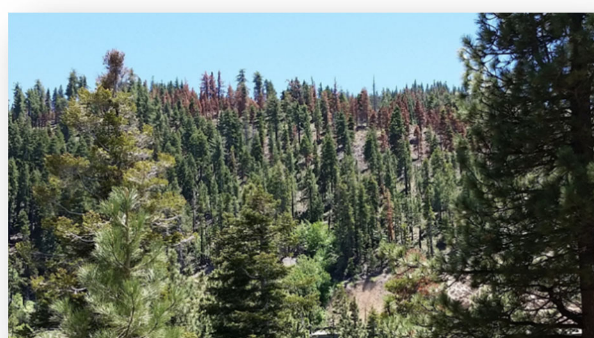
Assessment of Spooner Hazardous Fuels Reduction and Healthy Forest Restoration

Prepared by: Scott Dailey[1] & Alicia Reiner[2]. Final Draft delivered 7/21/2020



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Executive Summary

The objective of this report is to provide land managers with information for a better understanding of the effectiveness of hazardous fuel reduction treatments and forest restoration efforts carried out as part of the Spooner Hazardous Fuels Reduction Project on the Lake Tahoe Basin Management Unit.

Thinning treatments began in 2010, and included mostly hand thinning and piling, with limited areas of cut-to-length mechanical thinning. Thinning treatments were followed by either pile burning, or pile burning combined with broadcast burning (fire creep across areas among the burn piles). Prescribed burning began in 2013. A period of exceptional drought and warmer than average temperatures affecting California and western Nevada occurred as treatments were being implemented, with the period from fall 2011 through 2014 proving to be the driest on record for the state of California (Hanak et al 2015).

On completion of pile burning and pile/broadcast burning treatments, unexpectedly high levels of tree mortality were observed in isolated patches. Trees in the project area were suffering from drought stress, and it is presumed that they lacked typical resistance to the heat injury from fire, resulting in the areas of observed tree mortality following burn treatments.

Field data was collected to assess fuel loading and vegetation structure that existed pre- and post-treatment, quantify the levels of tree mortality which occurred, as well as factors such as burn pile density and closeness to trees that might have been associated with differences in tree mortality.

Key Findings/Observations

After review of information gathered on weather and climatic data, records provided by the LTBMU, and field data collected within the Spooner Project areas, the following key findings were determined:

- Most project objectives were met for reducing fuel loading and tree density
- Mean tree mortality across areas where burn treatments had been implemented was 12%. It's important to note that in areas thinned, but yet to be burned, mean tree mortality was 6.5%.
- "High severity" plots were selectively located within isolated areas (1 to 4 acre patches) which showed greatest fire effects. In these areas tree mortality averaged 55%.
- It appears that burn pile density and burn pile closeness to trees did not have a substantial influence on tree mortality.
- We found that tree mortality was substantially less where trees were exposed to heat from burn piles only (5%), compared to mortality where trees were exposed to heat from a combination of both burn pile and broadcast burning (22%).
- For the isolated patches where fire effects were higher, there are benefits to be considered for the gaps in the forest that were created. Creating gaps in the forest provides heterogeneity that has been identified as an objective for restoring landscape level forest structure to improve ecological health, habitat, and forest resilience. In the portion of the Spooner Project area measured for this assessment (south of Highway 50), the gap size created (mean = 2.1 acres, median 1.5ac, range 1.3 to 4.1ac), falls in line with the recommendations for gap size creation that falls within the natural range of variability for improved ecological function and resilience.

Contents

Background

Historic Site Conditions

A study by Taylor (2004) which included data collected in the Spooner Project area showed that conditions prior to the late 1800's consisted of forests dominated by widely spaced, large-diameter Jeffrey pine (*Pinus jeffreyi*), western white pine (*Pinus monticola*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*), white (*Abies concolor*) and red fir (*Abies magnifica*). The fire regime was typically that of frequent, low to moderate severity surface fires that reduced the amount of understory seedling and pole-sized trees, shrubs, shade tolerant tree species and dead and downed fuel accumulations. Jeffrey pine-white fir stands ranged from 11 to 46 trees per acre, with average diameters ranging from 21 to 34 inches diameter at breast height (dbh). Basal area during this time averaged 111 square feet per acre. The historic mean fire return interval for Jeffrey pine-white fir forests, such as the area of this assessment, was 11.4 years, with 92 percent of the fires occurring during the dormant season (late summer or fall).

Pre-Treatment Conditions (2008)

Comstock era clear-cutting of forests in the area during the late 1800s, along with aggressive fire suppression over the last century shaped the vegetation and fuel structure that existed pre-treatment. Forests consisted largely of aged stands, and with a near absence of fire in the project area there was a substantial accumulation of surface and ladder fuels, especially the growth of dense, small-diameter suppressed trees, which contributed to increased potential for crown fires. There were two insect outbreaks in the project area (1980's and 1990's) which left many insect-killed trees on the ground, adding to the dead and down fuel load, especially course woody debris (See Figure 1).

In 2008, data was collected in common stand exam plots located across the Spooner Project area to describe the existing condition for project planning. Analysis of pre-treatment conditions showed that wildfires occurring under 90th percentile weather conditions were likely to escape initial attack. Fire effects modeling also predicted high levels of tree mortality for fires burning under 90th percentile conditions. The project area had tree densities ranging from 124 to 565 trees per acre. Basal area across the whole Spooner Project area averaged 190 ft^2/acre, ranging from 60 to 390 ft^2/acre.

In the southern portion of the Spooner Project targeted for this assessment, pre-treatment tree density was in the range of 165 to 200 trees per acre, with a mean of over 45 snags per acre. Basal area in the assessment area was approximately 165 ft^2/acre. Dead and down surface fuels for the project area averaged 34 tons/acre and ranged from 5 to over 100 tons/acre.

Figure1: Typical pre-treatment conditions in the Spooner Project area in 2008. Photo by Scott Dailey, USFS.

Spooner Project Objectives/Treatment Design

The Spooner Hazardous Fuels Reduction and Healthy Forest Restoration Project (Spooner Project) was established to address issues identified in the 2007 Lake Tahoe Basin Multi-Jurisdictional Fuel Reduction and Wildfire Prevention Strategy (USFS et al, 2007). The objective of the Spooner Project was to reduce the potential for catastrophic wildland fire, improve forest health, return fire into fire-adapted ecosystems, and provide defensible space for adjacent developed communities (USFS, 2009). The Spooner Project covered approximately 3,750 acres on the eastern side of the Lake Tahoe Basin. In areas north and south of Spooner Summit, on both sides of the Hwy 50 and State Route 28 corridors (see project map, Appendix A). Treatments planned for the project area included mostly hand thinning and piling, with limited areas of cut-to-length mechanical thinning, followed by pile burning and broadcast burning. Smaller areas of mechanical cut-to-length treatments were performed, totaling approximately 220 acres, but are not included in this assessment.

The 2011 to 2017 Drought

Implementation of fuel treatments began in 2010. Soon after thinning work initiated, and just over a year before burning treatments would start on the Spooner Project, a period of extended drought began. This drought would last from fall 2011 until spring 2017. The period from fall 2011 through winter of 2014 would prove to be the driest on record for the state of California (Hanak et al 2015). The drought was identified as a California event, but included areas well beyond the state boundary into western Nevada where the Spooner Project is located just a few miles east of the California-Nevada border. Temperatures that were well above average during this period exacerbated the impact of low precipitation (Figure 2). Estimates of 1,000-hr fuel moisture based on local RAWS data showed minimum recorded values in the years 2013 through 2015. Records from local SNOTEL sites showed soil moisture contents that were well below average. Details of the 2011-2017 drought can be found in Appendix D.

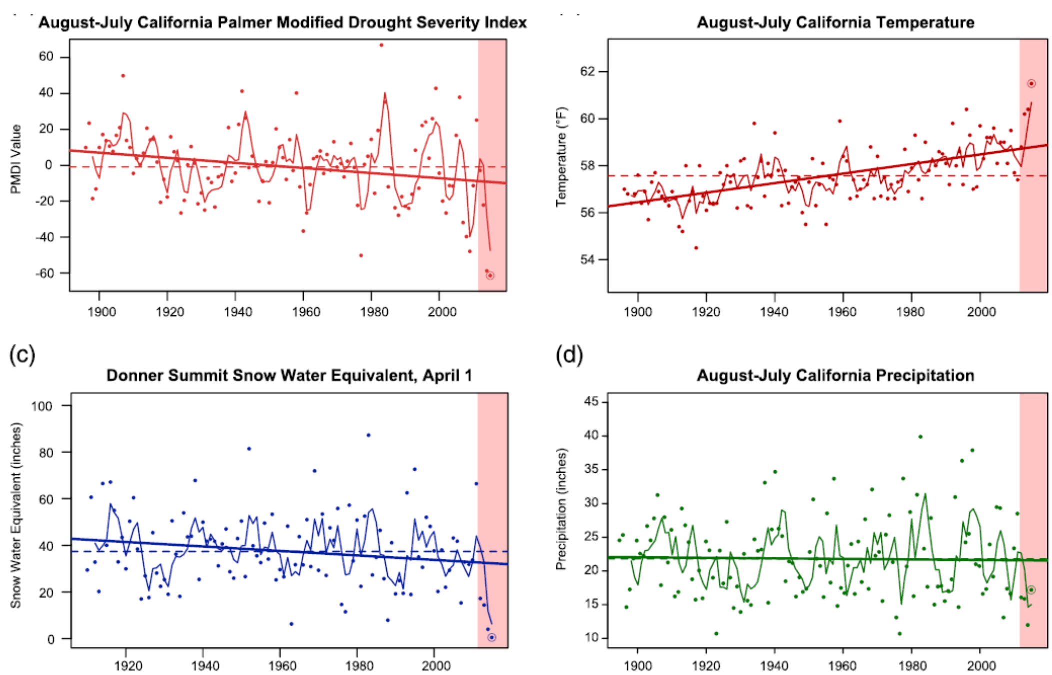

Figure 2: Various indices illustrating the severity of the drought. The area shaded red highlights the period from 2012 to 2015. Source of figure: Swain, 2015.

The Effect of Drought and Fire on Trees

It's been found in several studies that during periods of extended drought trees will suffer diminished resilience to secondary disturbances including fire injury (Dickinson and Johnson 2001, van Mantgem et al 2013, Hood et al 2018). Van Mantgem et al 2013 found evidence that both drought and heating from fire can impair xylem conductivity. They also found that longer-term climatic stress, as long as 5 years prior to fire, predisposed trees to be killed from short-term fire damage, however the exact mechanisms are unclear. Some thoughts on these mechanisms include the concept that fire can cause problems with water transport in trees due to cavitation in xylem and deformation of xylem, and when water deficits are high, repairs to these mechanisms and/or water supply may be insufficient. Data was not collected within the treatment units on growth (tree ring analysis), foliar moisture or soil moisture at the time burn treatments were performed, so we are unable to quantify the level of onsite tree stress. It's likely that the drought of 2011 to 2017 resulted in trees across the project area with reduced vigor to contend with heat stress experienced during burn operations.

It's normal and expected for some tree damage (scorch) and tree mortality to occur when prescribed fire treatments are applied. Tree injury from fire can occur in different ways, including foliage necrosis (crown scorch), tree bole damage, and root damage (Van Wagner 1973, Dickinson and Johnson 2001, van Mantgem et al 2013, Hood et al 2018). Pile burning carried out for the Spooner Project did include fire creep between piles, which was described as an option in treatment planning.

It's worth noting that results from a recent study (Low et al, in review) looking at the impact of the 2011 to 2017 drought on trees located on the west shore of the Lake Tahoe Basin, indicates that trees in untreated areas were not impacted in terms of tree ring growth. Treated stands in this study showed significant increases in tree growth. It's speculated that despite moisture deficits, the increased length of the growing season allowed for similar (untreated), or increased (treated) annual growth. Because increased growth is a sign of increased vigor, it brings into question the idea that drought automatically equates to reduced vigor, and subsequently the ability to maintain resistance to disturbances such as fire. However, the impact on resistance to fire injury has not been investigated in the Low et al study. Furthermore, precipitation on the west shore of the Lake Tahoe Basin is typically much greater than the east shore, so drought severity for the Spooner Project area on the east shore was likely greater.

Tree Mortality Issue Surfaced

With the completion of hand thinning/piling treatments which were initiated in 2010, pile and broadcast burning was carried out in Montreal unit 14 in February 2013 (details of the Montreal unit 14 burn treatment are presented in Appendix B). According to fire staff on site during the burning operation, there was minimal isolated torching of trees and typical scorching of the lower branches, with limited tree mortality observed overall. In the days to weeks following the burn treatment, the needles of overstory trees began turning orange in patches on the order of 1 to 6 acres (See Figure 3). These areas of tree mortality were large enough that they got the attention of both the public and LTBMU staff. Field data was collected by LTBMU staff in 2014. Analysis of that data showed that across the entire treatment unit, Montreal unit 14, tree mortality was 6.6%, which is within burn plan objectives to limit mortality to 10%. Conditions in Montreal 14, measured by LTBMU staff in 2014 are reported along with the results of our analysis performed on data collected in 2017/2018 in other Spooner Project treatment units located south of Hwy 50, but data from Montreal 14 was not included in analysis of the 2017/2018 data.

 

Figure 3: Typical tree mortality found in the high burn severity patches occurring following pile and broadcast burning in Montreal units 14 and 31 in February 2013. Photos taken in May 2013 by LTBMU staff.

Figure 4. Photo of Montreal unit 14 taken from Highway 50, looking north. Note the isolated pockets of dead trees on the mid to upper slopes of the hill. Also note gaps in the forest to the far right, which existed prior to the project. Photo taken in June 2015, by Scott Dailey, USFS.

