Low Intensity Wildfire Resulted in Severe Effects in Old-Growth on the H. J. Andrews Experimental Forest

2023 Lookout Fire, Willamette National Forest

29 November 2023

Pre-, active-, and post-fire images from Plot 5

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Summary

The Lookout Fire ignited by lightning on August 5th, 2023, on the H. J. Andrews Experimental Forest (HJA) within the Willamette National Forest in Oregon. Fire growth to the northwest in the Lookout and McRae Creek drainages provided opportunities for the Fire Behavior Assessment Team (FBAT) to install plots ahead of the fire in forest with old-growth characteristics, including large overstory trees and downed logs, many of which had rotted into duff. We installed plots primarily in stands dominated by large Douglas firs with a significant representation of smaller western hemlock, western redcedar, and yew. Past snag felling had occurred in and around some plots that were near roads or clearcut blocks. Surface fire was the dominant spread mode through plots and consumption of duff and downed logs was substantial. Seven of 12 plots we installed burned between 14 and 19 September, 10-15 days after a wetting rain. Despite the rain, drought was moderate to severe when plots were burning and the Energy Release Component (ERC), an indicator of fire hazard, ranged between 82 and 97% relative to its peak values for those days since 2018. A time-lapse is available online showing general progression of the fire between 21 August and 17 October, capturing the area and timeframe for the southernmost plots closest to Lookout Creek (USDA Forest Service, 2023a).

Fire regimes on the HJA have been described as a mix of stand replacing fires occurring on a multi-centuries time scale with regional synchroneity and more frequent, lower intensity fires known from fire scarring within bark crevices of overstory, fire-tolerant Douglas firs (Morrison & Swanson, 1990; Weisberg, 2004). No wildfires had been recorded in available databases in the areas where the plots were installed but plots on upper slopes are known to have experienced stand-replacing fire in the 1800's while plots in wetter landscape positions, the ones that burned, had experienced stand-replacing fires centuries earlier. Plots that burned scored from 33-55% on a fire refugia probability index. The presence of fire scars and bark char in some plots indicated that surface fires had occurred in the past. These lower-intensity fires have been shown to have limited effects on the Douglas fir overstory but result in more variable stand structures and midstories that are, on average, composed of larger-diameter trees than occur in stands that did not experience such fires (Weisberg, 2004). Our objectives in this report are to describe the fuels, fire behavior, and fire effects during low intensity wildfire in stands with old-growth character growing on the west slopes of the Cascades. We provide a first-person account of fires and their effects that otherwise would have to be inferred from stand reconstructions performed years afterwards.

Based on video and measured fire effects on tree canopies, fire spread through plots as surface fire with low rates of spread (FBAT, 2023a). Local spread rates estimated from video ranged from <0.1 to 1.3 ch/hr (<7 ft/hr to 85 ft/hr) while spread rates estimated over entire plots from fire-arrival sensors ranged from 0.01 to 0.23 ch/hr (0.7-15 ft/hr) reflecting uneven and often patchy spread. In Plot 5, the plot with the highest rate of spread, fire carried on bark and moss up the trunks of large trees and there was short-range spotting. This behavior was observed 10 days after rain when air temperatures were 82° F and relative humidity (RH) was 21% and fire was backing against a 2.5 mph wind with gusts up to 6 mph. Despite the relatively low intensities, fire effects on trees are expected to be significant, particularly for poles and overstory species other than Douglas fir. Of all overstory trees in the plots, Pacific yews, red cedars, and western hemlocks often experienced severe heating of their primary roots (36.5% of trees) causing mechanical failure (tree fall) in 10.5% of trees. Western hemlocks, the most common overstory tree, experienced root damage 15% more often than expected from its abundance. Part of this effect appears to have been a result of a tendency for hemlocks to regenerate on

downed and rotten logs (known as nurse logs) that consumed in the fire. After fire, these trees were often left perched above the mineral soil. Added root heating was also caused by their habit of root growth at the surface of the mineral soil below the duff. There was limited canopy injury recorded on Douglas fir trees and they experienced no apparent damage to primary roots because of their habit of rooting in mineral soil after stand replacing fire. A few Douglas firs in plots experienced some degree of stem damage from combustion of rotten wood derived from past injuries. The effects of combustion of deep duff around the bases of Douglas firs is unknown but will become apparent in the coming years. Generally, canopy heating causing injury to foliage (e.g., scorch) occurred most extensively on pole and small-statured overstory trees. Effects on understory vegetation such as vine maple, rhododendron, and an array of smaller shrubs and herbs was substantial because of duff consumption. Soil heating and effects were generally low to moderate except where logs and deep duff burned. Pre- and post-fire photos along plot transects are shown in the Appendix.

Elevated rates of tree fall in old-growth and mature forest during the later stages of the Lookout Fire created hazardous conditions for fire management personnel even as fire spread in surface fuels. In preparation for future fire management operations around old-growth, management activities that reduce tree vulnerability to failure along planned containment lines may be a way to reduce risk to personnel and increase effectiveness of containment operations. Western hemlocks appear to be particularly vulnerable to root damage from the combustion of deep duff associated with old, downed logs. Canopy-dominant Douglas firs were resistant to surface fire effects, though long-term monitoring will be required to understand the full effects of basal duff combustion. A larger sample of the fates of overstory trees is required but our results suggest that trees associated with deep duff and with stem rot from past injuries will be particularly vulnerable to failure. Even with reduced tree fall hazards along containment lines, the tendency for fire to carry up tree boles during dry conditions, often resulting in spotting, will continue to present problems for containment and may be difficult to mitigate, especially during windy conditions. Effects of low intensity fire on trees in our plots are consistent with findings from past studies in old growth dominated by Douglas fir on the west slopes of the Cascades (Weisberg, 2004) and provide an expectation for future effects of similar fires during moderate to severe drought in areas that rate highly as fire refugia.

Introduction

This report summarizes the results of the Fire Behavior Assessment Team's (FBAT's) plot-based measurements of pre-fire fuels and vegetation, active fire behavior, and post-fire fuels and fire effects on the Lookout Fire within the H. J. Andrews Experimental Forest (HJA). In consultation with HJA staff, FBAT installed plots in old-growth forest along a site productivity gradient from the ridgeline northwest of McRae Creek to riparian areas along Lookout Creek (Figures 1 and 2). Ultimately, plots installed on lower slopes were the ones that burned.

FBAT objectives on the Lookout Fire were to:

1. Describe fuels, fire behavior, and fire effects in west-slope Cascades old-growth forest
2. Safely and efficiently maximize the number of plots inventoried pre- and post-fire for fuels, vegetation, fire behavior, and fire effects
3. Begin a collaboration with National Forest staff to build a dataset of fuels, fire behavior, and fire effects in west-slope Cascades ecosystems
4. 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 decision-making
5. Deliver a summary report that would support fire and land managers, FBAT data archive users, and long-term plot monitoring

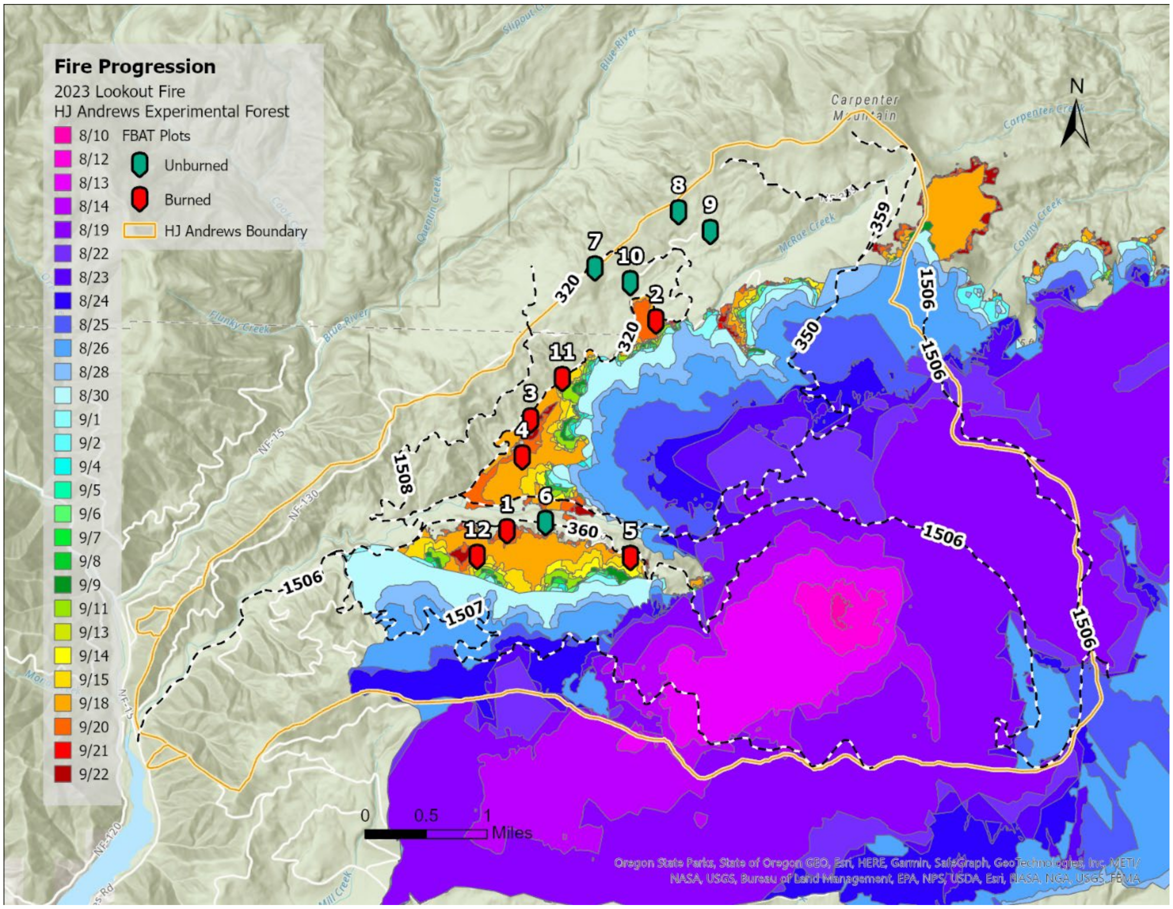


Figure 1. Progression of the Lookout Fire within the H. J. Andrews Experimental Forest and FBAT plot locations. Updated through September 22, 2023.

Methods

The general layout of an FBAT plot is shown in Figure 3 where measurements include: fixed radius plots for pole-sized and overstory trees; modified Brown's line transects for duff, litter, and downed woody material; belt transects for understory vegetation centered on the modified Brown's line; an array of fire arrival detectors for rate of spread; and a video camera and anemometer at 4.5 ft. Canopy cover measurements are taken at intervals along the modified Brown's lines and an instrument measuring soil heating profiles is placed at a designated position along each transect. Transect measurements are repeated post-fire and fire effects assessments are conducted 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 ([FBAT, 2023b](#)).

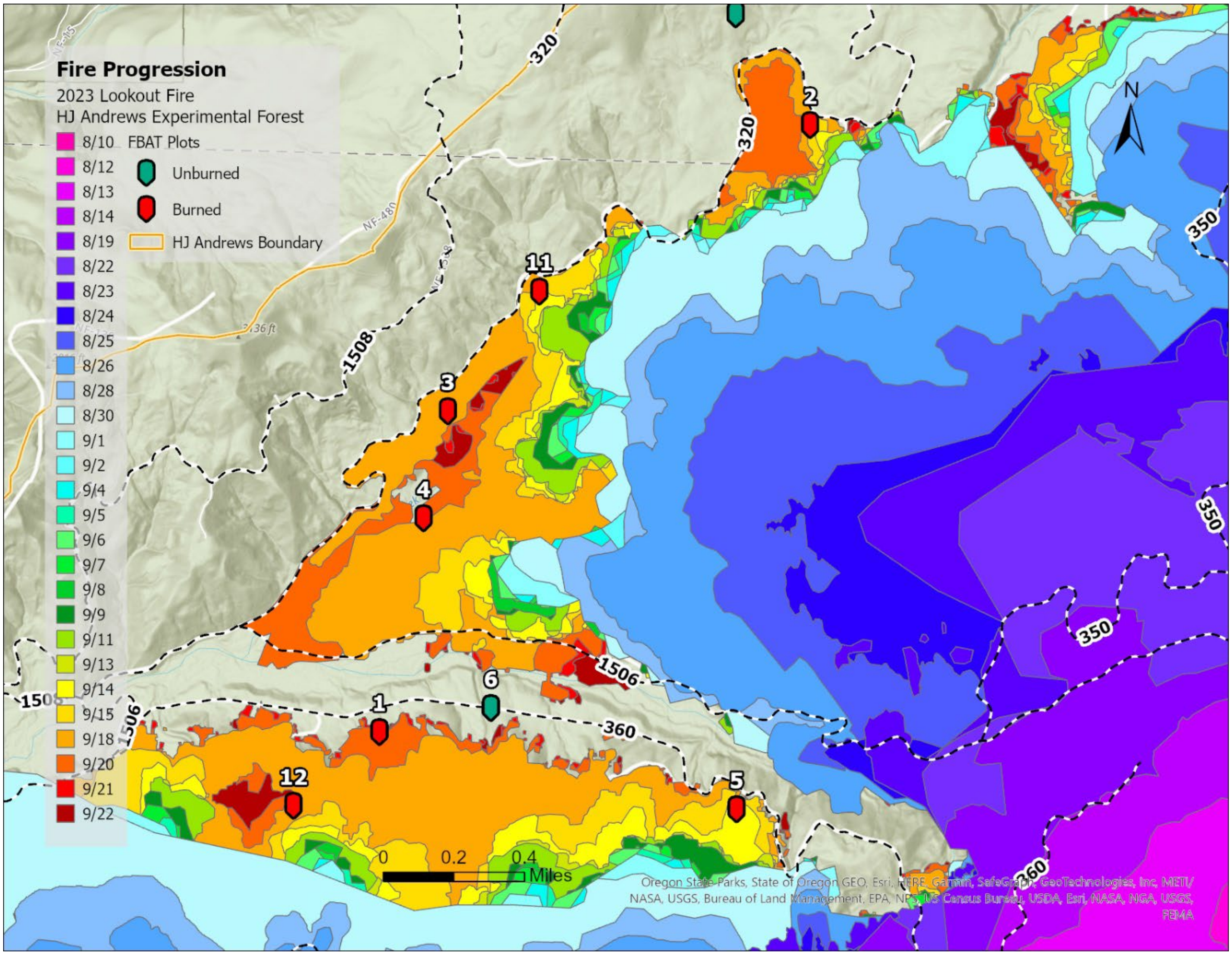


Figure 2. Close-up of the burned plots (1-5, 11, 12) within the progression map for the Lookout Fire and the H. J. Andrews Experimental Forest. Updated through September 22, 2023.

