Ashland Forest Resiliency Project 2017 Prescribed Burn Legacy Tree Fire Effects Monitoring – Initial Report

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This report provides an initial summary of methods and results from monitoring of prescribed fire impacts to legacy trees across four adjacent Forest Service units in the Skyline Mine area, burned during May and early June 2017. Units 28n, 28s, 28y, and 31c cover 220 total acres within the Ashland watershed and Siskiyou Mountain Ranger District (SMRD) of the Rogue River-Siskiyou National Forest. These prescribed underburns were part of the Ashland Forest Resiliency (AFR) project, a partnership of the U.S. Forest Service (USFS), City of Ashland (COA), Lomakatsi Restoration Project (LRP) and The Nature Conservancy (TNC). AFR prescribed burns are intended to meet both fire management and ecological goals by reducing fuel loads and fire risk, and reintroducing beneficial fire for forest restoration while protecting and enhancing habitat values.

The 2017 burns were an important increase in the scale of AFR prescribed burning, were safely conducted, successfully dispersed smoke, substantially reduced fuel loads, and returned many benefits of fire to the forest habitat. At the same time, these burns exceeded the upper thresholds of several burn objectives. Heat generated in units 28s, 28y, and 31c led to unanticipated levels of crown scorch, fire injury, and mortality from the understory through to upper canopy trees. These fire effects include stress and likely mortality for a substantial number of the legacy trees, counter to core objectives of the AFR project. A full report covering general fire effects monitoring, prescribed burn implementation, fire weather and behavior, unit and fuel conditions, and objective attainment for these units was released earlier this year (AFR 2017 FEMO report). Responding to stakeholder and partnership concerns, supplemental monitoring was developed to track and quantify fire impacts to legacy trees. This report covers context, methods, and preliminary post-fire results from the same growing season as the burn for that legacy tree monitoring.

Legacy Trees and Fire Effects

Within the AFR project, “legacy trees” are defined as large, old (> 150 years) trees with complex form, large branches, and open structure that provide important habitat features and aesthetic value. Legacy trees include representatives from all species, both hardwood and conifers. They are typically the biggest and oldest living structures in the ecosystem, having persisted long enough to develop large and complex forms that provide unique and practically irreplaceable habitat features. Legacy trees often developed under different conditions of stand structure and disturbance processes than are currently present, and so can have forms or features not found in younger adjacent individuals. Legacy tree fire effects monitoring in the 2017 AFR burns covered the four conifer species and one canopy-stratum hardwood abundantly represented in those units: Douglas-fir (*Pseudotsuga menziesii*, PSME), white fir (*Abies concolor*, ABCO), ponderosa pine (*Pinus ponderosa*, PIPO), sugar pine (*Pinus lambertiana*, PILA), and pacific madrone (*Arbutus menziesii*, ARME). Field selection of sample trees focused on both diameter (thresholds from local data) and overall form to identify individuals confidently as over 150 years of age and representing the characteristic structure and values of legacy trees.

Fire effects to legacy trees include direct impacts from the fire (first-order fire effects) and secondary effects related to tree stress or altered stand conditions. First order fire effects are evident shortly after the fire and include canopy foliage killed by heat (crown scorch) or consumed by fire (crown torch), bole char from fire climbing the trunk, and cambium (layer of living tissue beneath the bark) heat-killed by intense surface fire or smoldering duff at the base of the tree. Secondary effects are evident from one to several years post-fire and include insect attack, disease, delayed cambium or canopy death from stress or infestation, and tree mortality (Hood 2010). In addition to fire intensity, the stand structure, pre-existing tree disease or infestation, tree phenological state at time of fire, and post-fire weather all likely contribute to the type and degree of fire effects. Prior radial thinning around legacy trees located within closed-canopy forest may have created a “chimney effect” for some trees where the structure of the lower canopy trapped and channeled convective heat directly into legacy crowns. In some cases, slash piles from thinning or harvest activity located near or around legacy trees likely added to this effect. Stress from pre-existing diseases, including white pine blister rust (PILA) and dwarf mistletoe (PSME, PIPO, ABCO), or prior injury to crowns or as basal scars, may have rendered some trees more susceptible to fire damage and mortality. Timing of the fire relative to tree phenology may have exacerbated crown scorch, because during the main 2017 burns, trees were in spring growth and pine crowns were full of elongating, tender new shoots (“candles”) not yet hardened to heat or moisture stress.

