burn, cover of Gambel oak was reduced by about two-thirds, and woody surface fuel loading decreased. However, Gambel oak often re-sprouts readily following disturbance. Repeated treatment may facilitate both maintaining fire hazard reduction and improving wildlife management objectives to encourage re-sprouting of top killed oak. Minimal ponderosa pine regeneration is occurring, and future monitoring and considering impacts of repeated treatments is important. This burn helped state agencies build partnerships and capacity for conducting prescribed fire on non-federal forested lands.

Project Information

Grant Recipient	Colorado Parks and Wildlife
Award Date	October 2016
Location	Dolores County, CO
Year Completed	2017
Area Monitored	52 acres
Forest Type	Ponderosa pine/Gambel oak
Implementation Method	Mastication (2013), followed by broadcast burn (2017)

Pre-burn photo point

1 yr post-burn photo point

Forest and Fuels Inventory

Summary	**Pre-burn**	**1 yr post-burn**
Year sampled	2017	2018
Live basal area* (ft²/ac)	56 ± 49	57 ± 47
Live tree density (trees per acre)	33 ± 37	34 ± 37
Canopy cover (%)	30 ± 30	16 ± 32
Canopy base height (ft)	16 ± 10	22 ± 11
Gambel oak cover (%)	34 ± 14	12 ± 16
Average shrub height (ft)	6.3 ± 0.6	10.0 ± 1.4
Fine Woody Fuel Loading (tons/acre)	1.32	1.4

*Basal area is the cross-sectional area of tree stems at breast height (4.5 ft.) for a given area.

<u>*Prescribed fire severity assessment*</u>

The burn was extensive throughout the area, with all monitoring plots showing signs of fire and an average 61% of the ground visibly burned.

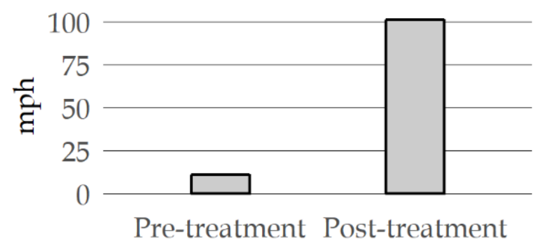
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 12 field plots pre-burn (post-mastication) and post-burn. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

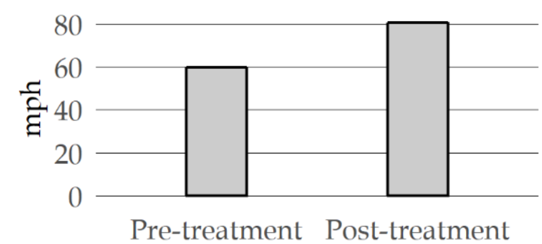
Modeled Fire Behavior

	Pre-treatment		**1 yr post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Surface	Surface	Surface
Total flame length (ft)	14.0	3.9	3.3	1.3
Surviving tree basal area (ft^2/ac)	3 (5%)	46 (82%)	52 (91%)	52 (91%)

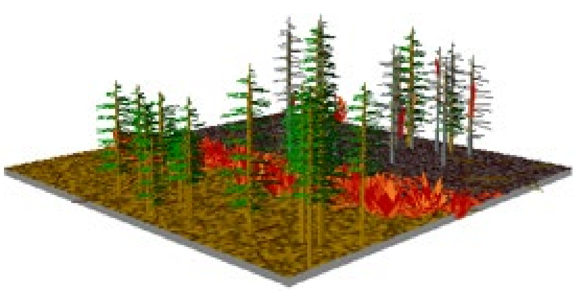
Windspeed needed to initiate crown fire activity



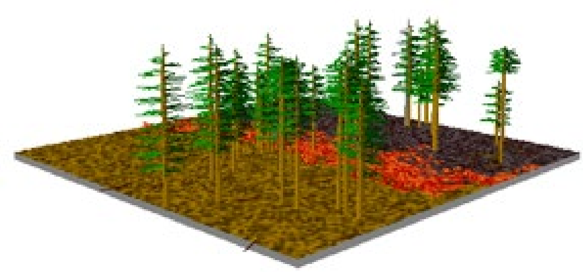
Windspeed needed to carry a crown fire



Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary:
Mueller State Park

Wildfire Mitigation Strategy: A mixed conifer stand was thinned and all residual material was redistributed on-site via mastication in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard.

Project Highlights: Tree density was substantially reduced, but surface fire hazard and fine woody surface fuel loading increased massively, adding over 10 tons/acre of fuel one year after mastication. While some metrics of potential fire behavior improved following the mastication, modeled flame lengths remained high and fire-caused tree mortality was at 99% under severe fire conditions. While tree density and basal area were reduced, using mastication in combination with other alternative management methods, such as removal or pile burning, may be more effective in productive moist mixed conifer forests to reduce fire hazard and increase the resilience of forests to wildfire.

Project Information

Grant Recipient	Coalition for the Upper South Platte
Award Date	August 2013
Location	Teller County, CO
Year Completed	2014
Area Monitored	146 acres
Forest Type	Mixed conifer
Implementation Method	Mastication
Slash Treatment	Mastication

Pre-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	1 yr post-treatment
Year sampled	2013	2014
Live basal area* (ft²/ac)	103 ± 45	69 ± 25
Live tree density (trees per acre)	332 ± 263	134 ± 64
Canopy cover (%)	57 ± 15	47 ± 15
Canopy base height (ft)	14 ± 7	18 ± 7
Fine Woody Fuel Loading (tons/acre)	5.01	15.84


1 yr post-treatment photo point

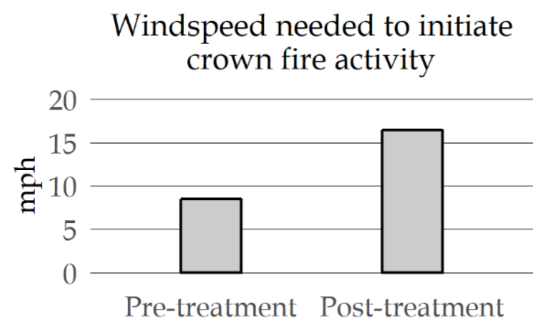
* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

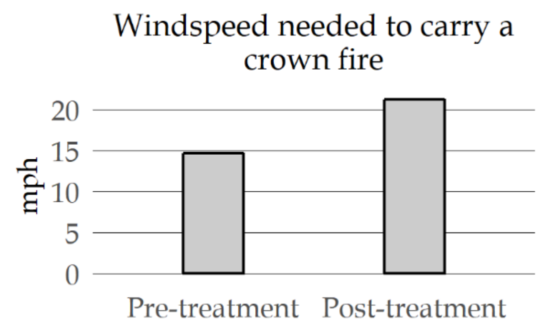
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 7 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

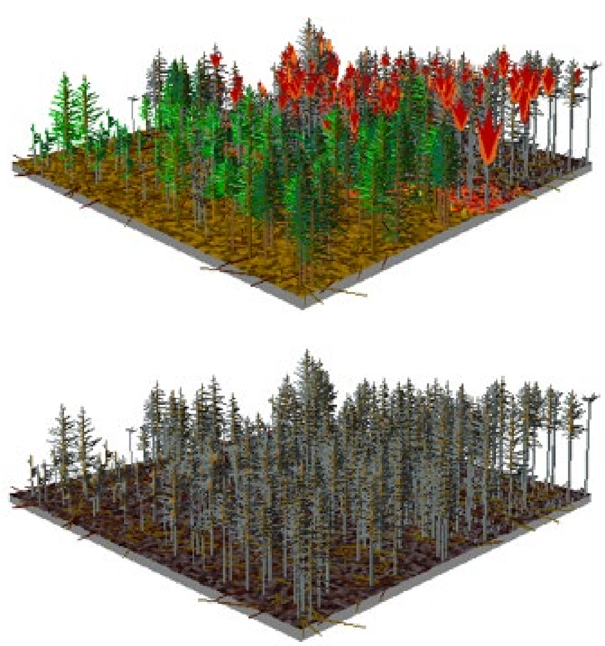
Modeled Fire Behavior

	Pre-Treatment		1 yr post-treatment	
Fire weather and fuel conditions	*Severe*	*Moderate*	*Severe*	*Moderate*
Fire type	Active	Surface	Passive	Surface
Total flame length (ft)	56.6	0.8	31.6	3.2
Surviving tree basal area (ft^2/ac)	0 (0%)	57 (55%)	1 (1%)	38 (55%)

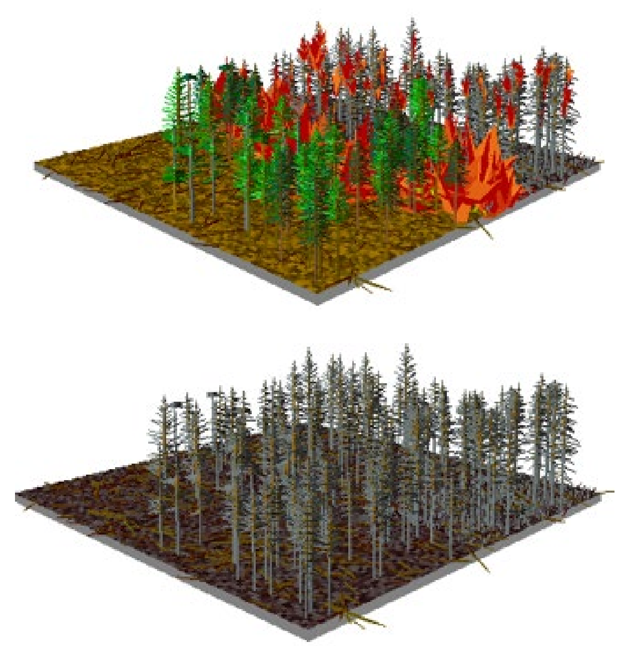




Pre-treatment



1 yr post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary

No Name Creek

Wildfire Mitigation Strategy: A lodgepole pine-dominated stand with heavy beetle-caused tree mortality was clearcut in a Wildfire Risk Reduction Grant Program funded project designed to reduce wildfire hazard.

Project Highlights: Overstory tree removal changed predicted fire type from passive crown fire to surface fire and greatly reduced predicted fire intensity. Slash was pile burned, resulting in a net reduction of woody surface fuels following the treatment. As expected, aspen regeneration increased after overstory removal. Many standing dead trees were removed from the site near high value power transmission lines, improving public safety, recreation access, and likely providing opportunities for additional fire suppression tactics to be applied.

