

# 2014 King Fire Eldorado National Forest

## Fire Behavior Assessment Team Summary Report



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**Photos immediately before and after  
the fire at plot 6, and from video  
while the area burned.**



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# Introduction

Wildland fire management relies on quality fire behavior and resource effects predictions. Existing prediction models are based upon limited field data from wildfires, especially quantitative data. The Fire Behavior Assessment Team (FBAT) collects data to improve our ability to predict fire behavior and resource effects in the long-term and provides short-term intelligence to wildland fire managers and incident management teams on fire behavior, fuels, and effects relationships. Increasing our knowledge of fire behavior is also important to firefighter safety; so we can mitigate hazards and prevent accidents. FBAT has seen their data used for a variety of purposes (see Appendix C) and is working to facilitate further applications to safety zone research, fire and fire effects model evaluation, and fuel treatment effectiveness assessments.

This report contains the results of a one and a half week assessment of fire behavior, vegetation and fuel loading, consumption, and fire effects for the King Fire. The King fire started on September 13th, 2014 due to arson. The fire started near Pollock Pines, CA and grew to over 97,000 acres. The fire ran an amazing 15 miles to the northeast towards Desolation Wilderness between September 17<sup>th</sup> and 18<sup>th</sup>. The fire destroyed 12 homes and 68 minor structures, caused the evacuation of several thousand residents, and air quality impacts for a large area.

Fuels and vegetation plots and fire behavior equipment were installed at 10 locations in the vicinity of the King fire, but only three were burned by the fire. FBAT installed plots between September 17<sup>th</sup> and 23<sup>rd</sup>. Fire growth was significant in the first three days of burning and then slowed with changes in weather. The greatest acreage burned was between the 17<sup>th</sup> and 19<sup>th</sup> (Figure 2). Three plots burned in the days following the large run when there was minimal fire perimeter growth.

## **Objectives**

Our objectives were to:

1. Characterize fire behavior and quantify fuels for a variety of fuel conditions, especially fuel treatment areas. Safety considerations, access, and current fire conditions restrict which areas can be measured.
2. Gather energy transport data during actively burning fires, in conjunction with site characteristics, for the Missoula Fire Lab's safety zone research.
3. Gather and measure representative vegetation and fuel samples to calculate moisture content to support emission and fire behavior modeling.
4. Assess fire severity and effects based on immediate post-fire measurements.

# Approach/Methods

FBAT selects study sites to represent a variety of fire behavior and vegetation/fuel conditions. Plot selection priorities are also based on safe access and areas that would most likely be burned over within the timeframe that FBAT could be at the incident. Within each plot both fuels and fire behavior data are gathered; a graphic of a plot set up is shown below (Figure 1), though the plot layout changes based on terrain, fuels, and additional objectives (radiant and convective heat for safety zone dataset). The map (Figure 2) displays daily fire progression and approximate plot locations.

Figure 1: Schematic of FBAT fuels and fire behavior study site.

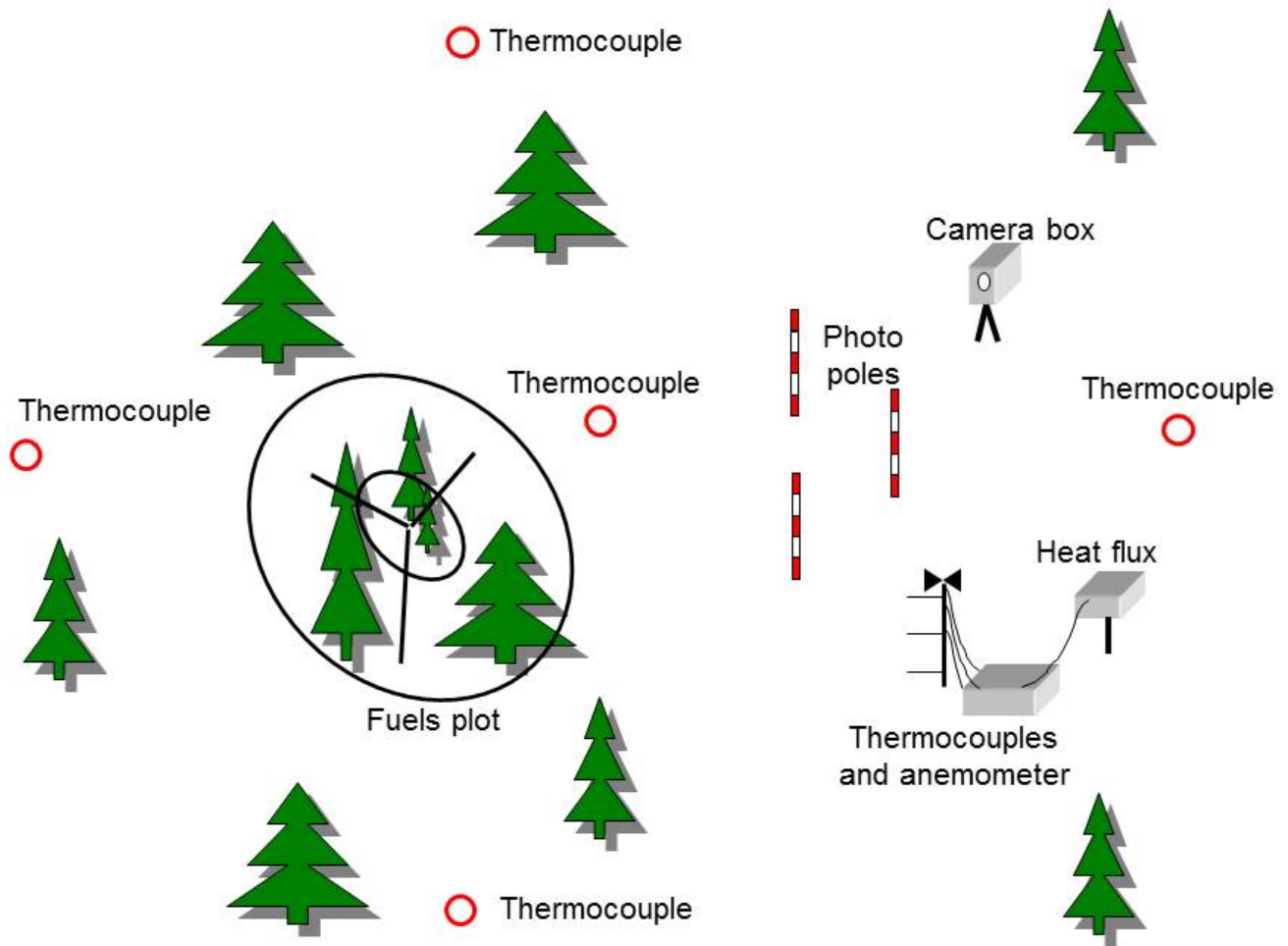
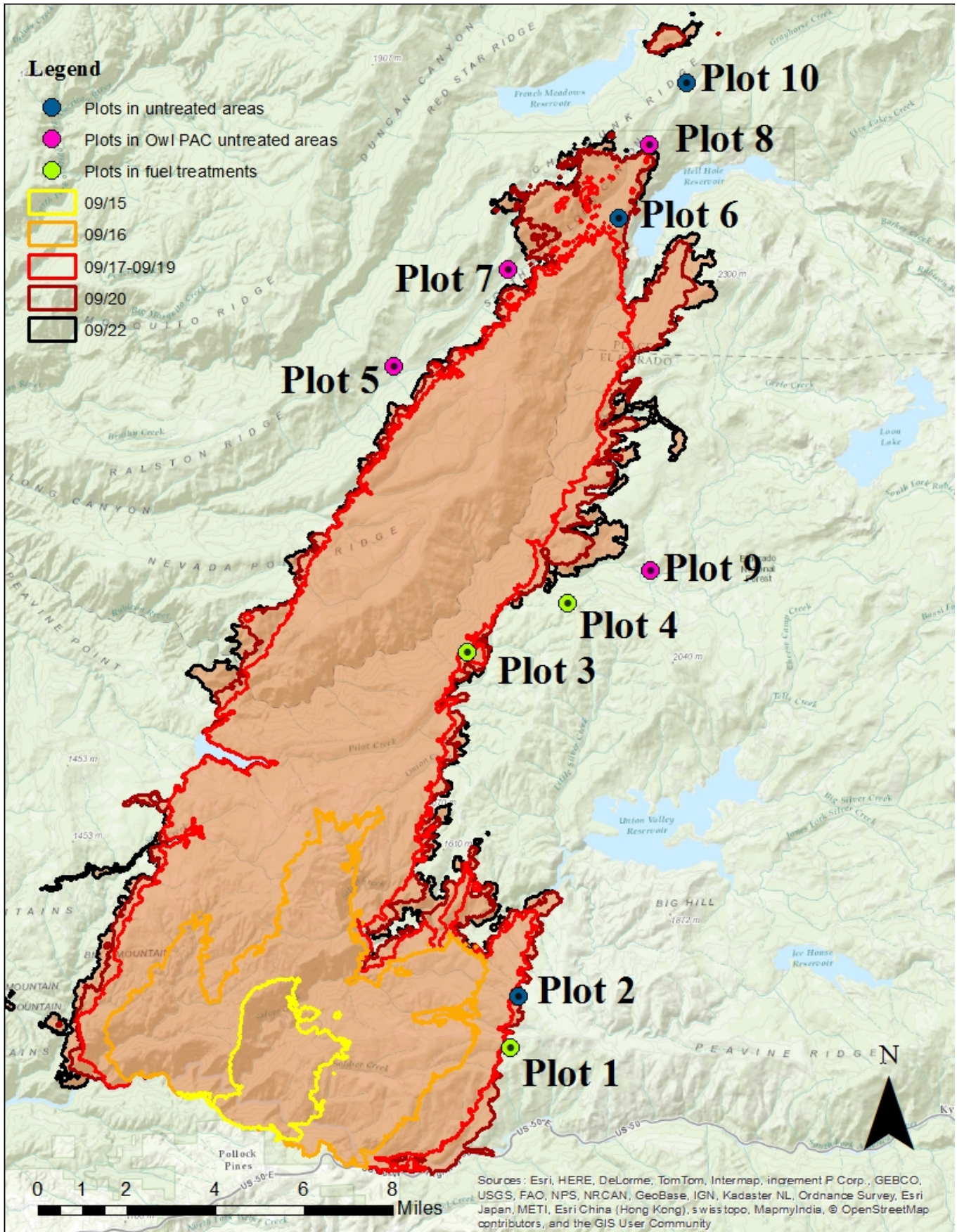