Monitoring Methods

Design and sample selection

A grid sampling design was used to achieve a proportional and representative sample of legacy trees across all four 2017 units. An offset grid of 55 points at approximately 600-foot spacing was generated in GIS and overlaid on the final burn unit perimeters. GPS was used in the field to navigate to the grid points. The conifer tree with clear legacy diameter and characteristics that was closest to each point while still in the burn unit was selected for sampling. For the sample to be representative of species proportions and fire impacts, legacy tree selection was not influenced by species or evident fire effects. However, to focus on fire effects (and lacking pre-burn data), trees that showed evidence of being dead prior to the burn were not selected. To include legacy hardwoods in the sample, when a legacy madrone was present near a grid point both the madrone and the nearest conifer were selected. And to bring the conifer sample size to a minimum of ten trees for each species, three additional white fir and six additional sugar pine were selected as those nearest to the FEMO fire effects monitoring plots in these units. In analysis, these additional legacy tree samples were used only in species-level summaries and were excluded from unit or overall summary. Map 1 displays the location and species of all sample legacy trees, and specifically identifies the additional samples.

Tree and plot data

Field monitoring of legacy trees was completed by TNC and USFS staff during the summer and fall immediately after the burns, from August through November 2017. Once selected, each sample legacy tree was field-marked with a unique identifier tag and GPS recorded for re-location. Species, diameter, slope, and aspect were recorded along with first-order fire-effects of crown scorch and crown torch, bole char height, and cambium kill. Crown scorch was visually estimated as both percent by length and percent by volume to provide inputs for a range of predictive mortality models. Because initial monitoring occurred in late summer during the same season as the burn, it was not possible to determine if the areas of the tree crowns that had been scorched were killed (including buds) or just damaged (foliage only). Scorched canopies can re-sprout if some buds and branch cambium are still alive. In the 2017 burn units, the trees appeared to have already initiated or completed their seasonal growth prior to the burns, so that even if branch buds were still alive most trees did not express any new growth. It will not be until the next growing season (2018) that it will become evident how much of the crown scorch was damage versus kill.

Cambium was sampled following the quadrant method in Smith and Cluck's (2011) guide, using a wood chisel or large-bore leather punch to expose and assess the cambium with minimal bark removal. Fuel loading and fire effects relevant to understanding heat impacts to the legacy tree were measured within a 0.1-acre circular plot centered on the tree, specifically: pre-burn fuel model (Scott and Burgan 2005), percent area of moderate or high soil burn severity (Parsons *et al*. 2010), and consumption of duff in direct contact with the tree base. Visual evidence of post-burn insect attack was recorded by insect species within categories of mortality-causing or stress-indicating beetles (Hood 2010) without destructive subcortical sampling. Other data relevant to understanding fire effects and potential mortality included evidence of disease or injury present prior to the burn, and stand structure that could potentially have a chimney-effect, funneling heat up into legacy crowns. Appendix 1 at the end of this report provides a complete table of definitions and field protocol for the full set of monitoring metrics.

Mortality estimates from modeling

Monitoring during the same season as the burn cannot provide definitive results on tree mortality from fire. Follow-up monitoring during the summer of 2018 will provide clearer evidence of post-burn legacy tree mortality (e.g. crown kill) and indicators of delayed mortality linked to fire stress and injury (e.g. insect attack) (Hood 2010). For this report, published predictive mathematical models incorporating same-season data were used to provide the AFR partnership and stakeholders with reasonable estimates of anticipated mortality. Guided by an unpublished review of mortality models by Sharon Hood (2018), Forest Service and TNC staff applied a series of predictive tools ranging from simple models with species and crown scorch as the only inputs, to fuller models incorporating diameter, cambium kill, and insect attack. Table 1 summarizes the output for simple and full models from Smith and Cluck (2011) or recommended by Hood's review (Ganio and Progar 2017; Grayson et al. 2017; Hood and Lutes 2017). The above sources cover conifer species only, so an alternate reference was used for estimating madrone mortality (Auten 2012). None of the models included tree disease as an input.

