USFS PSW Region
FBAT Fire Behavior in Tree Mortality
Cedar Fire Report

September 29, 2016

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Acknowledgements: We thank the Forest Service Pacific Southwest (PSW) Region Fire and Aviation Management (FAM), Sequoia National Forest FAM and their staff, and the USFS Washington Office FAM. We thank California Interagency Incident Management Team 5, including division supervisors, Jeff Shelton (LTAN and FBAN), Dan Harty (IMET) and Logistics for providing work space. We thank Brent Skaggs for supporting FBAT work on SQF fires and helping connect science monitoring results to fire management and Yvonne Stockdale and Donna Johnson for helping us find a home for the fuel drying. We appreciate the help of Al Augustine as a safety lead for FBAT during the Cedar fire. We would also like to thank Jennifer Anderson, PSW RO, for her help with short-turn around maps for field use. We appreciate the help of numerous people working in dispatch on Forests and incidents who helped FBAT meet monitoring goals on the Cedar fire including Pam Greenwood. We thank Tim Sexton for helping to brainstorm on FBAT methods and program operations. A huge thanks to Mark Courson for serving as not only a liaison, but also an excellent operations lead and mentor. Thanks to Carol Ewell for gear preparation and report edits.

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Background

In July 2016, the USFS PSW Region Fire and Aviation Management (FAM) tasked the Fire Behavior Assessment Team (FBAT) to help in assessing the effects of an upsurge in tree mortality on fire behavior in the southern Sierra Nevada. The Cedar Fire ignited on Tuesday August 16th, 2016, at approximately 1600 on the Sequoia National Forest in the southern Sierra Nevada. The FBAT arrived on the fire on August 18th and conducted field work Aug. 19-30th.

FBAT worked for 13 days on the Cedar Fire installing and collecting fuel and fire behavior data on plots. FBAT also collected and delivered fire weather and behavior observations to the Incident Management Team (IMT) and characterized tree and shrub foliar moisture. The last day of the tour, FBAT collected tree-mortality map evaluation data.

Goals and Objectives

The Pacific Southwest Region asked FBAT to answer the question, “What is the actual fire behavior in tree mortality areas?” FBAT’s goal coming into fire season was to collect short-turnaround intelligence on fuel/weather/topography/fire behavior conditions to support Fire Behavior Analysts (FBAN) and Long Term Analysts (LTAN) on current and future incidents by helping analysts improve fire behavior predictions in areas experiencing high tree mortality levels. As a means of defining objectives, FBAT focused on specific questions that could be answered with field data and observations:

- How does tree mortality affect the thresholds for torching and sustained crown-fire spread?
- Are spotting distances substantially different from fire behavior model predictions?
- Do crown fire runs spread faster than predicted by fire behavior models?
- Are moisture contents of foliage on dead trees similar to dead and down fuels?
- How accurate are current tree mortality maps and how can they be updated and delivered to incidents as tree mortality areas expand?
- Do fire management strategies and tactics change in areas with high tree mortality?

The methods we used to answer these questions include FBAT field plot sampling, Fire Effects Monitor (FEMO)/Field Observer (FOBS)-type observations, and airborne imaging.

Accomplishments

- Safety was maintained as first priority.
- Monitoring questions were framed into more useful and answerable formats.
- Approach and methods were developed, tested, and vetted, including additions to standard FEMO/FOBS observations and the use of airborne infrared imagery.
- Installed 7 plots (fuels measured and fire behavior instrumentation installed), of which 3 burned.
- Provided FBAN with fireline observations of weather, fire behavior and smoke over 7 days.
- Summarized spotting distance and spread rates from an infrared aerial image from Aug. 19th.
- Collected live and dead tree and shrub foliage for fuel moisture determinations.
- Provided fuel loading data to incident Air Resource Advisor.
- Provided field-based tree mortality data to PSW RO staff for initial evaluation of the Ecosystem Disturbance and Recovery Tracking System (eDaRT) tree mortality mapping data.
- Assembled summary report of data and observations during the Fire, including video links.

Field Data during the 2016 Cedar Fire

FEMO/FOBS Observations

Fire behavior was observed at several opportune times and locations from Aug. 20-24th. FEMO/FOBS-type observations were used. Although this dataset is limited, several trends and lessons learned occurred (Table 1).

The documented fire behavior observations, plus observations noted by fireline personnel, indicated that backing and flanking fire are similar regardless of presence of tree mortality. However, differences in fire behavior due to mortality are likely to occur during heading fires.