Project Information

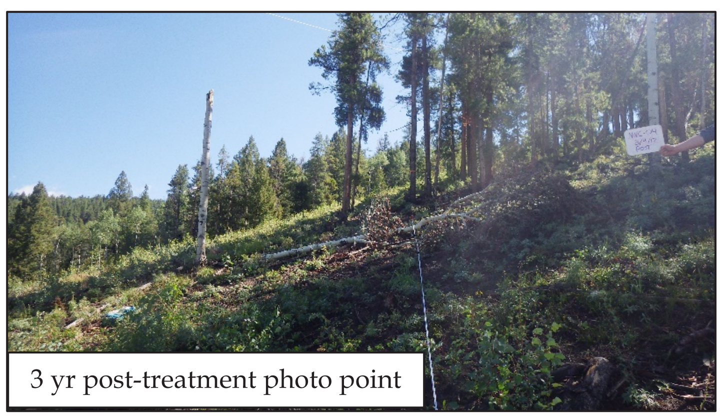
Grant Recipient	Uncompahgre Com, Inc.
Award Date	May 2014
Location	Gunnison County, CO
Year Completed	2017
Area Monitored	18 acres
Forest Type	Lodgepole pine
Implementation Method	Clearcut
Slash Treatment	Pile Burn

Pre-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	3 yr post-treatment
Year sampled	2014	2017
Live basal area* (ft²/ac)	116 ± 46	11 ± 0
Live tree density (trees per acre)	1094 ± 2228	15 ± 0
Dead basal area* (ft²/ac)	56 ± 32	0 ± 0
Dead tree density (trees per acre)	877 ± 2343	0 ± 0
Canopy cover (%)	50 ± 21	14 ± 26
Canopy base height (ft)	16 ± 9	15 ± 7
Fine Woody Fuel Loading (tons/acre)	6.56	2.36

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.



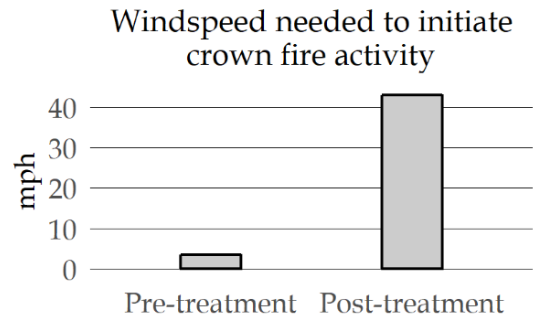
3 yr post-treatment photo point

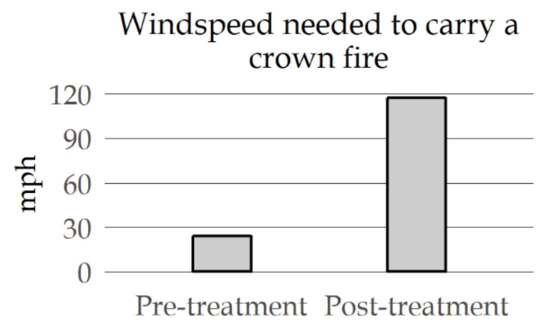
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 9 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

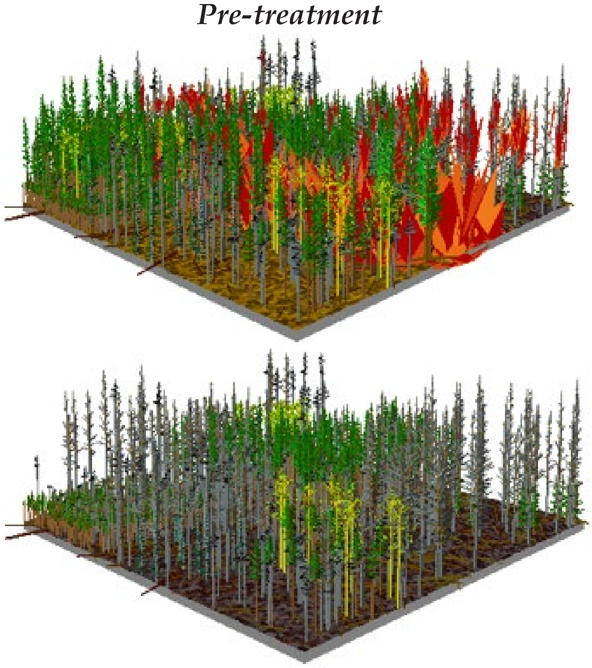
Modeled Fire Behavior

	Pre-treatment		**3 yr post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Surface	Surface	Surface
Total flame length (ft)	36.1	0.7	7.7	1.5
Surviving tree basal area (ft^2/ac)	1 (1%)	45 (39%)	0 (2%)	7 (63%)

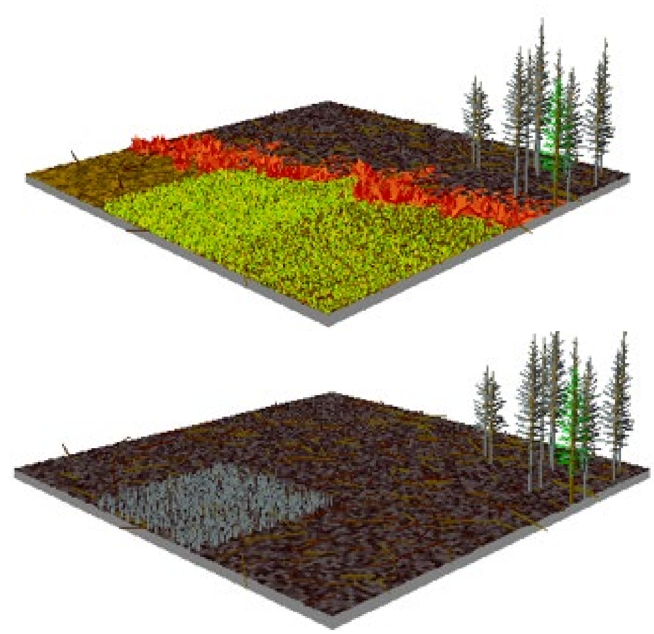




Pre-treatment



Post-treatment



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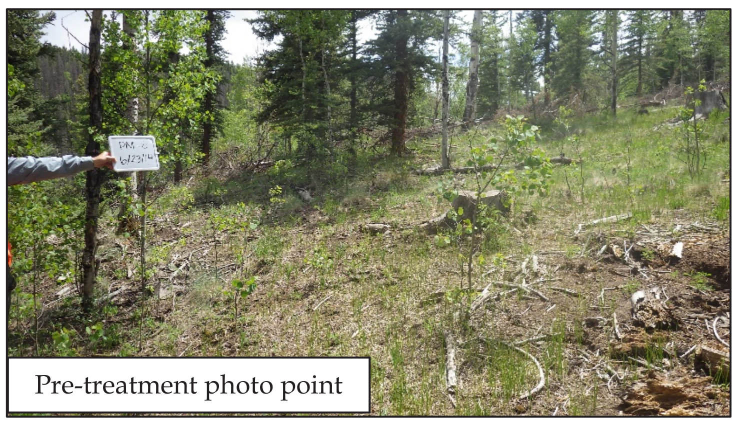
Wildfire Risk Reduction Grant Monitoring Summary: *Ptarmigan Meadows*

Wildfire Mitigation Strategy: A mixed conifer forest was mechanical thinned and residual slash was pile burned in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard.

Project Highlights: The thinning treatment reduced fire intensity within a fuel break around Ptarmigan Meadows community, decreasing modeled flame lengths and the likelihood of fire moving between tree crowns propagating through the forest, especially under severe fire conditions. However, passive crown fire was expected both before and after mitigation activities. Tree mortality remained high under all modeled fire events, as tree species present have low fire tolerance. While fine woody surface fuels decreased following thinning due to piling and burning of material, most piles were incompletely burned or unburned, leading to significant increases in coarse woody surface fuel loading following the treatment. The WRRG mitigation on non-federal lands was implemented in conjunction with an adjoining US Forest Service fuel break to expand fire hazard reduction benefits.

Project Information

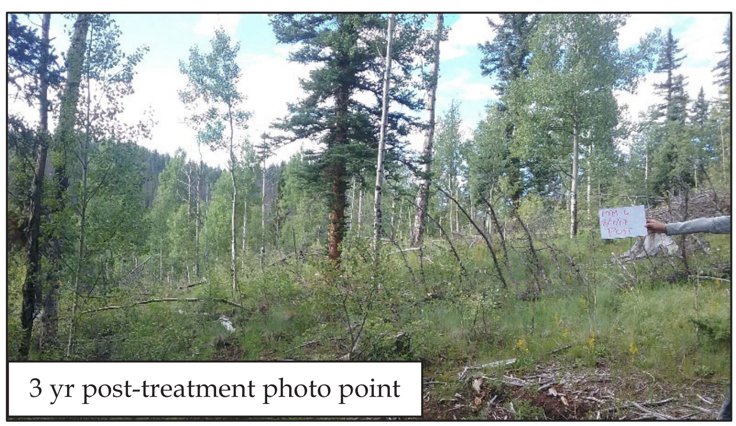
Grant Recipient	Rio Grande Restoration Foundation
Award Date	May 2014
Location	Hinsdale County, CO
Year Completed	2014
Area Monitored	58 acres
Forest Type	Mixed conifer
Implementation Method	Thin
Slash Treatment	Pile Burn



Pre-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	3 yr post-treatment
Year sampled	2014	2017
Live basal area* (ft^2/ac)	103 ± 47	69 ± 42
Live tree density (trees per acre)	570 ± 437	247 ± 182
Canopy cover (%)	46 ± 16	35 ± 23
Canopy base height (ft)	17 ± 12	20 ± 12
Fine Woody Fuel Loading (tons/acre)	5.28	2.19



3 yr post-treatment photo point

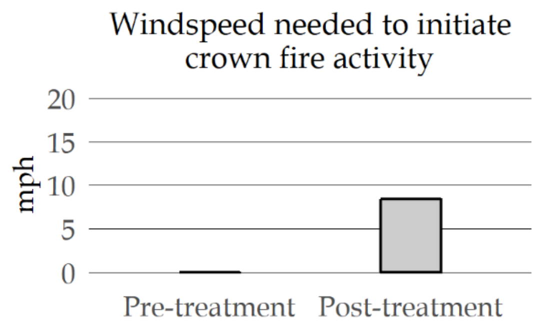
* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