Figure 2: Fire progression and location of FBAT fuels and fire behavior plots in the King Fire. Note the progression date does not always match the date fire behavior was captured due to green islands burning and the time of day of infra-red mapping.



## **Pre- and Post-Vegetation and Fuel Measurements**

Vegetation and fuels were inventoried both before the fire reached each plot and then again after the fire at plots. Plots were marked with rebar to provide options for long term monitoring (Figure 3).

Figure 3. Re-measuring trees post-fire at plot 3.



### **Overstory Vegetation Structure and Crown Fuels**

Variable radius sub-plots were used to characterize crown fuels and overstory vegetation structure. A relescope (slope-correcting tree prism) was used to create individual plots for both pole (>2.5 to 5.9 in diameter at breast height (DBH) and overstory (>6 in DBH) trees. When possible a basal area prism factor was selected to include between 5 and 10 trees for each classification. Tree species, status (alive or dead), DBH, height, canopy base height, and crown classification (dominant, co-dominant, intermediate or suppressed) was collected for each tree before the fire. Tree height measurements were completed with a laser rangefinder; DBH was measured with a diameter tape.

After the fire, maximum bole char, crown scorch, torch heights and percentages scorch and torch were recorded for each tree. After fire, trees were assumed to be alive if any green needles were present. Changes in canopy base height were estimated from heights of scorch and torch on tree branches, or if necessary from percent of scorch rather than the maximum heights because uneven scorch values occurred sometimes due to trees affected by slope and alignment with heat. Because of smoke and poor lighting, visibility of the full crown is sometimes difficult. If a more accurate assessment of tree survivorship in the plots is desired we recommend another plot visit next year.

The Forest Vegetation Simulator program (FVS, Crookston and Dixon 2005) and its Fire and Fuels Extension (FFE-FVS, Reban 2010) was used to calculate canopy bulk density, canopy base height, tree density, and basal area both pre- and post-fire. FVS/FFE-FVS is stand level growth and yield program used throughout the United States. The Western Sierra variant was used for all calculations.

### **Understory Vegetation Structure and Loading**

Understory vegetation was measured in a one meter wide belt along three 50-foot transects before and after the fire. The fuel and vegetation transects were always in view of the video camera (which will be described below in the “Fire Behavior Measurements and Observations” section). Species, average height and percent cover (based on an ocular estimation) were recorded for all understory shrubs, grasses and herbaceous plants. Biomass of live woody fuels (shrubs and seedlings) and live herbaceous fuels (grasses, herbs, subshrubs) were estimated using coefficients developed for the Behave Fuel Subsystem (Burgan and Rothermel 1984), but calculations were done on a spreadsheet (Scott 2005).

## Surface and Ground Fuel Loading

Surface and ground fuels were measured along the same three 50-foot transects as the understory vegetation at each plot. Surface fuel loadings (litter, 1-hr, 10-hr, 100-hr and 1000-hr time lag fuel classes and fuel height) were measured using the line intercept method (Brown 1974, Van Wagner 1968). One and 10-hr fuels were tallied from 0 to 6 ft, 100-hr from 0 to 12 ft and 1000-hr from 0 to 50 ft. Maximum fuel height was recorded from 0 to 6 ft, 6 to 12 ft and 12 to 18 ft. Litter and duff depths were measured at 1 and 6 ft. All measurements were taken both pre- and post-fire. The measurements were used to calculate surface and ground fuel loading with basal area weighted species specific coefficients (van Wagendonk *et al.* 1996; 1998); and ultimately percent fuel consumption.

## Burn Severity

A rapid assessment of burn severity was completed along each transect and for the entire plot area to document the effects of fire on the surface and ground (USDI National Park Service 2003). The National Park Service (NPS) uses fire severity ratings from 1 to 5 when evaluating fire severity. In this rating system 1 represents unburned areas, and 5 represents areas with high fire severity (Appendix B).

## Fire Behavior Measurements and Observations

At each plot, multiple sensors (thermocouples, heat flux sensors, and anemometers) and a video camera were set up to gather information on fire behavior. The thermocouples arrayed across the plot have the capability to capture day and time of temperatures from which rate of spread can be calculated. The heat flux sensors capture total, radiant, and convective heat flux from the flame front while the associated anemometers capture wind speed. The video camera is used to determine fire type, flame length, variability and direction of rate of spread, flame duration, wind direction and the direction of fire spread in relation to slope and wind. The sensors are described in more detail below.

Figure 4: Examples of fire behavior equipment set up at the King Fire.



## **Rate of Spread and Temperature**

Rate of spread was determined both by estimating rate of spread from video analysis and by calculating rate of spread with time stamps from sensors (data loggers with a thermocouple attached). The data loggers are buried underground with the thermocouple at the surface of the fuel bed. The thermocouple is able to record temperature up to six days or until the thermocouple and/or data logger is damaged by heat. The distances and azimuths among thermocouples were measured and these geometrical data and time of fire arrival were used to estimate rate of spread from Simard *et al.* (1984).

## **Fire Type**

Fire type is classified as surface fire (low, moderate or high intensity) or crown fire. Crown fire can be defined as either passive (single or group torching) or active (tree to tree crowning). Fire type was determined from video as well as post-fire effects at each plot. For example, plots where there was complete consumption of tree canopy needles indicate at least torching or passive crown fire.

## **Flame Length and Flaming Duration**

Flame length was primarily determined from video footage. If needed, flame length values could be supplemented by measured tree char height. Flaming duration was based on direct video observation and/or when temperature was measured, from those sensors as well.