Our fire behavior observations all occurred during wind speeds of 0-4 mph with gusts up to 6 mph, on Aug. 20-24th, when the general direction of fire spread was only downslope, and against or perpendicular to wind. Additionally, aerial suppression actions dampened observed fire behavior on Aug. 20-21st and 23-24th. Fire behavior was more intense during the first several days of the fire, prior to FBAT being fully engaged. Figure 1 shows plume development from the last major run in timber for the Cedar Fire on Aug. 19th. The fire had room to move uphill during the first several days, whereas the days when FBAT was fully engaged, fire spread was mainly limited to moving downslope.

Figure 1. Plume development during August 19th from the last major uphill run of the 2016 Cedar Fire in forested fuels.

Observations during a burnout operation were made on August 22nd that were affected by ignition operations, but not by aerial suppression (Table 1). The photograph in Figure 2 illustrates fire behavior on August 25th during aerial ignition. This photo illustrates possible fire behavior when fire is not backing or being slowed by aerial water or retardant drops, as was the case for fire behavior observations in Table 1.

Figure 2. Photograph of a large group torching event (lower left) on August 25th on the 2016 Cedar Fire after aerial ignition in a recent tree mortality area.

Table 1. Fireline observations of fire behavior and weather during the 2016 Cedar Fire.

Date/time	Location	Winds (gusts) mph, direction	Temp (° F)	Relative Humidity (%)	Fire spread type	Fire Behavior*	Notes
8/20 1421	Sugarloaf Mnt.	0-2(3), variable	76	38	backing downslope	no torching	aerial suppression
8/20 1430	Sugarloaf Mnt.	0-2(3), WNW	76	38	backing downslope	no torching	aerial suppression
8/21 1000	Drop Point (DP) 12**	2-4(6), NW			backing		aerial suppression
8/21 1040	DP 12	2-4(6), NW	79	32	backing		aerial suppression
8/21 1310	DP 12	2-4(6), NW	81	33	flanking, backing		aerial suppression
8/21 1355-1720	DP 12	0-4(6), NW	80	30	running, backing, flanking		aerial suppression
8/21 1800	DP 12	0-2(3), NW	78	31	backing, flanking		Aerial suppression
8/22 1430	Panorama Heights	2-3, NW	81		backing, flanking	ROS 0.5-2 ch/hr	80% tree mortality, 10-15% slope, burnout
8/22 1800	Panorama Heights	2-3(4), NW			backing	FlmL 1-2 ft	15% slope, burnout
8/22 1800	Panorama Heights	*2-3(4), NW*			*head*	FlmL *10-15 ft*	15% slope, burnout
8/23 1230	Spear Creek	*2(3)*	*68*	*47*	*backing, flanking*	FlmL 3 ft & isolated *torching*	40% slope
8/23 1704	Spear Creek	1	70	37	flanking	FlmL 1 ft	105% slope
8/23 1705	Spear Creek	2-3	70	37	flanking	FlmL 2 ft	105% slope
8/23 1707	Spear Creek	calm	70	37	flanking	FlmL 0.5 ft	105% slope
8/23 1731	Spear Creek	0-2			flanking	FlmL 0.5 ft	30 seconds after water drop
8/24 1100	Poso Park	3(5), NW	73	33	backing		40% slope, scooper drops
8/24 1400	Poso Park	5(6), WWN	77	27	backing		40% slope, bucket drops
8/24 1600	Poso Park	1(3), SW	77	25	backing		40% slope, bucket drops

*FlmL = flame length (feet), ROS = rate of spread (chains/hour)

** Drop point 12 was between Balance Rock and Poso Park on 23N16

Probability of torching is likely a key mechanism by which dead trees influence crown fire behavior. Low moisture content of dead foliage would reduce the energy required for ignition and combustion and the critical surface fireline intensity required for crowning (see below). Over 130 single-tree and small-group torching observations during the Cedar Fire were collected in areas primarily of dead incense cedar trees. Only a few live trees were involved in group torching events and none in single-tree torching. We observed no notable increases in the presence of ladder fuels from recent dead foliage and branches, but this and associated increases in forest floor solar radiation and wind may occur in future years. We did observe incense cedar bark burning on the leeward sides of tree boles which carried fire into the tree crowns (Figure 3). Videos of flame spread up tree boles and torching behavior are posted on Youtube: https://youtu.be/3UMAeHxibAE and https://youtu.be/ssAc6zh-s6s

Figure 3. Leeward flaming on incense cedars that may be a mechanism by which their crowns are ignited.