Model predictions were reported using a 70% probability of mortality as the threshold at or above which legacy tree mortality was considered likely. These predicted outcomes were remarkably consistent across all models at both the species and burn unit scale. The mortality estimates from the "Hood review full" models (Table 1) were deemed most robust and used in the following presentation of results. Figure 1 provides a graphical summary of the number of sample legacy trees by species across the range of predicted mortality probabilities. A 70% probability threshold is marked on the figure and shown to be a natural break in this sample, as well as a threshold with established precedent in our region (e.g. Goheen 2001; Smith and Cluck 2011). This conservative mortality threshold provides a higher level of confidence for predicting tree mortality, but relatively lower confidence in estimating the survival of trees with less than 70% probability of mortality.

Table 1. Comparison of predicted mortality rates (proportion of trees with ≥ 70% probability of mortality) for legacy trees in the 2017 AFR prescribed burn units 28s, 28y, and 31c by species and unit from a series of models with inputs ranging from simple crown scorch to full models factoring in diameter, species, cambium kill, and insect attack. Model sources: Smith and Cluck (2011), or as compiled and reviewed by Hood (Grayson *et al*. 2017: ABCO; Hood and Lutes 2017: PILA, PIPO; Ganio and Progar 2017: PSME), or Auten (2012) for ARME.

	White fir, ABCO	**Madrone, ARME**	**Sugar pine, PILA**	**Ponderosa pine, PIPO**	**Douglas-fir, PSME**	**Unit 28s**	**Unit 28y**	**Unit 31c**
Legacy tree sample size	9	5	10	27	13	16	16	18
Smith & Cluck simple	22%		30%	7%	23%	25%	13%	11%
Smith & Cluck full	22%		30%	7%	23%	25%	13%	11%
Hood review simple	22%		30%	4%	23%	19%	13%	11%
Hood review full	22%	20%	30%	7%	23%	25%	13%	11%