## **Energy Transport**

Energy transport data are collected with a heat flux sensor, where flux refers to the rate of energy transfer onto the surface of the sensor measured in units of  $\text{kW/m}^2$ . As with other recent work (e.g., Frankman *et al.* 2012, Butler *et al.* 2014), we use a Medtherm® Dual Sensor Heat Flux sensor (Model 64-20T), along with calibration relationships derived from laboratory measurements and theory, to provide incident total and radiant energy flux. Radiant flux is detected behind a sapphire window while total flux is detected underneath a blackened surface on the face of the copper plug that houses the detectors. The difference between total and radiant flux is an estimate of convective flux to the sensor (e.g., Frankman *et al.* 2012). Though safety zone guidelines are based on radiant flux alone, Butler (2014) recommends a consideration of total heat flux. The maximum incident heat flux tolerable by firefighters (wearing nomex and protective head and neck equipment) was described as  $7 \text{ kW/m}^2$  by Butler and Cohen (1998) in their work on safety zone guidelines. Apart from firefighter safety, heat flux data are useful in developing a fundamental understanding of wildland fire spread and fire effects on trees and soils. Orientation of the sensor relative to the oncoming fire is critical and a successful data collection requires that the flame front approach the sensor within less than approximately  $\pm 30$  degrees of the sensor face (where perpendicular is 0 degrees). The sensor is placed at 1 m above the ground surface and, for small flames, may not be impacted directly by flames, resulting in low heat flux at the sensor.

## **Plot Wind Speed**

Wind data collected with cup anemometers placed 5 feet above ground at the locations of the heat flux sensors gives an indication of the wind experienced at each plot as the fire passed through. Wind data on plots with intense fire are only valid only up until the plastic anemometer melts or otherwise is compromised. Wind data were recorded at 1 second intervals and averaged over 10-seconds.



# Findings/Results

Pre-fire data were collected at all ten plots that we established on the King Fire, however post-fire fuels and fire behavior data were only collected at the three plots which burned (plots 2, 3, and 6). The ten plots represented different forest/vegetation types and management areas (Table 1). Paired photographs of plots with fuels data are available in Appendix A. Video cameras and rate of spread sensors functioned properly on plots 3 and 6. Unfortunately, mostly due to time constraints and equipment failures, wind speed was not collected successfully on plot 2, and heat flux measurements were only obtained on plot 3.

Table 1: Site description of the 10 plots.

Plot	Forest/Vegetation Type	FACTS History	Slope %	Aspect	Elevation (ft)
1	Mixed Conifer	Commercial thin 2012	21	250	4,764
2	Mixed Conifer	Untreated	18	300	4,966
3	Mixed Conifer	Commercial thin 2012	20	270	5,134
4	Mixed Conifer	Pre-commercial thin 2012	13	285	6,007
5	Mixed Conifer	Spotted owl PAC*	25	90	4,240
6	Mixed Conifer and shrub	Untreated	4	0	5,478
7	Mixed Conifer	Spotted owl PAC	30	130	4,842
8	Mixed Fir	Spotted owl PAC	25	320	6,204
9	Mixed Conifer	Spotted owl PAC	22	200	4,921
10	Mixed Fir	Untreated	23	140	6,379

\* PAC is a designated Protected Activity Center.

## Fuel Moistures

Fuel moistures were collected on 9/18/2014 approximately mid-day at the junction of Wentworth road and the 12N30Y road (GPS location on file). The samples were taken at 5,200 ft elevation on a 12-18 percent NW facing slope. Additional moistures were taken on the 9/21<sup>st</sup> and 23<sup>d</sup> to support the incident management team, however, these dates were after all FBAT plots were burned and after thunder showers, so are not presented here.

Table 2. Range of live fuel moisture percentages collected on 9/18/14 on the King fire.

Sample Type	Fuel Moisture %
Green leaf manzanita leaves, near roadside	61
Green leaf manzanita leaves	71 - 72
Ponderosa pine needles	112 - 123

## Pre- and Post-Vegetation and Fuel Measurements

### Overstory Vegetation Structure and Crown Fuels

Canopy base height, canopy bulk density, and canopy continuity are key characteristics of forest structure that affect the initiation and propagation of crown fire (Albini 1976, Rothermel 1991). Canopy base height (CBH), or the bottom of the tree canopy fuels, is important because it affects crown fire initiation. As stated in Scott and Reinhardt (2001), “Defined in terms of its consequences to crown fire initiation, CBH is the *lowest height above the ground* at which there is sufficient canopy fuel to propagate fire vertically through the canopy.” Canopy Bulk Density (CBD), is the mass of canopy fuel available per unit canopy volume (Scott and Reinhardt 2001).

Forest treatments that target canopy base height and canopy bulk density can be implemented to reduce the probability of crown fire (Graham *et al.* 2004). Canopy bulk density varies considerably within the stands measured on the King fire, and reaches a maximum value of 0.35 kg/m<sup>3</sup> at untreated plot 2 and a minimum value of 0.04 kg/m<sup>3</sup> at treated plot 3 prior to the King fire. Thinning to reduce canopy bulk density to less than 0.10 kg/m<sup>3</sup> is generally recommended to minimize crown fire hazard (Agee 1996, Graham *et al.* 1999), and for the most part below this point, active crown fire is very unlikely (Scott and Reinhardt 2001). Canopy bulk densities were at or below this threshold for King fire plots 3, 4, 7, 9, and 10 before the fire, and only one of these burned. Tree mortality and canopy fuel changes cannot be determined with certainty until one or more years post-fire due to delayed mortality effects and tree recovery rates. Based on immediate post-fire data, the CBD did not change post fire on plots 2 and 3 because surface fire did not transition to crown fire and consume canopy fuels. Canopy base height was reduced on plot 2 and 6, but on plot 3, canopy base heights were high pre-fire to not be greatly affected by the surface fire. The CBD changed dramatically on plot 6 due to the fire transitioning from shrub to tree canopy causing high mortality. Plot 6 data represents a higher tree density (trees/acre), canopy cover, and CBD compared to the general area due to the location of plot center near a cluster of oak and cedar regeneration. The higher shrub loading (Table 3) and shrub canopy cover that propagated fire into the tree canopy explains the high mortality rate and reduction in canopy fuels for plot 6. In plot 6, tree crowns were 100% scorched, and some had torching, with a maximum scorch height of 87 feet on a large pine. At plot 6 trees were estimated to be dead (100% scorched) for FVS-FFE analysis, a program that doesn’t calculate canopy characteristics for dead trees.

Table 3: Overstory tree and crown fuel data pre-fire and post-fire for plots 2, 3, and 6. QMD is the quadratic mean diameter based on tree data collected at the plot scale.

Site	Overstory (>6 in DBH) trees/acre		Pole-size (<6 in DBH) trees/acre		QMD (in)		Basal Area (ft <sup>2</sup> /acre)		Canopy Cover (%)		Canopy Height (ft)		Canopy Base Height (ft)		CBD (kg/m <sup>3</sup> )	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	103		0		12		82		26		39		5		0.13	
2	613	613	0	0	12	12	513	513	89	89	112	112	18	33	0.35	0.35
3	68	68	0	0	29	29	322	322	71	71	115	115	30	30	0.04	0.04
4	66		0		24		214		43		88		7		0.06	
5	61		244		15		386		63		116		8		0.13	
6*	678	0	756	0	8	0	512	0	100	0	40	0	1	0	0.16	0
7	53		0		21		182		43		92		12		0.07	
8	184		543		7		180		61		92		1		0.31	
9	51		97		15		181		52		70		3		0.07	
10	52		159		11		151		31		88		1		0.10	

\*Note that a zero in post-fire data where pre-fire data was greater than zero indicate all trees were scorched or torched and appeared dead at the time of post-fire sampling. FVS-FFE does not calculate canopy characteristics for dead trees.

## Fire Effects: Tree Canopy Scorch, Torch, and Bole Char

A few days after the fire burned through each plot (allowing for smoldering combustion to complete and some fire-weakened trees to fall) additional measurements were gathered (char height, maximum heights and percentage of crown scorch and torch) to better assess the fire effects at each plot. Percentage values were determined using ocular estimations, and heights were measured with a laser rangefinder. Severity or fire effects can be assessed from the percentage of scorch and torch for each study plot (Figures 5 and 6). On plots 2 and 3, the fire had only scorched (caused browning of) portions of tree canopies in the plots while the majority of tree canopies remained green. In plot 6, the entire canopy was either scorched or torched (foliage consumed). The average bole char height was essentially the same in all three burnt plots, but average height to live crown was lower in plot 6 explaining the higher maximum scorch heights and mortality.

Figure 5. Average live, scorch, torch per plot as a percentage of tree crown. The portion of tree crown which is still living (not scorched or torched) is labeled "green."

