2014 French Fire
Sierra National Forest

Fire Behavior Assessment Team (FBAT) Summary Report

French fire smoke column on the afternoon of August 1st, 2014 when FBAT plots burned.

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And
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April 8, 2015 (update)

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INTRODUCTION

Wildland fire management is dependent upon quality fire behavior and resource effects predictions. Existing prediction models are based upon limited field data from active wildfires, especially quantitative data. The Fire Behavior Assessment Team (FBAT) collects data to support improvements in fire behavior and resource effects prediction in the long-term and provides short-term intelligence to wildland fire managers and incident management teams on fire behavior, fuel, and effects relationships. Increasing our knowledge of fire behavior is important for firefighter safety because incorporating that knowledge will help mitigate hazards and prevent accidents. As well, a better understanding of fire behavior and effects will create a better foundation for improving natural resource management. 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 week assessment of fire behavior, vegetation, fuel loading, consumption, and fire effects to vegetation and soil resources for areas within the French Fire. The French Fire probably started from an abandoned campfire on the Bass Lake Ranger District of the Sierra National Forest. The fire grew to over 13,000 acres. Pre-fire data was collected at five plots. Two plots were burned and post-fire vegetation and fuel conditions were successfully measured at those sites. Individuals from Stanislaus NF (STF), Sierra NF (SNF), and a few Forest Service fire researches joined and trained with FBAT on fire behavior equipment and fuels/vegetation inventory techniques.

Incident and Related FBAT Program Objectives

Our objectives were to:

1. Safely characterize fire behavior and quantify fuels for a variety of fuel conditions. Safety, access, and current fire conditions restrict which areas can be measured.
2. Gather energy transport data during active burning fires, in conjunction with site characteristics, for the Missoula Fire Lab’s safety zone research.
3. Measure moisture content of representative fuels to support emission and fire behavior modeling and provide pre-and post-fire fuel loading to Air Resource Analyst.
4. Assess fire severity and effects based on immediate post-fire measurements.
5. Cross-train and collaborate with wildland firefighters, fuels managers, and incident staff during the field study, as well as with Sierra National Forest and Fire Lab staff after the fire.
6. Begin testing soil sampling protocol for quantifying black carbon production and loss during fires in conjunction with Michigan State University.

METHODS AND RESULTS

In the following, we first describe study site selection and general sampling layout and then present methods and results on pre- and post-fire vegetation and fuels and active fire behavior. We combine methods and results for the reader's convenience and provide enough detail that future users of the results will have a general guide to methods and available data for which more detail is available in the associated protocols and datasets.

Site Selection and Layout

FBAT selects study sites to represent a variety of fire behavior and vegetation/fuel conditions. Site selection priorities are also based on safe access and areas that would most likely be burned over within the timeframe that FBAT was at the incident. Within each site data are gathered on both fuels and fire behavior; a graphic of a site set up is shown below (Figure 1), though the site layout changes based on terrain, fuels, and additional objectives (radiant and convective heat for safety zone dataset). Pre-fire fuels measurements were recorded at 5 sites, and post-fire fuels and fire severity measurements were recorded at 2 of those sites near the NW corner of the fire from July 30th to Aug. 5th, 2014. Study sites 1-4 are found below road 4S81 and site 5 is found in between the 5S25 road and Chiquito Creek. The map (Figure 2) displays daily fire progression and approximate site locations.

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

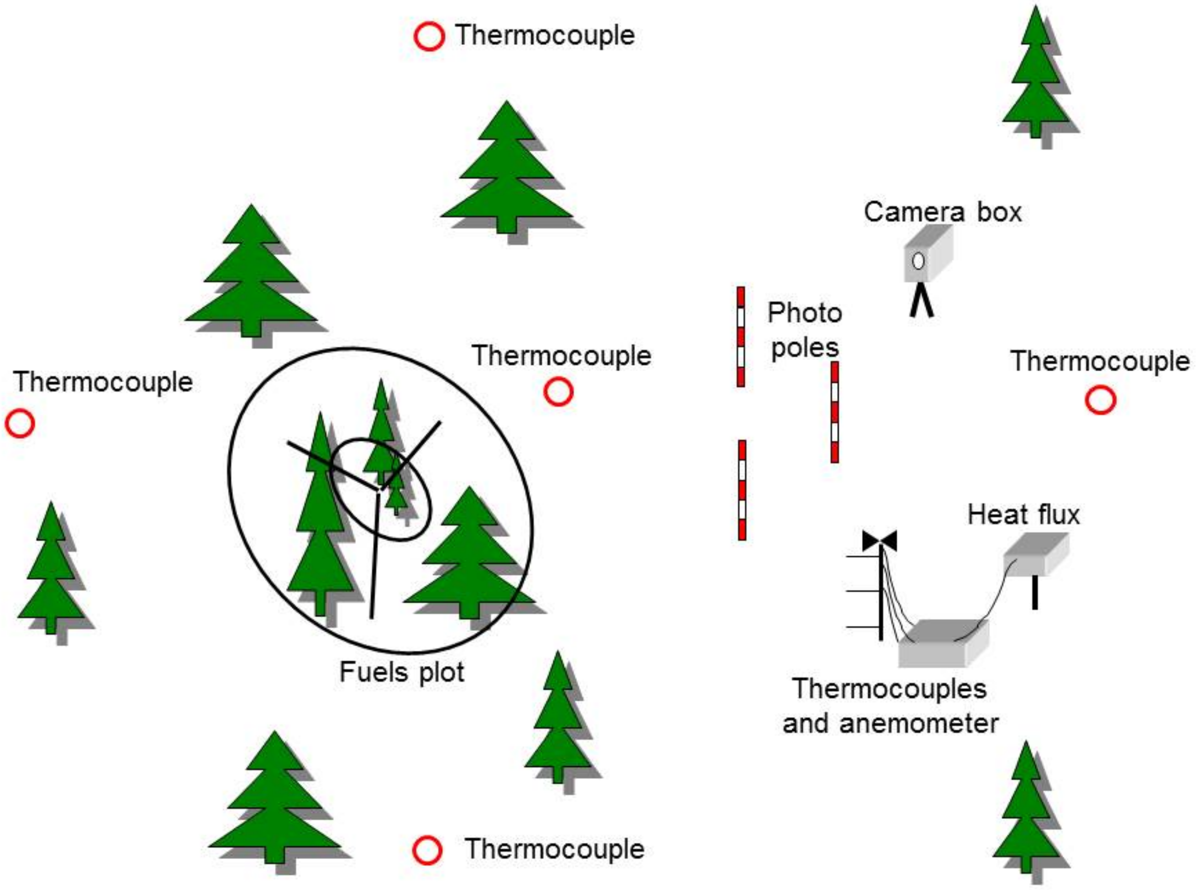
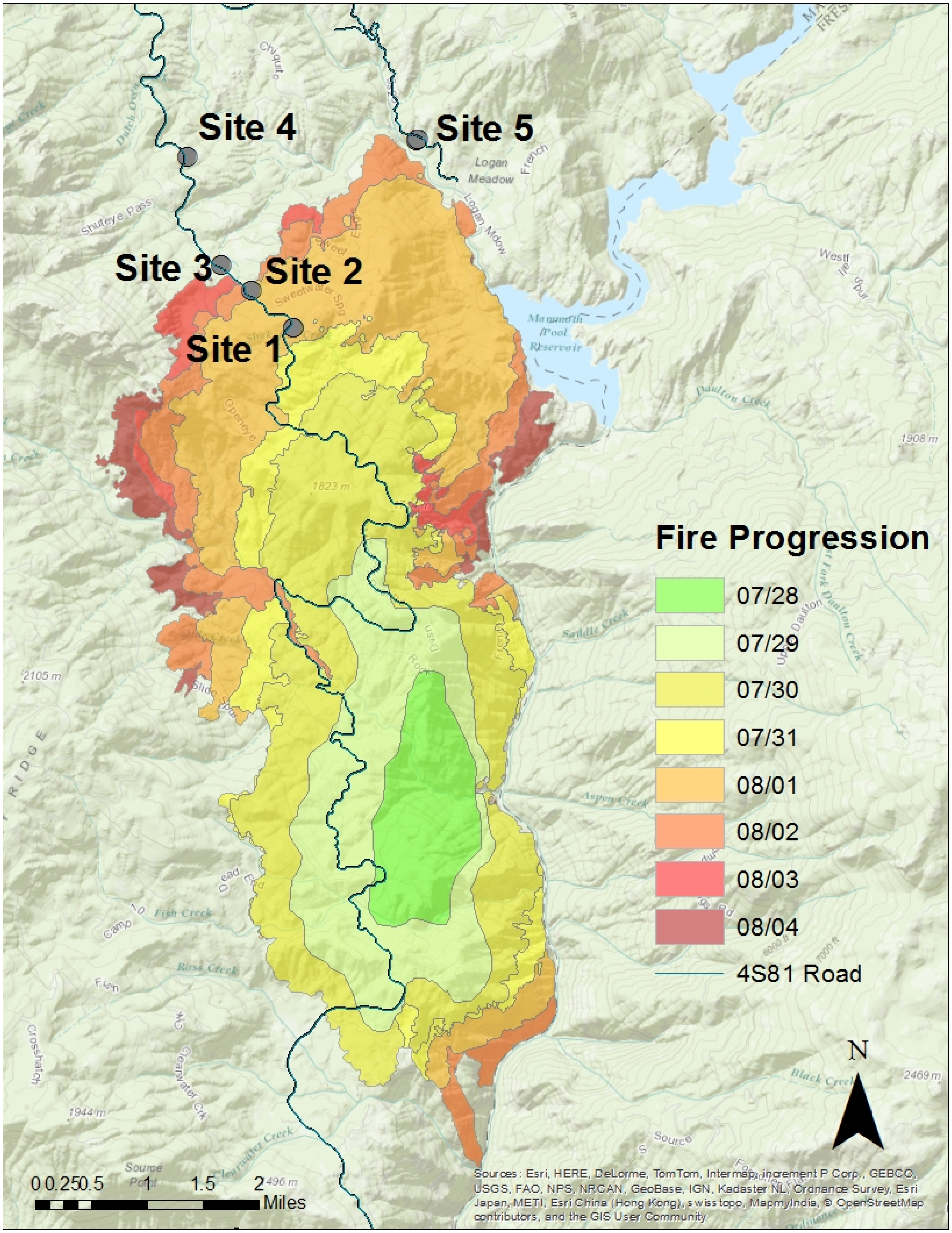


