FUEL TREATMENT EFFECTIVENESS AND EFFECTS MONITORING IN THE PACIFIC SOUTHWEST REGION

1999-2006

MANAGER'S SUMMARY

PREPARED FOR

PACIFIC SOUTHWEST REGION FIRE AND AVIATION MANAGEMENT

NOVEMBER 2007

BY

JO ANN FITES-KAUFMAN
Fire Ecologist/Team Leader, Adaptive Management Services Enterprise Team

ALICIA REINER
Fire Ecologist

SID BECKMAN
Fire Management Specialist

SCOTT DAILEY
Fire Ecologist

ERIN NOONAN
Fire Ecologist

CAROL EWELL
Fire Eologist

TODD DECKER
Fire Ecologist

This report contains a summary of the objectives, design, protocol, results to date, and adaptive management implications of fuel treatment effectiveness and effects monitoring in the Pacific Southwest Region from 1999 to 2006. More detail is contained in the companion General Technical Report.

Contents

Page

I Introduction …………………………………………… 7

1. Goal and Objectives…………………………………… 8
2. Monitoring Protocol…………………………………… 8
3. Design: Selection of Sites and Characteristics to Monitor…………………………………………… 8
4. Characteristics Measured: Response Variables………… 9
5. Field Protocol………………………………………… 10
6. Statistical Analysis…………………………………… 10

II Results…………………………………………… 12

1. Short Needle Dominated Types with Douglas Fir and White Fir………………………………………… 14
   - A. Prescribed Fire Treatments…………………… 14
   - B. Mechanical Treatments………………………… 18
2. Ponderosa and Yellow Pine Dominated……………… 26
   - A. Prescribed Fire Treatments…………………… 26
   - B. Mechanical Treatments………………………… 31
3. Red Fir………………………………………………… 39
   - A. Mechanical Treatments………………………… 39

About the Authors

This report's authors, the USDA Forest Service's Adaptive Management Services Enterprise Team, is led by Dr. Jo Ann Fites. Her team is comprised of 20 persons, many of whom have expertise in fire management, fire science, and fire ecology. The Adaptive Management Services Enterprise Team specializes in fuels, fire behavior, and fire effects monitoring and assessment, as well as related management plans.

III Discussion and Management Implications ..….……… 46

1. Effectiveness of Treatments on Fuels and Potential Fire Behavior……….…………….………… 46
2. Recommendations for Post-Treatment Fuel Model Assignments……..………. ………..…… 46

IV References ……………….……………………………………… 50

V Appendices …………….……………………………….……. 53

Appendix A – Monitoring Protocol and Data Analysis………53

Appendix B – Statistical Analysis…………………………… 62

Appendix C – Additional Results.……………….…………… 65

Figures

Figure 1 – Box plots diagram showing the 25th, 50th, and 75th percentiles..…………………………………..…...……………………..10

Figure 2 – Number of plots that have reached the second year post Treatment within each vegetation type………………………………………… 13

Figure 3 – Percent understory of cover associated with prescribed fire treatments in Douglas fir and white fir………………….……………….. 15

Figure 4 – Tree density associated with prescribed fire treatments in short-needle dominated Douglas Fir and White Fir Type…………………. 16

Figure 5 – Small diameter fuels associated with prescribed fire treatments in short-needle dominated Douglas Fir and White Fir Type…………………. 16

Figure 6 – Surface fuels by type associated with prescribed fire treatments in short needle dominated, Douglas Fir and White Fir type………………….. 17

Figure 7 – Canopy base height associated with prescribed fire treatments in Douglas Fir and White Fir type…………………………………………….. 17

Figure 8 – Canopy bulk density measurements associated with prescribed fire in Douglas Fir and White Fir type……………………………………... 18

Figure 9 – Modeled flame length measurements associated with prescribed fire in Douglas Fir and White Fir types……………………………………… 19

Figure 10 – Modeled rate of spread measurements associated with prescribed fire treatments in Douglas Fir and White Fir types……………….. 20

Figure 11 – Understory cover measurements associated with mechanical treatments in Douglas Fir and White Fir types…………………… 20

Figure 12 – Tree density measurements associated with mechanical treatments in Douglas Fir and White Fir types………………………………… 21

Figure 13 – Small diameter fuels measurements associated with mechanical treatments in Douglas Fir and White Fir types…………………… 21

Figure 14 – Surface fuels by type measurements associated with mechanical treatments in Douglas Fir and White Fir types…………………… 22

Figure 15 – Canopy base height measurements associated with mechanical treatments in Douglas Fir and White Fir types…………………… 22

Figure 16 – Canopy bulk density measurements associated with mechanical treatments in Douglas Fir and White Fir types…………………… 23

Figure 17 – Modeled flamelength measurements associated with mechanical treatments in Douglas Fir and White Fir types……………… 23

Figure 18 – Modeled rate of spread measurements associated with mechanical treatments in Douglas Fir and White Fir types…………….. 24

Figure 19 – Understory cover associated with prescribed fire treatment in Ponderosa and Yellow Pine…………………………………….. 26

Figure 20 – Tree density measurements associated with prescribed fire treatment in Ponderosa and Yellow Pine……………………… 27

Figure 21 – Small diameter fuels associated with prescribed fire treatment in Ponderosa and Yellow Pine……………………………………… 28

Figure 22 – Surface fuels by type associated with prescribed fire treatment in Ponderosa and Yellow Pine……………………………………… 28

Figure 23 – Canopy base height measurements associated with prescribed fire treatment in Ponderosa and Yellow Pine……………………… 29

Figure 24 – Canopy bulk density associated with prescribed fire29 treatment in Ponderosa and Yellow Pine……………………………………..29

Figure 25 – Modeled flame length associated with prescribed fire treatment in Ponderosa and Yellow Pine……………………………………… 30

Figure 26 – Modeled rate of spread associated with prescribed fire treatment in Ponderosa and Yellow Pine……………………………………… 30

Figure 27 – Understory cover measurements associated with mechanical treatment in Ponderosa and Yellow Pine………………………… 33

Figure 28 – Tree density measurements associated with mechanical treatment in Ponderosa and Yellow Pine………………………… 33

Figure 29 – Small diameter fuels measurements associated with mechanical treatment in Ponderosa and Yellow Pine………………………… 35

Figure 30 – Surface fuels by type associated with mechanical treatment in Ponderosa and Yellow Pine……………………………………… 35

Figure 31 – Canopy base height measurements associated with prescribed fire treatment in Ponderosa and Yellow Pine……………………… 36

Figure 32 – Canopy bulk density associated with prescribed fire treatment in Ponderosa and Yellow Pine……………………………………… 36

Figure 33 – Canopy bulk density measurements associated with mechanical treatment in Ponderosa and Yellow Pine………………………… 37

Figure 34 – Modeled rate of spread measurements associated with mechanical treatment in Ponderosa and Yellow Pine………………………… 37

Figure 35 – Understory cover measurements associated with mechanical treatment in Red Fir……………………………………………… 39

Figure 36 – Tree density measurement associated with mechanical treatment in Red Fir………………………………………………… 40

Figure 37 – Small diameter fuels measurements associated with mechanical treatment in Red Fir………………………………………………… 42

Figure 38 – Surface fuels by type associated with mechanical treatment in Red Fir…………………………………………….… 42

Figure 39 – Canopy base height measurements associated with mechanical treatment in Red Fir………………………………………………… 43

Figure 40 – Canopy bulk density measurements associated with mechanical treatment in Red Fir………………………………………………… 43

Figure 41 – Modeled flamlengths measurements associated with mechanical treatment in Red Fir………………………………………………… 44

Figure 42 – Modeled rate of spread measurements associated with mechanical treatment in Red Fir………………………………………………… 44

Figure A-1 – Forest plot layout……………………....…………………….. 56

Figure A-2 – Chaparral plot layout…………………………………………… 57

Figure A-3 – Mixed forest chaparral plot layout……………..………………. 58

Tables

Table 1 – Monitoring response variables…………….....……………….….. 9

Table 2 – Number of plots within each vegetation type, treatment type, and monitoring status……………..…………………………………………… 13

Table 3 – Changes in surface and crown fuel levels after prescribed fire and mechanical treatments in the short-needle Douglas fir and white fir type…….. 25

Table 4 – Changes in vegetation after prescribed fire and mechanical treatments in the short-needle Douglas fir and white fir type……………..….. 25

Table 5 – Fire and mechanical treatments in long-needled yellow pine (ponderosa and Jeffrey pine) types…..……………………………..……… 38

Table 6 – Changes in surface and crown fuel levels after prescribed fire and mechanical treatments in long-needled yellow pine (ponderosa and and Jeffrey pine) types…..……………………..…………………..………38

Table 7 – From pre- to post-prescribed fire and mechanical treatments in red fir type……………….……………....…………………….. 45

Table 8 – Crown fuel levels mechanical treatments in red fir types………….. 45

Table A-1 – Summary of plot layout and protocol by vegetation and fuel component……………………………………………………..….. 55

Table B-1 – The following five vegetation-treatment groups were compared: Doug-RX, Doug-mech, Yellow-RX, Yellow-mech and Red-mech. Sample numbers for other vegetation and treatment types were not high enough for statistical analysis………………………………………………… 62

Table B-2 – Results of statistical tests between pre- and 1-year post-treatment fuel and vegetation parameters………………………………… 64

Table C-1 – Changes in seedling densities by species in the short-Needled, Douglas fir/white fir type after prescribed fire……………..…….. 65

Table C-2 – Changes in seedling densities by species in the short-Needled, Douglas fir/white fir type after mechanical treatments……….…….. 66

Table C-3 – Changes in seedling densities by species in the yellow pine type after prescribed fire…………………………………………….…...…….. 66

Table C-4 – Changes in seedling densities by species in the yellow pine type after mechanical treatment……………………..……………….…..…….. 67

Table C-5 – Changes in seedling densities by species in red fir after mechanical treatment………………………..……………….…..…….. 67

The purpose of this monitoring was to produce a quantitative assessment of the effectiveness and effects of these treatments *and* to provide information to fire managers to aid in "adaptive management."

I Introduction

Fire has long been part of California ecosystems (Sugihara and others 2006). Throughout California and the western United States, fire suppression and other land management actions have helped produce increases and changes in fuel conditions that have lead to higher intensity and severity wildland fires.

These trends in fire—coupled with an expansion of homes in the wildland-urban interface—resulted in the development of the nationwide *Cohesive Strategy* and *National Fire Plan* (USDA and USDI 2001). Both of these reports emphasize increases in hazardous fuel reduction treatments and the restoration of fire as a key ecosystem process.

To measure the effectiveness and effects of these fuel hazard reduction treatments, the Forest Service's Pacific Southwest Region initiated a region-wide programmatic monitoring program from 1999 to 2006. (Monitoring is a National Fire Plan component.) The purpose of this monitoring was to produce a quantitative assessment of the effectiveness and effects of these treatments *and* to provide information to fire managers to aid in "adaptive management."[1]

This region-wide, programmatic monitoring effort is complementary with other ongoing landscape-level monitoring such as the national, interagency fire severity monitoring program (Lutes and others 2006). In addition, this monitoring program is described as "programmatic" because it was designed to look at effectiveness and effects by major vegetation types and treatments *overall* in the Pacific Southwest Region. This contrasts to *project specific* monitoring that focuses on an individual project's effectiveness or effects, which would be more costly.. This monitoring approach is based on collection of data before and after prescribed fire or mechanical application.

The overall approach of this Pacific Southwest Region monitoring study was modeled largely on programmatic monitoring conducted by the National Park Service and the California Department of Parks and Recreation throughout California public parks. This report's approach was designed to facilitate information sharing and enhance the ability to conduct joint analysis using the combined data to address such needs as validating tree mortality predictions for existing species—or developing ones for missing species.

[1] Adaptive management is a process in which management actions are modified based on feedback from monitoring and research. For example, monitoring could show that treatments are not as intense as may be needed to meet stated post-treatment fire behavior goals.

1. Goal and Objectives

The goal of the monitoring was to measure the effectiveness of fuel hazard reduction treatments and the effects of those treatments on wildlife habitat and vegetation structure and composition. Specific objectives:

1. Evaluate changes in surface, ladder, and crown fuels from pre- to post-treatment by vegetation types and types of treatments (prescribed fire or mechanical).
2. Evaluate changes in wildlife habitat and vegetation structure and composition from pre- to post-treatment by vegetation types and types of treatments (prescribed fire or mechanical).
3. Develop recommendations for post-treatment surface fuel model assignments to utilize in burn plans, fire management plans, project plans, and land use plans.

2. Monitoring Protocol

A summary of the sample site selection, characteristics measured, field protocol, and data analysis is featured below. (More detailed information on the protocol is contained in Appendix A.)

3. Design: Selection of Sites and Characteristics to Monitor

The goal for each year was to:

- Conduct monitoring on one prescribed fire or other fuel treatment projects prior to treatment on most National Forests throughout the Pacific Southwest Region, and
- Monitor post-treatment conditions at 1, 2, 5, 10, and 20 year intervals.

The individual National Forests were asked to provide one or several candidate projects that would be burned or treated in the current or following year. Initially, the focus was on prescribed burning and vegetation types—or locations that were the highest priority for treatment in the region. This included mixed conifer, Douglas-fir and pine dominated forests, as well as chaparral in southern California.

More recently, there has also been an emphasis on evaluation of mechanical treatments, including mastication—a method increasingly used in the wildland-urban interface, even though little is known about its effects or fire behavior implications.

The overall design was to track responses by major vegetation types rather than individual projects. It was determined that this would be the most cost effective method for collecting enough data to assess effects of treatments in a short time frame. Although, theoretically, it would have been preferable to randomly select the projects to be sampled, based on prior experience, it was determined that this would not yield results as rapidly. Given variation in burn windows and mechanical contract implementation schedules, a given project (randomly selected) is not necessarily likely to be treated with predictability within a year.

Therefore, this study's approach—utilizing the Forests and Districts' judgment for which projects would most likely be treated soon—increased the likelihood that projects sampled pretreatment would be treated soon, and the post-treatment monitoring could be conducted promptly.

A minimum of three plots were randomly placed within each project. Because it provides the minimum needed to compute statistics for a project, a sample size of three replicates was chosen for the pilot. In 2003, to better represent variability within units, the protocol was modified to collect surface fuels data across six plots, rather than three.

4. Characteristics Measured: Response Variables

All aspects of vegetation, excluding nonvascular plants (lichens and mosses), were monitored, including: fuel configuration and amount, vegetation density, size, cover, and species composition (Table 1). Based on key management issues, some additional measures included in the National Park Service (NPS) protocol were included (for instance, tree canopy cover).

Table 1 – Monitoring Response Variables

		Resource Addressed			
Response Variable	**Measure**	**Fuels**	**Wildlife Habitat**	**Soil Quality Standards**	**Plant Species and Community Response**
ground and surface fuels	tons/acre by size & depth	x	x	x	
herbs and grasses	cover by species	x	x		x
shrubs	cover, height, and % dead by species	x	x		x
	stem density & size (chaparral only)	x			x
tree density, size and crown bulk density	density by dbh and species	x	x		x
	height to live crown and crown height	x	x		
	overstory tree cover	x	x		
	snag density, dbh	x	x		
predicted fire behavior	flamelength	x			
	rate of spread	x			
	fire type	x			

5. Field Protocol

Field measurements were based—with some modifications—on the monitoring protocol of the National Park Service's Western Region (NPS 2001). These modifications included:

- ❖ Changing plot shape from rectangular to circular—to greatly increase the speed of data collection;
- ❖ Including overstory canopy cover measurements; and
- ❖ Measuring total and height-to-live crown for all trees—to enable the ability to calculate crown fuels.

Finally, a separate protocol was developed for chaparral that was based on the Pacific Southwest Research Station Riverside Fire Laboratory methods—utilizing the station's biomass equations to compute shrub fuel loading.

6. Statistical Analysis

Plots were assigned to vegetation types subjectively—based on the dominant tree or shrub species—and grouped by similarities in fuel characteristics and expected fire behavior. Therefore, those with long-needle pines (ponderosa or Jeffrey pine) and those with short-needles (white fir or Douglas-fir) were both grouped.

Formal statistical analysis of the monitoring data was conducted and is summarized in Appendix B (Statistical Analysis). Greater detail on the statistical analysis is included in the companion scientific publications *Comparison of effects of prescribed fire and mechanical fuel reduction treatments to vegetation composition and structure in California National Forests* and *Effects of prescribed fire and mechanical fuel reduction treatments to fuels and potential fire behavior in California National Forests*. In addition to the formal statistical tests, tables and graphs with descriptive statistics were generated to portray the range of characteristics. The most common type of graph included was a box plot, generated in SPSS statistical software (Norius 1999). (An example of a box-plot and interpretation is illustrated below in Figure 1.)

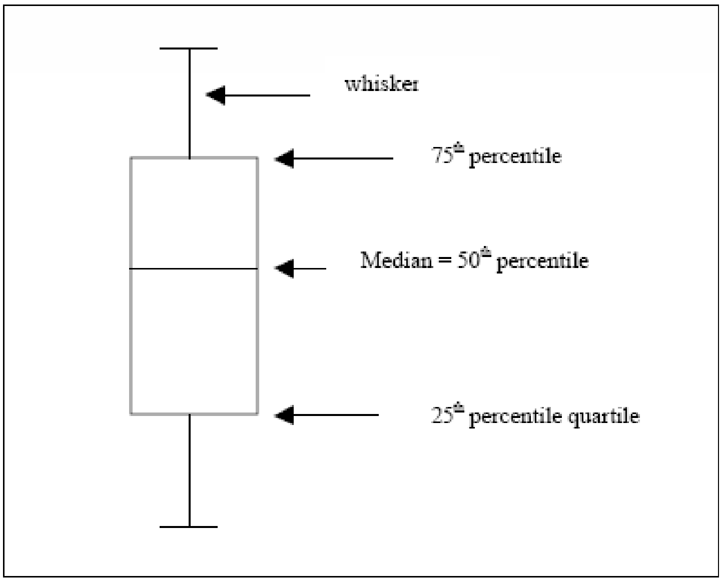


Figure 1 – Box plots diagram showing the 25th, 50th, and 75th percentiles.

Box plots, that include the median 25th and 75th percentiles as well as high and low ranges, were created using SPSS (1999). Figure 1 shows the box and whisker plot and the 25th, 50th, and 75th percentiles. The median line represents the middle value after the data have been sorted from lowest to highest.

The median therefore represents the 50th percentile, where 50% of the values fall below the median value and 50% fall above the median. The upper boundary of the box represents the 75th percentile and therefore 75% of the values fall below this value.

The bottom boundary of the box represents the 25th percentile and therefore 25% of the values fall below this value. The whiskers are lines that extend from the box to the highest and lowest values excluding outliers. Outliers are values that are greater than 1.5 times the box length away from the median and less than 3 times the box length away from the median.

The SPSS software uses the Tukey method for calculating the percentiles (called “hinges” in the Tukey method) in the box plot. This method uses the following steps:

1. Find the median of the data.
2. Divide the data into two groups using the median, half above and half below.
3. Count the median in both groups when there are an odd number of values.
4. The 75th percentile is the median of the upper half.
5. The 25th percentile is the median of the lower half.

II Results

A total of 214 plots were sampled, most of which fell into the ponderosa/yellow pine-dominated group (Table 1). Of these, 90 plots were sampled at one-year post-treatment, 88 at two years post treatment and five at five-years post treatment. None of the chaparral plots have been treated and different than other types, all plots are shown whether treated or not.

Throughout this "Results" section, the term "significant" is used. It is used specifically where there has been a statistical test and the results are statistically significant.

The results for modeled fire behavior are an important aspect of addressing one of the key monitoring objectives of whether fuel treatments are effective. Most fuel treatments were designed for the purpose of reducing fuel hazard and potential fire behavior. Modeling carries with it assumptions and uncertainties that are important to consider when interpreting or applying the results.

First, at this time, there is no perfect fire behavior model but there are useful models that are generally good at predicting many types and aspects of fire behavior. For example, when looking at modeled flame lengths for a certain set of weather assumptions, it is important to realize that actual flame lengths may and likely will vary some from the predicted flame lengths.

A key uncertainty for modeling fire behavior, particularly changes in fire behavior, revolves around the selection of fuel models. Fuel models are "stylized" depictions of fuel conditions that are important or drive the fire behavior models as they exist. As a result, if you use the actual, measured values for fuel conditions such as the amount of 1-hour fuels, it does not necessarily reflect accurately the specific fire behavior that might occur.

Because our understanding of fire behavior physics and how to model are still incomplete, there are generally adjustments made to fuel models or a selection of a fuel model that best represents the expected fire behavior instead of actual fuel condition inputs. In the case of monitoring data, there are few if any fuel models designed specifically to characterize post-treatment fuel conditions. For this monitoring report, we applied standard available fuel models (Scott and Burgan 2005) based on both measured fuel conditions and expected fire behavior. Fuel model selections were made by several very experienced fuels and fire behavior analysts with extensive field experience.

Despite the extensive experience of those selecting fuel models, the selections and associated predicted fire behavior—particularly post treatment—have an unknown level of uncertainty. Another related effort is underway to utilize an alternative approach that removes the uncertainty of fire behavior model selection. For this related effort, we will be imputing the actual data rather than assigning models and conducting statistical analysis on the results.

Plots at Post-treatment Year 1, 2, & 5 Monitoring Status																
Vegetation Type	Total Plots Installed	**Prescribed Burn**			**Mechanical**			**Mechanical and Prescribed Burn**			**Wildfire**			**Total**		
Treatment History		**post 1**	**post 2**	**post 5**	**post 1**	**post 2**	**post 5**	**post 1**	**post 2**	**post 5**	**post 1**	**post 2**	**post 5**	**post 1**	**post 2**	**post 5**
Chaparral	24	0	0	0	0	0	0	0	0	0	3	3	0	3	3	0
Douglas fir/ White fir	65	12	12	1	11	10	0	0	0	0	0	0	0	23	22	1
Ponderosa/Yellow Pine Dominated	162	30	29	2	18	18	0	2	2	2	3	3	0	53	52	4
Red Fir dominated	33	0	0	0	11	11	0	0	0	0	0	0	0	11	11	0
Total	**284**	42	41	3	40	39	0	2	2	2	6	6	0	**90**	**88**	**5**

Table 2 – Number of plots within each vegetation type, treatment type, and monitoring status.
(“Post 1” = one year post treatment; “post 2” = two years post treatment; “post 5” = five years post treatment.)