Foliar Moisture and Critical Fireline Intensities for Torching

Foliage moisture from dead ponderosa pines and incense cedars was low (average of 7%), and was in the range of values predicted for fine dead fuels (1-hr time lag class size) during peak burning periods during the Cedar Fire (Table 3). Moisture of green incense cedar foliage was highly variable, perhaps because of varying levels of moisture stress among trees in the sample. A group of incense cedar foliage samples, from what were probably recently dead trees, had dead foliar moistures intermediate between dead and green foliage, likely because it takes some months for recently dead foliage to lose all its water retention capabilities (e.g., waxy cuticles).

Consequences for crown fire initiation in areas with high densities of dead trees is indicated from Van Wagner's (1972) critical fireline intensities for crown fire initiation. The critical value is the surface fireline intensity that would cause torching in stands with a known crown base height and foliar moisture content (which determine energy required for ignition). Surface fireline intensity is a function of fuel consumption and flame front rate of spread (also known as Byram's intensity). In calculations of critical fireline intensity (Table 2), a constant crown base height of 20 feet was used along with the measured foliar moisture contents. Dead foliage leads to about a 10-fold reduction in the critical intensity. The implication is that dead trees will be much more likely to torch than live trees, even if their crown base heights are higher. The results are consistent with the Cedar Fire observations, that the vast majority of individual and small-group torching events involved dead trees.

Table 2. Fuel Moisture contents for two conifer tree species that have high mortality rates in the southern Sierra Nevada and two common shrub species that are associated on sites with low to moderate tree cover. The critical fireline intensity for crown fire initiation for a 20 ft crown base height and the measured moisture contents are shown for ponderosa pine and incense cedar.

Species	Class	Moisture %	Standard Deviation	Number of samples	Critical intensity (BTU/ft-s)
Ponderosa pine	Dead	7	1	8	73
	Live	120	13	15	926
Incense cedar	Dead	7	1	6	69
	Recent dead	30	6	4	190
	Live	113	31	11	863
Manzanita, green leaf	Live	115	19	8	
Manzanita, white leaf	Live	131	23	15	

Field Study Plot Results

Understory and Surface/Ground Fuels

Tree data were collected and will be archived. Canopy fuels were not significantly consumed in plots. Understory, surface and ground fuels are displayed below (Tables 3 to 5). Pictures of representative transects are at the end of this report.

Table 3. Pre-fire surface and ground fuels for field plots on Cedar Fire.

Plot	1-hr (ton/ac)	10-hr (ton/ac)	100-hr (ton/ac)	Litter (ton/ac)	Duff (ton/ac)	Fuel ht (in)	1000-hr (tons/ac)
1	0.6	0.9	1.2	7.5	24.8	6	1.9
2	0.1	0.5	0.0	5.5	26.4	22	0
3	0.6	1.1	0.6	4.1	23.1	7	4.4
4	0.8	2.2	1.9	5.1	21.5	8	12.2
5	0.1	0.9	0.3	4.8	36.4	4	0.7
6	0.5	1.3	2.5	5.8	76.0	19	0
7	0.2	0.3	0.9	5.5	9.9	36	0

Table 4. Pre-fire live and dead grass/herbaceous fuels for field plots on the Cedar Fire.

Plot	Live Grass (tons/ac)	Dead Grass (tons/ac)	Total Grass/herb (tons/ac)
1	0	0	0
2	0	0	0
3	0	0.001	0.001
4	0	0.028	0.028
5	0.002	0	0.002
6	0.001	0	0.001
7	0	0	0

Table 5. Pre-fire live and dead shrub fuels for FBAT plots on the Cedar Fire.

Plot	Live Shrubs (tons/ac)	Dead Shrubs (tons/ac)	Total Shrubs (tons/ac)
1	0.340	0.109	0.449
2	0.344	0.706	1.051
3	0.003	0	0.003
4	0.006	0	0.006
5	0.018	0	0.018
6	0.742	0.155	0.897
7	0.522	0.002	0.524

Fire Behavior

No FBAT field plots burned in crown-fire runs, however, a range of surface fire behavior was observed from creeping spread to intensities that led to individual and group-tree torching in the vicinity of the plots. Plots 3 through 5 were in Division G on the western side of the fire and burned during a burnout operation with flanking fire and patchy spread. Pictures of representative transects from plots 3 to 5 are at the end of this report.