Overstory Vegetation Structure and Crown Fuels

Fixed radius plots were used to characterize crown fuels and overstory vegetation structure (Figure 3). Fixed-radius plots were implemented in 2022. In prior years a variable radius plot was used. 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 from 50 – 35 ft in an attempt to sample around 10-15 each of overstory and pole-sized trees.

Post-fire measurements were collected 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”). Changes in canopy base height were estimated from the average height to which the crown was affected.

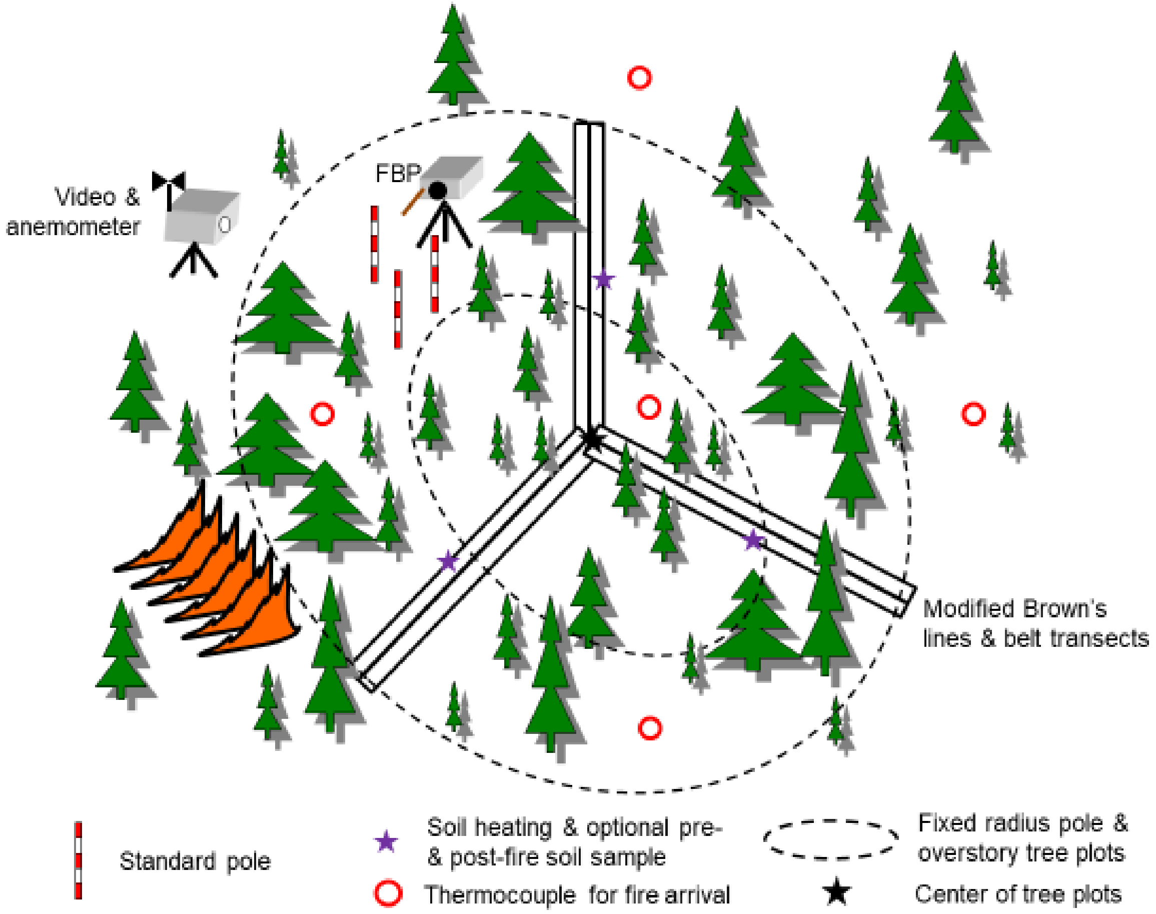


Figure 3. Plot layout. Modified Brown’s lines and understory vegetation belt transects are anchored at plot center. The concentric circles represent fixed-radius plots for pole and overstory trees. The thermocouples (TC) are for determining fire arrival times for calculating rate of spread (ROS), and the standards are positioned

within the field of view of the camera. The centers of the thermocouple array and tree plots are offset from plot center. Soil temperatures are measured at three depths at one location along each transect.

Plot data and the Forest Vegetation Simulator (FVS, Crookston & Dixon, 2005) were used to summarize tree characteristics from pre-fire 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. The Western Cascades variant was used. 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 & 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 (Figure 3). Surface fuel loading and fuel height were measured using the line-intercept method (Brown, 1974; Van Wagner, 1968). 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 modified Browns line transects (Figure 3). 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 along the 50 ft x 3 ft transect) 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 & Rothermel, 1984). Calculations were completed using an Excel spreadsheet developed in 2005 by Joe Scott and adapted for use with FBAT data.

Fire Weather and Behavior

At each plot, thermocouples, an anemometer, and a video camera were set up to gather information on wind and fire behavior (Figure 3). The thermocouples arrayed across the plot captured date and time of fire arrival and were used to estimate rate of spread. An anemometer affixed to the camera box at 4 ft above ground recorded wind speeds leading up to the fire. Where imagery was successfully captured, it was used to determine fire type, flame lengths, and variability in direction and rate of spread of fire in relation to slope and wind, flame duration, and wind direction. The camera was triggered by fire arrival at thermistors (which act as circuit breakers) connected into a wire circuit that was placed surrounding the plot.

Rate of spread was determined both from video analysis and by calculating rate of spread from fire arrival times at thermocouples at known positions. Data loggers used for recording temperatures were buried underground with the attached thermocouple positioned at the surface of the fuel bed. Distances from the central to outer thermocouples is about 50 ft. Thermocouples recorded temperatures at two second intervals. The distances and azimuths among thermocouples were measured and these position and time of fire arrival were used to estimate fire rate of spread through the plot (Simard et al., 1984). Rate of spread can be calculated with any combination of three sensors forming a triangle. If more than one triangle of sensors triggered, all rates of spread were calculated and mean and standard deviation are available.

Fire type was classified as surface fire (low, moderate or high intensity) or crown fire. Crown fire can be defined as either passive (single or group torching) or active (tree to tree crowning). Fire type was determined from video as well as from post-fire effects at each plot. For example, plots with complete consumption of tree canopy needles (torching) indicate at least passive crown fire.

Flame length was primarily determined from video footage. Reference poles in the video camera's field of view are marked in 1-foot increments, allowing flame length to be estimated. Flaming duration (where it is possible to measure) is based on direct video observation.

Wind speeds were estimated from the anemometer and video was used to estimate wind direction. The anemometers are not fire hardened and are damaged by heat during intense fires, indicating fire arrival at the anemometer. The maximum wind speed and average over 20 minutes before fire arrival is reported. If the anemometer is not damaged, the 20 minute averaging period ends after peak winds occur while the fire is near the anemometer (as indicated by arrival at nearby ROS sensors). If no peak is evident, the time of fire arrival at the nearest ROS sensor determines the end of the averaging period.

We used the Wx_NFDRS_Matrix_2023_NFDRSv4.xlsb spreadsheet to generate fire weather indices to provide historical context for the period during which FBAT plots burned. 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) 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). Loading (determined by fuel model) and moisture contents of larger-diameter woody fuel have a large influence on ERC, while the lighter fuels have less influence, and wind speed has none. ERC has relatively low variability and is the best fire danger index for indicating overall seasonal severity potential.

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). 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 fire line 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.

Soil heating

Soil temperature profiles are measured using an “iStake” (Brady et al., 2022). This device provides measurements of mineral soil temperature at 2, 4, and 6 in. (5, 10, and 15 cm) depths below the surface of the mineral soil. A high-temperature iButton logger is used at 2 inches and low-temperature loggers are used at 4 and 6 in. We collected pre-fire soil samples on the Lookout Fire. Duff and litter depth are measured at the soil stake location to correlate the ground fuel load with soil heating.

Results and Discussion

A complete set of pre-, active-, and post-fire measurements were collected for burned Plots 1-5 and 11-12. Site selection involved locating plots in areas with tall trees and limited gaps. Additionally, once on site, adjustments to plot position were made to reduce hazard to personnel from falling snags and live trees. As such, plots will not be an unbiased representation of all old-growth stands in the study area.

Site Description

The Lookout Fire (Figures 1 and 2) burned in the Cascades ecoregion and is classified as a moist and highly productive coniferous forests. The plots are located on the northwestern side of the HJA, which is operated by the Pacific Northwest Research Station in partnership with Oregon State University and is part of a long-term ecological research network (LTER). CS2MET, a meteorological station at the H. J. Andrews which has operated since 1957, has a mean annual precipitation of 92 inches and an average annual temperature of 48.6° F (Ward et al., 2020).

The experimental forest has historically focused on studying forest management and logging practices within the Douglas Fir dominated 15,800 acre old-growth forest that primarily encompasses the Lookout Creek Watershed (OSU, 2023). The FACTS (Forest Service Activity Tracking System) database indicates that clearcuts were the most common within the HJ Andrews, followed by commercial thins and shelterwood establishment cuts, as shown in Figure 4. The last clearcut occurred in 1987 and commercial thinning has been the only timber harvest activity listed since (USDA Forest Service, 2023b). The plots are located outside these areas among large diameter trees, but there was evidence of snag abatement within and surrounding some of the plots and Douglas fir appear to have been cut out of Plot 5 some decades ago.

Summary information for the plots is provided in Table 1. Plot elevations ranged from approximately 2000 to 3500 ft across a range of aspects. Slopes in plots were moderate, ranging from 14 to 46%. The plots are in an area where there is no recorded wildfire history, but some plots likely had low intensity fire given occasional fire scars and bark char. Local fire scar research indicates at least 35 fires between 1482 and 1952, with a mean fire return interval (MFRI) of 114 years, and fire rotation increasing dramatically after 1910 due to fire suppression (Teensma, 1988).

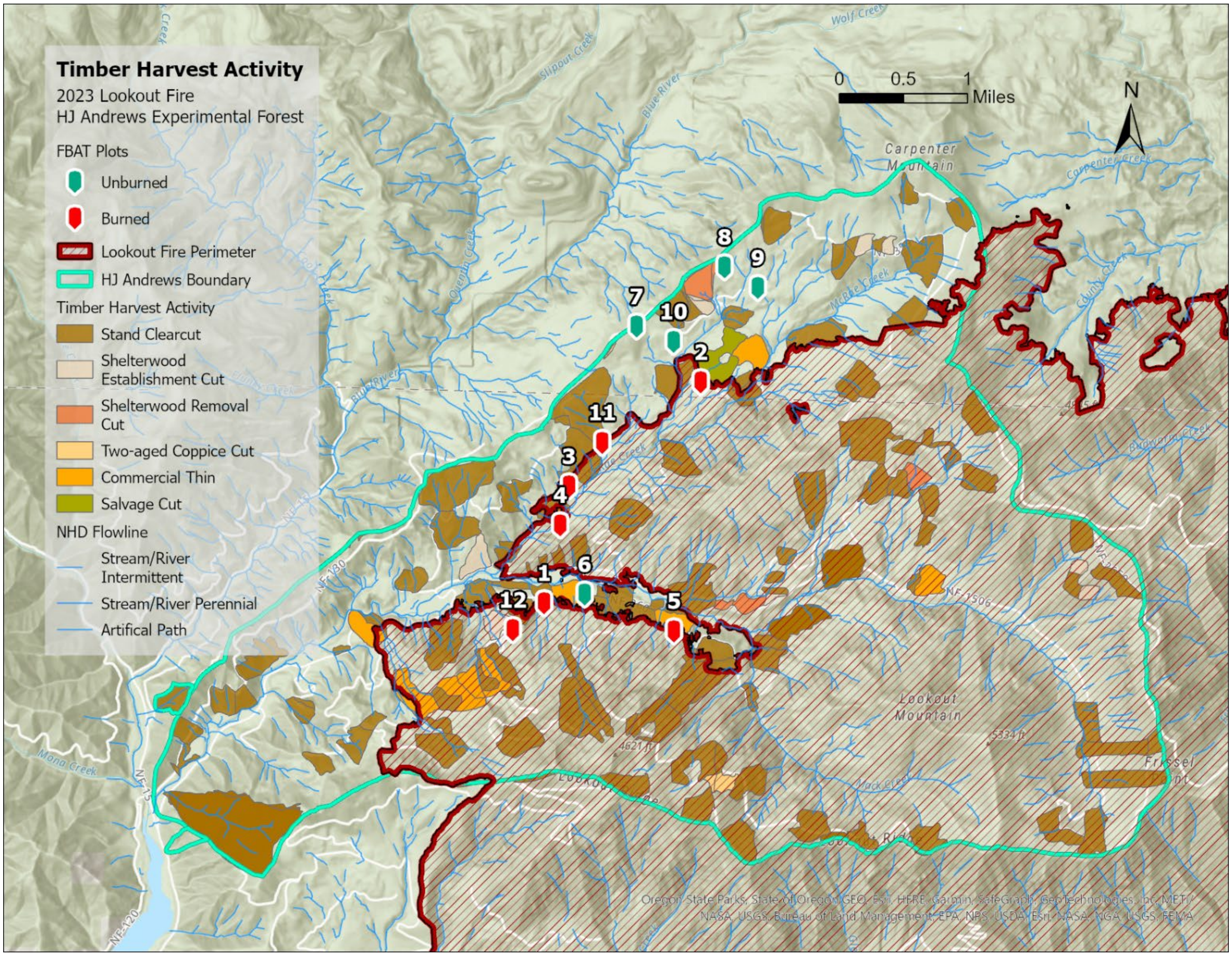


Figure 4. Past timber harvest activity within the H. J. Andrews Experimental Forest. Data sourced from the EDW FACTS dataset.