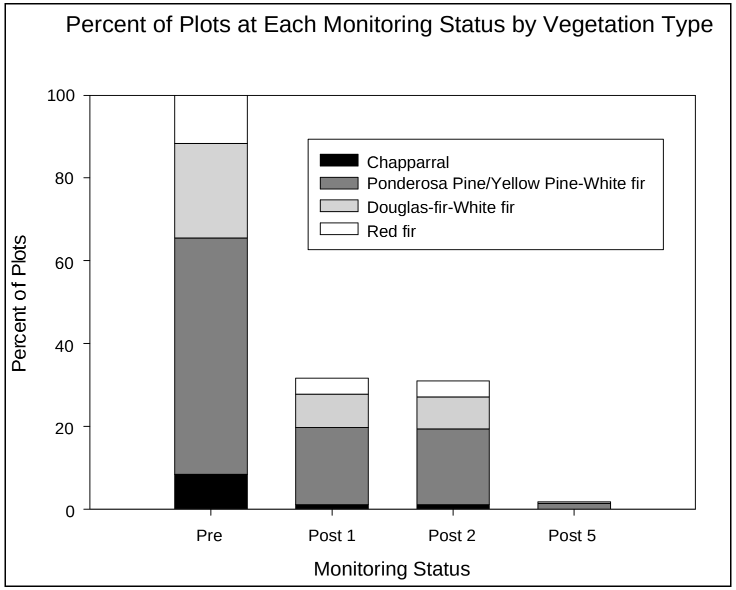


Figure 2 – Number of plots that have reached the second year post treatment within each vegetation type.

1. Short-Needle Dominated Types with Douglas Fir and White Fir

This vegetation type includes stands with a heavy component of Douglas fir and white fir. They were grouped based on a dominantly short-needle litter fuel type.

These sites may include other species including ponderosa pine, sugar pine, incense cedar and occasionally black oak.

Sixty-five plots were installed pre-treatment in this type. Of these 65 sites, 12 were treated with prescribed fire and eleven with mechanical treatments.

These included projects on the Six Rivers, Klamath, Plumas, Tahoe, and San Bernardino National Forests.

A. Prescribed Fire Treatments

Vegetation Structure and Composition

Understory Vegetation

Few changes were noted in canopy cover between pre and post treatment—only decreases in grass cover were statistically significant (Table B-1). Median (Figure 3) and mean herb cover decreased (Table 3) but was highly variable.

Tree and Overstory Vegetation

The only significant change in overstory structure was with quadratic mean diameter, which increased slightly but significantly (Table B-1) from 14 to 14.9 inches. Importantly, there was no significant change in tree canopy cover but small diameter (1-6” dbh) trees decreased (Figure 4).

Seedling density decreased 32 percent in year one but recovered to pre-burn levels in year two post-fire. Hardwood seedlings and sprouts remained similar, while white fir decreased 60 percent and yellow pine and Douglas-fir seedlings increased (Table C-1).

Prescribed Fire Treatment in Douglas Fir and White Fir

Same Photo Points:
1) Pre-treatment; 2) 1-year post treatment; 3) 2-year post treatment

Photo 1 – Pre-Treatment


Photo 2 – 1-Year Post Treatment


Photo 3 – 2-Year Post Treatment

Photo 5 – Pre-Treatment

Photo 6 – 1-Year Post Treatment

Photo 7 – 2-Years Post Treatment

Prescribed Fire Treatment
in Short-Needle Dominated Douglas Fir and White Fir Type

Same Photo Points:
1) Pre-treatment; 2) 1-year post treatment; 3) 2-year post treatment

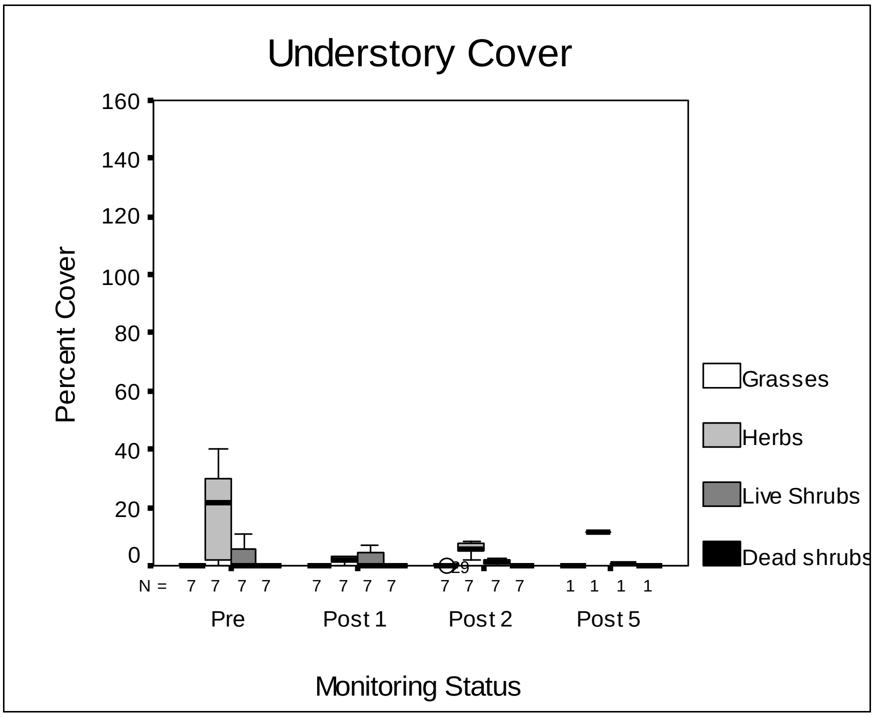


Figure 3 – Percent understory cover associated with prescribed fire treatments in short-needle dominated Douglas Fir and White Fir Type.

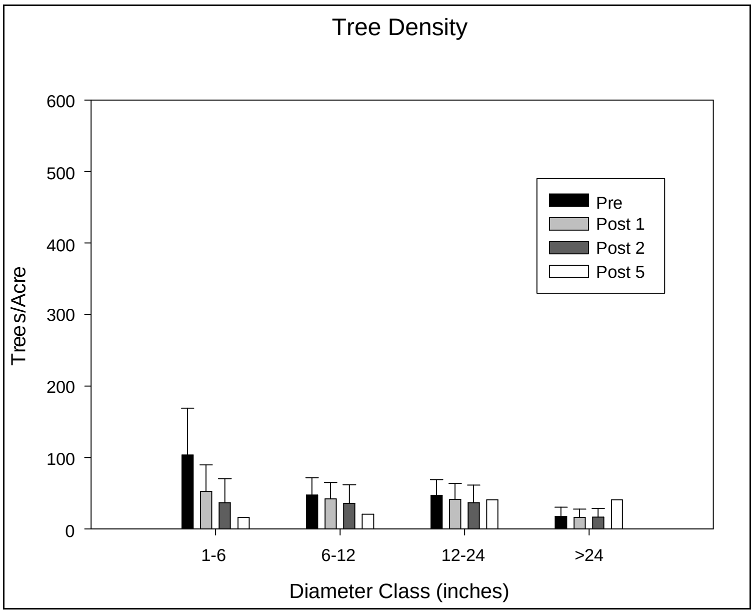


Figure 4 – Tree density associated with prescribed fire treatments in short-needle dominated Douglas Fir and White Fir Type.

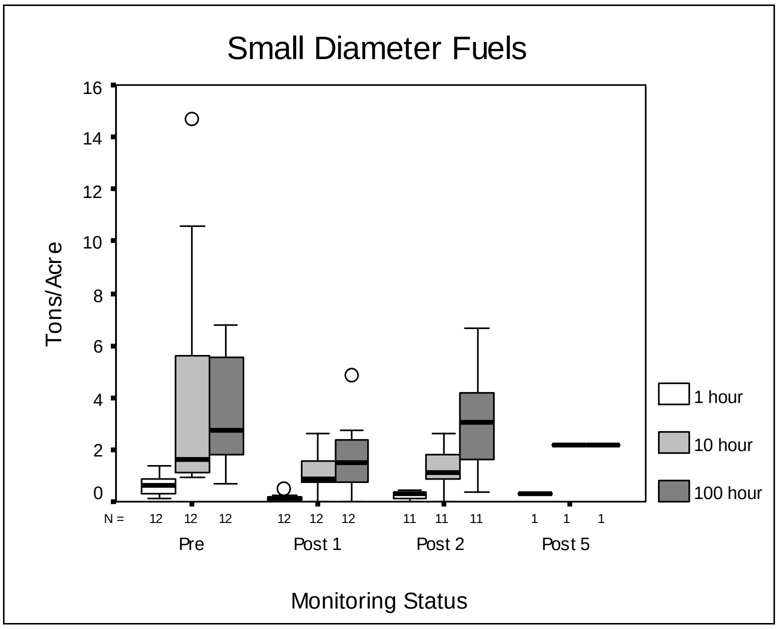


Figure 5 – Small diameter fuels associated with prescribed fire treatments in short-needle dominated Douglas Fir and White Fir Type.

Fuels

Surface Fuels

There were statistically significant decreases in all surface fuel components at 1-year post-treatment, except for 100-hour fuels (Table B-1). This included reductions in mean 1 hour, 10 hour, 1000 hour, litter and duff loadings and fuel depth of over 50 percent from pre-fire levels (Table 4, Figure 5). Mean litter and 1000-hour fuels were reduced over 90 percent from pre-fire levels. These reductions remained similar after two years, with only slight increases (Figure 6).

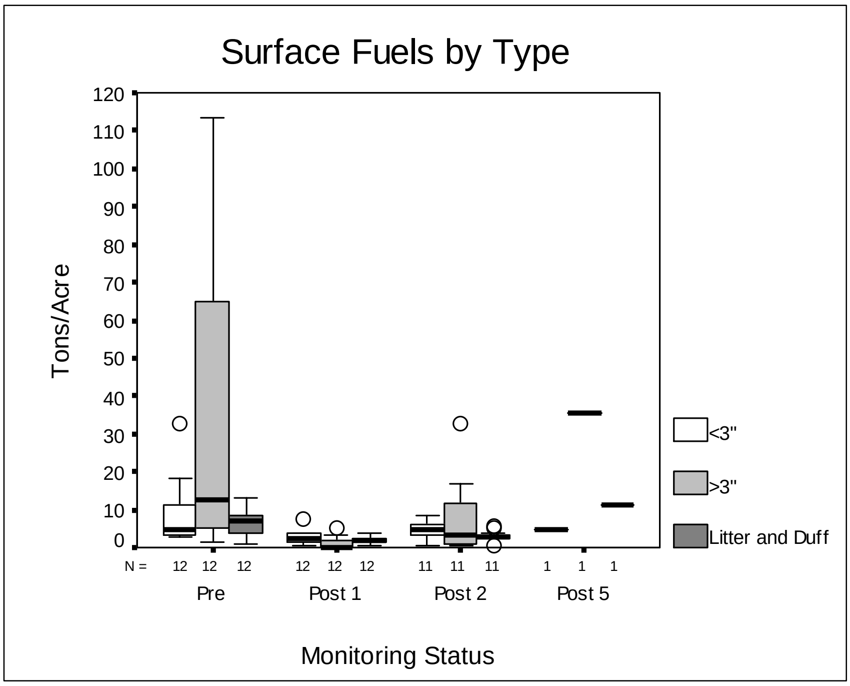


Figure 6 – Surface fuels by type associated with prescribed fire treatments in short needle dominated, Douglas Fir and White Fir type.

Canopy Fuels

Canopy base height increased significantly and canopy bulk density decreased significantly (Table B-1, Figures 7, 8). Mean canopy base height increased from 14 to 24 feet one-year post-treatment. Although canopy bulk density decreased significantly, the change in mean values was slight from 0.06 to 0.05 kg m^{-3} pre fire to 1 year post-fire.

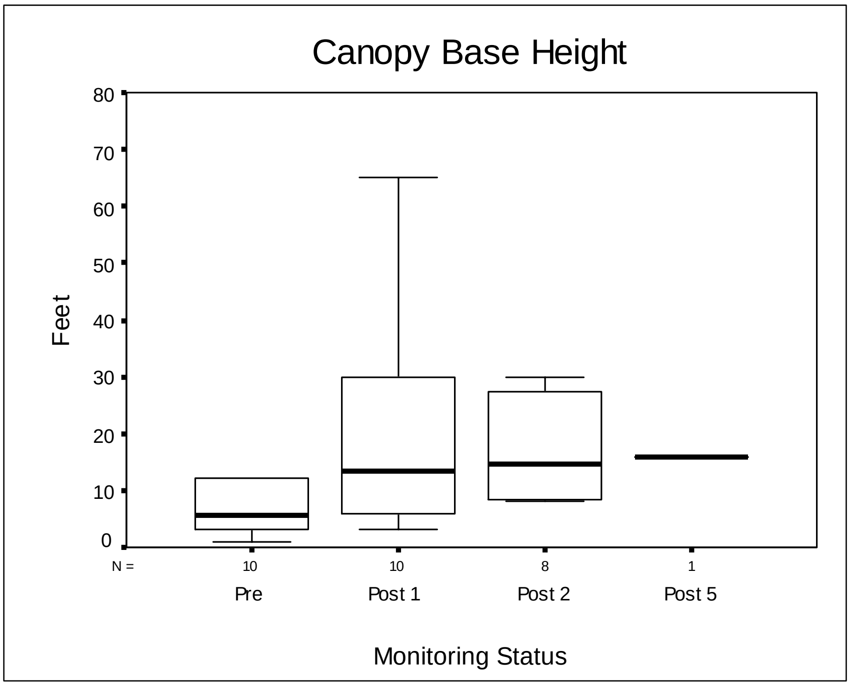


Figure 7 – Canopy base height associated with prescribed fire treatments in Douglas Fir and White Fir type.

Fire Behavior

There were reductions in modeled mean flamelengths and rates of spread one year after treatment with both weather scenarios modeled (11 and 23 mph winds). Mean predicted flamelengths dropped from 3.7 to 0.7 feet under 11 mph winds and from 13.5 to 6.6 feet under 23 mph winds (Figure 9). Mean predicted rates of spread dropped from 5.3 to 1.0 chains/hr under 11 mph winds, and 21.6 to 10.3 with 23 mph winds (Figure 10).

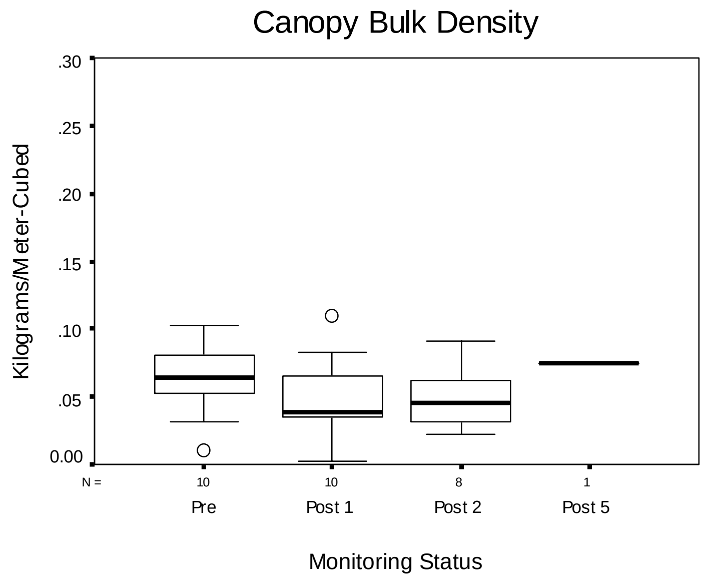


Figure 8 – Canopy bulk density measurements associated with prescribed fire in Douglas Fir and White Fir type.

B. Mechanical Treatments

There were 11 plots in the Douglas-fir-white fir type that were treated with mechanical methods (Table 2), and 10 of those plots had reached the second year post-treatment by the time of this report. The "detailed forest plot" protocol was used on six of these plots. Tree data is therefore available for six plots. The majority of the treatments involved hand cutting and piling fuels. Mechanical methods were used on at least one plot. To complete fuel reduction treatments, piles were burned on many of these plots.

Vegetation Structure and Composition

Understory Vegetation

There were no statistically significant changes in understory vegetation (Tables B-1, 3). Although there were reductions in mean shrub cover one year post-treatment, variability was high (Figure 11) and the change was not significant. Shrub cover recovered to similar levels in the second year post-fire.

Tree and Overstory Vegetation

In contrast to plots treated with prescribed fire, there were significant decreases in overstory tree cover, tree density, and basal area (Tables B-1, 3). Similar to the prescribed fire treatments, there was a significant increase in quadratic mean diameter. Mean tree cover decreased 24 percent, from 71 to 54 percent at one-year post-fire (Table 3). There was a slight increase in the mean cover to 59 percent cover in the second year when there was one less plot. This change could be due to different sample numbers or canopy growth. Decreases in mean tree density were greater, at 52 percent, while basal area was similar to canopy cover, with a 22 percent decrease. Mean QMD (Quadratic Mean

Diameter) increased from 7.1 to 9.6 inches. Small tree density decreased substantially (Figure 12).

Seedling density increased initially in the first year post-fire (71 percent) but then decreased to 40 percent pre-burn levels at year two post-fire. Ponderosa and sugar pine regeneration increased, tanoak increased then decreased at year two post-fire (Table C-2). Other oak seedling densities remained similar, including black oak, canyon live oak, and Oregon white oak.

Fuels

Surface Fuels

There were significant increases (>90 percent) in mean 10-hour and 1000-hour loadings (Tables B-1, 4). Mean 10-hour loadings increased from 1.1 to 2.1 tons/acre one year post-treatment and 100-hour loadings from 15 to 21 tons/acre. There was a high degree of variability in changes in surface fuel loadings, reflecting the variation in type of treatment applied (Figures 13, 14).

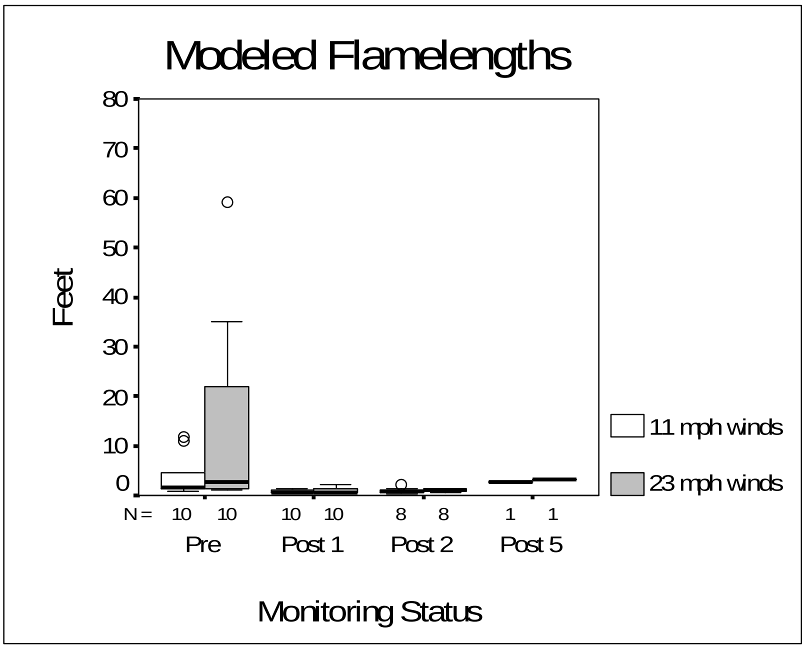


Figure 9 – Modeled flame length measurements associated with prescribed fire in Douglas Fir and White Fir types.

Canopy Fuels

There were significant decreases in canopy bulk density and increases in canopy base height (Tables B-1, 4). Mean canopy bulk density decreased by 36 percent one-year post treatment. Mean canopy base height increased 214 percent.

Fire Behavior

There was a slight increase in modeled flamelength under 11 mph winds from 1.4 pre-treatment to 1.8 feet post-treatment (Figure 17). The difference under 23 mph winds was greater with decreases in modeled flamelengths from 7.3 to 2.5 feet pre to post 1-year. Modeled rates of spread changed similarly to flamelength rates. Modeled rates of spread increased from 2.2 to 3.5 chains per hour from pre-treatment to post 1-year under 11 mph winds—reflecting, in part, a more open canopy (Figure 18). But under 23 mph winds, the modeled rates of spread decreased from 18 to 7 chains per hour—reflecting a decrease in the amount of crown fire, which can produce greater spread rates.