Plot 3: In plot 3, the fire activity observed in the plot was basically a creeping fire that burned patchy with 1-4 foot flame lengths in the ground litter. Observed in the background were sporadic torching events, apparently from single to multiple trees. The video did produce evidence of substantial ember wash from what was presumably a torching dead cedar located outside the plot. Embers were noted to be falling in the evening of Aug. 24th and created many spot fires within view (see video at https://youtu.be/IOWq8ZcDQJU). The prolific ember production suggests that torching dead cedars during wind events could result in enhanced spot fire initiation. Only two rate of spread sensors functioned on Plot 3 with one burning on Aug. 24th at 1755 and the other burning on Aug. 25th at 1312. The large gap in when fire arrived at the sensors indicates a patchy, slow-moving fire.

Plot 4: Plot 4 rate of spread sensors also indicate a patchy burn. The center and west sensors burned at 2236 and 2237 on Aug. 24th, respectively, and were located 50 feet apart. During that time, the winds were still (zero). The north sensor, 50 feet north of the center sensor burned on Aug. 24th at 2317. The data from the other sensors appeared unreliable. The video camera malfunctioned at this plot.

Plot 5: Rate of spread sensors on plot 5 showed patchy fire spread as well. Three of the sensors only showed diurnal temperature fluctuations, and data from the 4th sensor was suspect and the 5th sensor burned on Aug. 24th at 2308 pm. Video from Plot 5 was dark and smoky, and only showed patchy burning, and no real fire spread.

Crown Fire Rate of Spread and Spotting from Airborne Imagery and Webcams

A key objective for FBAT was to estimate crown fire rates of spread and spotting distances to provide IMTs guidance on whether these variables increase in high mortality and by how much. A coincident research project out of the Pacific Southwest Research Station (PSWRS) led by Phil Riggan involved flying over the Cedar Fire with an infrared imager on four separate days (Aug. 18 - 20, and 23rd) at ~15,000 ft above MSL. FBAT coordinated with PSWRS on flight opportunities and ground information. Once infrared images are processed, we expect to estimate rates of spread and spotting distances from crown runs that were coincident with the overflights. In the interim, Figure 4 shows minimum spotting distance and density during a late evening fire run that reached high elevations with heavy timber on the northwestern flank. Spotting distance and density are minimums because it takes time for a spot to generate enough heat to be detected and, meanwhile, the flame front has advanced towards the spots. Winds during this period at the high elevation RAWS stations on Peppermint and Breckenridge peaks were low and it appears that the fire behavior observed was terrain and fuels driven. Additional funding in 2017 would support the use of PSWRS airborne fire infrared imaging in assessing tree mortality effects on fire behavior.

Figure 4. Example of spotting information that could be derived from infrared imagery. The overflight was coincident with a late evening (21:00) crown fire run on Aug. 18th in forested fuels. The flames in the center of the webcam image are from the northwest run that appears on the infrared map of the whole fire (inset). The spotting information is from the fire seen on the upper right side of the webcam image that is partly obscured by the topography.

We estimated rate of spread (ROS) from distances between perimeters derived from a combination of 1) webcam imagery and the 2100 airborne infrared map and 2) the previous night's NIROPS fire perimeter and the 2100 infrared map. Both methods provide long-term average ROS (over hours) and so, are less than spread rates that would be seen over short, active crown-fire runs (10s of minutes). In the first method, we estimated the initial position of the fire front on a webcam (Figure 5) and the fire's final position from the 2100 airborne infrared map. The fire front on Tobias Peak webcam was mostly obscured by topography, so we estimated a minimum and maximum travel distance. In the second method (not shown), we estimate the starting position from the NIROPS perimeter from the night before (Aug. 17th) and the ending position from the 2100 airborne infrared map. In the second method, fire spread time begins at 1100 when the plume builds substantially (as seen from Breckenridge #2 webcam) until 2100. Rates of spread are 8-12 chains/hour by the first method (over 7.9 hours) and 18 chains/hour by the second (over 12.4 hours). These rates are at the low end of the range reported by Perrakis et al. (2014) for crown fire ROS in bug kill and 2-4 times lower than the FBAN's estimates of potential crown fire ROS of $\leq$80 chains/hour. Rates of spread of crown runs over short periods of time (10s of minutes) are needed and could be made most accurately from repeat daytime airborne imaging (i.e., the PSWRS flights, above) or from direct observation from a lookout location from which the fire was not obscured by topography or smoke.