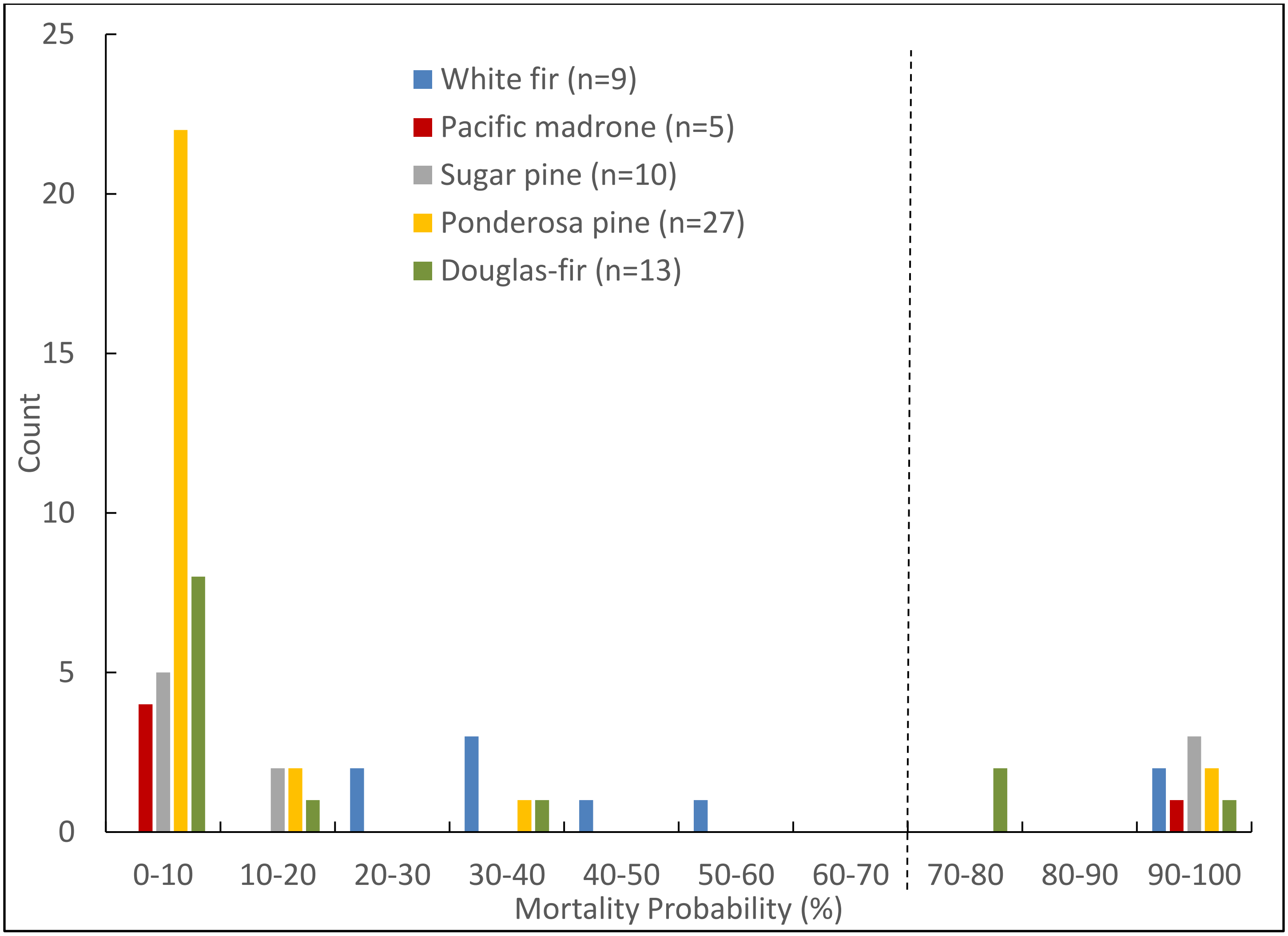


Figure 1. Number of sampled legacy trees by species within 10% mortality probability classes for the 2017 AFR burn units 28s, 28y, and 31c. The vertical dashed line shows the 70% threshold used for reporting likely mortality. Note that sample sizes (n) are unequal by species and the Y-axis is simply the count of trees in each mortality class.

Initial Monitoring Results

Burn unit conditions and general fire effects

Table 2 provides a summary of the 2017 AFR underburn units and relevant overall fire effects important for understanding the context of legacy tree impacts from these burns. (See the AFR 2017 FEMO report for a full fire effects monitoring (FEMO) summary of these burns). Units were typically steep (30% slope), and pre-burn surface fuel loads were relatively high, predominantly characterized by a timber litter 4 (TL4) fuel model (Scott and Burgan 2005) with substantial heavy fuels (≥ 1000-hour) in a bed of continuous litter and light fuels (1 – 100-hour). During the burn, fuel moistures were low and consumption was high (units were typically reduced to a TL1 light timber litter fuel model post-burn), with a high level of sustained heat generated. Although fire effects varied over a wide range, overall the 2017 units burned more intensely than intended resulting in surface and understory consumption and tree mortality beyond the range of burn plan objectives, including an objective to minimize legacy tree mortality.

Units 28s, 28y, and 31c contained 201 of the 220 acres burned in 2017 and were similar in timing, type, and intensity of fire effects: Fire burned through 93% of the unit area, predominantly ranging from moderate to high intensity surface fire. Especially in heavier fuel loads (natural accumulations, activity fuels, and unburned piles), on aspects with greater sun and wind exposure, and as daytime temperature climbed and humidity dropped, the fire reached greater intensity and persistence than desired. The cumulative heat and duration of fire generated strong updrafts of convective heating, scorching tree crowns across large areas and to over 100-foot canopy heights. Torching or crown consumption were practically absent, yet 25% of the total unit area had high levels of crown scorch impacting all canopy strata, including legacy trees (Map 1, high crown scorch areas defined as roughly ≥ 90% of trees having ≥ 70% of foliage killed by heat). Crown scorch and cambium injury impacts were greatest for understory and intermediate trees but occurred through the upper canopy strata. Based on a conservative threshold (simple observed 100% canopy scorch, no predictive modeling) plot-based FEMO monitoring found 54% mortality of intermediate trees 5-inch to 12-inch DBH, and 12% mortality of canopy trees 12-inch DBH and larger. These mortality rates are likely underestimates because cambium kill and insect attack were not recorded or factored in for these non-legacy trees. This report focuses on the legacy trees in these “high-scorch” units: 28s, 28y and 31c. In contrast, unit 28n (19 acres) was burned in early May as a training activity and characterized by ignitions not carrying or low intensity fire; while few burn objectives were achieved in 28n, there also was no anticipated legacy tree mortality associated with that burn.

Table 2. Summary of unit conditions and overall fire effects in the 2017 AFR burn units, including unit-level predictions of legacy tree mortality based on a 70% probability threshold.