The HJA contains Douglas fir/western hemlock late successional old-growth stands that are thought to serve as fire refugia, that is, sites where fires occur less often and at lower intensities than surrounding areas because of their landscape position relative to eco-hydrology and landscape fire spread dynamics. These areas help facilitate post-fire recovery of ecosystems and offer sanctuary to sensitive species in fire-prone landscapes increasingly subjected to severe drought and extreme temperatures (Downing, 2021). Figure 5 shows a fire refugia probability map developed by Oregon State for the HJA under an extreme fire weather scenario with 10th percentile relative humidity (RH) and 90th percentile maximum temperature (Tmmx) obtained through the Eco-Vis web app (https://firerefugia-app.forestry.oregonstate.edu/projects/v3). The probability data were generated from boosted regression tree (BRT) models, which incorporate information such as burn severity (RdNBR), fire weather, fire growth, and GNN vegetation structure. Highly predictive variables included live stand biomass, fire resistance score, relative position (e.g., relative to solar radiation and plot wetness), daily maximum temperature, minimum humidity, and the moisture content of 1000-hour fuels (Naficy, 2021). Plots ranged from 27 to 55% on the fire refugia probability index with burned plots on lower landscape positions ranging from 33 to 55%.

Table 1. Site descriptions for 12 FBAT plots sampled on the Lookout Fire. Latitude and longitude datum is WGS 84. Elevations are from GPS. Fire refugia probability (Figure 5) is averaged from a 100-ft buffer around plot center.

Plot	Latitude	Longitude	Slope (%)	Aspect (°)	Elevation (ft)	Fire Refugia Probability (%)
1	44.23018	-122.20075	28	355	1990	46
2	44.25553	-122.17710	23	164	2641	33
3	44.24340	-122.19734	14	124	2061	38
4	44.23899	-122.19856	13	312	2031	55
5	44.22742	-122.18024	34	272	2421	43
6	44.23129	-122.19442	17	5	2055	34
7	44.26160	-122.18741	46	124	3196	29
8	44.26853	-122.17385	32	125	3510	27
9	44.26630	-122.16853	14	120	3228	33
10	44.25998	-122.18152	20	140	2896	29
11	44.24840	-122.19230	30	220	2292	40
12	44.22707	-122.20554	16	316	2418	41

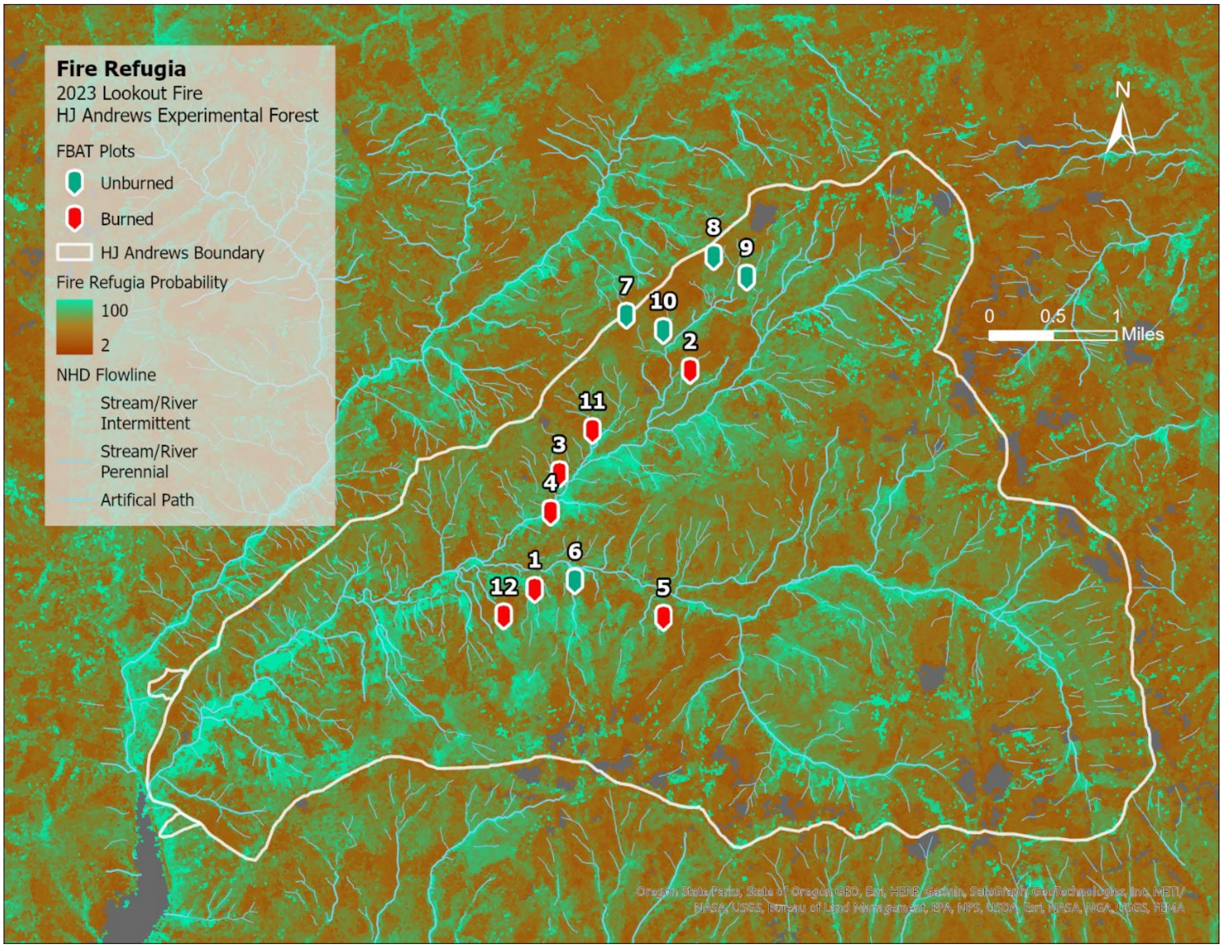
Plot Descriptions

The following plot descriptions are intended to support data use and re-sampling, as funding allows.

Plot 1

Access: Drive east along the 360 road from the 1506. Pass treatment block L105. Plot is south of road ~100 yards between two small drainages, west of L106. To get to the plot, follow a trail used to reach research plot. Trail leads to experimental tree 026. Tree has old rope and PVC running up the bole. Big Douglas fir. Tree 026 is ~150 ft from plot center. Azimuth from tree 360°.

Description: Dense canopy. Air was smoky on the day it was sampled. Chosen because of old-growth features (outside of treatment area). Salvaged mostly around plot, but there are about 5 stumps in the plot. Chosen non-randomly because of presence of large, tall trees. Intended to represent lower hillslope position old-growth.



Oregon State Parks, State of Oregon GEO, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, Esri, NASA, NGA, USGS, FEMA

Figure 5. Fire refugia probability and FBAT plot locations within the H. J. Andrews Experimental Forest. Fire refugia data were obtained from the Fire Refugia Project at firerefugia.forestry.oregonstate.edu.

Plot 2

Access: Plot is outside the edge of an H. J. Andrews “Big Plot” that also include long term reference stand plots. Between the 320 road and edge of plot. Along trail flagged from the road.

Description: Plot chosen with fire about 1/4 mile away, didn't have much time to find a plot without past logging disturbance. Trail goes to northern corner of Forest Geo plot. Salvage and maybe danger tree cutting in and around plot.

Plot 3

Access: On road at top of descending ridge between drainages. Uphill from the 322 spur between two drainages. Accessed east along the 322 road but going was difficult from downed trees. Will return to vehicles from the 320 road. Creek was right below the 322 road.

Description: Plot is in an area with minimal salvage, mostly uprooted trees that were cut. Fire scars on plot. Less duff because of past fires one suspects. Chosen for presence of large, big trees and minimal snag hazard.

Plot 4

Access: Plot is across the creek from the tallest tree on the H. J. Andrews off the SE edge of cutting unit L502. From end of the curve near the start of the 322 spur, go down towards the creek along the trail to tall tree. Pass the tree on the left and cross the creek on the log. Walk upstream for 150' approximately then up the bank past a huge stump.

Description: Plot is on the flat above the floodplain, dominated by large Douglas firs, with an understory of western hemlock and vine maple. Plot chosen to be on the fire side of the creek, in a riparian landscape position. Surface fuels are dominated by lichen and litter.

Plot 5

Access: Plot is in an old-growth area, near edge of unit L108.

Description: No cut stumps evident. Plot located to avoid snag fall into plot post fire. Lots of snags around. For all these plots, location choice often determined by safety. Stand is dominated by big Douglas fir with western hemlock reproduction. Plot is mid-slope to upper middle based on topography.

Plot 6

Access: Plot is part of an old-growth stand between road 360 and Lookout Creek. Location is as far away from 360 as possible before going off into the ravine along the creek. Stand is between L106 and L107A north of road 360.

Description: Position in stand is where snags will least likely fall into the plot after the fire. Stand is dominated by big Douglas fir with subdominant western hemlock. Yews in the lower canopy. Mix of moss with needle litter mixed in. Oregon grape is the dominant shrub with ferns and rhododendron.

Plot 7

Access: Parking location is at 44.06544, -122.97846, on the ridge at the intersection of Roads 320 and 410. Walk SW along the ridge on the 320 to near the base of a high point along the ridge. Plot is off the ridge to the SE of the high point.

Description: Plot is dominated by trees smaller than those at lower landscape positions, supporting the expectation that the plot burned in a stand replacement event in the 1800’s.

Plot 8

Access: Access 328 road approximately 0.15 miles NE of RAWS stations (parking location). Steep gain in elevation. Approximately 32-degree slope. The plot is just downslope (SE) of trail that runs below the ridge. Plot is upslope from a cluster of long-term reference stand plots. East of cut block/watershed 7.

Description: Charred bark on the ground and on trees indicates past fire. Stand looks multi-age with some big surviving Douglas fir and smaller western firs. No fire scars on trees, but it is thought that the plot burned within the 1800s. It is not clear whether Douglas fir were the only survivors of past fires or if other tree species were selectively culled or harvested to promote Douglas fir regeneration.

Plot 9

Access: Park near small A frame building at the end of road 327 (gauging station). Continue on old roadbed then slightly NE into a mature stand.

Description: Site is abundant in downed rotting logs. Douglas fir, cedar, and hemlock are present at site. Near the plot are uncommon lichens (*Chaenotheca furfuracaea*) and fungi (*Laricofomes officianales*) that are associated with stable, older growth stands. Lots of western hemlock and, even more red cedar advance regeneration and understory trees.

Plot 10

Access: Plot is west of the end of the road that serves the watershed 6 gauging station. Road continues past the trail to the gauging station, overgrown.

Description: Stand appears to have arisen from mixed severity fire. There's a smaller cohort of western fir and cedar. Center on big Douglas firs. Modest amount of downed large logs. Plot chosen to be mid-upper slope below ridge. Assigned on map and location adjusted to avoid snags

Plot 11

Access: Plot is south of road the 320 uphill from Plot 3, east of cutting block L404 old-growth stand. Plot is about 250' off the road. Walk in east of a drainage. There's an abandoned culvert at the road. An old trail can be followed for a bit. Plot is roughly 200 degrees from road.

Description: Douglas fir dominates with western hemlock in the midstory. Lots of downed trees and gaps. Understory is correspondingly more dense than other plots.

Plot 12

Access: Park at intersection of the 360 Rd and 363 Rd. Plot is NE of the last hairpin turn on the 363 Rd downhill ~75-100 yards.

Description: Plot is in forest that has been snagged/sanitized. It looks like some cut trees were Douglas fir. Canopy trees are entirely western hemlock. Midstory of suppressed western hemlock. Surface fuels are primarily moss and litter. Lots of 1-10hr woody fuels. Fire was observed creeping and torching downslope during plot installation.