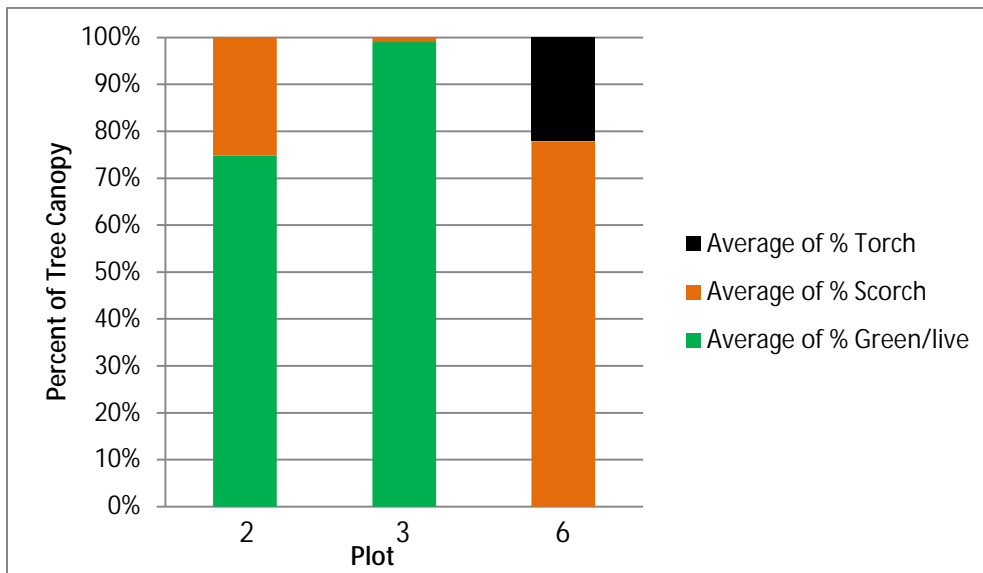
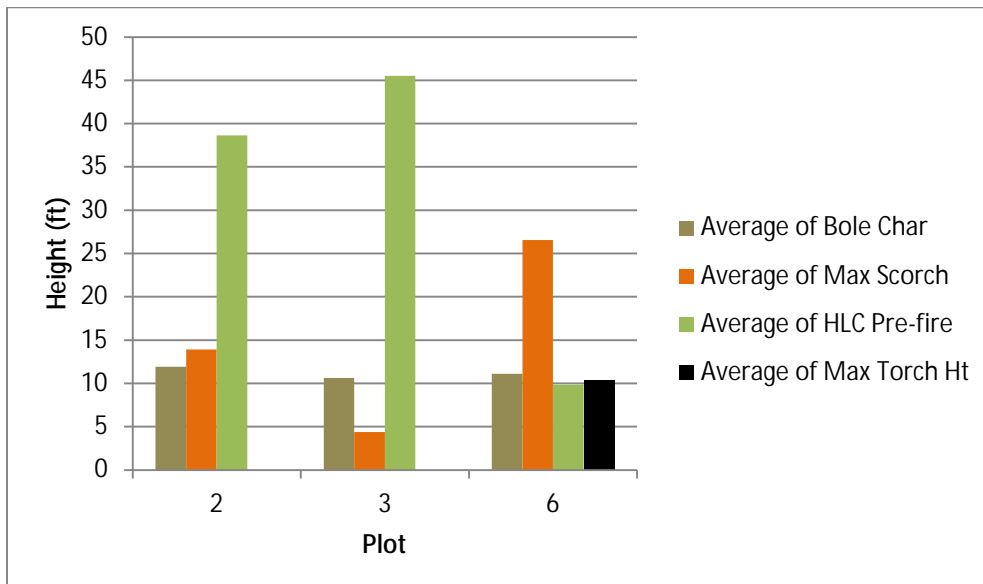


Figure 6. Average height of bole char, max scorch height, and pre-fire height to live crown (HLC).



## Understory Vegetation Loading and Consumption

The understory varied by forest type and treatment but there were very low levels of herbaceous fuels in all plots averaging 0.001 ton/ac (Tables 4 and 5). The shrub fuels were found to have higher loading, on average, with an average of 0.7 ton/ac, but shrub loading was also variable. Plots 1, 6, and 9 had a component of manzanita cover that was greater than 1 ton/ac. Understory vegetation fuel loading was influenced by recent fuel treatments in plots 3 and 4. Several of the plots without fuel treatments such as plots 2 had very dense tree canopies, thick surface fuels, and very little understory. Plot 6 was in an untreated area, but in a wet drainage that could account for the slightly higher shrub fuel loading. Understory vegetation consumption percentage in burned plots 2, 3, and 6 was found to be high (Table 5). Plot 3 had unburnt patches which accounts for the lower consumption percentage. The paired photographs in Appendix A show a sample of the distribution and density of understory flora for each plot, as well as illustrate the change post-burn.

Table 4: Average understory vegetation fuel loading pre-fire and post-fire for plots 2, 3, and 6.

Plot	Grass/Herb (ton/ac)						Shrub (ton/ac)					
	Pre-Fire			Post-Fire			Pre-Fire			Post-Fire		
	Live	Dead	Total	Live	Dead	Total	Live	Dead	Total	Live	Dead	Total
1	<0.005	<0.005	<0.005				2.26	0.10	2.36			
2	0	0	0	0	0	0	<0.005	<0.005	<0.005	0	0	0
3	<0.005	<0.005	<0.005	0	0	0	0.01	<0.005	0.01	<0.005	<0.005	<0.005
4	<0.005	<0.005	<0.005				0.01	0	0.01			
5	<0.005	<0.005	<0.005				0.06	<0.005	0.06			
6	0	<0.005	<0.005	0	0	0	1.21	<0.005	1.21	0	0.04	0.04
7	<0.005	<0.005	<0.005				0.01	0	0.01			
8	<0.005	<0.005	<0.005				0.03	0.01	0.04			
9	0	<0.005	<0.005				3.14	0.01	3.15			
10	<0.005	<0.005	<0.005				0.02	0	0.02			

Table 5: Average understory vegetation consumption percentage.

Plot	Consumption (%)	
	Grass/Herb	Shrub/seedlings
2	(no grass/herbs)	100
3	100	74
6	100	96

## Surface and Ground Fuel Loading

The predominant fuels making up the bulk of the total surface and ground fuel loadings were duff, followed by litter (Table 6). One- and 10-hour fuels contributed only slightly to total fuel loads. Hundred- and 1000-hour fuels were present, but not abundant, except for plot 10, which had 18 tons/acre of 1000-hour fuels. Fuel bed depths were generally about a half-foot, mirroring the relatively low numbers of 1-, 10- and 100-hour fuels. Consumption ranged from moderate to high consumption of surface and ground fuels (Table 7). Plot 3 located where recent fuel treatments had occurred (commercial thin in 2013), burned in a variable pattern leaving patches of unburnt fuel, probably due to the treatment. Where it did burn though, fuels were observed to be completely consumed.

Table 6: Average fuel loading and fuel bed depth based on three transects per plot. Post-fire data for burned plots (2, 3, and 6).

Plot	Mean Fuel Loading (tons/acre)														Fuel Bed Depth (ft)	
	Duff		Litter		1-hr		10-hr		100-hr		1000-hr		Total load		Pre	Post
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post		
1	21.0		13.4		0.1		0.3		0.4		0.2		35.6		0.37	
2	29.7	0	10.7	0	0.5	0.1	1.1	0.1	1.4	0.0	3.5	0.4	46.9	0.6	0.57	0.01
3	20.4	5.3	7.2	1.7	0.3	0.1	0.7	0.5	2.1	0.0	3.9	1.5	34.6	9.1	0.35	0.04
4	3.4		13.1		0.2		1.1		1.0		1.9		20.8		0.18	
5	67.7		18.3		0.2		0.5		0.8		0.6		88.2		0.96	
6	27.2	0	8.0	0	0.1	0	0.5	0	0.3	0	2.4	0	38.6	0	0.39	0.03
7	53.6		9.9		0.6		1.6		4.3		3.5		73.5		0.75	
8	22.9		4.7		0.4		2.0		1.2		0.3		30.4		0.25	
9	54.1		10.3		1.2		2.0		0.8		0.4		68.7		0.59	
10	23.5		3.6		1.1		2.0		4.4		18.0		52.7		0.87	