	All 2017 Units (220 ac.)	**Unit 28n**	**Unit 28s**	**Unit 28y**	**Unit 31c**	**High Scorch Units (201 ac.)**
Burn date	2017	5/4/2017	6/6/2017	5/26/2017	5/23/2017	2017
Unit acres	220	19	58	66	77	201
Primary aspect		E	NE	SE	NW	
Average slope	30%	28%	36%	31%	24%	30%
Unit area burned	89%	50%	98%	96%	87%	93%
Unit area in high scorch	23%	0%	38%	15%	25%	25%
Fuel model proportions pre-burn	TL3 : TL4 1 : 2	TL3 : TL4 2 : 1	TL3 : TL4 1 : 2	TL3 : TL4 2 : 3	TL3 : TL4 1 : 3	TL3 : TL4 1 : 2
Fuel model proportions post-burn	TL1 : TL3 9 : 1	TL1 : TL3 1 : 2	TL1 : TL3 9 : 1	TL1 : TL3 9 : 1	TL1 : TL3 9 : 1	TL1 : TL3 9 : 1
Intermediate tree mortality (5-12" DBH)	49%	0%	46%	56%	61%	54%
Canopy tree mortality (>12" DBH)	11%	0%	11%	7%	20%	12%
Legacy tree sample size	55	5	16	16	18	50
Predicted legacy tree mortality rate	14%	0%	25%	13%	11%	16%

Table 3. Species and pre-burn conditions relative to predicted mortality for legacy trees in AFR 2017 burn units, with predictions of legacy tree mortality based on a 70% probability threshold.

	White fir, ABCO	**Madrone, ARME**	**Sugar pine, PILA**	**Ponderosa pine, PIPO**	**Douglas-fir, PSME**	**High Scorch Units**
Legacy tree sample size	9	5	10	27	13	50
DBH (in) average	39.6	20.4	50.9	42.0	41.5	42.5
Fuel model proportions pre-burn	TL3 : TL4 1 : 2	≥ TL4 all	TL3 : TL4 2 : 3	TL3 : TL4 4 : 5	TL3 : TL4 1 : 2	TL3 : TL4 1 : 2
Pre-existing disease or injury proportion	66%	60%	90%	33%	69%	50%
Chimney effect proportion	44%	0%	50%	37%	31%	34%
Predicted legacy tree mortality rate	22%	20%	30%	7%	23%	16%

Legacy tree condition and sample characteristics

Based on species proportions in the grid sample, over half of the legacy trees in these units are ponderosa pine, Douglas-fir makes up another quarter of the legacy tree population, and white fir, sugar pine, and madrone are progressively less abundant as legacies. Table 3 presents a profile of the legacy trees in our representative sample from the high-scorch units, including sample size, average diameter, adjacent fuel-loading pre-burn, and the species-specific estimated mortality rates. Pre-burn fuel loads, including thinning-generated activity fuels, were generally higher in more productive settings (typical for white fir and Douglas-fir) and in stands with a high proportion of madrone. Impacts from a possible chimney effect associated with focused radial thinning are unclear and likely interacted with fuel loads, fire behavior, canopy form and height, and topography in ways that would require more intensive study to understand – but the potential for this dynamic was widespread across the conifer legacy trees in the high-scorch units.

Pre-existing stressors of disease or damage were common across all species in these units, and potentially contributed to legacy tree injury or mortality from the prescribed burns. Specific conditions observed and recorded in our monitoring included white pine blister rust on sugar pine and advanced dwarf mistletoe infection on Douglas-fir (Hawksworth DMR rating $\geq$ 4; Hawksworth 1977). Pre-burn crown die-back or low vigor (possibly indicating disease, prior insect attack or other stress) or prior basal scar (fire or mechanical) were also recorded. The above pre-burn stressors are merged and presented in Table 3 as "Pre-existing disease or injury" (see Appendix 1 for more information on how these were defined in the field). Because the models used to predict mortality do not incorporate input variables of disease or injury explicitly, the impact of these pre-existing conditions cannot be directly assessed, but all are known to physiologically stress trees or create greater risk of fire injury – and are typical of long-lived legacy trees.

