Prescribed burning to protect large diameter pine trees from wildfire – Can we do it without killing the trees we're trying to save?
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Field Locations: Lassen National Forest (LNF), Eagle Lake District, Grays Flat and Lassen Volcanic National Park (LVNP), Prospect Peak area, both located in northern California.

Brief Synopsis: Prescribed burning to reduce fuel in some areas with large diameter and old-growth trees is causing significant mortality of these high-value trees even with low intensity fires. A probable cause is the extended burning of large duff accumulations resulting from 100 years of fire exclusion. Burning when duff moistures are low can lead to root mortality and basal girdling from consumption of the duff mounds, which may then lead to tree mortality. Our project objectives were: 1) determine if removal of the litter and duff by raking around the base of large-diameter pine trees will increase their survivability when exposed to prescribed fire, 2) estimate time required to complete raking treatment, and 3) develop relationships between duff characteristics (depth, moisture content, mineral content) and duff consumption. This final report contains 3-post-fire year results for the LVNP site and 2-post-fire year results for the LNF sites (as measured by number of growing seasons since fire). We found no significant differences in tree mortality between raked and unraked trees 2 years after the prescribed burns on the Lassen National Forest and 3 years after the burn on the Lassen Volcanic National Park. Raking reduced cambium injury and red turpentine beetle attacks in the burn units. The average time to rake duff around the first 60 cm (2 ft) to mineral soil was 16 minutes/person. Raking time depended on the depth of the duff mound. Laboratory tests suggests that sustained smoldering of Jeffrey pine duff occurs above 40-50 moisture content and 65-85% for ponderosa pine.

INTRODUCTION

The use of prescribed fire has become a major tool for restoring fire-dependent ecosystem health throughout the west and use will likely increase in the future. Current management guidelines in Region 5, under the Sierra Nevada Framework, call for the use of fire as the primary management tool to deal with high surface fuel loads and dense conifer understories. The window of opportunity for carrying out a prescribed burn is limited by weather, fuel conditions, air quality concerns, and potential mortality of large diameter trees. Attempts to prescribed burn some stands have often resulted in increased mortality of these trees. Even with mechanical thinning to reduce ladder fuels and the probability of crown damage, the problem of deep duff mounds and below-ground injury still exists. Increased mortality of large diameter and old pine following fire has been reported in other areas as well and there is increased concern about maintaining large-diameter trees on the landscape (Kolb et al. 2007). Mortality of presettlement ponderosa pines in prescribed burn areas in Grand Canyon National

Park was higher than in control plots (Kaufmann and Covington 2001). Prescribed burns in Crater Lake National Park resulted in higher mortality of ponderosa pines greater than 9 inches diameter than in unburned areas, with early season burns having even higher mortality (Swezy and Agee 1991). McHugh and Kolb (2003) reported a U-shaped mortality curve for ponderosa pine, with smaller and larger diameter trees having higher mortality than mid-diameter trees.

Accumulation of litter and duff around large diameter trees has reached unprecedented levels in the California eastside pine type as a result of 100+ years of fire exclusion. The unprecedented litter and duff accumulations observed in most western forests are well documented and described by various authors including Sackett et al. (1996), Covington et al. (1997), Sackett and Haase (1998), and Haase and Sackett (1998). Because duff smoldering does not cause intense fire behavior, its consequences are often overlooked. Swezy and Agee (1991) stated, “Restoration burns in ponderosa pine stands where 80 years of fire exclusion have allowed duff to increase, especially at the base of large old pines, may result in greater duff consumption and higher soil temperatures than those experienced by trees subject to periodic low-intensity fires where duff layers are much thinner.”

Several studies have attributed large diameter tree mortality to basal injury caused by duff mound smoldering and bark beetle attacks. Long-term smoldering can cause high soil heating above 60^{o} C, the temperature required to kill living tree tissue. Hartford and Frandsen (1992) reported soil temperatures under smoldering duff mounds of 400^{o}C, with temperatures in duff above 100 ^{o}C for over 16 hours, compared to soil temperatures of less than 80 ^{o}C and duff temperatures above 100 ^{o}C for 1 hour under burning slash. Temperatures in smoldering duff mounds were above 300^{o}C for 2-4 hours during a prescribed burn in Glacier National Park, resulting in the mortality of 45% of the cambium samples (Ryan and Frandsen 1991). Bradley and Tueller (2001) stated that a burned tree was 24.81 times more likely to be attacked by a bark beetle than an unburned tree, and that trees with deep soil charring were 9.81 times more likely to be attacked than all other trees combined.

Brown et al. (1991) found duff depth reduction is strongly dependent on preburn duff depth on sites in the Northern Rockies. In deeper duff they hypothesized that duff moisture content and large diameter fuel reduction are more significant factors. Laboratory studies of smoldering combustion, conducted using commercial peat moss as a substitute for duff, identified moisture and mineral content as significant factors influencing energy output and consumption in mixtures of organic and non-organic materials (Frandsen 1987; Hartford 1989).

Other experimental studies of ignition or sustained combustion limits have been conducted using organic soils from a wide range of wetlands and forest floor/duff from non-wetland sites (Hungerford et al. 1995; Frandsen 1997). The results supported the conclusions of previous studies conducted using peat moss. The likelihood of ignition or sustained combustion decreased with increasing moisture content and was dependent on organic bulk density and mineral content. More recent work by Reardon et al. (2007) reported that the limits of sustained combustion in thick organic soil horizons in North Carolina were a function of moisture and mineral content.

Although some work has been done on the effect of duff and litter removal, little is known about the factors that determine its success or failure as a practical management tool. In a study conducted by Covington et al. (1997) and Feeney et al. (1998) duff was removed across the entire treatment unit to simulate presettlement conditions. Swezy and Agee (1991) removed the litter only from the base of the trees, leaving the duff, but reported the death of one of the raked trees. Laudenslayer et al. (2002) found improved survivorship in prescribed burns trees in Lassen

Volcanic National Park by raking duff mounds around the base of large diameter trees. Sample sizes in these studies were very small and there were no controls or raking-only treatments. Fowler et al. (2007) reported that raking reduced cambium kill at the bases of old-growth ponderosa pine. However, the cambium kill did not result in tree mortality and no trees, either raked or unraked, died in the study.

Our study examines the feasibility of removing deep duff mounds around ponderosa and Jeffrey pine trees prior to prescribed burning. By removing duff, managers could burn under a wider range of weather conditions and different seasons, leading to more acres treated with potentially fewer bark beetle attacks and less large-diameter tree mortality. It includes a duff removal-only treatment, in order to determine if the impact of raking alone causes tree mortality. We also conducted a pilot study to determine the threshold moisture content that supports sustained smoldering in Jeffrey pine and ponderosa pine duff.

METHODS

Site Descriptions

Three planned burned units were chosen that contained large (>63.5 cm (> 25 inches) DBH) ponderosa and Jeffrey pine. These areas had not burned in over 100 years (Taylor 2000). Two sites were established in the Grays Flat area on the Eagle Lake District of the Lassen National Forest (LNF) in Summer/Fall 2003. Our original plan included only one site on the LNF. However, an ideal second site that bordered the first site was identified after the proposal was funded. Both LNF sites were dominated by mature ponderosa and Jeffrey pine, with mature white fir scattered throughout the units. White fir ingrowth dominated the midstory. There was a heavy shrub component of *Ceanothus velutinus* and *Arctostaphylos patula*. Slopes were between 0-25 percent, with a north aspect. Elevation ranged from 1920-1980 m (6298-6495 ft). An adjacent unit that was not included in the burn plan served as a control.

Both LNF burned units were thinned from below between January and June 2002 to remove much of the white fir ingrowth. Residual logging slash was scattered throughout the units. The fuels and shrubs on the second LNF site were then masticated in 2003. Adding this second site allowed us to investigate a relatively new fuels treatment with very little additional cost. The control unit was not thinned.

In the fall of 2004 we established a third site in the Prospect Peak burn unit in Lassen Volcanic National Park (LVNP). The entire burn unit was approximately 1620 ha (4000 acres); however, study trees were located in the southeastern portion of the unit only, near Butte Lake campground. The majority of the trees in the study area of the unit were mature Jeffrey pine. The understory was very open, with virtually no ingrowth or shrubs. Slopes were between 3-19 percent, with a south-southeast aspect. Elevation was between 1860-1950 m (6100-6396 ft). The area east of the trail leading to Prospect Peak and west of Butte Lake campground served as the control.

Treatments

Raking

Ponderosa and Jeffrey pine trees greater than 63.5 cm (25 inches) DBH with no sign of insect attack were chosen randomly throughout the units. All sample trees in each unit were paired based on species and similar size, vigor class, and close proximity to each other. One tree in each pair was then randomly selected to receive the raking treatment unless a fire scar was present. In this case, the tree with the fire scar was designated for raking. At each designated raked tree, a crew of 2-3 people used McClouds and rakes to remove all litter and duff to mineral soil in the first approximate 60 cm (2 ft) around the tree base. All shrubs located in this area were also clipped to ground level. The material was spread out around the tree so as not to form a mound of raked material. Trees were raked in the late summer/fall of 2003 on the LNF sites and 2004 on the LVNP site. We recorded the total time and number of persons required to complete the raking treatment for each tree.

Prescribed Burns

The LVNP study area of the Prospect Peak unit was prescribed burned June 14-15, 2005. The entire study area was ignited by strip-headfires as part of a blacklining operation to secure the south and east perimeters before aerially igniting the interior of the unit. This area was a fuel model 9 (Anderson 1981) and the primary carrier of the fire was Jeffrey pine needle cast. Fire behavior was primarily a low intensity surface fire with some individual small tree torching. Rate of spread was approximately 10-20 m (33 ft) per hour and average flame lengths were generally less than 0.5 m (2 ft). Temperatures during the burn on June 14 ranged from 17-21 degrees C (63-70 degrees F), with relative humidity from 21 to 40. Winds were from the south and southeast and ranged between 5-8 km/hour (3-5 miles/hour) with gusts to 11 km/hour (7 mph). Temperatures on June 15 were cooler, between 15-18 degrees C (60-65 degrees F), and RH ranged from 23-40. Winds were similar to the day before. A strong Pacific storm entered the area the day after burning (June 16). This storm caused a dramatic drop in temperatures and increase in RH throughout the day. It started to rain steadily on the evening of June 16, and turned to snow during the night. By the morning of June 17 about 2.5 cm (1 inch) of snow blanketed the study area.

The LNF Grays Flat thinned unit was prescribed burned October 21, 2005 and the masticated unit was prescribed burned October 22, 2005. Both LNF units were ignited by strip-headfires. A fuel model 9 best fit the thinned unit and a fuel model 8 fit for the masticated unit. In the thinned unit, fire behavior was a low intensity surface fire, with flame lengths between 0.25-0.5m (0.5-1.5 ft) and rates of spread between 40-60 m (2-3 chains/hour). Fire behavior in the masticated units was also a low intensity surface fire. In this unit, flame lengths were less than 0.25 m (1 ft) and rates of spread were extremely slow (< 5 m/hour (15ft/hr)). Temperatures during the burn on October 21 ranged from 15-20 degrees C (60-68 degrees F). RH was 24-28. Winds were southeast at 5-10 km/hr (3-6 mph) with gusts to 23 km/hr (14 mph). On October 22, burn time temperatures were 15-21 degrees C (60-70 degrees F) and RH as 12-26. Winds were southeast from 0-6 km/hr (0-4 mph) with gusts to 16 km/hr (10 mph). No precipitation occurred on site for at least 1 week after the fire.

Pre-fire Sampling

Within each LNF unit, we selected and tagged 60 trees for a total of 180 trees. A small portion of the thin+burn unit containing 10 paired trees was not ignited. Therefore, we added these unburned trees to the control unit. Within each LVNP unit, we selected and tagged 100 trees for a total of 200 trees (table 1). One LVNP tree that was selected for raking was accidentally missed. We measured DBH, total tree height, crown base height, and Keen's vigor class (Miller and Keen 1960), and noted species and any fire scars. Prior to raking, we also measured total forest floor depth (duff + litter) at 0, 30, 60, 90, 120 cm (0, 1, 2, 3, 4 ft) and dripline in the cardinal directions by carefully placing a trowel in the material and pulling it back just far enough to insert a ruler to mineral soil. Dripline was determined by looking up at the tree canopy and estimating the distance of the farthest tree branch at each cardinal direction. The circumference of the tree base that had shrubs growing in the removal area was also noted.

On the non-raked trees, we installed litter pins (helix spiral 50 lb. nails) flush with the top of the litter at 0, 30, 60, 120 cm (0, 1, 2, 3, 4 ft), and the dripline at cardinal directions. For the raked trees, litter pins were placed at 120 cm (4 ft) and the dripline in the same manner as the non-raked trees after raking was completed. At each tree, we installed 4 mini-fuel transects in the cardinal directions, starting with 0 at the tree bole and extending out to the dripline (for fuel loading around trees). On each transect we recorded fine fuels located in the first 120 cm (4 ft) by 30 cm (1 ft) sections (ex.-all 1, 10, 100, and 1000 hour fuels in the 0-30, 30-60, 60-90, and 90-120 cm sections). We recorded diameter, location, and decay class of 1000 hour fuels along the entire transect. We recorded the length and width by species of all shrubs along each transect.

Table 1. Number of trees by treatment and site in the Grays Flat and Prospect Peak areas.

Treatments	**Raked Trees**	**Non-raked Trees**
Lassen National Forest		
Unburned	35	35
Thinned + Burned	25	25
Thinned + Masticated + Burned	30	30
Lassen Volcanic National Park		
Unburned	50	50
Burned	49	51

We installed site-level fuel transects in order to characterize the fuels on the site (Brown 1974; Brown and others 1982). In each burn unit, site level fuel plots were placed along a grid throughout the unit based on a random start location, with 2 transects at each point. We determined the first azimuth by looking at the second hand on a watch and rounding to the nearest 5, the second azimuth was located by adding 90 to the first azimuth. Transects were monumented by nailing a duff pin and pin flag at the 0 end and pin flags at 12.2 m (40 ft) and 22.9 m (75 ft) along the transect. At the end of each transect, a photograph was taken facing toward plot center at the 22.9 m (75 ft) and 10.7 m (35 ft) points along the tape. One and 10 hour fuels were counted between 3.1-4.9 m (10-16 ft), 100 hours between 3.1-6.1 m (10-20 ft), and 1000 hr between 3.1-22.9 m (10-75 ft). Eight fuel plots were established on the LNF thinned unit and 10 plots in both the LNF masticated unit and LVNP unit.

In the LNF masticated unit, both dimensions of all masticated (2-dimensional) fuel along the 3.1-6.1m (10-20 ft) section of the site level fuel transect and from 0-120 cm (0-4 ft) along the tree mini-fuel transects were also recorded. Dimensions of masticated material along the tree fuel transects were also recorded. This method was used after initial measurements using traditional fuel intercept transects seemed insufficient. We later refined our method using the techniques outlined in Hood and Wu (2006) to better estimate fuel loadings in masticated areas.

Immediately before and during each burn we collected samples of each fuel size class, duff, and litter from the interspaces between tree crowns within the units to determine site level fuel moisture. On a portion of the sample trees, we collected a small amount of duff, litter, and mineral soil at 60 cm (2 ft) and the dripline between the north-east transect and the south-west transect. Fine fuels were also collected within the dripline of these trees. Samples were placed in soil bags to retain moisture and were weighed within 12 hours of collecting. The samples were taken to the Fire Sciences Lab for drying and weighing to determine moisture content. We also installed sets of thermocouples in the duff mounds and at driplines of several randomly selected sample trees to record soil heating over time in the units. Eight sets of thermocouples were installed in the LVNP burn unit and 10 sets in the LNF burn units. Dataloggers recorded thermocouple temperature readings every 5 seconds for approximately 34 hours.

Post-fire Sampling

Immediately after each burn, once all smoldering combustion in the duff mounds was complete, mini-fuels transects established before burning were relocated and measured to determine any changes in fuel loading around the sample trees. Duff and litter consumption were determined by measuring the length of nail exposed and the depth of material remaining.

Post-fire vigor, crown and cambium injury, site level fuel consumption, and insect attacks were measured on the LVNP unit in Sept. 2005 and June 2006 in the LNF units. Each tree was assessed for percent crown volume scorched, percent crown volume killed, post-fire crown base height, and post-fire Keen's vigor class. Stem injury was assessed by sampling cambium at groundline in each of the four cardinal directions at the base of each tree with a 2.54 cm (1 inch) hole saw bit attached to a power drill. The status of the exposed cambium was visually determined following the methods in Ryan (1983) and Ryan and Noste (1985). Only quadrants with bark char were sampled for cambium injury. Cambium in uncharred quadrants was assumed alive. Any insect signs, such as frass, boring holes, and pitch tubes were also noted.

We resampled the trees again in October 2006 and late August 2007 for changes in vigor and insect activity. This final report contains 3-post-fire year results for the LVNP site and 2-post-fire year results for the LNF sites (as measured by number of growing seasons since fire).

Data Analyses

We used a general linear model to predict the time needed for one person to rake duff and litter from the tree bole out to 60 cm (2 feet) to mineral soil. The average duff depth at the tree base, based on the four, pre-raked zero point duff depth measurements, and amount of shrubs in the removal area were used as independent variables.

We summed the number of dead cambium samples per tree to create a cambium kill rating (CKR) between 0 and 4. General linear models were used to test for differences in crown volume scorched (%), crown volume kill (%), CKR, fuel consumption, insect attacks, and mortality between raked and unraked trees by unit. Fuel loading in the masticated area was calculated by averaging the 2 dimensions measured for the masticated pieces to obtain a count of fine woody debris. Differences between sites were not tested, as they were not designed to be replicates.

We compared the actual pre- and post-fire duff depths and soil temperature to the values predicted by the First Order Fire Effects Model (FOFEM) (Reinhardt et al. 1997; http://fire.org/index.php?option=content&task=category&sectionid=2&id=12&Itemid=31) using the measured loadings and fuel moisture inputs.

Smoldering Combustion Thresholds Analysis

Duff samples were collected from the duff mounds of Jeffrey pine (n =14) and ponderosa pine (n=14) trees in an area adjacent to the LNF burn units. Duff profile samples were not taken from the duff mounds around any sample trees.
The samples were heterogeneous mixtures of pine needles, pine cone scales, bark and other organic and inorganic components. Because the coarser materials consistently resisted rewetting, the samples were sieved and further testing was conducted on the finer decomposed soil materials.

The samples were prepared to target moisture contents based on previous research by Frandsen (1997). The moisture contents reflected a range of conditions from those that were not expected to support smoldering to conditions favorable for sustained smoldering. Gravimetric moisture was determined using standard lab procedures. Mineral content was calculated on a total oven dry weight basis. To determine the mineral content, the oven dried samples were placed in a muffle furnace at 500^{o}C for 24 hours. Mineral content was calculated as the ratio of mineral (ash) content to total oven-dry soil weight.

Burning was conducted in an open-topped box (10x10x10 cm) constructed of ceramic insulation material that restricted heat loss from the smoldering duff. The prepared duff samples were placed in the burn box and exposed to a standardized ignition source. The ignition source consisted of 10.0 grams of dried peat moss that was placed in contact with a lateral sample edge and ignited using an electric heating element. The electric power to the heating element was discontinued when the ignition material sustained smoldering. After contact with the smoldering ignition material, smoldering combustion of the sample was either sustained or failed. Sample response was recorded as either burned, which was characterized by significant or total consumption, or unburned, which was characterized by little or no consumption.

RESULTS

Raking Treatment Times

Average time to rake the duff away from the tree bole was 16 minutes/person. Therefore, a crew of 2-3 people could clear the area in approximately 6 minutes/tree. The time required was dependent of the depth of litter and duff at the tree base ($p<0.0001$) and the amount of shrubs in the duff removal area ($p=0.0001$) (figure 1). The presence of shrubs could increase the amount of time necessary to clear the area to mineral soil by up to 10 minutes.

Fuel Consumption

Site Level

In the LVNP burn unit, fine fuels (1-100 hr) were reduced by 44% and 1000 hr fuels by 7%, although these differences were not statistically significant due to high variability among the site level fuel transects. Duff and litter depth was reduced by 79%. In the LNF thinned unit, fine fuels were reduced by 57%, 1000 hr fuels by 84%, and duff and litter depth by 49%. In the LNF thinned and masticated unit, fine fuels were reduced by 91%, 1000 hr fuels by 61%, and duff and litter depth by 80% (table 2).

Tree Level

Duff mound consumption was almost complete in both LNF sites (figure 2). On the LVNP site, duff consumption around the sample trees was lower and much more variable, with a median of 30-55% consumed between 0 and 120 cm of the tree bole (figure 2). Average duff mound moisture at burn time for the LNF sites was 24% and 101% for the LVNP site.

Fine fuel loading (1-100 hr) around the first 120 cm (4 ft.) of the sample trees was significantly reduced by the prescribed burns for all treatments except the LVNP raked trees (table 3). The fine fuels around the unraked trees were reduced by 60-95%. Consumption around the raked trees was lower, especially in the LVNP site (33-87%). No sample trees had any 1000 hr fuels within the first 120 cm prior to burning.

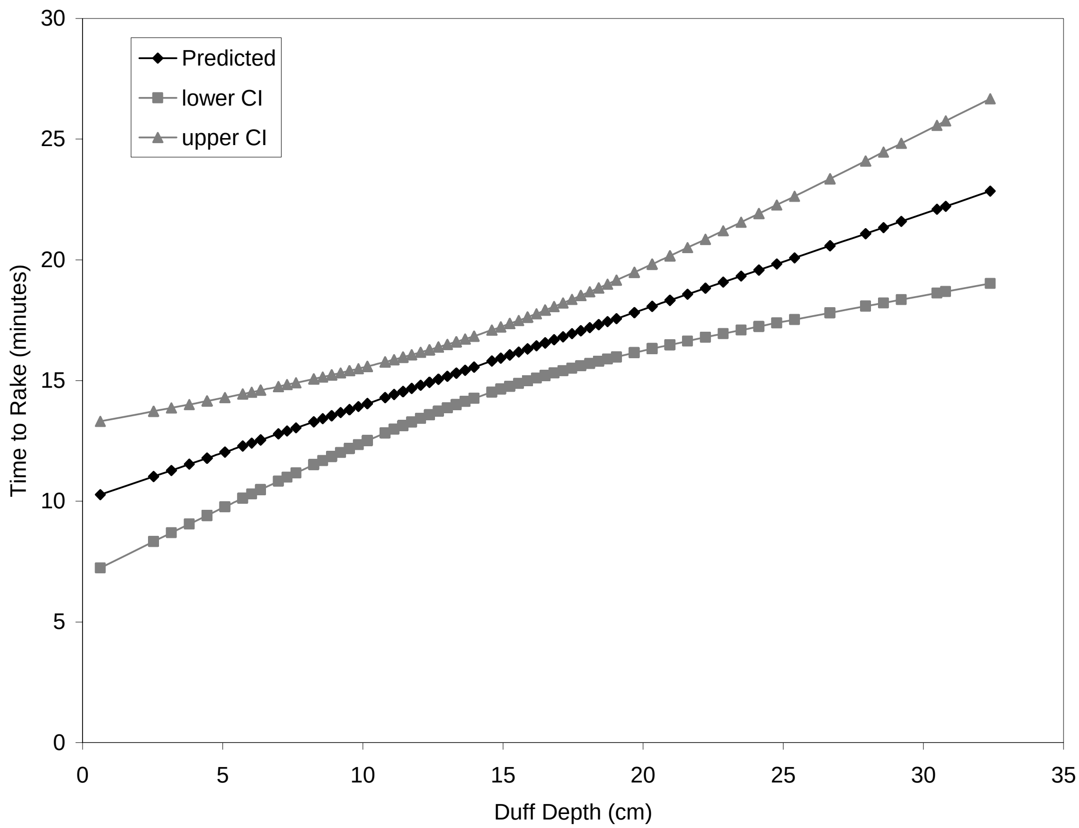

Figure 1. Predicted time and upper and lower confidence intervals for one person to rake duff and litter away from tree bole to 2 feet to mineral soil when no shrubs are present in the removal area.

Table 2. Average site-level fuel loadings pre- and post-fire by site. Different letters between pre- and post-fire fuels by site indicate a significant difference in loadings (<0.05).

Site	Fine Fuel Loading (1-100 hr)		Coarse Fuel Loading (1000 hr)		Duff and Litter Depth	
	Pre-fire	Po-fire	Pre-fire	Post-fire	Pre-fire	Post-fire
	--------------------kg/m^2--------------------				-------cm-------	
LNF thinned+burned	1.13a	0.48b	3.9a	0.59a	4.2a	2.1b
LNF masticated+burned	1.64a	0.13b	2.54a	0.97a	4.35a	0.87b
LVNP burned	0.35a	0.19a	3.02a	2.79a	6.5a	1.4b

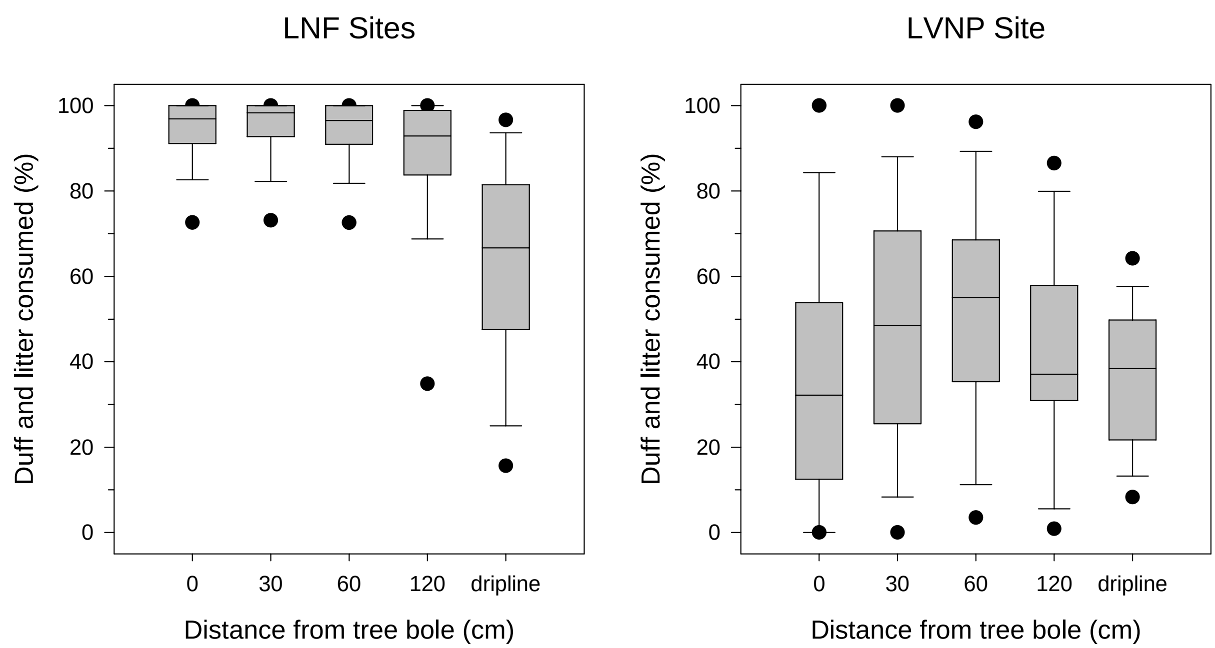

Figure 2. Median litter and duff consumption for unraked trees by study site. The LNF sites were combined for simplicity due to very similar results. Solid bars in boxes are median values and dots are 5th and 95th percentile outliers.

Table 3. Average fuel loading within first 120 cm (4 ft) of sample trees by site and treatment. Different letters between raked and unraked by site indicate a significant difference in pre- and post-fire loadings (p<0.05).

Site	Unraked Trees		Raked Trees	
	Pre-fire fuel loading	Post-fire fuel loading	Pre-fire fuel loading	Post-fire fuel loading
	-------------------------------kg/m^2-------------------------------			
LNF thinned+burned	3.1a	0.4b	0.6a	0.08b
LNF masticated+burned	5.9a	0.3b	0.6a	0.3b
LVNP burned	1.5a	0.6b	0.3a	0.2a

Tree Injuries and Beetle Attacks

There were no significant differences in crown injury between raked and unraked trees for any site. Unraked trees had more cambium injury than raked trees, although the difference was only significant for the LNF masticated site (table 4).

Unraked trees in the LNF burn units had significantly more red turpentine beetle (RTB) attacks the first year after the burns (table 5). While unraked trees in the LVNP burn unit also had more RTB attacks than the raked trees, the difference was not statistically significant. RTB continued to attack unraked trees more than raked in 2007, although the differences were not statistically significant. Only one tree in the LNF unburned unit had RTB attacks.

In 2004 two raked trees and in 2007 1 unraked tree in the LNF unburned unit were mass attacked by western pine beetle. These trees were very close to each other and near an existing pocket of bark beetle activity. Beetle activity increased in 2007, with 7 trees having new attacks by either western or Jeffrey pine beetle. Six of the 7 trees were in burned units. Heavy attacks by RTB seemed to predispose the trees to attack by primary bark beetles, with 7 of 9 of the attacked trees having more than 15 RTB pitch tubes. Attacks occurred in raked and unraked trees, and there was not a significant difference in attack rates between the raking treatments (table 5).

Table 4. Average level of tree injury for raked and unraked trees by site. Different letters between raked and unraked by site and injury indicate a significant difference in values (p<0.05).

Site	Crown Volume Killed (%)		Crown Volume Scorched (%)		Cambium Kill Rating (0-4)	
	Unraked	Raked	Unraked	Raked	Unraked	Raked
LNF thinned+burned	2a	1a	7a	4a	1.9a	0a
LNF masticated+burned	1a	3a	4a	4a	1.3a	0b
LVNP burned	14a	10a	31a	26a	0.3a	0a

Table 5. Average level of red turpentine bark beetle attacks (RTB) and number of trees attacked for raked and unraked trees by site. RTB attacks in 2007 only include new attacks from that year. Primary bark beetles were either Jeffrey pine beetle or western pine beetle. Different letters between raked and unraked by site indicate a significant difference in values (p<0.05).

Site	2006 RTB Pitch Tubes (#)		2007 RTB Pitch Tubes (#)		Number of Trees with RTB		Number of Trees with Primary Beetle Attacks	
	Unraked	Raked	Unraked	Raked	Unraked	Raked	Unraked	Raked
LNF unburned	0	0	0.6a	0a	1a	0a	1a	2a
LNF thinned+burned	4.2a	0.4b	1.8a	0.1a	15a	3b	0	0
LNF masticated+burned	9.9a	0.6b	8.1a	0.5a	25a	6b	2a	0a
LVNP unburned	0	0	0	0	0	0	0	0
LVNP burned	1.8a	1.0a	3.6a	3.0a	13a	11a	3a	1a

Tree Mortality

To date, 2 unraked trees and 3 raked trees have died (table 6). There was not a significant difference in mortality rates between the raking treatments. We also expect the 7 newly attacked trees to die by the next mortality assessment in 2008. The 2 dead raked trees in the LNF unburned unit died from mass attacks by western pine beetle. The raked tree in the LNF masticated unit and 1 of the unraked trees in LVNP that died had catfaces that ignited and caused the center of the trees to burn out. This unraked tree was designated a raked tree, but was inadvertently missed when the other trees were raked. Residual duff in the fire scar of the dead raked tree must have ignited and causes the fire scar to begin burning. The other dead tree in LVNP had no recorded cambium or crown injury, but was heavily attacked by red turpentine and western pine beetles. We will continue to monitor tree mortality and beetle attacks for at least 5 years post-burn.

Table 6. Mortality by site. Numbers in parenthesis are percentage of total trees by site and raking treatment. There were no significant differences in mortality rates between unraked and raked trees in any site.

Site	Total Dead	
	Unraked	Raked
LNF unburned	0	2 (6%)
LNF thinned+burned	0	0
LNF masticated+burned	0	1 (3%)
LVNP unburned	0	0
LVNP burned	2 (4%)	0

Soil Heating and FOFEM Validation

FOFEM was not accurate in predicting duff consumption and therefore, the soil heating predictions were also inaccurate (Appendix 2). All duff was consumed above the majority of the thermocouples sets (table 7). However, FOFEM will never predict 100% percent consumption because the duff consumption algorithms are linear and the intercept does not go through 100 (FOFEM 5, help section). Pre-burn soil moisture greatly affects predicted soil heating in FOFEM. The only way we could force FOFEM to predict soil heating when several centimeters of duff remained post-fire was to set the soil moisture to 0%. FOFEM predicted consumption of the down woody debris accurately. The soil heating module in FOFEM was developed from consumption data with lower duff loadings. The inaccurate predictions could be due to the deeper duff depths in this study.

Table 7. Inputs used to run FOFEM soil heating model. Litter and duff depths were measured above the thermocouple sets by tree. Litter loading was calculated by estimating 5 tons/acre/inch. Down woody debris loadings were calculated from the 4 mini-fuel tree transects. Duff and soil moistures were determined by collecting samples during thermocouple installation immediately before the burn at the datalogger burial location. The 10 hour fuel moisture is an average of 3 samples collected around the tree.

Site	Tree	TC Location	Litter depth (in)		Duff depth (in)		Litter load (ton/acre)		1hr (ton/acre)		10hr (ton/acre)		100hr (ton/acre)		10hr fuel moisture (%)	Duff moisture (%)	Soil moisture (%)	Location of TC to tree
			pre	post	pre	post	pre	post	pre	post	pre	post	pre	post				
LNF	1	bole	1.18	0.00	4.72	0.00	5.91	0.00	0.05	0.00	3.19	0.46	0.00	0.00	22	25	12	se
LNF	1	dripline	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	3.19	0.46	0.00	0.00	18	26	7	se
LNF	12	bole	0.47	0.00	1.50	0.00	2.36	0.00	0.03	0.03	8.66	0.00	18.15	0.00	16	16	10	se
LNF	12	dripline	0.79	0.00	2.36	0.00	3.94	0.00	0.03	0.03	8.66	0.00	18.15	0.00	15	9	5	se
LNF	13	bole	0.91	0.00	1.38	0.00	4.53	0.00	0.10	0.03	6.38	0.46	0.00	3.63	18	16	8	se
LNF	13	dripline	0.59	0.00	2.95	0.00	2.95	0.00	0.10	0.03	6.38	0.46	0.00	3.63	18	19	10	se
LNF	46	bole	.	0.00	.	0.00	.	0.00	0.29	0.00	5.05	1.37	0.00	0.00	.	.	.	ne
LNF	46	dripline	.	0.00	.	0.00	.	0.00	0.29	0.00	5.05	1.37	0.00	0.00	.	.	.	ne
LNF	92	bole	0.98	0.00	3.54	0.00	4.92	0.00	0.48	0.00	15.50	0.46	18.15	0.00	11	33	14	ne
LNF	92	dripline	0.39	0.00	1.97	0.00	1.97	0.00	0.48	0.00	15.50	0.46	18.15	0.00	11	19	10	ne
LVNP	735	bole	0.79	0.00	3.54	0.00	3.94	0.00	0.05	0.00	2.28	0.00	0.00	0.00	13	128	3	ne
LVNP	735	dripline	0.39	0.00	1.77	0.79	1.97	0.00	0.05	0.00	2.28	0.00	0.00	0.00	13	204	23	ne
LVNP	738	bole	0.98	0.00	4.33	0.00	4.92	0.00	0.00	0.00	4.55	0.00	0.00	0.00	9	33	2	ne
LVNP	740	bole	1.38	0.00	5.51	0.00	6.89	0.00	0.05	0.00	3.19	0.00	0.00	0.00	17	78	4	ne
LVNP	740	dripline	0.59	0.00	2.17	1.77	2.95	0.00	0.05	0.00	3.19	0.00	0.00	0.00	17	188	9	ne
LVNP	741	bole	0.79	0.00	3.54	0.39	3.94	0.00	0.03	0.00	3.65	0.00	0.00	0.00	17	98	2	sw

Smoldering Combustion Thresholds Analysis

The moisture content range for ponderosa pine and Jeffrey pines duff samples was 45% to 98% and 24% to 66% respectively. The combined mineral content of both duff types range from 23.1% to 80.8% (figure 3).

The results of the laboratory burning of Jeffrey pine duff samples suggest a sustained smoldering moisture threshold between 40% and 50% (figure 4). Laboratory results from burning ponderosa pine duff samples suggest a sustained smoldering moisture threshold between 65% and 85% (figure 5).

Comparison of the results suggests that ponderosa pine duff will sustain smoldering at higher moisture levels than Jeffrey pine duff. The range of uncertainty appears greater in ponderosa pine than Jeffrey pine but further analysis was limited by the small sample size in this study. These estimates are consistent with estimates for other high mineral content duff reported by Frandsen (1997).

A larger sample size is needed for the development of a predictive relationship between moisture content and the likelihood of sustained smoldering. Additional work is also needed to examine the effects of the coarse material (cone scales, bark pieces, etc.) on smoldering moisture limits.

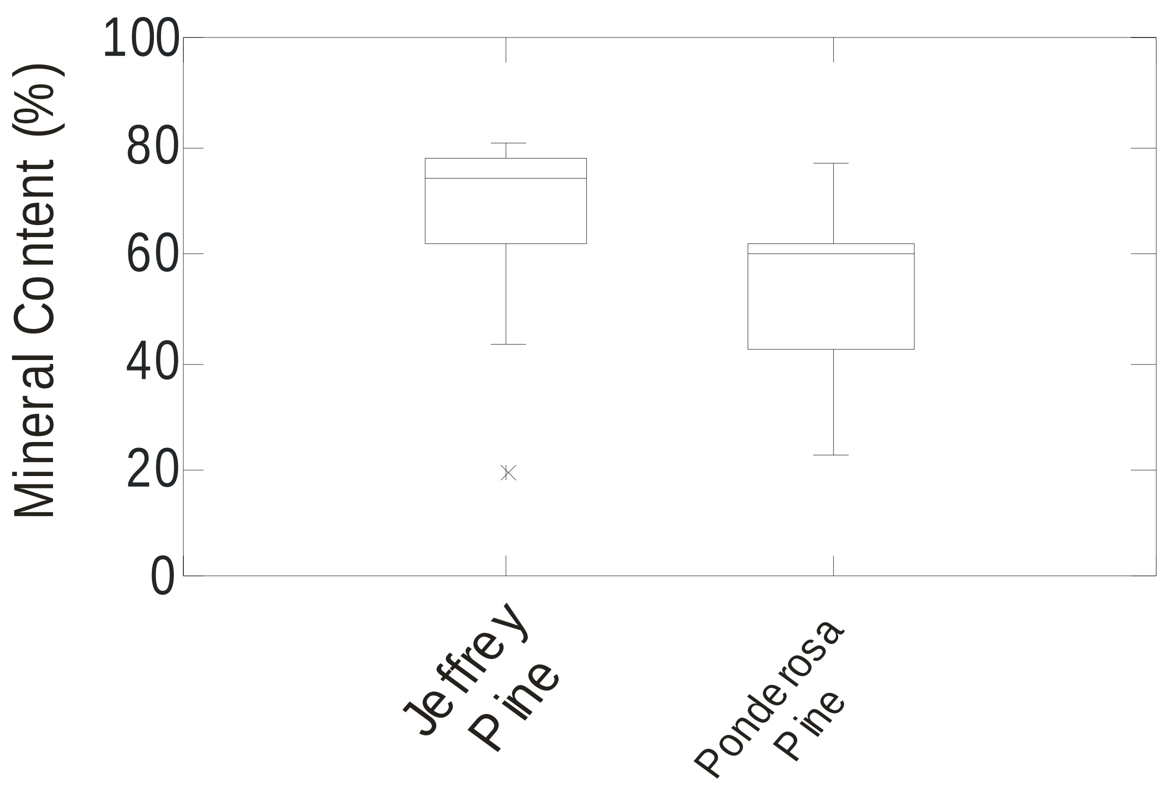

Figure 3. Mineral content of Ponderosa Pine and Jeffrey Pine duff samples. Solid bars in boxes are median values and dots are 5^{th} and 95^{th} percentile outliers.

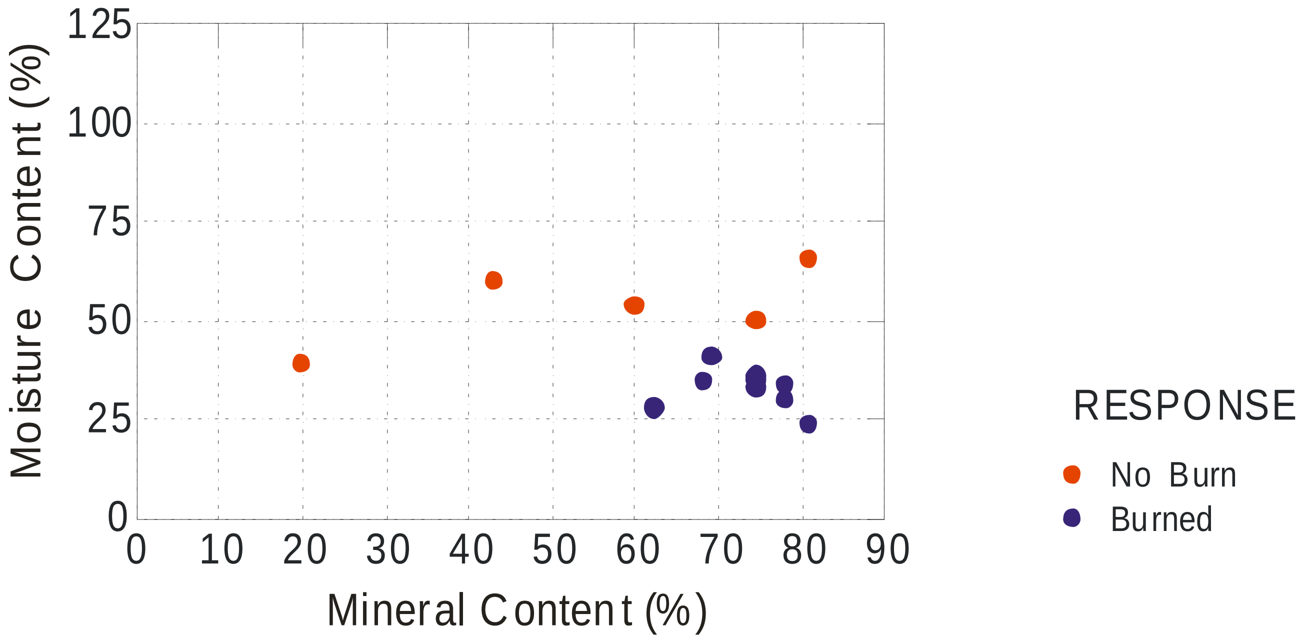

Figure 4. Laboratory burning results for Jeffrey pine.

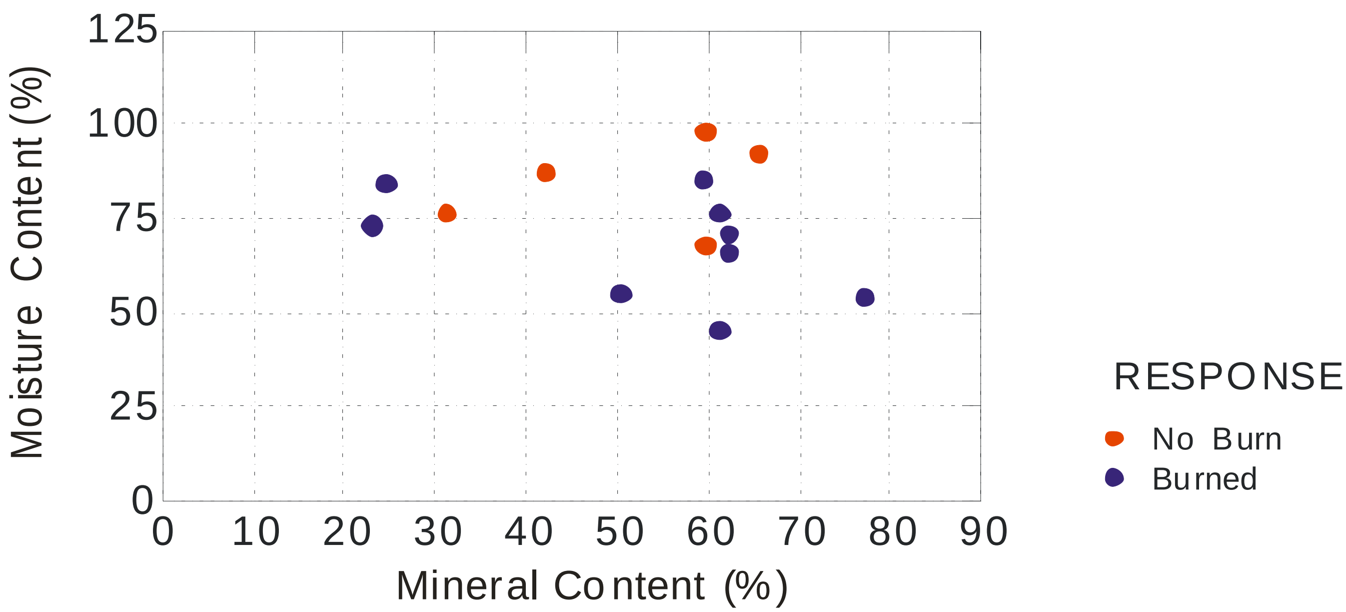

Figure 5. Laboratory burning results for ponderosa pine.

CONCLUSIONS

Raking the duff mounds away from tree boles did not cause tree mortality. Three out of 189 raked trees (<2%) in this study died and one of those was due to a fire scar igniting and burning out the center of the tree. The trees in this study have been raked for 4 years on the LNF sites and 3 years on the LVNP site.

Raking reduced the probability of red turpentine beetles attacks in the burned units. We found significantly more red turpentine beetle attacks on the unraked, burned trees than the raked, burned trees. Only 1 tree was attacked by RTB in the unburned units. While the number of trees attacked by western pine beetle or Jeffrey pine beetle was low, most of the attacked trees had previously been heavily attacked by RTB. This seems to indicate the burned trees with numerous RTB attacks are susceptible to attacks by primary bark beetles. It is unclear if it was the charring of the tree bole or cambium injury that attracted the RTB.

Raking decreased cambium injury by limiting heating at the base of the trees in the burned units. However, to date very few trees have died in the burned units, whether or not they were raked. We believe that it is still too early in our study to expect much tree mortality. If mortality is going to occur, it will probably take several years to happen. Based on the results to date, 2 and 3 years post-fire, the decision to rake should be based on the management objectives for large trees in the prescribed fire area, current bark beetle activity, amount of duff around the large trees and the burning conditions. Given conditions similar to those in this study, raking may not be worth the time or effort involved. However, it is preliminary to conclude from our study whether raking will reduce tree mortality.

Raking allows managers to burn under a wider range of duff moisture scenarios without worry that the raking treatment alone will cause tree death. It is difficult to predict the percent of duff consumption in duff mounds based on pre-fire duff moisture to determine when to burn. We found that FOFEM does not accurately predict duff mound consumption, and should not be used for this purpose. Laboratory burning of ponderosa pine duff suggests that smoldering cannot be sustained above moistures of 65-85% and 40-50% for Jeffrey pine. However, these results were based on a small sample size and warrant future research.

In areas of deep duff, where the potential for basal cambium injury is high, raking minimizes injury to the tree bole near groundline from long-term duff smoldering. By reducing the residence time of the fire, the chance of cambium injury and bole char is reduced. In our study, we reduced the duff to mineral soil; however, this is probably not necessary. Raking the majority of the duff will prevent long residence times and the time required to rake. However, a large factor in burning large-diameter or old-growth is existing fire scars. If fire scarred trees are in the unit, raking to mineral soil and complete removal of duff in the scar is important. Two of the 3 dead trees to date in our burned units had fire scars that ignited and burned through.

Our study found that raking is a viable option when there is concern that burning will cause large-diameter, old ponderosa and Jeffrey pine mortality. Crews of 2-3 can clear duff away from a tree bole in approximately 6 minutes per tree. While raking may not be appropriate for every prescribed burn in old stands of ponderosa and Jeffrey pine, it should be considered a tool managers can use when trying to limit tree mortality from fire.

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We would like to thank Mike Lewelling, Fuels Management Officer at Lassen Volcanic National Park during the burn, and Dave Ramirez, Fuels Management Officer at Eagle Lake District of

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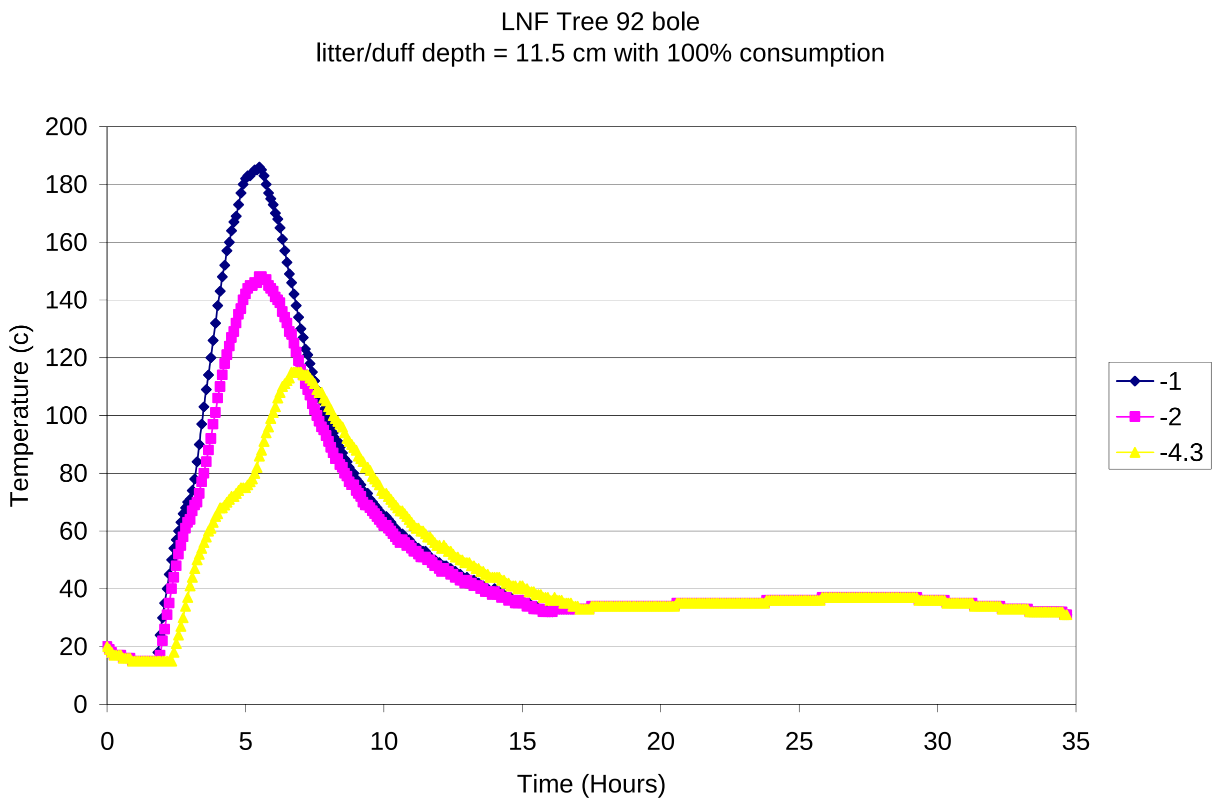
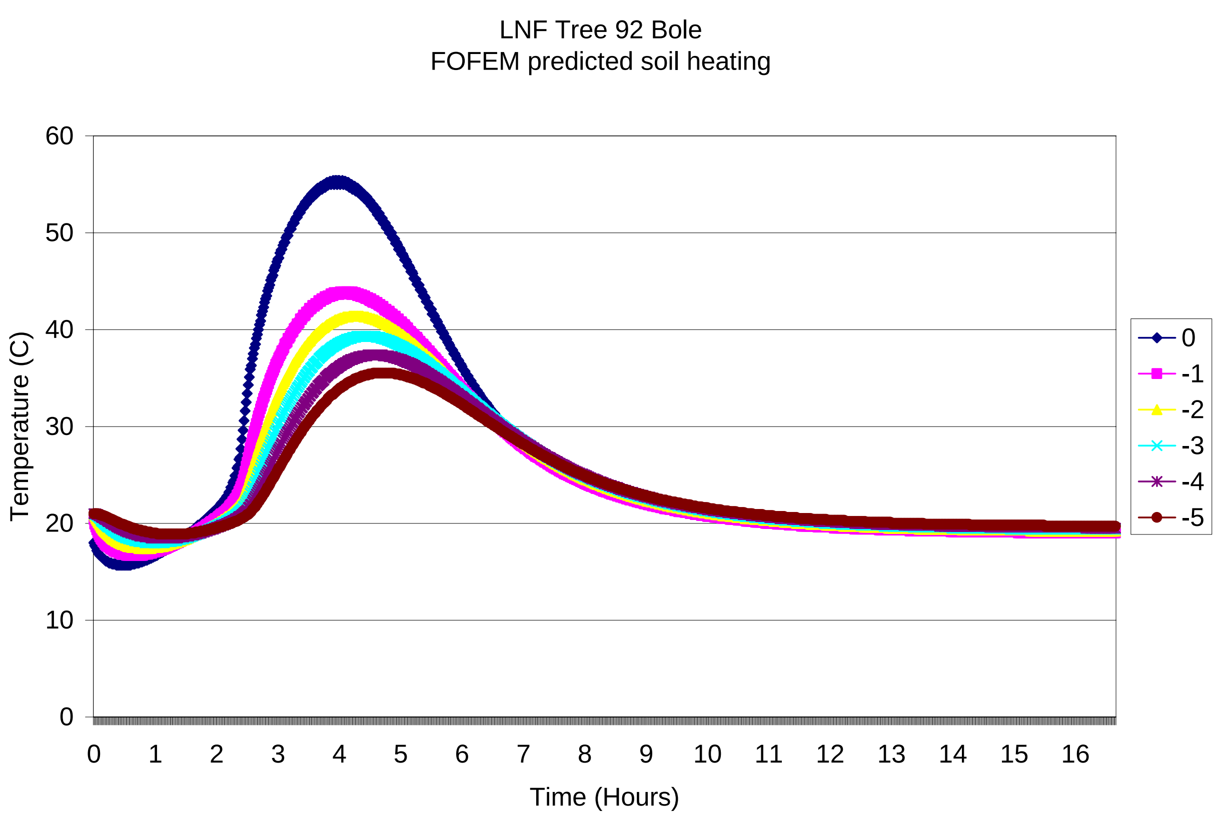
Appendix 1. Crosswalk between proposed and delivered outreach activities for JFSP #03-3-2-04.

Proposed	Delivered	Status
Publication	Hood, S. M.; Wu, R. 2006. Estimating fuel bed loadings in masticated areas. In: P. L. Andrews; B. Butler, eds. Fuels Management-How to measure success: Conference Proceedings. 28-30 March 2006. Portland, OR. Proceedings RMRS-P-41. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO: 333-340.	completed
Publication	Journal article planned about major findings of project after 2 more years of mortality data collection	Planned for 2009
Website	http://www.firelab.org/index.php?option=content&task=view&id=686	ongoing
Presentation	Hood, S.; Wu, R. Estimating fuel bed loadings in masticated areas. Presented at Fuels Management. Presentation given 03/28/06 at 1st Fire Behavior and Fuels Conference: How to measure success; Portland, OR.	completed
Presentation	Hood, S.; Reardon, J. Forest floor consumption and tree injury after prescribed burning old-growth pine sites in California. Presentation given 11/14/06 at 3rd International Fire Ecology and Management Congress; San Diego, CA.	completed
Poster	Prescribed burning to protect large diameter pine trees from wildfire- Can we do it without killing the trees we're trying to save? Poster for the JFSP board visit. Missoula, MT Sept. 14, 2006.	completed
Workshops/Personal communications with managers	Results to date have been transferred by Forest Health Protection staff in California to Forest Service and National Park Service land managers planning prescribed burns in areas where large, old trees occur. Specific examples include Terri Walsh, Silviculturist, Tahoe National Forest, Ryan Thompkins, Forester, Plumas National Forest, Tom Rickman, Wildlife Biologist, Lassen National Forest, Anne Mileck, Silviculturist, Modoc National Forest, Jon Arnold, Forester, Lassen Volcanic National Park.	ongoing

Appendix 2. Actual and predicted soil heating using FOFEM. FOFEM reports included for trees where fuel moisture data was collected and soil heating was recorded. All soil heating graphs show soil heating by depth. Positive values are the location of thermocouples above the soil, 0 indicates the soil/duff interface, and negative values are the depth of the thermocouples in the soil.



LNF Tree 92 bole
litter/duff depth = 11.5 cm with 100% consumption
Temperature (c)
Time (Hours)
-1
-2
-4.3
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35



LNF Tree 92 Bole
FOFEM predicted soil heating
Temperature (C)
Time (Hours)
0
-1
-2
-3
-4
-5
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

TITLE: Tree 92 bole results of FOFEM model execution on date: 12/7/2006

FUEL CONSUMPTION CALCULATIONS

Region: Pacific_West
Cover Type: SAF/SRM - SAF 247 - Jeffrey Pine
Fuel Type: Slash
Fuel Reference: FOFEM 021

FUEL CONSUMPTION TABLE

Fuel Component Name	Preburn Load (t/acre)		Consumed Load (t/acre)	Postburn Load (t/acre)	Percent Reduced (%)	Equation Reference Number	Moisture (%)
Litter	4.92	u	4.92	0	100	999	
Wood(0-1/4inch)	0.48	u	0.48	0	100	999	
Wood(1/4-1inch)	15.5	u	15.5	0	100	999	11
Wood(1-3inch)	18.15	u	18.04	0.11	99.4	999	
Wood(3+inch)Sound	0	u	0	0	0	999	30
Wood(3+inch)Rotten	0	u	0	0	0	999	30
Duff	44.25	u	30.82	13.43	69.6	2	33
Herbaceous	0	u	0	0	0	22	
Shrubs	0	u	0	0	0	23	
Crownfoliage	0	u	0	0	0	37	
Crownbranchwood	0	u	0	0	0	38	
TotalFuels	83.3		69.76	13.54	83.7		

'u' Preburn Load is User adjusted

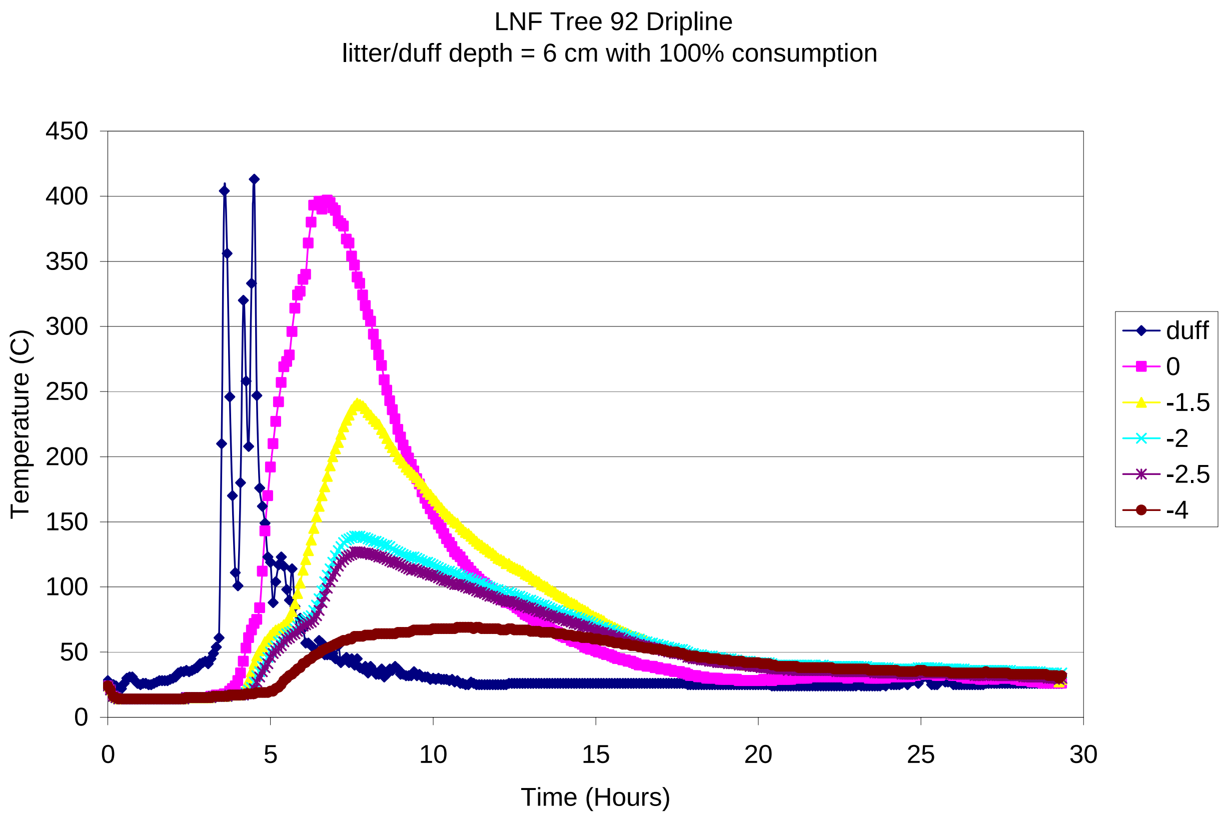
FIRE EFFECTS ON FOREST FLOOR COMPONENTS
Duff Depth Consumed (in) 2.1 Equation: 6
Mineral Soil Exposed (%) 56.9 Equation: 10

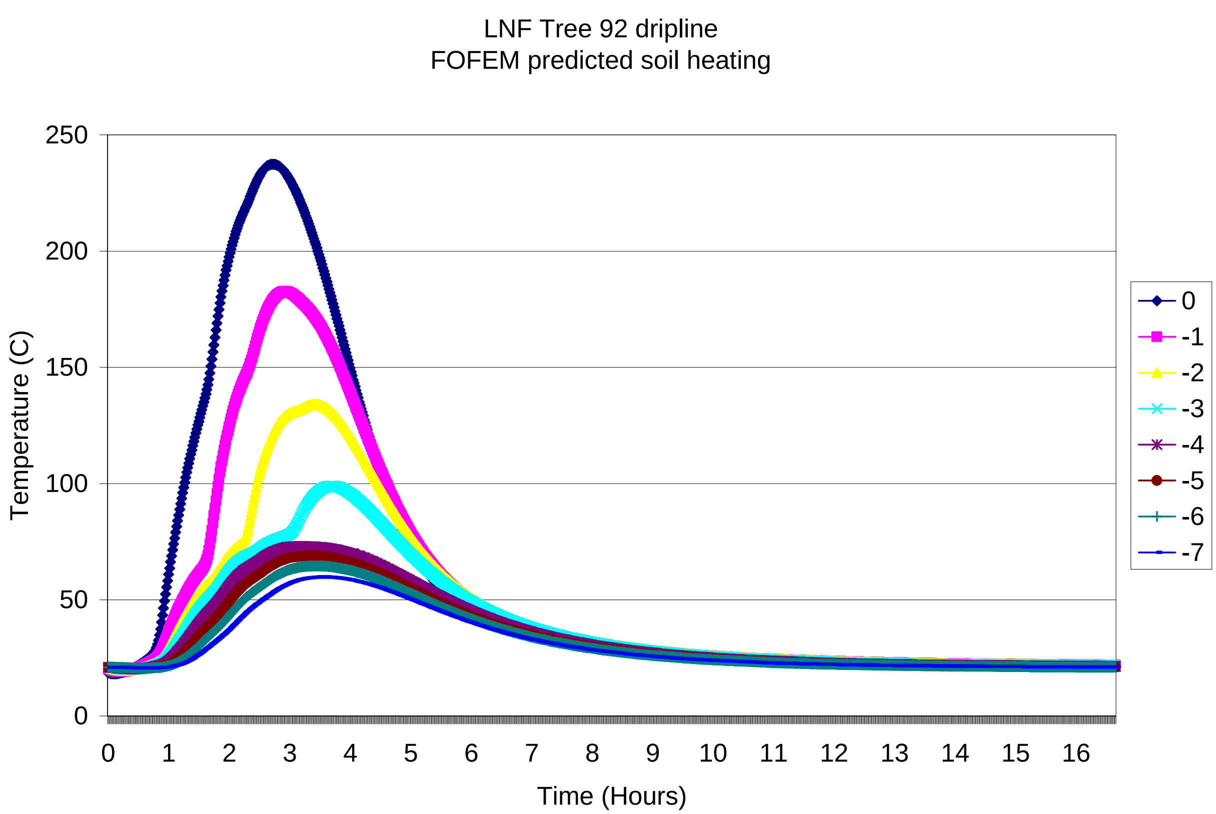
Soil Heat Report

Cover Type.....: SAF/SRM - SAF 247 - Jeffrey Pine
Duff Depth.....: Pre-Fire: 8.99 cm., Post-Fire: 3.61 cm.

Soil Layer Maximum Temperature
(measurements are in centimeters and Celsius)

Depth 0 1 2 3 4 5 6 7 8 9 10 11 12 13
Temp. 55 43 41 39 37 35 33 31 30 28 26 24 22 21
Time 238 248 257 267 276 284 292 298 304 308 312 314 316 1
Max Depth Having 60 degrees: - None -
Max Depth Having 275 degrees: - None -


LNF Tree 92 Dripline
litter/duff depth = 6 cm with 100% consumption
Temperature (C)
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
Time (Hours)
duff
0
-1.5
-2
-2.5
-4


LNF Tree 92 dripline
FOFEM predicted soil heating
Temperature (C)
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Time (Hours)
0
-1
-2
-3
-4
-5
-6
-7

TITLE: Tree 92 dripline results of FOFEM model execution on date: 9/18/2007

FUEL CONSUMPTION CALCULATIONS
Region: Pacific_West
Cover Type: SAF/SRM - SAF 247 - Jeffrey Pine
Fuel Type: Slash
Fuel Reference: FOFEM 021

FUEL CONSUMPTION TABLE

Fuel Component Name	Preburn Load (t/acre)		Consumed Load (t/acre)	Postburn Load (t/acre)	Percent Reduced (%)	Equation Reference Number	Moisture (%)
Litter	1.97	u	1.97	0	100	999	
Wood(0-1/4inch)	0.48	u	0.48	0	100	999	
Wood(1/4-1inch)	15.5	u	15.5	0	100	999	11
Wood(1-3inch)	18.15	u	18.04	0.11	99.4	999	
Wood(3+inch)Sound	0	u	0	0	0	999	30
Wood(3+inch)Rotten	0	u	0	0	0	999	30
Duff	24.62	u	18.61	6.01	75.6	2	19
Herbaceous	0	u	0	0	0	22	
Shrubs	0	u	0	0	0	23	
Crownfoliage	0	u	0	0	0	37	
Crownbranchwood	0	u	0	0	0	38	
TotalFuels	60.72		54.61	6.11	89.9		

'u' Preburn Load is User adjusted

FIRE EFFECTS ON FOREST FLOOR COMPONENTS

Duff Depth Consumed (in) 1.6 Equation: 6
Mineral Soil Exposed (%) 74.4 Equation: 10

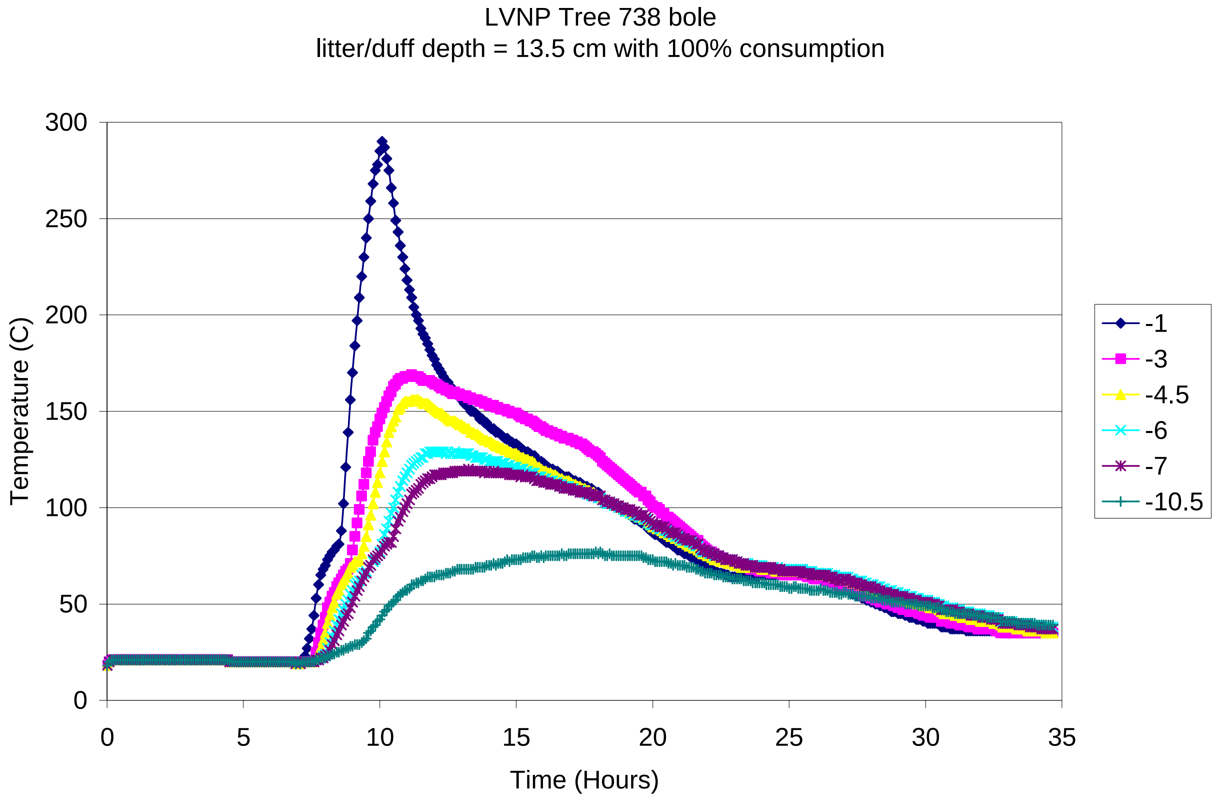
Soil Heat Report

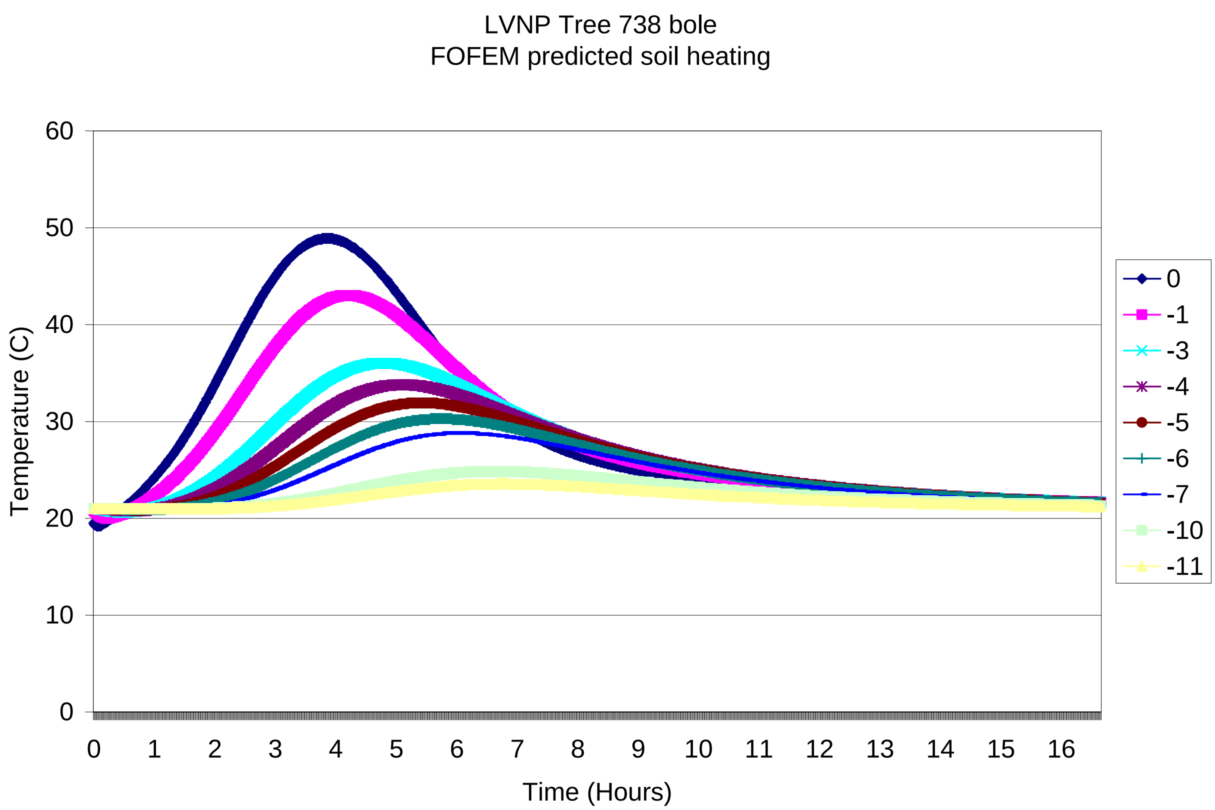
Cover Type.....: SAF/SRM - SAF 247 - Jeffrey Pine
Duff Depth.....: Pre-Fire: 5.00 cm., Post-Fire: 1.03 cm.

Soil Layer Maximum Temperature
(measurements are in centimeters and Celsius)

Depth	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Temp.	237	182	134	98	72	68	64	59	54	49	42	36	28	21
Time	164	177	206	223	190	202	208	213	218	222	225	228	230	1

Max Depth Having 60 degrees: 6
Max Depth Having 275 degrees: - None -


LVNP Tree 738 bole
litter/duff depth = 13.5 cm with 100% consumption
Temperature (C)
Time (Hours)
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
-1
-3
-4.5
-6
-7
-10.5


LVNP Tree 738 bole
FOFEM predicted soil heating
Temperature (C)
Time (Hours)
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0
-1
-3
-4
-5
-6
-7
-10
-11

TITLE: Tree 738 bole results of FOFEM model execution on date: 12/7/2006

FUEL CONSUMPTION CALCULATIONS
Region: Pacific_West
Cover Type: SAF/SRM - SAF 247 - Jeffrey Pine
Fuel Type: Natural
Fuel Reference: FOFEM 021

FUEL CONSUMPTION TABLE

Fuel Component Name	Preburn Load (t/acre)		Consumed Load (t/acre)	Postburn Load (t/acre)	Percent Reduced (%)	Equation Reference Number	Moisture (%)
Litter	4.92	u	4.92	0	100	999	
Wood(0-1/4inch)	0	u	0	0	0	999	
Wood(1/4-1inch)	4.55	u	4.55	0	100	999	9
Wood(1-3inch)	0	u	0	0	0	999	
Wood(3+inch)Sound	0	u	0	0	0	999	30
Wood(3+inch)Rotten	0	u	0	0	0	999	30
Duff	54.12	u	37.69	16.43	69.6	2	33
Herbaceous	0	u	0	0	0	22	
Shrubs	0	u	0	0	0	23	
Crownfoliage	0	u	0	0	0	37	
Crownbranchwood	0	u	0	0	0	38	
TotalFuels	63.59		47.16	16.43	74.2		

'u' Preburn Load is User adjusted

FIRE EFFECTS ON FOREST FLOOR COMPONENTS
Duff Depth Consumed (in) 2.5 Equation: 6
Mineral Soil Exposed (%) 56.9 Equation: 10

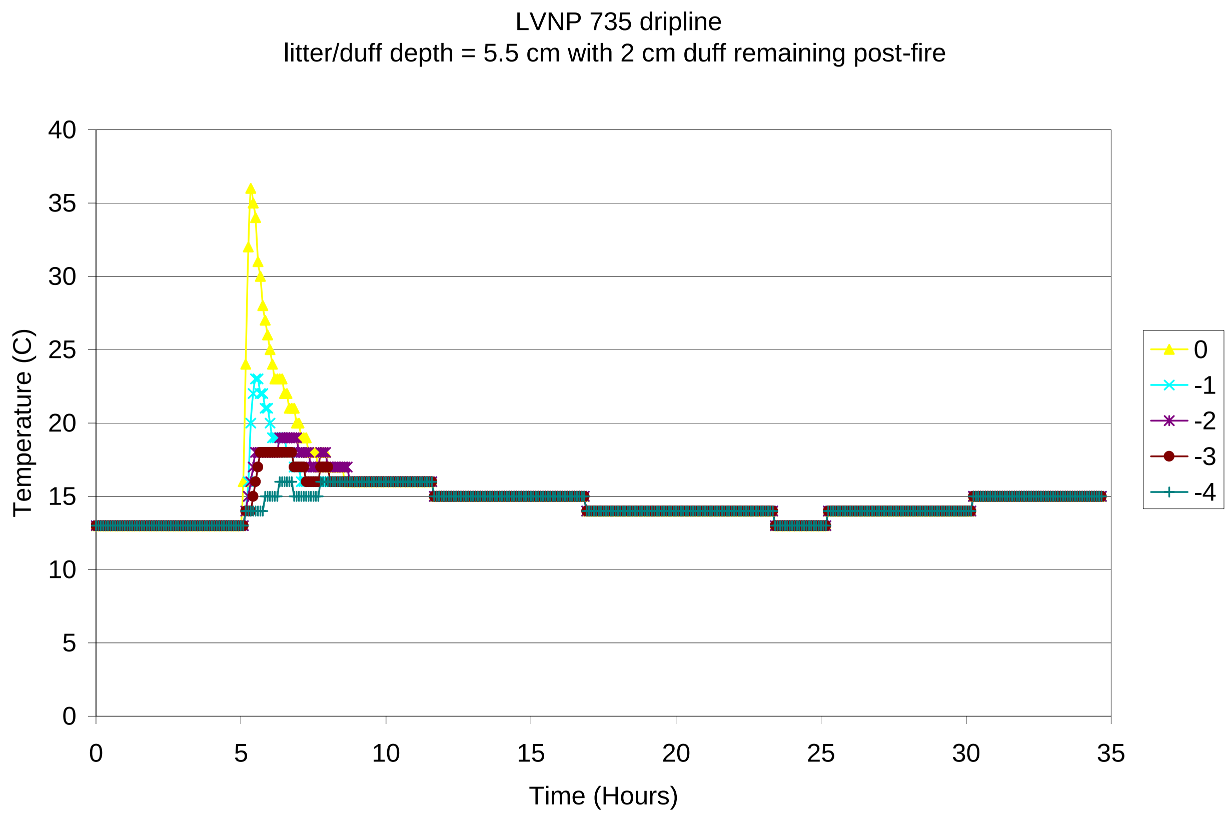
Soil Heat Report

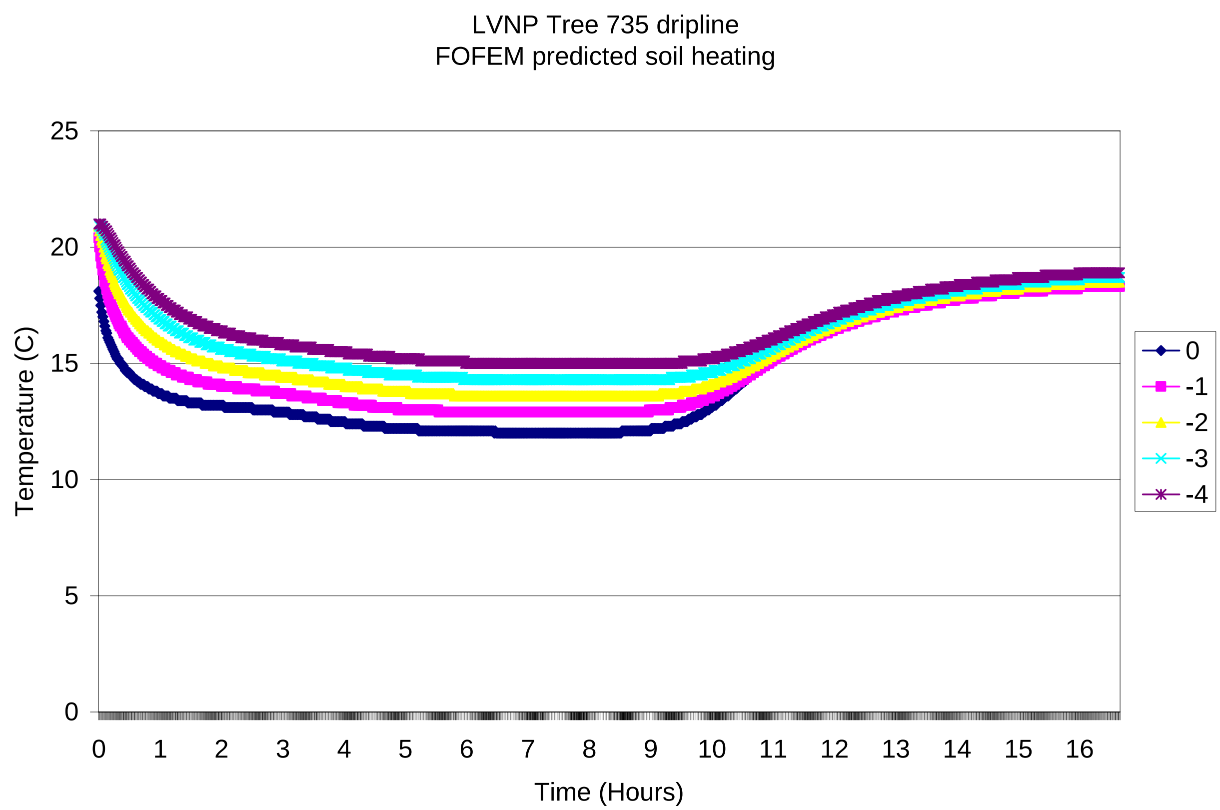
Cover Type.....: SAF/SRM - SAF 247 - Jeffrey Pine
Duff Depth.....: Pre-Fire: 11.00 cm., Post-Fire: 4.74 cm.

Soil Layer Maximum Temperature
(measurements are in centimeters and Celsius)

Depth	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Temp.	48	43	38	36	33	31	30	28	27	26	24	23	22	21
Time	232	253	271	288	308	326	346	363	378	391	400	407	411	1

Max Depth Having 60 degrees: - None -
Max Depth Having 275 degrees: - None -
Due to Post Duff Depth a minimal amount of heat will be transferred to soil.


LVNP 735 dripline
litter/duff depth = 5.5 cm with 2 cm duff remaining post-fire
Temperature (C)
Time (Hours)
0
-1
-2
-3
-4


LVNP Tree 735 dripline
FOFEM predicted soil heating
Temperature (C)
Time (Hours)
0
-1
-2
-3
-4

TITLE: Tree 735 dripline results of FOFEM model execution on date: 12/7/2006

FUEL CONSUMPTION CALCULATIONS
Region: Pacific_West
Cover Type: SAF/SRM - SAF 247 - Jeffrey Pine
Fuel Type: Natural
Fuel Reference: FOFEM 021

FUEL CONSUMPTION TABLE

Fuel Component Name	Preburn Load (t/acre)		Consumed Load (t/acre)	Postburn Load (t/acre)	Percent Reduced (%)	Equation Reference Number	Moisture (%)
Litter	1.97	u	1.97	0	100	999	
Wood(0-1/4inch)	0.05	u	0.05	0	100	999	
Wood(1/4-1inch)	2.28	u	2.18	0.1	95.7	999	13
Wood(1-3inch)	0	u	0	0	0	999	
Wood(3+inch)Sound	0	u	0	0	0	999	10
Wood(3+inch)Rotten	0	u	0	0	0	999	10
Duff	22.12	u	0	22.12	0	2	197
Herbaceous	0	u	0	0	0	22	
Shrubs	0	u	0	0	0	23	
Crownfoliage	0	u	0	0	0	37	
Crownbranchwood	0	u	0	0	0	38	
TotalFuels	26.42		4.2	22.22	15.9		

'u' Preburn Load is User adjusted

FIRE EFFECTS ON FOREST FLOOR COMPONENTS

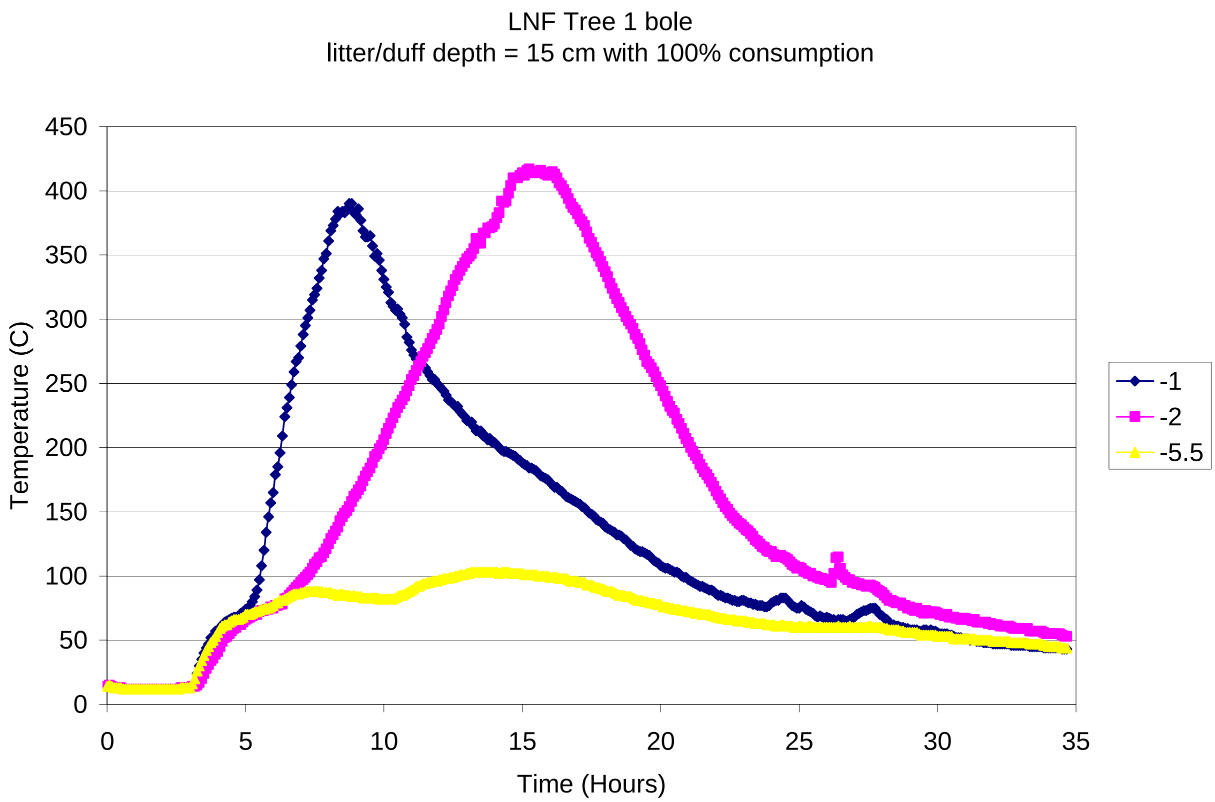
Duff Depth Consumed (in) 0.0 Equation: 6
Mineral Soil Exposed (%) 0.5 Equation: 10

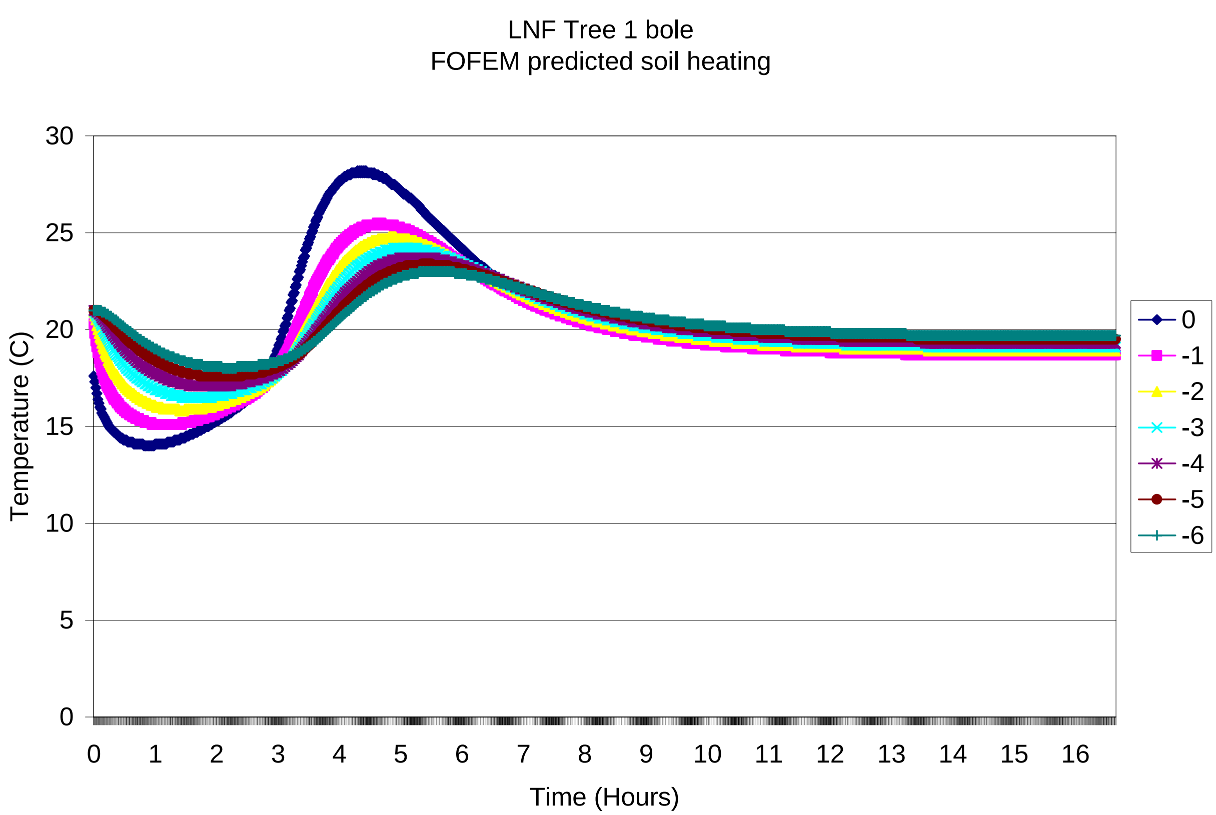
Soil Heat Report
Cover Type.....: SAF/SRM - SAF 247 - Jeffrey Pine
Duff Depth.....: Pre-Fire: 4.50 cm., Post-Fire: 4.50 cm.

Soil Layer Maximum Temperature
(measurements are in centimeters and Celsius)

Depth 0 1 2 3 4 5 6 7 8 9 10 11 12 13
Temp. 18 20 20 20 20 20 20 20 20 21 21 21 21 21
Time 999 1 1 1 1 1 1 1 1 1 1 1 1 1

Max Depth Having 60 degrees: - None -
Max Depth Having 275 degrees: - None -
Due to Post Duff Depth a minimal amount of heat will be transferred to soil.


LNF Tree 1 bole
litter/duff depth = 15 cm with 100% consumption
Temperature (C)
Time (Hours)
0
50
100
150
200
250
300
350
400
450
0
5
10
15
20
25
30
35
-1
-2
-5.5


LNF Tree 1 bole
FOFEM predicted soil heating
Temperature (C)
Time (Hours)
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0
-1
-2
-3
-4
-5
-6

TITLE: Tree 1 bole results of FOFEM model execution on date: 12/7/2006

FUEL CONSUMPTION CALCULATIONS
Region: Pacific_West
Cover Type: SAF/SRM - SAF 247 - Jeffrey Pine
Fuel Type: Slash
Fuel Reference: FOFEM 021

FUEL CONSUMPTION TABLE

Fuel Component Name	Preburn Load (t/acre)		Consumed Load (t/acre)	Postburn Load (t/acre)	Percent Reduced (%)	Equation Reference Number	Moisture (%)
Litter	5.91	u	5.91	0	100	999	
Wood(0-1/4inch)	0.05	u	0.05	0	100	999	
Wood(1/4-1inch)	3.19	u	3.19	0	100	999	22
Wood(1-3inch)	0	u	0	0	0	999	
Wood(3+inch)Sound	0	u	0	0	0	999	30
Wood(3+inch)Rotten	0	u	0	0	0	999	30
Duff	59	u	43.1	15.9	73.1	2	25
Herbaceous	0	u	0	0	0	22	
Shrubs	0	u	0	0	0	23	
Crownfoliage	0	u	0	0	0	37	
Crownbranchwood	0	u	0	0	0	38	
TotalFuels	68.15		52.25	15.9	76.7		

'u' Preburn Load is User adjusted

FIRE EFFECTS ON FOREST FLOOR COMPONENTS

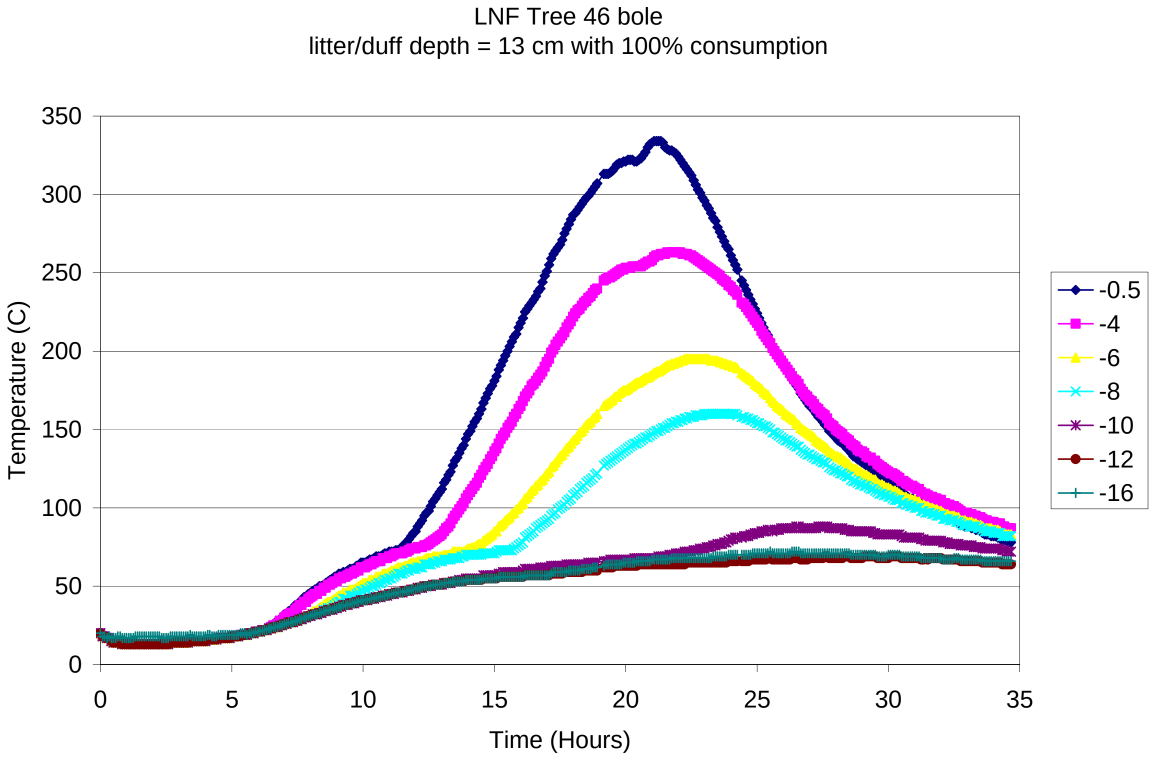
Duff Depth Consumed (in) 2.7 Equation: 6
Mineral Soil Exposed (%) 65.7 Equation: 10

Soil Heat Report
Cover Type.....: SAF/SRM - SAF 247 - Jeffrey Pine
Duff Depth.....: Pre-Fire: 11.99 cm., Post-Fire: 5.10 cm.

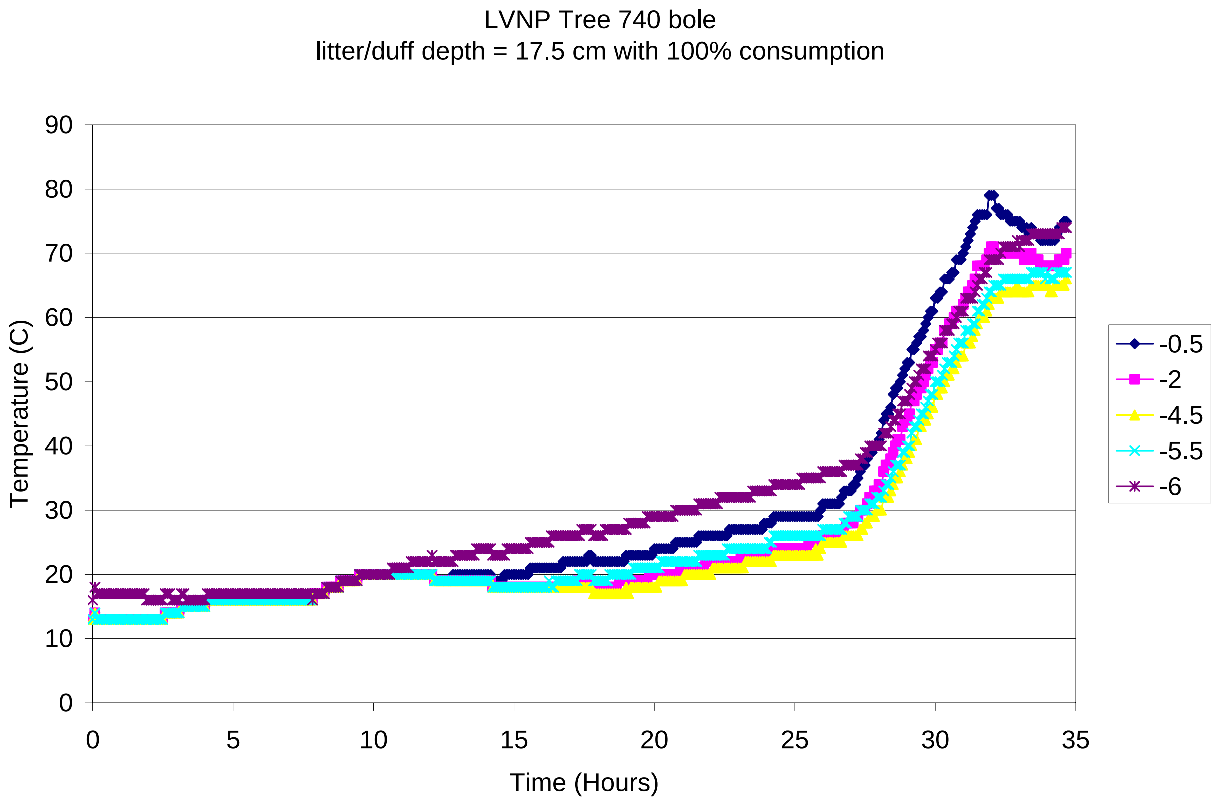
Soil Layer Maximum Temperature
(measurements are in centimeters and Celsius)

Depth	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Temp.	28	25	24	24	23	23	23	22	22	22	21	21	21	21
Time	263	280	294	305	317	327	335	343	349	355	359	361	363	1

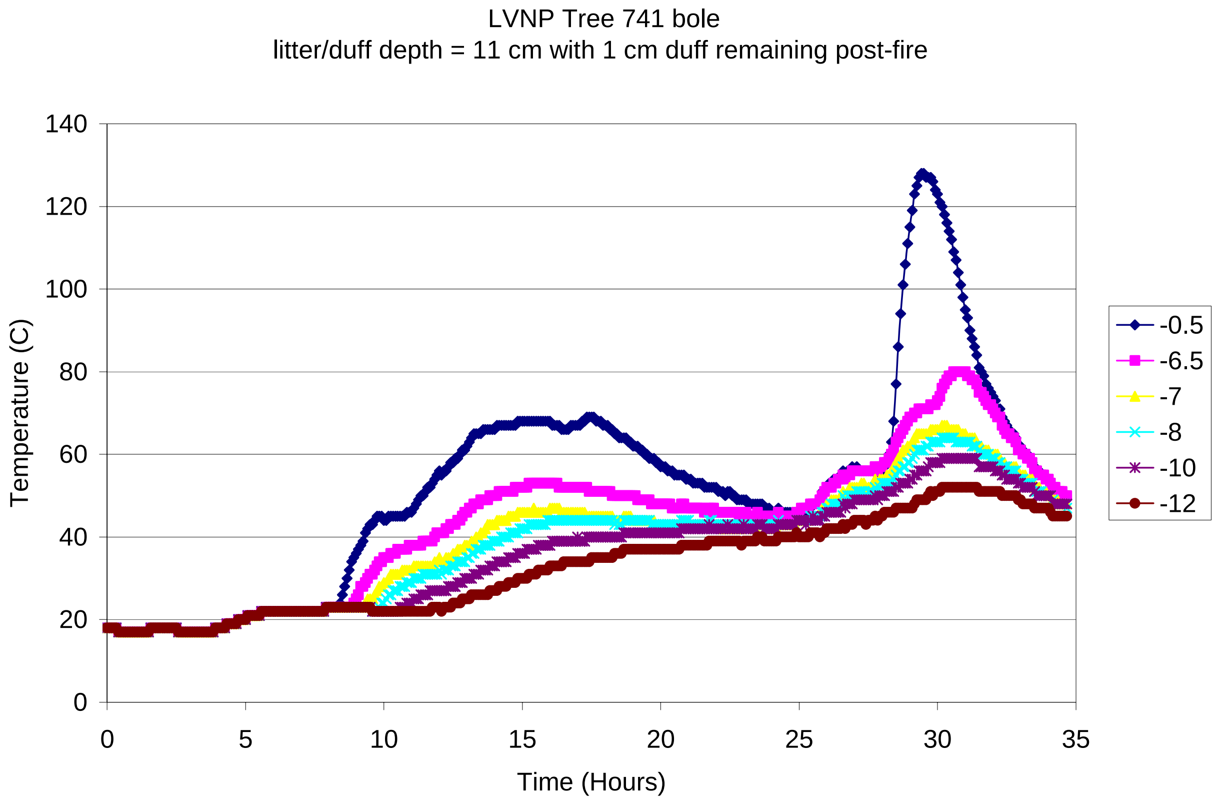
Max Depth Having 60 degrees: - None -
Max Depth Having 275 degrees: - None -
Due to Post Duff Depth a minimal amount of heat will be transferred to soil.



Moisture data not collected.



Batteries died on datalogger.



Duff consumption began and then slowed during the night and resumed again the next day. FOFEM is not able to model such situations.