In December 2014 pile and broadcast burning was carried out in portions of Summit units 23 and 32 with patches of tree mortality that was similar to what was seen at Montreal unit 14, Figure 5. (Details of the Summit 23 and 32 burn treatment are presented in Appendix C)

Figure 5: Tree mortality patches in unit Summit 23, looking south from Montreal unit 14. For location reference, Highway 50 can be seen in the bottom of the photo. Photo taken in June 2015 by Scott Dailey, USFS.

In both instances of tree mortality, patches of dead and scorched trees were in locations that were in clear view of local residents and those driving the well-travelled route over Spooner Summit via Highway 50, and likely contributed to a greater number of concerns raised.

Methods

In 2015, at the request of the LTBMU, members of the Enterprise Program[3] began an assessment on the level of tree mortality occurring on the Spooner Project. This assessment was to include suspected contributing factors, specifically the ongoing drought. Site visits were performed. Project information was provided by LTBMU staff. A literature review was carried out, locating previous work on conifer resilience to fire stress during drought conditions. Also, data was collected from local remote area weather stations (RAWS), and SNOTEL sites to define climatic conditions. A draft version of this report was prepared in 2016 which summarized available data on collected by LTBMU staff on Montreal unit 14, weather conditions during burn operations, data defining the magnitude of the drought. It was determined that the draft report on weather and climate conditions held limited value without field measurements of vegetation structure, fuels conditions, burn pile metrics, and data on levels of tree mortality. To meet this need for data on fuels and vegetation, plot data was collected in the Spooner Project area during the field seasons of 2017 and 2018. Many elements of the 2016 report were retained for this final (2019) report.

Overall, the Spooner Project covers an area of approximately 3,500 acres, and was originally broken out into 30 treatment units. This assessment is focused on the southern portion of the Spooner Project, covering approximately 900 acres on 7 treatment units where the unexpected patches of tree mortality

3 Adaptive Management Services Enterprise Team (AMSET) was the Enterprise unit working on the project when it was initiated in 2015. AMSET was consolidated along with other individual Enterprise groups into a single unit, the Enterprise Program, in 2017.

was observed following prescribed burning which occurred from 2013 to 2017: Montreal units 14, 21 and 22, and Summit units 23, 24, 32, and 35. These units are located adjacent to Highway 50 at North Logan House Creek in the south, and Highway 50 at Genoa Peak Road to the north (See Figure 6). Field data was collected in 2014 within Montreal unit 14 by LTBMU staff. Results from the Montreal 14 assessment is presented separately in this report (See Appendix B). Additionally, data was collected in the 6 other Spooner Project units noted above. Field data was collected on those plots in 2017 and 2018.

The objective for the field data analysis was to provide empirical data to compare the vegetation and fuels conditions pre-and post-treatment to determine the effectiveness of fuel treatment activities, and to better understand factors related to tree mortality which occurred following prescribed burn treatments in the Spooner Hazardous Fuels Treatment Project during severe drought conditions. The results from this assessment may be used to help inform management decisions related to burning during future drought conditions.

It was decided to utilize pre-treatment (2008) plot locations for post-treatment field data collection in 2017/2018, which would allow us to compare pre/post-treatment conditions. Also, we coordinated with Region 5 Ecology Program staff on the data collection protocol in order to incorporate elements of their ongoing study of fuel treatment influence on areas suffering from elevated tree mortality caused by drought and beetle kill in the Central and Southern Sierras (Restaino et al 2019). At the time the protocol was being planned, it was considered possible that the high levels of drought and bark beetle caused tree mortality occurring in areas further south, would begin occurring on the LTBMU. R5 Ecology Program field crew staff performed field data collection.

Thirty field plots were established to collect post-treatment conditions, and centered at the locations of Common Stand Exam plots established in 2007/2008[4]. This allowed for valuable comparison of conditions that had existed pre-treatment, and the ability to quantify how fuel treatments met project objectives for fuel load and stand density reduction. Two plots were dropped due to situations where plots were partially burned. Ultimately a total of 28 plots were used, with 13 plots to represent areas where thin/pile treatments had been implemented (burning treatments yet to occur), and 15 plots where thin/pile/burning treatments had occurred.

Data was collected to define general site conditions, overstory trees, as well as surface and ground fuels. Ground fuels, surface fuels, vegetation cover and tree strata were measured using common stand exam protocols. Surface fuels were measured according to Brown (1974). These measurements were used to calculate surface and ground fuel loading (fuel/ area) with basal area weighted species-specific coefficients (van Wagtendonk et al. 1996; 1998).

The Forest Vegetation Simulator program (FVS, Crookston and Dixon 2005) and its Fire and Fuels Extension (FFE-FVS, Rebain 2010) were used to calculate tree density, and basal area. FVS/FFE-FVS are stand level growth and yield programs used throughout the United States. The Western Sierra variant was used for all calculations.

4 GPS coordinates were recorded for the pre-treatment plot centers in 2008, but neither permanent plot center markers nor monument trees were established. Using GPS, the post-treatment plots were located as close as possible to the original plot locations (likely within 1 to 2 meters). This lack of precision in plot center location for pre vs. post-treatment plots is a potential source of sampling error for comparing pre and post conditions.

Data was also collected to describe burn pile metrics for both existing (un-burned), and pre-existing burn piles[5] (burned). Fire severity metrics were collected for those areas where burn treatments occurred (The full data collection protocol is presented in Appendix E).

In 2018, data were also collected in isolated patches where fire effects on overstory trees were noticeably greater than average, as these areas were not represented by the limited number of randomly located plots. The intent of these "high severity plots" was to provide descriptive data that could be used to characterize post-treatment conditions where higher severity effects occurred in patches of 1 acre or greater. A total of 4 high severity plots were installed, with 1 plot located in each of 4 separate high severity patches found. The sizes of the high severity patches ranged from 1.25 to 4.1 acres, with a mean of 2.1, and median of 1.5 acres. Budgetary and time constraints limited the number of plots, therefore locations representative of conditions across each particular high severity patch were intentionally selected (see plots HS-1 through HS-4 in Figure 6). The same data was collected in the high severity plots as the standard plots. Analysis results for the high severity plots have value in describing elevated fire effects in the project area, but should not be considered to have any statistical significance because plot locations were intentionally selected (with no element of randomness), and they lack an adequate sample size.

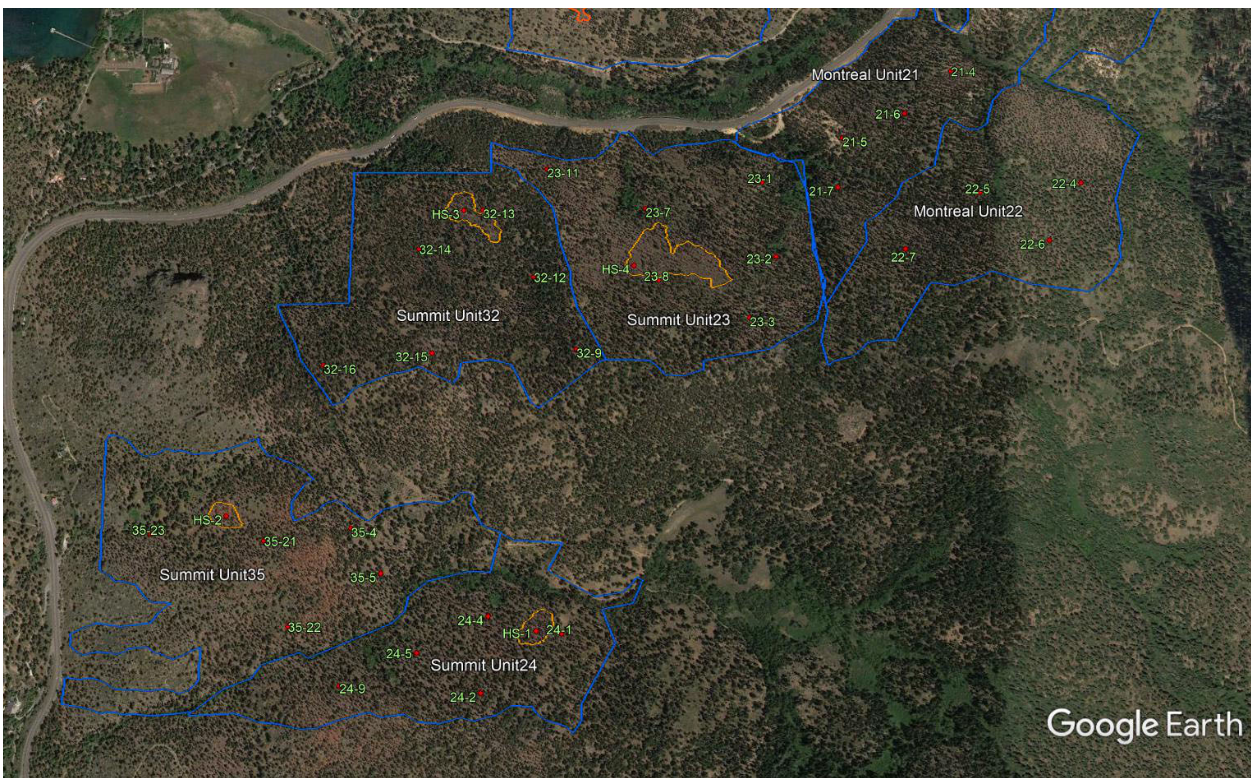

Figure 6: Spooner Project Units and plot locations included in the 2017/2018 field assessment.

[5] Measurements were taken to quantify the density, dimensions (diameter only), and distance from trees of burn piles which had been previously burned. This was possible, as the locations of burn piles have left scars on the ground which identify the location and size of piles that had existed.

Results

Surface and ground fuels

Thin/Pile Only (burning not yet implemented):

Field data indicates that Thin/Pile treatments (where burning had not yet occurred at the time of data collection) resulted in a mean increase of combined 1 and 10 hour fuels by 2%, and 100 hour and 1000 hour (CWD) fuels were reduced by reduced 49% and 58% respectively (See Table 1). Data also show that ground fuels were reduced by 43%, which is unlikely, as no steps had been taken to remove ground fuels. It can be assumed that the data is showing the effects of litter and duff compaction from snow, and/or compaction or displacement from concentrated foot traffic of hand treatment crews. Thin/Pile treatments reduced total surface fuel load by 54%, with a mean of 38 tons/ac remaining in unburned burn piles.

Thin/Pile/Burn:

Combined 1 and 10 hour fuels were increased slightly, by 1%. We speculate that this small increase in smaller sized fuels is the result of broken and scattered twigs and small branches that occurred during the process of cutting and piling understory vegetation and surface fuels. Such small fuels can be unreasonably time consuming to pick up for piling, so tend to be left in place. It's also possible this increase in smaller fuels resulted from shedding of small twigs and branches from overstory trees that were scorched during burning. Fuel consumption targets were met in the 1" to 3" (100 hour fuel) as well as fuels >3" (1000 hour fuel), with reductions of 67% and 80% respectively. Completed treatments in the assessment area reduced ground fuels by 45%, and surface fuels by 76%.

Pre-burn data was not collected on the fuel load of burn piles in Thin/Pile/Burn plots, so it's not possible to confirm that the objective of 60-80% consumption was met. However, if the burn pile fuel load measured for Thin/Pile plots is used as a proxy, then it can be estimated that 94% of piled material was consumed in Thin/Pile/Burn plots. It can be reasonably assumed that the objective for burn pile consumption was met.

High Severity:

Pre-treatment data was not collected for high severity plots, therefore it's not possible to report the amount of fuel reduction, but using the pre-treatment conditions from other Thin/Pile/Burn plots as a proxy, then the following approximations can be made for fuel reductions for high severity plots: combined 1 and 10 hour fuels decreased by 17%, 100 hour fuels decreased by 35 to 40%, and 1000 hour fuels decreased by 90%. It's estimated that 95% of burn pile material was consumed.

Fuels reduction objectives were presented in the Spooner Project Proposed Action, as well as the Prescribed Burn Plan for Montreal/Summit/Logan units. Based on data collected in the assessment area, all objectives were met for the reduction of fuels, with the exception of fuels < 1" diameter (1 hour and 10 hour fuels). Fuels under this size class were slightly increased by 2% and 1%, in Thin/Pile and

Thin/Pile/Burn treatment areas. We speculate that this small increase in smaller sized fuels is the result of broken and scattered twigs and small branches that occurred during the process of cutting and piling understory vegetation and surface fuels. Such small fuels can be unreasonably time consuming to pick up for piling, so tend to be left in place. It's also possible this increase in smaller fuels resulted from shedding of small twigs and branches from overstory trees that were scorched during burning.

Table 1: Mean ground and surface fuel loading reported in tons per acre, comparing pre- and post-treatment and treatment type, including areas of High Severity effects within Thin/Pile/Burn treatments. Change in percent pre to post-treatment is shown in parenthesis. Green font indicates where project objectives were met, red = not met. Pre-treatment data were not collected in areas of High Severity, but could be assumed to be similar to other areas measured pre-treatment.

	Thin/Pile	Thin/Pile/Burn	High Severity
N =	13	15	4
Duff – pre	13.2	6.7	-
Duff - post	5.7	7.6	2.8
Litter - pre	8.9	19.4	-
Litter - post	6.9	6.7	6.0
Total Ground Fuel - pre	22.1	26.1	-
Total Ground Fuel - post	12.6 (-43%)	14.3 (-45%)	8.7
1hr - pre	0.14	0.13	-
1hr - post	0.20	0.14	0.15
10hr - pre	0.79	0.90	-
10hr - post	0.71	0.90	0.70
1+10hr - pre	0.93	1.03	-
1+10hr - post	0.91 (+2%)	1.04 (+1%)	0.85
100hr - pre	3.1	3.5	-
100hr - post	1.6 (-49%)	1.2 (-67%)	2.2
CWD - pre	17.7	29.3	-
CWD - post	7.4 *(-58%)*	6.0 (-80%)	2.9
Total Surface Fuel - pre	21.8	33.9	-
Total Surface Fuel - post	*9.9* (-54%)	8.2 (-76%)	5.98
Burn Pile Fuel - post	38.1	2.1 (-94%)	0.60

Trees

Thin/Pile Only (burning not yet implemented):

Live tree density was reduced from 199 to 66 trees/acre (-67%) in Thin/Pile treated areas. White fir and Jeffery pine which accounted for 70% and 23% of the trees pre-treatment, were reduced by 84% and 14% respectively in Thin/Pile areas. The remainder of reductions were to sugar pine and incense cedar (See Table 2).