Fire effects on legacy trees

Monitoring found substantial fire impacts to legacy trees (Table 4), including bole char heights averaging 20' (range of 0 – 57') and average crown scorch volume of 26% (range of 0 – 100%) across all legacy trees in the high scorch units. At the species-level, average crown scorch volume was higher than this combined average for all species except ponderosa pine (14%): Average crown scorch was 30% and 35% respectively for sugar pine and Douglas-fir, and was especially high for white fir and madrone at 52% and 69% respectively. These results point to species differences in crown height, architecture, foliage exposure, and resistance to heat. At the unit scale, average bole char heights and crown scorch levels were generally linked to the proportion of the unit area in moderate to high soil burn severity, and were highest in unit 28s. Strikingly, the average crown volume blackened or consumed by torching was 1% or less for all units and species (except 2% for the low-crowned madrone) reinforcing the overriding role of convective heat transfer for crown injury in these burns. Cambium kill (as the average percent of basal circumference) was highest for the thin-barked madrone, but does not consistently correspond with levels of basal duff consumption or soil burn severity. After madrone, white fir and ponderosa pine had the highest rates of cambium kill (Tables 2 and 5).

Mortality estimates and determining factors

Of all the data collected (see Appendix 1), predictive models consistently emphasized crown scorch as the primary indicator of mortality. All models were species-specific, and most incorporated tree diameter. The more complex models also factored in the impact of cambium kill and insect attack. In Table 5, these predictive metrics and estimated mortality ($\geq$ 70% probability) rates are presented by species and for the high-scorch units overall. Legacy tree mortality was estimated at 16% overall, but with wide variation at the species level. Ponderosa pine had by far the lowest predicted mortality at only 7%. Because ponderosa pine was the most abundant legacy tree at > 50% frequency in our sample, it effectively lowered the overall average rate, masking far higher predicted mortality for all other legacy species (Table 5). Sugar pine mortality was the highest estimated, at a concerning 30% of legacy trees. And if estimated rates for Douglas-fir (23%) and white fir (22%) prove accurate, nearly a quarter of legacy trees for those species will die. Given madrone's vigorous capacity to basal-sprout, madrone mortality is defined here as 100% top-kill, and the predicted 20% madrone mortality rate may prove to be an underestimate. Because species were not evenly distributed by unit in our sampling design, this species-level variation obscures the general pattern of fire intensity and legacy mortality at the unit scale.

Table 4. Species and unit-scale summary of fire effects on legacy trees in the 2017 AFR high-scorch units, with predictions of legacy tree mortality based on a 70% probability threshold.

	White fir, ABCO	**Madrone, ARME**	**Sugar pine, PILA**	**Ponderosa pine, PIPO**	**Douglas-fir, PSME**	**High Scorch Units**	**Unit 28s**	**Unit 28y**	**Unit 31c**
Legacy tree sample size	9	5	10	27	13	50	16	16	18
Bole char height (ft) average	24	5	11	20	21	20	31	11	19
Crown torch % volume average	1%	2%	0%	< 1%	0%	< 1%	< 1%	0%	< 1%
Crown scorch % volume average	52%	69%	30%	14%	35%	26%	37%	15%	28%
Moderate soil burn severity % area	73%	70%	69%	76%	67%	72%	88%	62%	67%
High soil burn severity % area	3%	3%	1%	3%	4%	4%	6%	1%	3%
Basal duff % consumption	11%	20%	25%	32%	29%	30%	41%	30%	21%
Cambium kill % average	23%	45%	25%	18%	8%	16%	24%	6%	18%
Predicted mortality rate	22%	20%	30%	7%	23%	16%	25%	13%	11%

Table 5. Species-level and overall predicted mortality rates (≥ 70% probability threshold) and determining model inputs.

	White fir, ABCO	**Madrone, ARME**	**Sugar pine, PILA**	**Ponderosa pine, PIPO**	**Douglas-fir, PSME**	**High Scorch Units**
Legacy tree sample size	9	5	10	27	13	50
DBH (in) average	39.6	20.4	50.9	42.0	41.5	42.5
Crown scorch % volume ≥ 75%	33%	60%	30%	7%	23%	18%
Cambium kill ≥ 50% proportion	22%	60%	30%	22%	8%	18%
Stress-indicator insect attack rate	67%	20%	50%	48%	23%	46%
Mortality-causing insect attack rate	0%	0%	0%	4%	0%	2%
Predicted mortality rate	22%	20%	30%	7%	23%	16%

Mortality causes and thresholds – initial assessment

For some tentative insight into the potential causes and predictors of legacy tree mortality, Table 6 presents a summary comparing relevant metrics for sample trees “able to survive” (< 70% probability of mortality) and those “likely to die” (≥ 70% probability of mortality). Note that initial insect detections were essentially limited to early-arriving, stress-indicating species, most frequently red turpentine beetle. There was only a single post-burn detection of mortality-causing insect attack, western pine beetle in a ponderosa pine, but presence of these tree-killing beetles is likely to increase over time with most impact during the first three years post-fire.