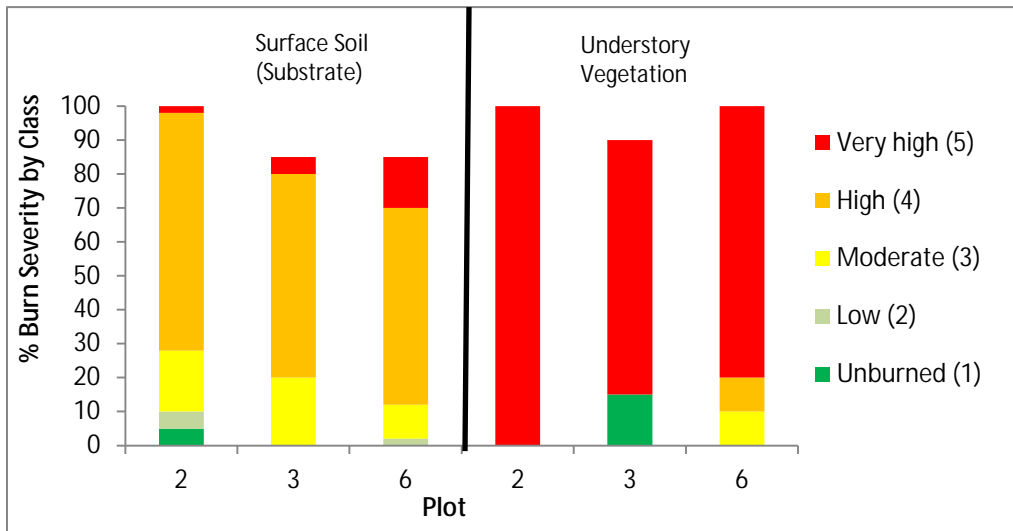
Table 7: Average percent fuel consumption per metric and for plot overall (based on Table 6).

Plot	Percent Consumption (%)							Total consumption on plot	Change in Fuel Bed Depth (%)
	Duff	Litter	1-hr	10-hr	100-hr	1000-hr			
2	100	100	89	89	100	89	99	98	
3	74	76	67	25	100	61	74	88	
6	100	100	100	100	100	100	100	94	

## Soil and Understory Vegetation Burn Severity

The National Park Service's severity categories were used to assess post-burn soil/substrate and understory vegetation severity along each transect and for the entire plot. Vegetation burn severity is only based on the vegetation that was documented pre-burn. For full descriptions of the categories, please see Appendix B. Substrate severity was mostly high in the three burned plots with small pockets of unburned, moderate and very high severity (Figure 7). Understory vegetation severity was found to be mostly in the very high range in all three burned plots (Figure 7). While fire behavior was observed to be different in the tree plots (Table 7), all plots experience high levels of consumption and residual burning which can explain the high and very high severity levels.

Figure 7: Post-fire surface soil (substrate) and understory vegetation severity rating by plot. Total percentage doesn't always represent 100% because of unburnable rock/dirt present on in plot area pre-fire.



### Fire Behavior Observations and Measurements

The narratives below describe fuels and the fire behavior movement through the plot. The metal poles in the video camera's field of view are marked in 1-foot increments; however, often it is difficult to determine how close the flame is to these poles, making flame length estimates approximate. Rate of spread was estimated from the video when possible, by timing the fire progress through a visually-estimated distance. The behavior of the main flame front is generally the behavior described in fire behavior models such as BehavePlus, however, fire spread is rarely that of a simple heading fire as sometimes captured by the video.

#### Plot 2, Mixed conifer in an untreated area

Plot 2 was located just west of 11N60 Jaybird Power House Road at the head of Jaybird Canyon. Many areas bordering the road appeared as having previous fuel treatments, but the plot area had not been treated (as recorded in FACTS), probably because it was located adjacent to a drainage. This plot had heavy fuel loading and consumption compared to plot 3. Currently, no camera footage captured at this plot is available due to the heat-warping the video cassette tape (needs to be sent for repair). Fire effects indicated that the fire approached from below in the drainage and burned through the plot to the road, where the final fire perimeter was established. While surface fuels were mostly to fully consumed, the char and scorch heights on trees were low. This plot appears to have had a continuous surface fire that was not carried by ladder fuels into the higher canopy. No wind or heat data was available from Plot 2 (sensor malfunctioned) however, winds recorded at Plot 4 (NW side of Hartless Mountain) on the same day were very low during the early evening, when this plot burned.

Figure 8. Plot 2 post-fire looking down drainage.



Plot 3, Fuel treatment area of mixed conifer

Plot 3 was located on the north side of Wentworth Springs Road across from the turn-off to Uncle Tom’s Cabin. The treated area is a small piece of public land on the ridge top that was commercially thinned in 2012. Soil disturbance or understory vegetation patchiness appeared due to heavy equipment tracks that were still evident and influenced fire spread in the area. Understory vegetation and fuels were sparse with patches of incense cedar and black oak regeneration. The fire approached the plot from below in the late morning and triggered the camera as a piece of 1000-hour fuel burned at the edge of the video image. The low, creeping surface fire burned slowly through the plot area. The winds recorded at plot 3 were approximately 7 mph just before the plot began to burn. The consumption within the plot area was complete due, probably due to the high residual time of burning and slow spread in many directions. Fire is observed to climb a tree bole at one point but there are no ladder fuels to carry it further.

Figure 9. Plot 3 burning from north to south across plot.



Plot 6, Mixed conifer and brush understory.

This site was located across the road from a retired fire station at Hell Hole Reservoir. It was on a small hill/ridge between the road and power line which had no known fuel treatments. The rocky terrain was mostly covered with Ceanothus and Manzanita understory with a patchy overstory of ponderosa pine, incense cedar, and black oak. The site location was chosen to capture fire activity from a burnout operation meeting the main fire. The camera was not triggered until after the shrubs in the plot area were fully engulfed in fire, but needle freeze indicates that the fire came from the direction of the road. The high intensity shrub fire had transitioned into the canopy of nearby trees at the time the camera was triggered. There was minimal slope to carry the fire and winds were between 3 and 5 mph before the plot burned. Only one minute after the camera triggered, the crown fire behavior transitioned to a surface fire, and only the understory shrub canopy was consumed. Tree torching can be seen in the distance to the south.

Figure 10. Plot 6 fire transitions into canopy.



Figure 11. Fire in plot area subsides and torching in distance.