Figure 2: Fire progression and location of FBAT fuels and fire behavior sites in the French Fire.



Pre- and Post-Fire Vegetation and Fuel Measurements

Vegetation and fuels were inventoried both before the fire reached each site and then again after the fire. Sites were permanently marked with rebar to provide options for long term monitoring.

Figure 3: Example paired photos where vegetation and fuel data collection is measured pre- and post-burn at Site 1.

Pre-fire transect 2: 0-50ft

Post-fire transect 2: 0-50ft

Pre-fire fuels data were successfully collected at five sites, and post-fire fuels/consumption and fire behavior data were successfully collected at sites 1 and 2. Sites 1-5 captured representative mixed conifer forest vegetation, but site 5 had a significant, tall manzanita component (Table 1). Paired photographs of representative site transects are available in Appendix A. Video cameras functioned properly and collected video on site 2, but not site 1. Rate of spread sensors and heat flux sensors captured data on both sites 1 and 2. Wind data were collected on all five sites.

Table 1: Description of the five sites.

Site	Forest/Vegetation Type	Slope (%)	Aspect	Elevation
1	Mixed conifer, bear clover	33	140	5,000
2	Mixed conifer, bear clover	25	130	5,000
3	Mixed conifer, bear clover	40	36	5,000
4	Mixed conifer, bear clover	50	70	5,000
5	Mixed conifer, manzanita	30	210	4,450

Overstory Vegetation Structure and Crown Fuels

Methods

Variable radius sub-plots were used to characterize crown fuels and overstory vegetation structure. A relascope (slope-correcting tree prism) was used to create individual nested 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 or timber cruising (Biltmore) stick if time was limited.

After the fire, maximum bole char, scorch, and torch heights and mean percentages 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 maximum heights where uneven scorch values occurred (e.g., because trees were on slopes or crowns were otherwise unevenly affected by heat). Due to smoke and poor lighting, visibility of the full crown is sometimes difficult. If a more accurate assessment of tree survivorship in the sites is desired, we recommend another site visit next year.

The Forest Vegetation Simulator program (FVS, Crookston and Dixon 2005) and its Fire and Fuels Extension (FFE-FVS, Rebain 2010) was used to calculate canopy bulk density, canopy base height, tree density, and basal area both pre- and post-fire for each study site (site data is used to represent a 1-acre stand). FVS/FFE-FVS is a stand-level growth and yield program used throughout the United States. The Western Sierra variant was used for all calculations. The 1-acre representation of the FBAT study site is sized to establish some trends based on the site level data collected, but some generalizations are made about the change in canopy characteristics overall.

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 height of the base of the tree canopy, is important because it affects crown fire initiation. Scott and Reinhardt (2001), which is the basis for canopy fuel calculations in FVS-FFE, stated "CBH is not well defined or easy to estimate for a stand. Neither the lowest crown base height in a stand nor the average crown base height is likely to be representative of the stand as a whole. Canopy base height is difficult to measure in multistory stands and stands with ladder fuels. 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, is the mass of canopy fuel available per unit canopy volume (Scott and Reinhardt 2001). Continuity of canopies is more difficult to quantify, but clearly patchiness of the canopy will reduce the spread of crown fire. 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). Thinning to reduce canopy bulk density to less than 0.10 kg/m^3 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 difficult to achieve (Scott and Reinhardt 2001).

Findings

At the French Fire study sites, the data summary listed in Table 2 provides a snapshot of stand characteristics for some areas on the northern end of the French Fire. Tree species within the five sites included: ponderosa pine, sugar pine, white fir, incense cedar, and California black oak. Canopy bulk density (CBD) was over the 0.10 kg/m^3 threshold mentioned above. CBD was calculated to be 0.19 and

0.12 kg/m^3 in the two burnt plots, and both plots experienced individual or group torching type fire (potentially a passive crown fire) resulting in high tree mortality. See smoke column photo on report cover of this area. The average canopy base height was very low in both plots which may explain a group torching event. Site 1 may experience a greater percentage of mortality due to scorch and torch than site 2 (Figure 4). The large number of pole-size trees with a low canopy base height probably propagated fire into the canopy of larger trees, compared to site 2. 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.

Table 2: Pre- and post-fire overstory vegetation and crown fuel data by site. QMD is the quadratic mean diameter based on tree data collected at the site scale.