Pre-Fire Vegetation and Fuels

The overstory trees (Figure 6) were predominantly Douglas fir, except for plots 7 and 12 which were dominated by western hemlock, and plot 10 which had an almost even mix of Douglas fir and western red cedar. Most plots were dominated by large trees and had moderate to dense canopies, although Plot 11 did have numerous gaps and low canopy cover. Shrub cover was present in most plots, but grass and forb cover was limited. In the understory, perennial bunch grasses were only present on a few sites (Plots 1, 8, and 10); forbs were present on several sites (Plots 1, 2, 4, and 9); shrubs were present on all sites except one (Plot 5); seedlings were found on all plots except one (Plot 12). Species included Cascade barberry (*Berberis nervosa*), salal (*Gaultheria shallon*), sword fern (*Polystichum munitum*), Pacific rhododendron (*Rhododendron macrophyllum*), *Rubus spp.*, red huckleberry (*Vaccinium parvifolium*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and vine maple (*Acer circinatum*).

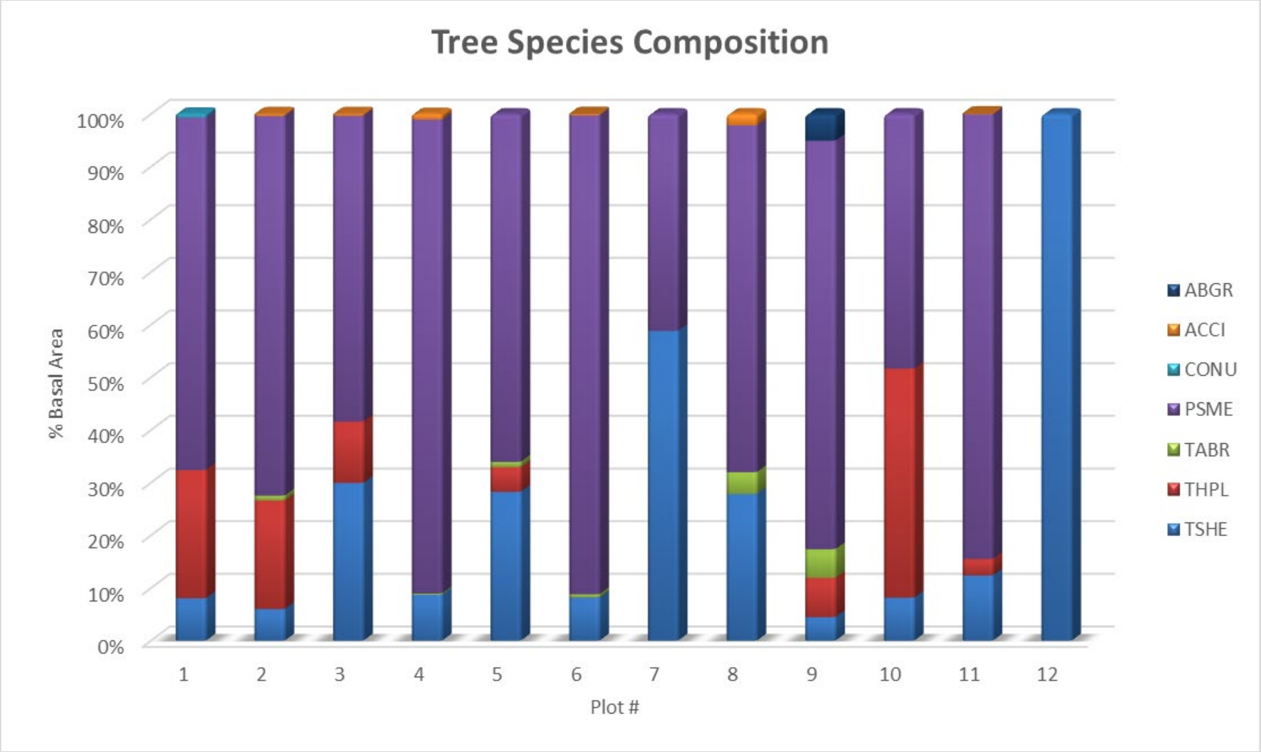


Figure 6. Overstory tree species composition on fixed-radius tree sampling plots. ABGR = grand fir (*Abies grandis*), ACCI = vine maple (*Acer circinatum*), CONU4 = Pacific dogwood (*Cornus nuttallii*), PSME = Douglas Fir (*Pseudotsuga menziesii*), TABR2 = Pacific yew (*Taxus brevifolia*), THPL = western red cedar (*Thuja plicata*), and TSHE = western hemlock (*Tsuga heterophylla*).

Overstory Vegetation Structure and Crown Fuels

Most plots low to moderate tree densities and higher basal areas as would be expected for old-growth stands (Table 2). All plots had pole trees and most had higher densities of pole trees than overstory trees indicating a developed mid-story, except for Plots 5, 7, 10, and 11. Plot 11, which had the lowest canopy cover and heights, also had a substantially lower QMD than other plots while still having relatively low tree densities. It exhibited the lowest live biomass per acre but had the highest biomass of snags per acre suggesting a unique stand condition compared to other plots (Table 3). Half of the plots had QMDs >20 inches as would be expected in old-growth stands (Plots 1, 3, 4, 5, 6, 9) while others exhibited comparatively lower QMDs especially given their pole densities (Plots 7, 8, 11, 12). Basal areas were highly varied across the plots.

CH varied between plots, but most were over 150 feet. The greatest canopy height of 278 feet was found in Plot 4, while the lowest of 99 feet was in Plot 11. Plot 11 also had the lowest CBH with only 13 feet, which is expected given the low QMD and CH. In contrast, Plot 3 had the highest CBH with 111 feet. On most plots, there is a substantial difference between canopy cover estimated by FVS and ground-based canopy cover measurements (using the Moosehorn device). Gound-based estimates of tree spatial patterning (even, random, clumped, etc.) were noted because they are needed as inputs to FVS to increase accuracy of cover estimates. The Moosehorn sample is not intensive.

Table 2. Pre-fire canopy characteristics for plots inventoried on the Lookout Fire. Outputs of FVS, based on plot data, are indicated. Abbreviations: quadratic mean diameter (QMD), basal area (BA), canopy height (CH), canopy base height (CBH), and canopy bulk density (CBD). 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)[3]**	**BA (ft^2/ac)[1]**	**Canopy Cover (%)**		**CH[1] (ft)**	**CBH[1] (ft)**	**Tree Foliage Loading (tons/acre)**	**CBD[3] (kg/m^3)**
	Overstory[1]	**Pole[2]**			**FVS[3]**	**Moose-horn**				
1	49.9	138.7	20.5	434	49	100	189	86	4.7	0.03
2	154.1	323.5	16.8	740	71	100	183	73	9.6	0.08
3	86.7	101.9	23.9	586	43	100	248	111	5.9	0.05
4	86.7	138.7	24.1	711	65	92	278	97	6.5	0.03
5	231.1	46.2	24.3	892	65	100	208	89	10.8	0.11
6	121.3	169.5	26.2	1087	90	100	250	79	11.8	0.09
7	266.2	77	12.8	306	77	100	115	48	8	0.13
8	221.8	369.7	10.3	343	43	100	163	83	9.6	0.09
9	123.2	138.7	21.0	632	59	92	180	68	10.3	0.08
10	177.5	107.8	17.6	481	81	100	124	57	7.1	0.10
11	107.8	89	8.4	75	17	92	99	13	3.2	0.06
12	155.3	308.1	13.8	479	84	100	118	35	5.6	0.08

[1]≥6 in DBH; [2]<6 in DBH; [3]FVS output

Table 3. Pre-fire tree biomass based on tree sampling and the Forest Vegetation Simulator (FVS).

Plot	**Biomass (tons/acre)**				
	Snags	**Foliage**	**Live (<3 in DBH)**	**Live (≥3 in DBH)**	**Total**
1	16	4.7	22.6	236	280
2	0	9.6	44.0	355	409
3	0.2	5.9	30.8	386	423
4	0	6.5	29.0	524	559
5	44.5	10.8	41.4	480	577
6	16.3	11.8	56.5	773	858
7	8.3	8.0	21.3	138	175
8	2.1	9.6	29.0	185	225
9	1	10.3	39.4	327	378
10	5.2	7.1	29.9	201	243
11	61.5	3.2	5.8	24	94
12	0	5.6	27.3	201	234

Surface, Ground, and Understory Vegetation Fuel Loading

The limited understory vegetation in most plots contributed little to fuel loadings and the largest fuel loadings were in duff and 1000-hr logs (Table 4). All plots had downed logs with an average diameter of 13 inches. Plot 11 had the highest number of down 1000-hr logs with 13 and an average diameter of 16.5 inches. Plot 11 also exhibited the greatest tons/acre of snags and the least of live trees in any size class (Table 3). Plots 4 and 8 had the least number of 1000-hr logs with two.

Table 4. Surface fuel loads and fuel bed depths for plots inventoried pre-fire on the Lookout Fire.

Plot	Loading (tons/acre)									Fuel Bed Ht. (in)
	Duff	Litter	1hr	10hr	100hr	1000hr	Grass & Forb	Shrub & Seedling	Total	
1	104.6	9.4	0.10	0.41	0.72	27.51	0.086	0.597	142.7	7.1
2	73.7	9.7	0.13	0.58	2.19	56.13	0.010	0.226	142.4	5.4
3	109.7	17.9	0.23	0.77	0.37	17.39	0.001	0.182	146.5	7.9
4	38.8	17.2	0.25	1.04	1.48	54.65	0.027	0.235	113.6	4.2
5	154.4	11.1	0.20	1.31	0.38	86.81	0.001	0.032	255.0	10.5
6	107.3	10.6	0.64	1.83	0.77	22.42	0.001	0.232	144.1	7.9
7	40.4	6.6	1.76	2.82	2.34	16.22	0.003	0.081	70.2	2.6
8	40.0	6.3	1.30	2.17	1.16	3.84	0.006	0.023	54.8	3.0
9	66.9	10.7	1.06	2.29	3.34	76.27	0.007	0.316	161.9	5.3
10	56.0	7.4	0.83	2.06	2.55	13.00	0.006	1.030	81.9	3.0
11	248.4	23.6	0.53	0.70	1.49	122.20	0.002	0.412	396.9	5.3
12	112.2	15.3	0.57	0.72	0.37	63.80	0.002	0.082	192.9	3.9

Fire Weather and Climatic Conditions

The U.S. Drought Monitor showed the area of the Lookout Fire as transitioning from moderate drought to severe drought between the 12th and the 19th when plots were burning (Figure 7; National Drought Mitigation Center, 2023). Weather data from the McKenzie Bridge Station shows above average temperatures in mid-September (Figure 8). From a global perspective, September 2023 was the warmest September and largest monthly anomaly for any month ever recorded (Rohde, 2023). The last day with measured rain preceding the plots burning was 4 September at the Trout Creek RAWS and 1 September at McKenzie Bridge (NWS, 2023).

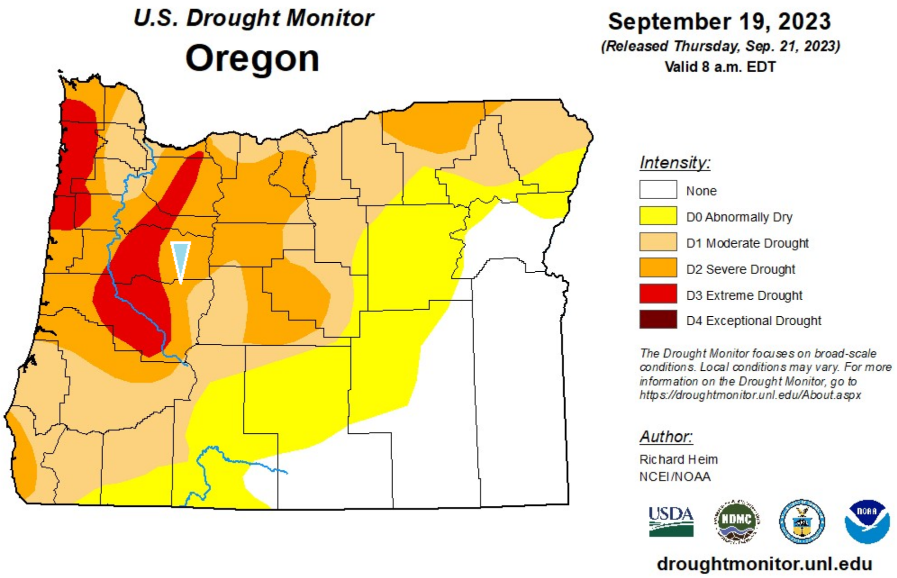


Figure 7. U.S. Drought Monitor map for Oregon during the week of September 19th, 2023. Location of the plots and the HJ Andrews indicated by the light blue pin.