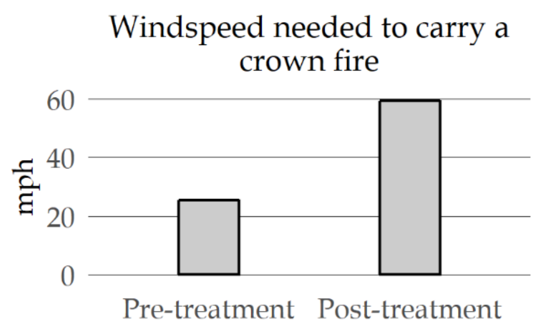
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 15 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

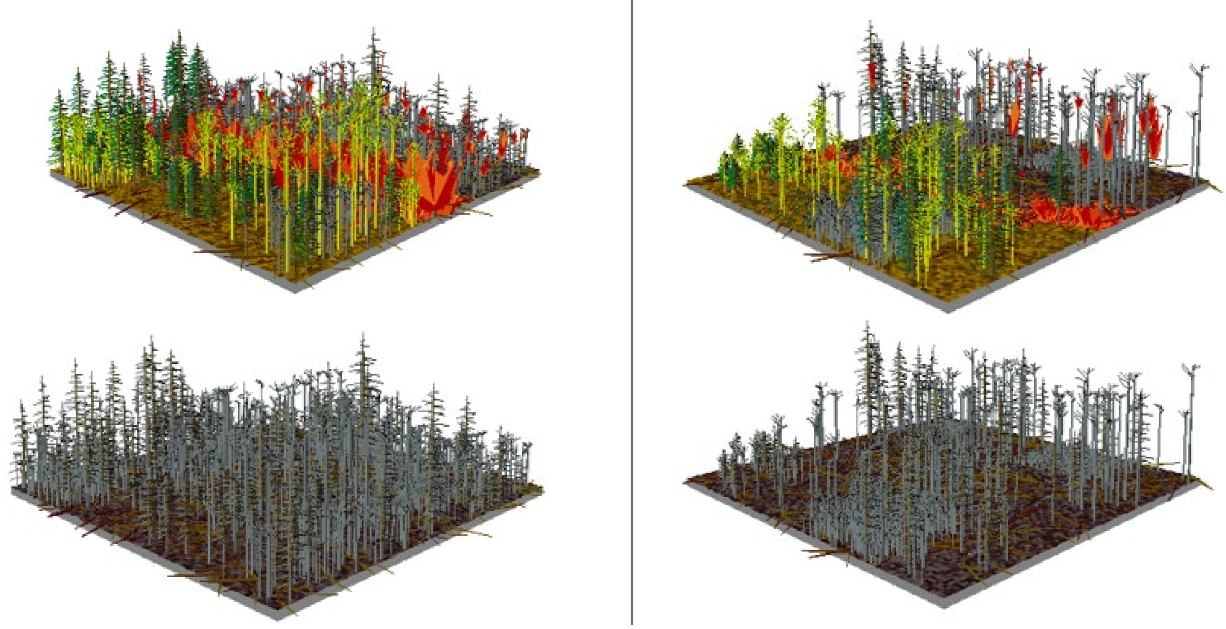
Modeled Fire Behavior

	Pre-treatment		3 yr post-treatment	
Fire weather and fuel conditions	*Severe*	*Moderate*	*Severe*	*Moderate*
Fire type	Passive	Passive	Passive	Surface
Total flame length (ft)	29.8	3.1	9.8	3.2
Surviving tree basal area (ft^2/ac)	1 (1%)	35 (34%)	1 (1%)	28 (41%)





Pre-treatment *Post-treatment*



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Wildfire Risk Reduction Grant Monitoring Summary

Red Rock Canyon

Wildfire Mitigation Strategy: A sparse ponderosa and pinyon pine stand with a heavy Gambel oak and mountain shrub component was thinned with residual slash removed or chipped in a Wildfire Risk Reduction Grant funded project designed to reduce fire hazard.

Project Highlights: While the stand contained few conifer trees before treatment, cover of shrubs was greatly reduced and accumulations of fine woody surface fuels post treatment were minimized, reducing fire hazard. Tree canopy base height remained very low, which contributed to high predicted conifer tree mortality, both prior to and following mitigation. The fire mitigation substantially reduced predicted flame lengths and surface fire intensity, increasing opportunities for fire suppression. Gambel oak and other shrubs often vigorously re-sprout following disturbance. Follow-up monitoring and maintenance with prescribed broadcast fire or continued mechanical fuel reduction would extend fire mitigation benefits. Youth corps gained training and education in forest management by completing this project.

Project Information

Grant Recipient	The City of Colorado Springs Parks and Recreation and Cultural Services
Award Date	August 2013
Location	El Paso County, CO
Year Completed	2014
Area Monitored	81 acres
Forest Type	Pinyon pine / Gambel oak
Implementation Method	Thin
Slash Treatment	Removal, Chip

Pre-treatment photo point

2 yr post-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	2 yr post-treatment
Year sampled	2013	2015
Live basal area* (ft²/ac)	4 ± 0	4 ± 0
Live tree density (trees per acre)	20 ± 0	15 ± 0
Canopy cover (%)	0 ± 0	0 ± 0
Canopy base height (ft)	1 ± 0	2 ± 0
Gambel oak cover (%)	40 ± 30	3 ± 0
Gambel oak height (ft)	3.3 ± 2	3.2 ± 0
Fine Woody Fuel Loading (tons/acre)	1.33	1.89

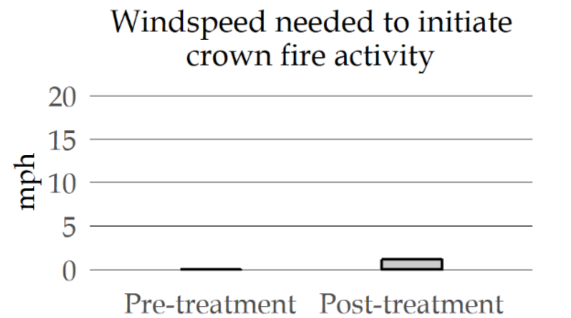
* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

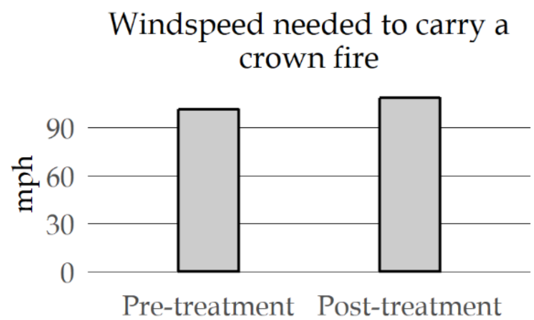
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 5 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

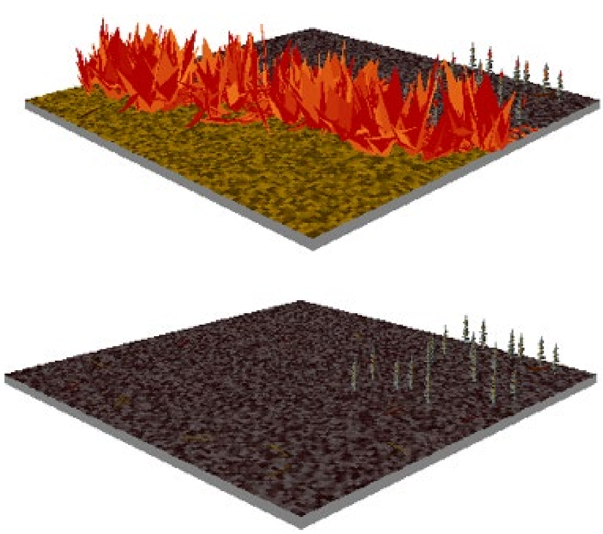
Modeled Fire Behavior

	Pre-treatment		**2 yr post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Passive	Passive	Passive
Total flame length (ft)	28.1	9.0	10.9	3.1
Surviving tree basal area (ft^2/ac)	0 (1%)	0 (1%)	0 (1%)	0 (1%)

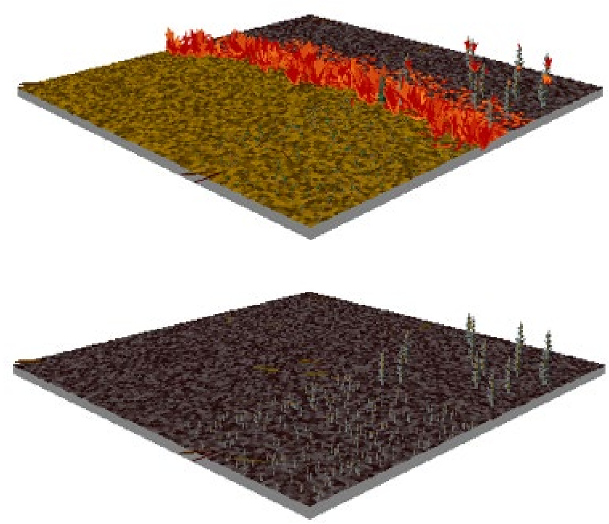




Pre-treatment



Post-treatment



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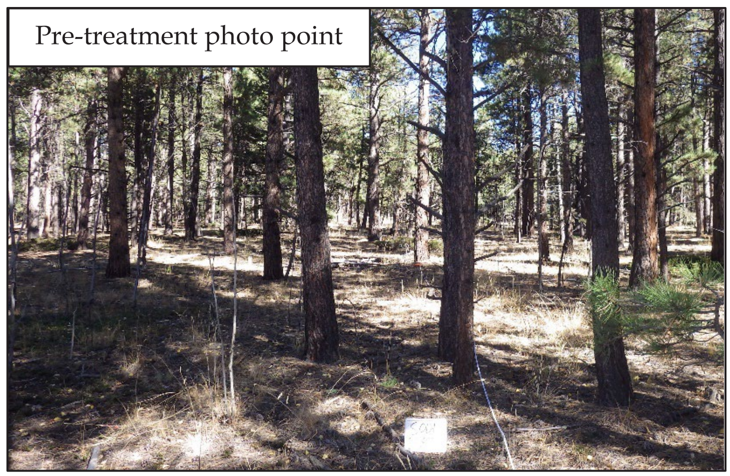
Wildfire Risk Reduction Grant Monitoring Summary:
Sourdough Unit 3

Wildfire Mitigation Strategy: A ponderosa pine stand was thinned and slash was chipped with partial removal in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard.