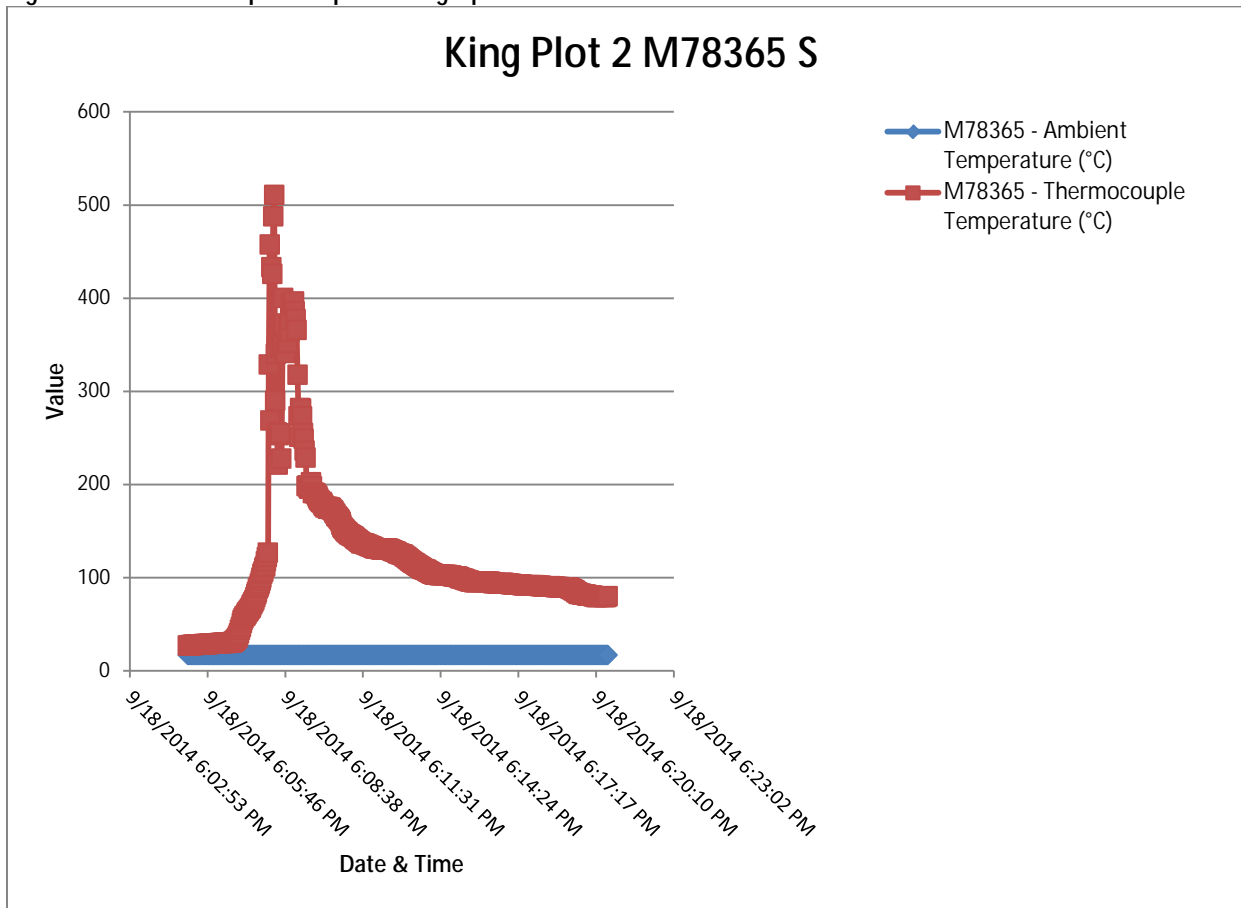




## Rate of Spread and Temperature

Rate of spread and thermocouple temperature data were gathered using five heat resistant data loggers, or sensors, at each plot. One rate of spread calculation can be performed for each triangle formed by three sensors, and rate of spread was calculated for the larger triangles when possible. If more than one triangle of sensors burned, the range spread rates were reported. The temperature sensors logged temperature at 2 second intervals. The south sensor for plot 2 shows a sharp increase in temperature, which marks fire arrival, and then decays through time (Figure 12). The peak in Figure 12 that is followed by a slow decay in temperature as fuels smolder is typical of most temperature data.

Figure 12: Thermocouple temperature graph for South sensor at Plot 2.



## Fire Type, Flame Length and Duration

In addition to the sensors, fire behavior data can be obtained from the video footage. Table 8 below lists the fire type, flame length, flame angle, and rate of spread (ROS) determined video analysis and the rate of spread sensors. Rate of spread was not calculated in plot 6 because the video triggered late, and because we did not have time to set up rate of spread sensors before our *safety window* closed.

Differences between fire behavior measurements obtained from video footage and rate of spread sensors were found for plot 3, which burned patchily. The ROS estimate from video is from spread across an isolated patch of fuels within plot 3, but may not describe the overall rate of spread within the plot area as recorded by the sensors which were 18 to 38 meters apart. The first two sensors were triggered 35 minutes apart, and the third sensor, which had to be used to calculate rate of spread from a triangle, was not triggered until an hour and a half after the fire arrived at the first sensor. The slow spread rate that arises from these data is not representative of individual, short surface fire runs. The ROS calculated from sensors in plot 2 indicates a more consistent spread to the SE judging by the fire arrival times and the uniform consumption within the plot.

Table 8: Fire behavior data based on the video camera footage and from sensors.

Plot	Fire Type	Flame Length (ft)	Flame Angle* (%)	ROS (ch/hr) camera	ROS (ch/hr) sensors	Date & Approximate Arrival Time**	End of Active Consumption
2	Camera malfunction <sup>2</sup>	NA <sup>2</sup>			<1	9/18/2014, 18:05	NA <sup>2</sup>
3	Low creeping surface fire	1 to 4	0 to 45	54.5	<1	9/18/2014, 11:32	12:53 end of tape and still burning
6	High intensity shrub crown fire and tree torching	NA <sup>3</sup>			NA <sup>1</sup>	9/19/2014, 17:35	18:00 Active flame reduced to residual heavy fuels burning

\*Approximate angle from the line between flame tip to center of flame base then to ground surface.

\*\*Time is local.

<sup>1</sup> Time constraints did not allow for sensor set up in plot.

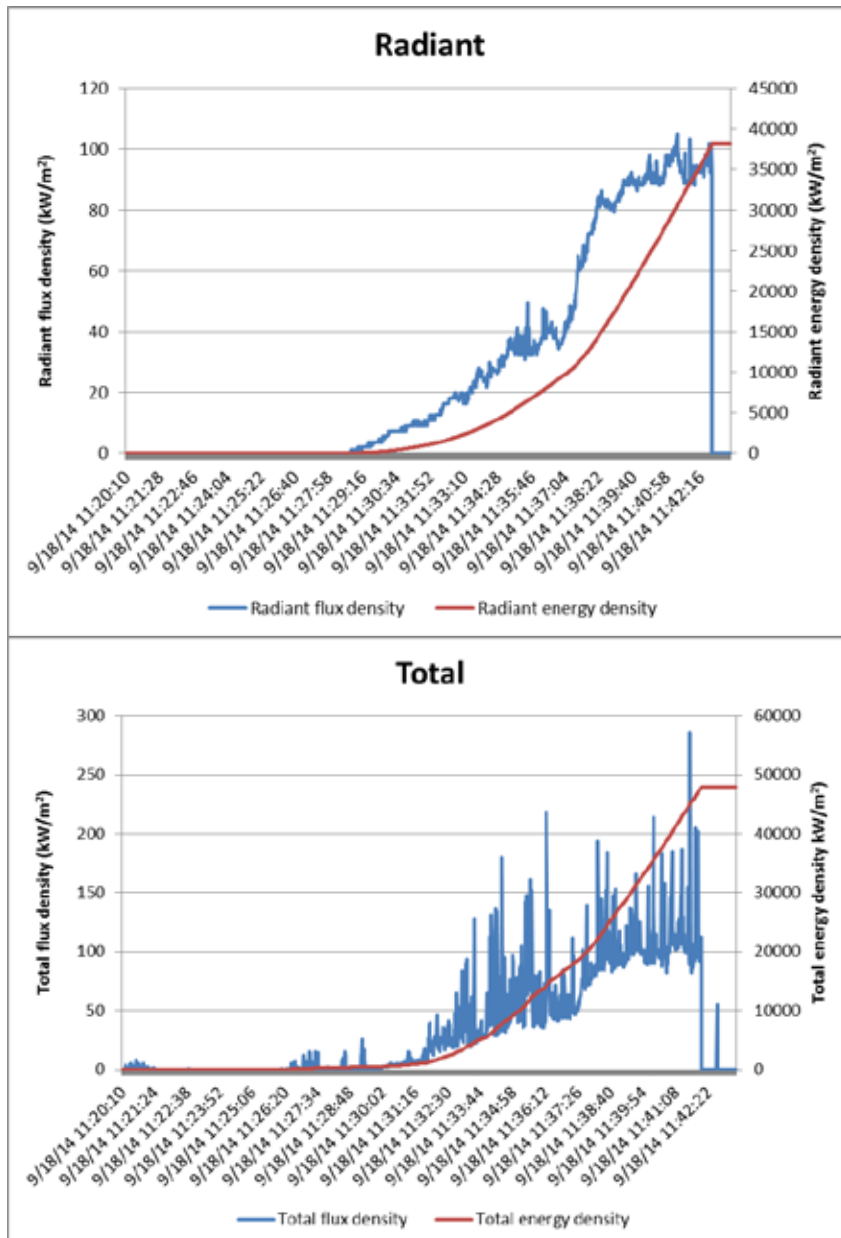
<sup>2</sup> Video tape was injured by heat.

<sup>3</sup> Camera triggered after fire had already transitioned into tree crowns. The flames are taller than the video view captured.

## Energy Transport

We successfully collected heat flux data from Plot 3 on the King Fire. Plot 3 was on mildly sloping topography in a recently treated stand with minimal fuels other than surface litter, duff, and some downed woody material (see above). The flame heights were lower than the height of the sensor. However, substantial smoldering combustion of duff and downed woody material occurred in front of the sensor resulting in relatively high radiant and total flux densities and energies (Figure 13). Because the sensor was oriented towards the oncoming fire and an area where residual smoldering occurred, the result suggests that tree stem heating in this situation would also be substantial up the trunk (1 m).