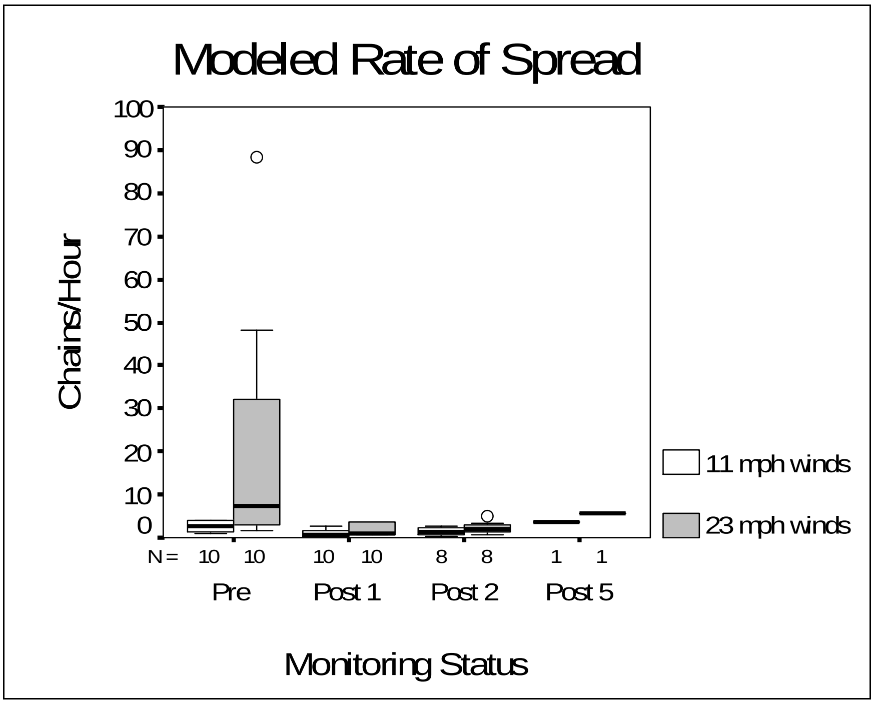


Figure 10 – Modeled rate of spread measurements associated with prescribed fire treatments in Douglas Fir and White Fir types.

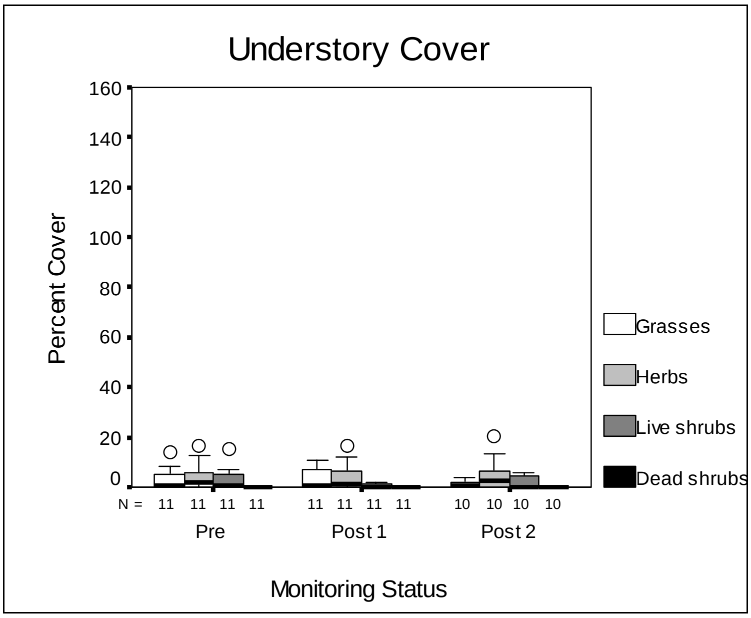


Figure 11 – Understory cover measurements associated with mechanical treatments in Douglas Fir and White Fir types.

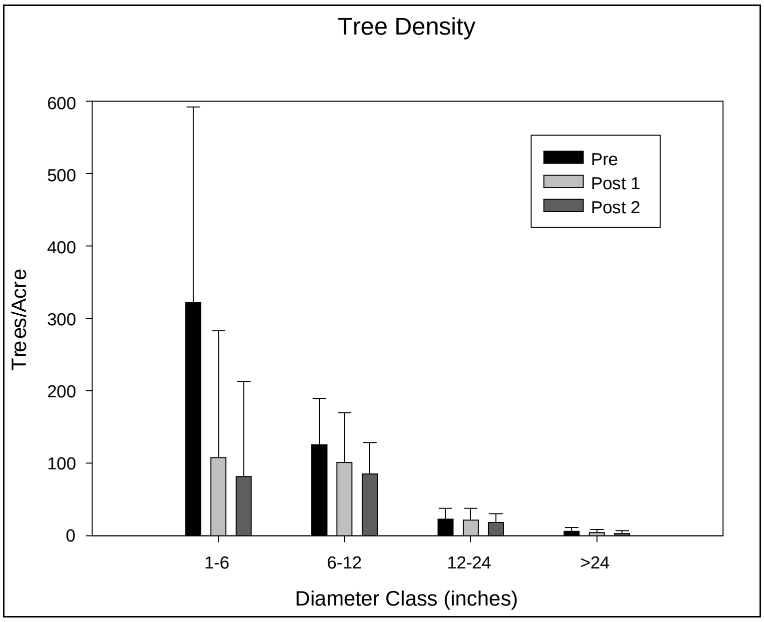


Figure 12 – Tree density measurements associated with mechanical treatments in Douglas Fir and White Fir types.

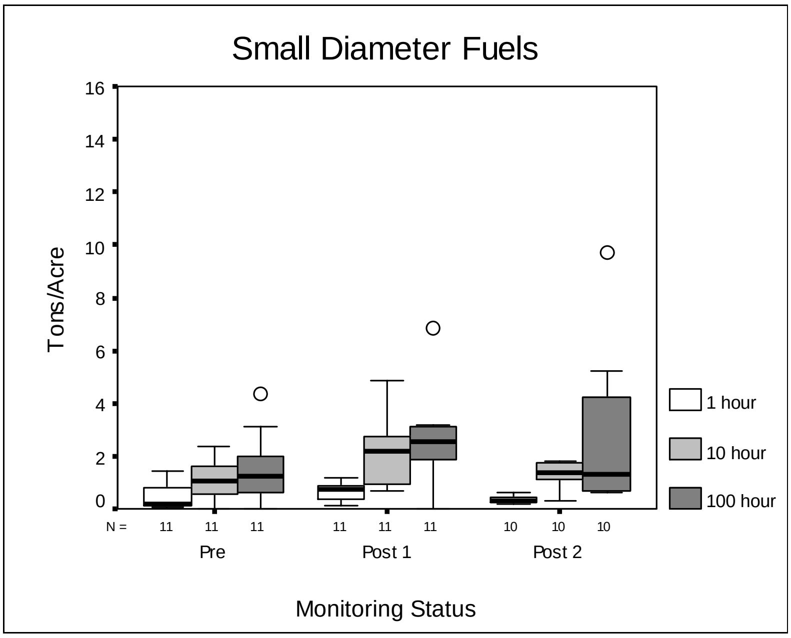


Figure 13 – Small diameter fuels measurements associated with mechanical treatments in Douglas Fir and White Fir types.

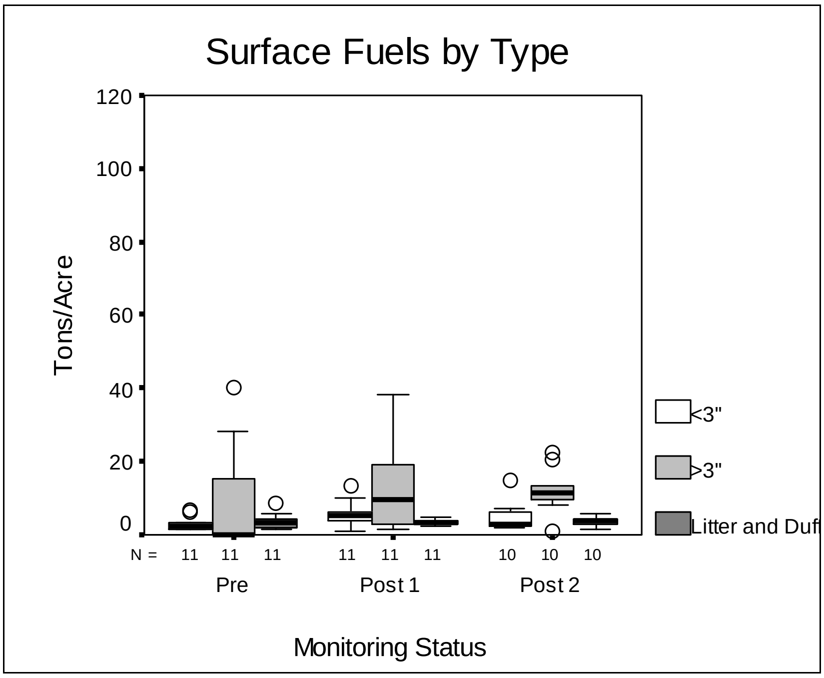


Figure 14 – Surface fuels by type measurements associated with mechanical treatments in Douglas Fir and White Fir types.

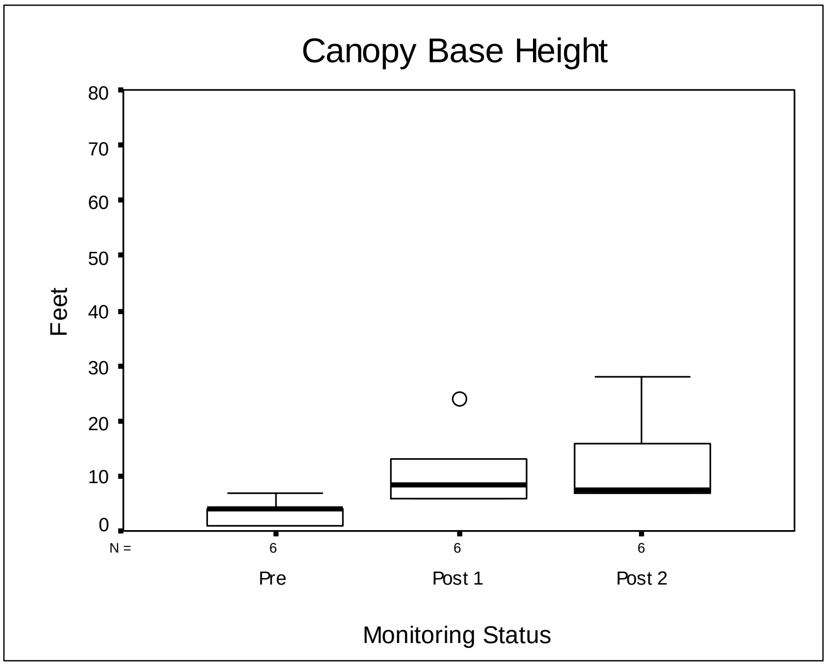


Figure 15 – Canopy base height measurements associated with mechanical treatments in Douglas Fir and White Fir types.

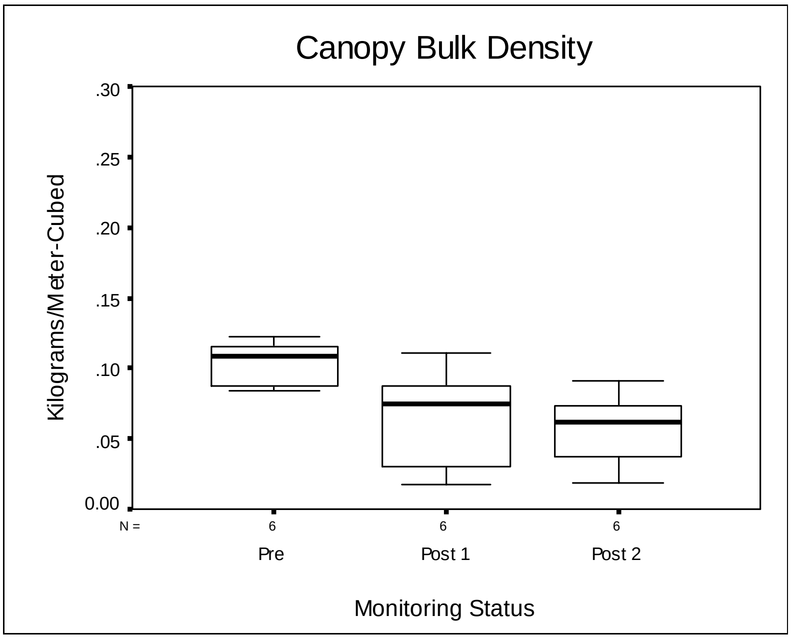


Figure 16 – Canopy bulk density measurements associated with mechanical treatments in Douglas Fir and White Fir types.

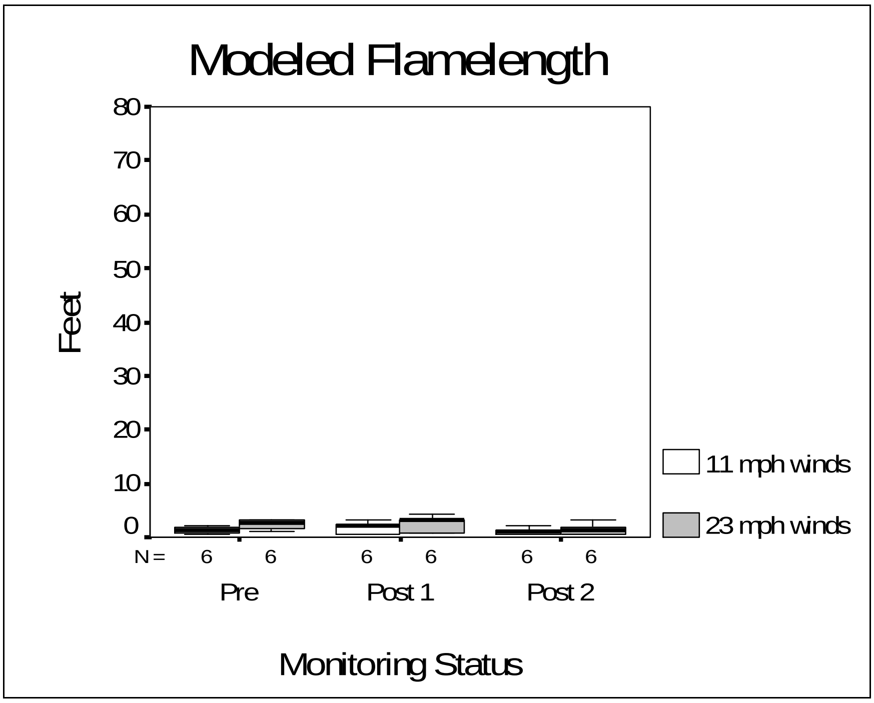


Figure 17 – Modeled flamelength measurements associated with mechanical treatments in Douglas Fir and White Fir types.

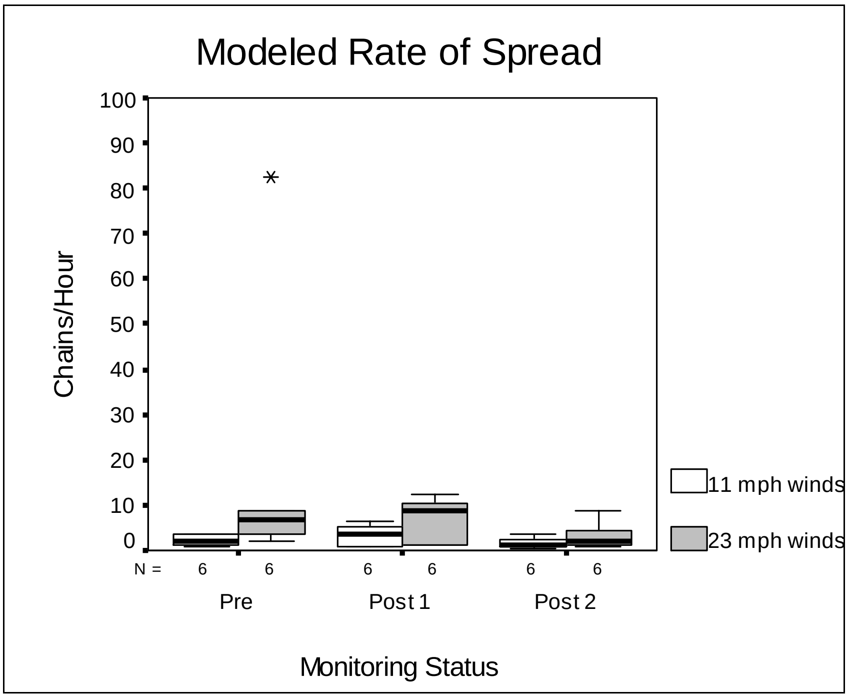


Figure 18 – Modeled rate of spread measurements associated with mechanical treatments in Douglas Fir and White Fir types.

Table 3 – Changes in Vegetation after Prescribed Fire and Mechanical Treatments in the Short-Needle Douglas Fir and White Fir Type

	Prescribed Fire									Mechanical								
Monitoring Status	Pre			Post 1			Post 2			Pre			Post 1			Post 2		
	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
	Understory																	
grass (% cover)	0	6	0-57	0	1	0-1	0	3	0-1	3	9	0-20	3	1	0-11	2	3	0-13
herb (% cover)	16	10	0-88	4	4	0-10	7	5	2-18	5	15	0-22	**4**	4	0-16	5	5	0-21
live shrub (% cover)	7	7	0-75	2	7	0-19	3	7	0-10	5	10	0-27	2	6	0-12	5	7	0-39
dead shrub (% cover)	1	1	0-7	0	4	0-0	0	2	0-0	0	2	0-1	0	3	0-3	0	2	0-3
shrub height (ft)	1.0	0.6	0-4	0.3	0.7	0-1	0.5	0.5	0-1	1.3	0.7	0-6	0.7	0.7	0-4	0.5	0.5	0-2
number of samples	11			11			11			11			11			10		
	Trees																	
tree density (trees/acre)	187	57	49-340	142	43	12-235	142	42	61-198	486	74	231-891	234	57	61-579	187	49	65-466
basal area (ft2/acre)	187	36	34-404	177	33	5-379	199	36	75-370	117	47	57-205	92	43	33-188	78	41	37-96
tree cover (%)	74	7	49-95	74	10	47-91	72	11	48-88	71	11	42-94	54	11	16-93	59	11	20-92
quadratic mean diameter (in)	14	2	13-36	15	2	10-37	16	3	17-38	7	3	9-29	10	3	10-36	10	3	10-36
number of samples	10			10			8			6			6			6		

Table 4 – Changes in Surface and Crown Fuel Levels After Prescribed Fire and Mechanical Treatments in the Short-Needle Douglas Fir and White Fir Type

	Prescribed Fire									Mechanical								
Monitoring Status	Pre			Post 1			Post 2			Pre			Post 1			Post 2		
	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
	Surface Fuels																	
duff (tons/acre)	58	6	16-122	20	5	0.8-44	26	5	22678	26	10	14-39	25	6	23316	20	6	39385
litter (tons/acre)	51.9	1.1	0.8-13.0	4.3	0.9	0.2-3.6	3.0	0.8	0.5-5.5	17.1	1.8	1.5-8.7	30.0	1.0	2.2-14.6	3.7	0.8	1.6-5.7
1-hour fuels (tons/acre)	0.6	0.09	0.1-1.4	0.1	0.1	0.02-0.5	0.3	0.09	0.01-1.0	0.5	0.1	0.07-1.5	0.7	0.15	0.1-1.2	0.4	0.1	0.2-0.6
10-hour fuels (tons/acre)	4.0	0.5	0.6-14.7	1.1	0.5	0-2.6	1.2	0.6	0-2.6	1.1	0.7	0-2.4	2.1	0.6	0.7-4.9	1.6	0.7	0.3-4.7
100-hour fuels (tons/acre)	4.3	0.6	0-16.9	2.2	0.9	0-9.1	3.0	0.7	0.3-6.7	1.5	1.0	0-4.3	2.9	1.0	0-7.6	2.6	0.7	0.6-9.7
1000 hour fuels (tons/acre)	44	12	1-225	2	0.1	0-15	11	0.1	0.3-48	15	18	0-93	21	0.1	2-112	12	0.1	39104
fuel depth (ft)	0.6	0.2	0.2-1.9	0.3	0.08	0.03-0.6	0.4	0.1	0.08-0.6	0.6	0.3	0.2-1.3	0.6	0.09	0.4-0.9	0.6	0.11	0.2-2.1
number of samples	12			12			11			11			11			11		
	Canopy Fuels																	
canopy base height (ft)	14	4	1-58	24	8	3-75	17	7	8-30	4	6	1-7	11	10	6-24	12	8	7-28
canopy bulk density (kg m^{-3})	0.06	0.01	0.01-0.10	0.05	0.01	0-0.11	0.05	0.01	0.02-0.09	0.1	0.00	0.08-0.12	0.1	0.02	0.02-0.11	0.1	0.02	0.02-0.09
number of samples	10			10			8			6			6			6		

2. Ponderosa and Yellow Pine Dominated

The yellow pine dominated group includes those with a high proportion of ponderosa pine, sometimes Jeffrey pine, or, occasionally, coulter pine. Other species might be present (including white fir, black oak, incense cedar, Douglas-fir or sugar pine) but the fuel type is dominated by long needles. Some sites may be classed as mixed conifer by others.

A total of 162 plots were installed in this type, with a total of 53 plots receiving treatment (Table 2). Of these 53 plots, 52 were measured two years' post-treatment, and four plots were measured five years' post-treatment.

Thirty plots were treated with prescribed fire, 18 with mechanical treatments, and 2 with both mechanical and prescribed fire treatments. Projects were included on the following national forests: the Klamath, Shasta-Trinity, Mendocino, Modoc, Lassen, Plumas, Tahoe, Stanislaus, Sierra, Los Padres and Mendocino.

A. Prescribed Fire Treatments

Vegetation Structure and Composition

Understory Vegetation

There were significant decreases in mean herb and grass cover (Tables B-1, 5). Mean grass cover decreased by 93 percent and herb cover by 77 percent. Mean live shrub cover also decreased 57 percent but was not statistically significant. There was a high degree of variability in grass, especially herb cover pre-treatment (Figure 19). After two years post-treatment, grass and herb cover increased slightly, however, not to pre-fire levels.