Project Highlights: The stand was variably thinned, with dramatic canopy reduction in some areas while other areas were essentially untouched, resulting in an overall 5 ft²/acre reduction in basal area. The windspeed expected to initiate crown fire activity raised substantially following mitigation, changing predicted fire behavior under severe fire conditions from passive crown fire to surface fire. However, predicted fire-caused tree mortality remained high, and the windspeed predicted to carry active crown fire was unaffected by the light thin. Grant recipients were eager to participate in adaptive management, and improved project outcomes based on monitoring results on subsequent projects.

Project Information

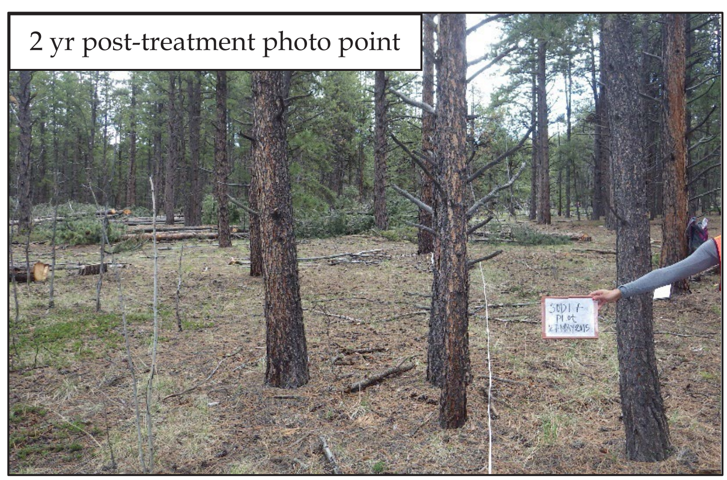
Grant Recipient	Coalition for the Upper South Platte
Award Date	August 2013
Location	Teller County, CO
Year Completed	2015
Area Monitored	33 acres
Forest Type	Ponderosa pine
Implementation Method	Thin
Slash Treatment	Chip & partial removal


Pre-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	2 yr post-treatment
Year sampled	2013	2015
Live basal area* (ft²/ac)	102 ± 57	97 ± 60
Live tree density (trees per acre)	214 ± 318	199 ± 323
Canopy base height (ft)	22 ± 9	25 ± 9
Fine Woody Fuel Loading (tons/acre)	1.89	1.55

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

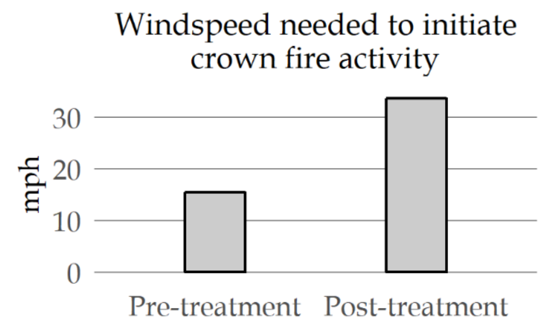

2 yr post-treatment photo point

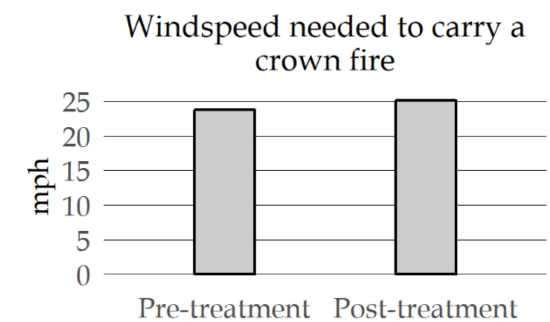
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 9 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

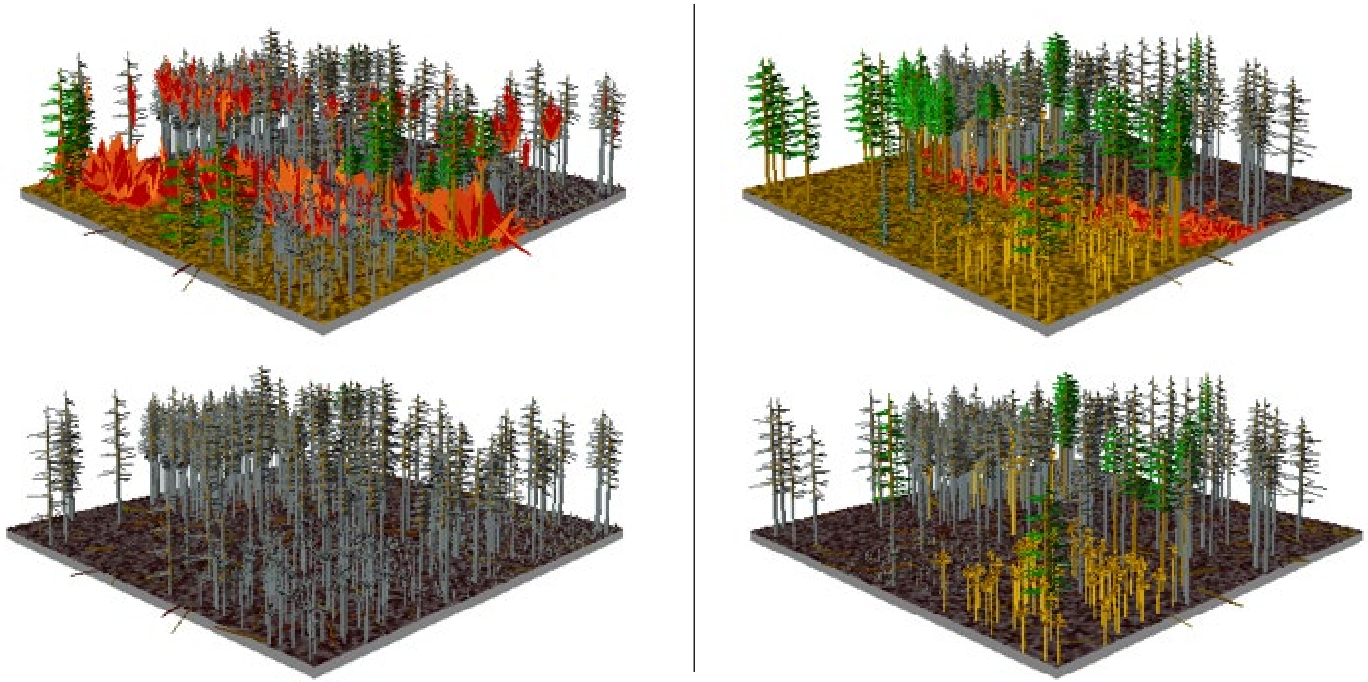
Modeled Fire Behavior

	Pre-treatment		2 yr post-treatment	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Surface	Surface	Surface
Total flame length (ft)	21.5	1.8	6.1	0.8
Surviving tree basal area (ft²/ac)	2 (2%)	81 (79%)	6 (6%)	77 (79%)





Pre-treatment ***Post-treatment***



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Wildfire Risk Reduction Grant Monitoring Summary:
Summit County—Prospector and Romance Units

Wildfire Mitigation Strategy: A dense lodgepole pine stand with heavy mountain pine beetle mortality was clearcut and all biomass was removed off site to a bio-energy facility in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard in the WUI near Breckenridge, Colorado.

Project Highlights: Modeled fire behavior switched from passive crown fire with 99% tree mortality to a less intense surface fire following treatment. Removing biomass minimized woody surface fuel accumulation and reduced flame lengths and fire intensity. Lodgepole pine regeneration was highly variable, but abundant, highlighting the need for continued monitoring and active management to maintain fire hazard reduction. In addition to reducing fire hazard, the utilization of all woody biomass provided economic opportunities. Many standing dead trees were removed from the site, improving public safety and recreation access, and substantially enhancing potential fire suppression opportunities and firefighter safety.

Project Information

Grant Recipient	Summit County and Town of Breckenridge
Award Date	August 2013
Location	Summit County, CO
Year Completed	2015
Area Monitored	35 acres
Forest Type	Lodgepole pine
Implementation Method	Clearcut
Slash Treatment	Removal


Pre-treatment photo point


3 yr post-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	3 yr post-treatment
Year sampled	2014	2017
Live basal area* (ft²/ac)	40 ± 16	0 ± 0
Live tree density (trees per acre)	154 ± 74	0 ± 0
Dead basal area* (ft²/ac)	120 ± 52	0 ± 0
Dead tree density (trees per acre)	264 ± 125	0 ± 0
Canopy cover (%)	12 ± 13	0 ± 0
Seedling density (seedlings per acre)	1,012 ± 2,023	10,117 ± 6,650
Canopy base height (ft)	14 ± 9	NA
Fine Woody Fuel Loading (tons/acre)	1.38	2.23

*Basal area is the cross-sectional area of tree stems at breast height (4.5 ft.) for a given area.

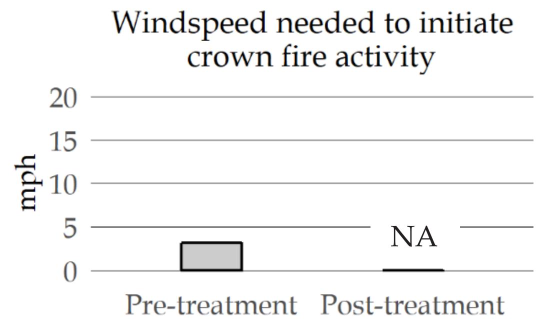
Fire Hazard Analysis

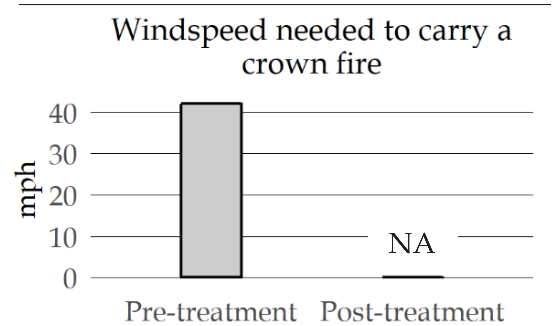
We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 4 field plots pre-treatment and 8 field plots post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

*NA indicates not enough trees were present to model crown fire behavior.