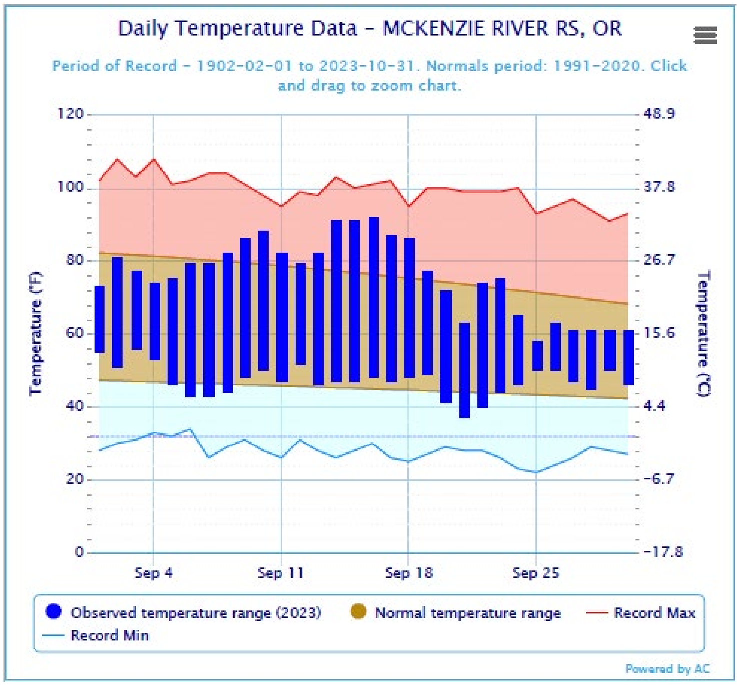
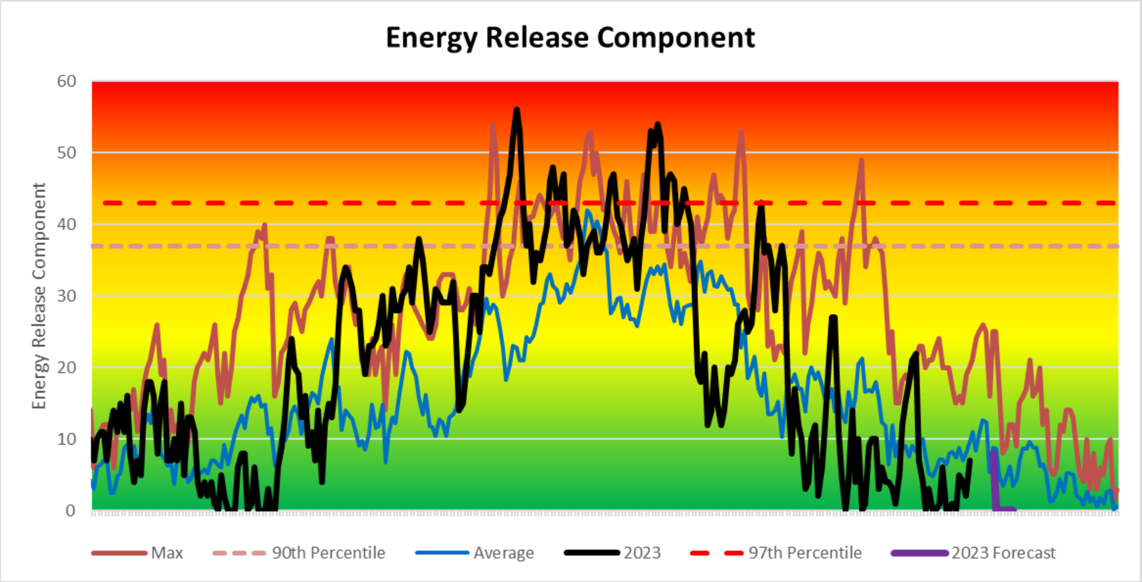


Figure 8. NOAA Weather (NOWData) for McKenzie Bridge Station during September, 2023 (National Weather Service, 2023).

Energy Release Component (ERC) charts for Trout Creek Remote Access Weather Station (RAWS) illustrate the seasonal to daily changes in fire potential for the area of the FBAT plots (Figure 9). Trout Creek RAWS is the most representative of the fire weather on North to South ridgelines and for the elevation range of the plots (Table 5). ERC values ranged from 82 to 97th percentile when plots were burning after recovering from relatively low values after a rainfall event in early September (Figure 9). The rainfall event had little apparent effect on large, downed woody fuels or deep duff whether that duff was derived from downed logs or other material.



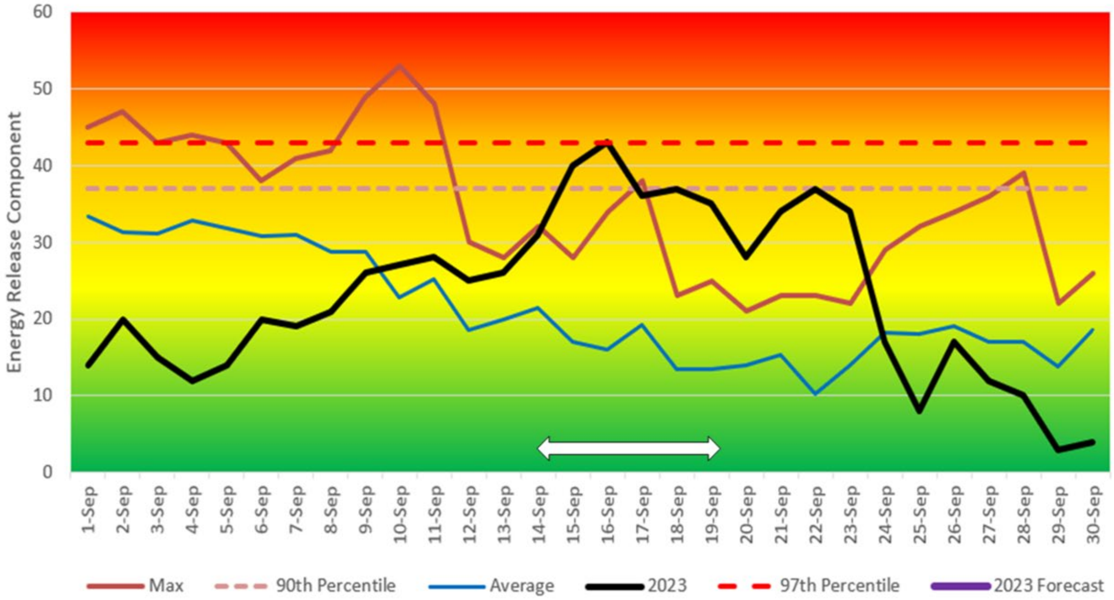


Figure 9. Seasonal trends from the Trout Creek RAWS are shown in the top figure while detail on the period during which FBAT plots burned is shown in the bottom figure. The white arrow in the lower figure shows the range in dates plots first experienced fire (14-19 September). Statistics were calculated from weather data from the Trout Creek RAWS from 2018-2023 (Table 5). Data from the Trout Creek RAWS were only available back to 2018. The Max and Average lines show the maximum and average ERC, respectively, for a given date between 2018-2022. The 90th and 97th percentile lines show the ERC values at which only 10% and 3% of values were larger, respectively. The 2023 line shows the conditions for the year the plots burned.

Table 5. Remote Automatic Weather Stations (RAWS) in the vicinity of the 2023 Lookout Fire. Distance refers to miles from the confluence of Lookout Creek and McRae Creek, near the location of FBAT study plots. Annual average rainfall on the H. J. Andrews Experimental Forest ranges from 90-140 inches.

RAWS Name	ID	Dist.	Aspect	Slope %	Slope Position	Elev. (ft)	Descriptive Location
Pebble Oregon	352554	10.5	WSW	5	Sloped bench	3560	Station is located in a seed orchard, approximately 10 miles east of study area
Trout Creek	352552	20.0	S	15	Ridgetop	2300	Station is 20 miles W-SW of study area on a N-S running ridgeline, about 2.5 miles south of McKenzie River
McKenzie Portable	NESS ID = 32A112C0	4.2	S	25	Mid-lower slope	1880	Station is south of the study site on a south facing slope, approx. 0.75 miles north of the McKenzie River

Ambient air temperature, relative humidity (RH), calculated fuel moisture, wind, and days since rain were obtained from the Trout Creek RAWS (Table 6) for the time of first arrival of the fire to each plot. We also measured wind at 4.5 ft on the plots at the time of first arrival. The temperatures, RH, and days since rain are likely to be representative of the plots, though winds are clearly not.

Table 6. Weather conditions in the area when the plots burned. Air temperature (at 4.9 ft), relative humidity (RH), and wind speed data for all plots was pulled from the H. J. Andrews Watershed 7 Meteorological Station (WS7MET), which is at an elevation of 3274 feet. Fuel moisture was obtained from the Trout Creek RAWS. Plot wind was taken with an anemometer at 4.5 ft above ground, which is affixed to the camera housing. See methods for how average and peak values are determined.

Plot	Temp (°F)	RH	Fuel Moisture (%)		Wind (mph)		Plot Wind (mph)		Days since rain[1]
			10-hr	1000-hr	20 min Avg	Peak	20 min Avg	Peak	
1	62.9	44.9	16	15	1.5	10.5	0	0	15
2	79.6	26.8	9	16	1.0	3.4	1.2	4	12
3	65.2	41.2	17	16	0.5	1.8	0.8	3	14
4	65.3	42.2	17	16	0.5	1.8	0	0	14
5	82.1	21.0	14	18	0.3	2.2	2.5	6	10
11	58.7	76.6	14	18	0.0	0.4	0	0	10
12	65.9	54.2	9	16	0.2	1.3	1.7	4	12

[1] Days since 4 September, the last day (before plots burned) with measured rain at the Trout Creek RAWS and McKenzie Bridge. We choose to use days since measurable rain instead of days since wetting rain (e.g., 0.1 inch) because of our expectation that it would best signal the start of a drying trend.

Fuel Consumption and Fire Behavior

There was considerable consumption of duff, downed-woody, live woody and herbaceous fuel on all plots (Tables 7 and 8). Plot 4 (Figure 10) demonstrated the lowest consumption at 32% and had the lowest pre-fire fuel loading of the burned plots. Plot 4 also scored highest on the refugia index (Table 2). The remainder of the plots ranged from 66% to 88% consumption, with near complete consumption of duff in all cases (Table 8). Consumption of 1000hr fuels varied widely across plots, ranging from 0-70%. 100hr and live vegetation experienced the greatest consumption, with Plots 3, 5 and 12 experiencing near 100% consumption of the above. Plot 5 pre-, active-, and post-fire imagery is provided on the cover page of this report.

Figure 10. Plot 4 post-fire sampling on November 16th, 2023. Photo by Benjamin E. Nash, Ecologist, USFS, PNW Research Station

Moss was included in litter depth measurements under the assumption that it would behave similarly to litter, however, we collected samples of this moss and litter layer to measure bulk density and compare it to an array of typical litter bulk densities. The average moss and litter sample bulk density was 0.16 $kg/m^2/cm$ on the low end of values measured for Sierra Nevada mixed-conifer forests that we use in our litter loading calculations (see van Wagtendonk et al., 1998). As such, estimates of litter fuel loading and consumption in Tables 4 and 7 might be overestimated (Table 7).

Table 7. Surface fuel loads and fuel bed depths for plots inventoried post-fire on the Lookout Fire.

Plot	Consumed Loading (tons/acre)								
	Duff	Litter	1hr	10hr	100hr	1000hr	Grass & Forb	Shrub & Seedling	Total
1	94.4	7.5	0.07	0.16	0.72	12.77	0.05	0.47	116.2
2	62.0	7.2	0.07	0.42	1.46	39.87	0.01	0.07	111.1
3	101.0	14.2	0.20	0.69	0.37	12.16	0.00	0.17	128.8
4	29.3	10.5	0.21	0.60	1.11	0.30	0.01	0.10	42.2
5	152.2	9.7	0.19	1.13	0.38	16.31	0.00	0.03	180.0
11	233.4	22.9	0.5	0.0	0.4	42.9	0.0	0.38	300.3
12	99.0	11.1	0.4	0.4	0.4	15.0	0.0	0.07	126.2
Avg	110.2	11.9	0.2	0.5	0.7	19.9	0.01	0.18	143.6

Table 8. Percent consumption of forest floor, downed-woody, and herb and live woody fuel.

Plot	Percent Consumption (%)								
	Duff	Litter	1hr	10hr	100hr	1000h	Grass & Forb	Shrub & Seedling	Total
1	90%	80%	77%	40%	100%	46%	83%	79%	81%
2	84%	75%	55%	71%	67%	71%	75%	29%	78%
3	92%	79%	85%	89%	100%	70%	100%	95%	88%
4	76%	61%	81%	58%	75%	0%	50%	44%	32%
5	99%	87%	91%	87%	100%	19%	100%	100%	71%
11	94%	97%	85%	-1%	24%	35%	87%	91%	76%
12	88%	73%	65%	50%	100%	24%	100%	83%	66%
Avg	89%	79%	77%	56%	81%	38%	85%	74%	70%

A description of fire behavior in plots follows and is summarized in Table 9. Appendix 1 contains pre- and post-fire photos along fuel sampling transects. Local spread rates estimated from video ranged from <0.1 to 1.3 ch/hr while spread rates estimated over entire plots from fire-arrival sensors ranged from 0.01 to 0.23 ch/hr reflecting uneven and often patchy spread. Rates of spread only temporarily increased with occasional flareups in small trees and brush on Plot 3 and Plot 5. Plots 2, 3, and 11 were near the 320 road, which was used during a burnout operation and likely influenced fire arrival times and behavior. Plot 4, 5, and 12 were not within the burnout area, and the fire progressed naturally through the plot areas. Fire behavior increased from late-afternoon into early-evening, coinciding with fire entering plots between 1455 and 2132 PDT, and continued to burn at night or into the morning. Plot 5 began burning during peak burning hours at 1655 as part of an overall increase in Fire behavior in the area on September 14, which increased the rate of spread (1.31 ch/hr) and fire behavior compared to other plots even while general spread was backing. Spotting behavior was observed in Plot 5 which may have increased plot-scale spread rates. Litter, duff, and 1000-hr fuels continued to smolder after fire had exited plot areas and had long-residence times within the plots. Fireline intensity (Byram's intensity) indicates heat release rates and is a function of consumption of surface fuels and rate of spread. Fireline intensities were low. Surface fuels are defined here as fuels that would normally be most important in flame front propagation and included litter, woody fuels up to 100-hr, and herb and shrub fuels.

Table 9. Fire behavior on Lookout Fire FBAT plots. Flame length (FL) and flame angle (FA) were estimated from video where available. For rate of spread (ROS), a flame front moving at 1 chain/hour is roughly 1 foot/minute. Rate of spread estimated from both video and fire arrival sensors are reported where available. The mean and standard deviation for ROS based on fire arrival is provided where there were two or more estimates available (i.e., two or more triangles of sensors with useable data). Fire arrival is the time the fire was first detected at the Plot. Departure time is the last time a fire arrival sensor was burned. Fireline intensity (also known as Byram's intensity) is a measure of flame-front heat release rate. Surface fires typically range up to 2000 kW/m and these fires were on the very low end of that range as a result of low spread rates.