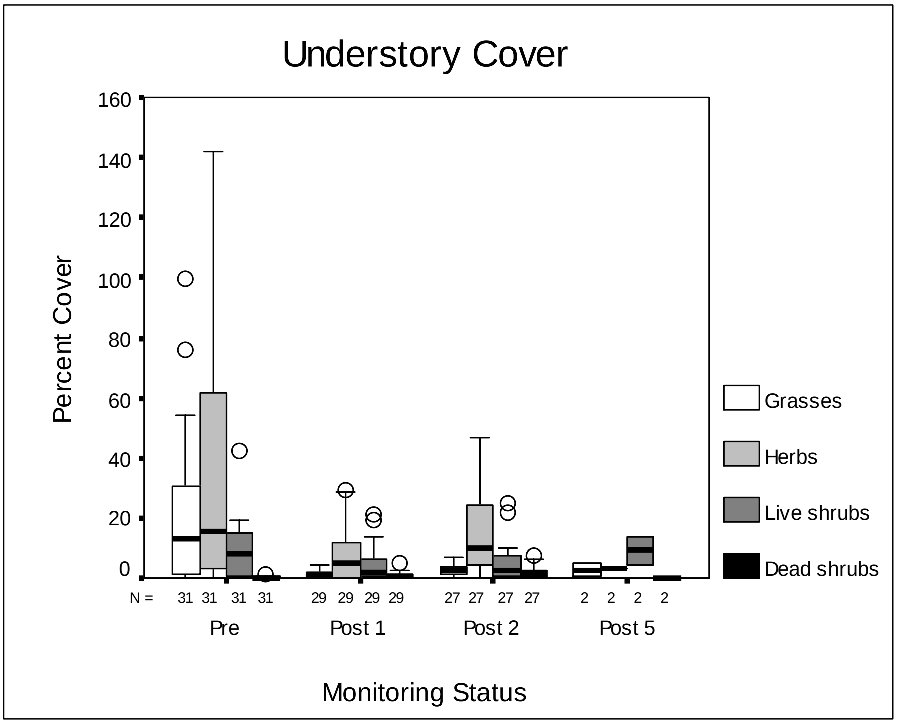


Figure 19 – Understory cover associated with prescribed fire treatment in Ponderosa and Yellow Pine.

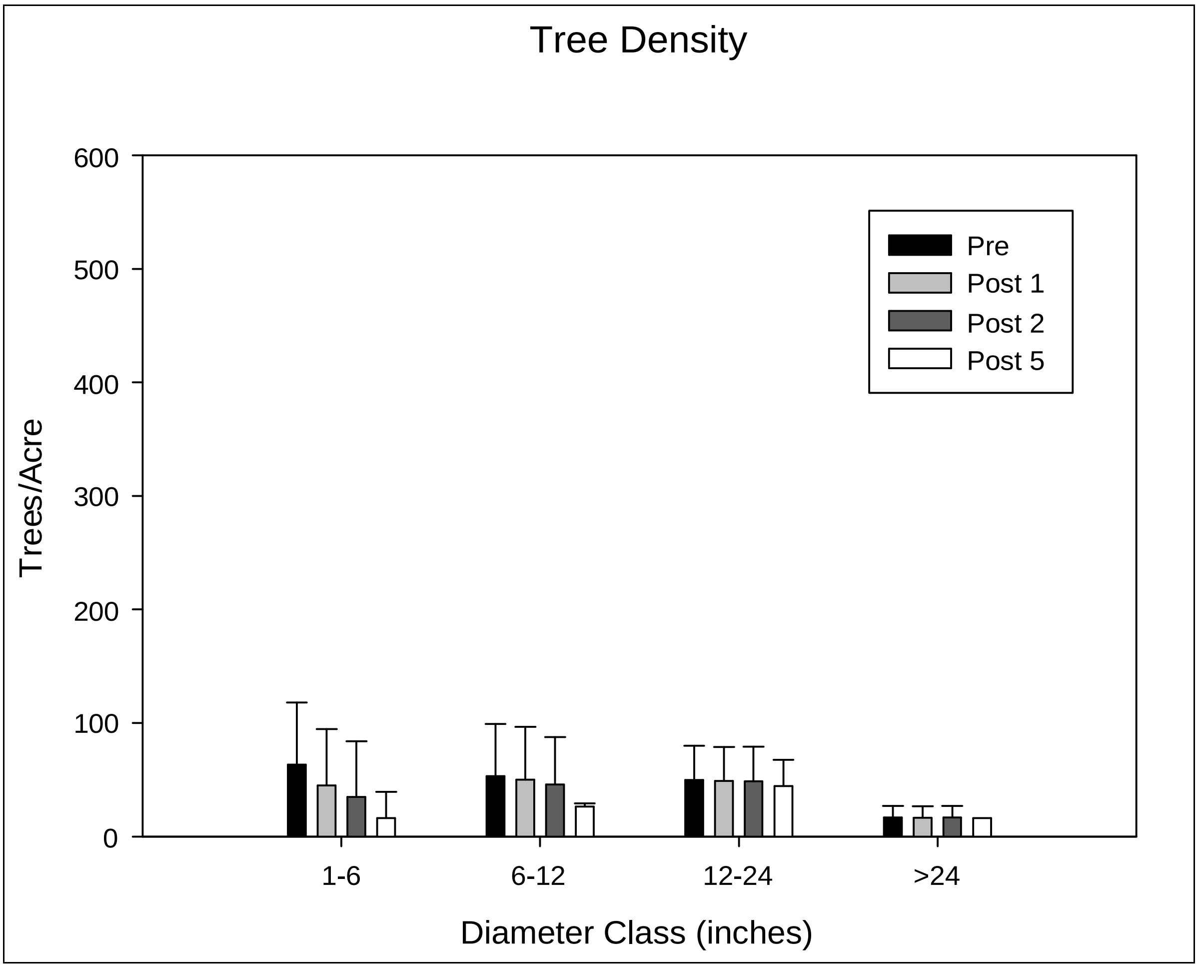


Figure 20 – Tree density measurements associated with prescribed fire treatment in Ponderosa and Yellow Pine.

Tree and Overstory Vegetation

There were no significant changes in tree cover, tree density, basal area, or QMD (Tables B-1, 5). Changes in mean levels were less than 13 percent but small tree (1-6" dbh) density decreased (Figure 20).

Seedling densities fluctuated, with a 91 percent reduction in year-one post-fire, and a recovery to 100 percent mean density in year-two post-fire. Ponderosa pine regeneration increased and white fir decreased initially in year-one post-fire, but increased to pre-fire levels in year two post-fire (Table C-3). Douglas fir decreased and incense cedar increased, while hardwoods (including black oak, big leaf maple and dogwood) remained similar. California nutmeg increased, one of the few conifers that sprouts.

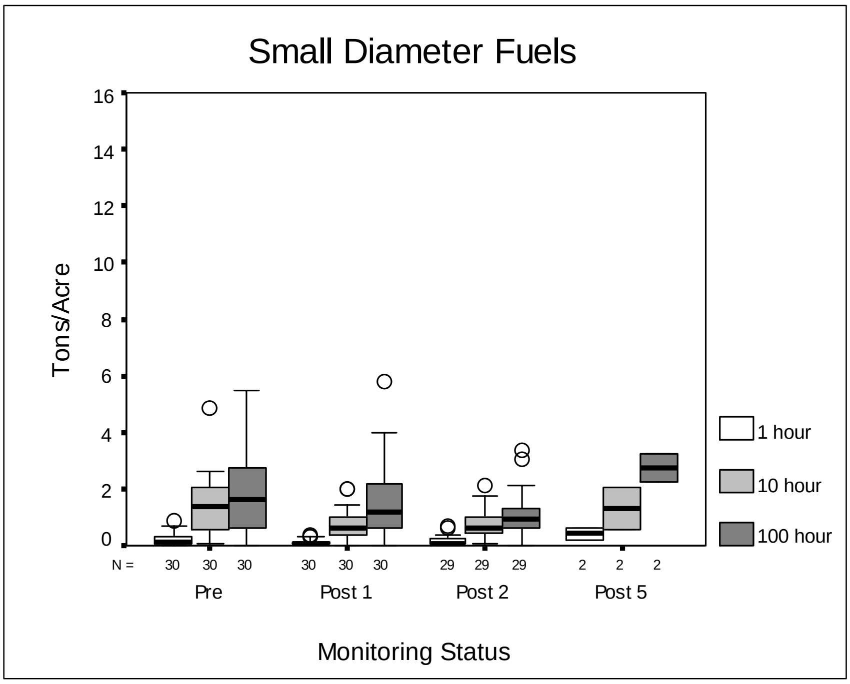


Figure 21 – Small diameter fuels associated with prescribed fire treatment in Ponderosa and Yellow Pine.

Fuels

Surface Fuels

Litter and duff loadings and fuel bed depth decreased significantly (Tables B-1, 6). Ten-hour loading also decreased significantly, but with greater variability resulting in a lower

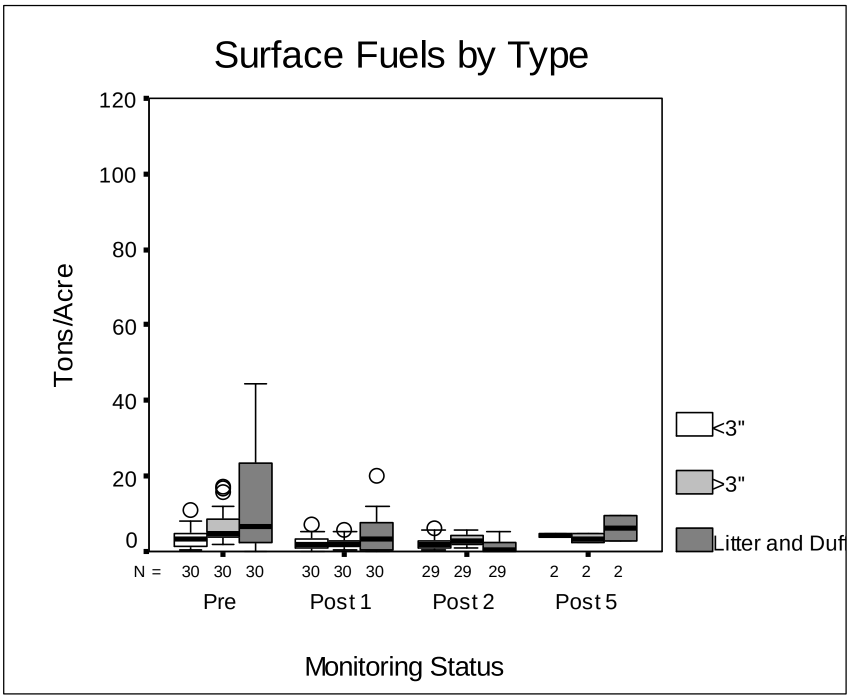


Figure 22 – Surface fuels by type associated with prescribed fire treatment in Ponderosa and Yellow Pine.

significance level (Figure 21). Similarly, while 1-hour fuel loading—excluding litter—decreased substantially, it was only significant at a probability level of 0.14. Mean 1-hour and duff loadings decreased by over 55 percent, litter by 89 percent and fuel depth by 71 percent.

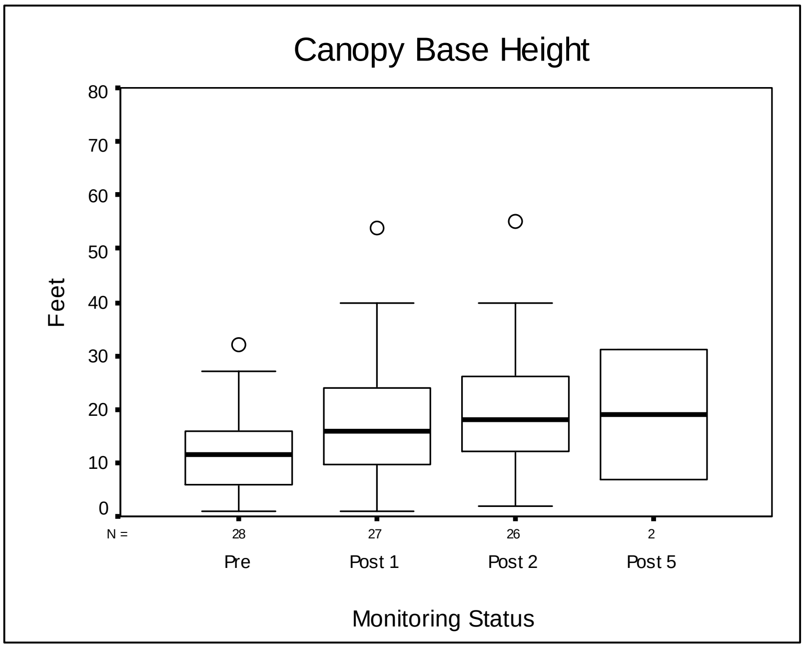


Figure 23 – Canopy base height measurements associated with prescribed fire treatment in Ponderosa and Yellow Pine.

Canopy Fuels

While canopy base height increased significantly, canopy bulk density did not change significantly (Table B-1). Mean canopy base height increased 59 percent one-year post-treatment from 12.4 to 19.7 feet. Mean canopy bulk density remained at 0.1 kg m^{-3}. There was high variability in canopy bulk density among plots (Figure 32).

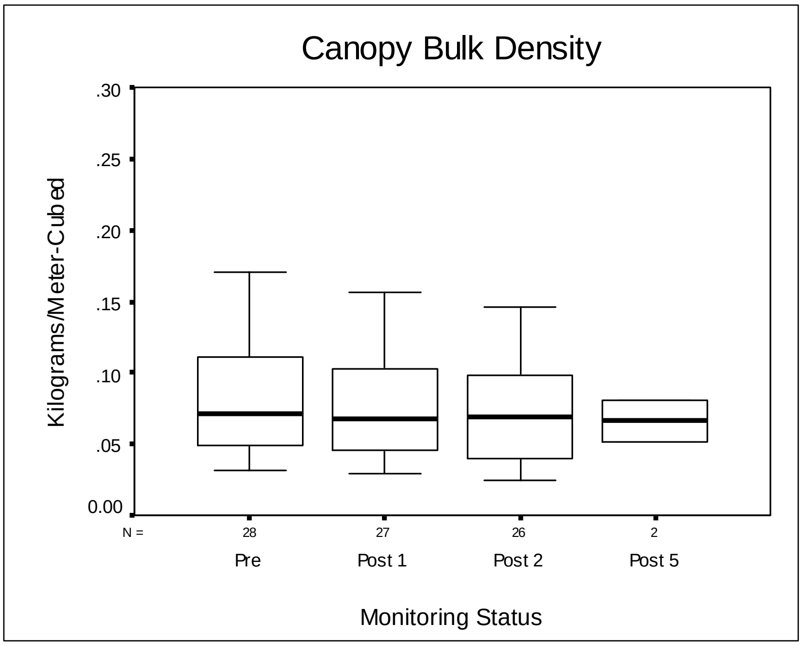


Figure 24 – Canopy bulk density associated with prescribed fire treatment in Ponderosa and Yellow Pine.

Potential Fire Behavior

Modeled flamelengths exhibited similar reductions after treatment, similar to the Douglas-fir/white fir vegetation group treated with prescribed fire (Figure 25). Mean modeled flamelengths decreased from 2.2 to 1.0 feet under 11 mph winds, and from 11 to 5 feet under 23 mph winds. Modeled rates of spreads decreased similarly, changing from 2.9 to 1.5 chains per hour post-treatment under 11 mph winds, and from 16 to 8 chains per hour under 23 mph winds (Figure 26). Two years post-treatment there were slight increases.

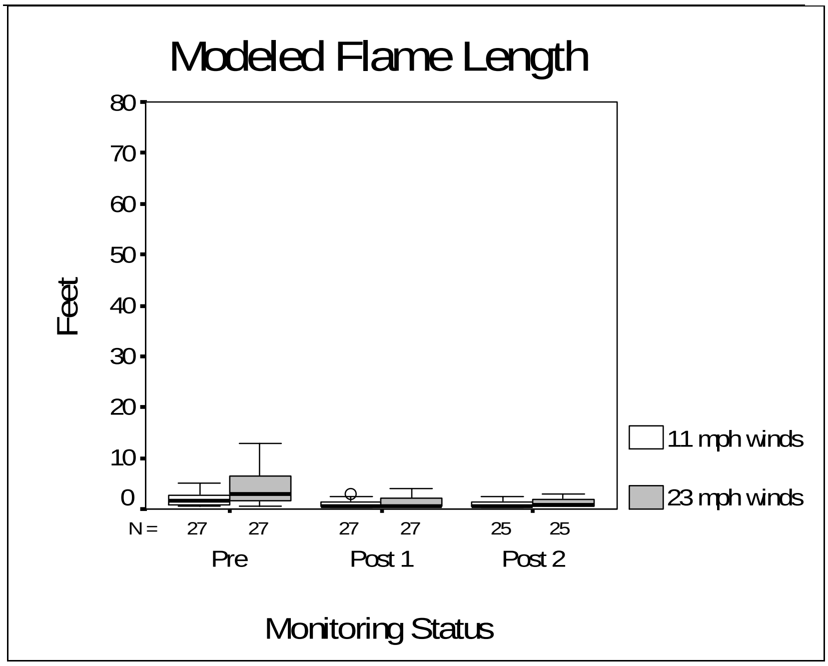


Figure 25 – Modeled flame length associated with prescribed fire treatment in Ponderosa and Yellow Pine.

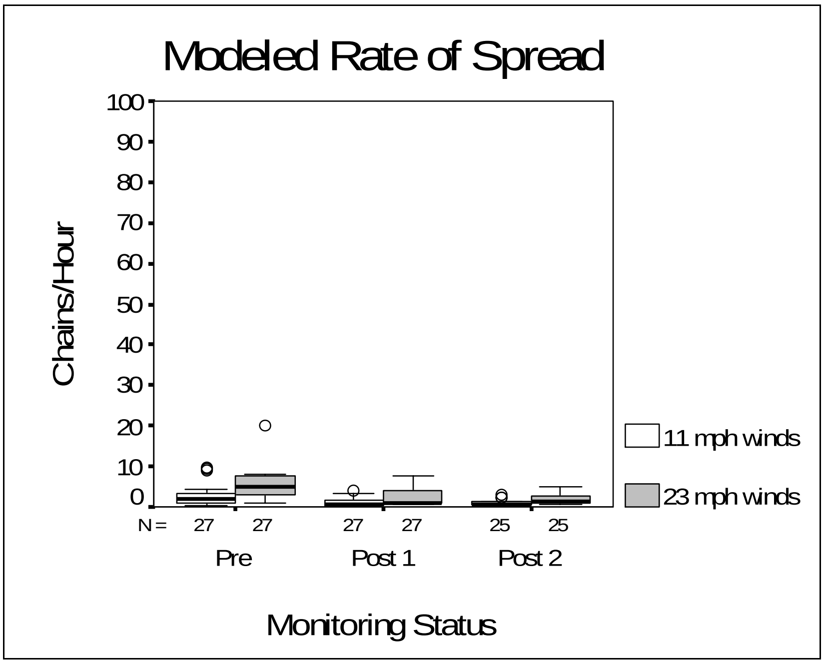


Figure 26 – Modeled rate of spread associated with prescribed fire treatment in Ponderosa and Yellow Pine.

B. Mechanical Treatments

Eighteen Ponderosa/yellow dominated pine plots were treated with mechanical methods (Table 2). Tree data were gathered on 14 of these plots. The majority of the mechanical treatment methods used in this group were thinning, some of which were commercial thinning.

Vegetation Structure and Composition

Understory Vegetation

There were no statistically significant changes in understory vegetation (Tables B-1, 5). While mean live shrub cover decreased 44 percent from pre to post 1-year treatment, there was high variability. In the second year post-treatment on some plots, mean live shrub cover increased (Figure 27). Herbaceous and grass cover showed similar as well as highly variable responses.

Tree and Overstory Vegetation

Similar to plots treated mechanically in the Douglas-fir/white fir group, there were statistically significant decreases in tree canopy cover, tree density and basal area, and increases in QMD (Tables B-1, 5),. One year post-treatment, tree cover decreased 44 percent, tree density 57 percent, and basal area 28 percent. In the second year post-treatment, tree cover recovered to 66 percent of pre treatment levels, increasing from a mean of 34 to 40 percent cover. Mean QMD increased from 15 to 18 inches one year post-treatment. Medium (12-24” dbh) and small (1-12” dbh) tree densities decreased (Figure 28).

Similarly to the prescribed burn treatments, seedling densities decreased—after mechanical treatments—by 42 percent and recovery to 90 percent pre-burn levels in the second year after treatment. White fir densities decreased 60 percent in year one and 90 percent in year two (Table C-4). Incense cedar regeneration increased while pine regeneration remained similar.

Photo 1 – Pre-Treatment

Photo 2 – 1-Year Post Treatment

Photo 3 – 2-Years Post Treatment

Mechanical Treatment
in Ponderosa and Yellow Pine

Same Photo Points:
1) Pre-treatment; 2) 1-year post treatment; 3) 2-year post treatment

Photo 1 – Pre-Treatment

Photo 2 – Immediate Post-Treatment

Photo 3 – 1 Year Post-Treatment

Photo 4 – 2 Years Post-Treatment

Mechanical Treatment
in Ponderosa and Yellow Pine

Same Photo Points:
1) Pre-treatment; 2) Immediate post treatment; 3) 1-year post treatment; 4) 2-years post treatment

Fuels

Surface Fuels

There were significant increases in 10 and 100-hour fuels one-year post-treatment (Tables B-1, 6). Mean loadings increased 158 percent and 191 percent from 1.3 to 3.3, and 1.6 to 4.6 tons per acre for 10 and 100-hour fuels respectively (Figure 29). Although not statistically significant, mean 1000 hour fuel levels decreased 56 percent and litter 24 percent (Figure 30).