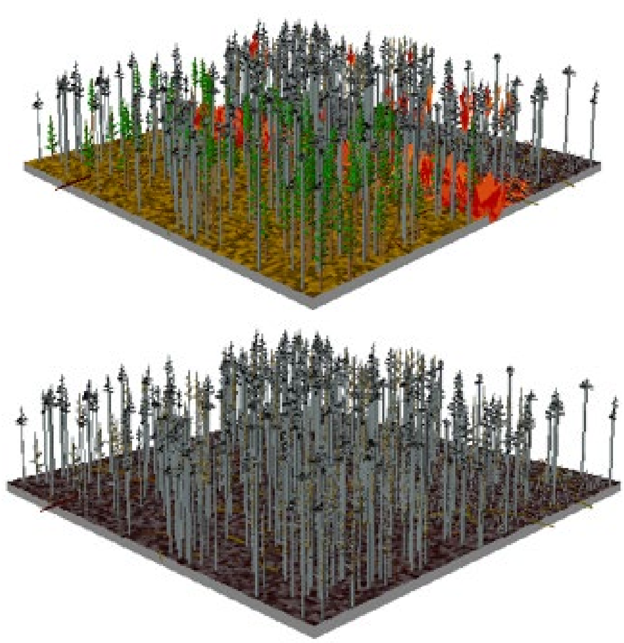
Modeled Fire Behavior

	Pre-treatment		3 yr post-treatment	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Surface	Surface	Surface	Surface
Total flame length (ft)	14.8	1.0	9.5	1.2
Surviving tree basal area (ft^2/ac)	0 (1%)	40 (100%)	NA	NA

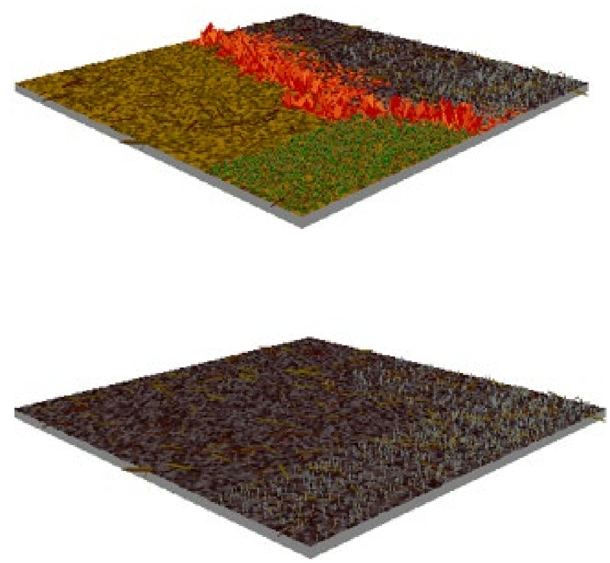




Pre-treatment



Post-treatment



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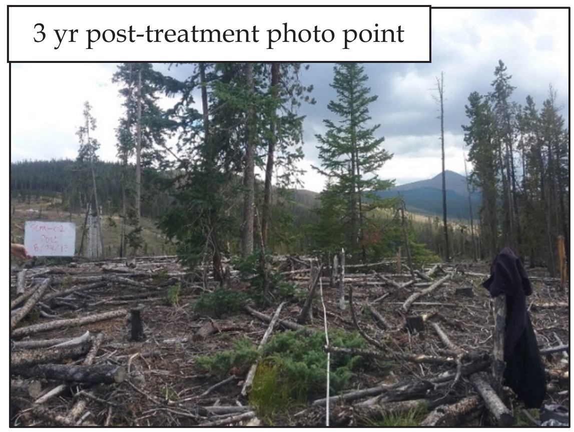
Wildfire Risk Reduction Grant Monitoring Summary:
Summit County—Rac Jac Unit

Wildfire Mitigation Strategy: A dense lodgepole pine stand with heavy mountain pine beetle mortality was clearcut, with most trees and slash scattered on site, in a Wildfire Risk Reduction Grant funded project to reduce wildfire hazard in the WUI near Breckenridge, Colorado.

Project Highlights: Fine woody surface fuel loading was high before fire mitigation, more than tripled following the clearcut, but returned to near pre-treatment levels after 3 years. Larger coarse woody fuels increased six-fold and persisted throughout the monitoring period. Lodgepole pine regeneration was highly variable, but prolific, highlighting the need for continued monitoring and active management to reduce fire hazard. While most metrics of fire behavior and severity were unchanged or increased following treatment, many hazardous standing dead trees were rearranged from standing to the forest floor, improving public safety and recreation access.

Pre-treatment photo point

3 yr post-treatment photo point



Project Information

Grant Recipient	Summit County and Town of Breckenridge
Award Date	August 2013
Location	Summit County, CO
Year Completed	2015
Area Monitored	26 acres
Forest Type	Lodgepole pine
Implementation Method	Clearcut
Slash Treatment	Lop and scatter

Forest and Fuels Inventory

Summary	Pre-treatment	1 yr post-treatment	3 yr post-treatment
Year sampled	2013	2015	2017
Live basal area* (ft^2/ac)	92 ± 58	0 ± 0	1 ± 0
Live tree density (trees per acre)	927 ± 990	0 ± 0	12 ± 0
Dead basal area* (ft^2/ac)	84 ± 30	0 ± 0	0 ± 0
Dead tree density (trees per acre)	690 ± 752	0 ± 0	0 ± 0
Seedling density (seedlings per acre)	0 ± 0	3,035 ± 7,554	80,263 ± 141,198
Canopy cover (%)	24 ± 25	0 ± 0	0 ± 0
Canopy base height (ft)	18 ± 7	0 ± 0	1 ± 0
Fine Woody Fuel Loading (tons/acre)	5.02	15.91	7.92

*Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

Fire Hazard Analysis

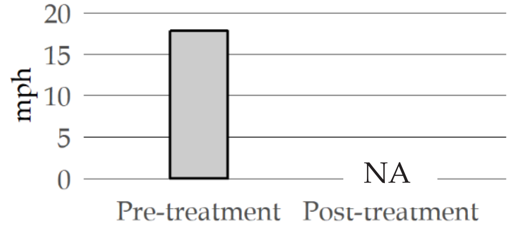
We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 5 field plots pre-treatment and 8 plots for each post-treatment measurement. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

*NA indicates not enough trees were present to model crown fire behavior.

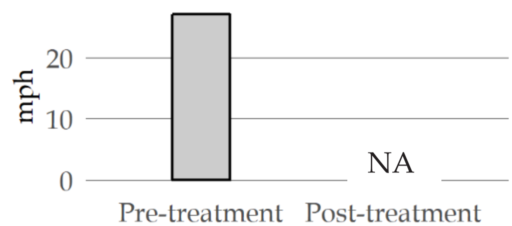
Modeled Fire Behavior

	Pre-treatment		**1 yr post-treatment**		**3 yr post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Surface	Surface	Surface	Passive	Passive
Total flame length (ft)	10.9	0.8	12.8	4.8	9.2	3.7
Surviving tree basal area (ft²/ac)	1 (1%)	23 (25%)	NA	NA	0 (1%)	0 (1%)

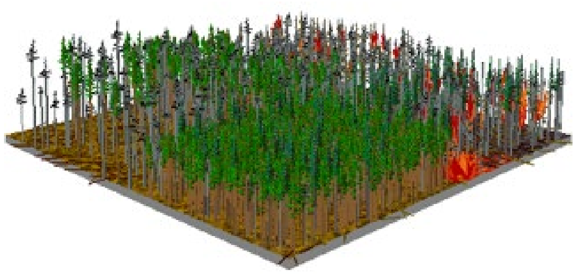
Windspeed needed to initiate crown fire activity



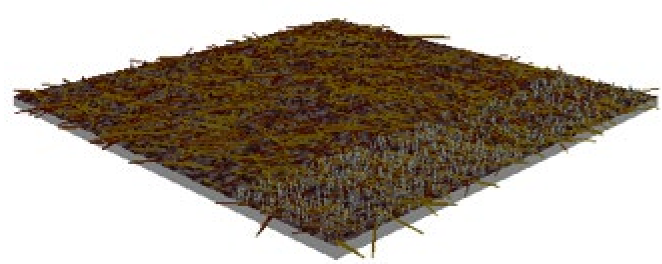
Windspeed needed to carry a crown fire



Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary:
Sunshine Canyon Drive

Wildfire Mitigation Strategy: Wildfire mitigation activities funded by a Wildfire Risk Reduction Grant consisted of thinning and pile burning slash, although at the time of re-measurement piles were not yet burned.

Project Highlights: Fire hazard was low before treatment; surface fire was predicted under moderate and severe fire conditions, both prior to and following mitigation. However, the windspeed predicted to initiate crown fire activity increased substantially following mitigation, which led to a large decrease in expected tree mortality under severe fire conditions. Mitigation likely improved roadside egress and community safety in the event of a wildfire.