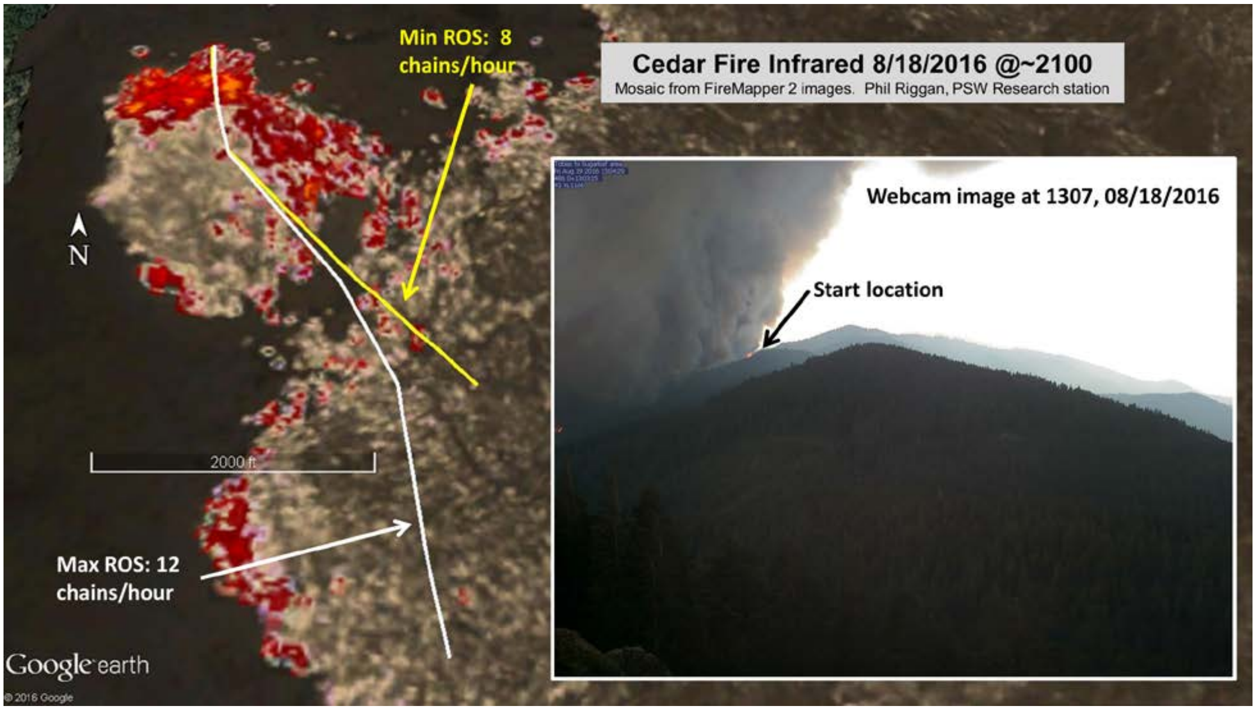

Figure 5. Minimum and maximum rates of spread over 7.9 hours during which we assume that fire spread in a north to northwest direction. Start time and position (obscured by topography) are estimated from the Tobias peak webcam (inset). End time and position are provided by an airborne infrared map of the fire collected at 2100. It appears that spotting had a substantial effect on spread behavior (e.g., the NW part of the fire in the infrared image likely originated as a spot fire).

Challenges and Lessons Learned

This fire behavior in tree mortality objective is unique for FBAT, not only in the focus of the work, but also in the extent of consultation and planning conducted to prepare for the fire season. Planning occurred over a short period of time, beginning in late July 2016, and goals, objectives, and methods are still being developed. Interest and involvement in the process is an exceedingly positive development. However, the time window was short and bringing plans to a near-complete stage will take more time.

This work on the Cedar Fire helped us to dive into the process and quickly realize the need for clarifying objectives and related methods. The simple question of "what is fire behavior in tree mortality" required development of measureable objectives and associated methods that would allow us to clearly define for firefighters and managers how fire behavior in tree mortality is different.

We encountered challenges with obtaining optimal data from our standard ¼-acre, instrumented FBAT plots. In general it is a challenge to gather situational awareness and develop fire growth expectations on a fire quickly enough to install plots prior to fire containment in an area near urban development. We found that when we add the additional constriction of establishing these plots in tree mortality areas, opportunities became more limited. As well, aerial suppression activities, which were used extensively in the Panorama Heights/Sugarloaf area (Division G) prevented us from making valid observations of freely-developing fire in tree mortality. In general, the Cedar Fire ran uphill during the first 4 days of growth, and then largely backed downhill in tree mortality areas during the days FBAT was fully engaged with plot installation. The downhill growth and fire suppression limited availability of acreage for obtaining high-intensity fire behavior from plots. The typical ¼-acre FBAT plot approach works well on fires which have large growth for the first 7 to 10 days because more opportunity exists for FBAT to arrive, gain situational awareness, and insert a number of plots which will burn relatively unaffected by suppression.

Additional methods, such as direct observation of fire by observers on the ground as well as analysis of weather data and aerial images, show promise to gather information not readily measureable via the ¼-acre instrumented-plot method. We feel that direct observations of the fire are useful to narrow in on the weather, terrain, and fuel factors influencing fire behavior in tree mortality. We took the opportunity on the Cedar Fire to create a new fire behavior observation datasheet to help in gathering all pertinent data. In situations where fire is moving uphill with intensity, and ground observers cannot safely observe from a nearby location, the ¼ acre plot or aerial imaging method might work better. We feel the use of aerial images holds promise during the first 3 to 4 days of fire growth when that growth might be less affected by suppression action and before FBAT plot installation is likely. Once FBAT team members arrive, FBAT can gather information on suppression activities and coordinate with overflights in order to avoid confounding effects of suppression actions and tree mortality on fire behavior.

Although FBAT-instrumented fuels plots were a less useful tool on the Cedar Fire, video from plots was useful for observing the unexpected such as ember production from torching events. On future fires, we expect that coordinated weather and fire behavior observations will be an effective focus. We are optimistic from initial analyses that repeat airborne infrared imaging of crown fire runs will be a useful tool for characterizing upper-limit spread rates and spotting behavior.

Conclusions

We moved toward success in answering the general question of, "what is fire behavior in tree mortality?" We more clearly defined a set of specific questions and identified methods to answer those quesitons. We learned about the feasibility of using various methods to address tree mortality effects, including ¼ -acre FBAT plots, direct observations, aerial images, and webcams and started to amass data. Answering the tree mortality and fire monitoring questions adequately will take data and observations from multiple fires.

Immediate trends FBAT sees relative to fire behavior in tree mortality include:

- Backing and flanking fire behavior do not seem to be as different in tree mortality zones than behavior of head fires which lead to crown fire initiation.
- Anecdotal evidence supports the concept that torching potential and ember production are greater in tree mortality areas.
- FBAT's small sample of crown foliar moisture data indicate that dead needles have moisture contents that are within the range of fine dead fuels and needle moisture from dying trees are intermediate between fine dead fuels and live tree foliage.
- The Cedar fire was not wind tested during the days FBAT was fully engaged. How wind and tree mortality interact in their effects on fire behavior are not clear yet.

References

Perrakis, D. D., Lanoville, R. A., Taylor, S. W., & Hicks, D. 2014. Modeling wildfire spread in mountain pine beetle-affected forest stands, British Columbia, Canada. Fire Ecology 10(2):10-35.

Van Wagner, CE. 1977. Conditions for the start and spread of crown fire. Canadian Journal of Forest Research 7: 23-34.

Methods

Please see field data methods in previous FBAT reports at:
http://www.fs.fed.us/adaptivemanagement/projects_main_fbat.php

Time Lapse Imagery

Fire behavior and smoke throughout the August 20th burning period. Camera was located at the transfer station near Pozo Park. The view is towards the Spear Creek drainage and Sugarloaf Mountain.

https://youtu.be/WUhzQ8TRO5w

Background on FBAT

FBAT is long term program and involves a group which collects fuels and fire behavior data on active wildland fires. FBAT can be ordered in ROSS. FBAT is made up of several arduous fire fighter qualified members from Adaptive Management Services Enterprise Team (AMSET) many on-call members from various agencies, collaborators, as well as several wildland fire modules who are trained in FBAT methods and equipment use. More information can be found at:
http://www.fs.fed.us/adaptivemanagement/projects_main_fbat.php

Pre- and Post-fire Pictures of Fuels Transects on FBAT Plots

Plot3 Transect1, Pre-fire, 0-50ft

Plot3 Transect1, Post-fire 0-50ft

Plot4 Transect 3, Pre-fire, 50-0ft

Plot 4 Transect 3, Post-fire, 50-0ft

Plot 5 Transect 3, Pre-fire, 50- 0ft

Plot 5 Transect 3, Post-fire, 50- 0ft