Acknowledging the limits of our initial data and very low sample size for likely-mortality trees, some patterns seem potentially important:

- Crown scorch ≥ 75% is an overriding factor in initial mortality predictions for all legacy species.
- Cambium kill ≥ 50% around the tree’s base is strongly linked to mortality of legacy conifers, but not madrone.
- Basal duff consumption was generally *lower* for trees likely to die (except sugar pine), suggesting that cambium mortality was strongly influenced by factors other than duff smolder or surface fire contact. (Damage from insect attack or stress from tree injury can also lead to cambium death, especially for trees with lower vigor due to pre-existing disease.)
- The simple summary in Table 6 suggests that insect attack is an important mortality factor or indicator for all species, except white fir to date.
- White fir mortality predictions do not follow these patterns for insect and disease stress or soil burn severity.

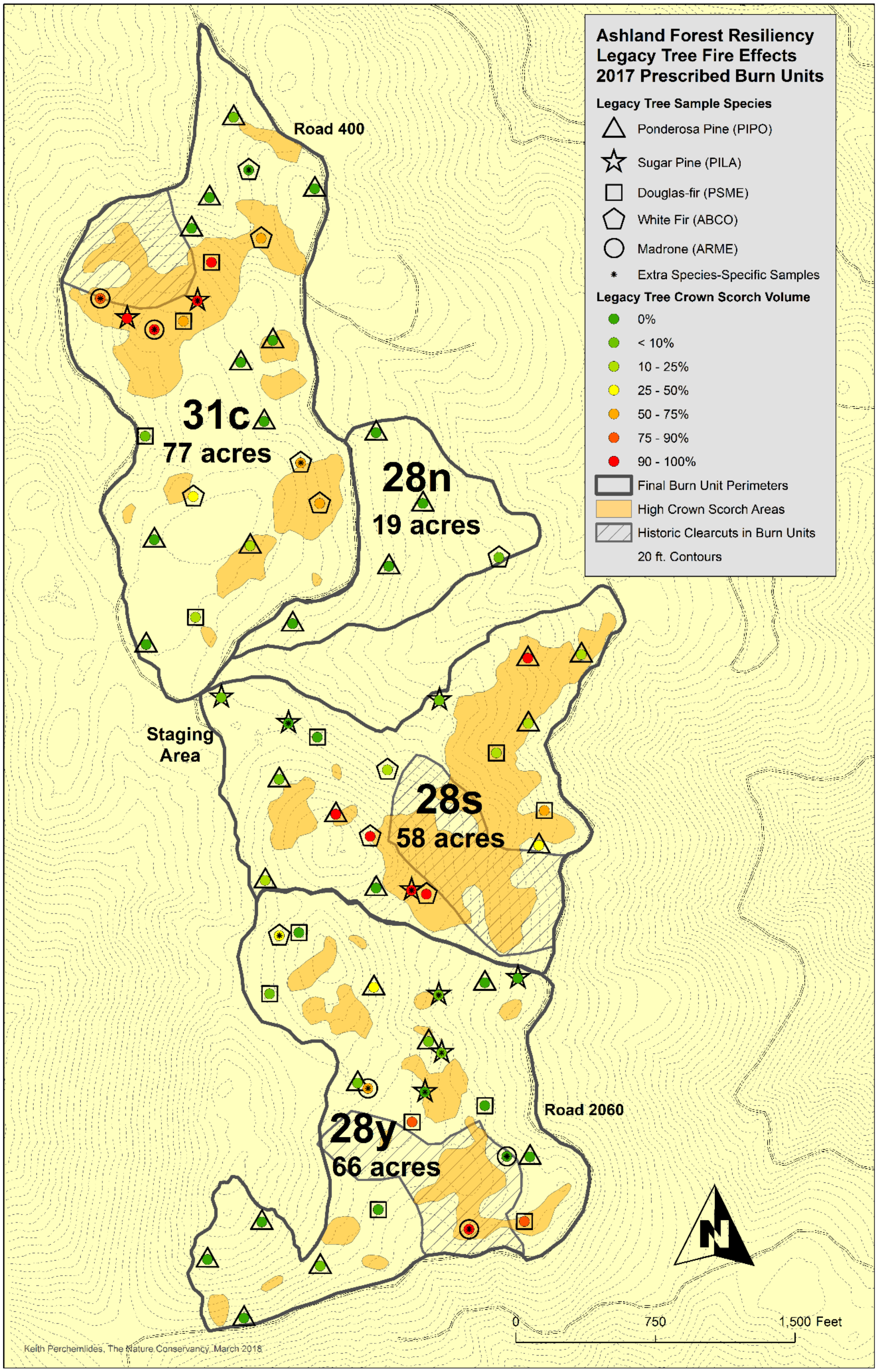
Table 6. Summary comparison of predictive metrics for legacy trees with < 70% probability of mortality (top) and those with ≥ 70% probability of mortality based on initial sample data. Note low sample sizes.