Project Information

Grant Recipient	Sunshine Fire Protection District
Award Date	August 2013
Location	Boulder, CO
Year Completed	2015
Area Monitored	5 acres
Forest Type	Ponderosa pine
Implementation Method	Thin
Slash Treatment	Pile Burn

Pre-treatment photo point

Forest and Fuels Inventory

Summary	**Pre-treatment**	**1 yr post-treatment**
Year sampled	2014	2015
Live basal area* (ft²/ac)	90 ± 26	70 ± 20
Live tree density (trees per acre)	109 ± 105	80 ± 69
Canopy cover (%)	50 ± 36	32 ± 24
Canopy base height (ft)	18 ± 7	14 ± 6
Fine Woody Fuel Loading (tons/acre)	1.01	0.95

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

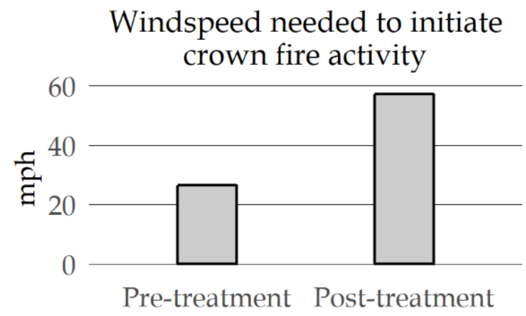
1 yr post-treatment photo point

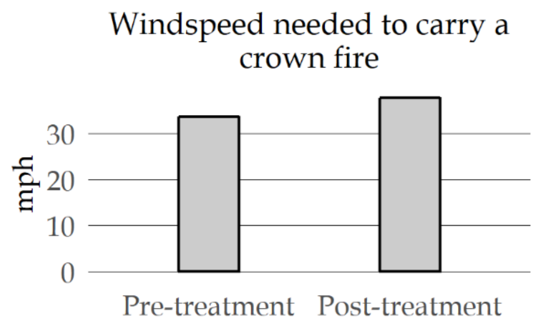
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 4 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

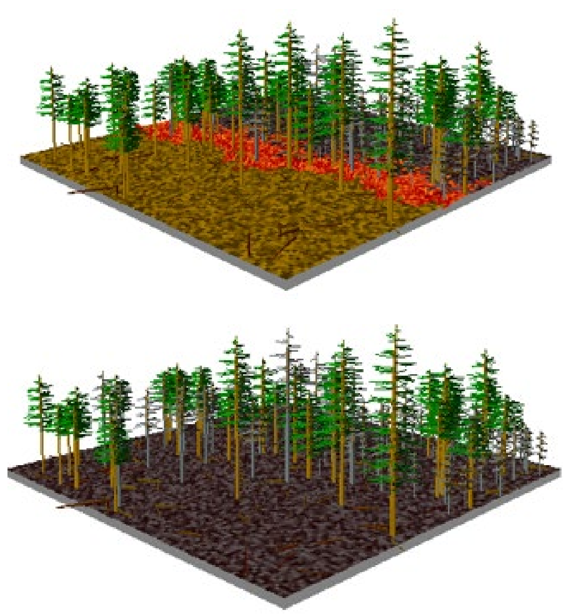
Modeled Fire Behavior

	Pre-treatment		**1 yr post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Surface	Surface	Surface	Surface
Total flame length (ft)	4.9	0.4	2.9	1.2
Surviving tree basal area (ft^2/ac)	24 (27%)	77 (86%)	60 (86%)	61 (87%)

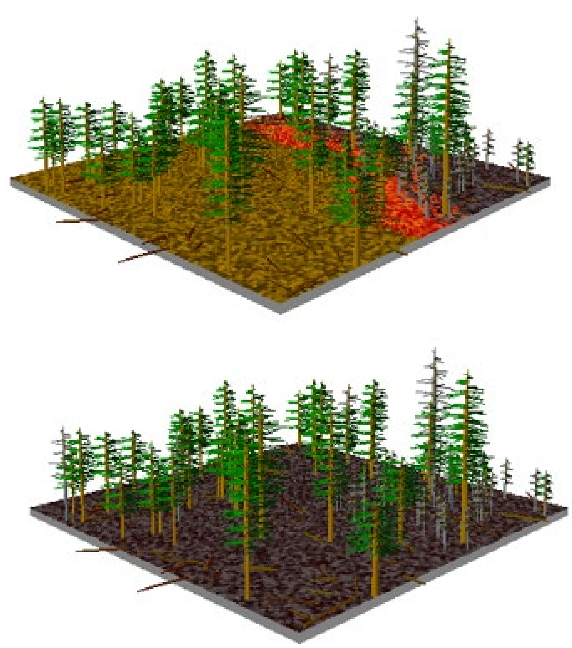




Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary

Timberdale Ranch

Wildfire Mitigation Strategy: Gambel oak was masticated in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard.

Project Highlights: A less continuous shrub layer reduced potential for modeled fire behavior to transition from surface to the tree crowns, improving post fire tree survival under both severe and moderate fire conditions. While all the oak was mulched on site, surface fuel accumulations were minimal and modeled surface fire intensity was reduced. Through a separate WRRG capacity building grant, Timberdale Ranch purchased a tractor mowing attachment to manage shrub and tree regeneration re-growth on a frequent basis and maintain fire hazard reduction longevity in this residential area. Creating more gaps in the tree canopy would reduce the potential for active crown fire and enhance ecological benefits of the mitigation.

Project Information

Grant Recipient	FireWise of southwest Colorado / San Juan Mountains Association
Award Date	May 2014
Location	La Plata County, CO
Year Completed	2015
Area Monitored	39 acres
Forest Type	Ponderosa pine/Gambel Oak
Implementation Method	No overstory treatment
Slash Treatment	Mastication

Forest and Fuels Inventory

Summary	Pre-treatment	1 yr post-treatment
Year sampled	2014	2015
Live basal area* (ft^2/ac)	127 ± 49	127 ± 49
Live tree density (trees per acre)	164 ± 171	164 ± 171
Canopy cover (%)	58 ± 20	64 ± 15
Canopy base height (ft)	47 ± 11	47 ± 11
Gambel oak cover (%)	37 ± 26	4 ± 4
Gambel oak height (ft)	2.8 ± 1.0	0.7 ± 0.4
Fine Woody Fuel Loading (tons/acre)	1.09	1.20

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

Pre-treatment photo point

1 yr post-treatment photo point

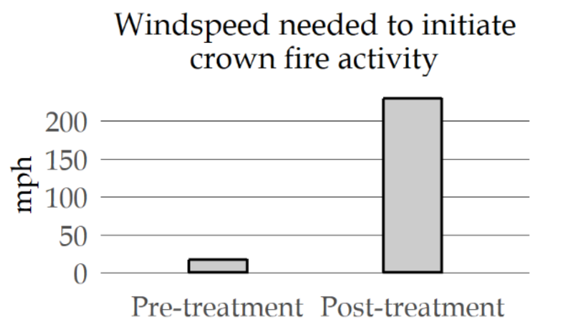
WWRG capacity grant mower attachment

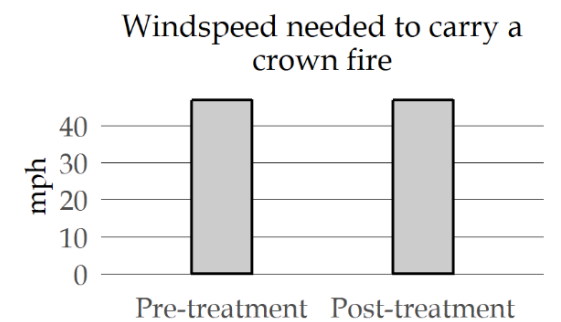
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 8 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

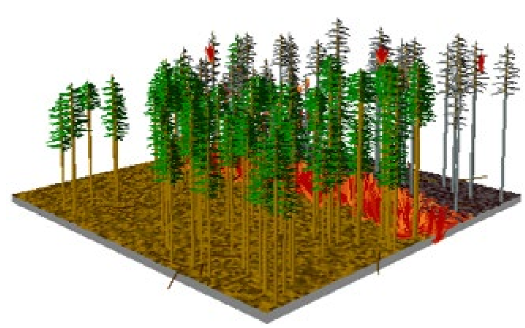
Modeled Fire Behavior

	Pre-treatment		**1 yr post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Surface	Surface	Surface
Total flame length (ft)	16.7	5.8	2.6	1.2
Surviving tree basal area (ft^2/ac)	123 (97%)	38 (30%)	22 (17%)	22 (17%)





Pre-treatment



Post-treatment

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Wildfire Risk Reduction Grant Monitoring Summary:
Top of the Pines

Wildfire Mitigation Strategy: A ponderosa pine stand was thinned, with slash lopped and scattered on site, in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard.

Project Highlights: Top of the Pines had relatively low fire hazard prior to thinning, with surface fire predicted even under severe fire conditions. The windspeed projected to sustain active crown fire was raised following mitigation by reducing tree density and disrupting crown continuity. Small increases of woody surface fuels lowered the windspeed projected to initiate tree torching, but fire intensity, as measured by modeled flame lengths, remained low. Follow-up maintenance with prescribed broadcast burning would further reduce surface fuels and enhance ecological benefits of the fuels mitigation.

Project Information

Grant Recipient	West Region Wildfire Council on behalf of Ouray County
Award Date	August 2013
Location	Ouray County, CO
Year Completed	2015
Area Monitored	31 acres
Forest Type	Ponderosa pine
Implementation Method	Hand thin
Slash Treatment	Lop and scatter


Pre-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	1 yr post-treatment
Year sampled	2013, 2015	2016
Live basal area* (ft²/ac)	98 ± 64	59 ± 34
Live tree density (trees per acre)	88 ± 98	43 ± 39
Canopy cover (%)	28 ± 24	27 ± 24
Canopy base height (ft)	13 ± 6	12 ± 6
Fine Woody Fuel Loading (tons/acre)	0.59	1.51

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.