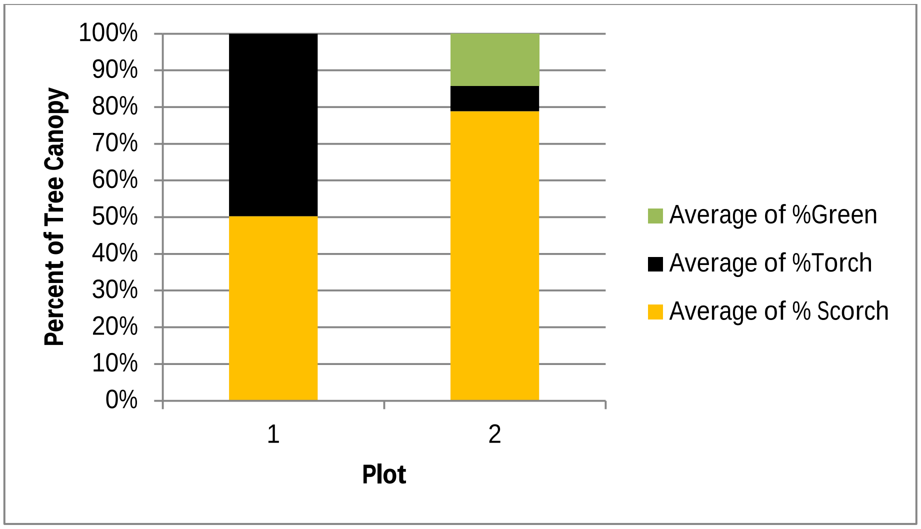
Plot or Site	Overstory (>6 in DBH) trees/acre		Pole-size (<6 in DBH) trees/acre		QMD (in)		Basal Area (ft^2/acre)		Canopy Cover (%)		Canopy Height (ft)		Canopy Base Height (ft)		CBD (kg/m^3)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	327	0	634	0	6	0	211	0	74	0	72	0	1	0	0.19	0
2	350	181	236	0	12	14	437	181	85	53	101	82	5	22	0.12	0.04
3*	29	-	1121	-	6	-	226	-	66	-	88	-	33	-	0.03	-
4*	339	-	111	-	13	-	420	-	69	-	94	-	10	-	0.13	-
5*	217	-	130	-	13	-	335	-	83	-	77	-	13	-	0.13	-

***** Sites not burned.

Fire Effects: Tree Canopy Scorch and Torch

A few days after the fire burned through each site (allowing for smoldering combustion to complete and some fire-weakened trees to fall) additional measurements were gathered (char height, maximum scorch and torch heights, and percentage of the crown scorched and torched) to better assess the fire effects at each site. Percentage values were determined using ocular estimations, and heights were measured with a laser rangefinder. Severity or fire effects can be accessed from the percentage of scorch and torch for each study site (Figure 4). The fire had scorched (caused browning of) portions of most tree canopies, but only torched (consumed) portions of some tree canopies. The majority of trees in both plots 1 and 2 were scorched and torched resulting in a subsequent high tree mortality rating.

Figure 4: Overstory canopy average percent scorch and torch at each site.



Understory Vegetation Structure and Loading

Methods

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 class (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).

Findings

At the French Fire study sites the understory vegetation was sparse to patchy with less than one ton/acre loading in most sites (Table 3). Site 5 had the highest loading of the shrub component compared to the other sites because of manzanita cover. Nine different forb/grass species and 11 shrub/seedling species were found across all the combined plot transects. In areas of open canopy, bear clover occupied a high percentage of the herb layer. In areas of closed canopy the thick litter and duff inhibited growth of understory vegetation and low cover percentages of all vegetation was found. The understory vegetation cover at site 1 was completely consumed by the fire in both the open canopy area and the dense closed-canopy area. At site 2 the understory vegetation cover was completely consumed except for some seedling cover remaining in the form of scorched branches (Table 4). The paired photographs in Appendix A show a sample of the distribution and density of understory flora for each site, as well as the changes post-fire.

Table 3: Pre-and post-fire understory vegetation fuel loading.

Site	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**	**<0.005**	**0**	**0**	**0**	**0.11**	**<0.005**	**0.12**	**0**	**0**	**0**
2	**<0.005**	**0**	**<0.005**	**0**	**0**	**0**	**0.10**	**0.04**	**0.15**	**0.02**	**0**	**0.02**
3*	**<0.005**	**0**	**<0.005**	-	-	-	**3.17**	**0.25**	**3.42**	-	-	-
4*	**<0.005**	**0**	**<0.005**	-	-	-	**0.11**	**<0.005**	**0.11**	-	-	-
5*	**<0.005**	**0**	**<0.005**	-	-	-	**17.43**	**0.93**	**18.36**	-	-	-

***Asterisk denotes that the plot was not burned.**

Table 4: Mean understory vegetation consumption at burned sites.

Site	Consumption (%)	
	Grass/Herb	Shrub
1	100	100
2	100	88

Surface and Ground Fuel Loading

Methods

Surface and ground dead and down fuels were measured along the same three 50-foot transects as the understory vegetation at each site. 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 when applicable. The measurements were used to calculate surface and ground fuel loading using basal-area-weighted species-specific coefficients (van Wagtendonk et al. 1996; 1998). The comparisons of pre- and post-fire measurements were used to estimate percent fuel consumption.

Findings

The predominant fuels were litter and duff in all five sites (Table 5). Site 1 had the highest 1,000-hr fuel component of 5.11 tons/acre, while sites 2 to 5 had less than 1 ton/acre. The fuel bed depth was found to be less than 1 ft in all the plots. Plot 3 had the greatest total fuel loading due to a deep duff layer.

Table 5: Average pre-and post-fire dead and down fuel loading and fuel bed depth.

Site	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	23.6	0	5.5	0	0.1	0	0.3	0	0.4	0	5.1	0	34.9	0	0.3	0.1
2	35.0	0	6.9	0	0.7	0	0.9	0	1.2	0.4	0.2	0.2	44.9	0.6	0.8	0.3
3*	68.1	-	11.6	-	0.3	-	0.6	-	0.8	-	0.6	-	81.9	-	1.0	-
4*	26.2	-	8.9	-	0.1	-	0.2	-	0.4	-	0.2	-	36.0	-	0.3	-
5*	18.9	-	4.4	-	<0.0	-	0.5	-	1.4	-	0	-	25.3	-	0.6	-

* Plots that did not burn.

Consumption varied both by fuel category and site, but total fuel consumption was nearly 100 percent in both sites (Table 6). Litter and other woody debris quickly begin to accumulate at a site after the fire burns through, and sometimes before FBAT is able complete the re-measurements. However, we do not count post-fire fuel accumulation during the immediate post-fire site visit. Site 2 experienced very high post-fire fuels recruitment with several green trees falling into the site area due to burned-out bases (see photos Appendix A). Future monitoring of plot 2 would find a very high recruitment of 1000-hour fuels.

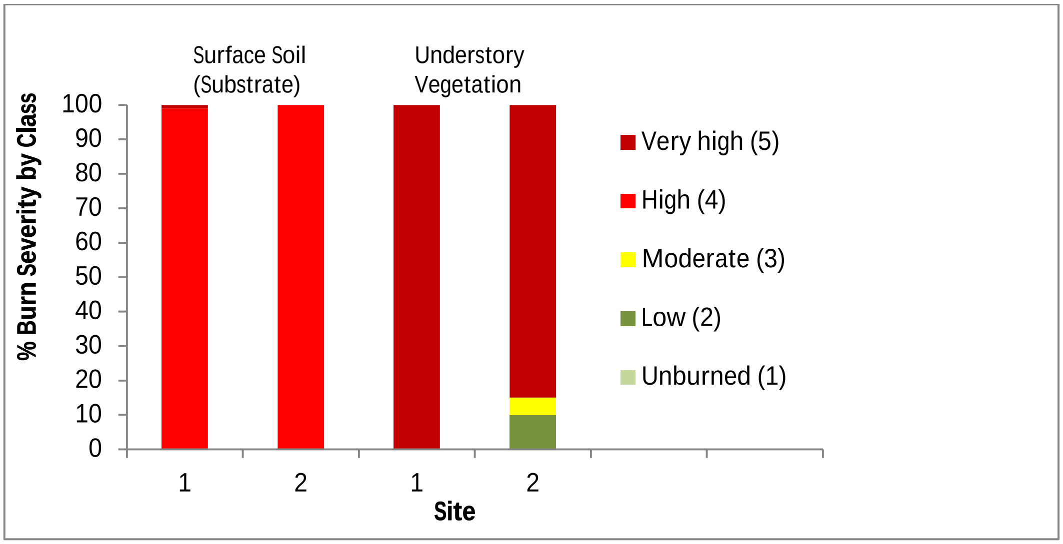
Table 6: Average percent downed fuel consumption per fuel class and for the site overall, based on Table 5.