Basal area (ft2/ac) was reduced from 161 to 110 (-32%) in Thin/Pile treated areas. White fir and Jeffery pine showed basal area reductions of 70% and 43% respectively in Thin/Pile treated areas. The basal area target according to the Spooner Project Proposed Action (LTBMU, 2010) was 80 to 150ft2/acre. Our field data shows that this objective was met in Thin/Pile Only treated areas.

Thin/Pile/Burn:

Live tree density was reduced from 164 to 69 tpa (-58%) in Thin/Pile/Burn areas. White fir and Jeffery pine which accounted for 57% and 40% of the trees pre-treatment, were reduced by 69% and 28% respectively.

Basal area was reduced from 166 to 93 (-44%) in Thin/Pile/Burn areas. White fir and Jeffery pine accounted for basal area reductions of 47% and 44% respectively in Thin/Pile/Burn areas. The basal area targets were met in Thin/Pile/Burn treatments.

High Severity:

Pre-treatment tree data was not collected for high severity plots, therefore it’s not possible to report the amount of tree reduction, but using the pre-treatment conditions from other Thin/Pile/Burn plots as a proxy, then the following approximations can be made for fuel reductions for high severity plots: Live tree density reduced from 164 to 45 tpa (-73%). White fir and Jeffery pine accounted for the majority of all tree density reductions in High Severity plots at 70% and 25% respectively, as well as basal area reductions at 53% and 38% respectively.

Table 2: Live tree metrics by species reported in trees per acre and basal area. Conditions shown pre- vs post-treatment, and by treatment stage. Live tree metrics for high severity areas are also shown.

			Live Trees					
			ABCO	PIMO3	PILA	PIJE	CADE	Total
Trees/acre	Thin/Pile Only	Pre	140.0	0	12.3	46.2	0	198.5
		Post	29.2	4.6[6]	4.6	27.7	0	66.2 (-67%)
	Thin/Pile/Burn	Pre	93.3	0	2.7	65.3	2.7	164.0
		Post	28.0	0	2.7	38.7	0	69.3 (-58%)
	High Severity	*Post*	*10.0*	*0*	*0.0*	*35.0*	*0*	*45.0*
Basal Area (ft2/ac)	Thin/Pile Only	Pre	72.1	0	5.8	83.3	0	161.2
		Post	36.7	6.9	5.3	61.4	0	110.3 (-32%)
	Thin/Pile/Burn	Pre	65.1	0	7.5	91.9	1.2	165.8
		Post	31.1	0	1.6	59.3	0	93.1 (-44%)
	High Severity	*Post*	*8.6*	*0*	*0.0*	*51.8*	*0*	*60.4*

Tree Mortality Following Burn Operations

High levels of tree mortality was one reason that treatments was deemed necessary for the Spooner Project area in the 2000s. Insect mortality associated with drought in the late 1980's and early 1990's, resulted in both heavy dead and downed course woody material and a large number of dead standing trees. Pre-treatment plot data reflects this high level of tree mortality. Pre-treatment, in 2008, mean tree mortality in the assessment area was about 20%, with snag density of 44 to 48 tpa (Table 3). Post-treatment data shows that nearly all of the snags which existed pre-treatment were removed, with a mean of 3 trees/acre remaining for older (advanced decay) snags in Thin/Pile Only areas, and no older snags found in Thin/Pile/Burn and High Severity plots. It is likely that plot data does not accurately capture snag retention for the overall project area, as snags were often left in clumps and streamside management zones in steeper terrain where both treatment and plot placement was avoided.

Tree mortality ("Recent Tree Mortality") was observed following burn operations in Montreal units 14 and 31, carried out in winter 2014. Field data was collected and analyzed by LTBMU staff at 20 plots across Montreal unit 14, and 12 plots in unit 32 in fall 2014. Analysis showed that there was 6.9% recent mortality (occurring after treatment) across unit 14, and zero recent mortality in unit 31 (See Appendix B for more details on the analysis of Montreal 14 and 31).

Summit units 23 and 32 were burned in December 2014, and showed similar tree mortality to what was seen in Montreal unit 14. Some isolated patches of tree mortality appeared following treatments in Summit units 24 and 35, which were burned between early 2015 and early 2017. Field data was collected across these units, along with Montreal units 21 and 22 in order to quantify tree mortality levels. For comparison, field plots were also established in partially treated areas where thinning and

6 Field data shows an increase of Western white pine from pre- to post-treatment. This is possible if a tree or 2 grew in size to now be included. It's also possible that it's due to inconsistencies in plot footprint due to precision of relocating the pre-treatment CSE plot center, or tree identification errors by field crew.

piling had been implemented, but burning had yet to occur. Data was also collected in 4 plots selectively located within areas where higher tree mortality was evident.

The data showed that in Thin/Pile Only areas, were burning had yet to occur, recent tree mortality was a mean of 6.5%; 100% were White fir, at 4.6 trees/acre. There was some evidence of insects, but it's not clear whether or not those insects were the cause of tree mortality. It's assumed that recent tree mortality in these areas was influenced by drought stress. Across Thin/Pile/Burn plots, recent tree mortality was 11.9%; 43% were White fir, and 57% were Jeffery pine, for a combined 9.3 trees/acre. In areas where burning treatments had occurred, it's difficult to differentiate whether tree mortality was the result of burning or not, as dead needles on trees killed by other causes appear similar to scorch resulting from heat stress. In high severity plots, mean recent tree mortality was 55%, at 55 trees/acre.

Table 3: Tree mortality data by species in trees per acre and basal area, pre- and post-treatment, by treatment type, including areas of High Severity effects. "Old Snag" tree density values represents trees that were in advanced stages of decay, so are certain to have been snags well before recent treatment efforts.

			Recent Tree Mortality								
			ABCO	PIMO3	PILA	PIJE	CADE	Recent Snags Total (%Change)	OLD Snag Total	All Snags Total	Live Total
Trees/Acre	Thin/Pile Only	Pre	13.8	0	0	4.6	0	18.5	29.2	47.7	198.5
		Post	4.6	0	0	0	0	**4.6 (6.5%)**	3.1	7.7	66.2
	Thin/Pile/Burn	Pre	2.7	0	0	2.7	0	5.3	40.0	45.3	164.0
		Post	4.0	0	0	5.3	0	**9.3 (11.9%)**	0	9.3	69.3
	High Severity	*Post*	*50.0*	*5.0*	*0*	*0*	*0*	***55.0 (55%)***	*0*	*55.0*	*45.0*
Basal Area (ft2/ac)	Thin/Pile Only	Pre	5.1	0	0	10.1	0	15.2	31.7	46.9	161.2
		Post	7.4	0	0	0	0	7.4 (6.2%)	9.6	17.0	110.3
	Thin/Pile/Burn	Pre	2.5	0	0	3.5	0	6.0	38.4	44.4	165.8
		Post	5.7	0	0	4.4	0	10.1 (9.8%)	0	10.1	93.1
	High Severity	*Post*	*57.4*	*1.3*	*0*	*0*	*0*	***58.7 (49.3%)***	*0*	*58.7*	*60.4*

Burn Pile Size and Arrangement

Beginning in 2018, for each tree inventoried, the distance from the drip line of the tree to the edge of all burn piles within 10 meters was recorded. For trees inventoried across all standard Thin/Pile/Burn plots, the mean distance of the closest burn pile was 3.3 meters (range = 2.6 to 3.8m) (Table 4). For clarity, this metric was determined by averaging the distances of the closest pile to each tree within a given plot to derive the mean of closest piles per plot. Plot level mean values for closest pile were then averaged for mean per treatment type. The mean distance of the closest pile in areas with high severity fire effects was 3.5 meters (range = 2.2 to 5.7m), which suggests that the closeness of the nearest burn piles to trees may not be the reason for higher levels of tree mortality in high burn severity areas. Reviewing the Slash Treatment Specifications, under item C.8-2.2 Piling: "Piles shall be at least 1-1/2 the diameter of the pile from residual trees". Mean pile diameter across all plots was found to be 3.4 meters (range = 2.1 to 4.5m).

The mean number of piles closer than 5 meters to each tree was 1.8 for Thin/Pile/Burn plots and 1.9 for High Severity plots. The mean density of burn piles is 52 piles per acre for Thin/Pile/Burn plots and 43 for High Severity plots. This data shows that on average, areas of High Severity effects have 17% fewer burn piles per acre than other areas where pile burning occurred.

Another burn pile metric for consideration is pile size. Mean pile height in Thin/Pile Only plots was found to be 1.3 meters. Because Thin/Pile/Burn and High Severity areas were measured post-burn, pile height was not possible to determine, but pile dimensions were found to be fairly consistent, so it can be assumed that mean pile height of piles burned was close to 1.3 meters. Pile diameter across treatment types is fairly consistent. Pile diameter in Thin/Pile Only plots was a mean of 3.5 meters. Pile diameter in Thin/Pile/Burn, and High Severity areas was measured according to the burned imprint left behind, and shows that mean diameter is essentially the same at 3.3 meters. Mean minimum and maximum pile diameters (mean values per plot) across all plots was found to be 2.1 and 4.5 meters, respectively. According to the specifications for hand piling of slash, "Minimum pile size shall be four feet (1.2m) diameter", also "Pile height and width should be proportionate; for example a 4-foot high pile should be 4-feet wide". No other specifications are given for the dimensions of hand-piled slash.

The estimated proportion of material in slash piles by fuel size class was 4.9% 1-hr fuels, 5.3% 10-hr, 10.8% 100hr, and 78.9% 1000-hr.

Table 4: Spooner burn pile metrics: Distance from trees, and pile dimensions. Standard deviation is provided in parenthesis. *Note that burn pile height values are not available on Thin/Pile/Burn or High Severity plots (The piles are consumed). Burn pile diameter was possible to determine from remnant material left at the site of each burn pile.

Spooner Project Burn Pile Metrics

	Thin/Pile	Thin/Pile/Burn	High Severity
Mean count of burn piles w/in 5m of each tree (standard deviation in parenthesis)	2.1 (1.2)	2.0 (0.7)	1.9 (1.1)
Closest pile to each tree, mean distance in meters	3.3 (0.8)	3.3 (0.6)	3.5 (1.5)
Mean burn pile density, piles per acre	58 (31)	52 (12)	43 (11)
Mean burn pile diameter, meters	3.5 (0.48)	3.3 (0.33)	3.3 (0.44)
Mean burn pile height, meters	1.3 (0.2)	n/a	n/a

Pile Burning vs. Pile plus Broadcast Burning

According to the Spooner Project Proposed Action, burn treatment was to include "the allowance for fire to creep between piles, while maintaining burn intensity to protect soil and water resources". The only exclusion noted is for flagged areas with sensitive plants and noxious weeds. Fire creep is referred to as "broadcast burning" in this report.

The presence of bole char was used to differentiate those trees that had been exposed to pile burning with broadcast burning, while those without bole char were presumed to be areas of pile burning only. It's assumed that broadcast burning patches were limited in size by a combination of snow on the ground during winter burning, fuel moisture, fuel continuity, or precipitation falling during burn implementation.

Based on the evidence of bole char on trees, for general areas (non- High Severity) treated with fire, 55% was pile burn only, and 45% was pile burning with broadcast burning. In ‘High Severity’ areas there was a greater amount of pile and broadcast burning which occurred, with 37% pile burn only, and 63% with a combination of pile and broadcast burn (Table 5).

Mortality levels were lower in areas treated with pile burn only (no broadcast burning), compared to areas with both pile and broadcast burning. In standard burn areas (non- High Severity) where pile burning alone was carried out, there was a mean of 5.4% tree mortality. In those same standard burn areas where both pile and broadcast burning occurred, mean mortality was 21.7%. In High Severity areas where pile burning alone was carried, tree mortality was a mean of 50%, while areas of combined pile and broadcast burning had a mean of 58% mortality.

Live trees remaining in the burn treatment areas showed greater crown injury in areas of pile and broadcast burning, compared to areas of pile burning only. To quantify the degree of crown injury from fire scorch, scorch height percent was determined by calculating scorch height as a percent of the total tree height for each tree (for instance, if scorch height = 4m and total tree height = 10m, scorch height percent = 40%). Across standard burn areas (excluding high severity patches) mean scorch height percent for pile burn only was 13%, versus a mean scorch height of 31% for pile and broadcast burn. In high severity patches, mean scorch height percent was 79% and 91% for areas of pile burn only and pile and broadcast burn, respectively.

The mean DBH of trees killed by burn treatments was lower in areas of pile burning alone compared to areas of pile and broadcast burning. Trees killed in areas of pile burning had a mean DBH of 27cm compared to a mean of 35cm DBH for trees killed in areas of pile and broadcast burning. In High Severity areas the mean DBH for trees killed was 29cm and 37cm for pile burn, and pile with broadcast burn, respectively.

Table 5: Tree Damage by Burn Type: Pile Burn only, versus combined Pile Burn and Broadcast Burn. Mean values reported, with standard deviation shown in parenthesis. "Mean % scorch height" is the scorch height as a percent of total tree height.