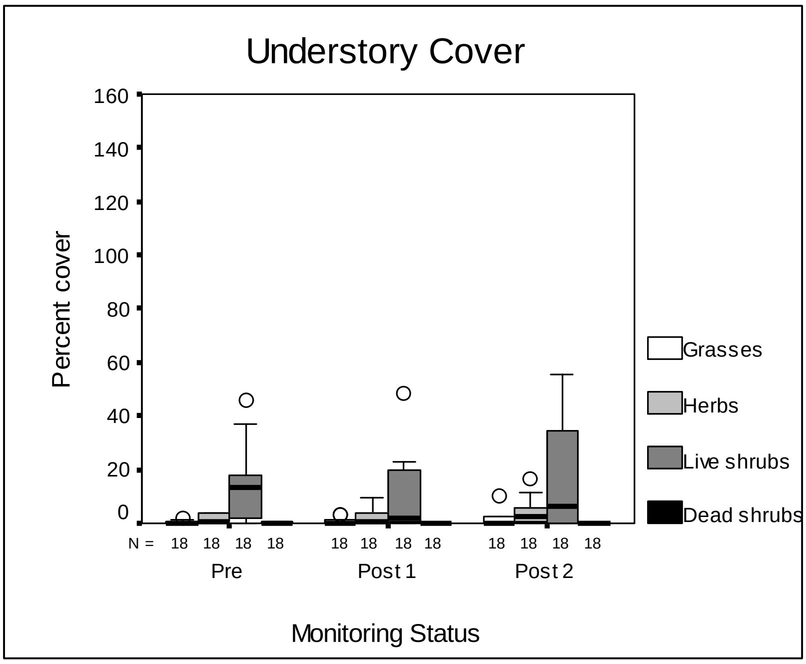


Figure 27– Understory cover measurements associated with mechanical treatment in Ponderosa and Yellow Pine.

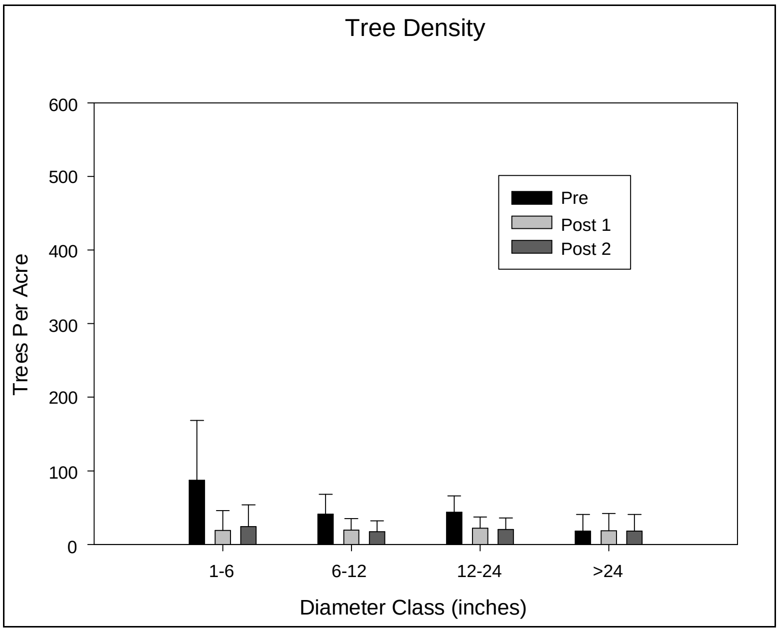


Figure 28– Tree density measurements associated with mechanical treatment in Ponderosa and Yellow Pine.

Canopy Fuels

Similar significant increases in canopy base height and decreases (Tables B-1, 6) in canopy bulk density occurred as with the mechanically treated plots in the Douglas-fir/white fir group. Mean canopy base height increased 86 percent from 13 to 25 feet one-year post-fire (Figure 31). Mean canopy bulk density decreased 26 percent from 0.5 to .04 kg m^{-3} (Figure 32).

Fire Behavior

Modeled flame lengths at 11 and 23 mph winds decreased one-year post treatment from 3.1 to 2.3 feet and 6.5 to 3.5 feet respectively (Figure 33). There was little change in rates of spread, with slight increases in modeled levels from 5.8 to 6.1 chains per hour under 11 mph winds, and 15.2 to 14.3 chains per hour under 23 mph winds (Figure 34). Plots in the ponderosa pine group included a wide array of understory fuel conditions, resulting in fuel models ranging from long-leaf litter types to grass or shrub dominated types. These generally sustain higher rates of spread, regardless of forest conditions.

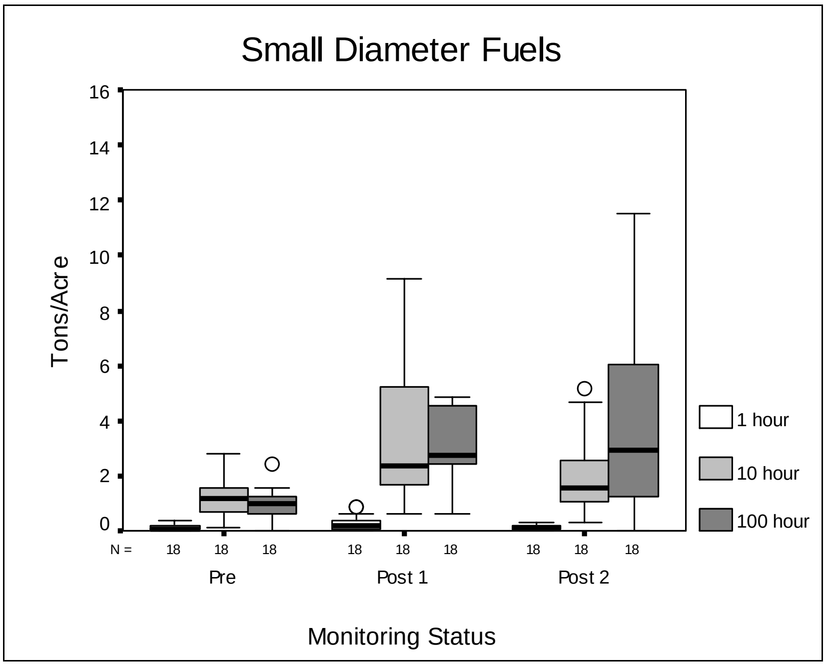


Figure 29 – Small diameter fuels measurements associated with mechanical treatment in Ponderosa and Yellow Pine.

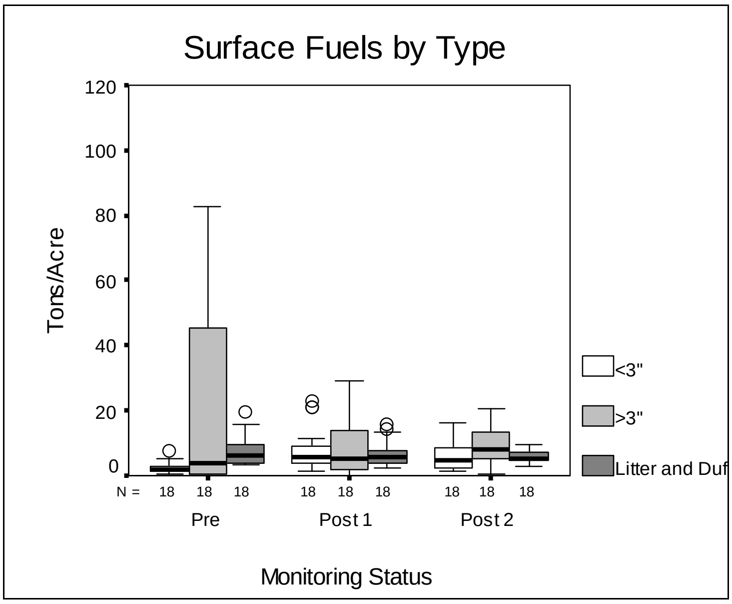


Figure 30 – Surface fuels by type associated with mechanical treatment in Ponderosa and Yellow Pine.

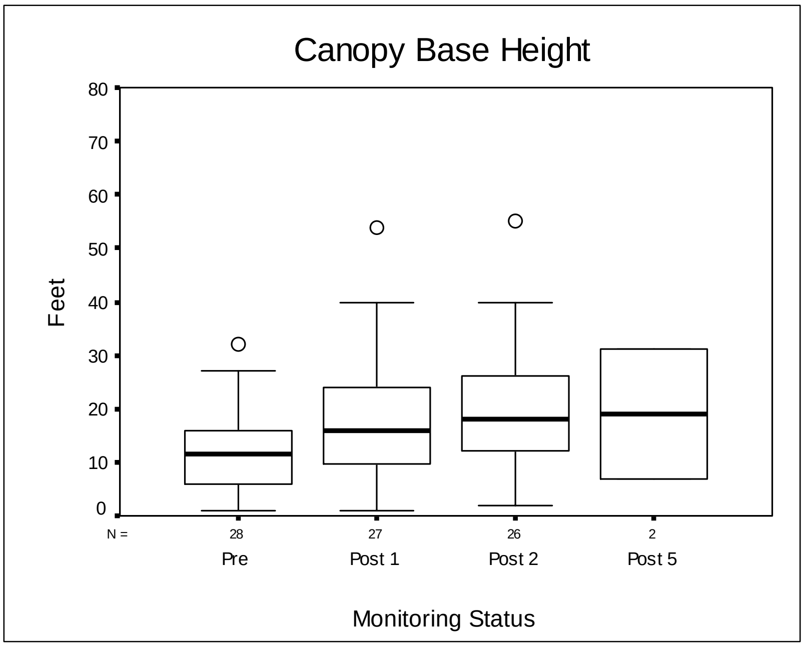


Figure 31 – Canopy base height measurements associated with prescribed fire treatment in Ponderosa and Yellow Pine.

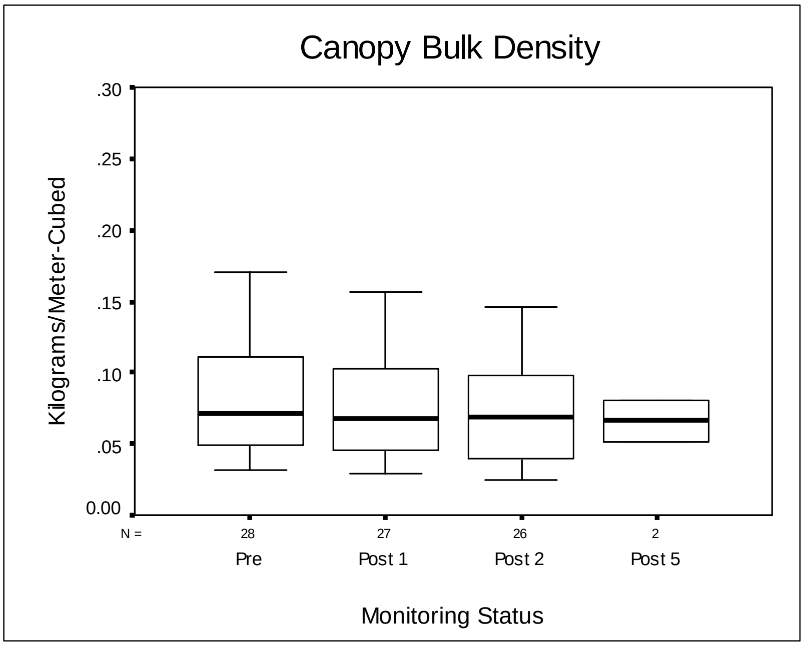


Figure 32 – Canopy bulk density associated with prescribed fire treatment in Ponderosa and Yellow Pine.

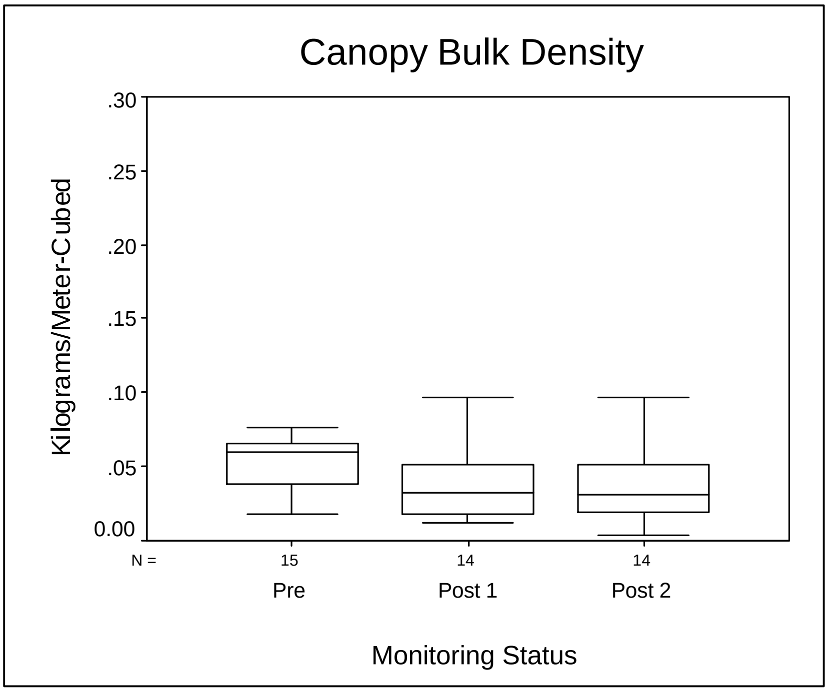


Figure 33 – Canopy bulk density measurements associated with mechanical treatment in Ponderosa and Yellow Pine.

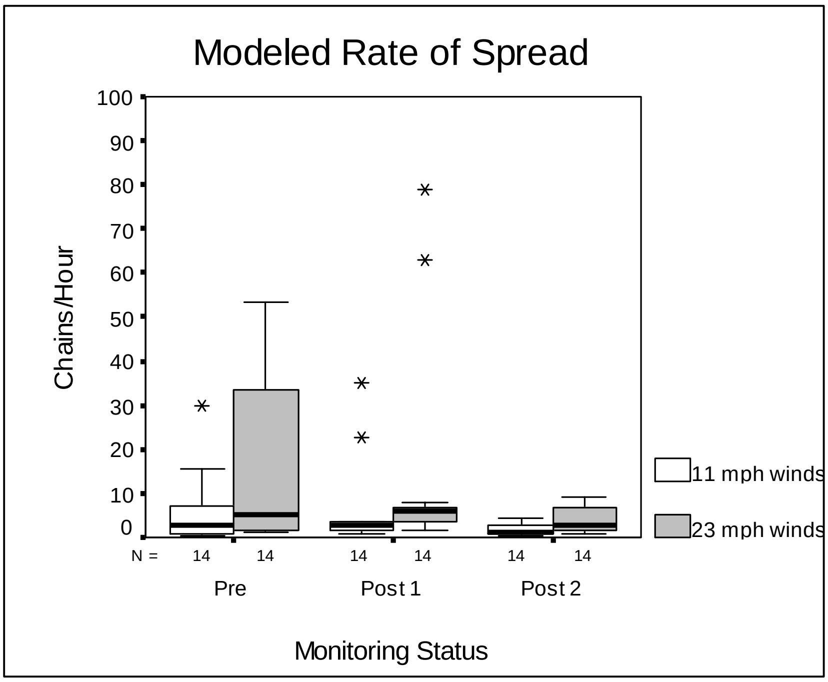


Figure 34 – Modeled rate of spread measurements associated with mechanical treatment in Ponderosa and Yellow Pine.

Table 5 – Fire and Mechanical Treatments in Long-Needled Yellow Pine (Ponderosa and Jeffrey Pine) Types

	Prescribed Fire									Mechanical								
Monitoring Status	Pre			Post 1			Post 2			Pre			Post 1			Post 2		
	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
	Understory																	
grass (% cover)	20	4	0-100	1	1	0-8	4	1	0-24	2	6	0-54	1	1	0-10	3	2	0-21
herb (% cover)	39	7	0-142	9	2	0-48	15	3	0-47	7	11	0-45	2	3	0-10	4	3	0-16
live shrub (% cover)	15	4	0-79	6	3	0-79	7	4	0-45	17	7	0-101	9	5	0-48	16	5	0-56
dead shrub (% cover)	1	1	0-44	4	2	0-63	3	1	0-42	2	1	0-18	0	2	0-1	0	2	0-4
shrub height (ft)	1.4	0.0	0-6.1	1.4	0.4	0-5.2	1.0	0.3	0-3.4	3.6	0.5	0-17.7	1.7	0.5	0-7.1	1.2	0.4	0-6.9
number of samples	30			30			29			18			18			18		
	Trees																	
tree density (trees/acre)	165	35	49-340	144	28	36-340	136	24	32-324	173	51	24-344	74	39	16-162	77	33	12-162
basal area (ft2/acre)	149	23	50-282	146	22	50-282	150	21	43-279	183	34	18-505	132	31	16-463	132	29	4-463
tree cover (%)	49	5	0-97	46	6	15-97	49	6	14-96	60	7	33-99	34	8	3-54	40	8	2-70
quadratic mean diameter (in)	14	1	11-44	15	1	11-44	16	2	12-44	15	2	14-35	18	2	14-36	17	2	10-36
number of samples	27			27			26			14			14			14		

Table 6 – Changes in Surface and Crown Fuel Levels after Prescribed Fire and Mechanical Treatments in Long-Needled Yellow Pine (Ponderosa and Jeffrey Pine) Types

	Prescribed Fire									Mechanical								
Monitoring Status	Pre			Post 1			Post 2			Pre			Post 1			Post 2		
	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
	Surface Fuels																	
duff (tons/acre)	42	4	13-88	18	4	7-42	23	3	5-51	54	7	11-131	46	5	22-79	42	4	15-78
litter (tons/acre)	59.4	0.8	1.8-17.0	6.5	0.6	0.6-5.8	3.2	0.5	1.1-5.6	82.6	1.2	1.9-19.8	63.0	0.8	2.4-15.7	6.3	0.6	2.7-14.7
1-hour fuels (tons/acre)	0.3	0.06	0-1.3	0.1	0.09	0-0.3	0.2	0.05	0-0.7	0.1	0.09	0-1.5	0.3	0.11	0-0.9	0.1	0.07	0-0.3
10-hour fuels (tons/acre)	1.6	0.3	0-7.6	0.8	0.3	0-3.2	0.9	0.4	0.1-2.9	1.3	0.5	0.2-4.2	3.3	0.5	0.6-9.2	2.5	0.5	0.3-11.8
100-hour fuels (tons/acre)	1.7	0.4	0-17.0	1.5	0.6	0-5.8	1.3	0.4	0-4.6	1.6	0.7	0-9.2	4.6	0.8	0.6-15.1	3.9	0.5	0-11.5
1000 hour fuels (tons/acre)	13	8	0-194	7	0.1	0-88	5	0.1	0-84	19	13	0-83	8	0.1	0-29	9	0.1	0.6-20
fuel depth (ft)	0.8	0.1	0.06-3.1	0.2	0.05	0.05-0.5	0.2	0.06	0.05-0.7	0.5	0.2	0.1-1.5	0.7	0.07	0.2-1.9	0.7	0.08	0.1-1.6
number of samples	30			30			29			18			18			18		
	Canopy Fuels																	
canopy base height (ft)	12	3	1-32	20	5	1-74	21	4	2-74	13	4	2-41	25	7	3-73	27	6	4-73
canopy bulk density (kg m-3)	0.1	0.00	0.03-0.17	0.1	0.01	0.03-0.16	0.1	0.01	0.02-0.15	0.1	0.00	0.02-0.08	0.0	0.01	0.01-0.10	0.0	0.01	0-0.10
number of samples	27			27			26			14			14			14		

3. Red Fir

Thirty-three plots were installed in red fir dominated and red fir-white fir mixed stands. Of these, 11 plots were treated with mechanical methods. These treatments involved thinning and mastication. One of the projects incorporated pile burning. All of these projects were located on the Inyo National Forest or the Lake Tahoe Basin Management Unit.

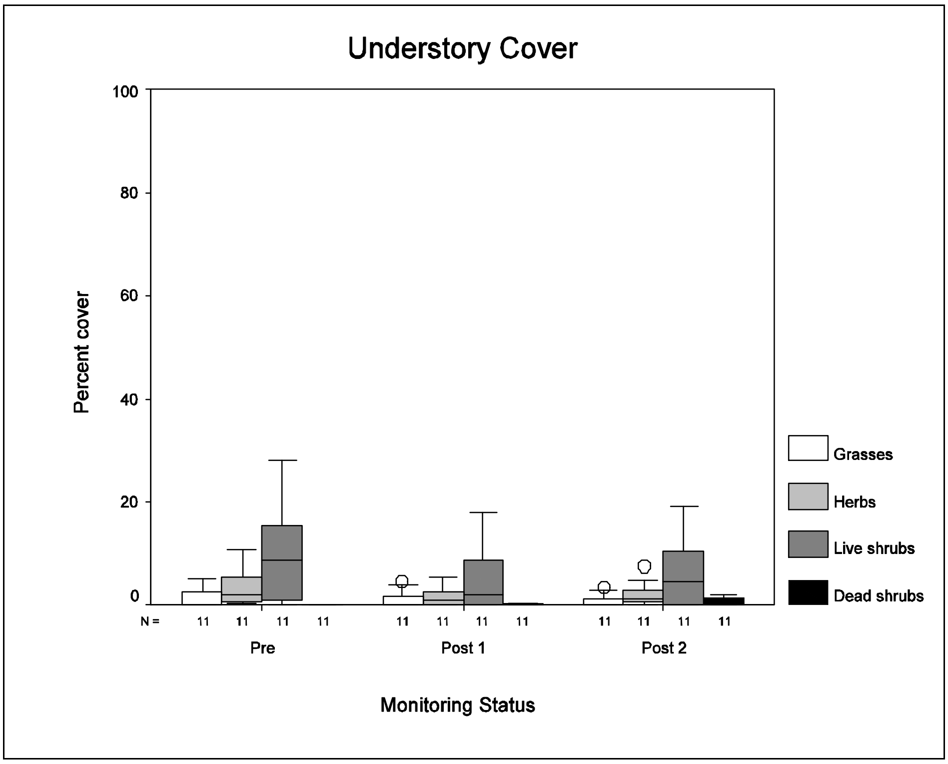


Figure 35 – Understory cover measurements associated with mechanical treatment in Red Fir.