Site	Percent Consumption (%)							Change in Fuel Bed Depth (%)
	Duff	Litter	1-hr	10-hr	100-hr	1000-hr	Total load on site	
1	100	100	100	100	100	100	100	84
2	100	100	100	100	65	18	99	63

Substrate and Vegetation Burn Severity Rating

A rapid assessment of substrate (soil) and understory vegetation burn severity was completed along each transect and for the entire site area to document the effects of fire on the surface and understory (USDI National Park Service 2003). The National Park Service uses fire severity ratings from a 1 to 5 code scale when evaluating fire severity. In this rating system 1 is representing unburned areas and 5 is representing areas with high fire severity (Appendix B; the scale was reversed from NPS standards to be more intuitive). Vegetation burn severity is only based on the understory vegetation that was observed or documented pre-burn. Figure 5 shows the site-level estimates. Both sites 1 and 2 experienced high surface soil severity and very high understory vegetation severity.

Figure 5: Post-fire surface soil (substrate) and understory vegetation burn severity rating.



Fuel Moisture

Fuel moisture samples were taken near the fire on 8/2/2014 at the Kinsman and Saginaw long term monitoring sites on the Sierra National Forest (Table 7). The data were also part of the Bass Lake Ranger District monthly fuel moisture monitoring dataset (pers. comm. Key 2014).

Table 7: Summary of fuel moisture calculations collected on 8/2/2014 at Kinsman and Saginaw sites (T85 R24E S35).

Species	Average Moisture Percent	Moisture Range Percent	Last Year 08/07/13	Remarks
Manzanita				
Old leaves	67.2 %	66.4-67.7%	69.9%	No Flowering, or New Growth, or Fruits
Ceanothus				
Old leaves	64.2%	61.4-67.0%	59.8%	
Ponderosa Pine				
1,000-hr	4.3%	2.9-5.4%	8.9%	Thunderstorm precipitation in area on 7/30/14

Fire Behavior Observations and Measurements

At each site, multiple sensors (thermocouples, heat flux sensor(s), and anemometer) and a video camera were set up to gather information on fire behavior. The thermocouples arrayed across the plot collect temperatures at 2 second intervals from which rate of spread can be calculated. The heat flux sensors collect data from which total and radiant heat flux from the flame front can be calculated from calibration relationships. Convective heat flux to the sensor is the difference between the total and radiant flux. Anemometers positioned above the heat flux sensors capture wind speed (Figure 6). The videos are used to determine fire type, flame length, variability and direction of rate of spread, flame duration, wind direction, and direction of fire spread in relation to slope and wind. The sensors are described in more detail below.

Figure 6: Example of heat flux and wind equipment set up at the French Fire in an open, mixed conifer area.

Fire Type, Flame Length and Flaming Duration

Methods

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 site. For example, sites with complete consumption of tree canopy needles indicated at least torching or passive crown fire. Flame length was primarily determined from video footage. If needed, flame length values could be supplemented by tree char height measurements. Flaming duration was based on direct video observation, and can be supplemented by the temperature sensors as well. Rate of spread was determined by video analysis and by calculating rate of spread with time stamp from sensors.

Results

Below are site descriptions of fuels and fire behavior observations from onsite videos and the sensors. Table 8 below lists the fire type, flame length, flame angle, rate of spread and duration of active consumption. 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 across a visually-estimated distance across the forest captured in the video image. The behavior of the main flame front is generally the behavior described in fire behavior models such as BehavePlus, however, fire spread is rarely a simple head fire as can be seen by the video.

Table 8: Fire behavior data based on the video camera footage

Site	Fire Type	Flame Length (ft)	Flame Angle* (%)	ROS (ch/hr)	Date, Approx. Start of Fire	End of Active Consumption
1	Camera malfunction					
2 (Lower Dense Area)	High intensity surface fire transitioning to crown	Surface 4-6 Crown > 30	20	not captured well by video	8/1/2014, 16:52	8/1/2014, 17:23
2 (Upper Open Area)	Low surface fire	Surface <1 Torching < 30	75	2	8/1/2014, 15:40	8/1/2014, 16:40

*Angle from ground surface to the flame tip along the center of the flame's base.

<u>*Site 1, Mixed conifer with overstory pine and clusters of small cedar and pine.*</u>

Site 1 was located below road 4S81 in an area of no known recent fuel treatments or fire history in the last 100 years. Ponderosa pine was the dominant tree species with incense cedar and sugar pine also present, as well as bear clover in open canopy areas. The fuels and vegetation was measured in a dense area of suppressed pine and cedar (Figure 7). Very little understory vegetation was found under the dense canopy, possibly due to thick litter and duff accumulation. The camera triggering mechanism failed at the time of the fire, so no video was recorded. Temperature sensors had 10:57am as the first time of heat peak. Based on post-fire observations of tree char, scorch, and torch the site area experienced an intense surface and/or crown fire, such as group torching.

Figure 7. Site 1 area of clustered pine and cedar regeneration pre-fire (left) and post-fire (right).

Site 2, Mixed conifer with overstory pine, clusters of small incense cedar

Site 2 was located below road 4S81 in an area of no known recent fuel treatments or fire history. Ponderosa pine was the dominant tree species with other mixed conifer species present at the site. Two cameras were placed within the site to document the difference in fire behavior between an open canopy and dense canopy area with small conifer regeneration. Bear clover was nearly contiguous in the open area of the site, but very little understory vegetation was observed in the dense area of conifer regeneration. The downslope camera in the dense stand was triggered by fire at 16:52 and captured a high intensity surface fire that transitioned into intense crowning in small diameter trees. Potentially, the thick needle cast and duff layer caused the intensity of surface fire that was carried by small trees up into the canopy. The upslope camera in the open canopy area was triggered at 15:40 and mostly captured low intensity surface fire through bear clover. Torching of small cedars was observed due to a 1,000-hr fuel burning nearby. Based on video observations, potentially a spot fire or incident operations upslope resulted in the fire backing down into the site triggering the upslope camera first (Figure 8).

Figure 8. Upslope camera capturing low intensity surface fire (left) and downslope camera capturing high intensity surface fire moving into crown (right).

Rate of Spread and Thermocouple Temperature

Methods

Rate of spread was determined from time-of-arrival at 5 thermocouples at known locations as well as from video analysis mentioned above. The fire-resistant data loggers attached to the thermocouples are buried underground. The thermocouples are positioned at the surface of the fuel bed. The loggers are able to record temperature for up to six days or until the thermocouple or logger is damaged by heat. The temperature sensors logged temperature at 2 second intervals. The distances and azimuths of all thermocouples from a central thermocouple were measured, and these geometrical data and time of fire arrival were used to estimate rate of spread based on Simard et al. (1984). One rate of spread calculation can be performed for each triangle formed by three adjacent sensors of a 5-sensor array. Rate of spread is also calculated for the larger triangles when possible.