Tree Damage by Burn Type: Pile Burn VS. Pile+Broadcast Burn

	General T/P/B *N=14*		**High Severity** *N=4*	
	Pile Burn Only	Pile Burn+ Broadcast Burn	Pile Burn Only	Pile Burn+ Broadcast Burn
Mean % of burn type exposure, standard deviation (SD) in parenthesis	55.0% (39%)	45.0% (39%)	36.9% (26%)	63.1% (26%)
Mean % tree mortality among trees exposed to pile burn only, without broadcast burn	5.4	-	50.0	-
Mean % tree mortality among trees exposed to pile burn + broadcast burn	-	21.7	-	58.3
Mean % scorch height by burn type, live trees, (SD)	13.2% (22%)	31.4% (32%)	79.4% (3%)	90.7% (6%)
Live Trees, mean DBH in cm, (SD)	31.8 (13.7)	44.1 (18.3)	40.7 (9.5)	38.3 (4.4)
Dead trees, mean DBH in cm, (SD)	26.9 (9.7)	34.7 (18.6)	28.8 (7.6)	37.4 (9.9)

Conclusion

Summary

This assessment was initiated due to concerns about the levels of tree mortality that occurred following prescribed burning treatments that included both pile burning only, and pile burning combined with broadcast burning. The extreme drought, which occurred from 2011 to 2017 coincided with the implementation of Spooner Project treatments, and is assumed to have affected tree resilience to fire injury.

There are many factors in play influencing fire behavior and resulting fire effects. We performed statistical tests to see which factors influenced tree mortality. The following were tested and showed no influence on mortality: elevation, aspect, pre-treatment tree density, basal area reduction, distance of closest burn pile, burn pile density.

Other factors which may have influenced tree mortality and fuel consumption include: fuel moisture at time of burn, wind speed, RH, ignition patterns used by burn crews. We did collect and analyze weather data from local RAWS and looked at soil moisture data from a local SNOTEL site (these are included in the Appendix C and D). We also reviewed and spot weather forecasts, and onsite weather readings for Montreal unit14 (see Appendix B). Details on the timing of all treatment implementation was not available, so performing analysis of the influence of weather factors on fire behavior and fire effects was not possible. Details of crew actions such as patterns, density, and rate of ignitions applied were not available.

A comparison of pre- and post-treatment data shows that Spooner Project treatments met most established objectives for reducing fuels. We speculate that the small increase in smaller sized fuels (1% increase) is the result of broken and scattered twigs and small branches that occurred during the process of cutting and piling understory vegetation and surface fuels. These smaller fuels can be unreasonably time consuming to gather for piling, so tend to be left in place. It's also possible this increase in smaller fuels resulted from shedding of small twigs and branches from overstory trees that were scorched during burning.

Treatment objectives per Spooner proposed action and burn plans:

- Consumption of 60-100% of all piled material[7] (Accomplished)
- Reduce/consume fuels <1" in diameter (1+10hr fuels) by 60-80% [6] (Not accomplished)
- Reduce/consume fuels 1" to 3" in diameter (100hr fuels) by 40-80%[6] (Accomplished)
- Reduce/consume fuels >3" in diameter (CWD) by 60-80%[6] (Accomplished)
- Dead and down fuels reduced to near or below 10 tons per acre[8] (Accomplished)

The assessment found that in areas where burning treatments were implemented, overstory tree mortality was 12%, which exceeds the standard for limiting tree mortality to 10% that existed when the burn plan was written in 2014. The assessment identified recent mortality of 7% in treated areas yet to be burned. This 7% mortality was some combination of typical background mortality that was likely elevated to some degree by the severe drought conditions that occurred from 2011 to 2017 during the same period that thinning and burning treatments were being conducted. Given the 7% mortality found in areas yet to be burned, it's reasonable to assume that tree mortality resulting from burn treatments was actually below the 10% objective, possibly as low as 5%. Since the project was initiated, the LTBMU Land Management Plan (USDA 2016) has set a desired condition (DC31) to allow natural ecological process to occur, "including stand-replacing fire on an average of 15% of burned acres, with occasional more severe fires". According to this standard, the assessment of the Spooner Project shows that 12% tree mortality found in areas where burning was implemented is well within the target set to meet this future desired condition.

The size of high severity patches identified and sampled for this assessment ranged from 1.25 to 4 acres, with a mean of 2.1 acres, and median of 1.5 acres. Tree mortality measured across the 4 plots located in high severity patches averaged 55%. The creation of gaps has been identified as an objective for forest restoration in Sierra Nevada forests. The 2016 Land Management Plan calls for "contiguous areas of crown mortality after fire, less than 10 acres in size". The size of gaps created by high severity fire on the Spooner Project fall within this desired condition. Furthermore, the gaps created by high severity fire on the Spooner Project fall close or within the natural range of variability found in other studies, for example: 0.1 to 2 acres (Piirto and Rogers 2002), 0.25 to 2.5 acres (York 2007), and 0.02 to 1 acre (Lyderson 2013).

Data collected on burn piles suggests that burn pile arrangement on this project did not influence higher levels of tree mortality: Data from the High Severity plots showed that: 1) burn pile density was lower, 2) the count of burn piles closer than 5 meters was lower, 3) the mean distance of the closest pile to each tree was greater, and 4) pile size (diameter) was the same.

Recent tree mortality was higher in areas treated with both pile and broadcast burning, than areas where only pile burning occurred. Trees exposed to a combination of pile and broadcast burning averaged 22% mortality, compared to trees exposed to pile burn only which averaged 5% mortality. The results suggest that trees have a more difficult time coping with bole and root injury in addition to foliar injury, compared to foliar injury alone. This information should not be surprising, but the results found should be noted when burn treatment implementation will occur during times when trees are under elevated stress due to drought.

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[7] Objective source: Prescribed Burn Plan for Montreal/Summit/Logan units (LTBMU, 2014)

[8] Objective source: Proposal for Spooner Hazardous Fuels Reduction and Healthy Forest Restoration Project (LTBMU, 2009)

Recommendations

Extreme drought conditions coupled with elevated temperatures, as experienced during the 2001-2017 drought, should be expected to result in some higher levels of tree mortality associated with burn treatments. Extreme conditions such as this may become more common in the future with climate change. For future projects being carried out during more harsh conditions where trees are under stress, if management objectives call for limiting tree mortality, then it appears that avoiding pile and broadcast burning concurrently may help with limiting tree mortality. One alternative approach would be burning with multiple entries, where pile burning is carried out in the first entry, followed by broadcast burning in a second entry, at least 1 year later.

Burning treatments applied for the Spooner Project resulted in some levels of higher tree mortality in isolated patches which were initially unpleasing to the eye, but were in fact within the landscape-level prescription. Creating gaps in the forest provides heterogeneity that's been identified as a needed change in forest conditions, to improve ecological health, habitat, forest resilience, and otherwise diminish the undesirable impacts of future uncontrolled wildfires by creating 'speed bumps' for future large wildfires (Koontz et all, 2020). The results of Spooner Project can be considered a success. To ensure that the public and other land management partners clearly understand the intent, it's important that treatment objectives for newly proposed projects explicitly identify some elevated levels of tree mortality as an objective for achieving future desired conditions that meet forest restoration goals as identified by the LTBMU Land Management Plan.

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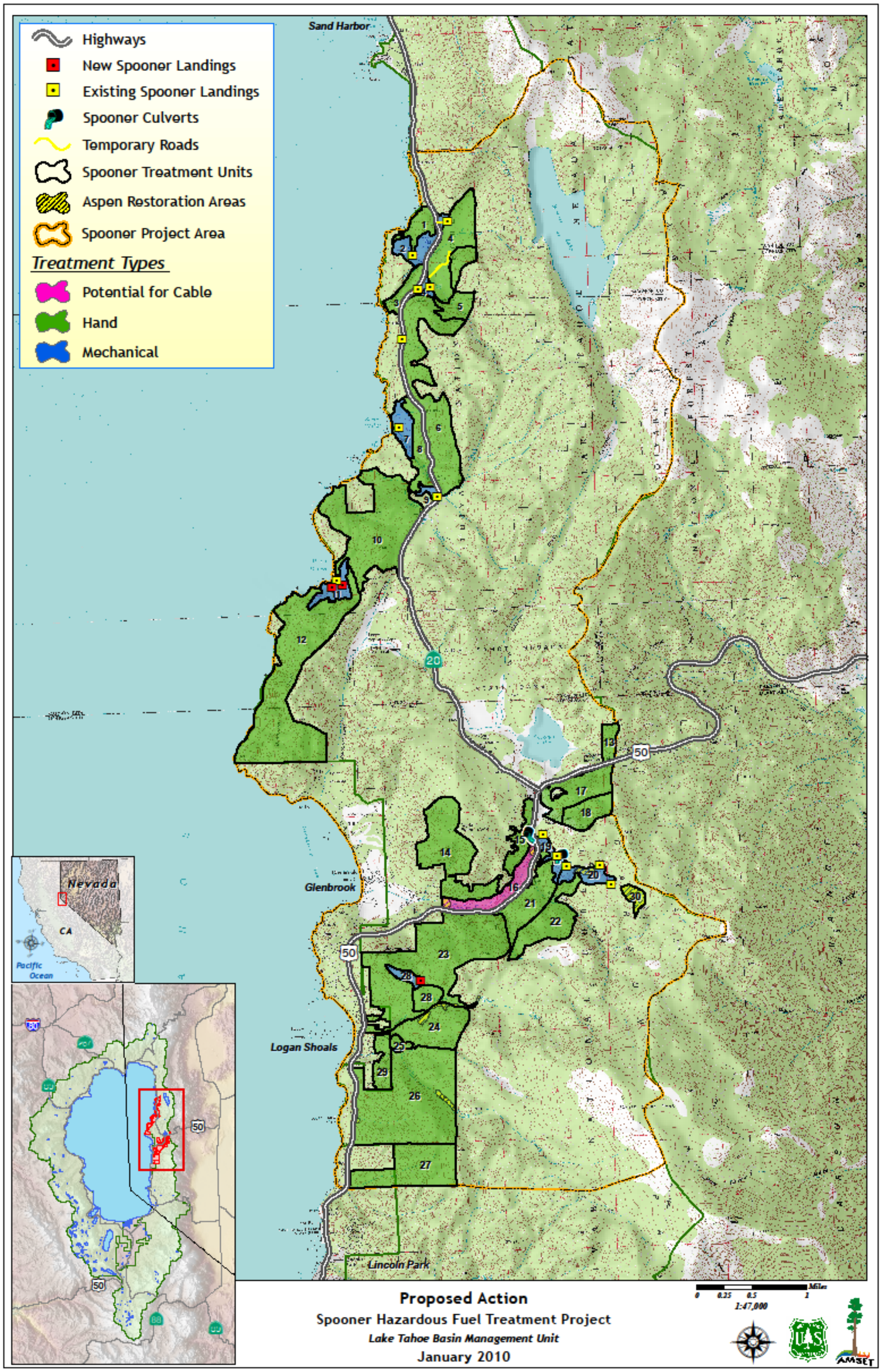
Appendix A: Proposed Action Treatment Map



Appendix B: Details of Prescribed Burning, Montreal Units 14 and 31

Montreal unit 14 is located on a south-facing slope east of Glenbrook, on the north side of Highway 50. This Unit was burned February 19th and 20th, 2013. The northern and eastern portions were burned on the 19th and a central portion was burned on the 20th (Figure B1). The unit consists of 135 acres total (according to FACTS, and 2/20/13 burn date is corroborated by FACTS). The unit was predominantly Jeffery pine overstory, with occasional incense cedar, sugar pine and white fir. Some areas had significant ground fuel loading.

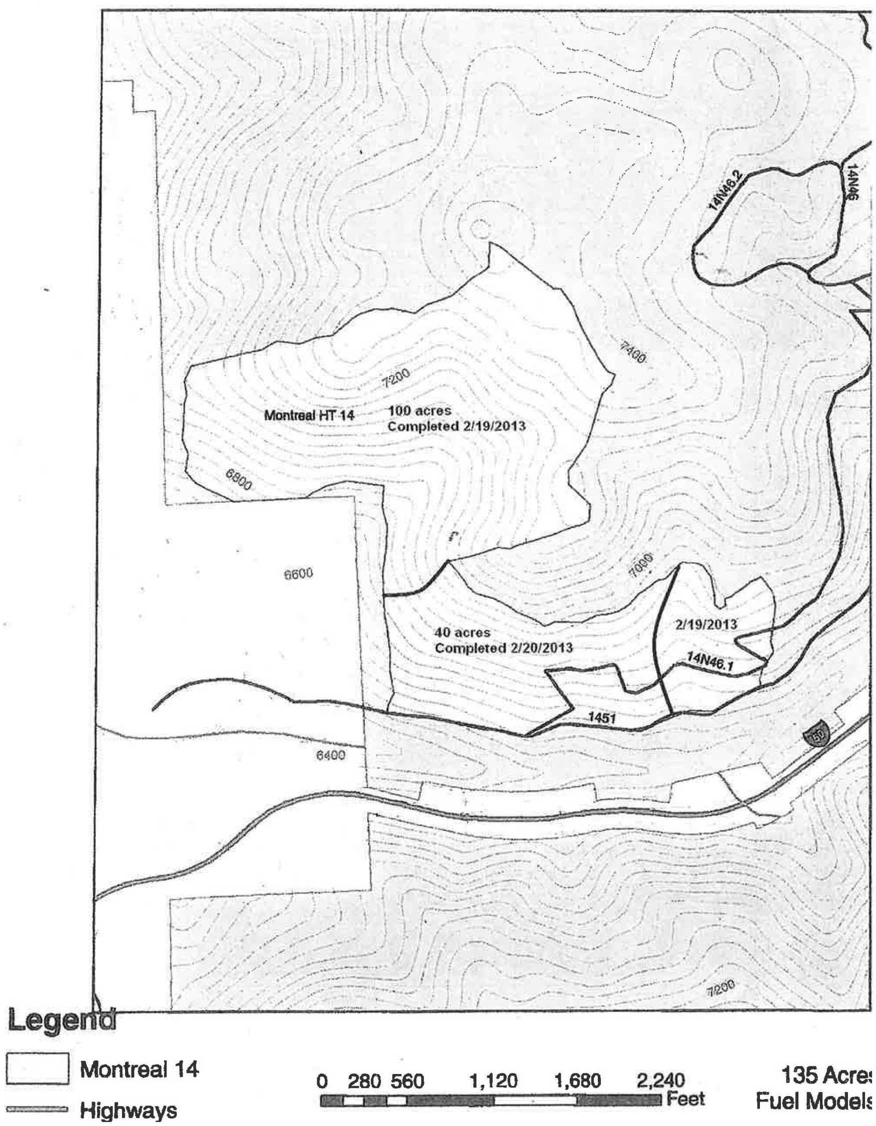


Figure B1. Map of Montreal Unit 14 and dates burned.