Plot	Fire Type	FL (ft)	FA (%)	ROS (ch/hr)		Fireline Intensity (kW/m)	Fire Detection Date & Time (PDT)	
				Video	Sensors		First	Last
1	Backing downslope	N/A	N/A	N/A	N/A	N/A	9/19/2023 13:19:44	N/A [1]
2	Backing downslope	0.5	75	<0.1	0.01 [2]	2.2	9/16/2023 15:02:02	N/A [1]
3	Backing downslope	1.0	65	1.2	0.05 (0.02)	18.2	9/18/2023 21:14:20 E	9/19/2023 02:53:30 W
4	N/A [3]	N/A	N/A	N/A	0.12 (0.02)	35.5	9/18/2023 21:11:36 S	9/19/2023 00:27:40 N
5	Backing downslope against wind, short-range spotting	3	25	1.31	0.23 (0.27)	61.4	9/14/2023 16:55:01 E	9/14/2023 18:21:10 N
11	Spreading upslope against down-slope winds	1	60	<0.1	0.02 (0.02)	11.2	9/14/2023 00:53:54 S	9/15/2023 21:34:34 N
12	Backing downslope against wind	0.6	45	<0.1	0.02 (0.01)	5.7	9/16/2023 21:32:36 S	9/19/2023 12:41:06 C [4]

[1] No definitive ROS sensor data to establish when the fire left the plot area.

[2] Statistic is based on one triangle including west base outlier. No standard deviation available.

[3] Camera data for Plot 4 is unavailable. Based on the ROS sensors, the spread can be speculated as being backing throughout the plot area.

[4] Center ROS center was triggered last. There was a significant patch of unburned moss in the center of the plot.

Fire Effects

Although fireline intensities on the Lookout Fire plots were low (Table 9), fire effects below the canopy-dominant Douglas firs are likely to be relatively severe because of high levels of consumption of duff and, secondarily, downed logs (Table 7 and 8). Fire spread was patchy on most plots but where duff burned it largely consumed along with the associated understory vegetation. Pole-sized trees experienced moderate to severe effects on their canopies (Table 10), bases, and root systems (Tables 11-14). Douglas firs appear to have been minimally affected, though effects of basal duff consumption (Table 11) can only be confirmed in the coming years. Other overstory species (esp. western hemlock) suffered root injury and consumption at high rates (Table 15) because of consumption of large accumulations of duff derived from logs that had rotted into the duff layer. The effects we observed below the Douglas fir overstory are consistent with fire history and stand structure studies that found an increase in the average size of trees on plots that had experienced low-severity fire (Weisberg, 2004). Severe effects on soils were limited to areas where downed logs consumed, whether those logs were rotted into the duff or still relatively intact and counted as 1000 hr fuels (Tables 7 and 8). Detail on effects on soils and vegetation strata follow.

Table 10. Plot average bole char height and height to live crown, scorch height, percent scorch and torch for overstory (≥6 in DBH) and pole trees (<6 in DBH).

Tree Diameter Class	Plot	Bole Char (ft)		Crown Effects (%)					
				Scorch[1]			Torch		
		Min	Max	Average	Min	Max	Average	Min	Max
Overstory	1	0.9	20.7	0.6	0.0	5.0	0.0	0	0
	2	1.4	7.5	9.0	0.0	25.0	0.1	0	0.5
	3	1.2	13.6	0.0	0.0	0.0	0.0	0	0
	4	4.8	20.6	9.1	0.0	100.0	16.7	0	100
	5	5.9	49.6	44.7	0.0	100.0	0.0	0	0
	11	0.3	2.1	25.1	0.0	45.0	0.0	0	0
	12	0.9	3.9	0.0	0.0	0.0	0.0	0	0
	Average	**2.2**	**16.9**	**12.6**	**0.0**	**39.3**	**2.4**	**0.0**	**14.4**
Poles	1	0.8	3.3	55.7	5.0	100.0	2.9	0	10
	2	0.3	0.3	3.6	0.0	20.0	0.0	0	0
	3	0.8	5.5	47.9	0.0	100.0	1.9	0	15
	4	2.2	3.3	16.7	20.0	80.0	16.7	0	60
	5	0.5	11.0	100.0	100.0	100.0	0.0	0	0
	11	0.8	2.6	73.6	0.0	100.0	0.7	0	10
	12	0.2	0.9	0.0	0.0	0.0	0.0	0	0
	Average	**0.8**	**3.8**	**42.5**	**17.9**	**71.4**	**3.2**	**0.0**	**13.6**

[1] Scorch is percentage of the canopy affected by both scorch and torch minus torch.

Understory Vegetation

Effects on understory vegetation was largely driven by consumption of litter and duff, with more localized and severe heating effects due to the consumption of 1000hr fuels. We estimated moderate to high consumption of understory vegetation across all plots driven by high levels of duff and surface fuel consumption (Table 8).

Trees

Bole charring was substantial on overstory trees (Table 10). Video suggests that it was caused by combustion of bark and associated moss and lichen as would be expected from the low fireline intensities. Plot 5 burned under the highest ambient temperatures and lowest relative humidities and had the greatest char heights and crown effects (see active-fire image on the cover of the report). Generally, poles experienced more crown effects than canopy trees, as expected. There was limited crown torching overall.

Duff depths at the bases of overstory trees were often substantial (Table 11) and consumed at high rates (Table 8). Deep duff (and large loadings in Table 4) often indicate the remains of rotten logs. Consumption of duff accumulations had significant effects on overstory trees growing below canopy-dominant Douglas fir (see below).

Table 11. Duff depths for the four main overstory species measured at the base of their boles prior to burning.

Species	N	Depth (in)		
		Mean	Min	Max
PSME	35	9.6	1	27
TABR2	10	5.9	1	20
THPL	14	4.5	2	8
TSHE	77	7.9	2	24

Tree defects and injuries can greatly increase vulnerability to fire, and injuries sustained during wildfire can impact mortality in subsequent fires or other disturbance events. Pre- and post-fire damage to trees was documented utilizing modified protocols from the NPS Fire Effects Monitoring Handbook (FEMH, USDI National Park Service, 2003). Due to the FEMH focus on pre-fire condition, additional damage codes were introduced to better document post-fire damage observed in FBAT plots (Table 12). This is a new addition to the FBAT protocols as of 2023, and current data are insufficient for in-depth analysis, but there are significant trends apparent in the limited dataset.

Impacts to trees varied widely based on species identity, pre-fire stand condition, fire intensity, and fuel loading. As expected, understory poles bore the brunt of the effects with 55.6% of poles experiencing mechanical damage either immediately through combustion or, we infer, they will experience mechanical impacts eventually as rot proceeds in severely heated tissue (Table 14). Overall, 52.7% of overstory trees suffered immediate or prospective structural damage during fire on the plots (Table 15). There is a modest excess of fire structural impacts in overstory western hemlocks (79.5% of all structural damage events vs 65.8% of all trees). The excess is greater for impacts to root systems (81.5% of root damage events vs 65.8% of all trees). Western hemlock are particularly vulnerable to fire due to their shallow roots, thin bark, flammable foliage, low branches, and high densities. According to the Fire Effects Information System, they also tend to occur in cool, moist systems which may serve as fire refugia (Teske, 1992). Furthermore, western hemlocks frequently grow on nurse logs and in heavy duff (Table 11), which contributes to a greater vulnerability to fire and leaves trees perched on exposed and severely heated roots (see Figure 10) that will make them structurally unstable, particularly as dead wood rots. Many of these trees show limited effects on the canopy, but we expect them to suffer high mortality rates in the coming years because of root heating. Douglas fir, being large, having thick bark, and being rooted in mineral soil (Uchytil, 1991) were underrepresented among trees that experienced structural impacts (7.7% of all structural damage events vs 21.9% of all trees). The underrepresentation was greater for root structural damage (0% of root damage events vs 21.9% of all trees).

Table 12. Description of post-fire injury codes. Note that not all damage codes were observed in the Lookout Fire plots.

Damage Code	Description
	Physical Causes
UPRT	Uprooting from effects other than burnout of root system (windthrow, toppling by failing snags, etc.)
BSTEM	Broken stem from effects other than burnout of the stem (failure of stem due to extant fire damage or timber defects, strikes from failing snags, etc.)
CDAM	Crown damage from indirect fire effects (impacts to the crown aside from torching or stem consumption, etc.)
	Fire Causes (no mechanical failure)
BBRN	Fire damage/scarring to the cambium below DBH, not resulting in mechanical failure
RBRN	Fire damage to the roots of the tree, not resulting in mechanical failure (including root scorch from duff burnoff)
SBRN	Fire damage to the stem cambium above DBH, not resulting in mechanical failure (burnout of cavities, burnoff of bark, etc.)
	Fire Causes (mechanical failure)
BMEC	Fire damage causing mechanical failure at the bole below DBH (burnout of catfaces or extant scarring, intense consumption at ground level, etc.)
RMEC	Fire damage causing mechanical failure at root level (burnout of nurse logs, consumption of roots in duff layer, etc.)
SMEC	Fire damage causing mechanical failure of the bole above DBH (burnout of cavities or rot, severe consumption of bole, etc.)
	Other Effects
BCAT	Burnout/consumption of extant "catface" scars on the bole
BTOP	Burnout of the top of tree, typically the result of spotting into dead tops
CHIM	Burnout of heartwood resulting in a chimney or stovepipe effect
DISJ	Scorching of the bole disjunct from the base, typically resulting from the ignition and consumption of moss/lichen via spotting
GONE	Complete consumption of tree or snag
JACK	Intense heating from adjacent heavy fuel "jackpot" such as burning snags or stumps (typically combined with BBRN, RBRN, SBRN, BMEC, RMEC, or SMEC)
PRCH	Roots exposed by virtue of nurse log consumption or burnoff of heavy duff layers

Table 13. Post-fire injury, broken out by species and size class for burned plots in the Lookout Fire. Species of pole and overstory trees included vine maple. Species in the table are (in order) vine maple, giant chinquapin, dogwood, western red cedar, and western hemlock (see Figure 6 for names).

Species and Size Class										
Damage Code	**ACCI**	**CHCH7**	**CONU4**	**PSME**	**TABR2**	**THPL**		**TSHE**		**Grand Total**
	Pole	**Pole**	**Pole**	**Overstory**	**Overstory**	**Overstory**	**Pole**	**Overstory**	**Pole**	
UPRT	-	-	-	-	1	-	-	1	-	**2**
BSTEM (snag abatement)	-	-	-	-	-	-	-	1	-	**1**
BSTEM (natural snag fall)	3	-	-	-	-	-	-	-	1	**4**
BBRN	-	-	-	-	-	-	1	-	3	**4**
RBRN	2	1	1	-	-	2	1	19	7	**33**
SBRN	1	-	-	3	-	-	1	7	-	**12**
BMEC	2	-	1	-	-	-	-	1	8	**12**
RMEC	1	-	-	-	2	1	1	3	14	**22**
SMEC	-	-	-	-	-	-	-	1	-	**1**
BCAT	-	-	-	-	-	1	-	-	-	**1**
DISJ	-	-	-	-	-	-	-	-	1	**1**
GONE	1	-	-	-	-	-	-	-	4	**5**
JACK	-	-	-	-	-	-	-	3	-	**3**
PRCH	-	-	1	-	-	1	-	11	2	**15**
Grand Total	**10**	**1**	**3**	**3**	**3**	**5**	**4**	**47**	**40**	**116**

Table 14. Occurrence of pole tree mechanical damage from intense heating and combustion. The table is divided into damage that caused mechanical failure (33.4% of all trees) and damage that did not immediately cause failure (22.2% of all trees). Species in the table are (in order) vine maple, giant chinquapin, Pacific dogwood, western red cedar, and western hemlock (see Figure 4 for species names).

Poles								
Damage Code	**Species**					**All Species**	**Damaged Trees (%)**	**All Trees (% by code)**
	ACCI	**CHCH**	**CONU4**	**THPL**	**TSHE**			
Fire structural damage causing mechanical failure								
RMEC	1	0	0	1	14	16	**35.6**	**19.8**
BMEC	2	0	1	0	8	11	**24.4**	**13.6**
SMEC	0	0	0	0	0	0	**0**	**0**
Fire structural impacts NOT causing mechanical failure								
RBRN	2	1	1	1	7	12	**26.7**	**14.8**
BBRN	0	0	0	1	3	4	**8.9**	**4.9**
SBRN	1	0	0	1	0	2	**4.4**	**2.5**
Sum - all damage codes	**6**	**1**	**2**	**4**	**32**	**45**	**100**	**55.6**
Sum - root damage (RMEC + RBRN)	**3**	**1**	**1**	**2**	**21**	**28**		
Expectation if damage codes are evenly distributed across species								
All Trees (total)	**22**	**1**	**5**	**4**	**49**	**81**		
All Trees (% of total)	**27.2**	**1.2**	**6.2**	**4.9**	**60.5**	**100**		
Statistics by Species - all damage codes								
Damaged Trees (% by species)	**13.3**	**2.2**	**4.4**	**8.9**	**71.1**	**100**		
Statistics by Species - root impacts (RMEC + RBRN)								
Damaged Trees (% by species)	**10.7**	**3.6**	**3.6**	**7.1**	**75.0**	**100**		

Table 15. Occurrence of overstory tree mechanical damage from intense heating and combustion. The table is divided into damage that caused mechanical failure (i.e., tree fall, 10.9% of all trees) and damage that did not immediately cause failure (41.9% of all trees). Trees that experienced structural damage but did not fall will likely fall in the future from wind and/or snow load, as rot progresses in dead wood, or during future fires where wounds that caused rot are burned out. Species in order are Douglas fir, Pacific yew, western red cedar, and western hemlock (see Figure 4 for species names).

Overstory Trees							
Damage Code	**Species**				**All Species**	**Damaged Trees (%)**	**All Trees (% by code)**
	PSME	**TABR2**	**THPL**	**TSHE**			
Fire structural damage causing mechanical failure							
RMEC	0	2	1	3	6	**15.4**	**8.1**
BMEC	0	0	0	1	1	**2.6**	**1.4**
SMEC	0	0	0	1	1	**2.6**	**1.4**
Fire structural impacts NOT causing mechanical failure							
RBRN	0	0	2	19	21	**53.8**	**28.4**
BBRN	0	0	0	0	0	**0**	**0**
SBRN	3	0	0	7	10	**25.6**	**13.5**
Sum - all damage codes	**3**	**2**	**3**	**31**	**39**	**100**	**52.7**
Sum - root damage (RMEC + RBRN)	**0**	**2**	**3**	**22**	**27**		
Expectation if damage codes are evenly distributed across species							
All Trees (total)	**17**	**3**	**6**	**48**	**74**		
All Trees (% of total)	**23.0**	**4.1**	**8.1**	**64.9**	**100**		
Statistics by species - all damage codes							
Damaged Trees (% by species)	**7.7**	**5.1**	**7.7**	**79.5**	**100**		
Statistics by species - root damage (RMEC + RBRN)							
Damaged trees (% by species)	**0.0**	**7.4**	**11.1**	**81.5**	**100**		

This is the first fire on which FBAT systematically cataloged post-fire effects and the coding is a work in progress (Table 12). Upon expansion of the dataset in future fires in old-growth and other systems, we expect to correlate pre-fire injury of trees with the likelihood of post-fire damage and mortality. With a life history dependent on a wet climate and a tendency to regenerate on nurse logs, we expect that western hemlock will be particularly vulnerable to future hotter droughts expected with climate change during which there will likely be substantial combustion of duff derived from large rotten logs such as we observed on the Lookout Fire (Tables 7, 8, 11). Trees with basal and stem injury that do not fall during fires or from progressive rot some years after fire will likely be vulnerable to future wildfires and prescribed fires during conditions dry enough for rotten wood to consume. FBAT data collection on future wildfires and long-term survival monitoring could provide greater insights into likely impacts of land management actions on species composition and tree fates in future fires.

Soils

Severity ratings for soils were primarily low to moderate with sizeable areas of a couple of plots with unburned surface fuels (Figure 10 and 11). Ratings in Figure 11 are generally in agreement with the Soil Burn Severity Map (Figure 12) showing low severity in the areas where FBAT plots were installed. It is worth considering whether the extensive duff consumption in these areas will have more effects on soils than implied by the Soil Burn Severity map which would tend to underpredict impacts on soils where the canopy is still green immediately after fire when imagery is collected.

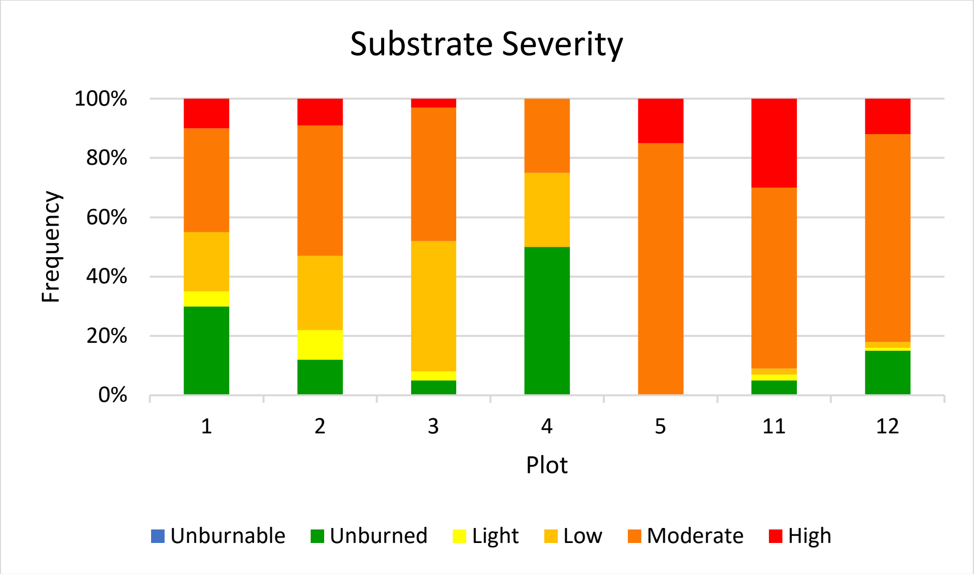
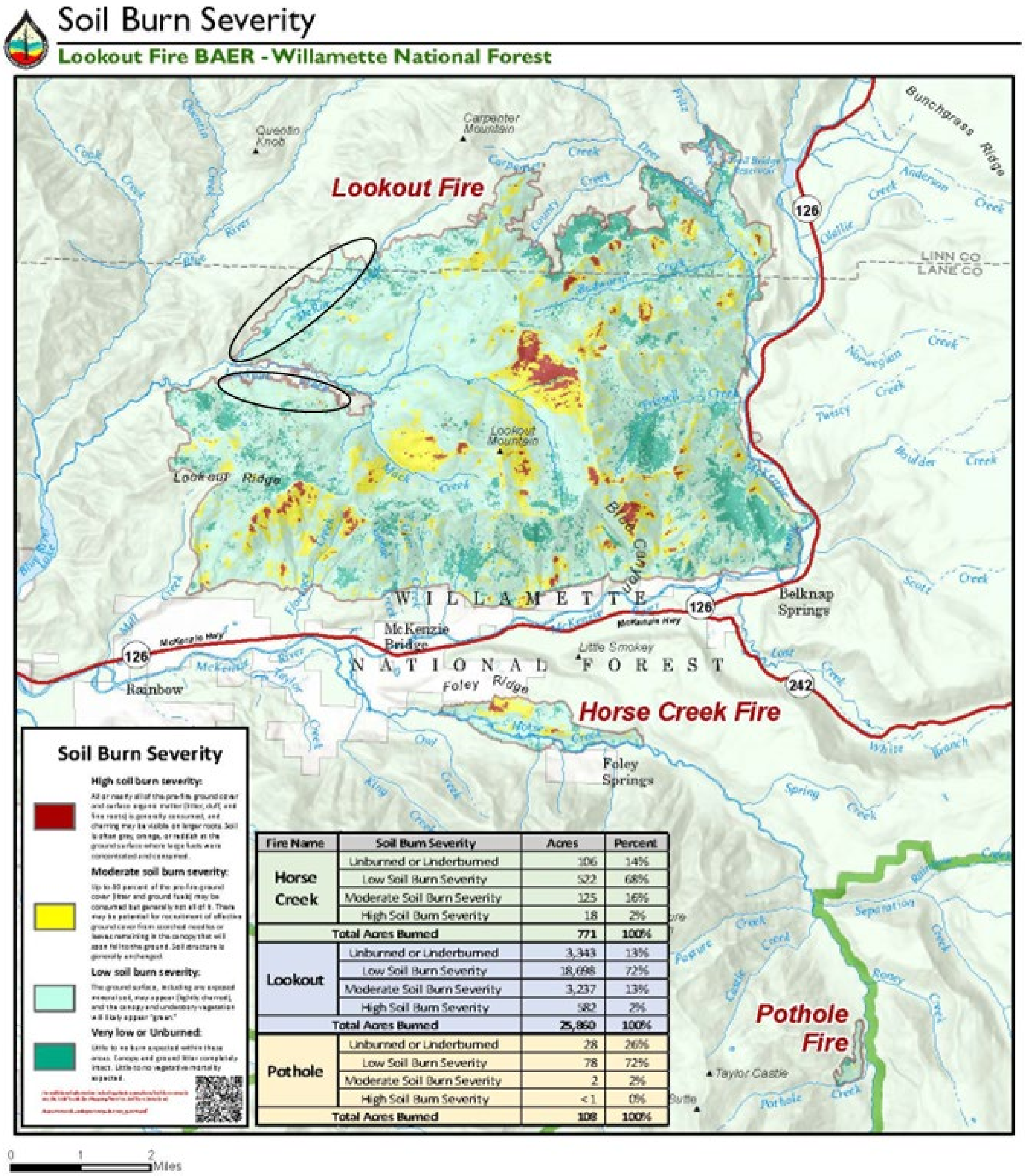


Figure 11. Severity of substrate effects for FBAT plots on the Lookout Fire. Ratings based on the National Park Service scale (see FBAT 2023b).

Diurnal soil temperatures were mostly in the 13-15 °C range, with little variation even at the shallowest measured depth (5 cm = 2 in, Table 16). We expect that diurnal heating is dampened by deep duff and late-season shaded conditions. Maximum soil heating at 2 inches (5 cm) at plot 12 reached 86.94 °C and took around a week to cool to pre-fire temperatures (Figure 13). Several plots (plots 1, 2, 5, and 11) got above 60 °C (Table 11), a commonly used threshold for root mortality and secondary fire effects. Overall, deeper duff and litter directly over the iStake led to higher soil heating, and decomposing logs and roots seemed especially important. Heating above 60 °C frequently paired with total forest floor depths around 5 inches, though there were exceptions likely driven by nearby logs or more active fire behavior. Overall plot level soil burn severity was mostly moderate within the plots but had a wide range from unburned (Figure 11).



Fire Name	Soil Burn Severity	Acres	Percent
Horse Creek	Unburned or Underburned	106	14%
	Low Soil Burn Severity	522	68%
	Moderate Soil Burn Severity	125	16%
	High Soil Burn Severity	18	2%
	Total Acres Burned	**771**	**100%**
Lookout	Unburned or Underburned	3,343	13%
	Low Soil Burn Severity	18,698	72%
	Moderate Soil Burn Severity	3,237	13%
	High Soil Burn Severity	582	2%
	Total Acres Burned	**25,860**	**100%**
Pothole	Unburned or Underburned	28	26%
	Low Soil Burn Severity	78	72%
	Moderate Soil Burn Severity	2	2%
	High Soil Burn Severity	<1	0%
	Total Acres Burned	**108**	**100%**

Figure 12. Soil burn severity map generated by the Burned Area Emergency Response (BAER) team. FBAT burned plots are located in the ellipses where soil burn severity was generally low.

Table 16. Plot-level average, minimum, and maximum temperatures for all plots that burned. Diurnal soil heating is determined from the temperature profiles over the days leading up to fire arrival, and plot maximum temperature is the single maximum temperature reached at that depth over the three iStakes installed on each plot. Plots which had unburned fuels above one or more iStakes are indicated with an asterisk. Data from iStakes that were not heated by fire are not included in the data summary (Plot 1: Transect 3 and there were no 10 cm or 15 cm depth measurements on Transect 1; Plot 2: Transect 1; Plot 4: Transect 2 and Transect 3). iStake data reflect soil heating outside of concentrations of duff which were avoided to protect the loggers from heat damage.

Plot	Depth (cm)	Average Diurnal Temp. (°C)	Average Max Diurnal Temp. (°C)	Average Min Diurnal Temp. (°C)	Max Temp. (°C)
1*	5	14.10	14.65	12.89	64.58
1*	10	14.37	15.00	13.50	43.50
1*	15	14.09	14.50	13.50	30.00
2*	5	14.09	15.20	12.68	67.55
2*	10	14.13	14.90	13.14	56.52
2*	15	13.87	14.69	13.18	44.06
3	5	14.87	15.74	13.39	54.04
3	10	14.57	15.28	13.60	47.10
3	15	14.40	14.93	13.75	39.60
4*	5	14.21	14.94	13.43	40.00
4*	10	14.21	14.97	13.47	32.99
4*	15	13.86	14.47	13.47	30.04
5	5	14.57	15.20	13.70	68.09
5	10	13.83	14.17	13.33	47.50
5	15	14.20	14.50	13.83	35.50
11	5	14.28	15.05	13.37	66.08
11	10	14.26	14.73	13.73	46.60
11	15	14.20	14.41	13.74	33.54
12	5	14.60	14.74	14.24	86.94
12	10	14.19	14.33	13.83	63.00
12	15	13.73	13.75	13.50	53.50

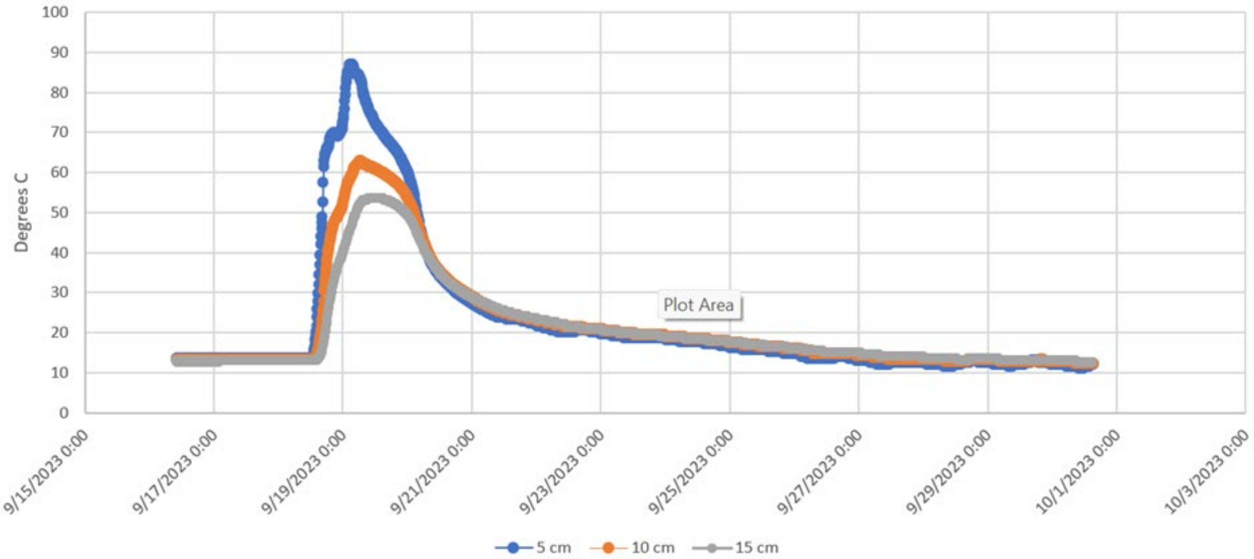


Figure 13. Heating across the hottest soil profile (Plot 12, Transect 2), including highly dampened pre-fire diurnal heating and fire-caused heating and subsequent cooling.