Findings

All sensors functioned properly at sites 1 and 2 which allowed a range of spread rates to be calculated (Figure 9, Table 9). The east sensor at site 1 shows a typical sharp increase in temperature, which indicates fire arrival. Then temperatures decline through time as the flames pass, smoldering proceeds to completion, and the ground cools (Figure 9).

Figure 9: Thermocouple temperature graph of fire temperature spike measured at Site 1.

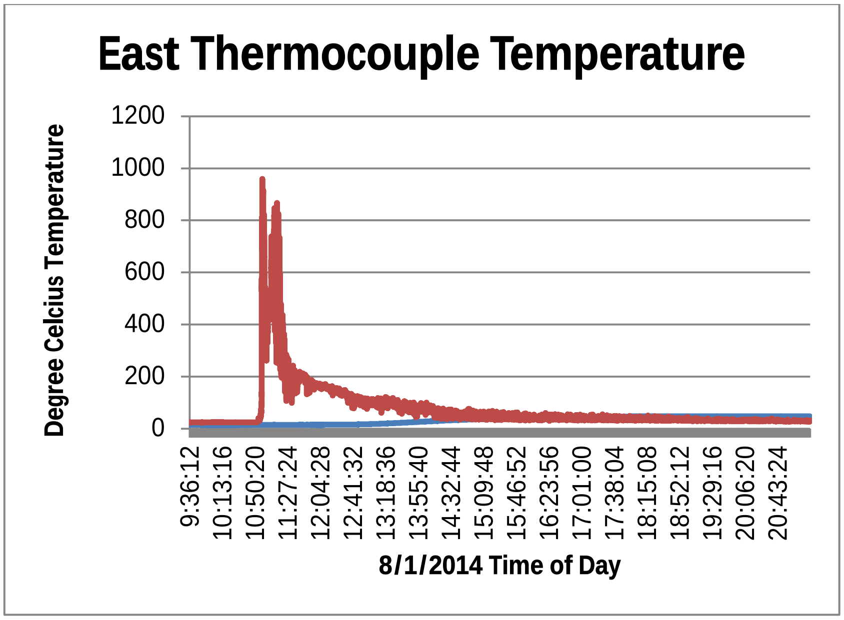


Table 9: Rate of Spread (ROS) and temperature recorded by thermocouple three sensors per site.

Site	ROS (ch/hr) Sensors	Date, Time fire detected by first sensor	Maximum Temperature (°C)	Heat Duration Range Above 80 °C (min)
1	10 to 42	8/1/2014, 10:57	948 to 1023	43 to 195
2	1	8/1/2014, 15:43	986 to 1044	107 to 417

Energy Transport

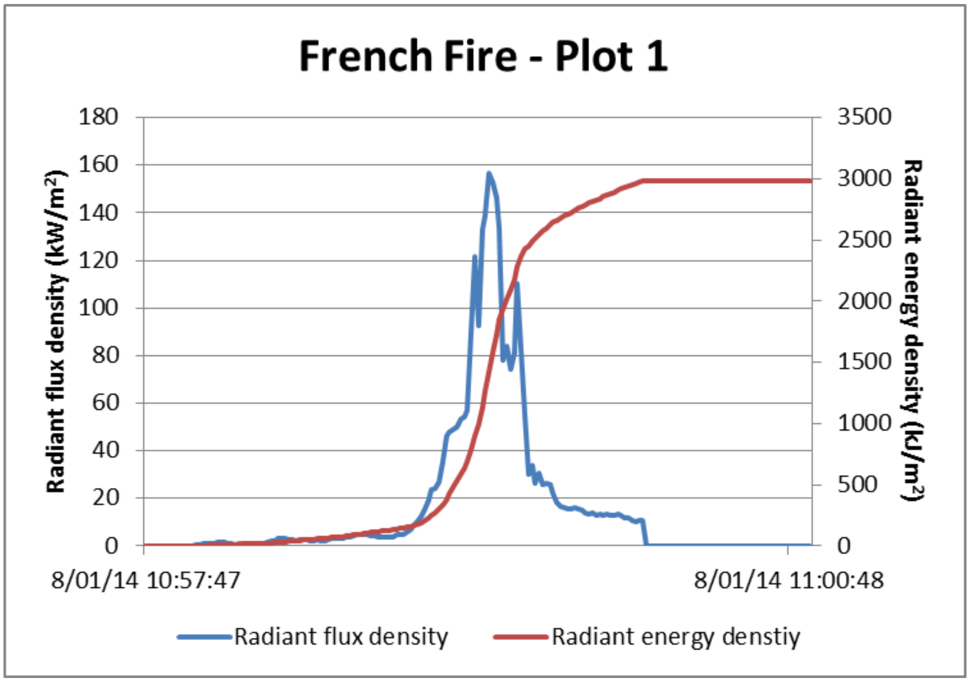
Energy transport data are collected with a heat flux sensor, where flux refers to the rate of energy transfer onto the surface of the sensor measured in units of kW/m^2. As with other recent work (e.g., Frankman et al. 2012, Butler et al. 2014), we use a Medtherm® Dual Sensor Heat Flux sensor (Model 64-20T), along with calibration relationships derived from laboratory measurements, to provide 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 were based on radiant flux alone, Butler (2014) recommended a consideration of total heat flux. The maximum heat flux tolerable by firefighters wearing nomex (and undergarments and protective head and neck equipment) was described as 7 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 vegetation 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 +/- 75 degrees of the sensor face (where perpendicular is 0 degrees, Butler et al. 2010). The FBAT places the sensor at 1 m above the ground surface, and it may not be impacted directly by flames with a height less than 1 meter. Small flames result in low heat flux at the sensor.

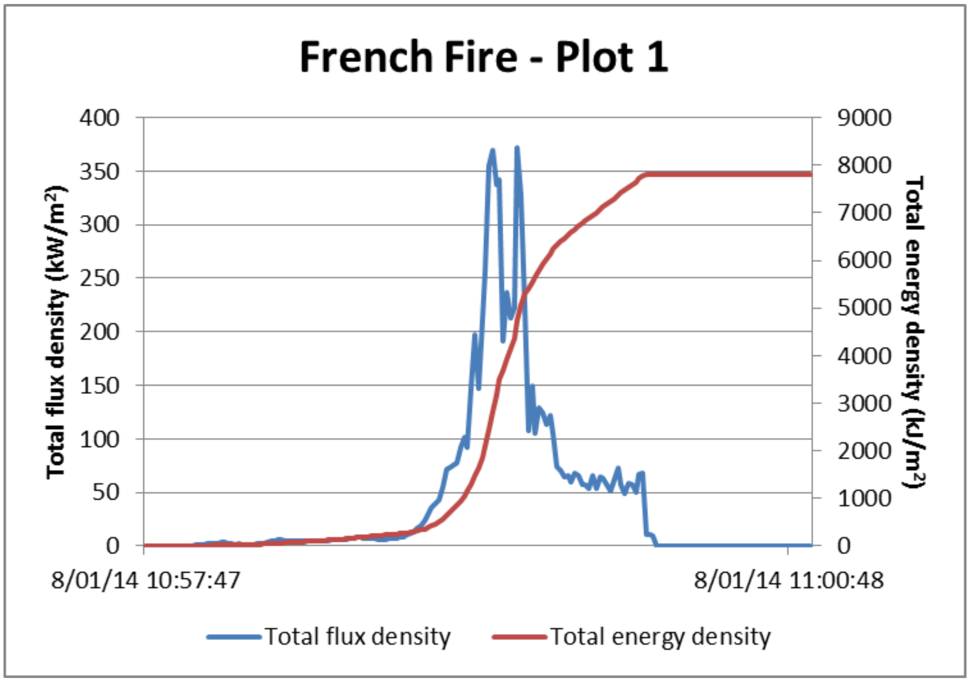
Plot 1 burned intensely while fire behavior in Plot 2 was mixed in both spread direction and intensity. In Plot 1, the flame front appears to have spread towards the front of the heat flux sensor and may be a useful dataset for safety zone research (Table 10, Figure 10); the heat flux sensor was in an open canopy area, but just upslope of a dense canopy area (which is where the vegetation/fuels measurements occurred). In Plot 2, heat flux to the sensor was low in the upper/open canopy and lower/dense canopy sensors, reflecting low intensity burning as the flames passed the sensor and also, potentially, spread from behind or upslope of the sensor. Energy in Table 10 and Figure 10 (energy density in legend) is time-integrated heat flux with units of kJ/m^2. Heat flux is recorded every 1 second, so energy is a simple sum of heat flux over the time period from fire arrival through cool down.