A. Mechanical Treatments

Eighteen Ponderosa/yellow dominated pine plots were treated with mechanical methods. On 14 of these, tree data were gathered. The majority of the mechanical treatment methods used in this group were thinning, some commercial.

Vegetation Structure and Composition

Understory Vegetation

There were significant decreases in herb cover, shrub height, and live shrub cover one-year post-treatment (Tables B-1, 7). Mean herb cover decreased shrub cover decreased 48 percent, from 9 to 5 percent cover one-year post treatment and then increased to 6 percent two years post-treatment.

Tree and Overstory Vegetation

Changes in tree and overstory vegetation with mechanical treatment were similar to those described above for the Douglas-fir/white fir and yellow pine groups. There were significant decreases in overstory tree cover, tree density, basal area and increases in QMD (Table B-1). Mean tree cover decreased 27 percent, from 38 to 28 percent cover one-year post-treatment. Mean basal area decreased similarly, at 24 percent, while tree density decreased by 43 percent. Quadratic mean diameter increased 32 percent, from a mean of 13 to 17 inches one-year post-treatment. There were substantial decreases in small trees (1-12” dbh) and moderate decreases in medium sized trees (12-24” dbh) (Figure 36).

Seedling densities decreased 97 percent one-year post treatment and slightly more in year two. White fir and red fir seedlings decreased 50 to 70 percent. By year two, western white and sugar pines increased (Table C-5).

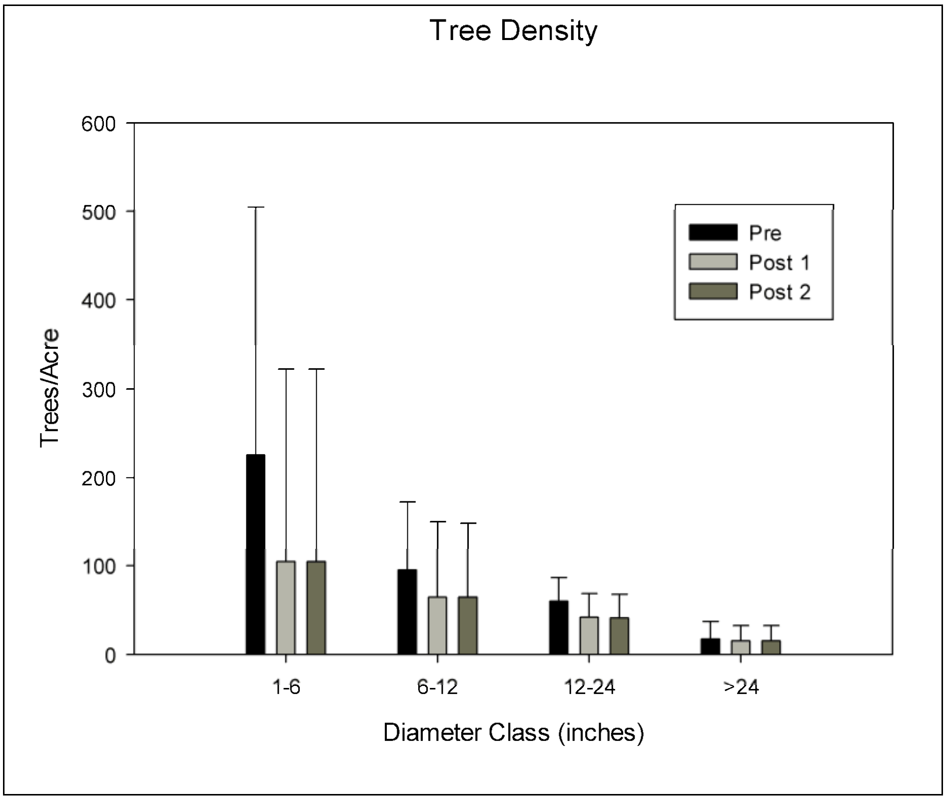


Figure 36 – Tree density measurement associated with mechanical treatment in Red Fir.

Fuels

Surface Fuels

There were no statistically significant changes in surface fuels (Tables B-1, 8). Overall, there was a high degree variability in fuel loadings both pre- and post-treatment (Figures 37, 38). This likely contributed to the lack of statistically significant changes. It should be noted that one of the projects included mastication that generated wood chips. The Brown's planar intercept method was used to quantify surface fuels for all projects. However, this method was not designed to capture masticated fuels. Therefore, there could be important changes that were undetected. Efforts are underway to develop better estimates using predictive regression equations of measured loadings from cover and depth for future use.

Similar to the other vegetation groups, there were increases in mean levels of 1-hour fuels (44 percent increase), 10-hour fuels (17 percent increase), and 100-hour fuels (13 percent increase). Duff showed little change one year post-treatment, but a 37 percent reduction from pre-treatment levels in the second year post-treatment.

Loadings, although, remained relatively high, above 24 tons/acre. Fuel bed depth decreased by 16 percent. Mean levels of 1000-hour fuel loadings decreased initially by 43 percent one-year post-treatment, but increased 36 percent in the second year post-treatment.

Photo 1 – Pre-Treatment

Photo 2 – 1-Year Post Treatment

Photo 3 – 2-Years Post Treatment

Mechanical Treatment in Red Fir

Same Photo Points:
1) Pre-treatment; 2) 1-year post treatment; 3) 2-year post treatment

Canopy Fuels

There were significant increases in mean canopy base height and canopy bulk density one-year post-treatment (Tables B-1, 8). Mean canopy base height increased 282 percent, from 3.7 to 11.4 feet (Figure 39). Mean canopy bulk density decreased 31 percent, from 0.18 to 0.12 kg m^{-3} one year post-treatment (Figure 40).

Potential Fire Behavior

There was little change in mean modeled flamelengths or rates of spread under 11 mph wind conditions. Under 23 mph wind conditions experienced substantial reductions in both mean modeled flamelength and rates of spread, but levels remained high. Mean modeled flamelength at 23 mph winds decreased from 45 to 21 feet. Mean rates of spread decreased from 48 to 25 chains per hour. There was a high degree of variability (Figures 41, 42).

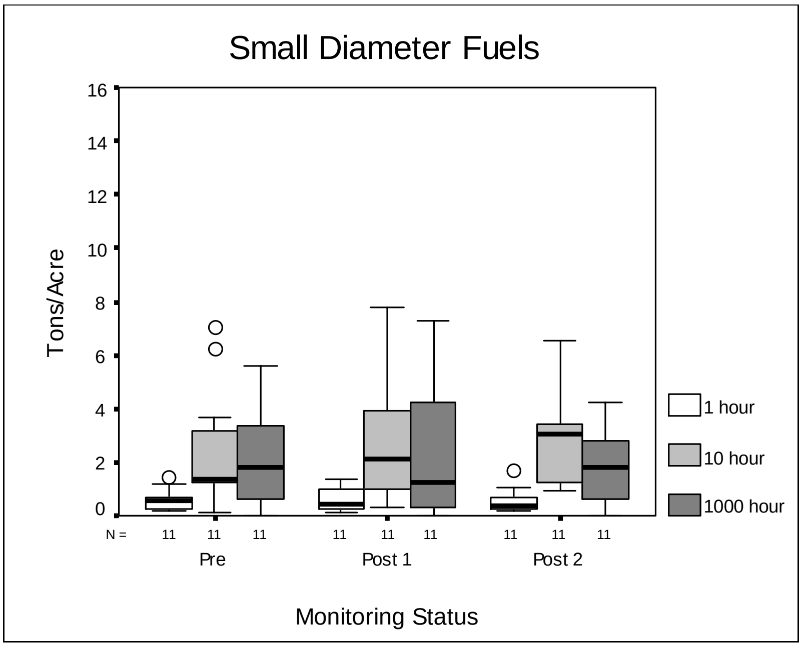


Figure 37 – Small diameter fuels measurements associated with mechanical treatment in Red Fir.

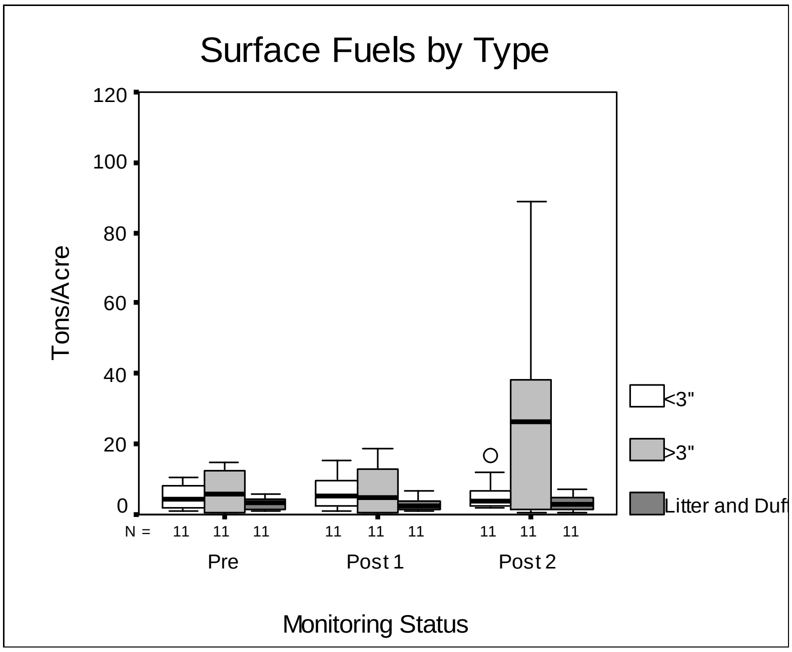


Figure 38 – Surface fuels by type associated with mechanical treatment in Red Fir.

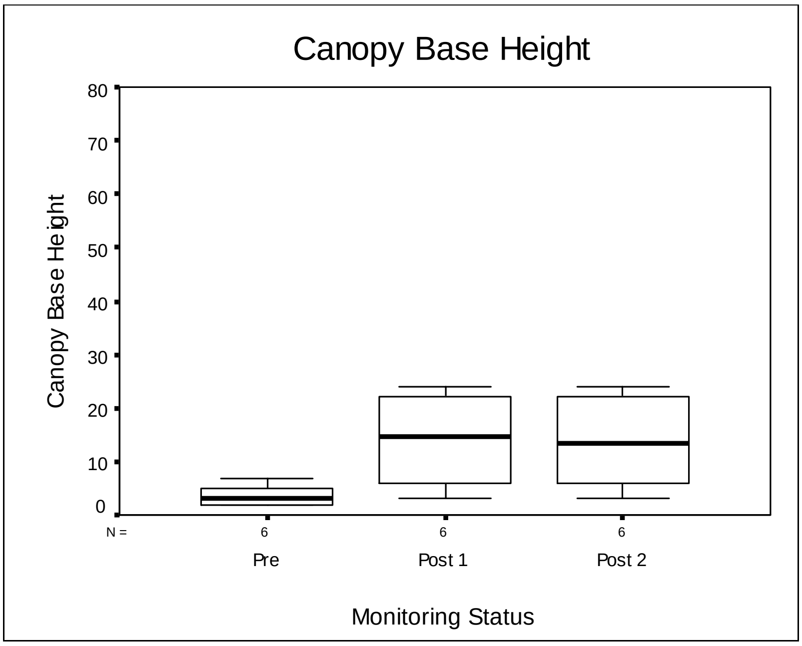


Figure 39 – Canopy base height measurements associated with mechanical treatment in Red Fir.

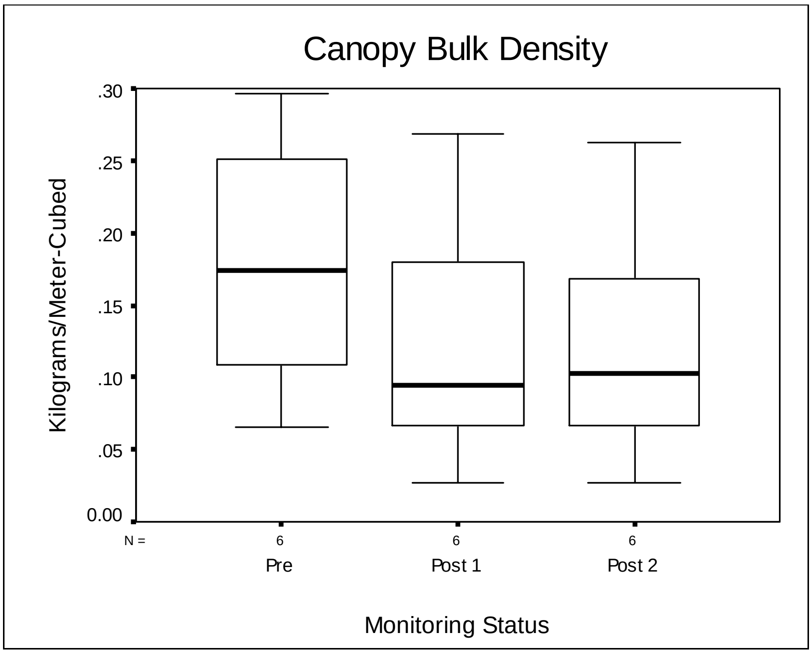


Figure 40 – Canopy bulk density measurements associated with mechanical treatment in Red Fir.

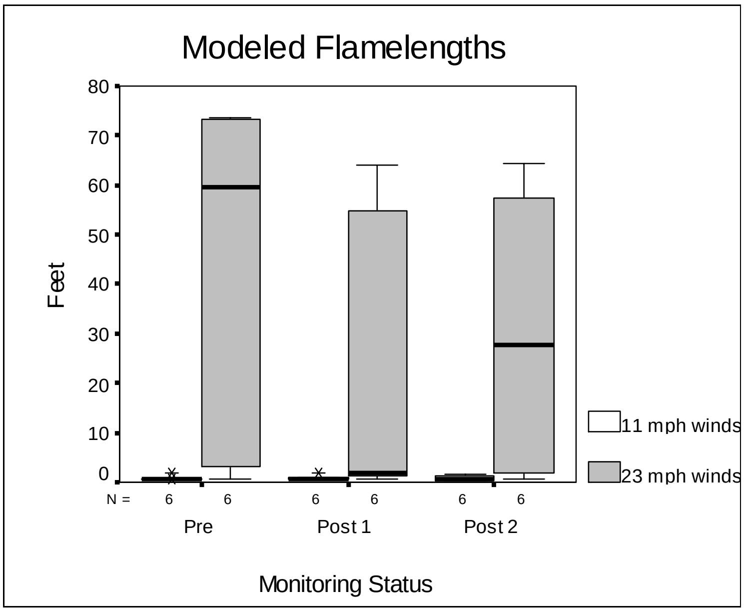


Figure 41 – Modeled flamlengths measurements associated with mechanical treatment in Red Fir.

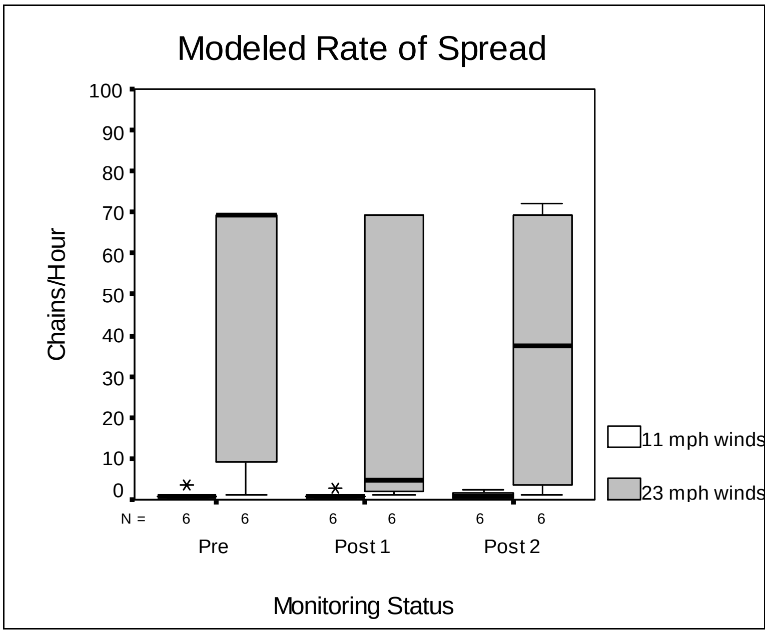


Figure 42 – Modeled rate of spread measurements associated with mechanical treatment in Red Fir.

Table 7 – From Pre- to Post-Prescribed Fire and Mechanical Treatments in Red Fir Type

Monitoring Status	Pre			Post 1			Post 2		
	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
	Understory								
grass (% cover)	1	11	0-5	1	1	0-5	1	3	0-4
herb (% cover)	4	19	0-11	2	5	0-6	2	5	0-8
live shrub (% cover)	9	11	0-54	5	7	0-18	6	8	0-19
dead shrub (% cover)	0	2	0-2	0	4	0-3	1	2	0-2
shrub height (ft)	1.1	0.8	0-4	0.7	0.7	0-2	1.0	0.5	0-3
number of samples	11			11			11		
	Trees								
tree density (trees/acre)	398	80	146-826	227	61	16-757	226	50	16-753
basal area (ft2/acre)	243	53	106-385	185	48	38-271	184	46	38-271
tree cover (%)	38	13	9-57	28	12	2-66	30	13	5-64
quadratic mean diameter (in)	13	3	16-27	17	3	16-29	17	4	16-29
number of samples	6			6			6		

Table 8 – Crown Fuel Levels after Mechanical Treatments in Red Fir Type

	Mechanical								
Monitoring Status	Pre			Post 1			Post 2		
	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
	Surface Fuels								
duff (tons/acre)	39	12	19-64	40	7	12-75	24	6	4-41
litter (tons/acre)	11.7	2.1	1.1-5.9	11.2	1.1	1.0-6.9	3.2	0.9	0.6-7.0
1-hour fuels (tons/acre)	0.6	0.2	0.2-1.5	0.8	0.2	0.1-3.7	0.6	0.1	0.2-1.7
10-hour fuels (tons/acre)	2.5	0.9	0.2-7.1	2.9	0.6	0.3-7.8	3.4	0.7	0.9-11.3
100-hour fuels (tons/acre)	2.1	1.1	0-5.6	2.4	1.1	0-7.3	1.7	0.7	0-4.2
1000 hour fuels (tons/acre)	19	22	0-92	11	0.2	0-60	26	0.1	0.4-89
fuel depth (ft)	0.5	0.3	0.3-1.5	0.4	0.09	0.2-0.8	0.4	0.12	0.2-0.7
number of samples	11			11			11		
	Canopy Fuels								
canopy base height (ft)	4	7	2-7	14	11	3-24	14	9	3-24
canopy bulk density (kg m-3)	0.2	0.02	0.07-0.30	0.1	0.02	0.03-0.27	0.1	0.02	0.03-0.26
number of samples	6			6			6		

III Discussion and Management Implications

1. Effectiveness of Treatments on Fuels and Potential Fire Behavior

Overall, there were statistically significant changes in fuel loading and configuration with all types of treatments across all vegetation types. The fuel components that changed and the magnitude of the change varied by treatment type and vegetation type.

Prescribed fire treatments showed significant reductions in most, or all, surface fuel components, as well as significant increases in canopy base height. Mechanical treatments showed significant reductions in canopy fuels, particularly tree density, canopy cover, and canopy bulk density—as well as significant increases in canopy base height. Depending on the type of mechanical treatment, varying effects occurred on surface fuels.

When all mechanical treatments were averaged within a vegetation group, there were no changes in some surface fuel components and statistically significant increases in other components—especially 10 and 100-hour loadings. While different mechanical treatments resulted in different changes, there was insufficient data to apply format statistical tests. These findings should therefore be considered preliminary.

In general, mechanical treatments that included whole tree yarding result in similar surface fuel conditions before and after treatment. This is because the material removed is from the crown fuels with minimal change to preexisting surface fuels, except for what is displaced by equipment operations.

When mechanical treatments include piling or burning surface fuels, a reduction in surface fuels occurs post-treatment. Mastication or other similar treatments result in a rearrangement—and sometimes compaction—of fuels from a live understory or 1,000 fuel component to 10 or 100-hour fuel components. Dead surface fuel depth may be increased or decreased depending on the type of equipment used to masticate the fuels and the contract specifications (whether it is incorporated into the soil or not).

One of the key management questions is how long treatments last. Unfortunately, there are very limited numbers of sites that had been measured at 5-years post fire. Conclusions on the longevity of these treatments are not possible at this time. Additional data at 5-years post-treatment—or even longer time periods—would be necessary to address longevity.

2. Recommendations for Post-Treatment Fuel Model Assignments

Assigning fuel models for fire behavior modeling is both an art and science (Alexander 2007). It requires a careful—often site-specific—examination of conditions on the ground and knowledge—based on experience—of fire behavior potential.

The commonly applied fire behavior prediction systems, such as BEHAVE, NEXUS, and FARSITE are based on underlying fire behavior models of Rothermel. Rothermel's surface fire spread models utilize surface fuel model characteristics that are not measured directly in the field (surface area to volume ratio and bulk density) but, rather, are derived from related measures in the field (counts of 1-hour fuels).

In essence, these models are mathematical representations of a complex, three-dimensional array of fuel loading and arrangements.

To date, the mathematical representation is not perfect. Therefore, the most important step in selecting a fuel model that will yield reasonably accurate fire behavior predictions is experience and knowledge of what fire behavior to expect for a given set of conditions.

The monitoring data provide a detailed set of inputs for the mathematical representation but not necessarily the final fuel model selection that will result in a reasonable prediction of fire behavior. There is no substitute for time spent on the ground observing the fuels at a particular site and the experience of observing fire behavior with varied fuels and weather or topographic conditions.

Wide Variety of Fuel Conditions

There were a wide variety of fuel conditions at the monitoring sites both before and after treatment. There is no simple set of rules that can be applied to predict post-fire fuel models. The fuel models assigned after treatment tend to be related, in part, on what was assigned *before* treatment.

For example, if there was high, live understory vegetation cover pre-fire that resulted in assignment of a fuel model such as 165, then the post-treatment fuel model generally stayed in the same group (to 163 or less), but often moved to a lower fuel loading.