The objectives of the treatment were to bring the stand into WUI defense zone desired conditions with a fairly open stand of fire tolerant trees and surface and ladder fuels such that crown fire ignition is highly unlikely. The prescription for the Unit was hand thinning: *Thin from below trees between 24 inches in height up to 14 inches dbh*. Residual trees would be spaced approximately 25 feet apart for a tree density target of 70 trees/acre. All slash plus most surface fuels up to 14 inches in diameter were piled.

A spot weather forecast was delivered from NWS for the burn day of February 19th, 2013. Weather observations were recorded onsite the day before and of the burn. On February 18th, the day before the burn, the 1300 weather recorded by a field observer was a temperature of 39ºF, relative humidity of 58% and winds from the southwest at 1-2 mph. On February 19th, temperatures started out at 29ºF at 0930 and rose to 33ºF by 1300. Relative humidity was between 66 and 77% the day of the burn and eye-level winds were observed to be between 5 and 10 mph with gust up to 20. On February 20th, temperatures for the burn fell between 30 and 37ºF and relative humidities were between 70 and 76%, with eye-level winds at 5 to 10 mph (Table B1).

Table B1. Weather and fuel moisture parameters in the burn plan and as measured in the field for unit Montreal 14. *eye level winds calculated from 20' winds by multiplying by a "partially sheltered" wind reduction factor of 0.3. **20' winds calculated from eye-level winds by dividing by a "partially sheltered" wind reduction factor of 0.3

	Burn Plan Thresholds	**Field Observations: Feb 19th, 2013**	**Field Observations: Feb 20th, 2013**
20' wind	<25 mph	(7.5 mph)*	(7.5 mph)*
Eye level wind	(10-33, gusts 67mph)**	5-10, gusts 20 mph	5 to 10 mph
Temperature	<80º F	29-33º F	30-37º F
Relative humidity	>20%	66-77%	70-76%

Immediately visible fire effects were several isolated patches ranging from 1 to 6 acres in size where trees were killed and canopy fuels were removed. Unit 31 which is the 81-acres unit located adjacent to the north of Unit 14 was burned on February 26, 2014. Field crews collected post-burn tree data in 32 CSE plots in Unit 14 and 31 in the fall of 2014 (Figure B2). In addition to the plot data, small areas of high and moderate severity were sketched onto plot maps (Figure B3). About 11 acres of high severity and 19 acres of moderate severity were outlined throughout the 220 acres of both units, with the majority of moderate severity and all of the high severity falling within Unit 14. Field data indicated that no immediate tree mortality occurred in Unit 31. In Unit 14 field data shows that tree mortality across the unit was 6.2%, which falls within burn plan objectives to limit mortality to 10%.

Table B2: Results of LTBMU analysis of post-burn conditions for Montreal units 14 and 31.

	Montreal14 (T/P/B)	**Montreal31 (T/P/B)**
N	20	12
Recent Mortality %	**6.9%**	**0.0%**
Recent Mortality TPA	6.0	0.0
Live TPA - post	81.0	88.0
Live BA - post	127.5	145.0
Snag - post	4.0	3.0

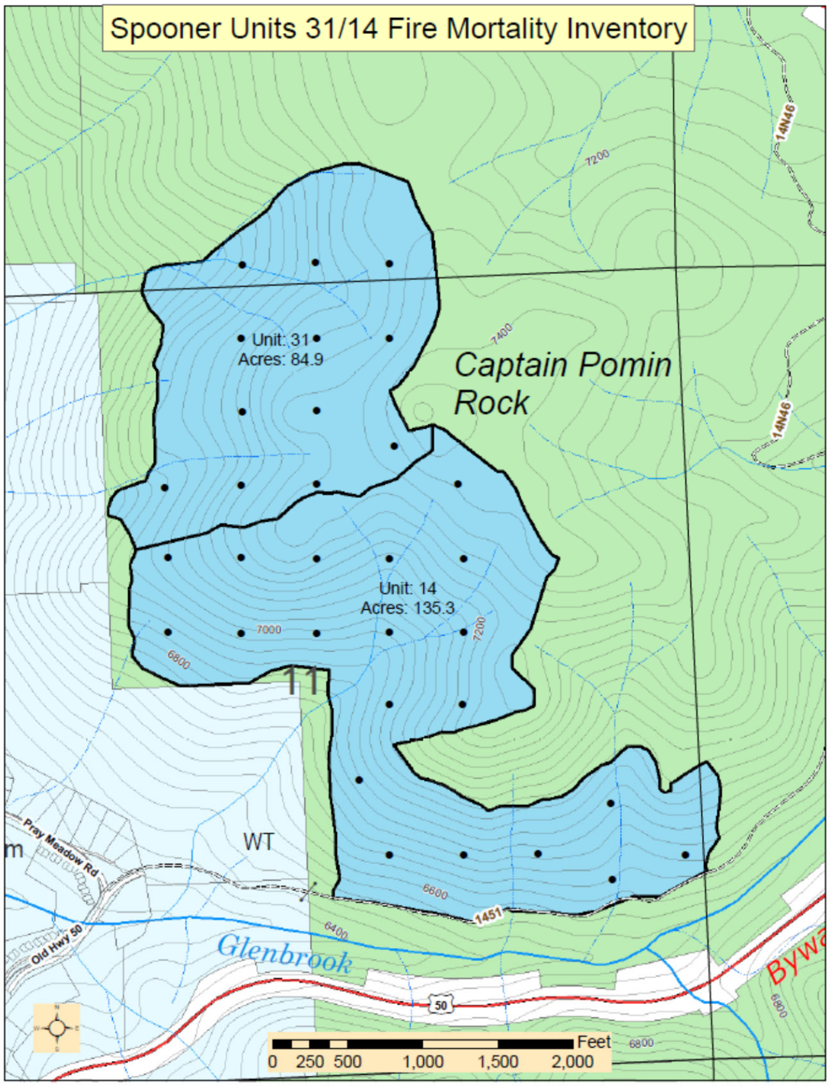


Figure B2. Map of post-burn field data plots established by LTBMU staff, for Montreal Units 14 and 31.

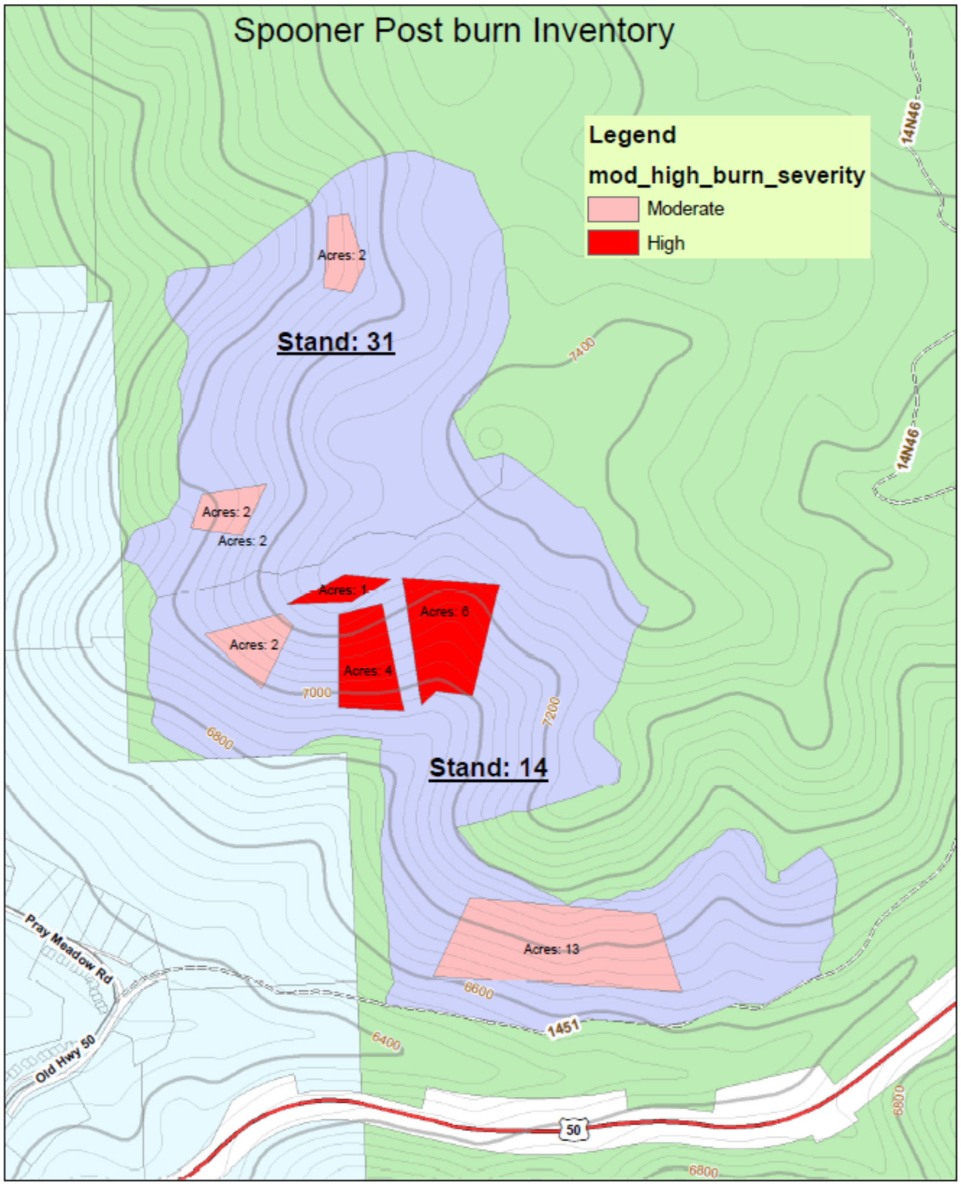


Figure B3. Map of post-burn field data plots established by LTBMU staff, for Montreal Units 14 and 31.

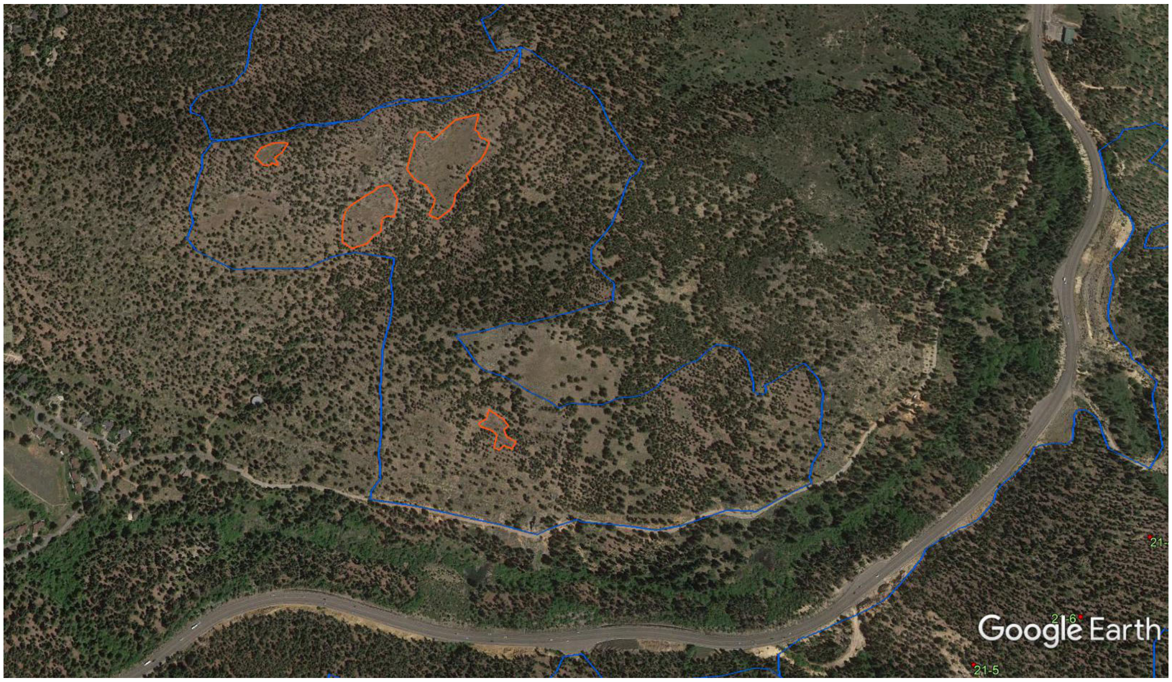


Figure B4: Polygons of elevated tree mortality ("high severity patches") in orange, located in Montreal Unit14, manually delineated in Google Earth based on visual interpretation. The polygons here range in size from 0.5 to 5.1 acres in size.