1 yr post-treatment photo point

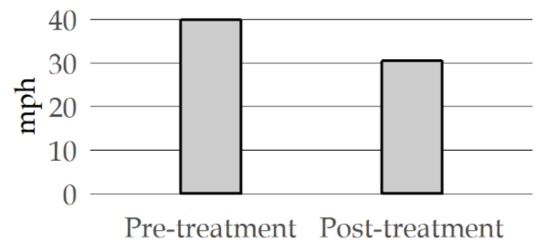
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 19 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

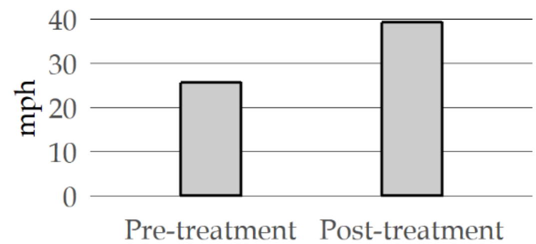
Modeled Fire Behavior

	Pre-treatment		1 yr post-treatment	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Surface	Surface	Surface	Surface
Total flame length (ft)	3.4	1.5	4.5	1.8
Surviving tree basal area (ft^2/ac)	74 (75%)	84 (86%)	39 (66%)	51 (87%)

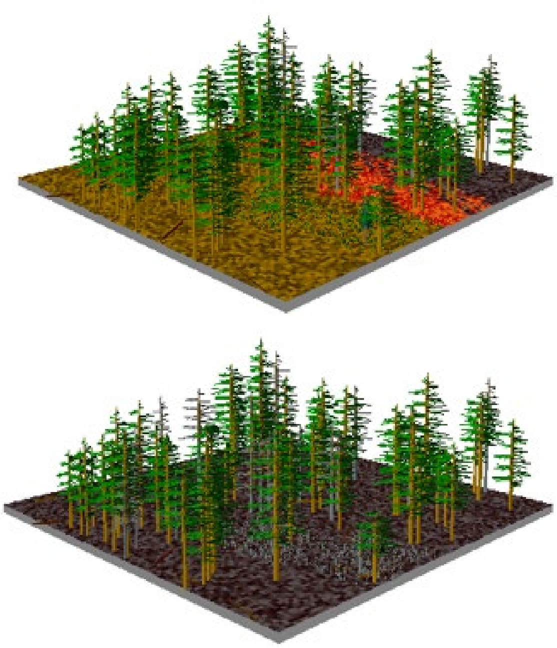
Windspeed needed to initiate crown fire activity



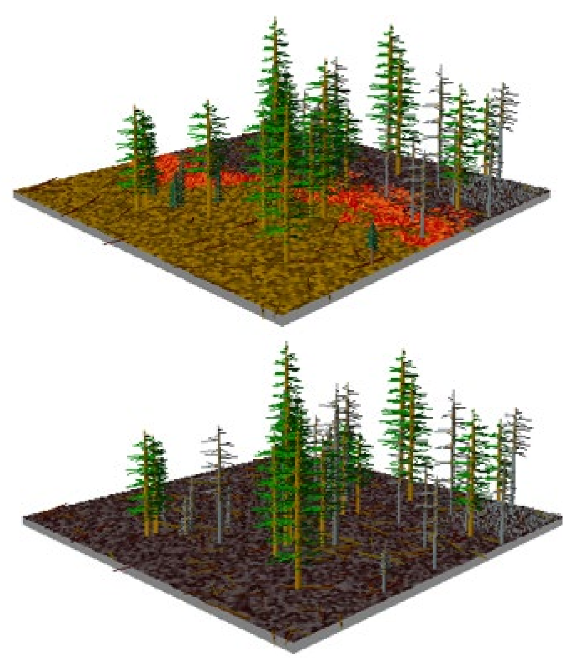
Windspeed needed to carry a crown fire



Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary

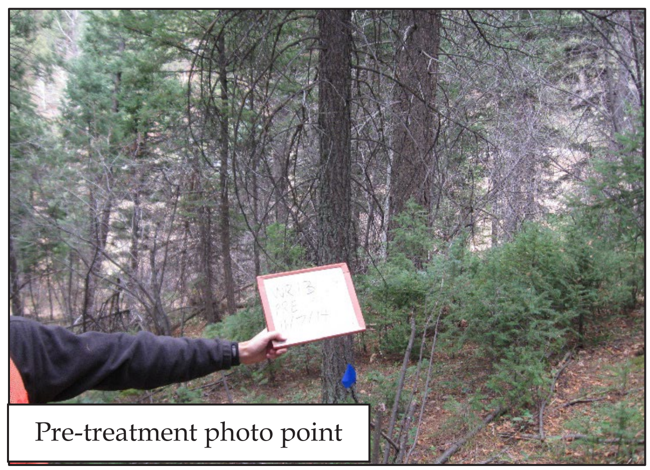
West Ranch Phase II

Wildfire Mitigation Strategy: A dry mixed conifer stand was mechanical thinned with slash removed off site in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard.

Project Highlights: Thinning reduced tree density by two thirds, while increasing variability in forest structure to enhance ecological benefits. Large reductions in tree density resulted in a less connected tree canopy, substantially lowering the potential for active crown fire spread. However, individual and groups of trees remain at risk to torching under very low windspeeds. Fine woody fuel loading was relatively high before fire mitigation and increased only slightly due to removal of all residual slash off site. Relatively high vegetation productivity and surface fuel loading likely contributed to increased flame lengths and potential post-fire tree mortality under moderate wildfire conditions. Follow-up maintenance activities, such as carefully applied broadcast burning, could further reduce surface fuel loading and extend benefits of fire mitigation.

Project Information

Grant Recipient	Jefferson Conservation District
Award Date	August, 2013
Location	Jefferson County, CO
Year Completed	2015
Area Monitored	33 acres
Forest Type	Mixed conifer
Implementation Method	Mechanical thin
Slash Treatment	Removal



Pre-treatment photo point

Forest and Fuels Inventory

Summary	**Pre-treatment**	**1 yr post-treatment**
Year sampled	2014	2015
Live basal area* (ft^2/ac)	154 ± 46	71 ± 44
Live tree density (trees per acre)	216 ± 111	75 ± 63
Canopy cover (%)	59 ± 19	25 ± 22
Canopy base height (ft)	30 ± 14	33 ± 13
Fine Woody Fuel Loading (tons/acre)	3.12	4.78

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

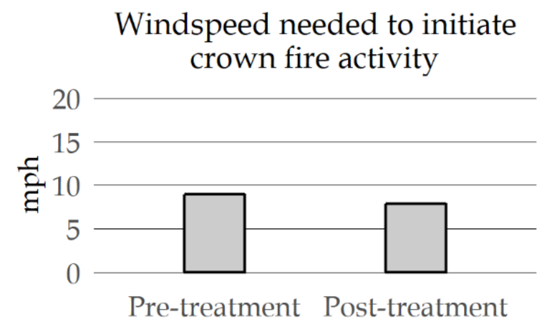
1 yr post-treatment photo point

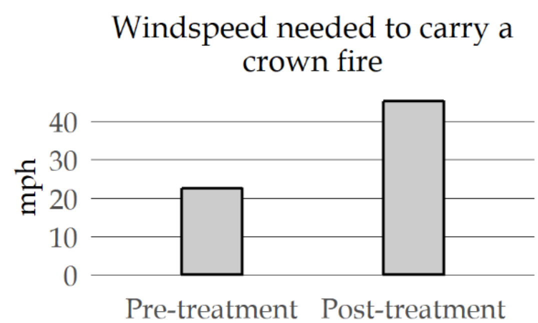
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 16 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

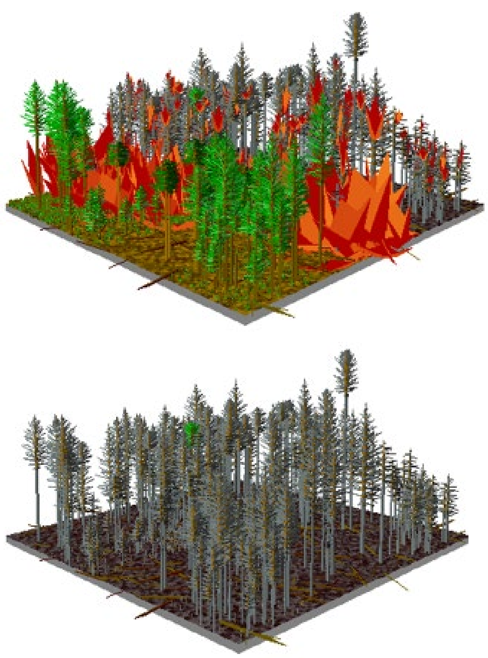
Modeled Fire Behavior

	Pre-treatment		**1 yr post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Surface	Passive	Surface
Total flame length (ft)	40.8	3.1	22.7	6.8
Surviving tree basal area (ft^2/ac)	2 (1%)	122 (79%)	2 (3%)	26 (36%)

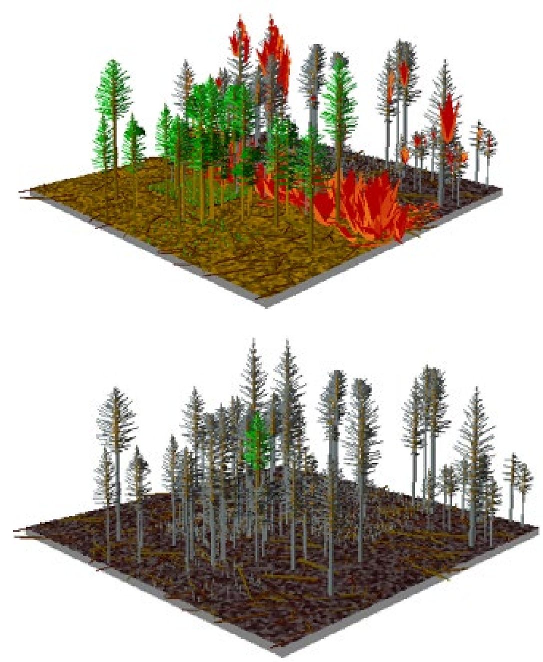




Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary:
Willow Creek

Wildfire Mitigation Strategy: A heavily beetle-killed lodgepole stand was clearcut with slash lopped and scattered in a Wildfire Risk Reduction Grant funded project designed to reduce wildfire hazard.

Project Highlights: Leaving slash on site substantially increased fine fuel loading one year after mitigation. Although most metrics of fire behavior were unchanged or increased following treatment, many hazardous standing dead trees were removed from the site, enhancing potential fire suppression opportunities and firefighter safety. The few trees that remained were predicted to be killed under severe fire conditions. However, surface fire would reasonably be expected across most of Willow Creek, as only one plot had trees remaining to carry crown fire following treatment. While the fuels mitigation had minimal impact on changing predicted fire intensity, other objectives of improved hunting recreation access and reducing future fuel inputs from standing dead trees were better achieved.