The trends are most apparent within the prescribed burn treatments and less apparent with the mechanical/manual treatments. This is because there was a variety of mechanical/manual treatments applied on top of the varied pre-fire conditions.

The next part of this section (beginning on next page) provides is a summary of post-treatment fuel model assignments and recommendations for model assignments by both vegetation and treatment type. These should be considered guidelines. The assignment for any situation (burn plan or fire management plan, etc.) should be based on site-specific information and knowledge. In general, there is not a set of fuel models designed specifically to characterize post-treatment fuel conditions for fire behavior modeling. However, there are a wide array of fuel models developed by Scott and Burgan (2005), in addition to the original thirteen models (Anderson 1982) that can be reasonably applied.

A. Prescribed Fire Treatments

Ponderosa and Yellow Pine Vegetation Type

Due to the varying understory and primary surface fuel components, the pre- and post-treatment fuel model assignments varied in this type, including:

- ❖ A high grass and low dry shrub component group,
- ❖ Others groups dominated by timber litter or broadleaf litter, and
- ❖ Even other groups dominated by live shrubs and timber litter.

Pre-treatment, most sites were assigned to fuel models in the timber litter group (180's), especially in the moderate load (183) and long needle litter (188) models. There were also a few sites that were assigned to the following models: Small, downed log (184), High load conifer litter (185), Moderate load broadleaf litter (186), Low load dry climate timber-grass-shrub (161), and Very high load dry climate timber-shrub (165).

In addition, there were several sites with a dry shrub component that were assigned to types in the dry climate shrub group (140s), including the low load (141) and moderate load (142) models. After treatment, most of the sites assigned in the timber litter group (180's) moved into the low load compact conifer litter model (181)—that has the lowest loading for the group.

Those that started with higher loadings (such as 188) moved into the moderate load conifer litter model (183). The sites that started as very high load, dry climate timber-shrub models (165) moved into the low load, dry climate timber-grass-shrub model (161). The sites that started in the dry climate shrub group (140s) moved mostly into the short, sparse, dry climate grass model (101)—or, into the low load, dry climate shrub-grass model (121).

Douglas-fir and White Fir Vegetation Type

Pretreatment, most sites were assigned to fuel models in the timber litter group (180s). The moderate load conifer litter (183), small downed logs (184), and high load conifer litter (185) models were most common.

After treatment, these sites shifted to the low load, compact conifer litter (181) or the moderate load conifer litter (183) models. Twenty percent of the plots were assigned to the very high load dry climate timber-shrub model (165) pre-treatment. Post treatment, these were reduced to low-load, dry-climate timber-grass-shrub model (161).

After two years, some sites shifted from the low load, compact conifer litter model (181) to the moderate-load conifer litter model (183). As understory sprouting plants increased in cover, other sites shifted into the low load, dry climate timber-grass-shrub model (161).

B. Mechanical Treatments

Sites treated with prescribed fire fit more readily into the set of 40 fuel models than those treated with mechanical treatment. This is due in part to the wide variety of mechanical treatments applied along with pre-treatment fuel conditions.

There was too great of variation among post-treatment conditions to make broad recommendations for post-treatment surface fuel models. At least eleven different types of mechanical/manual treatments were applied, including:

- Mastication,
- Mastication and pile burning,
- Thinning/chipping,
- Pile burning,
- Thin/pile,
- Thin/pile burning,
- Thin/salvage/biomass,
- Thin/biomass,
- Thin/dozer pile, and
- Thin.

The mastication treatments, alone, included application of varied equipment, contract specifications, and material masticated—as a result, the fuels vary greatly. There were no more than five plots in each category and often as few as two.

Before generalizations can be made on appropriate post-treatment fuel models, further monitoring and research will be necessary to quantify the effects of these varied treatments on fuel conditions.

IV References

Alexander, M.E. 2007. Simple question; difficult answer: How much fuel is acceptable? Fire Management Today 67(3): 6-11.

Andrews, P.L., Bevins, C.D., and Seli, R.C. 2005. BeharvePlus fire modeling system. Version 3.0. User's guide. USDA For. Serv. Gen. Tech. Rep. RMRS-GTR-106WWW.

Andrews, P.L. 1986. BEHAVE: fire behavior prediction and fuel modeling system- BURN subsystem, Part 1. USDA For. Serv. Gen. Tech. Rep. INT-194.

Albini, F. A.; Baughman, R. G. 1979. Estimating windspeeds for predicting wildland fire behavior. Res. Pap. INT-221. Ogden, Utah: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 12 p.

Anderson, H. E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Brown, James, K. 1974. Handbook for inventorying downed woody material. Intermountain Forest and Range Experiment Station. USDA Forest Service, Ogden, Utah.

Brown, J.K., R.D. Oberhau, and C.M. Johnston. 1982. Handbook for inventorying surface fuels and biomass in the interior west. USDA Forest Service, Intermountain Forest and Range Experiment Station General Technical Report INT-129. (Ogden, UT)

Crosby, J.S.; Chandler, C.C. 2004. Fire Management Notes.Get the most from your windspeed observations. Vol. 64, No. 1, Winter 2004. Reprinted from: Fire Control News 27(4): 12-13, 1966.

Finney, M. A. 2006. An overview of FlamMap modeling capabilities. In: Andrews, P. L.; Butler, B. W., comps. 2006. Fuels Management – How to Measure Success: Conference Proceedings. 28-30 March 2006; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U. S. Dept. of Agriculture, Forest Service, RMRS. 809p.

Finney, M. A. 1998. FARSITE: Fire Area simulator -- model development and evaluation. USDA For. Serv. Res. Pap. RMRS-RP-4.

FSMC Staff, 01/04/05, FORTRAN code file: FMCROWW.F, USDA Forest Service Forest Management Service Center, Fort Collins, CO.

Lutes, D.C., Keane, R.E., Caratti, J.F., Key, C.H., Benson, N.C., Sutherland, S. and Gangi, L.J. 2006. FIREMON: The fire effects monitoring and inventory system. Gen. Tech. Rep RMRS-GTR-164-CD, U.S. Department of Agriculture, Forest Service, Rocky Mountain

Research Station, Fort Collins, CO. 1 CD. Information available at the fire.org website: www.fire.org.

McCulloch, C. E. and S. R. Searle. 2001. Generalized, Linear, and Mixed Models. John Wiley & Sons, Inc., New York; 325p.

Miller, Rupert G., Jr. 1981. Simultaneous Statistical Inference. Spring-Verlag, New York.

Mori, Sylvia. Personal communication. Pacific Southwest Research Station. 800 Buchanan Street, West Annex Building, Albany, CA 94710-0011.

Nelson, R. M. 2000. Prediction of diurnal change in 10-h fuel stick moisture content. Can J. For Res. 30: 1071-1087.

Neter J. and W. Wasserman. 1974. Applied Linear Statistical Models. Richard D. Irwin, Inc., Homewood, Illinois.

Norius, M.J. 1999. SPSS for Windows.

Reinhardt, Elizabeth; Crookston, Nicholas L. (Technical Editors). 2003. The Fire and Fuels Extension to the Forest Vegetation Simulator. Gen. Tech. Rep. RMRS-GTR-116. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 209 p.

Reinhardt, E.D. and Crookston, N.L. (*Editors).* 2003. The Fire and Fuels Extension to the Forest Vegetation Simulator. USDA For. Serv. Gen. Tech. Rep. RMRS-GTR-116.

Reinhardt, E., Scott, J., Gray, K. and Keane, R. 2006. Estimating canopy fuel characteristics in five conifer stands in the western United States using tree and stand measurements. Can. J. For. Res 36: 1 - 12.

Reinhardt, E., Lutes, D., and J. Scott. 2006. FuelCalc: A method for estimating fuel characteristics. In: Andrews, P., Butler, B., comps. 2006. Fuels Management – How to Measure Success: Conference Proceedings. 2006 28-30 March; Portland, OR. RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 10 p.

Scott, J. H.; Burgan, R. E. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.

Scott, J.H., and Reinhardt, E.D. 2001. Accessing crown fire potential by linking models of surface and crown fire behavior. USDA for. Serv. Res. Pap. RMRS-RP-29.

Scott, J.H. 1999. NEXUS: a system for assessing crown fire hazard. Fire Manage. Notes, 59:21-24.

United States Department of Interior National Park Service (USDI). 2001. Fire Monitoring Handbook. Boise (ID): National Interagency Fire Center. 288p. Wilson, L. 2006. GAMMA Canopy Fuels. Unpublished.

USDA, Forest Service, and USDI, Bureau of Land Management. 2001. The National Fire Plan: Managing the Impacts of Wildfires on the Communities and the Environment. [Online]: http://www.fireplan.gov/index.cfm

van Wagtendonk, J. W., J. M. Benedict, and W. M. Sydoriak. 1998. Fuel bed characteristics of Sierra Nevada conifers. Western Journal of Applied Forestry 13(3): 73-84.
SAS Institute, Inc. 2005. SAS procedures guide, version 9.1. Cary, North Carolina, USA

V Appendices

Appendix A: Monitoring Protocol and Data Analysis

1. Monitoring Protocol

A summary of the monitoring protocol is included in Table A-1. Except for chaparral, the protocol is largely based upon the National Park Service Western Monitoring Handbook (USDI 2000).

The layout includes nested, fixed area plots and replicated subplot transects and quadrats. To decrease plot set-up and measurement time, plot shapes for forest plots were modified from rectangular to circular. Additional sampling for vegetation cover was added.

Chaparral plots were based on sampling chaparral stem density for application of Pacific Southwest Station, Riverside and other regressions for fuel loading. Based on dominant vegetation and fuel characteristics, three different types of plots were installed: chaparral, forest, mixed forest and chaparral.

Because this was a pilot effort, some modifications to the protocol were made early in the analysis process—based on preliminary results. Variability within a project and time to install plots were two primary drivers for modifications. This included decreases in within-plot replicates for fuel and understory vegetation transects and quadrats (Table A-1). To capture more within-project variability rather than within-plot variability, this was paired by an increase in the number of understory plots per project.

Plots were randomly selected with a project, with three to six plots randomly placed in one to several project units. Originally, only three plots were sampled per project—a minimum number needed to provide data for program-wide analysis. In the second year, an additional three plots were sampled per project to gain a better sample of variability. Only understory fuels and vegetation were measured. To meet budget objectives, overstory fuels were omitted on the additional plots.

Chaparral Plots
The following (see Figure A-1) were installed in the chaparral plots:

- A combination of line intercept for cover, height by species, and status (live or dead); and
- Quadrats with stem density by diameter class, species and status (Figure A-1).

Sample timing did not consistently coincide with annual species growing season. Therefore, annuals are not sufficiently sampled.

Forest Plots
The modified NPS plot protocol was applied (Figure A-2). This included: sampling and measures for tree density; species; diameter; heights; crown heights; shrub, grass, and herb cover by species; total tree cover; understory surface fuels by time-lag sizes; and ground fuels.

Mixed Forest and Chaparral Plots
Where a mixture of forest and chaparral vegetation occurred—generally with more than 30 percent shrub cover—both forest and chaparral type plots were installed (Figure A-3).

Table A-1 – Summary of Field Measurement Details and Protocol Differences

	Measurement Details	Protocol 2001	Protocol 2003 and Later
Plot Layout	All plots GPSed, slope, aspect, and general observations noted.	Nested, circular plots (overstory, pole and seedling trees), **two** understory transects, and **four** fuels transects	Nested, circular plots (overstory, pole and seedling trees), **one** understory transect, and **two** fuels transects
Number & Type of Plots		3 detailed plots (trees and understory)	3 detailed plots (trees and understory), **plus 3 rapid plots (no tree data)**
Photo point Monitoring	Photos taken at the following locations: 1) Origin to Ref. Point, 2) Ref. Point to Origin, 3) Understory transects A-B, 4) B-A, 5) C-D, 6) D-C, and 7-10) Fuels Transects F1, F2, F3, F4	**Ten** photos taken at designated locations	**Six** photos taken at designated locations (does not include photo points A-B, B-A, F3 and F4)
Overstory Canopy Cover	Number of "hits" (0 to 25) recorded for overstory canopy which intersects points seen through Moosehorn scope at 1m intervals along 50m transect	Data collected along **two** 50m transects (A-B and C-D).	Data collected along **one** 50m transect (C-D).
Shrubs	Species, status (live/dead), range (dm), and height (cm)	Data collected along **two** 50m line intercept transects (A-B, and C-D).	Data collected along **one** 50m line intercept transect (C-D).
Herbs/Grasses	Species, cover class, status (live/dead),	Data collected in $1m^2$ quadrats along **two** 50m transects (A-B, and C-D).	Data collected in $1m^2$ quadrats along **one** 50m transect (C-D).
Surface Fuel	Bearing and slope recorded. 1 and 10hr fuels tallied from 0-6', 100hr from 0-12'. 1000hr fuel (0-50') includes species, diam, decay class. Litter/Duff depths (to nearest cm) at 5' interval points. Fuel depth (to nearest cm) measured as tallest intercept w/in 5' interval sections.	**Four** 50ft Brown's planar intercept transects.	**Two** 50ft Brown's planar intercept transects.
Overstory Trees (dbh ≥ 15cm)	Tree tagged, species, status (live/dead), diameter (nearest cm), canopy class, canopy base height and total tree ht measured to nearest meter with impulse laser. Decay class for snags.	Data collected w/in 1000 m^2 (17.85m radius) plot.	**Tree data not collected in rapid plots**
Pole Trees (dbh < 15cm, ≥2.54cm)	Same data collected as Overstory Trees	Data collected w/in 250 m^2 (8.72m radius) plot.	**Tree data not collected in rapid plots**
Tree Seedlings (dbh < 2.54cm)	Species, status (live/dead), height class	Data collected w/in 50 m^2 (3.99m radius) plot.	**Tree data not collected in rapid plots**
Post Fire Measures	Overstory and Pole sized trees: char, scorch, and torch heights measured to the nearest meter with impulse laser. NPS burn severity ratings assigned for soils and vegetation at three random points w/in plot vicinity.		**Tree data not collected in rapid plots**
Chaparral Plots	Photo points taken at 8 locations for each 5x5m subplot. Along upper (A-B) and lower (C-D) edge of each subplot, line intercept data is collected for shrubs: species, status (live/dead), range (dm), and max height (cm). Within 1m quadrats at the four corners of each 5x5m subplot, the following is collected: species, status (live/dead), max ht (cm), stem diam ave., and stem count. Litter/Duff thickness (cm) is collected at the four corners of each 1m quadrat. Herb species and cover class are collected w/in each 1m quadrat.	**Eight** 5x5m subplots	**Four** 5x5m subplots