Appendix C: Treatment Units Summit 23 and 32, Burned Dec. 2014

Burn Units Summit 23 and 32 are located south of Highway 50, just East of Glenbrook (Figure C1). Unit 23 is 113 acres, and Unit 32 is 106 acres. The majority of Summit 32 was burned between Dec 5th and 9th, 2014. Unit 23 was burned Dec 11, 2014. These units consisted of even-aged-Jeffrey pine with some red fir, white fir and sugar pine. Much of the fir was dead or dying and created a continuous heavy fuel load throughout the stand. Live tree density was variable prior to the burn. Stand information for Unit 23 indicated 306 trees per acre (232 tpa of trees <12 and 7 tpa of trees >24) with a basal area of 166, canopy cover of 53% and 42 tons/acre of downed woody fuels.

The objectives of the treatments were to bring the stand into the desired conditions for WUI defense zones, which includes a fairly open stand, dominated by larger, fire tolerant trees, and to provide overall stand health and scenic quality. Surface and ladder fuels would be such that crown fire would be highly unlikely. The discontinuity of crown fuels, both horizontally and vertically would result in low probability of sustained crown fire. The prescription for Unit 23 was hand thinning, primarily of dead trees, and falling of all snags up to 20 inches in diameter. The piles in Unit 23 were made up of both existing down and dead fuels and the material cut for hand-thinning. This unit was hand-cut and piled in 2011. Unit 23 was lit before an early December storm. The unit was burned by lighting piles and allowing the fire to move between piles.

Although no on-site weather observations records were available for this Unit, it was noted that the winds for this unit were higher during the burn days. The closest and most representative RAWS, Knox, showed 1300 temperatures between 37 and 48° for the days Unit 32 was burned, and 35° the day Unit 23 was burned. Relative humidities recorded at the Knox RAWS were between 36 and 82% on the days which Unit 32 was burned, and were 78% the day Unit 23 was burned. Winds were recorded at 2 to 5 mph when Unit 32 was burned, and 12 mph when Unit 23 was burned. Weather observations from Unit 14 generally matched the Knox RAWS data, so it can be assumed the Knox RAWS data is approximately the weather which occurred at Units 32 and 23.

Immediate fire effects did not indicate the level of mortality which occurred several weeks after the burns in Units 23 and 32. During the fire there was little torching of canopy trees during the burns. Some of the surface fuels even remained in patches after the burn, indicating a patchy burn with relatively low fire effects to surface fuels, as well as understory and overstory vegetation. As Unit 23 is located on a north aspect, fuel moistures would likely be higher than on the Montreal 14 Unit, which was generally south-facing. However, several weeks after the burn, the needles on many of the trees in the Summit 23 Unit began showing injury with a color change to orange.

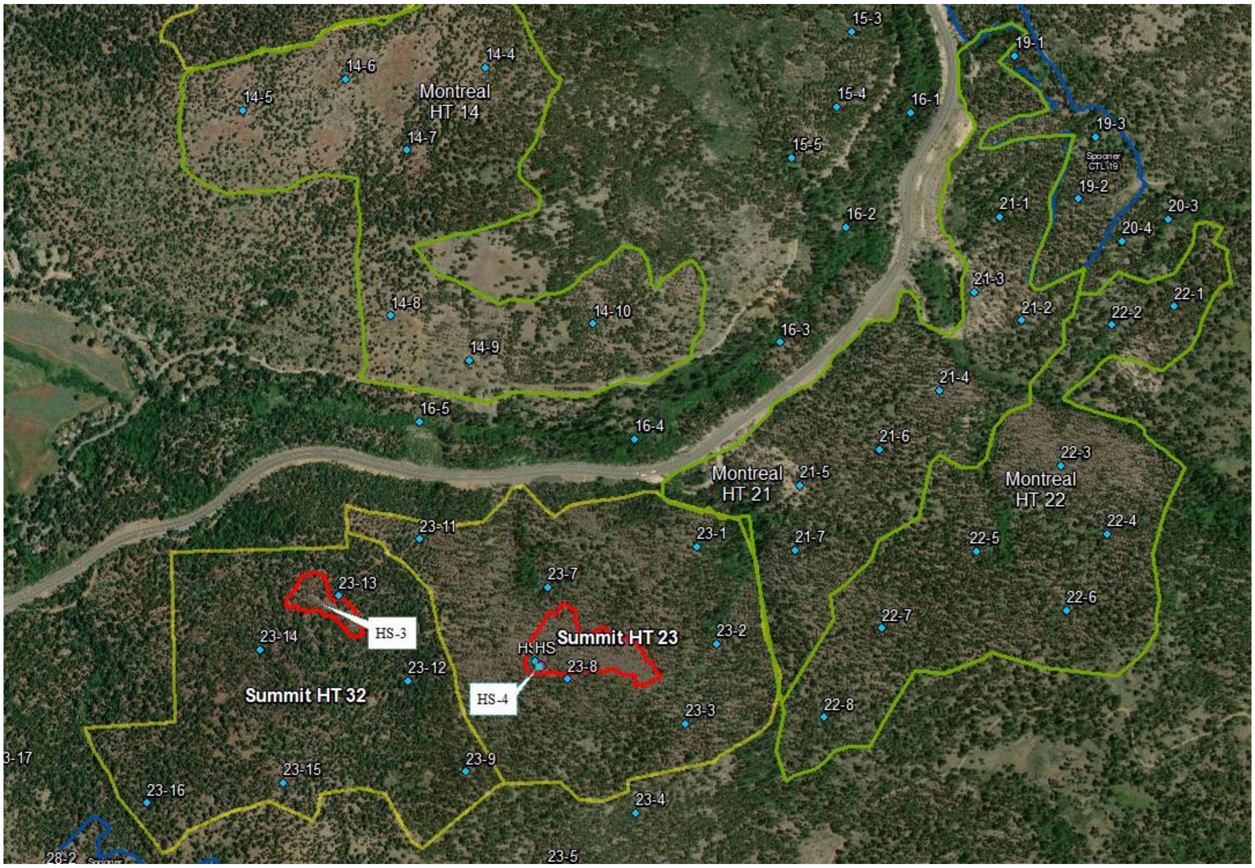


Figure C1: Polygons of higher tree mortality ("high severity patches") in red, located in Summit units 23 and 32, manually delineated in Google Earth based on visual interpretation. The polygons here range in size from 1.6 acres (in Summit 32) to 4.1 acres (Summit 23). Plots HS-3 and HS-4 were selectively located on the ground within the high severity patches in Summit 32 and 23 respectively, at locations which were deemed representative of high severity conditions in the patch.

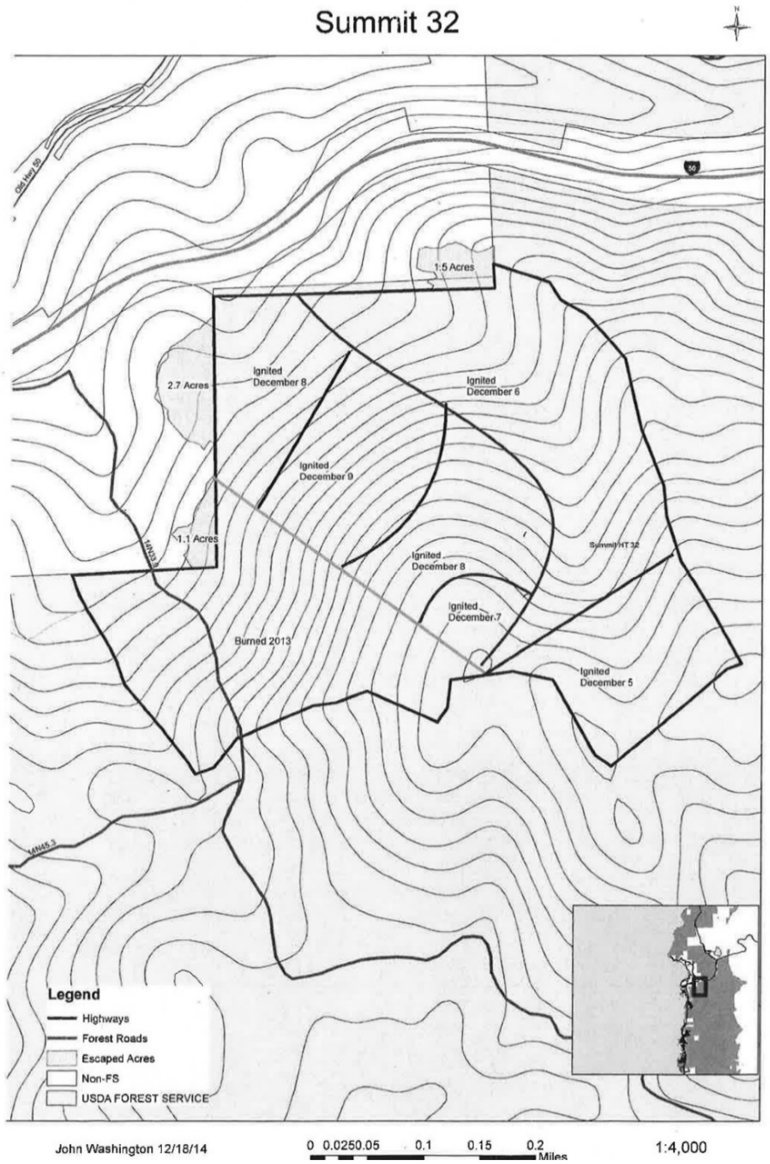


Figure C2. Dates for which portions of Summit 32 Unit was burned, December 5 through December 9, 2014.

Appendix D: The 2011-2017 Drought

Not long after ground work began on the Spooner Project, a period of extended drought began in the fall of 2011, and would last until spring 2017. The period from fall 2011 through 2014 would prove to be the driest on record for the state of California (Hanak et al 2015). A study utilizing various paleoclimate techniques describes 2014 as the most severe drought year in 1,200 years according to the Palmer Drought Sensitivity Index (Griffin and Anchukaitis, 2014). Temperatures that were well above average during this period exacerbated the impact of low precipitation (See Figure D2).

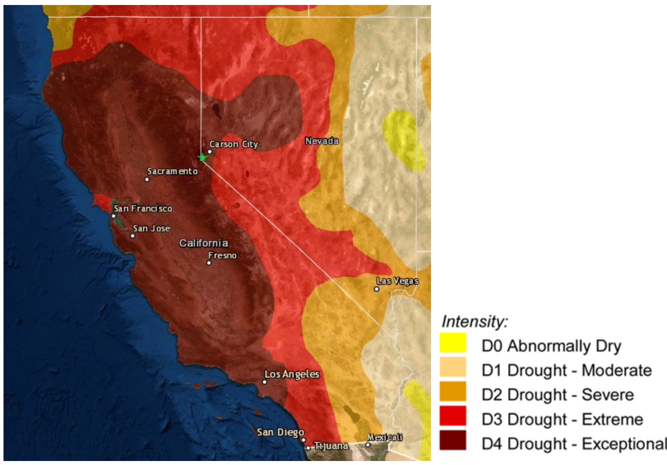


Figure D1: Drought map, showing the project area (green star), within area of drought classification D4. D4 = Exceptional, the highest drought intensity on a scale of 0 to 4. *Source: NOAA Modeling, Analysis, Predictions, and Projections Program.*

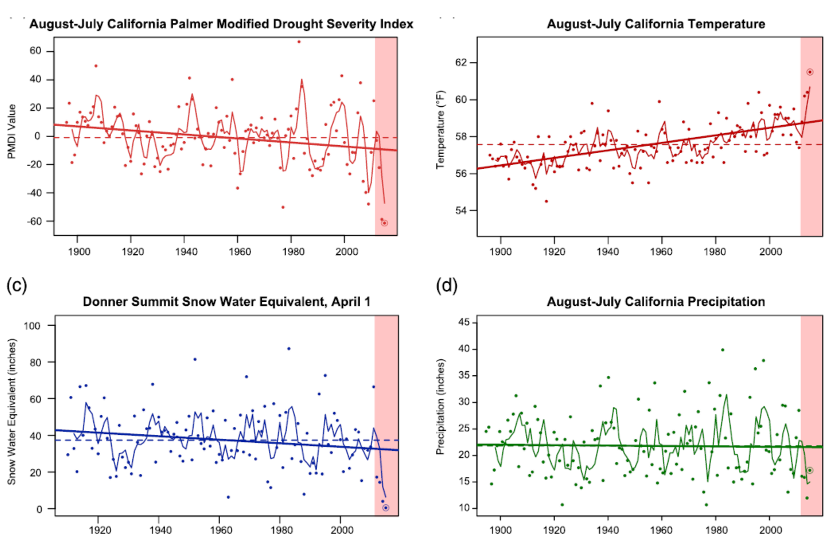


Figure D2: Various indices illustrating the severity of the drought. The area shaded red highlights the period from 2012 to 2015. Source of figure: Swain, 2015.

Soil Moisture

In response to drought conditions, soil moisture in the vicinity of the Spooner Project dropped to low levels. The water available to plants in the soil is a key to how trees are able to respond after prescribed fire during drought conditions. There are several forecasting tools and data repositories relevant to soil moisture available to plants. Despite historic or predicted data, land managers should take into account local soil types and terrain features. Aspects which receive more solar heating generally have lower soil moistures compared to those which have less solar heating. Granitic, volcanic, and meta-volcanic geologic formations found to the east side of the Lake Tahoe Basin, where the study sites are located, decompose into coarse grained, nutrient poor, loamy sands, with low soil water holding capacity. Drought stress is exacerbated in these sandy soils with low soil water holding capacity.

The Natural Resources Conservation Services warehouses data indicative of precipitation and soil moisture. The Snow telemetry data (SNOTEL) are collected and transmitted from SNOTEL stations and manual collection sites and are available on the NRCS website. Collection of soil moisture data from the Marlette Lake SNOTEL site began in 2003. This SNOTEL site is located approximately 5 miles to the north of the study site, at an elevation of 7,880 feet, where soil moisture data is recorded on a daily basis at depths of 2”, 8”, and 20”. The impact of the drought from fall 2011 through spring 2015 on soil moisture percent at all depths is evident (Figure D3).

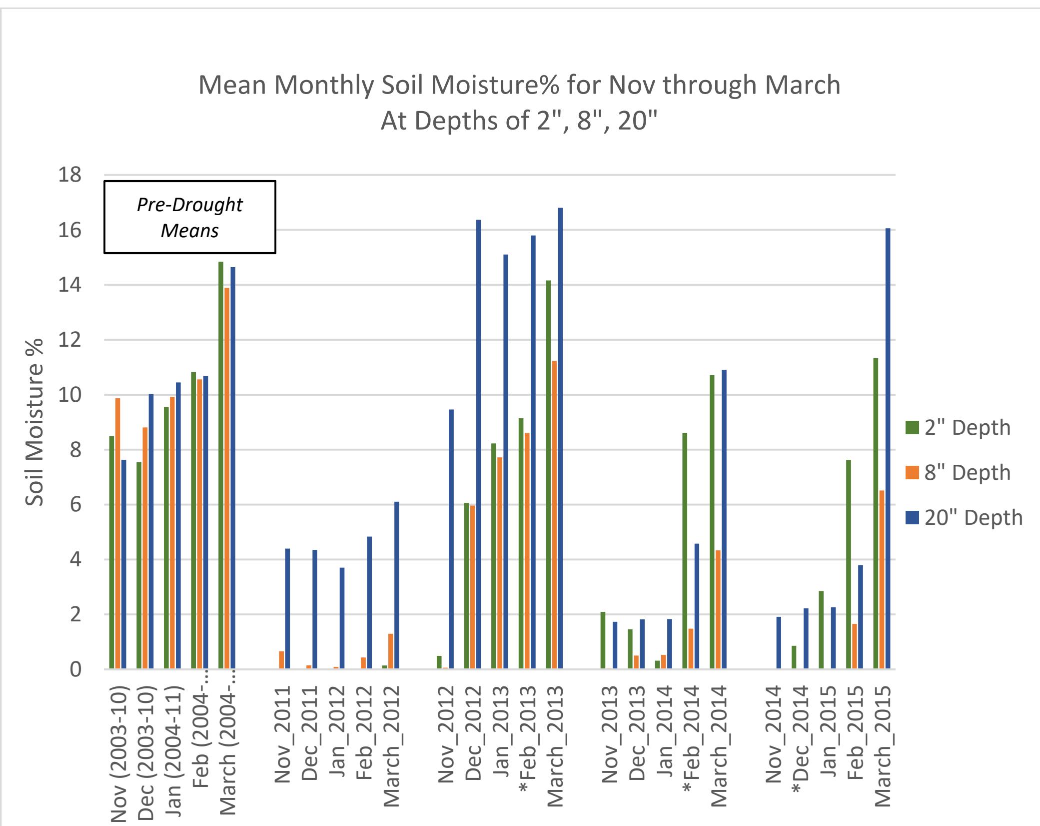


Figure D3: Soil moisture percent covering the months of November through March for the years 2003 to 2015. Data was averaged (mean) for the years preceding the drought. Data source is the NRCS SNOTEL site located at Marlette Lake, which is approximately 5 miles north of the study site. *Prescribed burning took place.

Local RAWS data

The Knox RAWS (remote automated weather station) was the closest and most representative RAWS for the Spooner treatments according to the burn boss (pers. comm. Kyle Jacobson). Data for the Knox RAWS goes back as far as July 2010.

Estimates of 1000-hour fuel moistures calculated from RAWS weather data, which can approximate drought (Kline et al. 2015), show a wide range of moistures for the 6 years between 2010 and 2016. In the winter months fuel moistures range from the 30's down to about 8%. During the late summer and early fall, these moistures range from 6 to 10%. Note that the 2014 overlay line matches the maximum for November and December, meaning that moistures were higher in the fall of 2015, and the same pattern shows for months January through May of 2013, where this year and season often had the highest moistures. They years of 2013, 2014 and 2015 had some of the lowest 1000-hour moistures of this 6-year period and track the minimum line in the graph (February-April 2015, June-July 2014, and parts of 2014 and 2015 in fall and early winter). Note that a month before and several months after the burn date of 2/19/2013, 1000-hour moistures at the Knox RAWS are close to the highest of the period 2010-2016; indicating lower levels of drought stress. Note that the fall prior to the burns of Dec 2014, 1000-hour moistures oscillated between average and low for the 2010-2015 period, however, from mid-February almost through the end of April 2015, 1000-hour moistures were at their lowest for the period (Figure D4), indicating very little moisture available for trees to recover from burning.

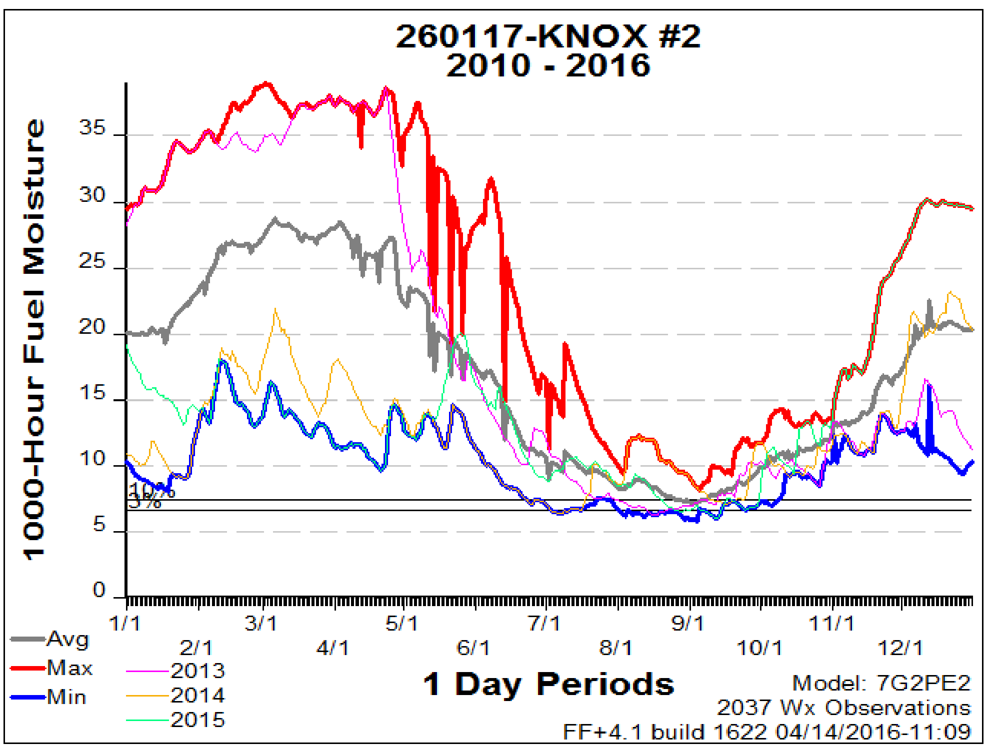


Figure D4. 1000-hour fuel moisture maximum, minimum and average for July 2010 to April 2016 with overlays of the years 2013, 2014, and 2015, Knox#2 RAWS.

Appendix E: LTBMU Spooner Monitoring Protocol

June 16, 2018 – Scott Dailey

Plot Data

The following general plot measures are taken for each plot:

Plot Data Form Requirements	
Required Fields	**Comments**
Region	05
Proclaimed Forest	Mendocino = 08
District	n/a
Project Name	Spooner
Unit#	Enter the unit number
Plot Number	Enter the plot number
Examiner	Enter initials of examiner
Date	Enter date
TimeIn	Enter time when plot was started
TimeOut	Enter time when plot was completed
GPS Projection	Enter GPS projection
UTM Easting	Enter UTM from the Garmin
UTM Northing	Enter UTM from the Garmin
Elevation	Enter elevation in meters from Garmin
Aspect	Enter aspect in degrees
Slope%	Enter slope in percent
Slope Horizontal Shape Slope Vertical Shape	BR: Broken, CC: Concave, CV: Convex, LL: Linear/Planar, PA: Patterned, UN: Undulating, UA: Unable to Assess. See Cheatsheet.
Slope Position	SU: Summit/Ridgetop, SH: Shoulder, BS: Backslope, FS: Footslope, TS: Toeslope, VB: Valley Bottom. See Cheatsheet.
Capable Growing Area	Enter the capable growing area, the % of the plot area capable of growing vegetation.
Scott Burgan	Record Scott/Burgan fuel model for the plot. Choose majority level.
Existing Vegetation	List the top three overstory species in order of dominance of the plot not the stand.
Plot History 1 Plot History 2	See Cheatsheet.
Fire Severity	Enter fire severity classification for each plot. Pre-treatment should all be Not Burned.
Notes	

Plot Photos

At each plot, take one photo looking due North, due East, due South, and due West. Record the Unit-Plot number and direction for each. A photo of the plot number will precede the photos so that they can be easily renamed in the office. Photos should be renamed as follows: Plot number (for each photo) followed by: N (For North), E (for East), S (for South), and W (for West).

Witness Trees

- Use aluminum nails to tag the bole of three witness trees with tree tags. Witness trees should be chosen based on maximum triangulation, tree size, and nearness to plot center. These trees should have an unobstructed “pull” to the plot center at the base of the stake. If down logs, rocks, and woody debris prevent a good “pull” to the plot center, find a different tree, even utilizing a larger sapling or other permanent landmarks (rock face with a crack a nail could be wedged into). Tree tags should face plot center.
- Record the tree tag number for each tree and its corresponding distance and azimuth on the datasheet. Distance should be to the nearest 0.1m. The azimuth should be from the nail head back to plot center.
- Be sure to note which trees are witness trees in Tree Data.

Ground Cover: (1/20th acre plot)

Estimate ground cover (below vegetation) that will add to 100%. Ground cover categories include: bare ground, rock, woody debris split into fine woody debris and coarse woody debris, litter, basal vegetation, dead basal vegetation, cryptograms, and other. For a 1/20th acre plot, about 4 m sq is equal to 2% cover.

Vegetation Cover (1/20th acre plot)

- Life Form, Canopy Cover (%), Modal Height.
- Enter the plot #
- Estimate % cover (to nearest 5%) of the total plot and modal height (in meters) (to the nearest 0.1) for the all vegetation categories. For the 1/20th acre plots, about 4 m sq is equal to 2% cover.
- “Total vegetation” is the cover of living vegetation as a % of the plot when viewed from an airplane/satellite
- “Total tree”, “tree ≥ 15cm DBH” and “tree <15cm DBH” refer only to live trees. Adding TOV and TSA together will probably give a value higher then TOT, due to crown overlap
- Under “shrubs”, all measures refer only to live shrubs. As above, adding ST, SM, and SL together will usually give a value > than TOS, due to crown overlap
- Modal height is the most common height, which is not always the average
- Graminoids include grasses, sedges, and rushes; forbs include any other vascular plant without significant woody tissue.

Vegetation Cover	
Required Fields	**Comments**
Unit	Enter the unit number
Plot Number	Enter the plot number
Total Vegetation (TV)	Cover percent, modal height (m)
Total Tree (TOT)	Cover percent, modal height (m)
Tree Overstory (TOV)	Trees≥ 15cm DBH. Cover percent, modal height (m)
Tree Saplings (TSA)	Trees<15cm DBH. Cover percent, modal height (m)
Total Shrubs (TOS)	Cover percent, modal height (m)
Tall Shrubs (ST)	Shrubs >1.86m tall. Cover percent, modal height (m)
Medium Shrubs (SM)	Shrubs 0.46m-1.86m tall. Cover percent, modal height (m)
Low Shrubs (SL)	Shrubs <0.46m tall. Cover percent, modal height (m)
Forbs (FB)	Cover percent, modal height (cm)
Graminoids (GR)	Cover percent, modal height (cm)
Notes	

Species Composition (1/20th acre plot)

- Enter the unit and plot number.
- Enter the species lifeform (Tree, Shrub, Forb, Graminoid)
- Start with all of the tree species, then do the shrub species, forb, and graminoid.
- Enter the layer code of the plants you are measuring (TOV, TSA, ST, SM, SL, FB, GR).
- Enter the 4 letter species code and record percent cover (live only) to nearest 1% for each layer.

Regeneration Seedlings (1/100th acre plot)

- Enter the unit and plot number.
- Fixed radius plot; 1/100th of an acre (3.59m from plot center)
- Record all trees <1.37 m tall categorized into two classes as follows:
- Age class 0 is all cotyledons, seedlings in their first year.
- Tally the number of seedlings by species
- Record modal height for each species
- Age class 1 is any seedling older than 1 year.
- Tally the number of seedlings by species
- Record modal height for each species
- Measure last year's growth (cm) for the tallest individual seedling of each species

<u>Tree Data:</u> (1/20th acre plot)

Saplings and Trees: fixed radius plot; 1/20th acre (8.03 m from plot center). Record all live and dead trees. Use a dbh cutoff of 7.5 cm DBH and1.37 m tall. This means that within the 1/20th acre plot, all live and dead trees at or above 7.5 cm DBH and 1.37 m tall will be individually measured.

Fire effects measures (char, scorch, and torch heights)

Measure is taken of max height to the nearest 0.1m. Please take these measures if possible. It's very likely that too much time has passed since the burn treatment to differentiate between scorch and torch (scorched needles likely to have fallen off). Please make note if it is apparent that scorch had occurred, but dead needles have fallen away. In this case, enter no measure for scorch height, but only torch height.

Tree/Sapling Data Form	
Required Fields	**Comments**
Project Name	Spooner Fuel Treatment Monitoring
Stand Number	Unit ##
Plot Number	##
Tree Number	Start at North end of plot and begin with 1 for tree number.
Species	(4 letter code, ie: PIPO, PIJE, ABCO, etc)
Tree Status	(L= Live, D = Dead, I= Infested but green crown (look for fresh pitch and signs of frass), M= Marginal crown (partially red for Pine and >50% red for CADE), D1= Dead & most needles retained, D2= Dead, most needles lost, D3= Snag decay class 2-5.
DBH	DBH for all Large and Pole sized trees to nearest cm, including snags
Snag Decay	Snag decay is only required for standing dead trees.
Height	Height of every Large and Pole size Tree, including snags, to nearest 0.1m
Height to Live Crown	For all large trees, to nearest 0.1 meter.
Crown Ratio	Crown ratio (%) is only required for live large trees
Crown Class	For all live trees. See table
Insects/Damage	See Insect and Damage codes below
Evidence of Insects	Yes/No
Level of Attack	0: no hits. Frass, or exit. 1: <5 hits, limited frass and exit holes. 2: >5 hits, exit holes and frass; or pitch tubes
Timing of Attack	Is the tree under attack currently? Fresh pitch from pitch tubes?
Health Code	See Table.
Char Height	Max height to nearest 0.1m, for all Large and Pole sized trees
Scorch Height	Max height to nearest 0.1m, for all Large and Pole sized trees
Torch Height	Max height to nearest 0.1m, for all Large and Pole sized trees
Witness Tree	Record witness tree tag number if applicable

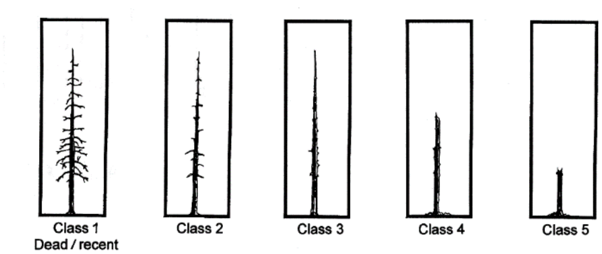
Crown Class Categories

Code	Name	Description
OP	Open-grown or Isolated	Tree crowns receive full light from above and from all sides. In even-aged stands, these trees have their crowns well above the general canopy.
DO	Dominant	Tree crowns receive full light from above and partly on the sides. Crowns extend above the general level of the crown cover of others of the same stratum and are not physically restricted from above, although possibly somewhat crowded by other trees on the sides. In even-aged stands, dominant trees rise somewhat above the general canopy.
CO	Codominant	Tree crowns receive full light from above, but comparatively little from the sides. Crowns form a general level of crown stratum, are not physically restricted from above and are crowded by other trees from the sides. In even-aged stands, codominants form the general canopy.
IN	Intermediate	Tree crowns occupy a definitely subordinate position and are subject to strong lateral competition from crowns of dominants and codominants. They receive little direct light from above through small holes in the canopy, but no light from the sides.
OV	Overtopped	Tree crowns receive no light from above or from the sides and are entirely below the general level of dominant and codominant trees.

Snag decay codes and descriptions

Code	Bark	Heartwood Decay	Sapwood Decay	Limbs	Top Breakage	Bole Form	Time Since Death
1*	Tight, intact	Minor	None to incipient	Mostly present	May be present	Intact	≤5 years
2	50% loose or missing	None to advanced	None to incipient	Small limbs missing	May be present	Intact	>5 years
3	75% missing	Incipient to advanced	None to 25%	Few remain	Approx. 1/3	Mostly intact	>5 years
4	75% missing	Incipient to advanced	25%+	Few remain	Approx. 1/3 to 1/2	Losing form, soft	>5 years
5	75%+ missing	Advanced to crumbly	50%+ advanced	Absent	Approx. 1/2+	Form mostly lost	>5 years

* Implies recent mortality, within the last 5 years



Evidence of Insects, other Damage:

- Evidence of insects
- Level of insect attack:

  0 = no hits or signs of frass or exit holes

  1 = fewer than 5 hits on bole, limited signs of frass and exit holes

  2 = more than 5 hits on bole, often with many exit holes and frass; or only handful of pitch tubes, but with additional signs of beetle (lots of frass and exit holes)

- Timing of insect attack: Fresh Pitch from pitch tubes (focused on beetle attack signs to understand if the tree is under attack currently)
  - Y = Yes
  - N = No
- Record health code based on the codes provided on the data sheet. Ignore pitching on the bole of the tree unless it has extensive coverage on the bole. Tree health codes include:
  - A = White pine blister rust aecia
  - D = Dead top
  - S = Split top
  - C = Catface
  - M = Mistletoe
  - A = Dwarf mistletoe (*Arceuthobium* sp.)
  - P = Extensive pitching on bole of tree
  - T = Red turpentine beetle – for status L and I (this will help to identify trees maybe susceptible in future)
- Other issue – Insert code from Other Damage Categories below

Other Damage Categories

Code	
10	General Insects
11	Bark Beetles
12	Defoliators
13	Chewing Insects
14	Sucking Insects
15	Boring Insects
16	Seed/Cone/Flower/Fruit Insects
17	Gallmaker Insects
18	Insect Predators
19	General Diseases
20	Biotic Damage
21	Root/Butt diseases
22	Stem Decays/Cankers
23	Parasitic/Epiphytic Plants
24	Decline Complexes/Dieback/Wilts
25	Foliage Diseases
26	Stem Rusts
27	Broom Rusts
30	Fire
40	Animal damage, source unknown
41	Wild animals
42	Domestic Animals
50	Abiotic Damage
60	Competition
70	Human Activities
71	Harvest

80	Multi-Damage (Insect-Disease)
90	Unknown
99	Physical Effects

Down Woody Material:

- Enter the unit and plot #
- Fuels data will be collected from four Brown's Transects (J.K. Brown. 1974. Handbook for inventorying downed woody material. USDA Forest Service Intermountain Research Station General Technical Report INT-16). The fuels transects are laid out at the cardinal directions, stretching from the plot center to 8m. The ends of the transects are the starting points, i.e. they are read starting from "0m" at the outer edge of the plot, heading towards the middle.
- Enter the azimuth of the transect. Since they will be in the cardinal directions, it is OK to write, N, S, E, or W for the four different transects, rather than putting the azimuth in degrees, but if you have to diverge from the cardinal directions, then write in the azimuth in degrees. There will be four transects with the same plot number
- Use a go/no go gauge to record the following on a section along each of the four 8m transects.
- The number of 1-hr fuels (<0.64 cm) that intersect the transect between the 3.0 and 5.0 m mark.
- The number of 10-hr fuels (0.64-2.54 cm) between the 3.0 and 5.0 m marks
- The number of 100-hr fuels (2.54-7.62 cm) between the 3.0 and 6.0 m marks
- Measure litter and duff depths at 3 locations. 1st measure taken at starting point (0m), 2nd measure at 3.8m, and 3rd measure at 7.6m.
- Measure fuel depth at 3 points along each of 4 transects, at 0m, 3.8m, and 7.6m.
- Course woody debris $\geq$7.62cm (3") is tallied within a fixed 1/20th acre plot, radius (8.03m).

Down Woody Material	
Required Fields	**Comments**
Region	
Forest	
District	
Project	
Stand#	
Plot#	
1st Duff	Measure duff to nearest cm at 0m mark on transect
1st Litter	Measure litter to nearest cm at 0m mark on transect
1st Fuel depth	Measure fuel depth to nearest cm at 0m mark on transect
2nd Duff	Measure duff to nearest cm at 3.8m mark on transect
2nd Litter	Measure litter to nearest cm at 3.8m mark on transect
2nd Fuel depth	Measure fuel depth to nearest cm at 3.8m mark on transect
3rd Duff	Measure duff depth to nearest cm at 7.6m mark on transect
3rd Litter	Measure litter depth to nearest cm at 7.6m mark on transect
3rd Fuel depth	Measure fuel depth to nearest cm at 7.6m mark on transect
1hr fuel	Tally for each of 4 transects, 1hr fuels
10hr fuel	Tally for each of 4 transects, 10hr fuels
100hr fuel	Tally for each of 4 transects, 100hr fuels

1,000hr fuel (CWD)	Tally of 1000hr fuel, course woody debris (CWD)
Decay Class	Average decay of CWD. Use code 1 thru 5
Diameter	Ave diameter (nearest cm)
Diam Lg. End	Ave large end diameter (nearest cm)
Diam Sm. End	Ave small end diameter (nearest cm)
Piece Length	Ave log length (nearest 0.1m)

Litter and Duff

Record the duff, in cm, to the nearest cm. Duff is the fermentation and humus layers of the forest floor. It does not include the freshly cast material in the litter layer. The top of the duff is where needles, leaves, and other castoff vegetative material have noticeably begun to decompose. Individual particles usually will be bound by fungal mycelium. When moss is present, the top of the duff is just below the green potion of the moss. The bottom of the duff layer is the start of the mineral soil.

Carefully expose a profile of the forest floor for the measurement. A knife or hatchet helps but is not essential. Avoid compacting or loosening the duff where the depth is measured.
When stumps, logs, and trees occur at the plot of measurement, offset one 0.5m perpendicular to the right of the sampling plane. Measure through rotten logs when the central axis is in the duff layer.

Fuel Depth (maximum of 2 numbers; may include one decimal)

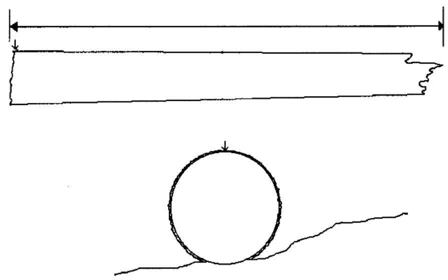
This is the total vertical dead fuel depth, in cm, to the nearest whole cm. Take three equally spaced measurements, along the transect, and record. The fuel bed is the accumulation of dead, woody residue on the forest floor. It begins at the top of the duff layer and includes litter, dead branches, and boles from trees, and dead material from shrubs, herbs, and grasses. Dead branches on trees, and dead stems and branches still attached to the ground (i.e. standing dead plants) are not included. Measure (to the nearest cm) from the top of the duff layer to the highest dead particle above the point. On suspended logs, (e.g. spanning a ravine) enter the distance between the top of the duff layer and the top of the log.

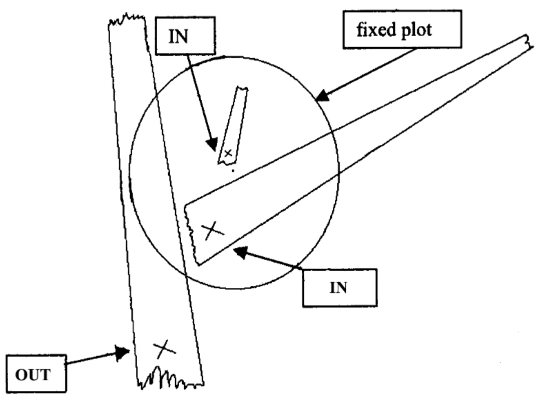
Course Woody Debris

Course woody debris is measured in a fixed area plot. This fixed area plot area is 1/20th acre, 8.03m diameter from plot center, the same as the Large Tree fixed plot.

Piece Count on a Fixed Area Plot

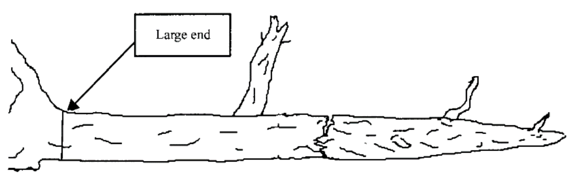
When collecting down woody data on a fixed area plot, the piece is tallied if the point on the upper most surface of the cylinder, the large end, is within the fixed area plot.





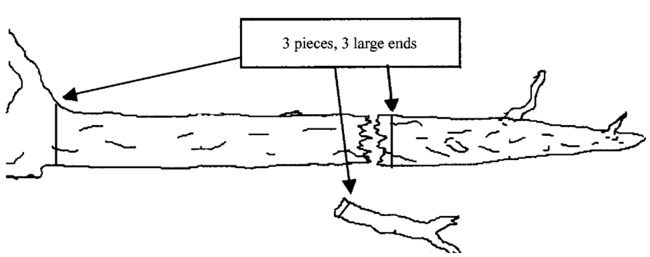
Position of large end of piece on the plot determines tally.

A down log may be broken into more than one piece. If a log is cracked, broken, or partially cut, but the two parts are still physically touching, then the log shall be considered one piece.

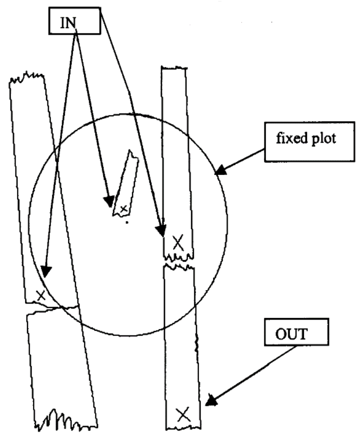


Large end on a one-piece log.

If the two or more parts are not physically touching, then they are considered separate pieces, each having their own large end. This may affect whether all parts of the down log are within the fixed radius plot.



Broken pieces not touching are measured separately.



Broken pieces have separate large ends that can affect which pieces are tallied

Log Decay Class

Code	Bark	Twigs	Texture	Shape	Wood Color	Portion of log on ground
1	Intact	Present	Intact	Round	Original	None, elevated on supporting points
2	Intact	Absent	Intact to soft	Round	Original	Parts touch, still elevated, sagging slightly
3	Trace	Absent	Hard large pieces	Round	Original to faded	Bole on ground
4	Absent	Absent	Soft blocky pieces	Round to oval	Light brown to faded brown	Partially below ground
5	Absent	Absent	Soft, powdery	Oval	Faded light yellow or gray	Mostly below ground