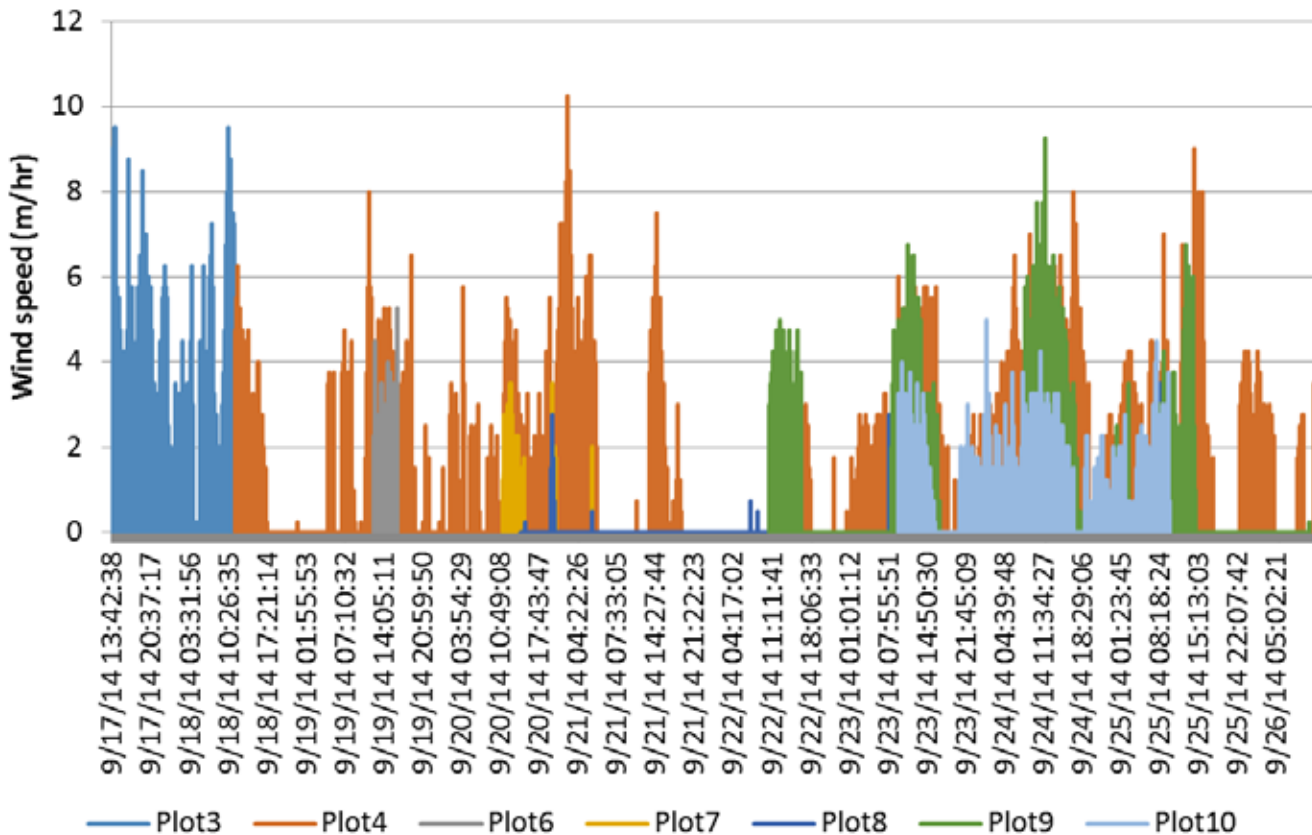
Figure 13. Plot 3 radiant and total flux density and energy density. The plot was in a recently treated stand and surface intensity was low with flame heights lower than the height of the flux sensor. The cable that runs from the sensors to the logger failed because of heating, resulting in the fall-off in temperature late in the heating period.



## Plot Wind Speed

Anemometers at 5 feet above ground were used to record wind speeds at the study plots. Data are averaged over 10 seconds and shown in Figure 18. We were not able to collect wind data from Plots 1 and 2, which were established on the 16<sup>th</sup> of September. However, plot 3 winds show somewhat higher speeds on the 17<sup>th</sup>, the day of the major run to the northeast, than on subsequent days. These are subcanopy winds, roughly mid-flame on a surface fire, so are less than tree-top winds. Red flag warnings occurred on the 23<sup>rd</sup> and 24<sup>th</sup> of September, but were not accompanied by significant winds and did not result in growth sufficient to burn over the plots on the northeast end of the fire.

Figure 18. Subcanopy wind data from seven plots. Note that winds on the 17<sup>th</sup>, the day of the major fire run, were somewhat higher than subsequent days. Note that wind data on plots 3 and 6 were collected up to the time of fire arrival and then the sensors melted (due to current sensor limitations).



# Summary

Our objectives were to:

1. Characterize fire behavior and quantify fuels for a variety of fuel conditions, especially in areas with treated fuels. Safety considerations, access, and current fire conditions restrict which areas can be measured and amount of sensors.
2. Gather energy transport data during active burning fires, in conjunction with site characteristics, for the Missoula Fire Lab's safety zone research.
3. Gather and measure representative vegetation and fuel samples to calculate moisture content to support emission and fire behavior modeling.
4. Assess fire severity and effects based on immediate post-fire measurements.

FBAT met our objectives on this incident, though we typically have higher success in terms of burned plot ratios. We installed and re-visited plots safely, mitigating for risks associated with data collection on active fires. Plot 3 captured the effects of a fuel treatment, and plot 1 didn't burn potentially because it was located in a fuel treatment area (location of dozer line and suppression actions). Some of the data were used immediately, and some will be used over the course of the next couple years. The King Fire Incident Management Team used the fuel moistures data immediately. FBAT also gathered heat flux data with newly calibrated equipment which will form part of a growing dataset used to develop improved firefighter safety zone guidelines. FBAT also beta-tested a new soils sampling protocol and sent several soil samples off to collaborators at Michigan State University for analysis, the first steps in integrating soil nutrient and black carbon effects into FBAT protocols. FBAT also collected integrated fuels, consumption, fire effects and fire behavior data which will be used along with data from other fires and years to evaluate and possibly calibrate fire behavior or fire effects models.

The King fire burned during drought conditions resulting in high fuel consumption and intense fire behavior. The data collected by FBAT will be used to improve understanding of fires burning under these extreme conditions.

The FBAT module was interviewed by Rae Brooks of the King Fire Incident Pubic Information group and published her story on an online wildfire news site located at: <http://wildfiretoday.com/2014/09/29/scientists-set-up-equipment-in-front-of-a-spreading-fire/>

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# Appendix A: Representative Paired Photographs from Pre- and Post-Vegetation and Fuel Plots