Project Information

Grant Recipient	Northern Colorado Water Conservancy District
Award Date	August 2013
Location	Grand County, CO
Year Completed	2014
Area Monitored	43 acres
Forest Type	Lodgepole pine
Implementation Method	Clearcut
Slash Treatment	Lop and scatter

Pre-treatment photo point

1 yr post-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	1 yr post-treatment
Year sampled	2013	2015
Live basal area* (ft²/ac)	26 ± 40	9 ± 28
Live tree density (trees per acre)	242 ± 400	79 ± 324
Dead basal area* (ft²/ac)	57 ± 57	7 ± 0
Dead tree density (trees per acre)	118 ± 112	11 ± 0
Live Canopy cover (%)	5 ± 5	1 ± 3
Canopy base height (ft)	19 ± 10	19 ± 13
Fine Woody Fuel Loading (tons/acre)	2.45	7.02

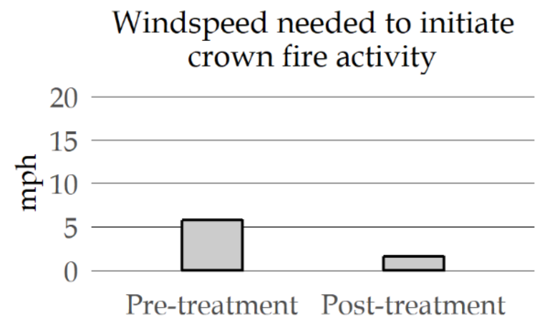
* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.

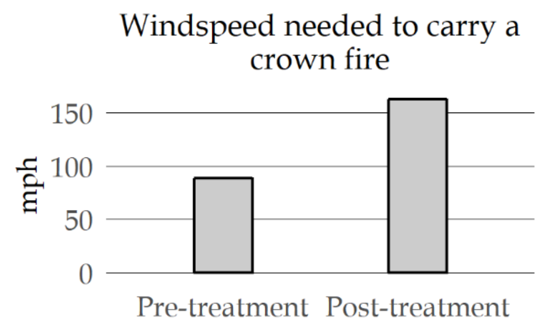
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 7 field plots pre-treatment and 9 plots post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

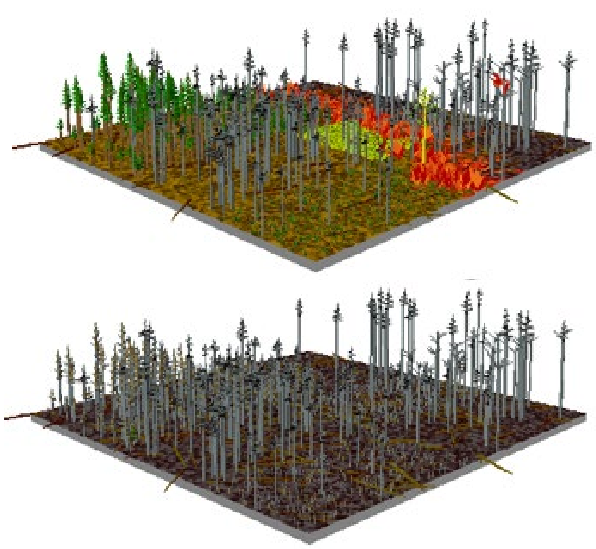
Modeled Fire Behavior

	Pre-treatment		1 yr post-treatment	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Surface	Passive	Surface
Total flame length (ft)	8.8	0.9	9.2	2.5
Surviving tree basal area (ft^2/ac)	0 (1%)	9 (36%)	0 (1%)	4 (41%)

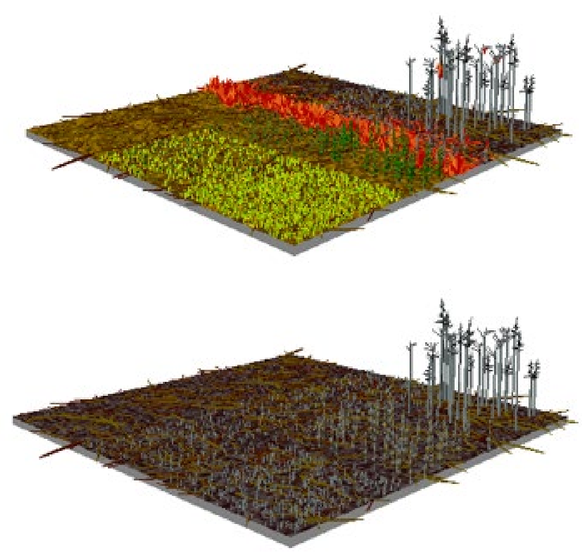




Pre-treatment



Post-treatment



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Wildfire Risk Reduction Grant Monitoring Summary:
Woodmoor Improvement Association

Wildfire Mitigation Strategy: A ponderosa pine stand with a Gambel oak understory was thinned with residual slash removed off site in a Wildfire Risk Reduction Grant funded project designed to increase defensible space in a dense residential area.

Project Highlights: Modeled fire intensity, as measured by flame lengths, was substantially reduced as a result of fuels reduction. The windspeed required to initiate a crown fire substantially increased by removing small trees and shrubs, although the windspeed needed to carry an active crown fire was unchanged; few large trees were targeted for removed and crowns of overstory trees remained connected after treatment. Potential tree mortality in severe fire conditions remained high after mitigation, while the mitigation was more effective at reducing modeled tree mortality under moderate fire conditions. Although vegetation management in dense residential areas is an important component to enhance community protection from wildfire, using ignition-resistant building materials and reducing structure vulnerability to protect against home ignition from embers are critical steps to compliment wildland fuels management.

Project Information

Grant Recipient	Woodmoor Improvement Association
Award Date	May 2014
Location	El Paso County, CO
Year Completed	2015
Area Monitored	5 acres
Forest Type	Ponderosa pine/ Gambel oak
Implementation Method	Hand thin
Slash Treatment	Removal


Pre-treatment photo point

Forest and Fuels Inventory

Summary	Pre-treatment	1 yr post-treatment
Year sampled	2014	2015
Live basal area* (ft^2/ac)	126 ± 101	106 ± 65
Live tree density (trees per acre)	512 ± 734	188 ± 160
Canopy cover (%)	51 ± 26	53 ± 25
Canopy base height (ft)	18 ± 8	20 ± 8
Gambel oak cover (%)	27 ± 21	15 ± 18
Gambel oak height (ft)	4.4 ± 2.0	2.4 ± 2.1
Fine Woody Fuel Loading (tons/acre)	0.68	0.67

* Basal area is the cross-sectional area of tree stems at breast height (4.5 ft) for a given area.


1 yr post-treatment photo point

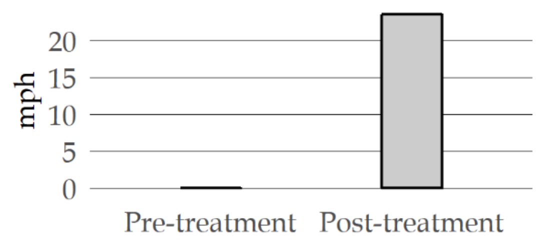
Fire Hazard Analysis

We assessed the effectiveness of fuels treatments to change expected fire behavior by collecting forest and fuels inventory data at 14 field plots pre-treatment and post-treatment. Field data was used to model potential fire behavior with the Fire and Fuels Extension to the Forest and Vegetation Simulator. The table displays fire behavior outputs modeled under severe and moderate conditions. The graph and images show changes in forest structure and modeled fire behavior under severe conditions.

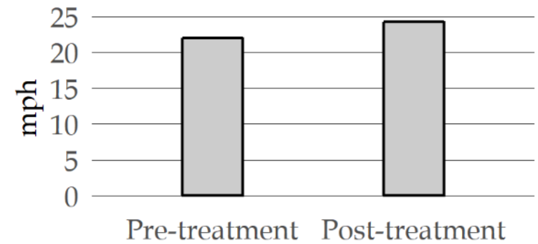
Modeled Fire Behavior

	Pre-treatment		**1 yr post-treatment**	
Fire weather and fuel conditions	***Severe***	*Moderate*	***Severe***	*Moderate*
Fire type	Passive	Passive	Surface	Surface
Total flame length (ft)	57.9	4.5	4.8	2.1
Surviving tree basal area (ft^2/ac)	1 (1%)	43 (34%)	28 (26%)	82 (77%)

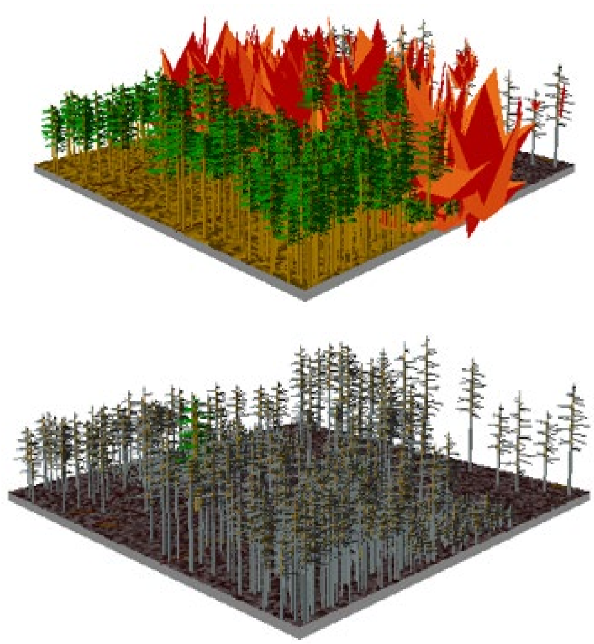
Windspeed needed to initiate crown fire activity



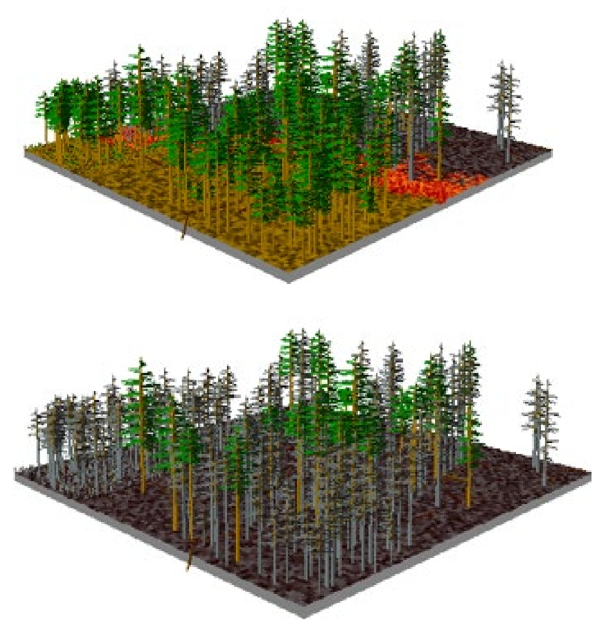
Windspeed needed to carry a crown fire



Pre-treatment



Post-Treatment



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