Fuels, Fire Behavior, and Fire Effects - Plot Summaries

Plot 1

Plot 1 is on a north facing aspect. The plot has an old-growth overstory, small tree midstory, shrub and moss/lichen understory. Fuels in this plot are mostly shaded. Fire entered this plot on September 19, at 1320 PDT. Fire carried through the ground fuels including fir needles, dead and down, moss, lichen with flame lengths up to 4 feet. The duff layer appeared to burn for a long time, consuming most of the duff in the plot. Fire moving up the old-growth Douglas fir trees was mostly due to moss growing on the bark. Larger diameter dead and down created higher intensity pockets, helping fire spread laterally and vertically. Winds were light during the time the plot burned. Soil burn severity ranged widely with approximately 55% of the unit experiencing low to moderate severity, and 10% experiencing high severity. Video of the fire was limited to a short period at night when heavy fuels were burning alongside large trees on the SW side of the plot.

Plot 2

Fire reached Plot 2 at 1500 PDT on September 16th. How the fire entered the plot is unknown, as the video camera was triggered when fire was already burning within the plot. The fire could have spotted into the plot area or a snag that fell into the plot area could have been on fire. Fire spread was influenced by a burnout operation that occurred near the plot area on the evenings of September 16th and 17th. Visual estimates of fire spread indicate less than 0.1 ch/hr rate of spread and arrival times at the thermocouples indicate a 0.01 ch/hr rate of spread (Table 10). The plot experienced low to moderate soil burn severity over approximately 70% of the area.

The fire progressed from the SW towards the NE. The fire was characterized by backing, creeping and smoldering. The fire rate of spread was less than 0.1 ch/hr. Several large diameter trees in the plot area had compromised bole wood at their base due to fire’s long residency time.

Plot 3

Plot is located on the 320 road, uphill from the 322 spur road. The 320 road was a primary holding line that was used during a burnout operation. Eastern ROS sensor was triggered first on September 18 at 20:14 PDT with the southern ROS sensor being triggered second at 20:46 PST. The fire progresses from SSE towards the NW downhill into the McRae Creek drainage and perpendicular to the wind direction. Fire characteristics and behavior include backing, creeping and smoldering with occasional flare ups in low-hanging brush. Fire rate of spread from video, a local measure, was 1.2 chains/hr while over the larger plot area, spread rate was estimated to be 0.05 ch/hr. Long duration fire residency consumed nearly all of the understory duff, litter and vegetation. Several large diameter trees in the plot area were compromised due to fire residency time. Understory hemlocks largely experienced root scorch due to duff consumption. The plot experienced approximately 44% low soil burn severity, and 45% moderate soil burn severity.

Several western red cedar near Plot 3 were actively burning up inside hollow trunks, and several other large trees had large compromising catfaces. One large diameter tree fell across the plot area.

Plot 4

The plot was located south of the 322 spur road across McRae Creek. The plot was near the riparian creek drainage and in an old-growth stand. The wind average was 2.5 mph and the wind max was 10 mph from start to end fire duration at plot. The southern ROS sensor was triggered first on September 18 at 21:11 PDT, and the eastern ROS sensor was triggered second at 00:27 PDT the next day. There was no camera footage available for the plot, but the ROS sensors indicate a slow-moving fire characterized by backing, creeping and smoldering. The slopes above the plot and drainage bottom had higher severity and consumption of vegetation compared with the plot area. Fuel consumption in the plot area was patchy. Several larger diameter trees in the plot area had compromised bole wood. Soil burn severity across the plot was approximately 50% very low, 25% low to moderate, and 25% moderate. There were no areas of high soil burn severity documented.

A large diameter tree fell across Plot 4, scattering unburned limbs and needles across the plot area before the post-assessment was done.

Plot 5

Site was located close to 360 road near 365 spur road. Plot located midslope at 25% grade. Very little shrub cover. Heavy duff, litter and moss loading. Multiple 1000 hr fuels within sight. Sparse understory. Wind speed average was 2.5 mph and wind speed max was 12.5 mph from fire start and end in plot. Fire entered the plot on September 14, at 16:55 PDT at the easternmost point in plot. A spotting event was observed in the video footage. We don't know the origin of the spot. No torching was recorded within the pole or overstory plots, however, September 14 was a day that there was a general increase in fire behavior, including individual tree torching. Vigorous burning up the bark of large trees in the imagery suggest that the spot might have been caused by burning moss. It took approximately 3 minutes for spots to converge in camera footage. By video, the main body of the fire moved at an average of 1.3 ch/hr through the standards, though it moved more quickly if consideration is given to the spotting in the ROS data. The southern ROS sensor activated second, 7 minutes after eastern ROS sensor. Over the entire plot, based on fire arrival times, spread was slower on average at 0.23 ch/hr. Fuels consumed thoroughly over long-duration residence time. Soil burn severity on plot 5 was mostly moderate (85%) with patches of high severity (15%), mostly under heavy down/dead logs.

Plot 11

Plot is located on the 320 road, approximately 250' downhill to the south. The 320 road was a primary holding line that was used during burnout operations. Wind speed average was 1.2 mph and wind speed max was 5 mph from fire start and end at plot. The southern ROS sensor was triggered first on September 14 at 00:53 PDT with eastern ROS sensor being triggered second at 01:57 PDT. The fire moved from the SW to the NE across the plot and downhill into the McRae Creek drainage. The vegetation was characterized by a shaded canopy and denser surface fuel loading. Fire spread was characterized by backing, creeping, and smoldering, with infrequent torching of small trees and shrubs. The rate of spread was approximately 0.2 chain/hr from local video observation and <0.1 based on arrival at sensors distributed across the plot. Long duration fire residency consumed most of the duff, litter and vegetation within the plot, but left several small patches of shrubs and herbs unburned. The fire exposed the roots of many of the larger diameter trees within the plot area, but typically stayed out of the bole wood. Soil burn severity on plot 11 was mostly moderate (61%) with larger patches of high severity (30%) mostly under heavy down/dead logs. Five % of the plot was left unburned, 2% scorched and 2% with low soil burn severity.

Plot 12

Plot is located in interior Division A/C, adjacent to the 363 road, a decommissioned logging road. It is at 16% slope. The stand has large western hemlock but the presence of large stumps suggest that it was high-graded for Douglas fir. The plot had sparse understory and vegetation loading. Fire reached the plot on September 16 at 21:33 PDT. It took more than two days for the fire to trigger all the sensors with an average estimated rate of spread of 0.02 ch/hr. Primary fire carrier was downed heavy woody material, moss, litter, and duff. Wind speed average was 2.5 mph and wind speed max was 7.5 from fire beginning and end in plot. Fire backed slowly down into the plot, driven largely by consumption of moss and duff. Very long residence time, which lead to most of the ground fuels being fully consumed in the areas with backing fire. Terrain heavily influenced fire behavior, slowing the fire spread as the flames were directed back into the black as it backed downhill. Though the plot had various portions of unburned, some large diameter trees became compromised due to fire spread into bole wood. Approximately 70% of the plot experienced moderate soil burn severity, and 15% experienced high soil burn severity.

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Lookout Ridge - September 12th, 2023, as the fire started becoming more active after the early September rainfall event. Photo was taken 2 days before the first FBAT plots burned. Photo by Benjamin E. Nash, Ecologist, USFS, PNW Research Station

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Lookout Fire Looking South on Day Nine - August 13th, 2023.

Photo by Benjamin E. Nash, Ecologist, USFS, PNW Research Station

Appendix 1: Pre- and Post-fire Plot Photographs

Pre- and post-fire photos from the center of the plot outwards along the three transects. Photos of Plots 5 and 11 were taken within days of the plots having burned and show ash cover. Photos of other plots were taken in November 2023, after multiple rainfall events. Post-fire sampling was delayed on these plots to mitigate risks associated with tree fall.

Plot 1 Transect 1, 50-0 Pre

Plot 2 Transect 1, 50-0 Pre

Plot 1 Transect 3, 50-0 Pre

Plot 1 Transect 1, 50-0 Post

Plot 1 Transect 2, 50-0 Post

Plot 1 Transect 3, 50-0 Post

Plot 2 Transect 1, 50-0 Pre

Plot 2 Transect 2, 50-0 Pre

Plot 2 Transect 3, 50-0 Pre

Plot 2 Transect 1, 50-0 Post

Plot 2 Transect 2, 50-0 Post

Plot 2 Transect 3, 50-0 Post

Plot 3 Transect 1, 50-0 Pre

Plot 3 Transect 2, 50-0 Pre

Plot 3 Transect 3, 50-0 Pre

Plot 3 Transect 1, 50-0 Post

Plot 3 Transect 2, 50-0 Post

Plot 3 Transect 3, 50-0 Post

Plot 4 Transect 1, 50-0 Pre

Plot 4 Transect 2, 50-0 Pre

Plot 4 Transect 3, 50-0 Pre

Plot 4 Transect 1, 50-0 Post

Plot 4 Transect 2, 50-0 Post

Plot 4 Transect 3, 50-0 Post

Plot 5 Transect 1, 50-0 Pre

Plot 5 Transect 2, 50-0 Pre

Plot 5 Transect 3, 50-0 Pre

Plot 5 Transect 1, 50-0 Post

Plot 5 Transect 2, 50-0 Post

Plot 2 Transect 3, 50-0 Post

		
Plot 6 Transect 1, 50-0 Pre	Plot 6 Transect 2, 50-0 Pre	Plot 6 Transect 3, 50-0 Pre

Unburned	Unburned	Unburned
Plot 6 Transect 1, 50-0 Post	Plot 6 Transect 2, 50-0 Post	Plot 6 Transect 3, 50-0 Post

		
Plot 7 Transect 1, 50-0 Pre	Plot 7 Transect 2, 50-0 Pre	Plot 7 Transect 3, 50-0 Pre

Unburned	Unburned	Unburned
Plot 7 Transect 1, 50-0 Post	Plot 7 Transect 2, 50-0 Post	Plot 2 Transect 7, 50-0 Post

		
Plot 8 Transect 1, 50-0 Pre	Plot 8 Transect 2, 50-0 Pre	Plot 8 Transect 3, 50-0 Pre

Unburned	Unburned	Unburned
Plot 8 Transect 1, 50-0 Post	Plot 8 Transect 2, 50-0 Post	Plot 8 Transect 3, 50-0 Post

		
Plot 9 Transect 1, 50-0 Pre	Plot 9 Transect 2, 50-0 Pre	Plot 9 Transect 3, 50-0 Pre

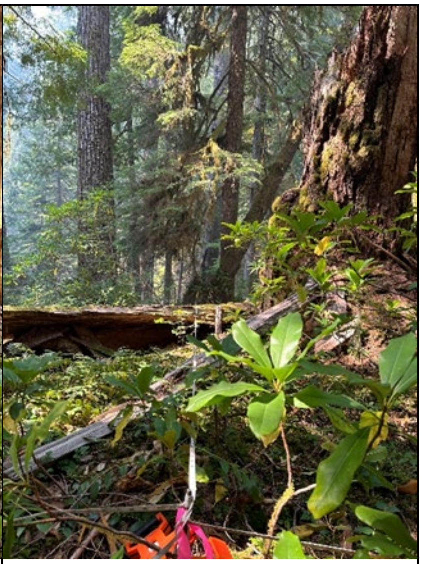
Unburned	Unburned	Unburned
Plot 9 Transect 1, 50-0 Post	Plot 9 Transect 2, 50-0 Post	Plot 9 Transect 3, 50-0 Post

		
Plot 10 Transect 1, 50-0 Pre	Plot 10 Transect 2, 50-0 Pre	Plot 10 Transect 3, 50-0 Pre

Unburned	Unburned	Unburned
Plot 10 Transect 1, 50-0 Post	Plot 10 Transect 2, 50-0 Post	Plot 10 Transect 3, 50-0 Post

Plot 11 Transect 1, 50-0 Pre

Plot 11 Transect 2, 50-0 Pre



Plot 11 Transect 3, 50-0 Pre

Plot 11 Transect 1, 50-0 Post

Plot 11 Transect 2, 50-0 Post

Plot 11 Transect 3, 50-0 Post

Plot 12 Transect 1, 50-0 Pre

Plot 12 Transect 2, 50-0 Pre

Plot 12 Transect 3, 50-0 Pre

Plot 12 Transect 1, 50-0 Post

Plot 12 Transect 2, 50-0 Post

Plot 12 Transect 3, 50-0 Post