Plot 2 Transect 1, 0-50 Pre



Plot 2 Transect 1, 0-50 Post



Plot 2 Transect 2, 0-50 Pre



Plot 2 Transect 2, 0-50 Post



Plot 3 Transect 2, 0-50 Pre



Plot 3 Transect 2, 0-50 Post

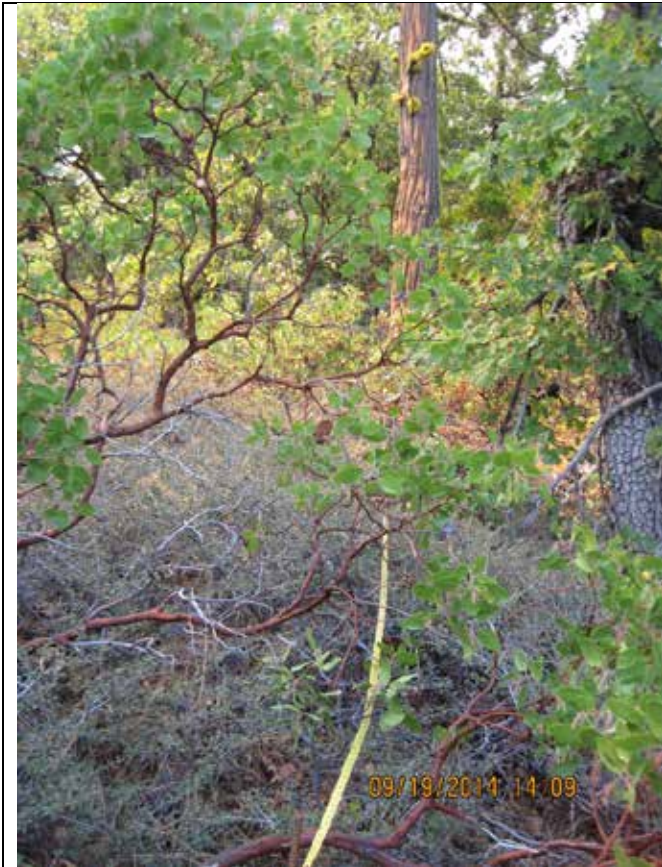


Plot 3 Transect 3, 50-0 Pre



Plot 3 Transect 3, 50-0 Post





Plot 6 Transect 1, 0-50 Pre



Plot 6 Transect 1, 0-50 Post



Plot 6 Transect 3, 0-50 Pre



Plot 6 Transect 3, 0-50 Post



Plot 1 Transect 2, 0-50 Pre



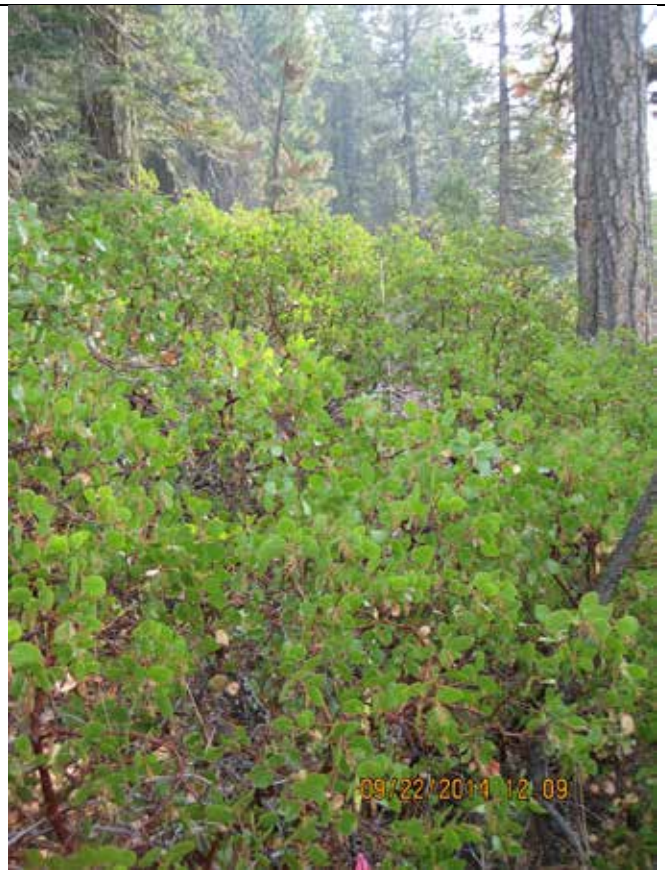
Plot 4 Transect 1, 50-0 Pre



Plot 5 Transect 1, 50-0 Pre



Plot 7 Transect 2, 50-0 Pre



Plot 8 Transect 1, 0-50 Pre

Plot 9 Transect 2, 0-50 Pre



Plot 10 Transect 1, 0-50 Pre

# Appendix B: Burn severity coding matrix from the National Park Service

Table 12. Burn severity coding matrix from the National Park Service (USDI 2003).

Code	Forests		Shrublands	
	Substrate	Vegetation	Substrate	Vegetation
Unburned (1)	not burned	not burned	not burned	not burned
Scorched (2)	litter partially blackened; duff nearly unchanged; wood/leaf structures unchanged	foliage scorched and attached to supporting twigs	litter partially blackened; duff nearly unchanged; wood/leaf structures unchanged	foliage scorched and attached to supporting twigs
Lightly Burned (3)	litter charred to partially consumed; upper duff layer may be charred but the duff layer is not altered over the entire depth; surface appears black; woody debris is partially burned	foliage and smaller twigs partially to completely consumed; branches mostly intact	litter charred to partially consumed, some leaf structure undamaged; surface is predominately black; some gray ash may be present immediately after burn; charring may extend slightly into soil surface where litter is sparse otherwise soil is not altered	foliage and smaller twigs partially to completely consumed; branches mostly intact; less than 60% of the shrub canopy is commonly consumed
Moderately Burned (4)	litter mostly to entirely consumed, leaving coarse, light colored ash; duff deeply charred, but underlying mineral soil is not visibly altered; woody debris is mostly consumed; logs are deeply charred, burned-out stump holes are common	foliage, twigs, and small stems consumed; some branches still present	leaf litter consumed, leaving coarse, light colored ash; duff deeply charred, but underlying mineral soil is not visibly altered; woody debris is mostly consumed; logs are deeply charred, burned-out stump holes are common	foliage, twigs, and small stems consumed; some branches (0.25-0.50 inch in diameter) still present; 40-80% of the shrub canopy is commonly consumed.
Heavily Burned (5)	litter and duff completely consumed, leaving fine white ash; mineral soil visibly altered, often reddish; sound logs are deeply charred and rotten logs are completely consumed. This code generally applies to less than 10% of natural or slash burned areas	all plant parts consumed, leaving some or no major stems or trunks; any left are deeply charred	leaf litter completely consumed, leaving a fluffy fine white ash; all organic material is consumed in mineral soil to a depth of 0.5-1 in, this is underlain by a zone of black organic material; colloidal structure of the surface mineral soil may be altered	all plant parts consumed leaving only stubs greater than 0.5 in diameter
Not Applicable (0)	inorganic pre-burn	none present pre-burn	inorganic pre-burn	none present pre-burn

## Appendix C: About the Fire Behavior Assessment Team (FBAT)

The Fire Behavior Assessment Team (FBAT) operates under the management of the Adaptive Management Services Enterprise Team (AMSET) of the USFS. We specialize in measuring fire behavior and fuels on active wildland and prescribed fires. We utilize fire-resistant sensors and video cameras to measure direction and variation in rate of spread, fire type (e.g. surface, passive or active crown fire behavior), onsite weather, and couple this with measurements of fire effects, topography, and fuel loading and moisture. We measure fuel load changes from fire consumption and compare the effectiveness of past fuel treatments or fires in terms of fire behavior and effects. We are prepared to process and report some data while on the incident, which makes the information immediately applicable for verifying LTAN or FBAN fire behavior prediction assumptions. In addition, the video and data are useful for conveying specific information to the public, line officers and others. We can also collect and analyze data to meet longer term management needs, such as calibrating fire behavior modeling assumptions for fire management plans, unit resource management plans, or project plans.

Since 2003, The FBAT program has built a rich dataset and library of products for fire and fuels managers; fire training and safety; and fuel, fire, and smoke scientific communities. FBAT video has been utilized by the Wildland Firefighter Apprenticeship Program and USFS PSW ecological restoration video series; and FBAT data and program information were shared with the [JFSP crown fire behavior knowledge synthesis project](#) and a [PSW Research Station project](#) that estimated carbon stocks and emissions in CA and evaluated FOFEM. Other collaborations to collect and utilize FBAT data are in progress including: supplying data to support fire safety zone research at the Missoula Fire Sciences Laboratory; submitting a JFSP grant proposal with P. Robichaud to create an ash guide for BAER teams; and testing sampling methods for black carbon measurements with Jessica Miesel at Michigan State University.

FBAT is a team of fireline qualified technical specialists and experienced fire overhead. The overhead personnel include a minimum of crew boss qualification, and more often one or more division supervisor qualified firefighters. The team can vary in size, depending upon availability and needs of order, from 5 to 12 persons. We have extensive experience in fire behavior measurements during wildland and prescribed fires. We have worked safely and effectively with over 17 incident management teams. We are comprised of a few AMSET FBAT core members and other on-call firefighters from the USFS and other agencies. We are available to train other interested and motivated firefighters while on fire incidences, as time allows.

We can be ordered from ROSS, where we are set up as “Fire Behavior Assessment Team”, and are in the CA Mobilization Guide (near the BAER Teams). We can be name requested, and we’ll request additional personal to join our team, like a Wildland Fire Module, based on the Module’s availability. Please contact us directly by phone to notify us that you are placing an order, which will speed up the process. You can reach Carol Ewell at 530-559-0070 (cell) or via the Stanislaus NF dispatch (209-532-3671 x212). Or you can reach Alicia Reiner at 530-559-4860 (cell). We may be available if you call dispatch and we are already assigned to a fire. We can work more than one fire simultaneously and may be ready for remobilization. This is the FBAT web page, which has links to most FBAT Incident Summary Reports: <http://www.fs.fed.us/adaptivemanagement/projects/FBAT/FBAT.shtml>