Figure A-1 – Forest Plot Layout

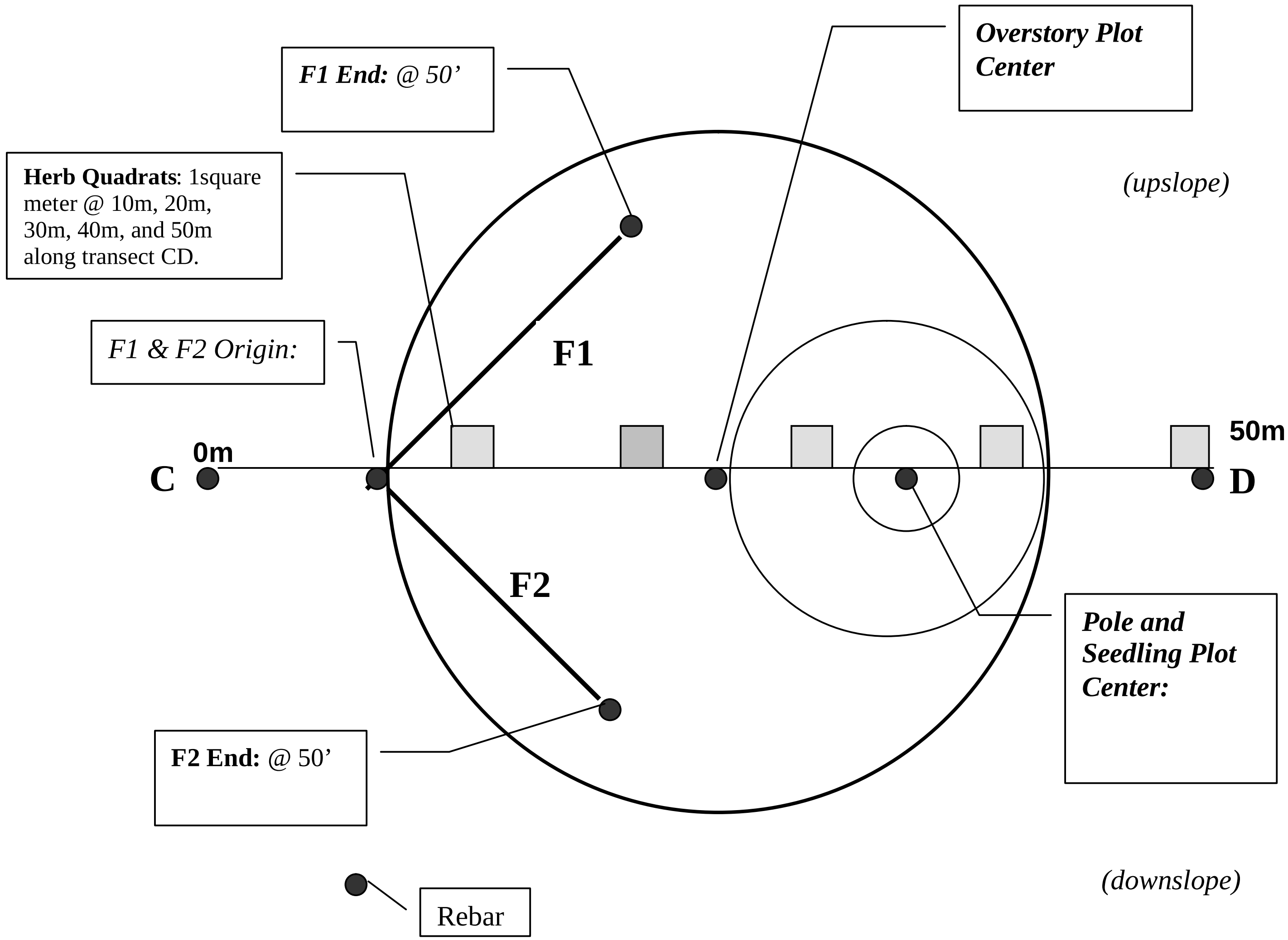


Figure A-2 – Chaparral Plot Layout

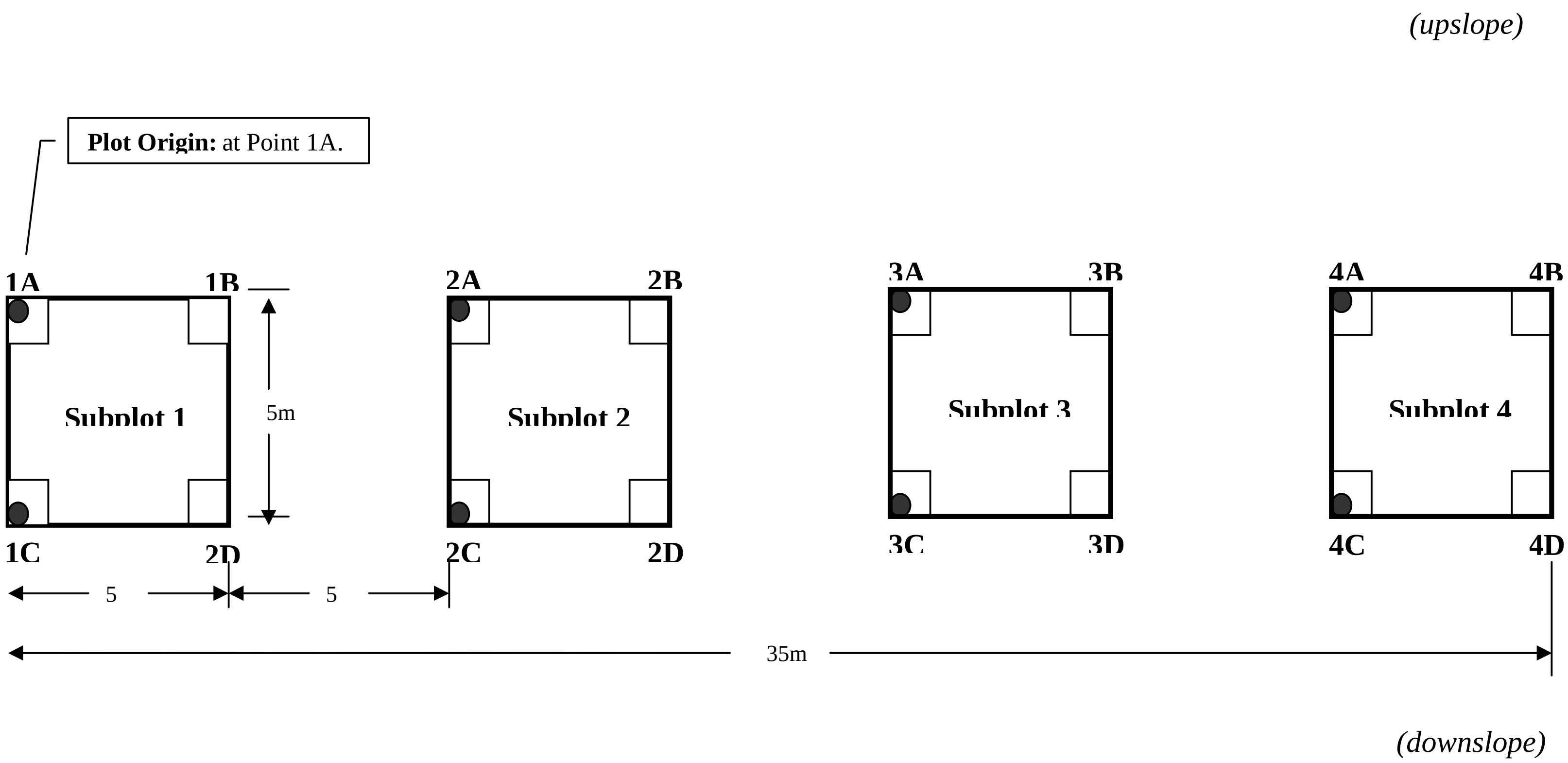
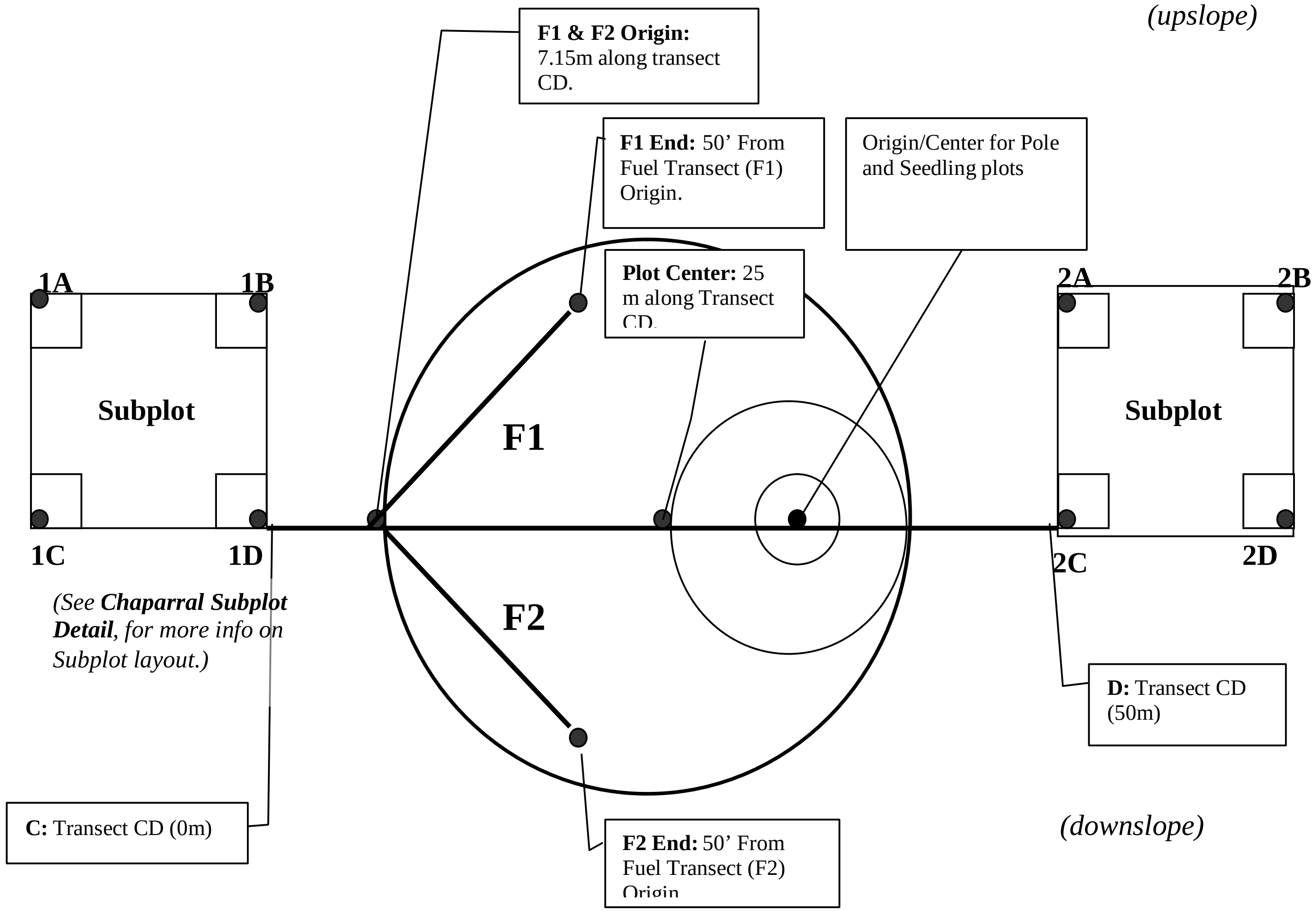


Figure A-3 – Mixed Forest Chaparral Plot Layout



2. Data Analysis

Data were entered into Access databases and Exel spreadsheets and analyzed primarily in the SPSS (Norius 1999) statistical software using custom programming code developed for the project. Exceptions were for some of the crown fuel and forest structure processed initially in GAMMA (Wilson 2006), a program developed in coordination with the Region 5 Lead Planning Analyst.

Formal statistical analysis of the monitoring data was conducted and is summarized in Appendix B (Statistical Analysis). This testing included whether fuels changed significantly after treatment and whether the change was an increase or decrease. Greater detail on the statistical analysis is included in the companion scientific papers. In addition to the formal statistical tests, tables and graphs with descriptive statistics were generated to portray the range of characteristics.

Vegetation

Canopy cover, based on Moosehorn readings, was computed in SPSS (Norius 1999). Tree density, basal area, and crown fuels were calculated in GAMMA (Wilson 2006), based largely on algorithms in the Forest Vegetation Simulator (FVS). Quadratic mean diameter was computed from the largest diameter trees, comprising 75 percent of the basal area.

Fuels

Fuel loadings were computed based on Brown (1974 and Brown and others 1982). Litter and duff loadings were based on the all "species" bulk densities from California forests (van Wagtendonk and others 1998). Canopy fuels, except for post-treatment, were calculated as in the FVS-FEE extension (Reinhardt and Crookston 2003).

Algorithms to assign crown mass in FVS-FEE do not vary with crown dimensions affected by treatments, particularly crown base height. To represent changes in canopy bulk density and canopy base height from increases in individual tree crown base heights after treatments, the fraction of crown volume reduced was multiplied by the average crown mass. This reduced crown mass number was then applied to the vertical distribution and calculations of canopy base height and canopy bulk density for the plot. Otherwise, for many tree species, measured changes in individual tree crown base height would not have been reflected in post-treatment changes in stand canopy base height or in canopy bulk density calculations.

Potential Fire Behavior

Predicted fire behavior was simulated using Nexus v2.0 (Scott 1999). A number of fire behavior variables are necessary to run Nexus, including the choice of fuel models, fuel moisture, canopy fuels, wind reduction factors, and 20-feet wind speed and direction. Output from Nexus includes plot-level fire behavior predictor variables such as fire type (surface, passive, conditional, or crown fire); crowning and torching indices; and other common surface and crown fire behavior variables (rate of spread, flame length, fireline intensity, etc).

Fuel Models
Fuel models for each plot were chosen for pre-treatment, post-1 year, post-2 year, and post-5 year measurements when applicable. Fuel models were chosen and evaluated by fire behavior analysts and researchers using both pictures and fuel loading information collected in the field.

Fuel Moisture
Fuel moisture values were first simulated using a fuel moisture conditioning model in FlamMap (Finney 2006). Using this model (Nelson 2000), dead fuel moistures for 10-hour fuels were conditioned for three days.

Dead fuel moisture conditioning computes predicted fuel moisture for each plot based on topography (slope, aspect, elevation); shading (cloud cover and canopy cover); weather; wind; and conditioning period length.

To do this, initial fuel moisture values were set to very low at 3, 4, 5, 30, 60 percent (1hr, 10hr, 100hr, live herbaceous, live woody fuel moistures in percent). These initial values were conditioned by aspect and slope and with wind and weather data generated in FARSITE (Finney 1998). This was done using 90^{th} percentile data from NOAA/NWS stations located within 15 miles of plot locations across California.

To force the simulation to maintain constant temperature and humidity for all plots, a mean elevation of 4500 feet was used for all of the plots. Wind files were used only to condition initial fuel moisture values for dead woody fuels.

Wind speed and Adjustment Factor Selection
Monthly average wind speed—based on hourly observations—was taken from 96 airports located across California. This data set, provided by the Western Regional Climate Center, was used because it best represented the entire region of California with hourly wind observations.

Using these data, 90^{th} percentile wind speed was 11 mph for the month of August from 1992 through 2002. Crosby and Chandler's wind gustiness table (2004) was used to account for possible wind gust speeds not captured with wind speed averages and resulted in probable momentary gusts of 23 mph. Wind speeds of 11 and 23 mph were used for separate simulations.

Wind adjustment factor was computed using methods created by Albini and Baughman (1979), modified by J. Scott (pers. Comm.) to account for cover present. Wind adjustment factor is computed as a function of cover (canopy cover, stand height, and crown ratio). Wind adjustment factors were computed from the top of the fuelbed to a height above ground, equal to two times the fuelbed depth.

3. Grouping Plots into Vegetation/Fuel Groups

Plots were assigned to vegetation types subjectively based on the dominant tree or shrub species, grouped by similarities in fuel characteristics and expected fire behavior. Therefore, those with long-needle pines (ponderosa or Jeffrey pine) were grouped and those with short-needles (white fir or Douglas-fir) were also grouped. A red fir group was separated from the white fir-Douglas-fir group because of differences in fuel characteristics from smaller needles, less productive environment with slower fuel accumulation, and greater compaction from snow.

Appendix B: Statistical Analysis

1. Model

The model used to compare treatment level (type) and status (before/after) was a 2-way ANOVA model for repeated measures in plots nested in blocks. This ANOVA model belong to the family of Mixed General Linear Models (McCulloch, C. E. and S. R. Searle. 2001). Statistical analysis was conducted using SAS (SAS Institute 2005). Plots were used as replicates, although there is some possibility that plots from the same project could be considered pseudoreplicates. We included project as a factor to account for this potential error. Post-hoc tests for pre and post differences within individual vegetation/treatment groups were conducted using the Bonferroni statistic.

To maintain ANOVA assumptions, the data were first tested for normality with the Kolmogorov-Smirnov test using SPSS (Norius 1999) and the Levene's test in SAS. If variables were found to be significantly non-normal, data were normalized with a natural log or square root transformation and unbiased estimators (back-transformed means) were used in statistical analysis. To assess the effect of treatment through time on different types of vegetation, tests of pairwise comparisons of mean responses or transformed mean responses were performed assuming an ANOVA model for repeated measures from the family of the Mixed General Linear models (Neter and Wasserman 1974, McCulloch and Searle 2001). Because not all treatments were applied to all vegetation types, a combined vegetation-treatment was created. The resulting 5 vegetation-treatment types are listed in Table B-1. Contrast statements were used to pairwisely compare the vegetation types and treatments.

Table B-1 – The following five vegetation-treatment groups were compared: Doug-RX, Doug-mech, Yellow-RX, Yellow-mech and Red-mech. Sample numbers for other vegetation and treatment types were not high enough for statistical analysis.

	Prescribed Fire	Mechanical
Short Needle Dominated Types with Douglas-fir and White Fir	Doug-RX	Doug-mech
Ponderosa and Yellow Pine Dominated	Yellow-RX	Yellow-mech
Red Fir		Red-mech

The assumed ANOVA model for repeated measures is:

Response=Veg_Treat + Status + Veg_Treat-Status-interaction + error1+error2+error3

"Status" is the year before or after treatment, "error1" is the random effect due to site, "error2" is the random effect due to plot nested within site, and "error3" is the residual error. The assumption of these random effects in the model accounts for the effect of repeated measures.

The parameters and parameter's contrasts were estimated with SAS (v.9.1.3) MIXED procedure, and the pairwise comparisons' significance was assessed using the Bonferoni's approach (Miller 1981) to conform the experiment-wise error rate of 0.05 (S. Mori, pers. comm.).

2. Results

Overall, there were significant differences between treatment types and the interaction of treatment type and status (pre or post treatment). There were significant changes in many of the individual fuel components with treatment in each vegetation and treatment group (Table B-2). There were differences in the fuel components that changed and direction (increase or decrease) among vegetation and treatment groups.

Prescribed Fire Treatments
Prescribed fire treatments resulted in statistically significant decreases in surface and ground fuel loading for four to six individual components (duff, litter, 1-hour to 100 hour, fuelbed depth). Litter, duff and 10-hour loadings and fuel bed depth all decreased significantly after prescribed fire treatments in both Douglas-fir/white fir and yellow pine plots.

While one-hour fuel reductions were marginally significant in the yellow pine group, this does not include the litter, which is the primary 1-hour component in most yellow pine dominated sites. In Douglas-fir/white fir plots, both 1-hour and 1000-hour fuel loadings also decreased significantly. Grass cover decreased significantly in both vegetation/fuels groups and herb cover as well in the ponderosa pine group.

Crown fuels and forest structure changed similarly between vegetation groups. Both had no significant change in canopy cover and significant increases in canopy base heights. In the Douglas-fir/white fir group, there were significant decreases in canopy bulk density and increases in quadratic mean diameter.

Manual/Mechanical Treatments
The effects of manual/mechanical treatments varied by vegetation/fuel group. There was no significant change detected in surface fuels in the red fir plots. Ten-hour fuels increased significantly in both yellow pine and Douglas-fir/white fir plots. One-hundred hour loadings also increased significantly on yellow pine plots and 1000-hour loadings on Douglas-fir/white fir plots. Live shrub cover, shrub height, and herb cover all decreased significantly in the red fir group.

Nearly all canopy fuel and forest structure characteristics changed significantly across all vegetation/fuel groups. Canopy bulk density, tree density, basal area and canopy cover all significantly decreased. Canopy base height and quadratic mean diameter significantly increased.

Table B-2 – Results of statistical tests between pre- and 1-year post-treatment fuel and vegetation parameters. Statistically significant changes from pre to post are illustrated, denoted as: a symbol means that there was a significant difference, a + symbol denotes an increase, and a - symbol represents a decrease. Bold symbols indicate they were significant at p=.01, and regular symbols signify that they were significant at =-.05. Other differences that were significant at a probability level greater than 0.05 but less than 0.15 are show in parentheses with the actual p-value noted. ns denotes non-significant (used only for live/dead shrub variables).

	Yellow Pine		**Douglas-fir/White fir**		**Red fir**
	Prescribed Fire	***Manual /Mechanical***	***Prescribed Fire***	***Manual /Mechanical***	***Mechanical***
Surface Fuels					
1-hour	(-, p=.14)		**-**		
10-hour	-	**+**	**-**	+	
100-hour		**+**			
1000-hour			**-**	**+**	
litter weight	**-**		**-**		
duff weight	**-**		**-**		
fuel depth	**-**		**-**		
Crown Fuels					
canopy base height	**+**	**+**	**+**	**+**	**+**
canopy bulk density		**-**	-	**-**	**-**
Vegetation Structure					
overstory tree cover (%)		**-**		**-**	**-**
tree density		**-**		**-**	**-**
basal area		**-**		**-**	**-**
qmd75		**+**	+	**+**	**+**
shrub cover (% live/dead)					**-/***ns*
shrub Height					**-**
herb Cover (%)	**-**				**-**
grass Cover (%)	**-**		-		

Appendix C: Additional Results

1. Seedling Densities and Composition

Changes in mean total and by species seedling densities were described (Tables C-1 to 7) but not tested statistically.

Yellow Pine Plots Treated with Prescribed Fire				
Species common name	Seedlings per acre			
	Pre	Post1	Post2	Post5
	Softwoods			
Douglas-fir	644 (2310)	21 (93)	354 (1102)	2873 (2346)
incense cedar	1122 (3201)	38 (149)	2569 (9698)	0 (0)
Jeffrey pine	23 (89)	9 (26)	17 (74)	0 (0)
ponderosa pine	119 (324)	17 (43)	209 (853)	0 (0)
sugar pine	27 (86)	0 (0)	0 (0)	0 (0)
western white pine	4 (18)	0 (0)	0 (0)	0 (0)
white fir	1684 (4890)	4 (19)	1014 (2178)	0 (0)
unknown fir	0 (0)	13 (56)	34 (149)	0 (0)
unknown pine	0 (0)	0 (0)	77 (236)	0 (0)
	Hardwoods			
big leaf maple	35 (56)	13 (56)	13 (56)	0 (0)
black oak	316 (752)	107 (260)	337 (898)	81 (0)
California bay laurel	0 (0)	0 (0)	5 (19)	0 (0)
canyon live oak	200 (704)	17 (74)	94 (316)	0 (0)
California nutmeg	42 (98)	47 (119)	89(243)	0 (0)
Pacific dogwood	890 (801)	243 (n/a)	728 (n/a)	0 (0)
Pacific madrone	8 (35)	4 (19)	0 (0)	0 (0)
tan oak	0 (0)	72 (221)	703 (2837)	0 (0)
unknown hardwood	0 (0)	4 (19)	0 (0)	202 (286)
Data Representation	Number of Plots			
	21	19	19	2

Table C-1. Changes in seedling densities by species in the yellow pine type after prescribed fire.

Yellow Pine Plots Treated with Mechanical Methods			
Species common name	Seedlings per acre		
	Pre	Post1	Post2
	softwoods		
Douglas-fir	63 (161)	818 (1248)	81 (162)
incense cedar	9 (27)	72 (187)	845 (1529)
lodgepole pine	0 (0)	18 (54)	0 (0)
Ponderosa pine	2194 (6372)	189 (537)	270 (719)
sugar pine	90 (196)	135 (176)	18 (54)
western white pine	90 (216)	36 (108)	9 (27)
unknown pine	0 (0)	0 (0)	1295 (2779)
	hardwoods		
black oak	144 (288)	153 (231)	54 (90)
canyon live oak	18 (54)	180 (336)	36 (82)
scrub oak	0 (0)	0 (0)	27 (81)
tan oak	162 (360)	0 (0)	0 (0)
Data Representation	Number of plots		
	9	9	9

Table C-2. Changes in seedling densities by species in the yellow pine type after mechanical treatment.

Yellow Pine Treated with Wildfire			
Species common name	Seedlings per acre		
	Pre	Post1	Post2
black oak	27 (47)	0 (0)	0 (0)
Data Representation	No. of Plots		
	3	3	3

Table C-3. Changes in seedling densities by species in the yellow pine type after wildfire.

Douglas-fir, white fir Treated with Prescribed Fire				
Species common name	Seedlings per acre			
	Pre	Post1	Post2	Post5
	softwoods			
Douglas-fir	61 (38)	172 (455)	425 (987)	0 (n/a)
incense cedar	0 (0)	324 (765)	71 (101)	0 (0)
ponderosa pine	0 (0)	132 (372)	152 (429)	81 (n/a)
sugar pine	425 (1074)	40 (114)	10 (29)	728 (n/a)
white fir	374 (574)	364 (846)	111 (188)	0 (0)
unknown pine	0 (0)	0 (0)	293 (564)	0 (0)
unknown softwood	0 (0)	567 (1602)	20 (57)	0 (0)
	hardwoods			
black oak	486 (1062)	132 (237)	223 (434)	243 (n/a)
canyon live oak	0 (0)	0 (0)	1507 (4264)	0 (0)
Pacific dogwood	81 (n/a)	2347 (n/a)	1457 (n/a)	0 (0)
Pacific madrone	142 (401)	0 (0)	0 (0)	0 (0)
tan oak	1568 (2805)	40 (114)	526 (1049)	0 (0)
unknown hardwood	0 (0)	0 (0)	223 (630)	0 (0)
Data Representation	Number of Plots			
	8	8	8	1

Table C-4. Changes in seedling densities by species in the short-needled, Douglas-fir/white fir type after prescribed fire.

Yellow Pine Treated with Mechanical Methods and Prescribed Fire				
Species common name	Seedlings per acre			
	Pre	Post1	Post2	Post5
	softwoods			
Douglas-fir	850 (286)	0 (0)	0 (0)	283 (172)
incense cedar	0 (0)	0 (0)	0 (0)	162 (229)
ponderosa pine	0 (0)	0 (0)	0 (0)	1497 (401)
sugar pine	0 (0)	0 (0)	0 (0)	1619 (114)
	hardwoods			
black oak	0 (0)	121 (172)	40 (57)	40 (57)
canyon live oak	769 (1087)	0 (0)	121 (172)	202 (286)
tan oak	6030 (2461)	7365 (9615)	445 (630)	2752 (114)
Data Representation	Number of Plots			
	2	2	2	2

Table C-5. Changes in seedling densities by species in the yellow pine type after mechanical methods and prescribed fire treatments.

Douglas-fir, white fir Treated with Mechanical Methods			
Species common name	Seedlings per acre		
	Pre	Post1	Post2
	softwoods		
Douglas-fir	35 (43)	2725 (6478)	863 (1998)
red fir	12 (31)	0 (0)	0 (0)
sugar pine	23 (39)	13 (33)	13 (33)
white fir	0 (0)	13 (33)	13 (33)
unknown pine	0 (0)	0 (0)	148 (363)
	hardwoods		
black oak	648 (1643)	1174 (2719)	540 (1207)
canyon live oak	1214 (1716)	1295 (2640)	1228 (2586)
Oregon white oak	127 (337)	283 (551)	526 (1069)
Pacific madone	0 (0)	13 (33)	13 (33)
tan oak	6128 (16178)	8539 (20876)	1470 (3562)
Data Representation	Number of Plots		
	7	6	6

Table C-6. Changes in seedling densities by species in the short-needled, Douglas-fir/white fir type after mechanical treatments.

Red Fir Treated with Mechanical Methods			
Species common name	Seedlings per acre		
	Pre	Post1	Post2
	softwoods		
red fir	2752 (917)	809 (256)	54 (98)
sugar pine	0 (0)	0 (0)	13 (33)
western white pine	0 (0)	54 (132)	13 (33)
white fir	499 (1106)	229 (363)	283 (440)
unknown fir	12370 (27881)	0 (0)	0 (0)
unknown softwood	6246 (15299)	0 (0)	0 (0)
Data Representation	Number of Plots		
	6	6	6

Table C-7. Changes in seedling densities by species in red fir type after mechanical treatments.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and, where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD).