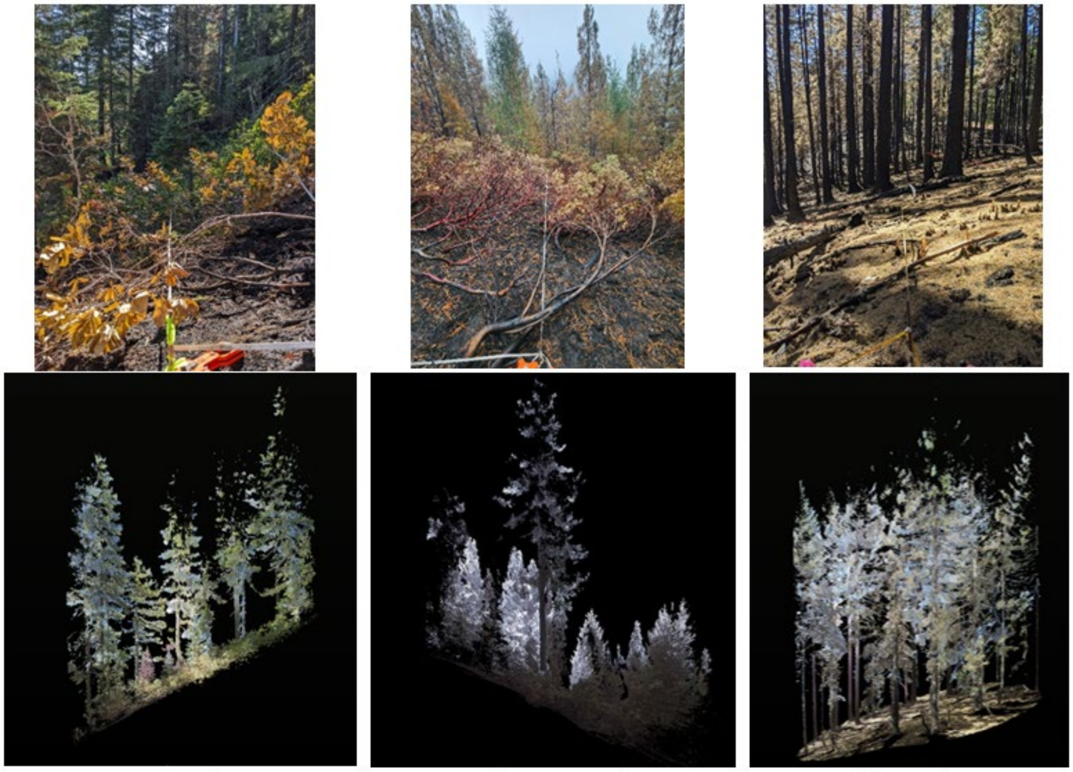
Fuels and vegetation in burned and unburned plots in mapped Humboldt marten habitat – 2023 Mosquito Fire, Six Rivers National Forest

15 April 2024



Low Severity
Plot 4
Plot 4 TLS

Moderate Severity
Plot 5
Plot 5 TLS

High Severity
Plot 11
Plot 11 TLS

Plot photos and Terrestrial Lidar Scans for low, moderate, and high severity plots.

Prepared by the

Fire Behavior Assessment Team (FBAT)

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Summary

The Mosquito Fire ignited on Thursday August 17th, 2023, and, with other nearby fires, was managed as the 2023 Six Rivers Lightning Complex. The Fire Behavior Assessment Team (FBAT) started monitoring on the Mosquito Fire on Wednesday September 27th, 2023. Study plots were located within GIS polygons designated as containing Physical or Biological Features that would support breeding, denning, resting, or foraging (hereafter called PBF 1 habitat) by the Humboldt marten. The objectives included assessing the range of variability in shrub and overstory vegetation across polygons mapped as PBF 1 Humboldt marten habitat and to get a rough assessment of effects of the strategic firing operation by comparing paired burned and unburned plots. Paired plots were primarily in closed and moderately open conifer-dominated stands with moderate to high shrub cover at elevations between 3750-4350 ft. In addition, a set pf four plots were established in stands with a significant hardwood component at lower elevations (2200-3200 ft) in anticipation of continued firing that, ultimately, did not occur.

Key findings and conclusions:

- The range of variability in shrub and tree conditions on unburned sites mapped as PBF 1 Humboldt marten habitat was large. Shrub cover ranged from 0% to 98% and average tree diameter ranged from 4 to 27 in. Tree species composition ranged from hardwood to conifer dominated and canopy cover ranged from an 10% to 85%. The range of variability in large, downed woody material (1000 hr fuels) was also large, ranging from 0 to 52 tons/acre. Given the large variability in fuels and vegetation within mapped PBF 1 habitat, FBAT should consider focusing objectives in future assignments on key features of PBF 1 habitat (e.g., high shrub cover, cavity trees, large downed logs) and how those objectives can best intersect with other information objectives under discussion with the Karuk DNR and national forests in northern California.
- Plot sampling around the perimeter of the strategic firing operation (burned Plots 2, 4, 5, 7, 9, 11, and 17 and paired unburned Plots 1, 3, 6, 8, 10, 12, and 18) showed a 58% reduction in ground and surface fuels and mixed fire effects. For burned plots, ground (duff) and surface fuels (1-hr, 10-hr, 100-hr, 1000-hr, litter, grasses, and shrubs) averaged 27 tons/acre while ground and surface fuels on paired, unburned plots averaged 62 tons/acre. Fire spread in the burned area is highly unlikely until fuels recover. Fire effects ranged from 2-29 ft bole charring, 0-96% canopy scorch, and 0-9% crown consumption (torch) while the soil substrate and understory vegetation were predominantly lightly burned. An initial severity map derived from remote sensing and provided in this report suggests that effects of strategic firing in the interior of the footprint will be similar to those we measured in plots around the perimeter.
- Terrestrial Laser Scanning (TLS) data processed with the Interagency Ecosystem Lidar Monitoring (IntELiMon) software (https://dmsdata.cr.usgs.gov/lidar-monitoring/data-processing) produced similar results to our field measurement methods in metrics related to overstory trees, particularly mean tree height, tree density (count), and basal area (except for one outlier). Using TLS as a field sampling method holds promise but will require a concerted development effort by the larger community of users and funders. Key needs are calibration data and improved processing for surface fuel and understory vegetation assessment. A national effort is on-going to address these issues (e.g., https://www.fs.usda.gov/research/nrs/projects/tls).

A primary value of the plots, and others that FBAT plans to install in future fires, will be their use for long-term monitoring of marten habitat recovery after fire, particularly the shrub vegetation. The typical FBAT approach is to conduct pre-fire fuels and vegetation, active-fire behavior, and fire effects monitoring on the same plots, an objective that was not possible to meet on this occasion. Plots were not well distributed across landscape positions. Plots were located primarily along ridges and missed topographically wet and productive areas with old-growth character and the greatest expected resistance to fire spread and severe effects under both current and future climactic conditions.

Contributors

Matthew B. Dickinson (USFS, Northern Research Station)
Brian Stearns (USFS, Huron-Manistee National Forest)
Alex Miyagishima (USFS, Six Rivers National Forest)
Matt Biggs (NPS, Yosemite National Park)
Josh Boeder (BLM, Eastern Montana/Dakotas District)
Jason Cole (USFS, Northern Research Station)
Lanny Flaherty (USFS, Wallowa-Whitman National Forest)
Lily Bunis-Haines (NPS, Yosemite National Park)
Ben Nash (USFS, HJ Andrews Experimental Forest)
Alan Petukh (USFS, Northern Research Station)
Paige Quinn (USFS, Six Rivers National Forest)
Theresa Schaffner (NPS, Yosemite National Park)
Marissa Vossmer (BLM, Arcata Field Office)
Megan Shea Ward (USFS, Six Rivers National Forest)
Reed Williams (USFS, McCall Smokejumpers)
Silas Yamamoto (Mid Klamath Watershed Council)

Introduction

FBAT first worked in northern California in 2006 and has recently renewed focus on the region with support from a CAL FIRE grant. Currently, FBAT is developing monitoring objectives in consultation with the Six Rivers (SRF) and Klamath National Forests, the Karuk Tribe Department of Natural Resources (KTDNR), and the Mid-Klamath Watershed Council. FBAT established monitoring plots in northern spotted owl activity centers in 2022, focusing on landscape positions rated as having a high likelihood of being “climate refugia” where fire spread potential would be lower and ecological effects reduced during 90th percentile fire conditions (FBAT 2022). In 2023, FBAT pursued monitoring in Humboldt marten habitat in the Klamath Mountains, the marten having been determined to be a coastal Distinct Population Segment of the western marten and listed as threatened by the USFWS in 2020 (USFWS 2021). Habitat maps produced through collaboration between the USFS and KTDNR and other partners served to guide plot siting. FBAT established plots in sites mapped as Physical or Biological Feature 1 (PBF 1) within and just outside the footprint of the Mosquito Fire (Figure 1). PBF 1 sites would provide conditions suitable for breeding, denning, resting, and foraging. To meet those criteria, stands would have: 1) A mature, conifer-dominated overstory on either low (e.g., serpentine) or high productivity sites; 2) A dense and spatially extensive shrub layer; and 3) Structural features that support denning or resting whether rock piles, large downed logs, or snags and live trees with decay elements (e.g., cavities) or resting structures (e.g., broken tops). On productive sites, old growth or late-mature seral stands best meet criteria. Research habitat needs found that high likelihood of marten detection is associated with high precipitation, sites with old growth character, sites on serpentine geology, and sites with high shrub cover (Slauson et al. 2021).

FBAT began monitoring in mapped PBF 1 habitat on Wednesday, 27 September 2023, focusing on burned and unburned plots that offered relatively safe post-fire access. With some exceptions, burned and unburned plots were paired by proximity, aspect, and vegetation. Most pairs were in the area where strategic firing operations had been conducted. Two of the plots were in serpentine geology. Four unburned plots, not paired with burned sites, were hardwood dominated and established in anticipation of continued firing that, ultimately, did not occur. The value of the monitoring plots described in this report will grow as more plots are added in subsequent years and as the plots are re-visited to track shrub recovery. This report summarizes the results of FBAT's plot-based measurement of vegetation, fuel loading, and fire effects in PBF 1 habitat.

FBAT objectives on the Mosquito Fire were to:

1. Safely and efficiently maximize the number of burned and unburned plots inventoried for fuels, vegetation, and fire effects within mapped PBF 1 Humboldt marten habitat
2. Describe the range of variability in fuels and vegetation within PBF 1 habitat and compare burned and unburned stands, focusing particularly on shrub cover and the overstory
3. Assess the use of Terrestrial Laser Scanning (TLS) as a methods for increasing the efficiency of data collection and data quality
4. Continue a collaboration with the SRF and KTDNR to establish monitoring objectives for wildfire incidents in the Klamath Mountains
5. Continue to build the FBAT data archive to reflect a broad range of fuels, vegetation, treatment, and climatic conditions in support of fire and land management
6. Deliver a summary report to support land and fire managers, FBAT data archive users, and long-term plot monitoring

Figure 1. Overview Map – location of the 2023 Six Rivers Lightning Complex.

Progression and Trends in Fire Indices

The Pearch, Mosquito, Bluff #1, Blue Creek #2, Marlow and Copper fires ignited on Thursday August 17th, 2023, and were managed as the Six Rivers Lightning Complex. The Copper, Blue Creek #2, Bluff #1 fires were subsequently merged with the Mosquito Fire. Plots that FBAT sampled on the Mosquito Fire burned over three days in September. FBAT Plots burned between September 17 and 22nd, 2023. The progression map is provided in Figure 2. Burned Plots 2, 4, 5, 7, 9, 11, and 17 burned during strategic firing operations on the north side of the Mosquito Fire while Plot 19 was close to the main Mosquito Fire.

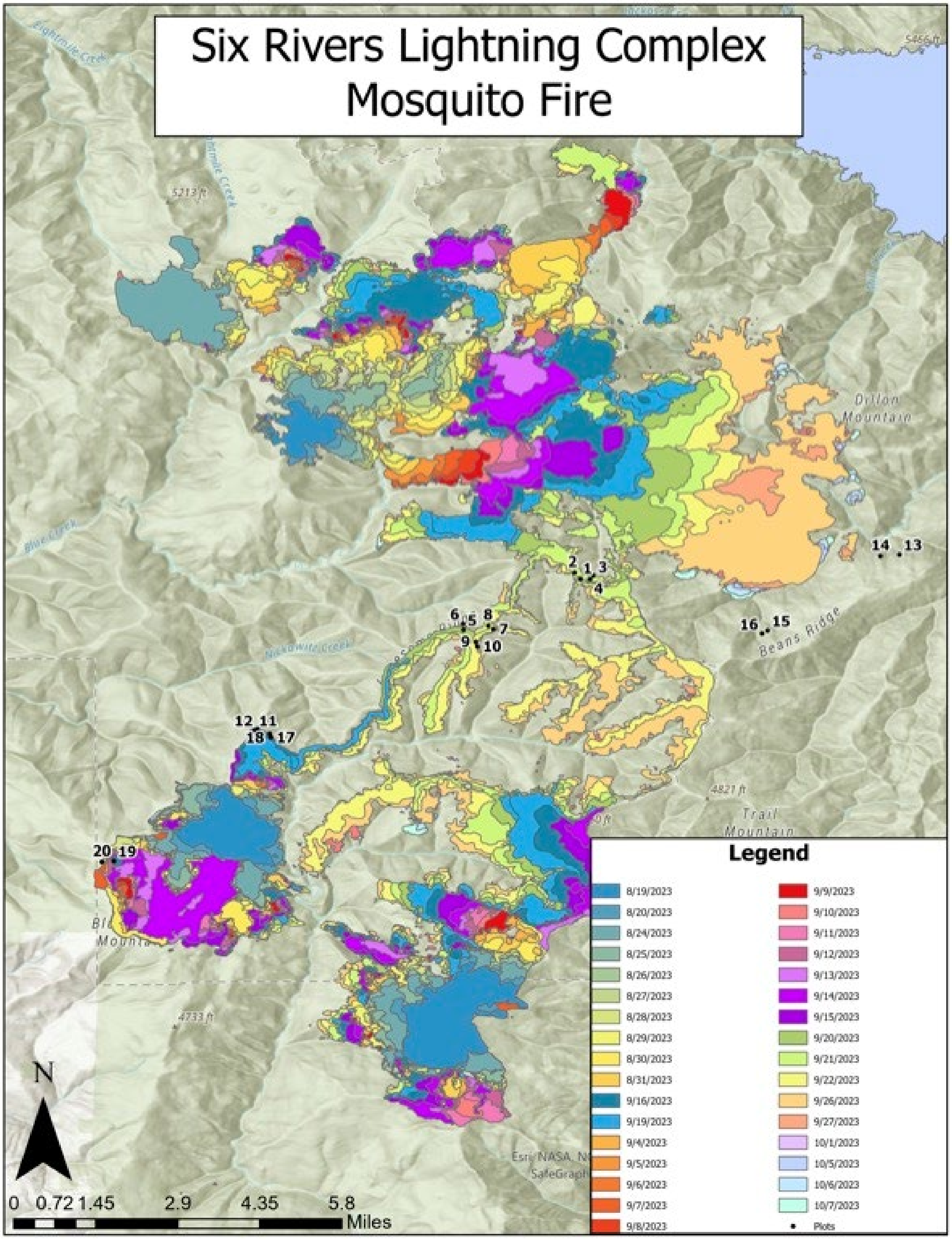


Figure 2. Progression map of the Mosquito Fire with FBAT plot locations. Updated through October 7th, 2023.

To provide a fire weather context for the fire and burn plots FBAT sampled, we plot fire weather indices (Figures 3-5). Energy Release Component (ERC) is a fire danger index used to describe potential fire energy release (related to fuel consumption and fire intensity) and resistance to suppression. ERC reflects the potential worst case, total available energy (BTUs) per unit area (in square feet) generated within the flaming front at the head of a fire. The ERC is a function of the fuel model and fuel moisture (live and dead). Fuel loading (determined by fuel model) and moisture content of large-diameter woody fuel have a higher influence on ERC, while the lighter fuels have less influence, and wind speed has none. ERC has low variability and is the best fire danger index for indicating overall seasonal severity potential. ERC2 x Wind reflects the compounding influence of dry fuels combined with wind. Fuels that are 10% drier will exhibit a 23% increase in fire behavior with the same windspeed. The Burning Period Index (BPI) estimates the potential difficulty of fire containment as it relates to the flame length at the head of the fire. Burn Period Index (BPI) = (Temperature ÷ Relative Humidity) x Windspeed.

BPI, ERC, and weather data was extracted from the Slate Creek Remote Access Weather Station (RAWS). The Slate Creek RAWS is located on the Six Rivers National Forest in Humboldt County (Station ID# 040430). The station is set on a ridge top near Slate Creek Butte, within the confluence of the Klamath River. The station was installed in November of 2010 and activated in June of 2011. Station receives low coastal influence, with moderate summer temperatures. The ground cover for the weather station is brush and mixed conifer.

The Burn Period Index (Figure 3), fire weather (Figure 4), and ERC (Figure 5) all relate as expected to the days of greatest fire growth except for the spikes in growth after the 19th of September. The spikes reflect the sum of burned area over several days during which requests for perimeter mapping were unable to be filled (UTF) and where strategic firing operations were conducted. The conditions for fire growth were not at their peak during this period but were suitable for firing operations.

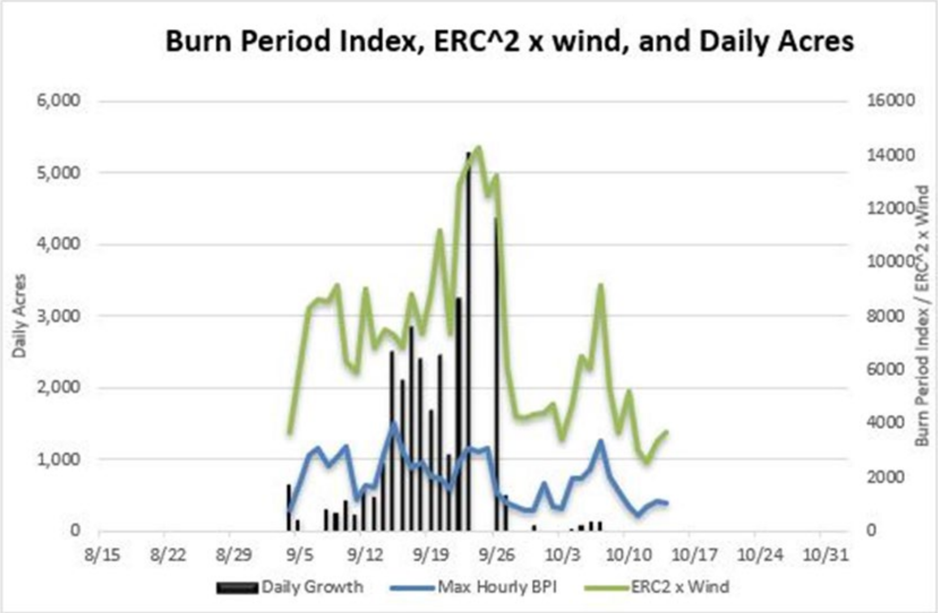


Figure 3. Fire growth relative to Burn period Index (BPI) and Energy Release Component (ERC) with wind (ERC^2 X wind speed - mph). Data collected from Slate Remote Automated Weather Station (RAWS). Daily growth references the entire acreage for the Six Rivers Lightning Complex.

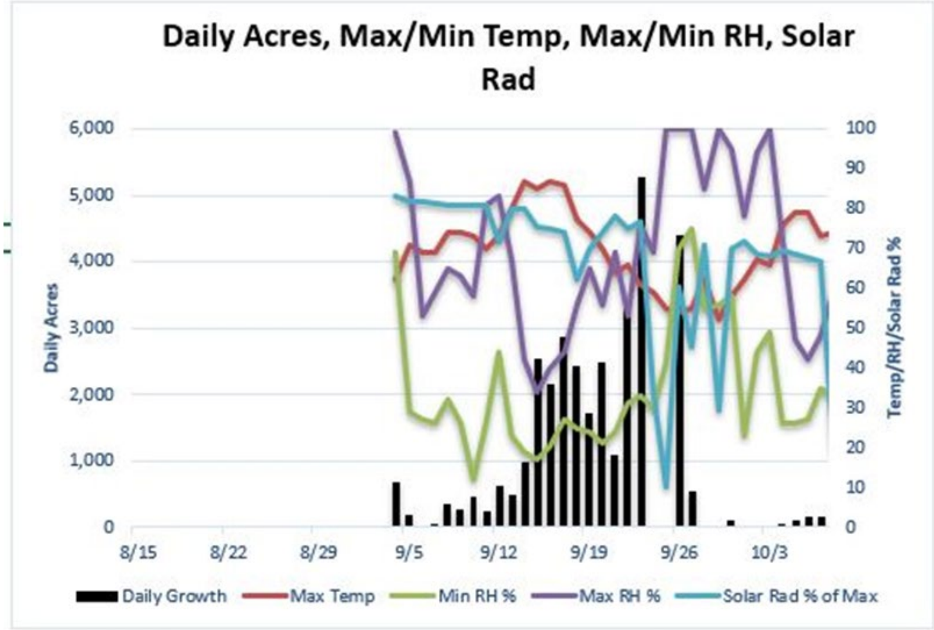


Figure 4. The graph depicts the daily fire growth relative to Temperature (ºf), Relative Humidity, and Solar Radiation. Data collected from the Slate RAWS. Daily growth references the entire acreage for the Six Rivers Lightning Complex.

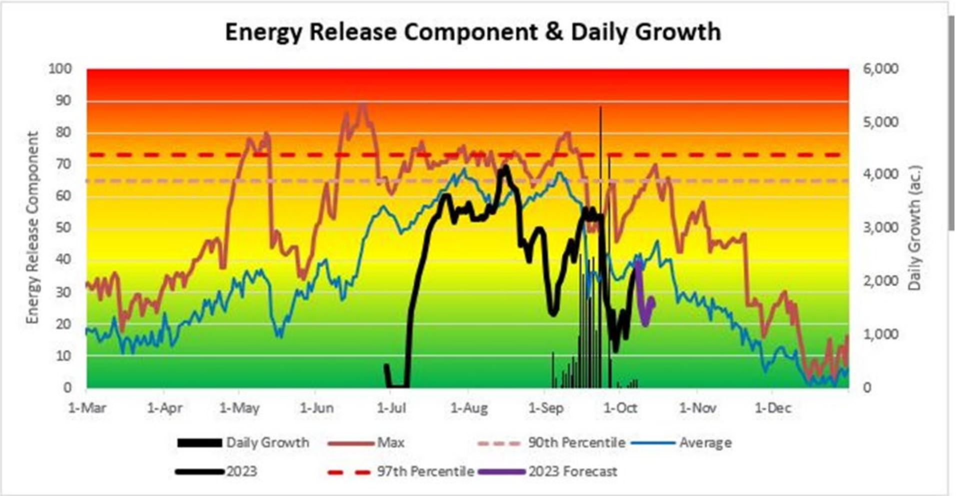


Figure 5. Fire growth related to the predicted and actual Energy Release Component for 2023. The purple line is the forecasted ERC conditions at the end of the data collection period for this report.

Methods

The general layout of an FBAT plot is shown in Figure 6 where measurements include: variable radius plots for pole-sized and overstory trees; modified Brown's line transects for duff, litter, and downed woody material; and belt transects for understory vegetation centered on the modified Brown's line. Canopy cover measurements are taken at intervals along the modified Brown's lines. Transect measurements were completed on burned and unburned plots on substrate, understory vegetation, and trees. The center and ends of the modified Brown's

Lines were monumented with rebar to facilitate long-term monitoring. The FBAT protocol document is available at: https://www.frames.gov/fbat/home. In this project, we collected information on fuels and vegetation in burned and unburned plots in mapped PBF 1 habitat for the Humboldt marten. We did not collect measurements on active fire. Post-fire fuels and fire effects data were collected on the burned plots.

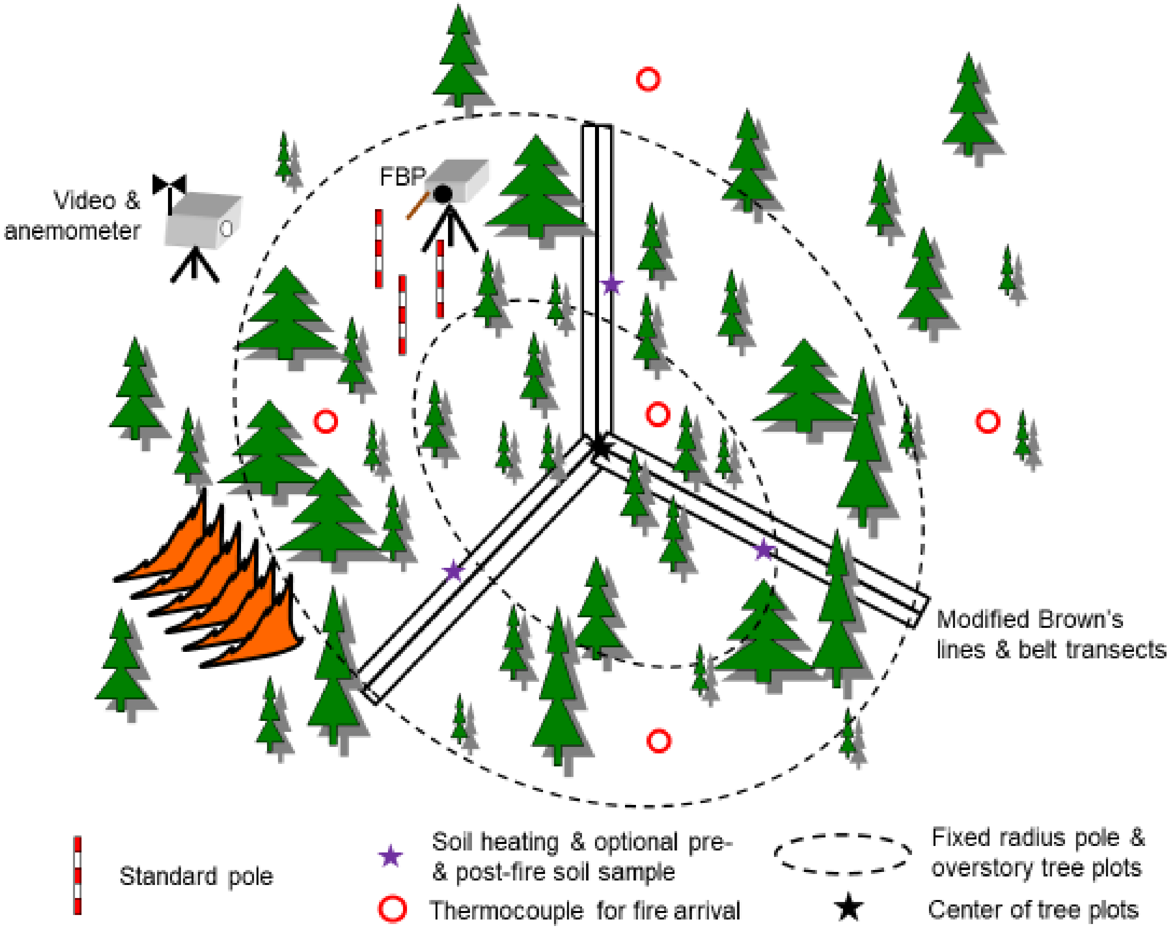


Figure 6. Standard FBAT plot layout. Modified Brown's lines and understory vegetation belt transects are anchored at plot center. The concentric circles represent pole and overstory tree fixed-radius plots. In this project, we worked on unburned and burned plots. The fire arrival measurements for determining rate of spread, the soil heating measurements, and the fire video and behavior package (FBP) were not used.

Overstory Vegetation Structure and Crown Fuels

Fixed radius plots were used to characterize overstory vegetation and fuel structure. Tree species, status (alive or dead), DBH, height, canopy base height, and distance and azimuth from the center were collected for each tree before the fire. Tree heights were measured with a laser rangefinder and DBH was measured with a diameter tape. Plot radii for overstory trees were adjusted according to the density of overstory and pole-sized trees within each plot.

In the burned plots, measurements for each tree, including minimum and maximum bole char, average height to which the crown was affected by the fire (i.e., injured in some way as indicated by either foliage scorch or consumption), the percentage of the crown that was affected by fire, and the percentage of the affected crown volume that was consumed (also known as "torch"). Trees are assumed to have survived the fire (at least in the short term) if any green needles were present after fire. Changes in canopy base height were estimated from the average height to which the crown was affected.

Plot data and the Forest Vegetation Simulator (FVS, Crookston and Dixon 2005) were used to summarize tree characteristics from unburned plot data. We used the latest software release. Tree densities and basal areas (BA) were estimated directly from plot data. Pole and tree data from the fixed-radius plots were entered into an Access database for input into FVS. Summary statistics include biomass, basal area (BA), and quadratic mean diameter (QMD) estimated for all trees (overstory and pole) and crown height, crown base height (CBH), and crown bulk density (CBD) estimated for the overstory. Canopy base height, canopy bulk density, and canopy continuity are key characteristics of forest structure that affect the initiation and propagation of crown fire (Albini 1976, Rothermel 1991). CBH, or the bottom of the tree canopy, is important because it is an indicator of the likelihood of passive (torching) or active crown fire behavior. CBH is defined in FVS as the height where the 13-foot running mean canopy bulk density is greater than 30 lbs/acre/ft, or 0.11 kg/m^3. CBD is the mass of canopy fuel available per unit canopy volume (Scott and Reinhardt 2001). Ground-based estimates of canopy cover were made with a Moosehorn device that estimates percent cover from multiple point-intercept measurements.

Surface and Ground Fuel Loading

Surface and ground fuels were measured pre- and post-fire along three 50-foot modified Browns lines. Surface fuel loading and fuel height were measured using the line-intercept method (Brown 1974). Fuel loading measurements were taken for 1-hr (<¼in. diameter), 10-hr (¼ to 1in. diameter), 100-hr (1 to 3 in. diameter), and 1000-hr (>3 in. diameter) time lag fuel classes. One and 10-hr fuels were tallied from 0 to 6 ft, 100-hr from 0 to 12 ft and 1000-hr from 0 to 50 ft. Maximum dead fuel height was recorded for the intervals of 0 to 6 ft, 6 to 12 ft and 12 to 18 ft. Litter and duff depths were measured at 1, 6, and 18 ft along each transect. These measurements were used to calculate surface and ground fuel loading (tons/acre) from bulk density estimates derived from the ratio of species-specific contributions according to tree basal area (van Wagtendonk *et al.* 1996; 1998). Basal area per species was derived from FVS, using inputs of variable radius plot data. Basal areas were determined from variable radius plot data using FVS. Fuel consumption was the difference between pre- and post-fire measurements.

Understory Vegetation Structure and Loading

Understory vegetation was characterized before and after the fire in a 3 ft wide belt centered on three 50-foot transects (see below). The fuel and vegetation transects were in view of the video camera. Species, average height, percent alive, and percent cover (based on an ocular estimation of the 50x3 ft area covered by each belt) were recorded for all understory shrubs, seedlings, grasses and herbaceous plants. Biomass of live woody fuels (shrubs and seedlings) and live herbaceous fuels (grasses, forbs, subshrubs) were estimated using coefficients developed for the BEHAVE Fuel Subsystem (Burgan and Rothermel 1984). Calculations were completed using an Excel spreadsheet developed by Scott (2005) and adapted for use with FBAT data.

Terrestrial Laser Scanning

A single terrestrial laser scan (TLS) was collected at plot center to characterize vegetation and fuels structure pre- and post-fire. All scans were taken from plot center. Where possible, the scanner was extended above the understory (shrub) vegetation. A placard was placed on one of the three fuels transects (most visible from plot center) 40 ft from plot center or where visible to orient the scans. Scan information collected include date and time of collection, status (pre-, post-fire), and conditions when the scan was taken (good/clear scan, smoke, fog/mist, snow, windy, sunny). To best represent the fire conditions, pre-scans were taken after all other plot measurements and post-scans were taken before any other observations were made. The scans were collected using a Leica BLK360 G1 scanner with the following configuration:

- Scan Density: Medium
- Image: HDR
- IR Emissivity: 0.95
- Image EV: 0
- IR Gain: High

The scans were then offloaded as .blk files and converted to .ptx files with Leica's Cyclone 360 Plus software. After the scans were converted to .ptx files, they were processed with the IntELlimon R script, under development by the USGS, Tall Timbers Research Station, and other partners. All of the variables in the IntELlimon script were kept constant in the processing, with the clipping radius set to 15 meters, the approximate size of the FBAT plot.

Two additional plots scanned pre- and post-fire and where CBI was sampled and used for fire severity calibration in the fire monitoring report (Heckel 2023). The scans are available on the FBAT Pinyon site as a special project (https://usfs.box.com/s/sqmc7zdtv04offuittzpn7zv2hwtbsd8). The fire seen in the video originated from a burnout operation.

Fire Effects

Burn Severity

A rapid assessment of burn severity was completed along each transect and for the entire plot area to document the effects of fire on the substrate and understory vegetation (USDI National Park Service 2003, Appendix 2). The National Park Service (NPS) uses fire severity ratings from 1 (high) to 5 (low) when evaluating fire severity. FBAT uses the same coding matrix but reverses the scale so that it is more intuitive, with 1 representing unburned areas and 5 representing high fire severity.

Trees

Fire-effects related measurements on trees included minimum and maximum bole char heights and canopy impacts. The combination of minimum and maximum char heights can be a better reflection of fireline intensity than maximum char height alone (Inoue 1999). Canopy measurements included scorch (foliage killed but not consumed) and torch (foliage consumed) heights and the percentage of the canopy that was scorched or torched. Percentage scorch and torch values were determined using ocular estimations and heights were measured utilizing an instrument that combines a laser rangefinder and clinometer.

Results and Discussion

Site Description

The Mosquito Fire, part of the 2023 Six Rivers Lightning Complex, was within the Orleans and Ukonom Districts of the Six Rivers National Forest and the southern portion of the Siskiyou Wilderness. The fire grew to 33,944 acres (as of 10/8/2023) northwest of Orleans, CA and west of the Klamath River. Plots were established within and adjacent to the Mosquito Fire perimeter in areas mapped as PBF 1 habitat for the Humboldt marten *(Martes caurina humboldtensis).* Summary information is provided in Table 1. Habitat maps were provided by the Six Rivers National Forest and were based on satellite imagery, forest stand information, vegetation quality, and topography (Figure 7). The criteria for plot location selection was based on the following factors: within mapped PBF 1 Humboldt marten habitat, no recent human disturbance (logging), no wildfire in the record, and safely accessible. Once in the general area that met these criteria, the plot was then randomized to the best of the team's ability to avoid a biased location. Snag hazards sometimes required adjustment of plot position. Plots 13-16 were unique in that they were on the FS 13N13 Road in the 2008 Mill Creek wildfire footprint where further strategic firing operations were considered. We established Plots 13-16 in anticipation of doing active fire monitoring but the firing plan was abandoned. Plots 13-16 had considerably more hardwood trees (live oak, tanoak, and chinquapin) than Plots 1-12 and 17-20 which were at higher elevations and dominated by conifers. Plot elevations ranged from approximately 2000 to 4400 ft across a range of aspects and slopes ranging from 7-50%. Burned Plots 2, 4, 5, 7, 9, 11, and 17 are part of the strategic firing operation. Plot 19 and 20 were chosen because they were on serpentine parent material. Plot 19 appears to have been burned during defensive firing.

Table 1. Site descriptions for 20 FBAT plots sampled on the 2023 Mosquito Fire. Latitude and longitude datum is WGS84 for Plots 1-4, 15, 17-20. For all others, datum is ITRF2000. ITRF accounts for continental drift but can be treated as identical to WGS84 in the case of FBAT where uncertainty from canopy interference is larger than uncertainty from drift. Approximate elevations and locations are from BadElf Flex GPS unit. Burned plots are highlighted in gray. The plot pair column matches the burned and unburned plots that share similar geographic and ecological characteristics. Fire history notes a record of fire within each plot location. Plots labeled as Yes within this Yes or No (Y/N) column were measured within the 2008 Mill Creek fire footprint. Treatment history indicates a historical record of treatment where plots are located. Plot 5 is labeled as Yes within this Yes or No (Y/N) column since records show a Patch Clearcut on 07/15/1990, a Broadcast Burn on 11/15/1990, a Tree Planting on 04/15/1991, and a Precommercial Thinning and Weeding on 09/15/2000.

Table 1, continued.

Plot	N Lat.	W Lon.	Slope (%)	Aspect (deg)	Elev. (ft)	Plot Pair	Fire History (Y/N)	Treatment History (Y/N)
1	41.48453066	-123.6465437	35	40	4300	2	Y	N
2	41.48613111	-123.6481151	27	42	4200	1	Y	N
3	41.48539855	-123.6433523	22	14	4125	4	Y	N
4	41.48443701	-123.6441721	25	52	4200	3	Y	N
5	41.47152047	-123.6764836	22	198	4000	6	N	Y
6	41.47303802	-123.6766022	36	300	3786	5	Y	N
7	41.47170704	-123.6688671	27	135	4000	8	N	N
8	41.47258384	-123.6702092	30	320	4200	7	N	N
9	41.46841435	-123.6733602	18	73	4200	10	N	N
10	41.46722787	-123.6729690	50	45	4000	9	N	N
11	41.44615032	-123.7298698	25	360	4100	12	N	N
12	41.44645981	-123.7291759	13	192	4150	11	N	N
13	41.49074298	-123.5650291	22	340	2200	N/A	Y	N
14	41.49037137	-123.5699051	15	17	2200	N/A	Y	N
15	41.47132285	-123.5987344	34	7	3200	N/A	Y	N
16	41.47051719	-123.6001675	26	326	3200	N/A	Y	N
17	41.44430699	-123.7257650	20	226	3750	18	N	N
18	41.44524263	-123.7260522	9	80	3750	17	N	N
19	41.41267790	-123.7658998	7	19	4350	20	N	N
20	41.41244056	-123.7689967	38	305	4350	19	N	N

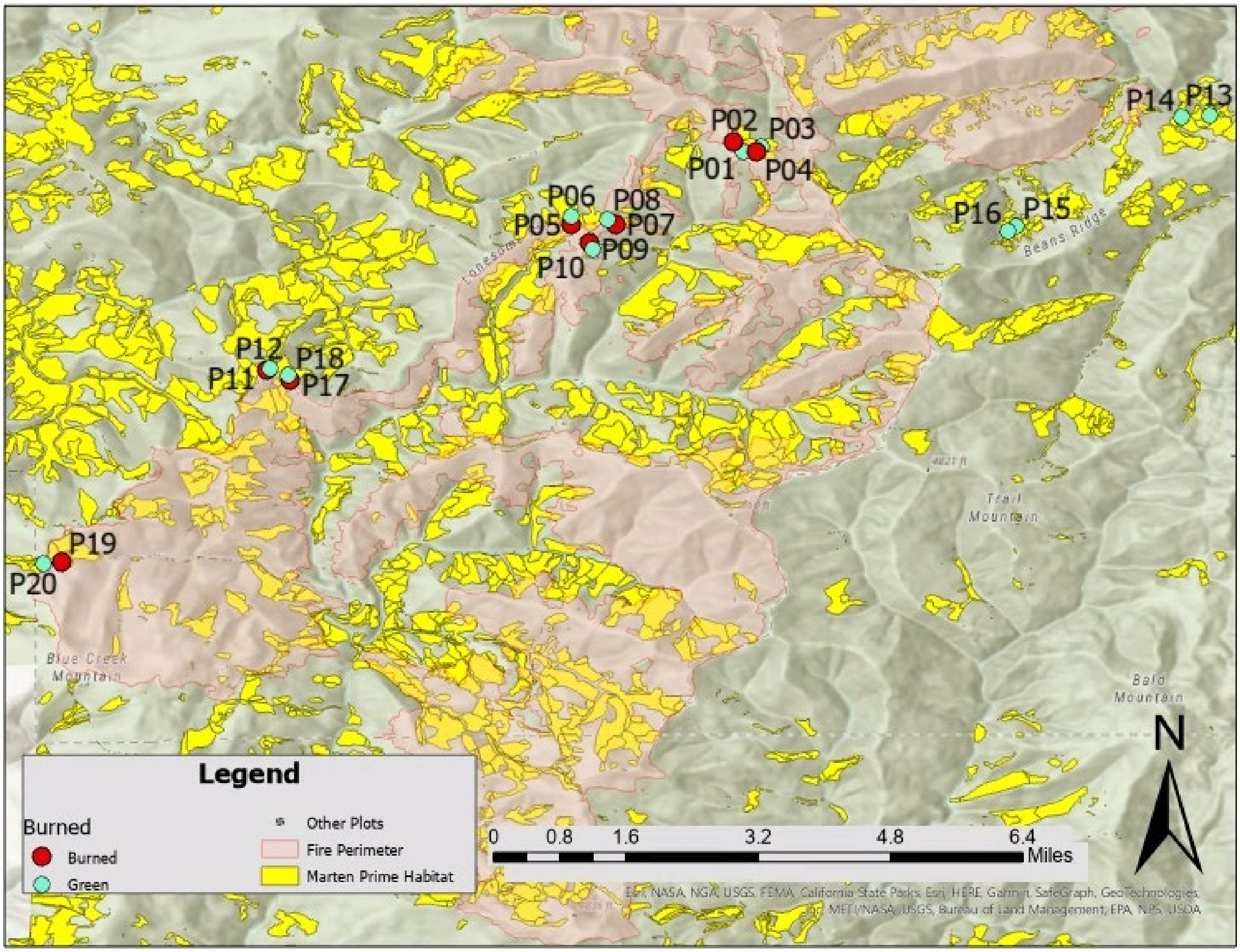


Figure 7. FBAT plot locations on the Mosquito Fire within the Six Rivers National Forest Lightning Complex. The mapped perimeter is from October 7th. Red plots correspond to burned FBAT plot locations. Green plot locations correspond to unburned FBAT plot locations. The yellow polygons correspond to PBF 1 Humboldt marten habitat (sites that meet needs for foraging, resting, and denning).

Plot Descriptions

All plots within the following descriptions were selected because they are withing mapped PBF 1 habitat for the Humboldt marten (PBF 1, Figure 7) and are either inside or in close proximity to the Mosquito fire perimeter. A majority of the unburned and burned plots are paired and compared to estimate first order fire effects. Additionally, unburned Plots 13-16 were placed in areas where there was a high likelihood of continued defensive and strategic firing operations to allow the opportunity for both pre-fire and post-fire data to be collected on the same plot as is standard for FBAT. Ultimately, these plots did not burn.

Plot 1

Plot 1 is at 4300 feet elevation on a northeast aspect within the 2008 Mill Fire footprint. The overstory is dominated by Douglas fir with Western white pine and white fir as the subdominant tree species, with several snags in the area. The understory is dense shrub cover composed of mainly rhododendron and Sadler oak. The dead and down fuel component is largely made up of one and ten hour fuels, with a low loading of hundred and thousand hours. Although the plot has past fire history from the Mill Fire there was no perceived damage or scarring to the overstory trees within the plot. The high shrub cover coupled with the tree stand characteristics of the plot would appear to meet some criteria for PBF 1 Humboldt marten habitat.

Plot 2

Plot 2 location was selected to serve as the burned counterpart to Plot 1 and was placed on a similar slope and aspect. This plot is within the 2008 Mill Fire footprint and was also ignited during the 2023 Mosquito firing operations via an aerial unmanned drone with a plastic sphere dispenser. From the rhododendron and chinquapin vegetation that remained post fire, we inferred that this could have been suitable Humboldt marten habitat. The fire burned through the plot with low intensity and left behind substantial patches of live fuel. The overstory is composed entirely of Douglas fir with no observed scorch on any of the trees, however some trees present signs of existing epicormic branching. The lower canopy is composed of dead pole trees. There is a minimal amount of fine fuels and a single thousand hour fuel remaining.

Plot 3

Plot 3 is unburned and placed on a north aspect at 4125 feet in elevation within the 2008 Mill Fire footprint. The overstory consists of moderately spaced white fir, Douglas fir, red fir, and sugar pine. The understory is mostly composed of dense rhododendron and Sadler oak. Char from past fire history was observed on the soil and trunks of multiple Douglas fir trees along with several burned snags, but no burned stumps were seen within the plot. Conifer regeneration was observed and the plot contains a high amount of lighter dead and down fuels. The combination of overstory and shrub characteristics observed in Plot 3 support the PBF 1 Humboldt marten habitat designation.

Plot 4

Plot 4 is the burned counterpart to Plot 3 and was placed at similar elevation, slope, and aspect. This plot was within the 2008 Mill Fire footprint, with sparse canopy cover dominated by Douglas fir with white fir and sugar pine as the subdominant species. The understory was composed of dense rhododendron, Sadler oak, huckleberry, and white fir and Douglas fir saplings. The fire severity in the plot was very low producing minimal consumption of the shrub cover. The understory characteristics observed would appear to meet PBF 1 habitat characteristics.

Plot 5

Plot 5 was selected to be compared to unburned Plot 6 with similar habitat characteristics, slope, elevation, and aspect; it is located in an area that was clear cut in 1990, broadcast burned in 1990, replanted in 1991 and burned in the Mill Fire in 2008. A high number of poles and sparse overstory of knobcone pine were observed in the plot. The dominant species in the understory is Sadlers oak and a dense manzanita shrub component. The fire severity varied throughout the plot. Brush and ground fuels were entirely consumed in some areas, but only scorching the vegetation and pole trees in others. Lack of large diameter trees and a high density of shrub cover was observed. This is likely due to treatments conducted within the Plot area in 1990, 1991, and 2000. The high understory density would appear to meet PBF 1 habitat characteristics.

Plot 6

Plot 6 is the unburned plot to be compared to Plot 5 and is placed on a northwest aspect within the 2008 Mill Fire footprint. The overstory is dominated by Douglas fir; moderate density rhododendron is the main species observed in the shrub layer. The plot has moderate fuel loading within the finer dead and down fuel component compared to other sampled plots, and a low heavy dead and down fuel component with a single thousand hour fuel observed. The overstory and understory characteristics of the plot appear to support mapping as PBF 1 habitat.

Plot 7

Plot 7 is the burned comparison to Plot 8 located on a southeast aspect at 4000 feet elevation. The dominant species in the overstory is Douglas fir, and the understory poles and shrub layer are composed of tanoak and canyon live oak. Fire was observed to have backed down hill with low to moderate severity in the brush. There is low fuel loading of the finer ground fuels with almost no litter and trace amounts of duff were left in most areas.

Plot 8

Plot Eight was selected due to the similar aspect, elevation and proximal location to its burned counterpart (Plot 7) along with its characteristics similar to Humboldt marten habitat. The overstory is dominated by Douglas fir and char on the overstory tree boles was observed to indicate past fire history in the plot. An old dozer line intersects transect two; previous logging activity may have taken place in the vicinity of the plot. No stumps were observed in the plot but several snags with char are present. The understory is composed sparse of bear grass and Sadler oak. There is moderate fuel loading in the finer ground fuels, and a single thousand-hour log in the plot.

Plot 9

Plot 9 is the burned plot being used for comparison to unburned Plot 10. The plot is located on a similar aspect and elevation. Douglas fir is the dominant species in the overstory, while the understory is composed of Douglas fir saplings, rhododendron, and bear grass. Fire severity varied throughout the plot but was generally low to moderate, showing minimal torching and 3-5 foot scorch heights to the overstory trees. In some areas of the plot the vegetation is only scorched, but other areas showed high consumption of the vegetation and finer ground fuels. Overall the plot showed lower fuel loading of the one, ten, and hundred hour fuels post-fire and no thousand-hour fuels were found in the plot.

Plot 10

Plot 10 is on a north aspect at 4000 feet elevation and was selected due to its characteristics of quality Humboldt marten habitat and proximity to Plot 9. The plot was unburned with Douglas fir as the dominant species in its sparse overstory. Dense rhododendron and Sadler oak constituted the shrub layer. Compared to other plots in the sample, plot ten has a higher load of one, ten, and hundred-hour fuels; no thousand-hour fuels in the plot.

Plot 11

Plot 11 is the burned plot selected to be compared with Plot 12 and was placed on a similar aspect and elevation. Both the overstory and understory are sparse with Douglas fir as the dominant tree species, while bear grass and bracken fern make up the brush layer. The fire severity is moderate to high consuming a large percentage of the vegetation in the understory, and leaving heavy char on the overstory trees. A majority of the finer ground fuels were completely consumed giving this plot the lowest total fuel loading of the sample and leaving trace amounts of duff and litter, although there is a higher number of thousand-hour fuels in the heavy dead and down fuel component of the plot.

Plot 12

Plot 12 is an unburned plot placed on a south aspect at 4150 feet in elevation and was selected because the old growth fir stand models suitable Humboldt marten habitat. The dense overstory is dominated by Douglas fir with the subdominant species being white fir. Sadler oak and bear grass constitute a majority of the sparse understory. Fine fuel load is moderate but the thousand-hour fuel component of the plot was higher compared to others.

Plot 13

Plot 13 is an unburned plot within the 2008 Mill Fire footprint on a north aspect at 2200 feet in elevation. This plot was selected because the high shrub cover could indicate suitable Humboldt marten habitat, and due to the likelihood of firing operations taking place in the area. This plot has a Douglas fir dominant overstory with tanoak and madrone observed in sparse understory. The hardwood characteristics in the mid-story of the plot may indicate that this is low quality habitat for the Humboldt marten (Slauson et al. 2019).

Plot 14

Plot 14’s location was selected due to high potential of strategic firing operations for the 2023 SRF Lightning Complex taking place in the area. Douglas fir trees dominate the overstory, but smaller diameter tanoak are present in the mid-story. The understory is made up of dense tanoak, chinquapin, madrone, and Douglas fir saplings. This plot was within the 2008 Mill fire footprint and moderate amount of hardwood slash was observed. Most living hardwoods in this plot have dry rot found on their uphill side. Snags and high amounts of dead/down fuels were present. The hardwood characteristics in the mid-story of the plot may indicate that this is low quality habitat for the Humboldt marten (Slauson et al. 2019).

Plot 15

Plot 15 was selected due to high potential of strategic firing operations for the 2023 SRF Lightning complex taking place in the area. The plot fell within the 2008 Mill Fire scar and fire mortality of the surface fuels indicated the past fire history. The overstory is dominated by tanoak; Douglas fir and chinquapin were observed as well. The understory ranges from moderate to high density madrone and tanoak throughout the plot. The plot has moderate loading of the fine fuels, but a higher amount of thousand-hour fuels compared to the other plots in the sample. The hardwood characteristics in the mid-story layer of the plot may indicate that this is low quality habitat for the Humboldt marten (Slauson et al. 2019).

Plot 16

Plot 16’s location was selected due to high potential of strategic firing operations for the 2023 SRF Lightning complex taking place in the area. This plot is also within the 2008 Mill Fire scar. Douglas fir, white fir, and sugar pine in the overstory. Tanoak, chinquapin, Sadler oak, and huckleberry were observed in the understory. Moderate heavy dead and down component with a high amount of slash observed.

Plot 17

Burned plot with Douglas fir and white fir overstory. High char heights were observed on the boles of trees. High overall tree density observed with several groups of trees interlocking branches. Douglas fir observed in the understory. Few shrub species observed. Down heavy fuels in the plot may be a result of a thinning project. Slash observed along the slope. The plot demonstrated moderate fire severity with the midstory showing needle and leaf scorch and the overstory still green. Most litter consumed.

Plot 18

Plot 18 is unburned and located on an east aspect on 9% slope with a significant amount of Douglas fir in the overstory with a moderate brushy understory component. Bear grass present in the surface layer. The litter and duff layers are slightly above average fuel loading for the area.

Plot 19

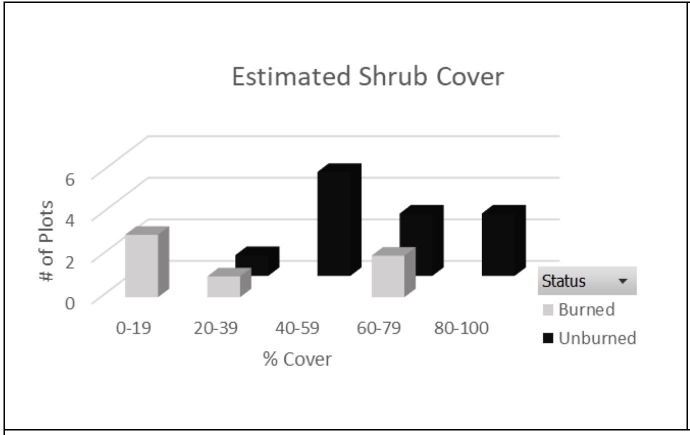
Plot 19 is the burned comparison to plot twenty, both on serpentine parent material, with and overstory composed of White fir and Western white pine as the dominant overstory trees with open canopy patches. Chinquapin, huckleberry, rhododendron, and bear grass were observed in the understory. Char and visible scorching observed on trees within the plot. The denser shrub cover coupled with the serpentine soil are consistent with characteristics of PFB 1 Humboldt marten habitat.

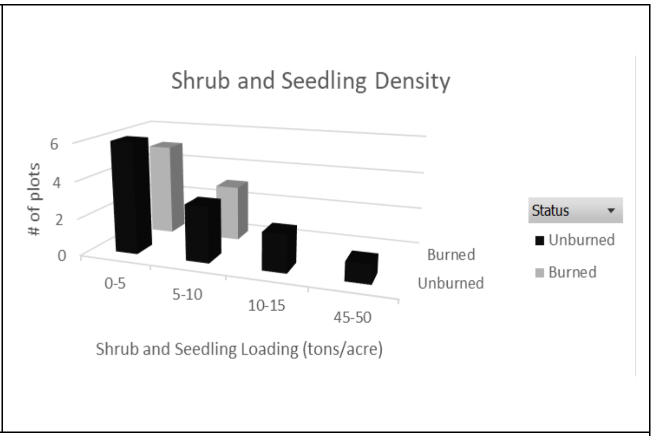
Plot 20

Plot 20 is unburned with a northwest aspect and 38% slope. The dominant species in the overstory is Douglas fir and the understory was composed of dense Sadler oak, Western white pine, bracken fern, California blackberry, and Beargrass. The denser shrub cover coupled with the serpentine soil are consistent with characteristics of PFB 1 Humboldt marten habitat.

Vegetation and Fuels

The overstory trees (Figure 9) were predominantly Douglas fir (PSME), except for Plots 5 and 13-16 which had a larger hardwood component composed mainly of tanoak (NODE3) or chinquapin (CHCH7) for Plots 13-15 and then of patch of canyon live oak (QUCH) for Plot 5. Plot 16 had experienced high levels of overstory mortality. Hardwoods had been top killed in the 2008 fire and were re-sprouting vigorously. Over 70% of plots had moderate to dense canopies, with burned Plots 5 and 19 exhibiting low canopy cover. Despite high canopy cover, moderate to high shrub cover (Table 4) was present in most unburned plots as expected for areas marked as suitable Humboldt marten habitat. Plot 10 had an exceedingly dense shrub layer with Pacific rhododendron and Sadler oak. Plots 8, 12, 13, 20 exhibited low shrub cover. Unburned Plots 14 and 16 had high seedling density. Grass and forb cover was limited in all plots. Shrub cover within burned plots was low except for Plots 4 and 19 that retained higher shrub density than even some unburned plots. The only burned plot with a complete lack of shrub cover was Plot 11. Overall, shrub density and cover estimates were higher in unburned plots but still present in most burned plots (Figure 8). Lichen was the most common damage code recorded for trees, with over 95% of plots containing trees with lichen and 12 plots had over 60% of their trees observed with lichen (Figure 8). The specific species of lichens was not recorded during measurements.





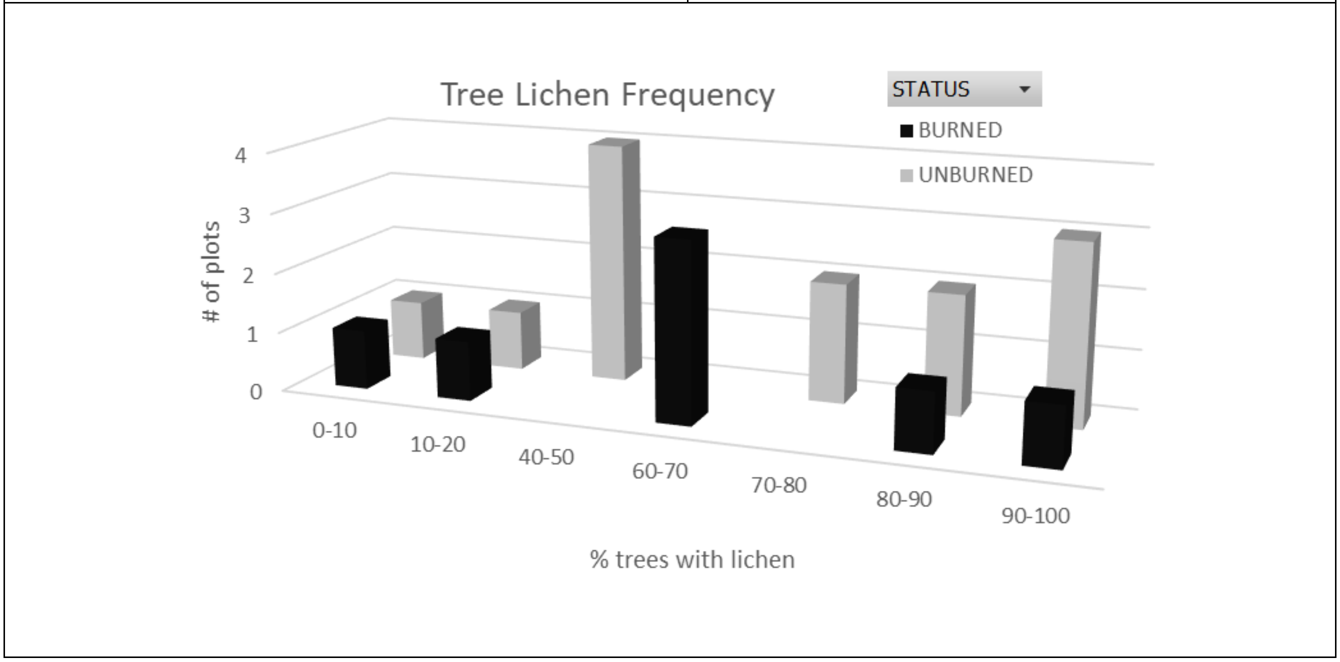


Figure 8: Estimated shrub cover comparing 18 burned and unburned plots; Plots 7 and 9 estimates were not collected (left). Estimated shrub and seedling fuel loading/densities within burned and unburned plots (right). Frequency of the percent of trees recorded with observed lichen in both burned and unburned plots (bottom)

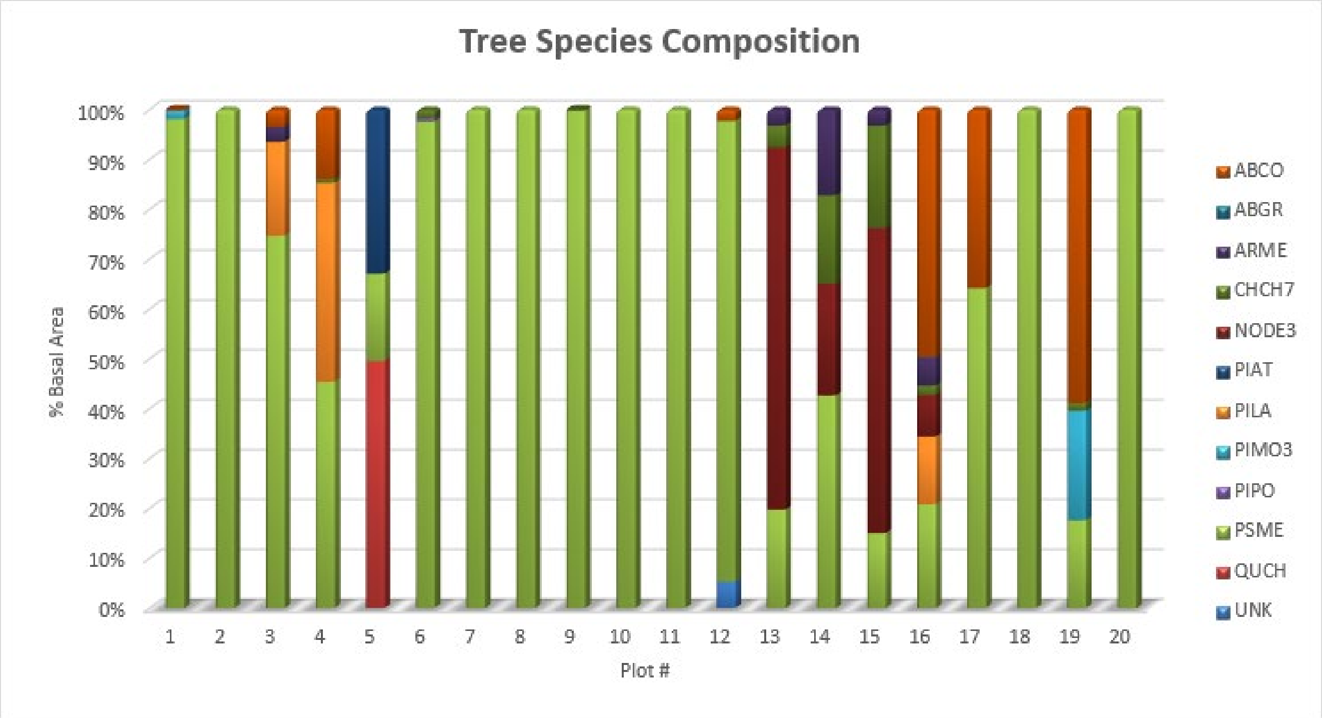


Figure 9. Overstory tree species composition on fixed-radius tree sampling plots. ABCO = white fir (*Abies* concolor), ABGR = grand fir (*Abies grandis*), ARME = Pacific madrone (*Arbutus* menziesii), CHCH7 = giant chinquapin (*Chrysolepis chrysophylla*), NODE3 = tanoak (*Notholithocarpus densiflorus*), PIAT = knobcone pine (*Pinus attenuata*), PILA = sugar pine (*Pinus lambertiana*), PIMO3 = (*Pinus monticola*), PIPO = ponderosa pine (*Pinus ponderosa*), PSME = Douglas Fir (*Pseudotsuga menziesii*), QUCH = canyon live oak (*Quercus chrysolepis*), and UNK represents unknown species.

In the understory, grass was only found on serpentine parent material in Plot 20; forbs were present on all unburned sites except Plots 1, 3, and 12 and were not present on any burned sites; shrubs were present on all sites except Plot 11; seedlings were found on all unburned plots except two (Plot 1, 20) and found on three burned Plots (Plots 4, 5, 19). Other species observed included beargrass (*Xerophyllum* tenax, Plots 2, 8-13, and 15-20), Sadler oak (*Quercus sadleriana*), salal (*Gaultheria shallon*), Pacific rhododendron (*Rhododendron macrophyllum*), red huckleberry (*Vaccinium parvifolium*), black huckleberry (*Vaccinium membranaceum*), evergreen huckleberry (*Vaccinium* ovatum), California Groundcone (*Kopsiopsis* strobilacea), California hazel (*Corylus cornuta*), pipsissewa (*Chimaphila umbellata*), Menzies' pipsissewa (*Chimaphila menziesii*), bracken fern (*Pteridium aquilinum*), and Western teaberry (*Gaultheria ovatifolia*).

Overstory Vegetation Structure and Crown Fuels

Most plots had between fifty and two hundred and fifty trees per acre (Figure 10), except for Plot 17 which had a significantly higher density of overstory trees than all other plots with an estimated four hundred and fifty trees per acre. Plot 17, 18, and 2 also represented the high end of basal area, as expected with either an unusually dense overstory (Plot 17) and areas with old growth characteristics. All plots but burned plots 2 and 7 had poles present and seven plots (3, 4, 5, 9, 10, 15, 19) had a higher number of poles than overstory indicating a developing mid-story. Tree densities are measured on a fixed radius plot and numbers are extrapolated to an acre, which sometimes results in unrealistic densities at the scale of an acre.

Average tree diameters per plot ranged from about four to twenty-six inches, with five plots (1, 2, 6, 8, 9) having a quadratic mean diameter (QMD) >20 inches as expected in old growth stands and plots with comparatively low QMDs commonly having higher densities of poles per acre. Basal areas were highly varied in burned plots, accounting for both the lowest and highest values of the range and there were moderate to high basal areas in the unburned plots (Figure 10).

Crown heights (CH) varied between plots, but over 75% of trees were over seventy-five feet tall (Figure 10). The tallest average crown height was in Plot 9 at one hundred and forty-six feet which was a Douglas fir dominated plot and the lowest was in Plot 15 at forty-seven feet as expected in a plot with a high hardwood component. Crown base height (CBH) was low in a mix of hardwood and softwood dominant plots and varied greatly whether burned or unburned. Plot 5 was unique with its history of a clear cut in 1990, broadcast burn in 1990 and planting in 1991. It had the lowest basal area, a low overstory component, the lowest QMD, lowest total biomass value, and highest number of poles per acre. Summary of this information is within Table 2.

On most plots, there was a substantial difference between canopy cover estimated by FVS and ground-based canopy cover measurements (using the moosehorn densitometer). Ground-based estimates of tree spatial patterning (even, random, clumped, etc.) were collected as inputs to FVS to increase accuracy of cover estimates.

Table 2. Comparison of canopy characteristics between unburned and burned plots inventoried on the Six Rivers Lightning Complex. All outputs are from FVS other than the Moosehorn measurements. Abbreviations: quadratic mean diameter (QMD) is the average diameter of the trees within the plot, basal area (BA), canopy height (CH), canopy base height (CBH), and canopy bulk density (CBD) is the density of available canopy and values range 0 to 45. BA is estimated for overstory trees from plot data while QMD is an FVS output for overstory and poles. Average CH, CBH, and CBD were estimated from overstory data.

	Plot	Density (trees/ac)		QMD (in)	BA (ft^2/ac)[1]	Canopy Cover (%)		CH[1] (ft)	CBH[1] (ft)	Tree foliage loading (tons/acre)	CBD (kg/m^3)
		Overstory[1]	Pole[2]			FVS	Moose-horn				
Unburned	1	61.0	38.8	21.3	247.5	51	38	99	14	5.8	0.07
	3	69.3	112.7	15.6	240.7	49	46	73	38	5.0	0.10
	6	66.6	16.6	21.9	217.7	48	46	98	36	5.0	0.08
	8	88.7	5.5	23.6	285.6	57	77	105	51	6.2	0.12
	10	61.0	169.5	14.3	257.8	51	46	116	28	6.0	0.07
	12	158.9	123.2	12.7	248.5	57	92	90	43	7.4	0.14
	13	181.1	30.8	11.7	159.3	72	100	69	20	4.0	0.03
	14	123.2	16.6	18.6	264.0	75	69	101	44	5.2	0.03
	15	244.0	46.2	10.3	167.2	74	69	47	17	4.5	0.04
	16	95.3	237.7	9.3	155.7	50	46	73	12	4.3	0.05
	18	221.8	15.4	19.4	486.4	84	92	120	65	12.6	0.26
	20	277.3	61.6	12.8	303.2	76	92	79	44	9.1	0.26
Burned	2	147.3	0	26.6	569.3	83	85	124	53	10.2	0.18
	4	54.8	169.5	12.7	197.6	39	46	93	32	4.6	0.06
	5	54.4	970.6	4.1	95.2	10	15	19	7[3]	3.4[3]	0.06[3]
	7	147.1	0	19.6	309.2	59	92	124	67	7.6	0.11
	9	22.2	33.3	25.5	196.2	39	54	140	64	3.3	0.04
	11	135.8	30.8	18.2	300.8	61	85	107	50	7.8	0.12
	17	450.6	107.2	13.2	527.8	85	100	86	45	18.3	0.35
	19	27.7	77.0	14.2	115.6	15	38	109	60	2.5	0.04

[1]≥6 in DBH; [2]<6 in DBH; [3] Height to live crown was not recorded for majority of trees <6 so they are excluded from this calculation.

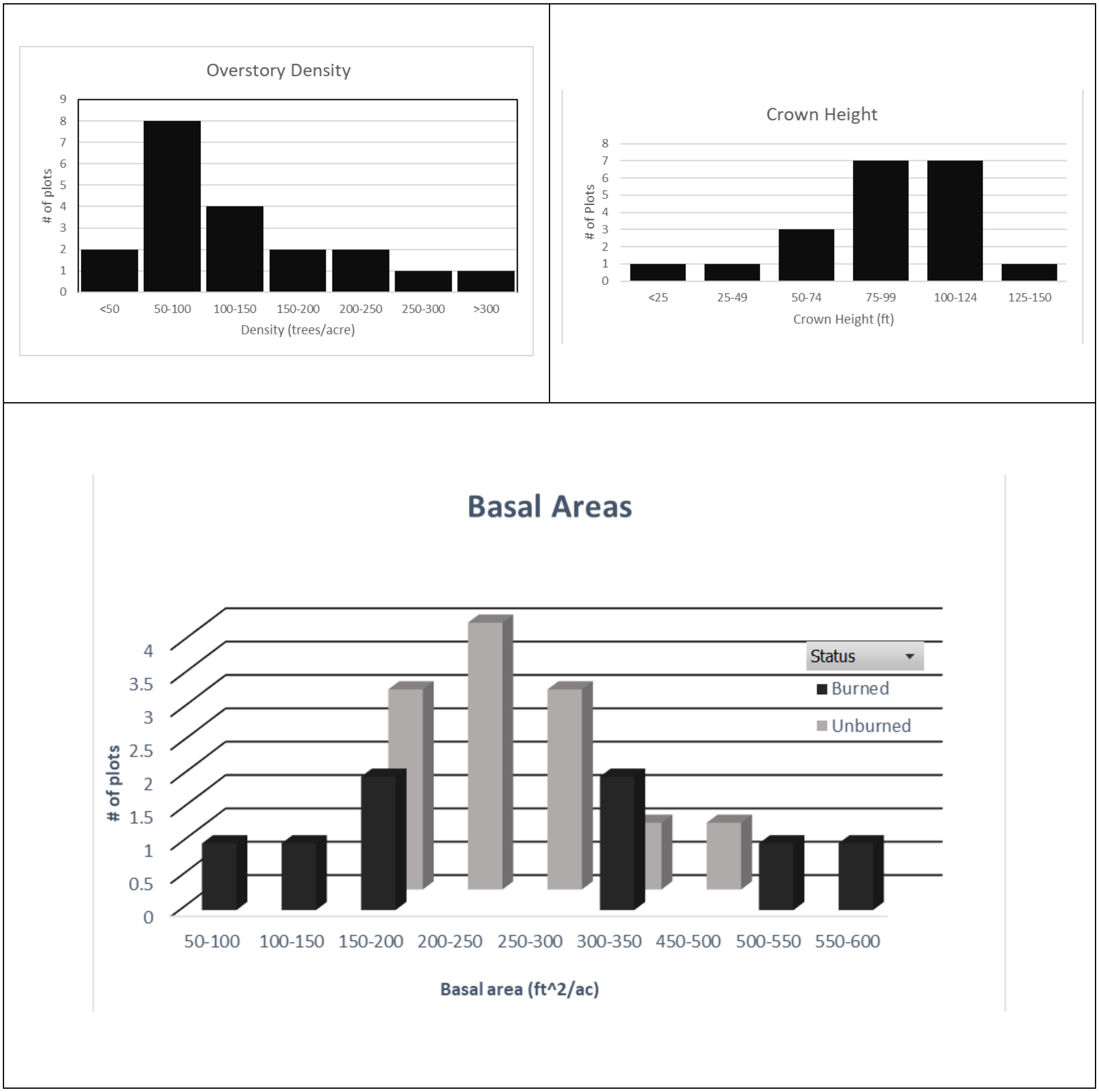


Figure 10: Overview of overstory density (trees/acre), average crown height (ft), and comparison of burned and unburned basal areas (ft^2/acre) of trees inventoried over 20 plots on the Six Rivers Lightning Complex Fire. Trees are defined as having >6 inches DBH as per protocol.

Table 3. Comparison of tree biomass between unburned and burned plots. Biomass is based on tree sampling and the Forest Vegetation Simulator (FVS). Biomass is measured in tons per acre and divided into four categories. Snag biomass is the total weight of biomass of snags. Foliage is the total weight of foliage including shrub, and all tree foliage. Live biomass (<3" and ≥3" DBH) is the total weight of all tree boles in the two DBH size classes, excluding foliage.

	Plot	**Biomass (tons/ acre)**				
		Snags	**Foliage**	**Live <3 in DBH**	**Live ≥3 in DBH**	**Total**
Unburned	1	1.8	5.8	23.6	112	143
	3	0.7	5.0	18.7	82	106
	6	1.1	5.0	20.1	99	125
	8	4.3	6.2	26.7	134	171
	10	0	6.0	21.5	133	161
	12	4.1	7.4	20.4	101	133
	13	1.8	4.0	17.9	90	113
	14	0.3	5.2	29.6	188	223
	15	0	4.5	18.8	70	93
	16	0	4.3	13.7	60	78
	18	30.7	12.6	42.0	261	347
	20	2.4	9.1	23.4	115	150
Burned	2	0.8	10.2	42.4	318	371
	4	0	4.6	15.7	69	89
	5	0	3.4[1]	11.6	29	44
	7	12.8	7.6	28.2	177	226
	9	4.4	3.3	15.9	126	150
	11	1.9	7.8	26.4	148	184
	17	5.1	18.3	46.2	188	257
	19	0.6	2.5	9.4	44	56

[1] Height to live crown was not recorded for a subset of the Pole trees and they are excluded from this calculation.

Surface, Ground, and Understory Vegetation Fuel Loading

Most plots had a substantial shrub component in the understory that contributed to fuel loadings in both unburned and burned plots (Table 3), however there was still high variability observed between unburned and burned plots (Figure 11). Generally the burned plots had lower fuel loadings in each category, with considerable differences in the duff and litter categories. All plots other than Plot 9 and Plot 10 had downed logs with an overall average diameter of 7.1 inches. Plot 16 had a substantial amount of fuel loading in the 1000-hr category and had the largest 1000 hour recorded at 31 inches. Plot 14 had the highest number of down 1000-hr logs with 13 with an average diameter of 7.8 inches. The presence of Lichen (Figure 8) was likely the leading contributor to percent scorch. On average the unburned plots had a higher fuel loading than the burned plots by approximately 38 tons/acre in total surface fuel loading and by approximately 16 tons/acre in total carrier fuel loading.

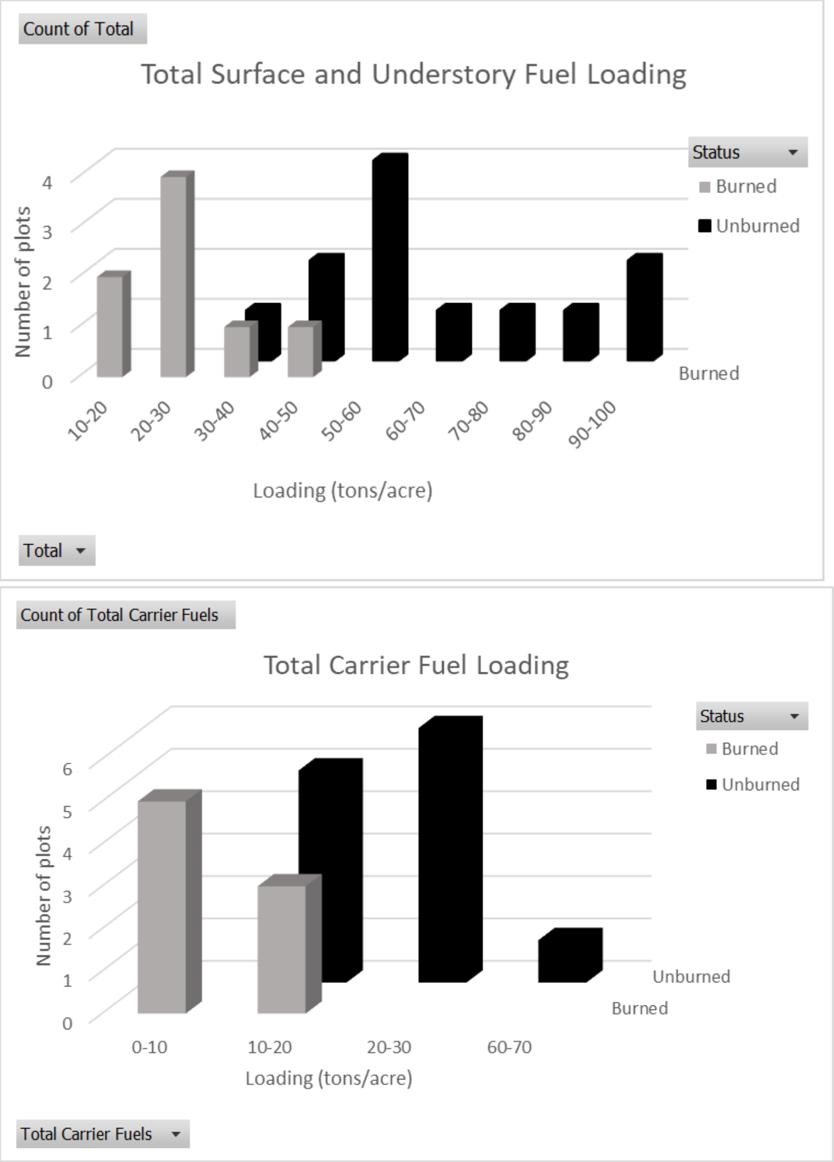


Figure 11. Range of variability for fuel loading in burned and unburned plots. Total surface and understory fuel loading references the total volume of fuel available to burn within a given plot, and total carrier fuel loading references the dead and down component available to burn within a given plot.

Table 4. Comparison of surface fuel loads and fuel bed depths for unburned and burned plots inventoried on the Six Rivers Lightning Complex Fire.

	Plot	Loading (tons/acre)								
		Duff	Litter	1hr	10hr	100hr	1000hr	Grass & Forb	Shrub & Seedling	Total
Unburned	1	23.3	11.3	0.20	2.04	1.90	5.9	0.000	10.753	55.4
	3	24.6	6.5	1.04	2.98	1.04	5.5	0.000	10.538	52.1
	6	27.4	7.6	0.51	1.88	2.68	1.4	0.001	4.660	46.2
	8	22.4	10.3	0.82	2.06	0.73	1.4	0.050	0.757	38.5
	10	37.2	6.3	0.87	3.76	3.88	0	0.014	47.267	99.2
	12	41.7	6.0	0.35	3.93	1.47	15.4	0.560	0.326	69.7
	13	6.0	7.0	0.67	1.66	2.18	29.0	0.000	1.305	47.8
	14	15.1	3.6	0.51	1.46	0.87	29.2	0.001	7.772	58.5
	15	5.3	6.2	1.86	4.23	4.49	22.7	0.023	8.347	53.2
	16	23.8	6.4	0.34	1.69	3.95	51.9	0.170	9.957	98.2
	18	43.2	19.6	1.07	2.15	1.85	2.7	0.012	4.387	74.9
	20	46.9	14.4	1.64	3.84	6.42	8.0	0.006	1.177	82.4
Burned	2	9.1	3.3	0.08	0.26	1.49	1.8	0.00	0.48	16.5
	4	21.7	4.6	0.66	2.25	1.11	2.6	0.00	8.85	41.8
	5	31.8	0.9	0.12	0.58	0.38	2.3	0.00	2.01	38.1
	7	12.6	2.7	0.36	1.31	1.14	4.4	0.00	1.20	23.8
	9	14.1	4.3	0.22	1.03	1.84	0	0.00	5.11	26.7
	11	0.8	0.0	0.00	0.00	0.00	11.7	0.00	0.00	12.5
	17	9.8	0.9	0.02	0.00	1.43	13.6	0.00	0.12	25.9
	19	9.9	5.1	0.17	1.51	1.76	2.1	0.01	8.03	28.6

Fire Effects

Satellite estimated burn severity was a mosaic across the Mosquito fire (Figure 12). Based on a comparison between burned and unburned plots the amount of carrier and surface biomass was significantly reduced in burned plots. The reduction in carrier and surface biomass in the burned plots produced a limited fuel bed condition where fire spread is either highly unlikely or the fuel bed is unburnable.

Char height was likely to have been influenced by lichen burning up the boles of trees. The presence of lichen on overstory and understory trees was observed frequently across the network of plots within the study area (figure 8). Variability between minimum and maximum char heights observed in certain plots may have also been influenced by percent slope within each plot.

Vegetation and substrate severity were estimated using a scale developed by the NPS Fire Monitoring Handbook (Appendix 2) where a value of 0 is unburned and a maximum value of 5 is heavily burned. Average plot substrate severity and vegetation severity were evaluated as either scorched (1) or lightly burned (2) in five of the eight plots. Plot 11 and Plot 17 displayed high max bole char height and high vegetation severity (Figure 14). Plot 4 had minimal severity as projected in Figure 14. This was likely due to minimal foliage and fuels consumption, as seen in Table 3. This was likely influenced by high consumption of on-the-ground and surface fuels. Summary of data seen in Table 5.

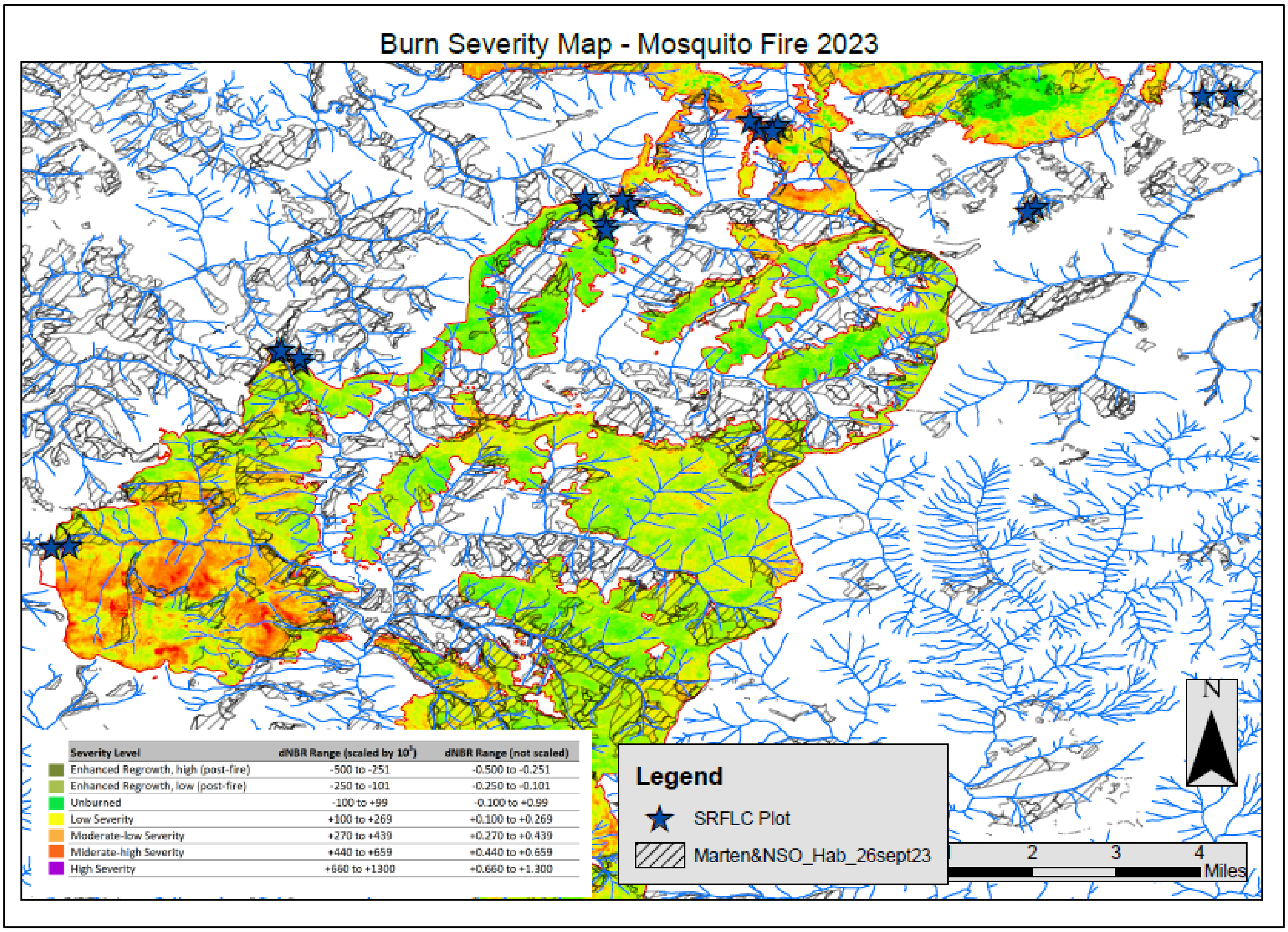


Figure 12. Burn severity map for the Mosquito Fire. This map depicts burn severity measured by Sentinel 2 satellite imagery measured in Normalized Burn Ratio (NBR).

Table 5. Plot average bole char height and height to live crown, scorch height, percent scorch and torch, and substrate and vegetation severity ratings. Substrate and vegetation severity ratings are averages based on the percentage of each plot that experienced no fire (1), scorch (2), light burn (3), moderate burn (4), and heavy burn (5), see Appendix 2.

Plot	Bole char (ft.)		Height (ft)		Percentage[2]		Severity	
	Min	Max	Live crown	Scorch[1]	Scorch	Torch	Substrate	Vegetation
2	1.7	16.6	47.43	0	0	0	2.7	2.9
4	0.47	2.10	13.22	9.08	13.95	3.75	1.6	1.5
5	0.58	4.39	13.40	14.97	74.14	7.43	2.8	3.7
7	0.28	14.63	43.75	7.68	1.18	1.47	1.9	2.7
9	0.54	9.51	31.98	16.1	4.29	0.50	2.4	2.5
11	24.74	31.84	36.06	62.97	96.50	8.57	4.0	4.0
17	3.09	29.33	30.18	47.71	73.25	0.50	4.2	4.8
19	1.48	15.76	21.39	19.38	61.50	6.00	3.1	2.6

[1] Trees that did not scorch are excluded.

[2] Percentage of all trees, including those that did not scorch or torch. Snags are not included.

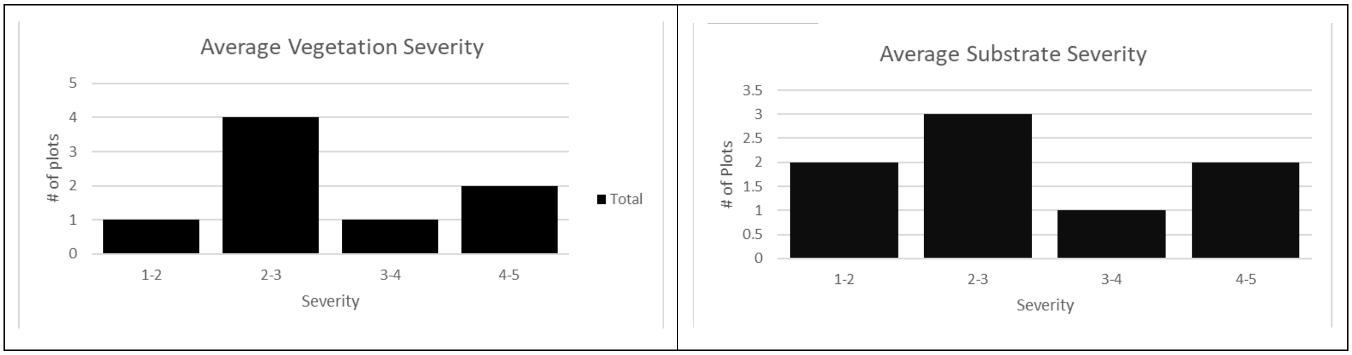


Figure 13. Substrate (right figure) and understory vegetation (left figure) assessed burn severity of eight burned plots. Bars are the number of plots burned at plot-averaged severities provided in Table 5.

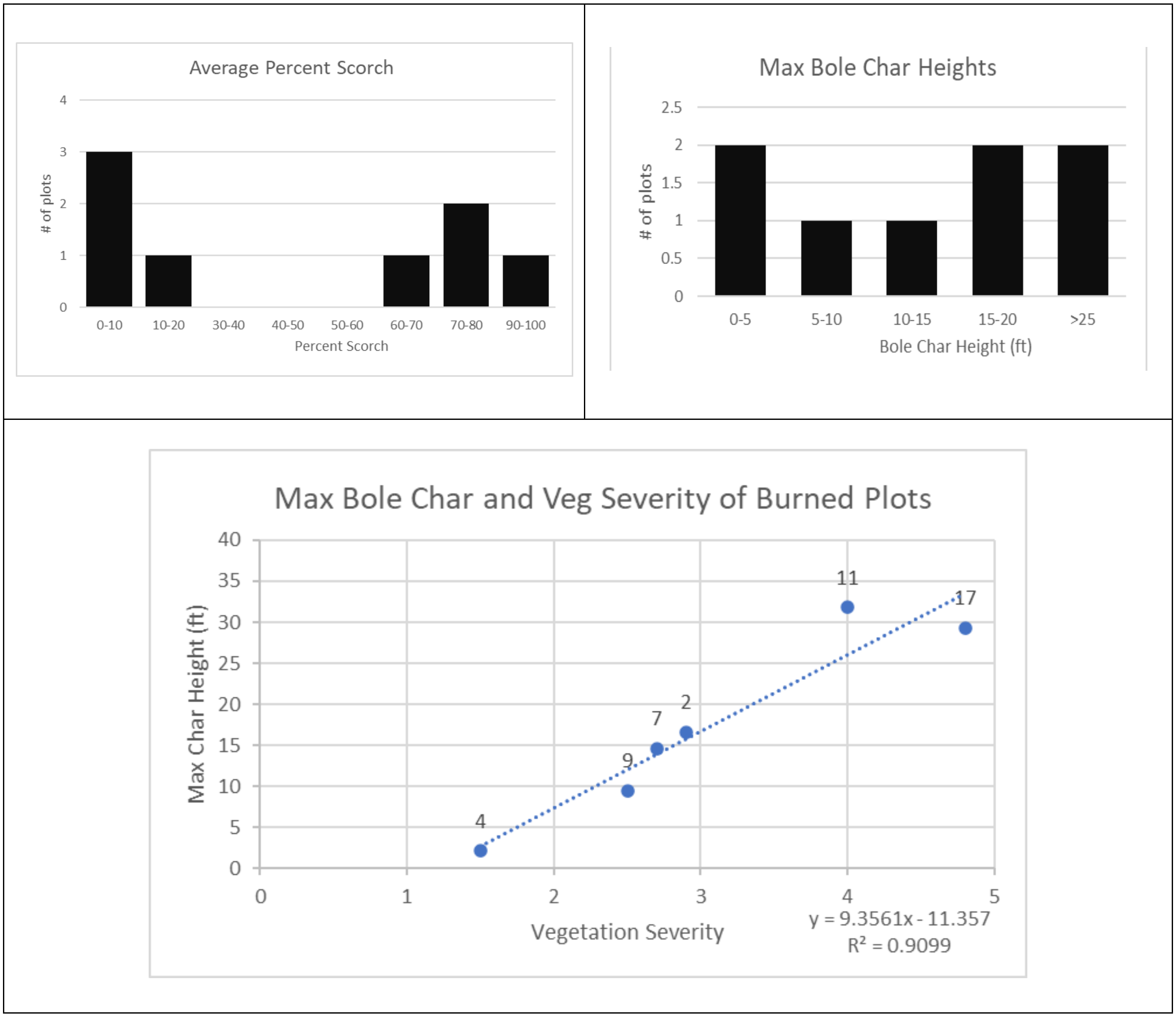


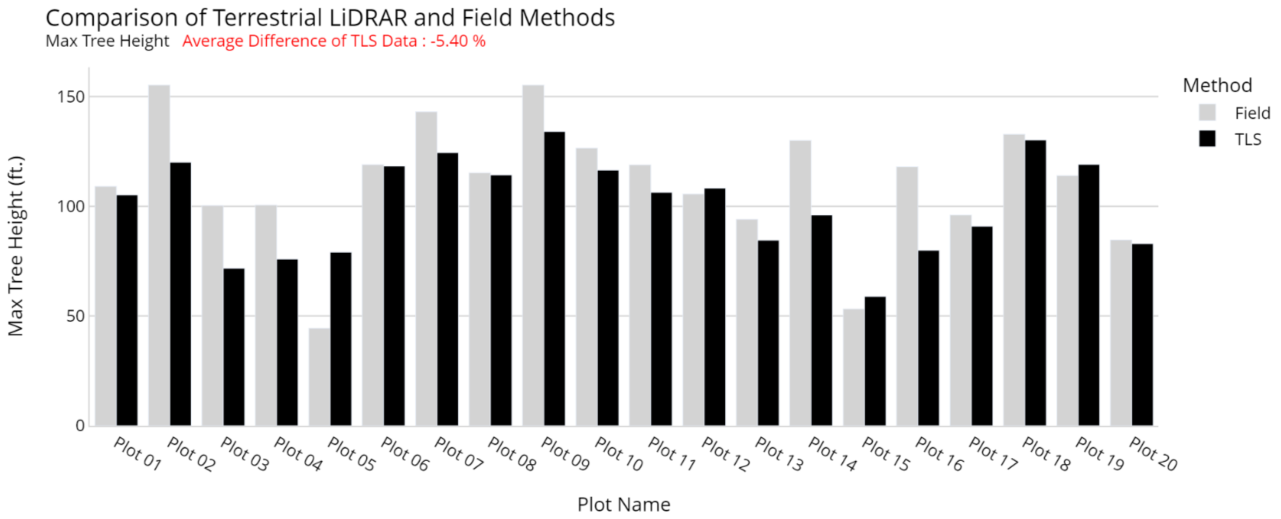
Figure 14. Number of plots and their percent overstory scorch (top left); number of plots and max char heights observed (top right); Scatterplot of max bole char observed on fixed diameter plots and estimated vegetation severity. Plot 5 was removed as an outlier due to its treatment history.

Using FBAT data to evaluate Terrestrial Laser Scanning Methodology

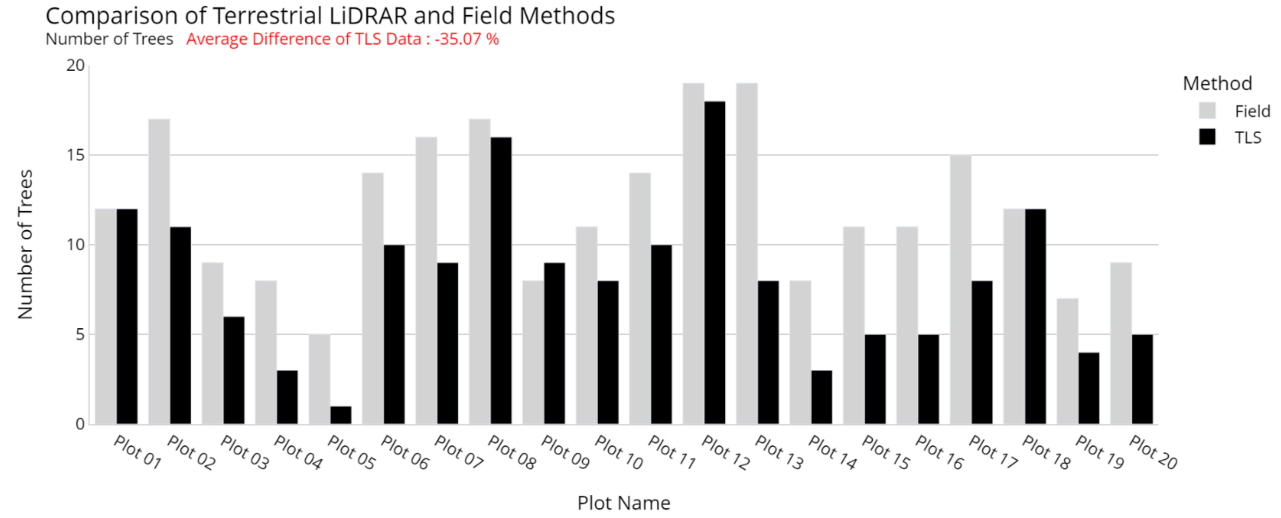
The FBAT team compared the tree canopy metrics output from the IntELiMon processing of our terrestrial LiDAR scans with those that overlapped with the metrics the FBAT team collected in the field. These metrics included maximum tree height, number of trees, mean tree height, standard deviation of tree height, mean basal area, total basal area, and mean diameter at breast height (DBH). We do not report loading of the 1-1000 hour fuel classes because IntELiMon requires additional processing software that was not available to us on assignment. IntELiMon produces tree metrics for all trees that fall within the Clip Radius, a variable set to 15 meters for our batch processing, and greater than 4 cm. DBH. The FBAT methodology collects overstory tree data for all tress that are over 6 in. DBH and are within a fixed radius, which is specific to every plot location. The IntELiMon tree inventory was filtered to FBAT standards before the two were compared.

The IntELiMon metrics that were most consistent with the results from our field sampling methods were metrics related to tree height and count. Mean DBH's of trees from plot sampling did not compare well with mean DBH from TLS.

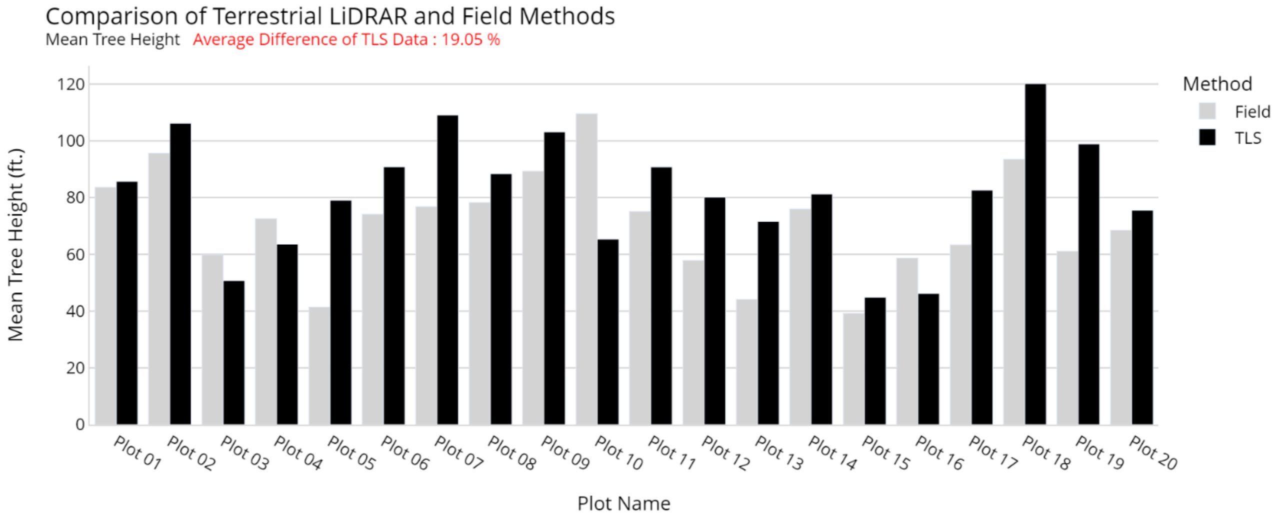
TLS and Field Method Side-By-Side Value Comparison


Comparison of Terrestrial LiDRAR and Field Methods

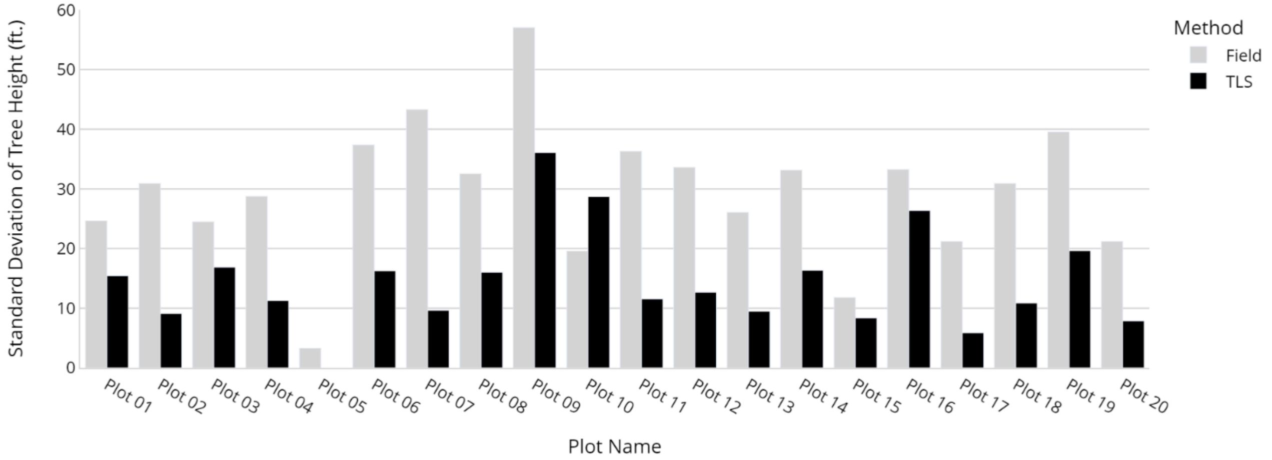
Max Tree Height Average Difference of TLS Data : -5.40 %


Comparison of Terrestrial LiDRAR and Field Methods

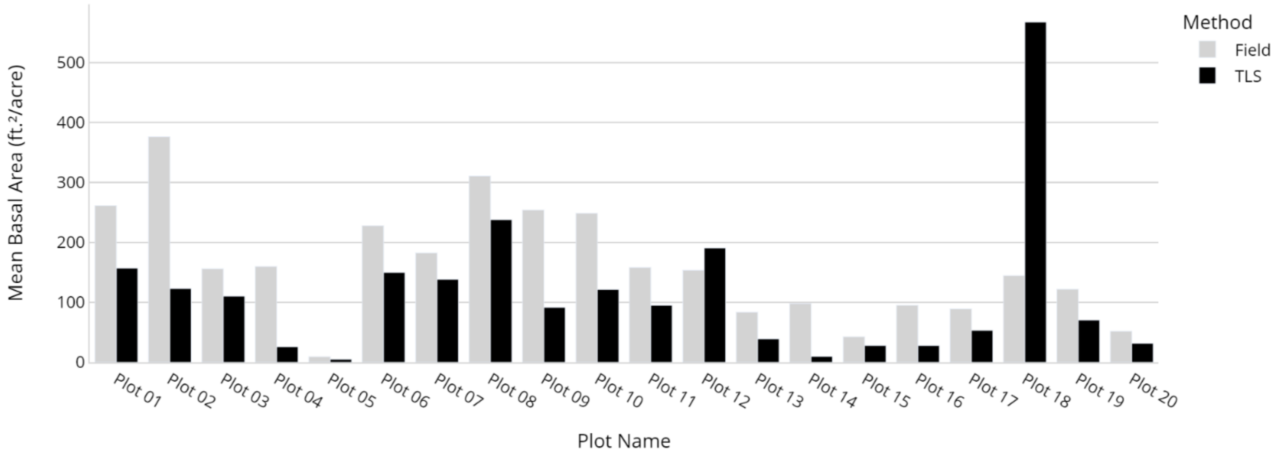
Number of Trees Average Difference of TLS Data : -35.07 %


Comparison of Terrestrial LiDRAR and Field Methods

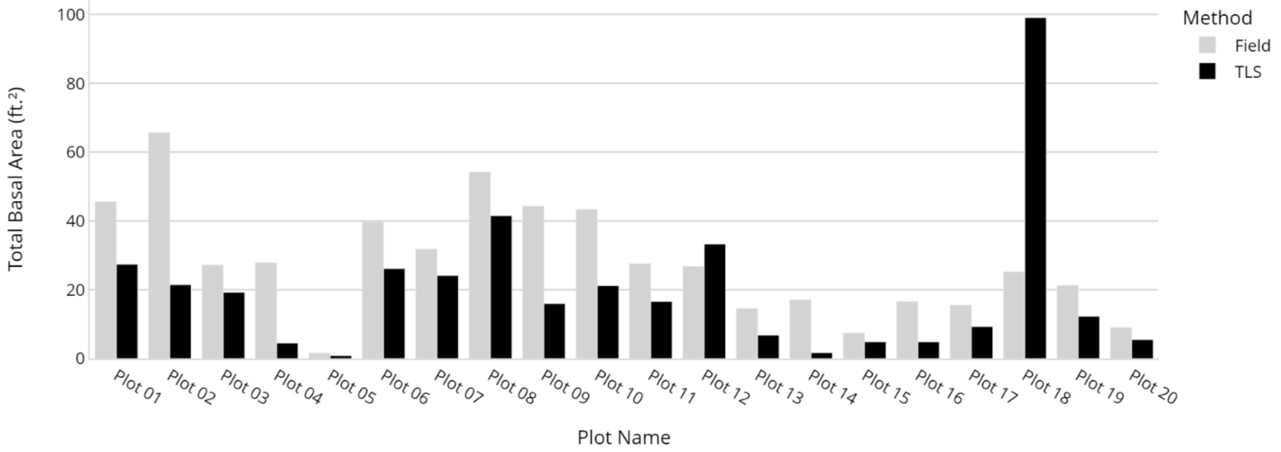
Mean Tree Height Average Difference of TLS Data : 19.05 %


Comparison of Terrestrial LiDRAR and Field Methods

Standard Deviation of Tree Height Average Difference of TLS Data : -48.44 %

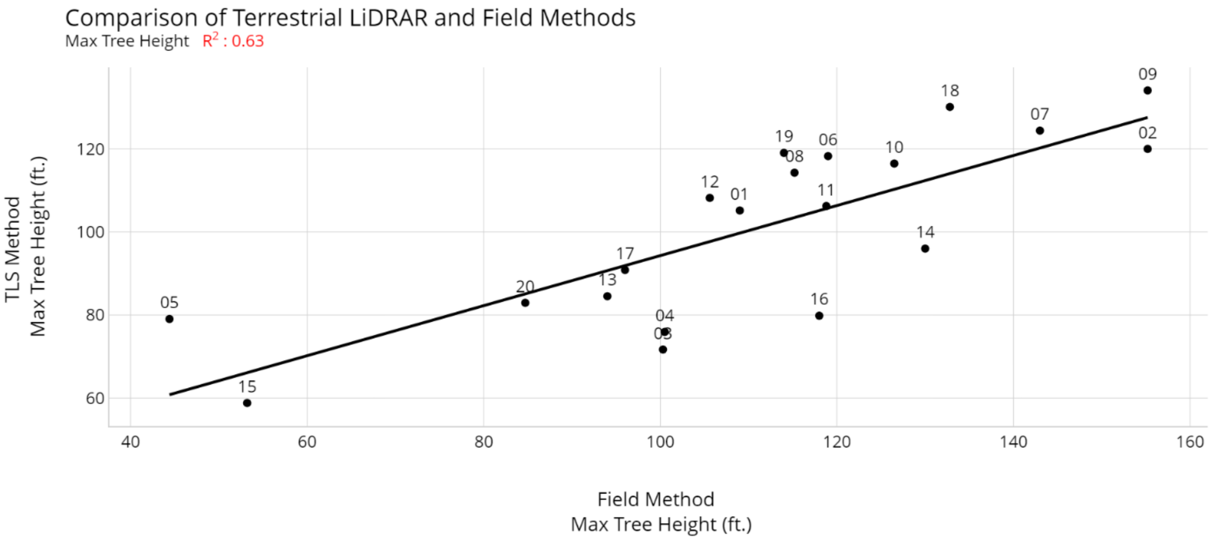

Comparison of Terrestrial LiDRAR and Field Methods

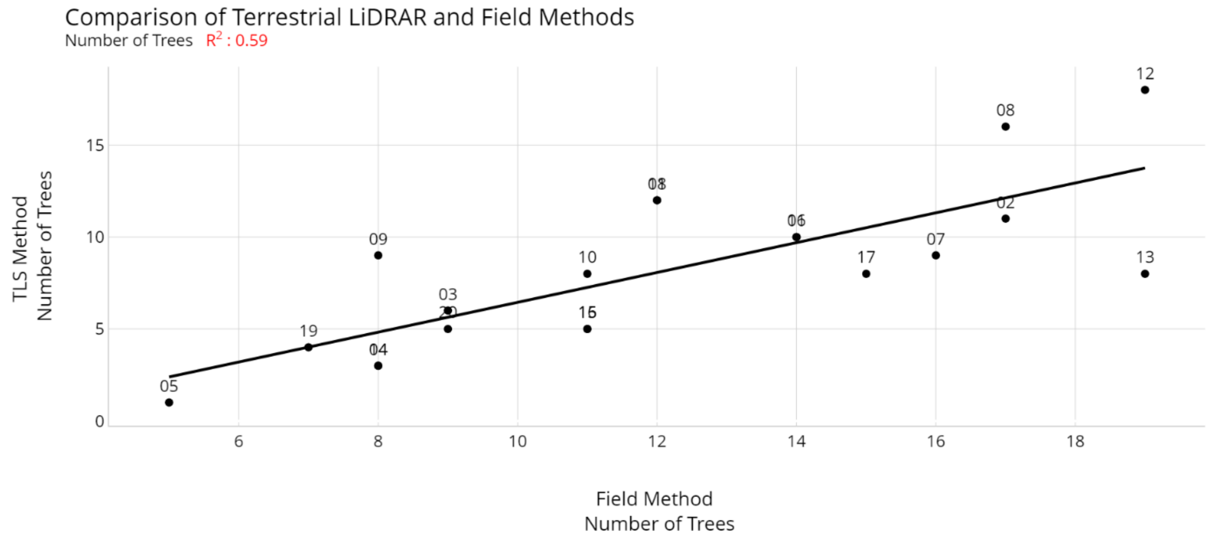
Mean Basal Area Average Difference of TLS Data : -27.78 %

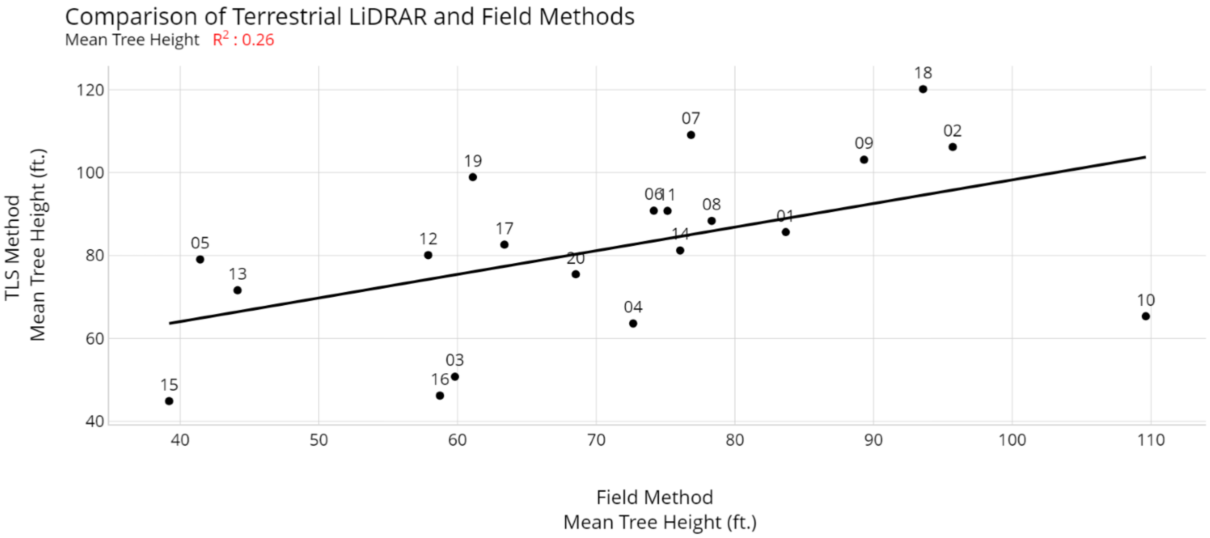

Comparison of Terrestrial LiDRAR and Field Methods

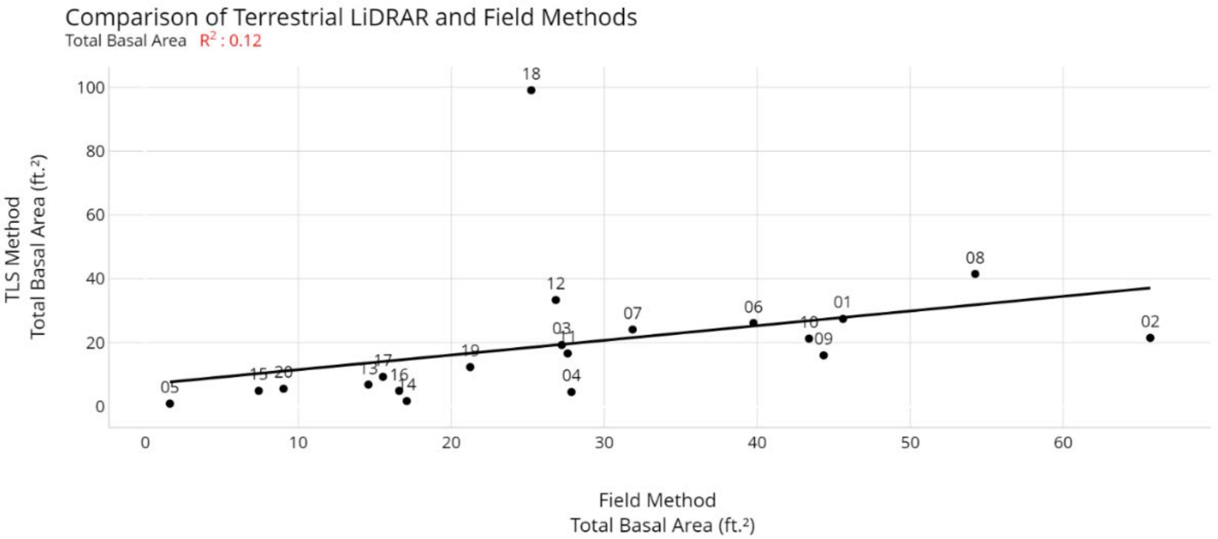
Total Basal Area Average Difference of TLS Data : -27.78 %

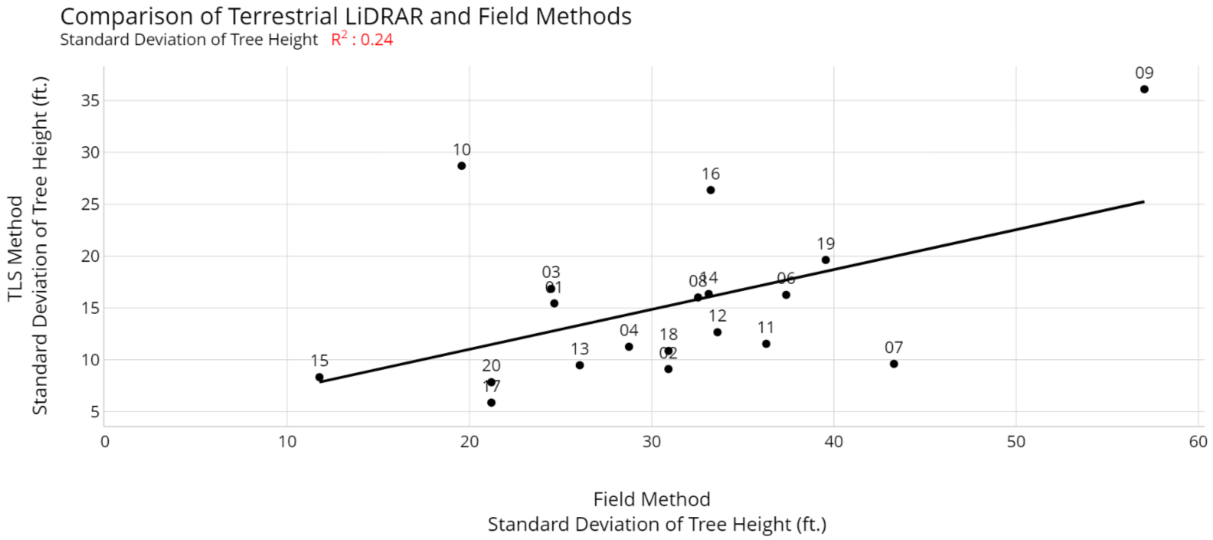
TLS vs. Field Method with Linear Regression

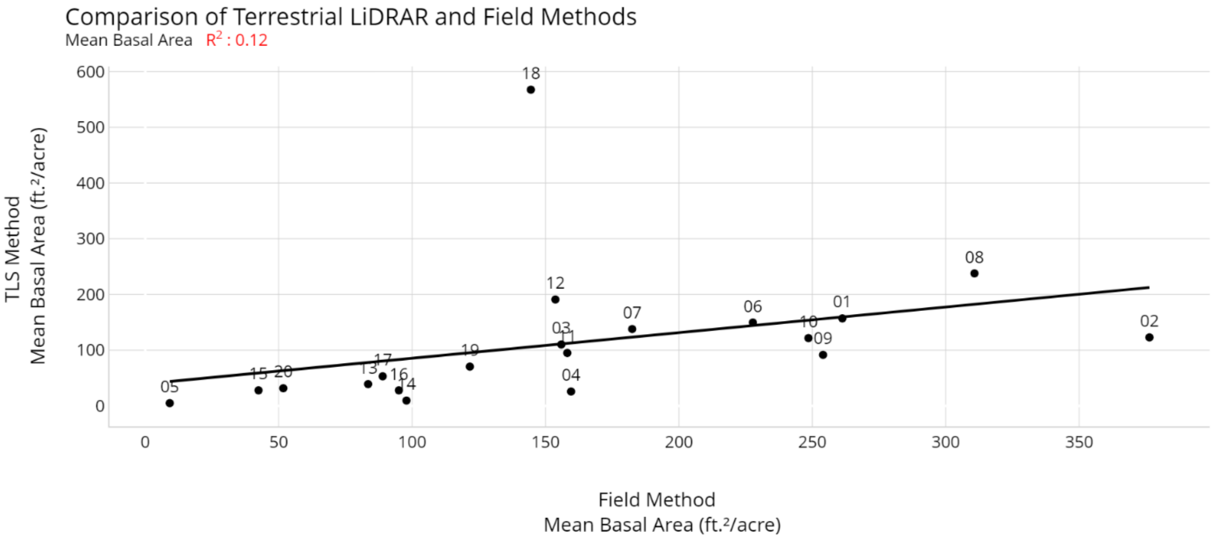

Comparison of Terrestrial LiDRAR and Field Methods
Max Tree Height R² : 0.63

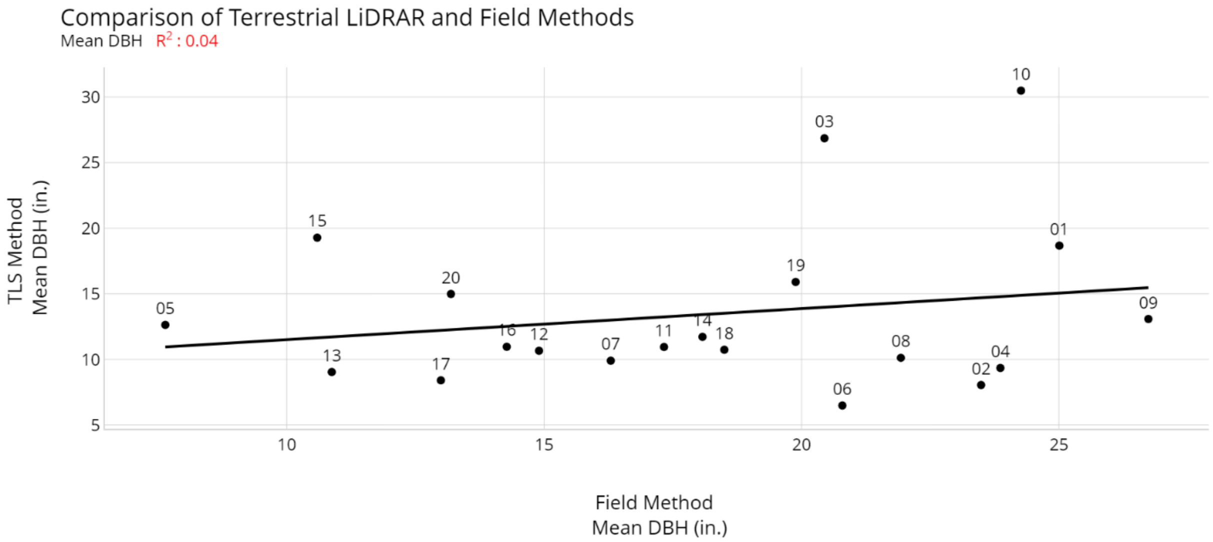

Comparison of Terrestrial LiDRAR and Field Methods
Number of Trees R² : 0.59


Comparison of Terrestrial LiDRAR and Field Methods
Mean Tree Height R² : 0.26


Comparison of Terrestrial LiDRAR and Field Methods
Total Basal Area R²: 0.12
TLS Method
Total Basal Area (ft.²)
Field Method
Total Basal Area (ft.²)
0
20
40
60
80
100
0
10
20
30
40
50
60
18
08
12
07
06
01
10
09
02
03
11
19
17
13
16
14
15
20
05
04


Comparison of Terrestrial LiDRAR and Field Methods
Standard Deviation of Tree Height R²: 0.24
TLS Method
Standard Deviation of Tree Height (ft.)
Field Method
Standard Deviation of Tree Height (ft.)
5
10
15
20
25
30
35
0
10
20
30
40
50
60
09
10
16
19
03
01
08
14
06
12
11
04
18
02
13
07
15
20
17


Comparison of Terrestrial LiDRAR and Field Methods
Mean Basal Area R²: 0.12
TLS Method
Mean Basal Area (ft.²/acre)
Field Method
Mean Basal Area (ft.²/acre)
0
100
200
300
400
500
600
0
50
100
150
200
250
300
350
18
08
12
07
06
01
10
09
02
03
11
19
17
13
16
14
15
20
05
04



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Van Wagtendonk, J.W., Benedict, J.M., Sydoriak, W.M., 1998. Fuel bed characteristics of Sierra Nevada conifers. *Western Journal of Applied Forestry*, *13*(3), pp.73-84.

Appendix 1. Paired Unburned and Burned Plot Photos and Scans

Transect photos of burned (B) and unburned (UB) plots paired by proximity and, as possible, by aspect, vegetation, and landform. Corresponding TLS scans are also shown. Unburned plots appear first in each pair, followed by burned plots.

Plot 1 Transect 1, 50-0 UB

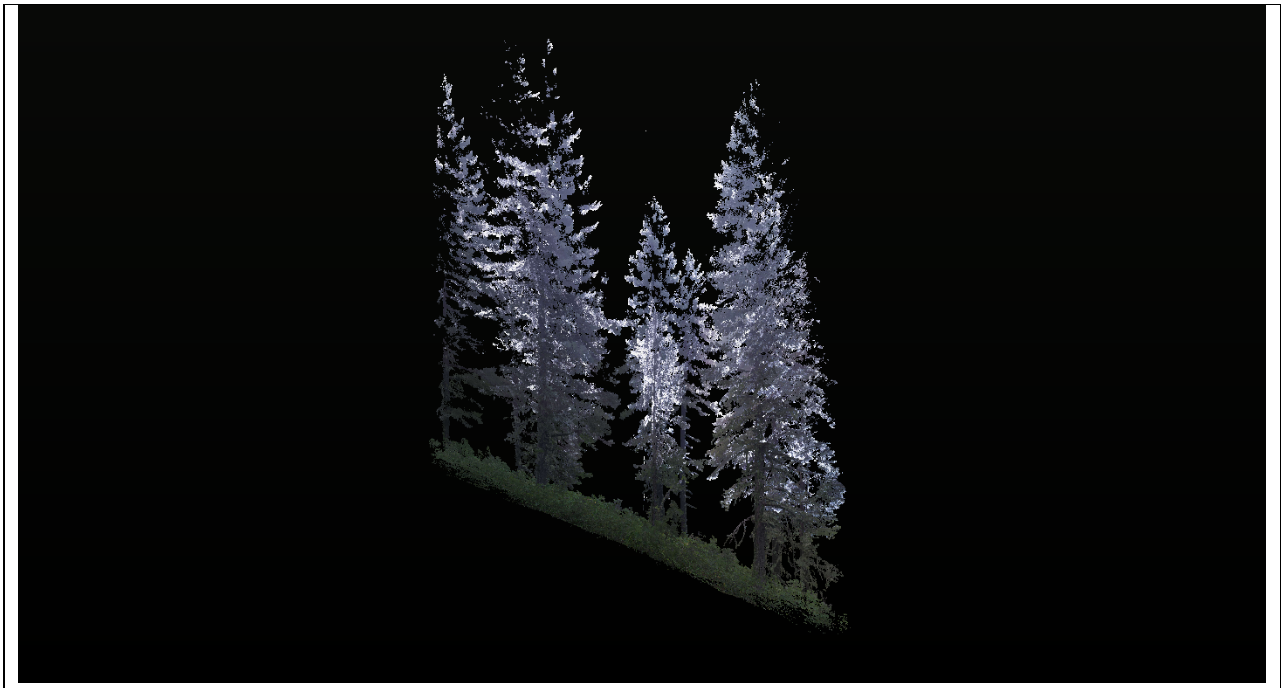
Plot 1 Transect 2, 50-0 UB

Plot 1 Transect 3, 50-0 UB

Plot 2 Transect 1, 50-0 B

Plot 2 Transect 2, 50-0 B

Plot 2 Transect 3, 50-0 B



Plot 1 UB TLS Scan

Plot 2 B TLS Scan

Plot 3 Transect 1, 50-0 UB

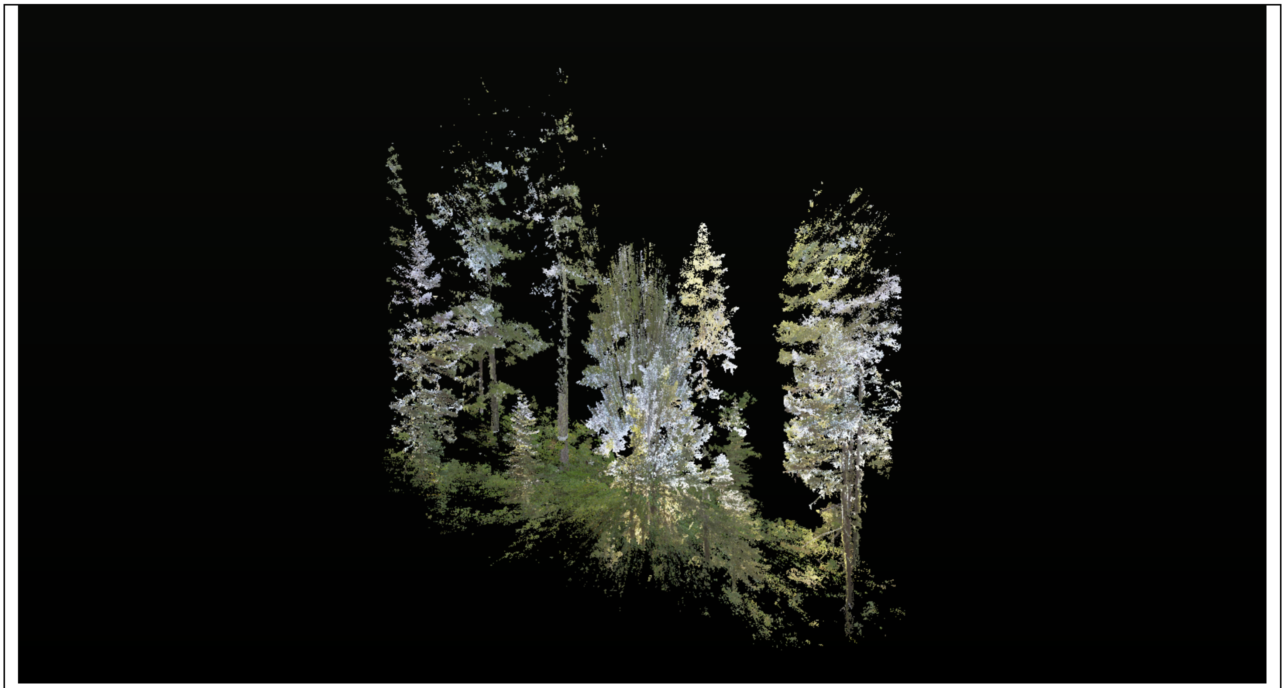
Plot 3 Transect 2, 50-0 UB

Plot 3 Transect 3, 50-0 UB

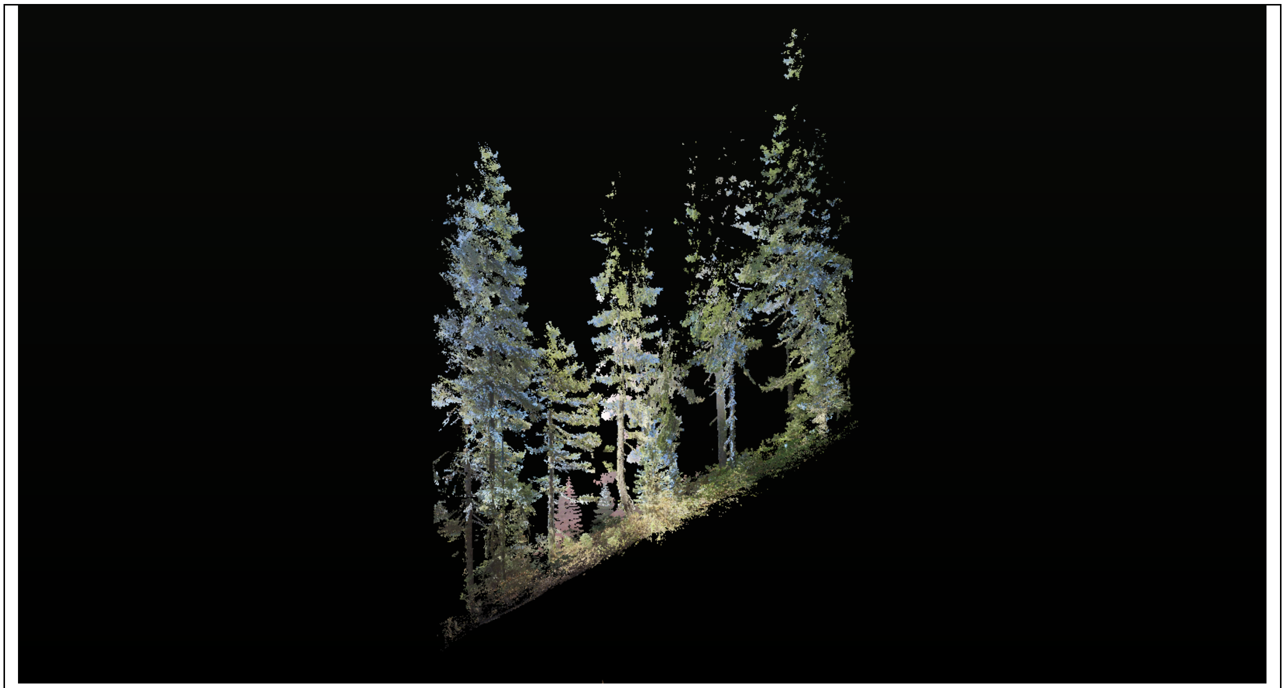
Plot 4 Transect 1, 50-0 B

Plot 4 Transect 2, 50-0 B

Plot 4 Transect 3, 50-0 B



Plot 3 UB TLS Scan



Plot 4 B TLS Scan

Plot 6 Transect 1, 50-0 UB

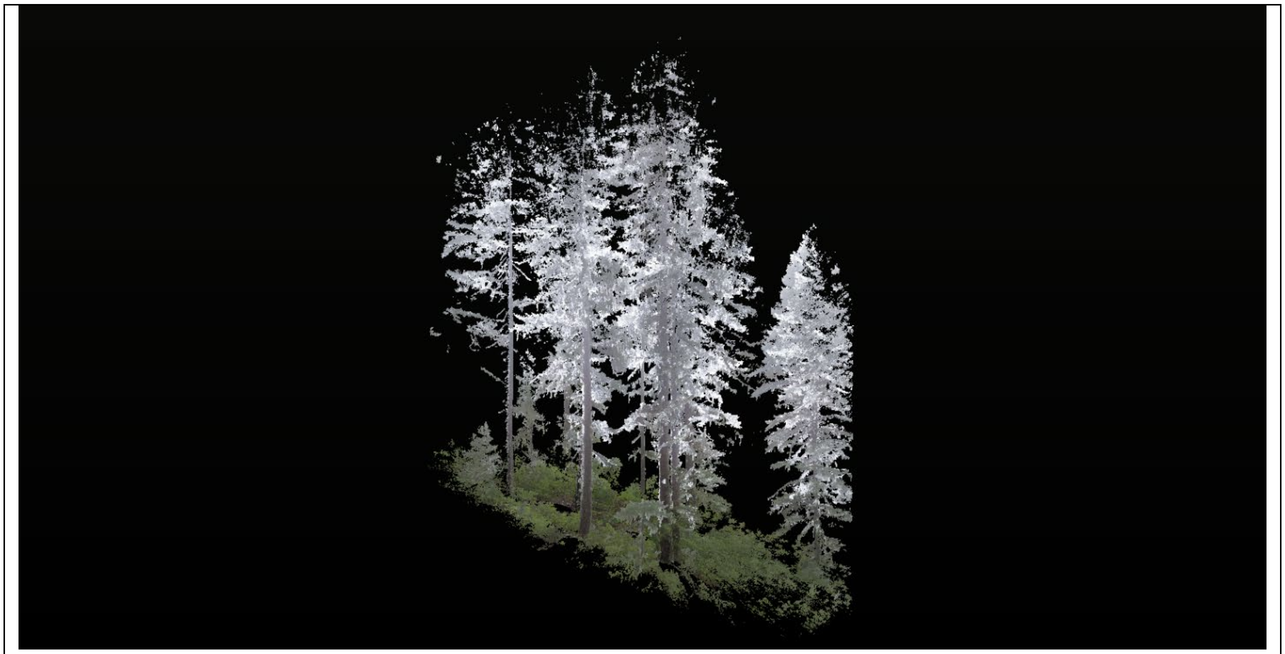
Plot 6 Transect 2, 50-0 UB

Plot 6 Transect 3, 50-0 UB

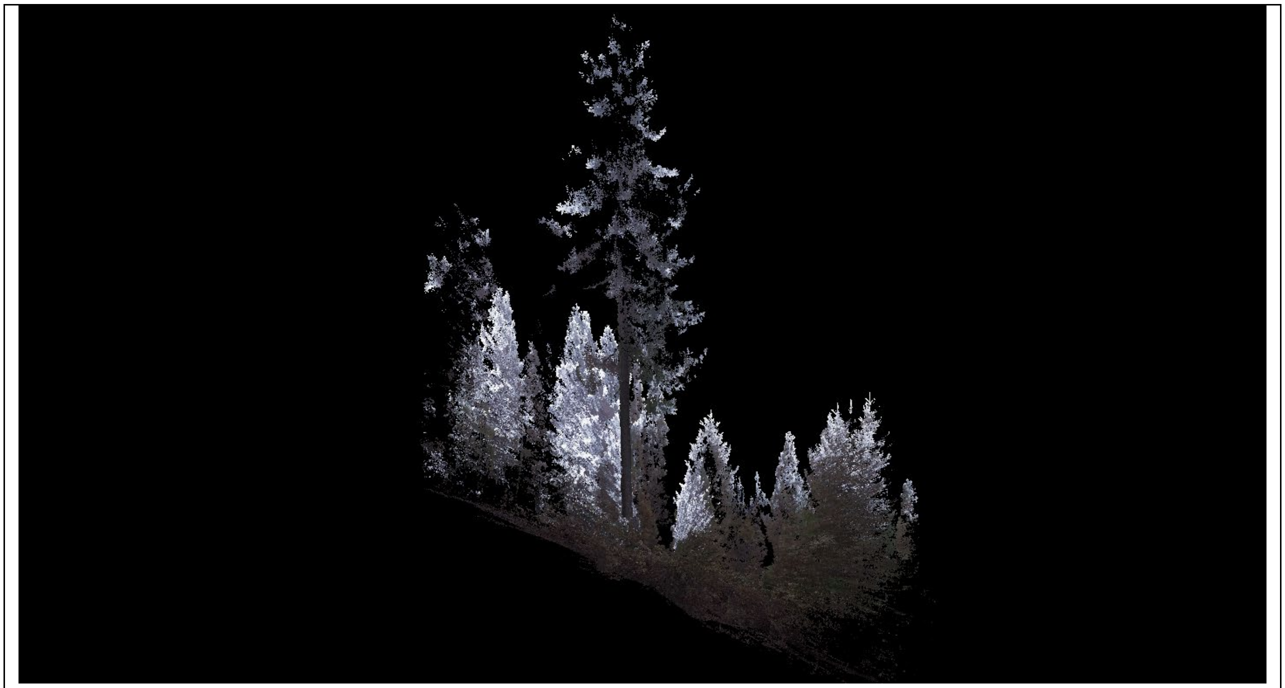
Plot 5 Transect 1, 50-0 B

Plot 5 Transect 2, 50-0 B

Plot 5 Transect 3, 50-0 B



Plot 6 UB TLS Scan



Plot 5 B TLS Scan

Plot 8 Transect 1, 50-0 UB

Plot 8 Transect 2, 50-0 UB

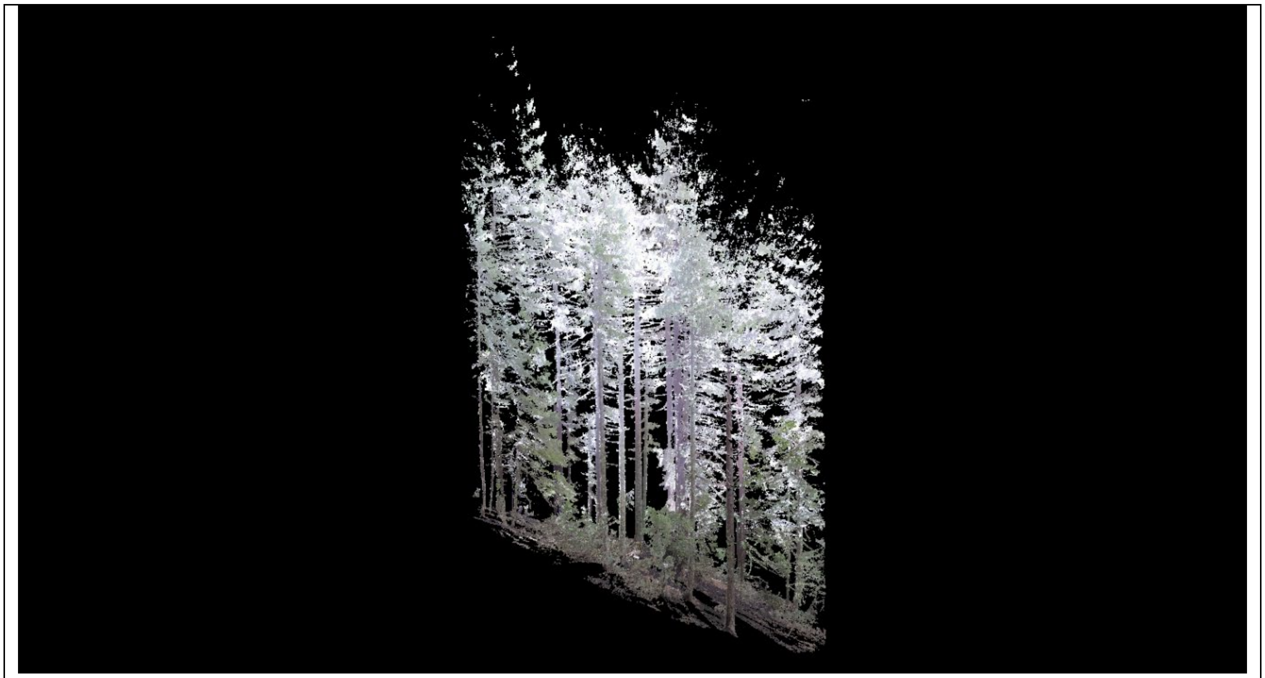
Plot 8 Transect 3, 50-0 UB

Plot 7 Transect 1, 50-0 B

Plot 7 Transect 2, 50-0 B

Plot 7 Transect 3, 50-0 B

Plot 8 UB TLS Scan



Plot 7 B TLS Scan

Plot 10 Transect 1, 50-0 UB

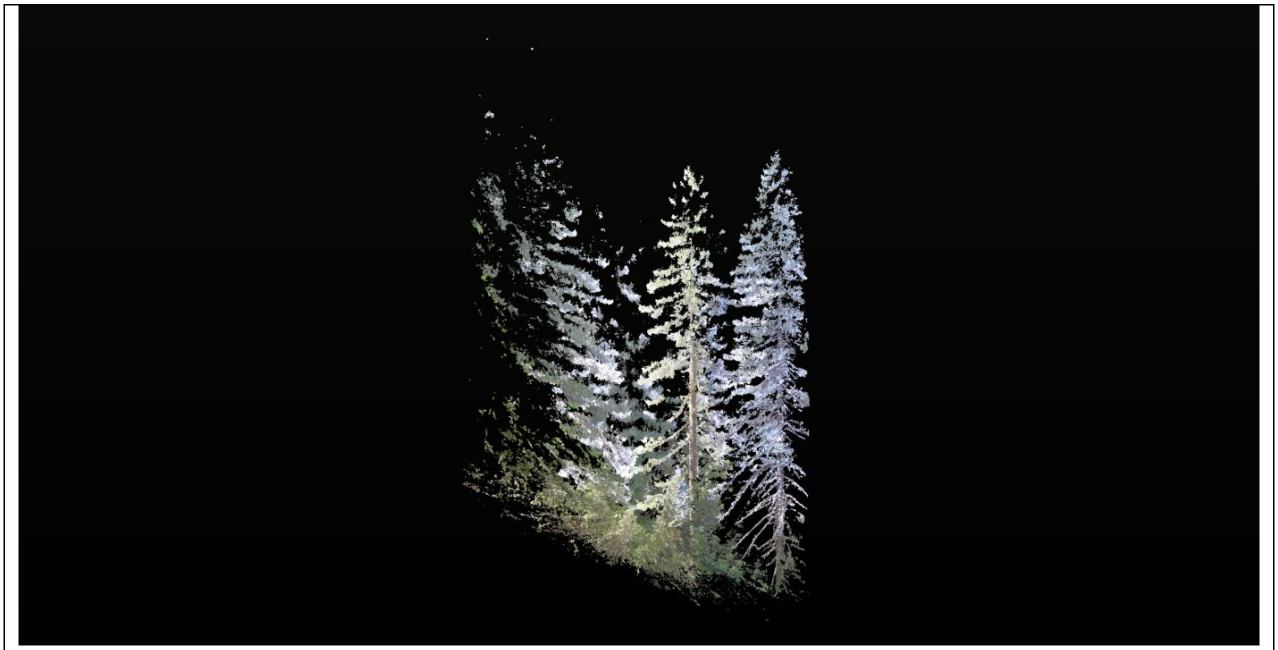
Plot 10 Transect 2, 50-0 UB

Plot 10 Transect 3, 50-0 UB

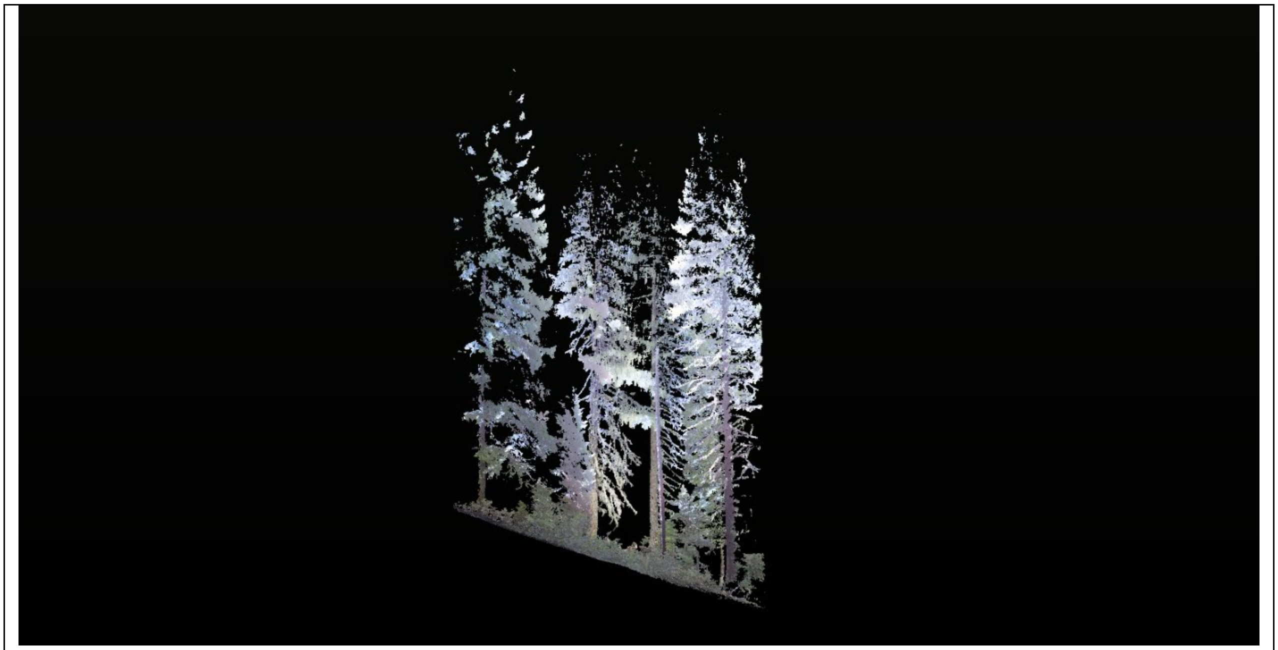
Plot 9 Transect 1, 50-0 B

Plot 9 Transect 2, 50-0 B

Plot 9 Transect 3, 50-0 B



Plot 10 UB TLS Scan



Plot 9 B TLS Scan

Plot 12 Transect 1, 50-0 UB

Plot 12 Transect 2, 50-0 UB

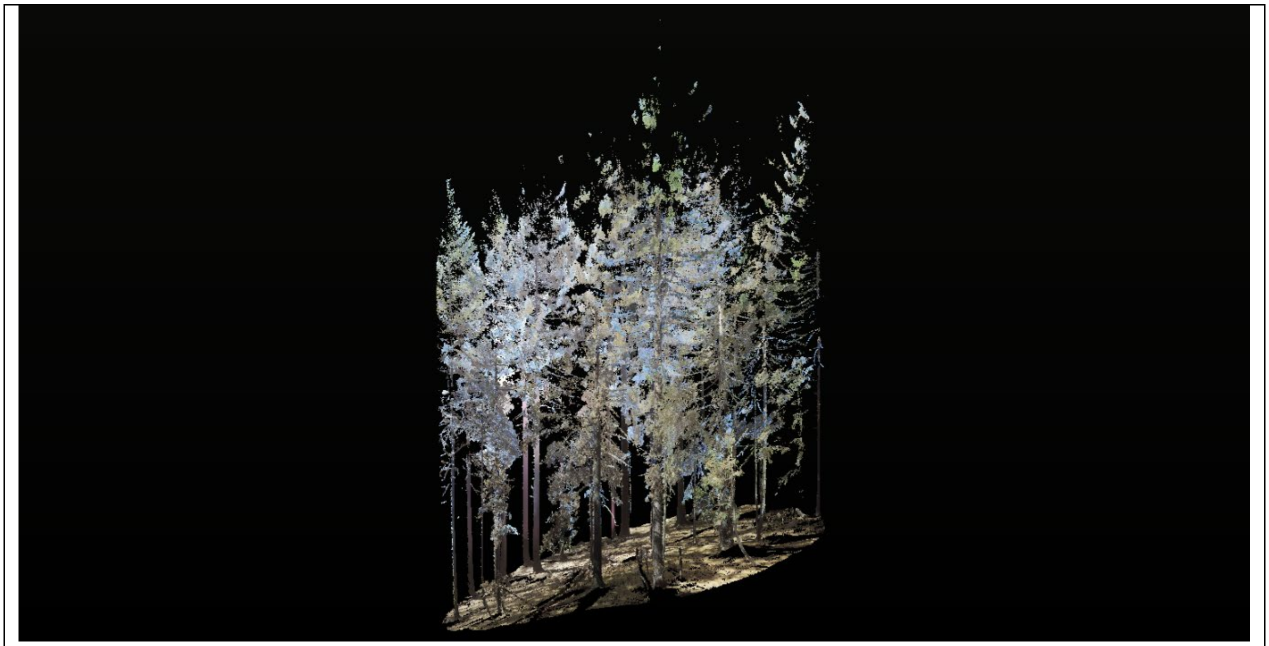
Plot 12 Transect 3, 50-0 UB

Plot 11 Transect 1, 50-0 B

Plot 11 Transect 2, 50-0 B

Plot 11 Transect 3, 50-0 B

Plot 12 UB TLS Scan



Plot 11 B TLS Scan

Plot 18 Transect 1, 50-0 UB

Plot 18 Transect 2, 50-0 UB

Plot 18 Transect 3, 50-0 UB

Plot 17 Transect 1, 50-0 B

Plot 17 Transect 2, 50-0 B

Plot 17 Transect 3, 50-0 B

Plot 18 UB TLS Scan

Plot 17 B TLS Scan

Plot 20 Transect 1, 50-0 UB

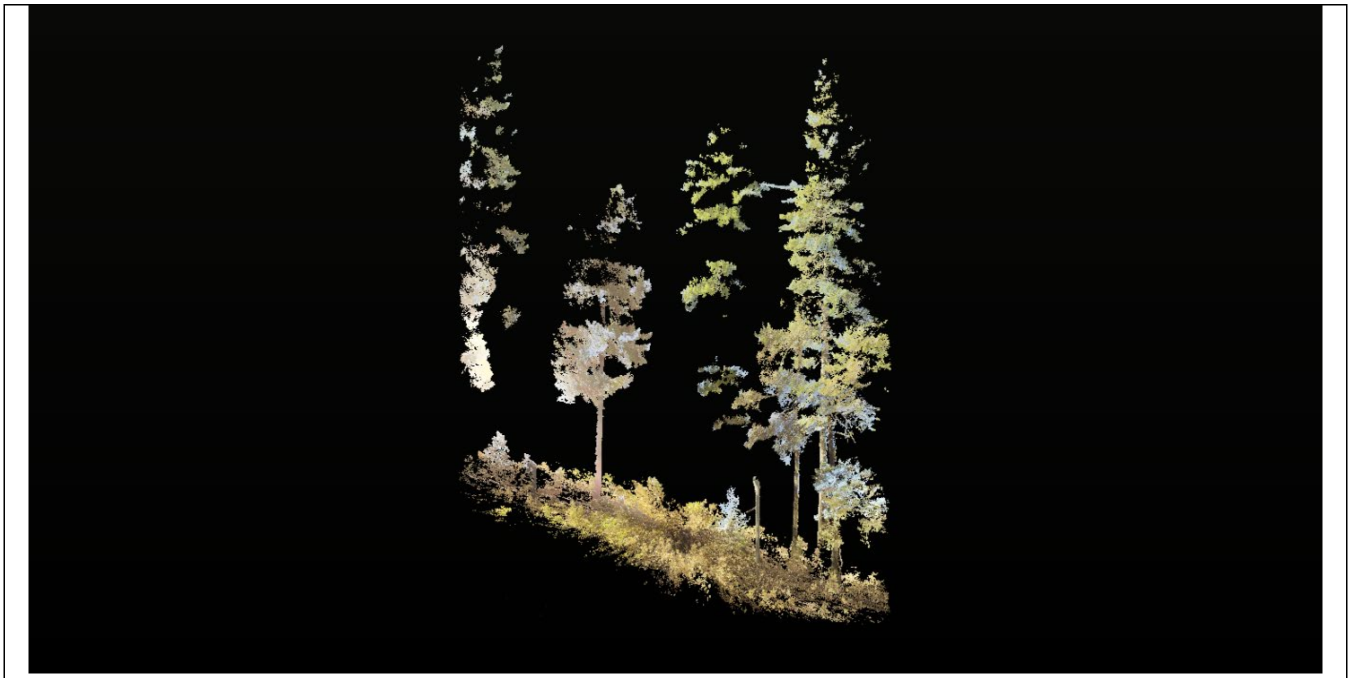
Plot 20 Transect 2, 50-0 UB

Plot 20 Transect 3, 50-0 UB

Plot 19 Transect 1, 50-0 B

Plot 19 Transect 2, 50-0 B

Plot 19 Transect 3, 50-0 B



Plot 20 UB TLS Scan

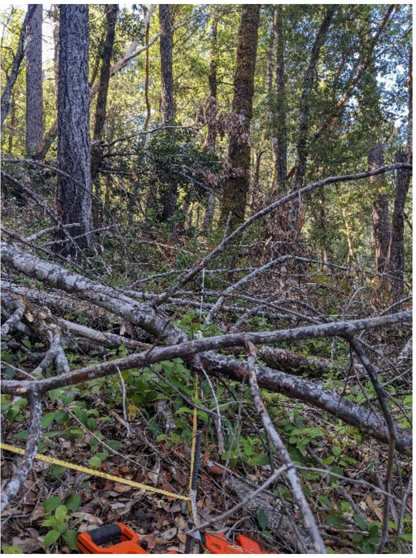
Plot 19 B TLS Scan

Appendix 2. Additional Unburned Plot Photos and Scans

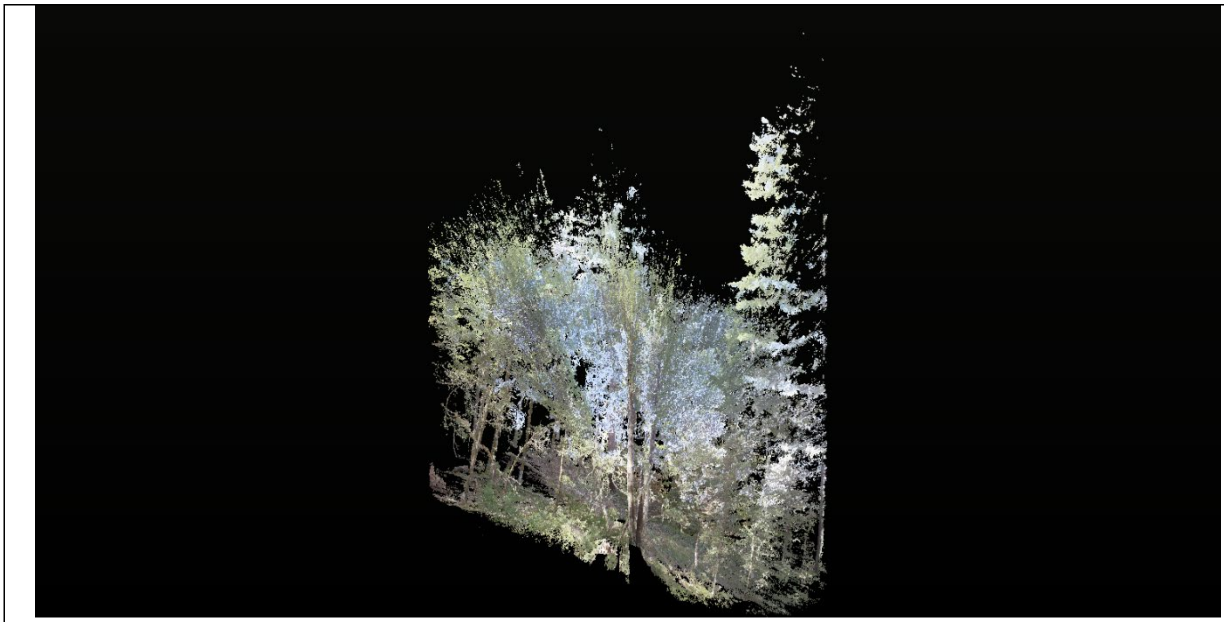
These plots, with a substantial hardwood component, were sampled in anticipation of continued strategic firing, which did not occur. The elevation is lower than other plots and hardwood representation higher.

Plot 13 Transect 1, 50-0

Plot 13 Transect 2, 50-0



Plot 13 Transect 3, 50-0

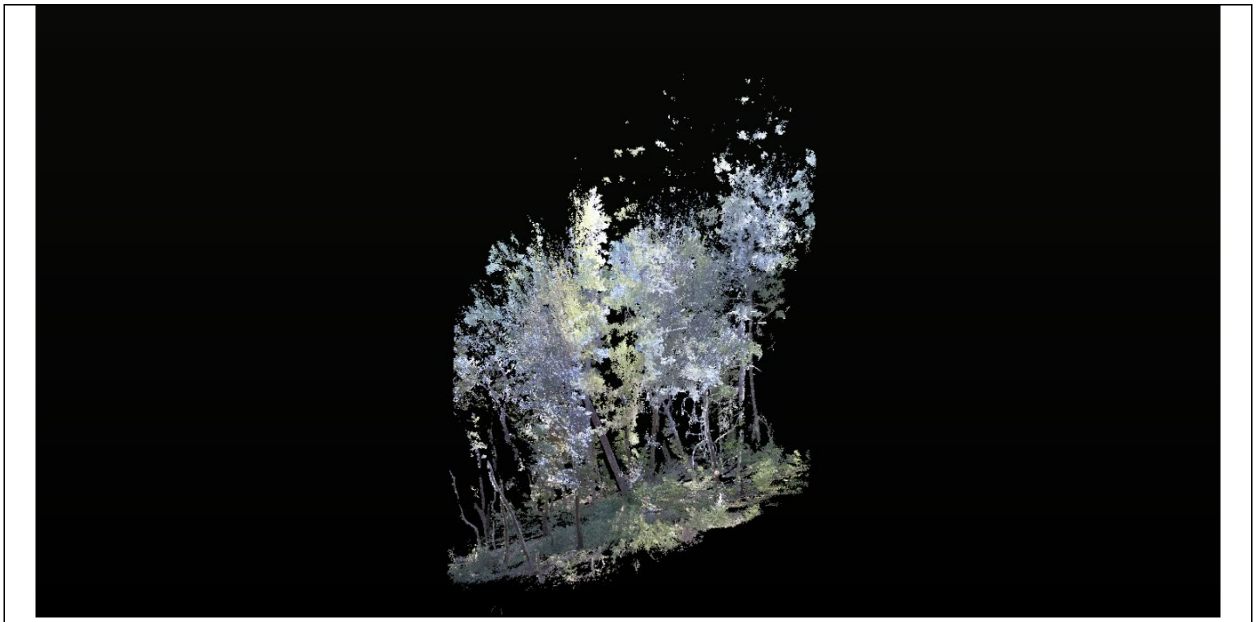


Plot 13 UB TLS Scan

Plot 14 Transect 1, 50-0

Plot 14 Transect 2, 50-0

Plot 14 Transect 3, 50-0



Plot 14 UB TLS Scan

Plot 15 Transect 1, 50-0

Plot 15 Transect 2, 50-0

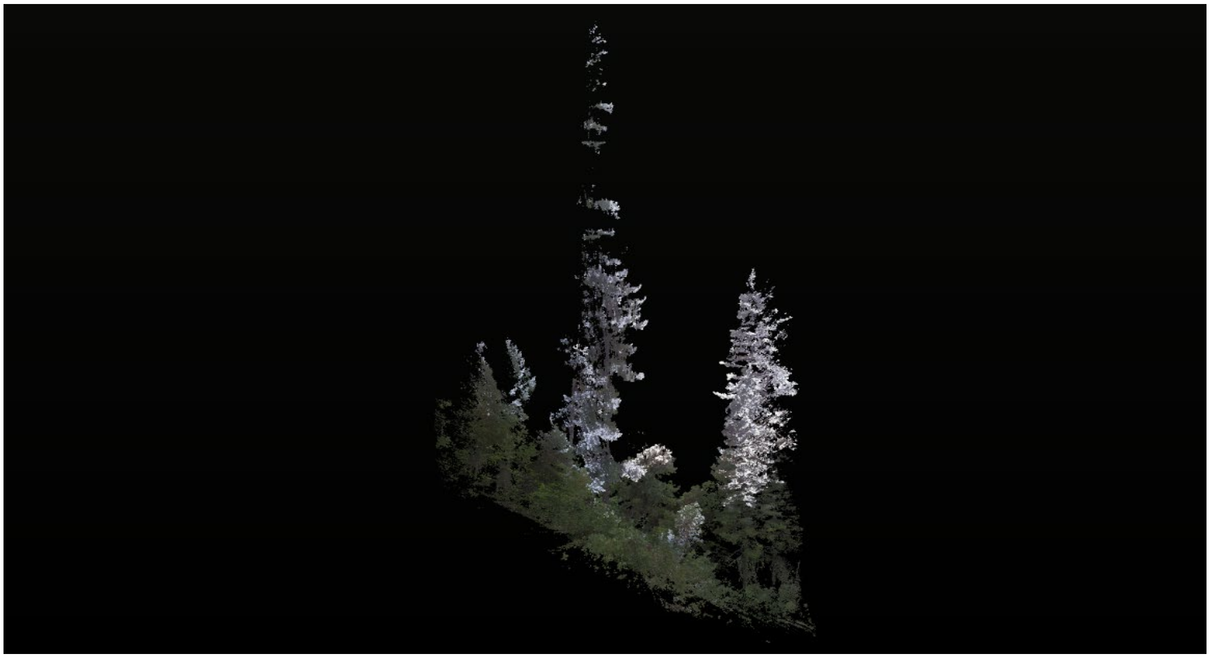
Plot 15 Transect 3, 50-0

Plot 15 UB TLS Scan

Plot 16 Transect 1, 50-0

Plot 16 Transect 2, 50-0

Plot 16 Transect 3, 50-0



Plot 16 UB TLS Scan

Appendix 3 - Substrate and Understory Vegetation Severity

Definitions of ordinal severity levels from the NPS Fire Monitoring Handbook. NOTE: FBAT reverses the scale in data collection and reporting because its more intuitive. That is, 1 = unburned and 5 = heavily burned.

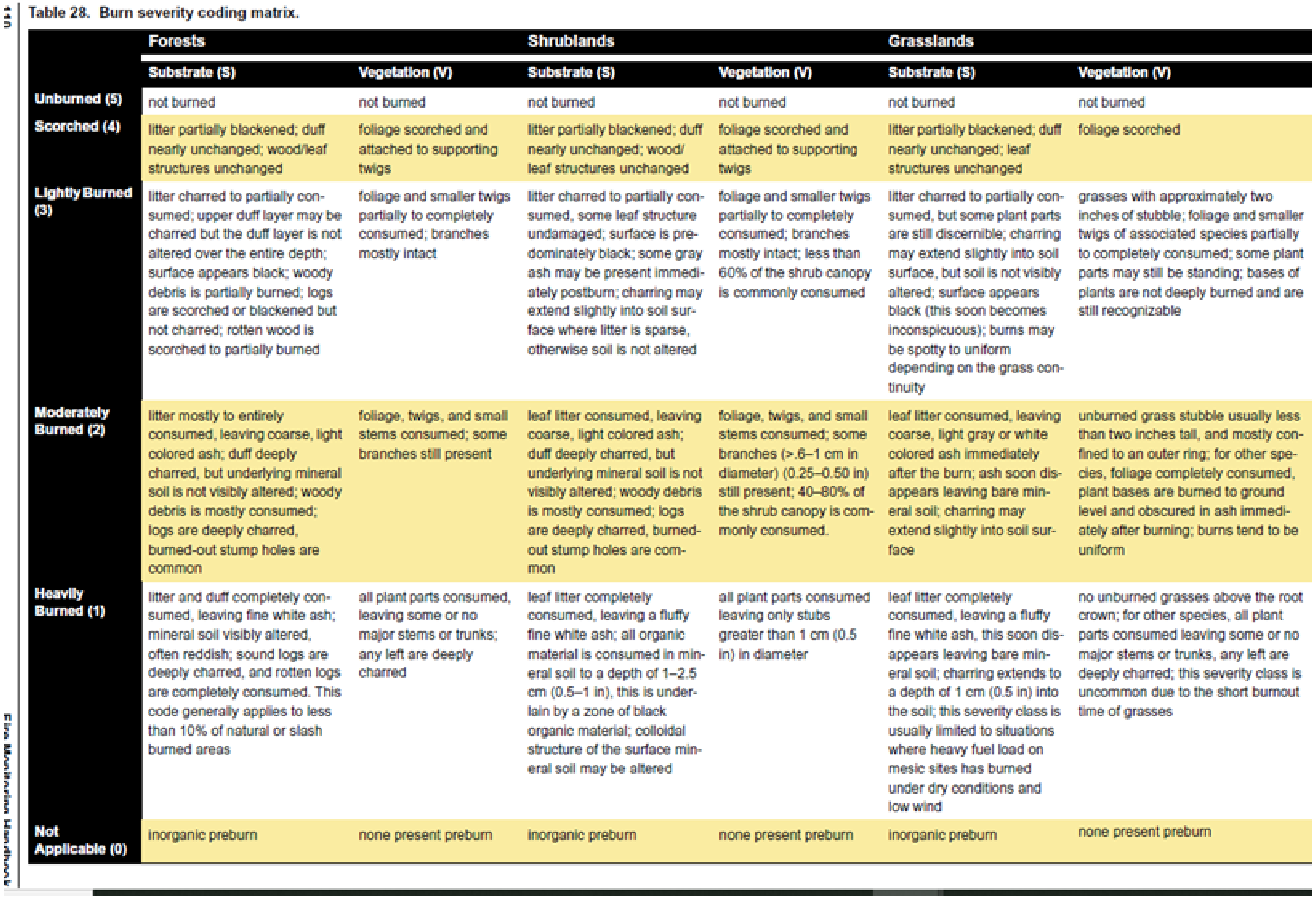


Table 28. Burn severity coding matrix.

	Forests		Shrublands		Grasslands	
	Substrate (S)	**Vegetation (V)**	**Substrate (S)**	**Vegetation (V)**	**Substrate (S)**	**Vegetation (V)**
Unburned (5)	not burned	not burned	not burned	not burned	not burned	not burned
Scorched (4)	litter partially blackened; duff nearly unchanged; wood/leaf structures unchanged	foliage scorched and attached to supporting twigs	litter partially blackened; duff nearly unchanged; wood/ leaf structures unchanged	foliage scorched and attached to supporting twigs	litter partially blackened; duff nearly unchanged; leaf structures unchanged	foliage scorched
Lightly Burned (3)	litter charred to partially consumed; upper duff layer may be charred but the duff layer is not altered over the entire depth; surface appears black; woody debris is partially burned; logs are scorched or blackened but not charred; rotten wood is scorched to partially burned	foliage and smaller twigs partially to completely consumed; branches mostly intact	litter charred to partially consumed, some leaf structure undamaged; surface is predominately black; some gray ash may be present immediately postburn; charring may extend slightly into soil surface where litter is sparse, otherwise soil is not altered	foliage and smaller twigs partially to completely consumed; branches mostly intact; less than 60% of the shrub canopy is commonly consumed	litter charred to partially consumed, but some plant parts are still discernible; charring may extend slightly into soil surface, but soil is not visibly altered; surface appears black (this soon becomes inconspicuous); burns may be spotty to uniform depending on the grass continuity	grasses with approximately two inches of stubble; foliage and smaller twigs of associated species partially to completely consumed; some plant parts may still be standing; bases of plants are not deeply burned and are still recognizable
Moderately Burned (2)	litter mostly to entirely consumed, leaving coarse, light colored ash; duff deeply charred, but underlying mineral soil is not visibly altered; woody debris is mostly consumed; logs are deeply charred, burned-out stump holes are common	foliage, twigs, and small stems consumed; some branches still present	leaf litter consumed, leaving coarse, light colored ash; duff deeply charred, but underlying mineral soil is not visibly altered; woody debris is mostly consumed; logs are deeply charred, burned-out stump holes are common	foliage, twigs, and small stems consumed; some branches (>.6–1 cm in diameter) (0.25–0.50 in) still present; 40–80% of the shrub canopy is commonly consumed.	leaf litter consumed, leaving coarse, light gray or white colored ash immediately after the burn; ash soon disappears leaving bare mineral soil; charring may extend slightly into soil surface	unburned grass stubble usually less than two inches tall, and mostly confined to an outer ring; for other species, foliage completely consumed, plant bases are burned to ground level and obscured in ash immediately after burning; burns tend to be uniform
Heavily Burned (1)	litter and duff completely consumed, leaving fine white ash; mineral soil visibly altered, often reddish; sound logs are deeply charred, and rotten logs are completely consumed. This code generally applies to less than 10% of natural or slash burned areas	all plant parts consumed, leaving some or no major stems or trunks; any left are deeply charred	leaf litter completely consumed, leaving a fluffy fine white ash; all organic material is consumed in mineral soil to a depth of 1–2.5 cm (0.5–1 in), this is underlain by a zone of black organic material; colloidal structure of the surface mineral soil may be altered	all plant parts consumed leaving only stubs greater than 1 cm (0.5 in) in diameter	leaf litter completely consumed, leaving a fluffy fine white ash, this soon disappears leaving bare mineral soil; charring extends to a depth of 1 cm (0.5 in) into the soil; this severity class is usually limited to situations where heavy fuel load on mesic sites has burned under dry conditions and low wind	no unburned grasses above the root crown; for other species, all plant parts consumed leaving some or no major stems or trunks, any left are deeply charred; this severity class is uncommon due to the short burnout time of grasses
Not Applicable (0)	inorganic preburn	none present preburn	inorganic preburn	none present preburn	inorganic preburn	none present preburn