Table 10: Summary of energy transport to heat flux sensors in sites burned.

		Radiant		Total		
Site	Sub-plot	Peak Flux (kW/m^2)	Energy (kJ/m^2)	Peak flux (kW/m^2)	Energy (kJ/m^2)	Comments
1	Open canopy	157	2,984	372	7,816	Intense flames burning towards sensor
2	Lower/ dense canopy	3	1,957	8	3,029	Small flames
2	Upper/ open canopy	6	9,526	13	8,734	Small flames

Figure 10. Heat flux at sensor on Plot 1. Upper figure is radiant flux and energy (sum) while the lower figure shows total flux and energy (sum). The fall-off in the signal in both figures during the cooling period indicates overheating of the sensor (subsequent values were set to zero).





<u>Wind Speed</u>

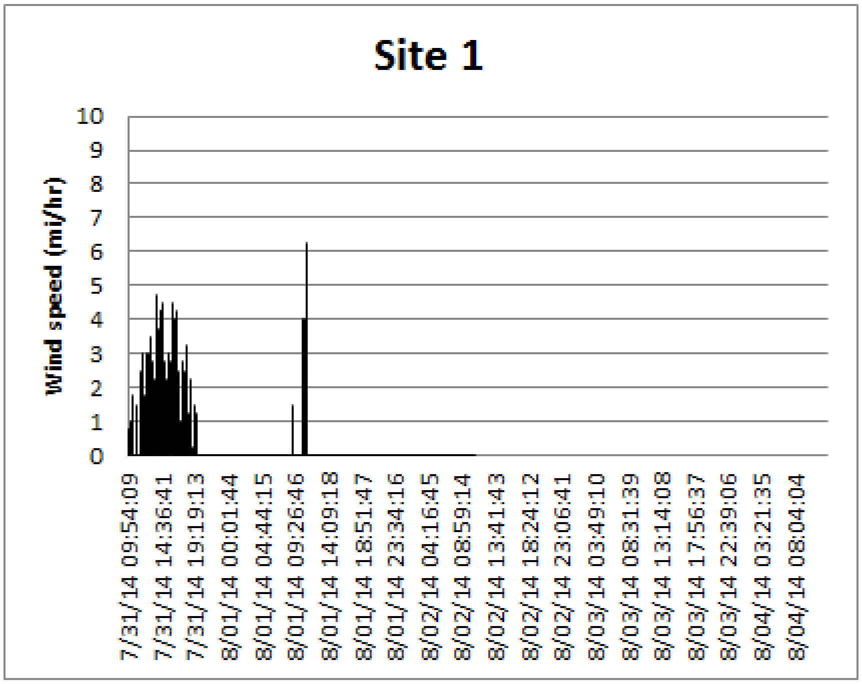
Methods

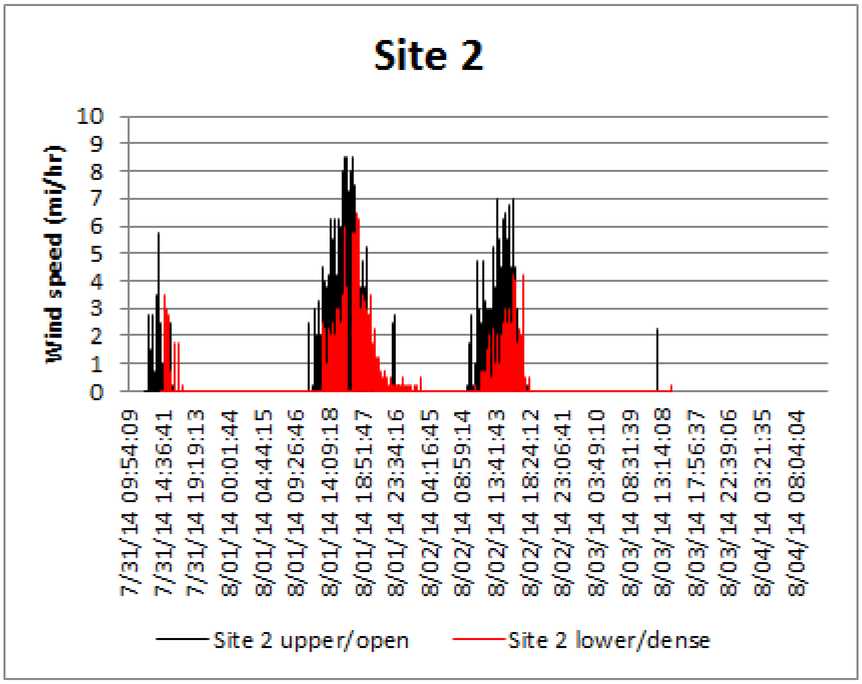
Wind data collected with cup anemometers placed 5 feet above ground at the locations of the heat flux sensors gives an indication of the wind experienced at each site as the fire passed through. Wind data on sites with intense fire is only valid only up until the plastic anemometer melts or otherwise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

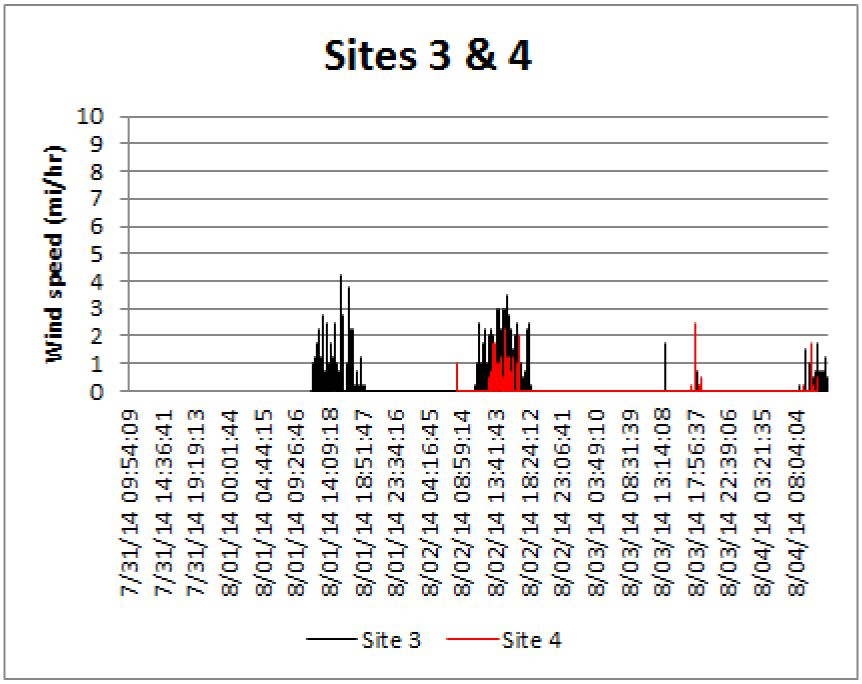
Results

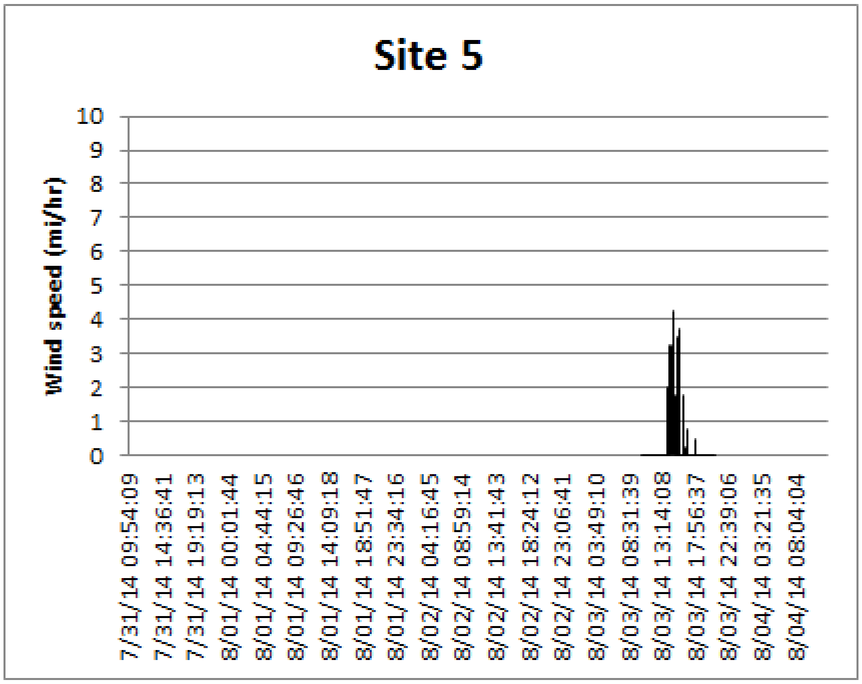
On the French Fire wind was variable across days and landscape positions (Figure 11). Sites 1 and 2 burned on August 1st. Conditions were generally windier on August 1st than on other days, coinciding with substantial growth of the fire (see Figure 2). The anemometer positioned on the upper side of Site 2 was in an open canopy area, while the anemometer on the lower side of the site was within dense vegetation and more sheltered from the wind as can be seen from relative wind speeds in Figure 11. Winds declined over the several days following August 1st and coincided with days of minimal fire growth. Sites 1 and 2 were aligned with prevailing wind direction while plots 3 and 4 were somewhat topographically sheltered. Site 5 was at lower elevation than other sites, but in a major drainage that roughly aligned with the prevailing wind on August 3rd. We found that Site 5 winds were higher than winds at Sites 3 and 4 on August 3rd because of the topographic alignment.

Figure 11. Wind data collected on the French Fire across the range of sites. As can be seen, the anemometer at Plot 1 melted during fire arrival on August 1st. Site 2 also burned over, but the two anemometers survived. Note that a time offset exists in Site 2 wind data indicated by a shift in peak wind speeds. Sites 3 to 5 did not burn, but the wind data is useful.






Sites 3 & 4
Wind speed (mi/hr)
0
1
2
3
4
5
6
7
8
9
10
7/31/14 09:54:09
7/31/14 14:36:41
7/31/14 19:19:13
8/01/14 00:01:44
8/01/14 04:44:15
8/01/14 09:26:46
8/01/14 14:09:18
8/01/14 18:51:47
8/01/14 23:34:16
8/02/14 04:16:45
8/02/14 08:59:14
8/02/14 13:41:43
8/02/14 18:24:12
8/02/14 23:06:41
8/03/14 03:49:10
8/03/14 08:31:39
8/03/14 13:14:08
8/03/14 17:56:37
8/03/14 22:39:06
8/04/14 03:21:35
8/04/14 08:04:04
Site 3
Site 4


Site 5
Wind speed (mi/hr)
0
1
2
3
4
5
6
7
8
9
10
7/31/14 09:54:09
7/31/14 14:36:41
7/31/14 19:19:13
8/01/14 00:01:44
8/01/14 04:44:15
8/01/14 09:26:46
8/01/14 14:09:18
8/01/14 18:51:47
8/01/14 23:34:16
8/02/14 04:16:45
8/02/14 08:59:14
8/02/14 13:41:43
8/02/14 18:24:12
8/02/14 23:06:41
8/03/14 03:49:10
8/03/14 08:31:39
8/03/14 13:14:08
8/03/14 17:56:37
8/03/14 22:39:06
8/04/14 03:21:35
8/04/14 08:04:04

SUMMARY AND ACCOMPLISHMENTS

Incident and Related FBAT Program Objectives

Our objectives were to:

1. Safely characterize fire behavior and quantify fuels for a variety of fuel conditions. Safety, access, and current fire conditions restrict which areas can be measured.
2. Gather energy transport data during active burning fires, in conjunction with site characteristics, for the Missoula Fire Lab's safety zone research.
3. Measure moisture content of representative fuels to support emission and fire behavior modeling and provide pre-and post-fire fuel loading to Air Resource Analyst.
4. Assess fire severity and effects based on immediate post-fire measurements.
5. Cross-train and collaborate with wildland firefighters, fuels managers, and incident staff during the field study, as well as with Sierra National Forest and Fire Lab staff after the fire.
6. Begin testing soil sampling protocol for quantifying black carbon production and loss during fires in conjunction with Michigan State University.

FBAT met the above objectives, and have communicated results through the distribution of this report. Data are being prepared for archiving to facilitate distribution to users. . Two sites were successfully measured and burned on August 1st 2014 at the northwestern end the French fire below the 4S81 road. While these two sites represent limited variation in fuel conditions, FBAT was able to capture higher intensity fire behavior and effects within the sites. Recent fuel treatments did not exist in the nearby projected fire growth areas; this area was in planning stages for vegetation and fuel treatments and the baseline data collected by FBAT will help contribute to planning efforts. The French fire burned during drought conditions resulting in high fuel consumption and intense behavior, as recorded in the two burned sites, as well as mixed severity fire effects across the fire area. The data collected by FBAT will be used to improve understanding of fires burning under these extreme conditions. Permanent transect markers of all five sites were left for any future resource monitoring by the Sierra National Forest or other researchers.

FBAT also gathered heat flux data with newly calibrated equipment which will start to build a dataset to contribute to Missoula Fire Lab safety zone research intended to improve firefighter safety. FBAT also beta-tested a new soil sampling protocol and sent several soil samples off to Michigan State University collaborators for analysis. Beta testing is the first step 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 to evaluate and possibly calibrate fire behavior or fire effects models. Ground data on fire behavior and effects are also valuable as evaluation and calibration datasets for remote-sensing studies of fire severity and fuel treatment effects. The value of FBAT's ground data will grow as data from future fires are combined with the growing archive.

The FBAT team on the French fire was a collaboration of firefighters representing a wide range of experience. The crew was composed of fire personnel from the Sierra NF, Stanislaus NF, researchers from the RMRS fire lab and Northern Research Station, a siviculturist from Sierra NF, and AMSET personnel. The French fire proved to be a good opportunity to cross-train and integrate fire science into fire operations and future planning.

Lessons Learned

The French fire area had many snags, and created many snags. After trees become fire weakened, they can be particularly hazardous. While quickly retrieving only time sensitive equipment on one plot during the French fire, we noticed two particularly hazardous burned snags with little holding wood angled straight for the plot (photos of tree fuels built up post fire on plot 2 in appendix below). We did not reread the plot that day, and did not spend much time in the area due to the hazard the snag posed. The following day we returned to the plot, and one snag had fallen into the plot and the other was cut by holding operations to improve both their and our safe working conditions. This raised our awareness of key protocols FBAT follows to steer away from snag hazards. Before installing a plot, the crew assesses current and potential post-fire snag hazards and will move the study site to minimize post-fire risk. Before the crew enters a plot post-fire, one leader walks through and identifies potential hazard trees. If a plot contains snags which are obviously fire-weakened and likely to fall soon, we either wait for the snag to fall, or have it fallen before entering the plot. FBAT avoids revisiting burned plots soon after the fire and during high winds which could trigger fire-weakened trees to fall. FBAT also uses a ‘snag-lookout’ while rereading plots in burned areas with hazard trees, as this could give an early alert to team members busy with plot measurements. FBAT also can choose to wait several days or more to reread burned plots, after snags have been wind-tested.

Acknowledgements

We send a special thanks and appreciation to the CA Central Sierra Incident Command Team for working with us and to Division Supervisors and lookouts with whom we worked. Thanks to Sierra National Forest staff members Denise Tolmie, Carolyn Ballard, Van Arroyo, Katherine Napier, and Hannah Key who helped facilitate FBAT work on the French fire. Katherine and Hannah also joined the FBAT during plot selection and pre- and post-fire sampling. Thanks to those who have contributed to maintaining FBAT financially, including the USDA Forest Service WO and PSW Regions FAM, JFSP, and others who helped build our FBAT program. We thank the Stanislaus NF firefighters who are consistent helpers on incidents, maintaining FBAT equipment, and equipment storage. We thank all of our ‘ride-alongs’ who make up the FBAT team, past and present – without you, the FBAT program would not exist. Thanks to Dr. JoAnn Fites-Kaufman for starting the FBAT program many years ago. We thank the Missoula Fire Lab and other fire scientists for past, present and future assistance with equipment and methods.

References

Albini, Frank A. 1976. Estimating wildfire behavior and effects. USDA Forest Service. GTR INT-30. Intermountain Forest and Range Experiment Station.

Agee, J.K. 1996. The Influence of Forest Structure on Fire Behavior. 17th Forest Vegetation Management Conference. University of Washington, Seattle, WA.

Brown, J.K., 1974. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. GTR-INT-16. 34 p.

Burgan, R. E. and Rothermel, R.C. (1984) BEHAVE: Fire Prediction and Fuel Modeling System -- FUEL Subsystem. General Technical Report, INT-167. USDA, Forest Service. Ogden UT. Calculation spreadsheet by Scott (2005), see below.

Butler, B.W. and Cohen, J.D. 1998. Firefighter Safety Zones: A Theoretical model based on radiative heating. Int. J. Wildland Fire 8(2): 73-77.

Butler, B., Jimenez, D., Forthofer, J., Sopko, A. P., Shannon, K., Reardon, J. Proceedings of 3rd Fire Behavior and Fuels Conference, October 25-29, 2010, Spokane, Washington, USA

Butler, B. W., Teskey, C., Jimenez, D., O’Brien, J. J., Sopko, P., Wold, C., Vosburgh, M., Hornsby, B. 2014. Observations of fire intensity and fire spread rate in grass and long leaf pine ecosystems – the RxCADRE Project. International Journal of Wildland Fire, in review.

Crookston, N.L., Dixon, G.E., 2005. The forest vegetation simulator: a review of its structure, content, and applications. Comput. Electron. Agric. 49, 60–80.

Frankman, D, Webb, BW, Butler, BW, Jimenez, D, Forthofer, JM, Sopko, P, Shannon, KS, Hiers, JK, Ottmar, RD. 2012. Measurements of convective and radiative heating in wildland fires. International Journal of Wildland Fire 22: 157-167.

Graham, R.T., Harvey, A.E., Jain, T.B., Tonn, J.R. 1999. The effects of thinning and similar stand treatments on fire behavior in Western forests. Gen. Tech. Rep. PNW-GTR-463. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Graham, R.T., McCaffrey, S., Jain, T.B. (tech. eds.). 2004. Science basis for changing forest structure to modify wildfire behavior and severity. Gen. Tech. Rep. RMRS-GTR-120. Fort Collins, CO: Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Rebain, S.A. (Comp.), 2010. The Fire and Fuels Extension to the Forest Vegetation Simulator: Updated Model Documentation. USDA For. Serv. Int. Rep. 408 p. (revised July 2013).

Rothermel, R.C. 1991. Predicting behavior and size of crown fires in the Northern Rocky Mountains. Research Paper. INT-438. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Scott, J.H., Reinhardt, E.D. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. Research Paper. RMRS-RP-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Scott, J.H. 2005. Behave Fuel Subsystem calculations adapted to an excel spreadsheet, Pyrologics, joe.scott@pyrologix.com.

Simard, A., J. Eenigenburg, K. Adams, R. Nissen Jr., and A. Deacon. 1984. A general procedure for sampling and analyzing wildland fire spread. Forest Sci., Vol. 30, No. 1.

USDI National Park Service. 2003. Fire Monitoring Handbook. Boise, ID: Fire Management Program Center, National Interagency Fire Center, 274p. Program information available online: http://www.nps.gov/fire/fire/fir_eco_mon_protocols.cfm (Aug. 2, 2011).

van Wagtendonk, J.W., Benedict, J.M., Sydoriak, W.M., 1996. Physical properties of woody fuel particles of Sierra Nevada conifers. Int. J. Wildland Fire. 6, 117–123.

van Wagtendonk, J.W., Benedict, J.M., Sydoriak, W.M., 1998. Fuelbed characteristics of Sierra Nevada conifers. West. J. Appl. Forestry. 13, 73–84.

Van Wagner, C.E. 1968. The line intersect method in forest fuel sampling. Forest Sci. 14:20-26.

FBAT crew members on last full day on French fire (Butler had left already).

APPENDIX A: REPRESENTATIVE PAIRED PHOTOGRAPHS

Below are representative photographs taken along the sampling transects. Pre- and post-fire photographs are paired to facilitate comparison and provide an archive for future reference.

Plot 1 Transect 1, 50-0ft, Pre

Plot 1 Transect 1, 50-0ft, Post

Plot 1 Transect 2, 0-50ft, Pre

Plot 1 Transect 2, 0-50ft, Post

See page 5 for two additional Plot 1 paired photos.

Plot 2 Transect 1, 0-50ft, Pre

Plot 2 Transect 1, 0-50ft, Post

Plot 2 Transect 2, 0-50ft, Pre

Plot 2 Transect 2, 0-50ft, Post


07/31/2014

Plot 2 Transect 3, 50-0ft, Pre


08/05/2014 11:46

Plot 2 Transect 3, 50-0ft, Post

Representative pictures of unburned plots are below.


08/01/2014

Plot 3 Transect 1, 0-50ft, Pre


08/01/2014

Plot 3 Transect 1,5 0-0ft, Pre

Plot 4 Transect 1, 50-0ft, Pre

Plot 4 Transect 3, 50-0ft, Pre

Plot 5 Transect 2, 50-0ft, Pre

Plot 5 Transect 1, 0-50ft, Pre

APPENDIX B: BURN SEVERITY CODING MATRIX

National Park Service burn severity coding matrix from (USDI 2003) used in FBAT data collection.

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 course, 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 course, 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

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 behavior sensors and fire-resistant 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 changes in fuel loads from fire consumption and can 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 or Air Resource Advisor predictions/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 (MFSL); submitting a JFSP grant proposal with Pete Robichaud to create an 'ash guide' for BAER teams; and testing sampling methods for black carbon measurements on wildfires with Jessica Miesel at Michigan State University.

We are 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. Our web page is below and has links to most of our Incident Summary Reports.

Website: http://www.fs.fed.us./adaptivemanagement/projects/FBAT/FBAT.shtml