Trees likely to survive, < 70% probability of mortality	**White fir, ABCO**	**Madrone, ARME**	**Sugar pine, PILA**	**Ponderosa pine, PIPO**	**Douglas-fir, PSME**	**High Scorch Units Grid**
Legacy tree sample size	7	4	7	25	10	42
Crown scorch volume ≥ 75% proportion	14%	50%	0%	0%	10%	5%
Moderate/high soil burn severity % area	80%	65%	57%	78%	68%	74%
Cambium kill ≥ 50% proportion	14%	50%	0%	16%	0%	10%
Basal duff % consumption	14%	25%	18%	34%	33%	33%
Insect attack proportion	71%	0%	29%	44%	0%	38%

Trees likely to die, ≥ 70% probability of mortality	**White fir, ABCO**	**Madrone, ARME**	**Sugar pine, PILA**	**Ponderosa pine, PIPO**	**Douglas-fir, PSME**	**High Scorch Units Grid**
Legacy tree sample size	2	1	3	2	3	8
Crown scorch volume ≥ 75% proportion	100%	100%	100%	100%	67%	88%
Moderate/high soil burn severity % area	60%	100%	97%	100%	81%	82%
Cambium kill ≥ 50% proportion	50%	100%	100%	100%	33%	63%
Basal duff % consumption	0%	0%	42%	0%	17%	16%
Insect attack proportion	50%	100%	100%	100%	100%	88%

Summary

Initial monitoring results predict 16% average mortality of legacy trees in the high-scorch units (AFR 28s, 28y and 31c), with predicted mortality driven by crown scorch injury, and further elevated by cambium kill or insect attack. At the unit scale, the degree of heat-related injury or stress and the predicted mortality rate for legacy trees generally aligned with the level of burn intensity. Species-level estimates present a more varied picture with considerably higher than average mortality rates for all species except ponderosa pine, well-known to be fire-adapted. With lofty crowns, thick bark, high pre-burn vigor, and located in areas of relatively lighter fuels, the ponderosa pine predicted mortality rate of 7% was less than half the overall average. In contrast, sugar pine had the highest predicted mortality at 30%, nearly twice the overall average. Douglas-fir and white fir have predicted mortality approaching one-quarter of legacy trees (23% and 22% respectively). Douglas-fir and white fir had the highest fuel-load environment and average crown scorch of all conifer species. For madrone, the predicted mortality rate of 20% seems questionably low given that these legacy trees had the highest pre-burn fuel loading, crown scorch and cambium kill, but may account for species-specific survival capabilities. Many hardwood species can withstand substantial canopy scorch and consumption and still re-sprout from branches or stems, though with reduced vigor due to partial cambium mortality. From an ecological perspective, even top-killing madrone can have negative consequences given the reliance of many wildlife species on cavities that only develop in large-diameter trees. Follow-up monitoring at 1-year and 2-years post-burn will have a far greater ability to detect developing indicators of mortality and may find different patterns and explanations than these initial results.



Map 1. Location, species, and crown scorch for the sample of legacy trees within the 2017 AFR prescribed burn unit final perimeters. Areas of high crown scorch (≥70% scorch on ≥90% of trees) are mapped in orange, and the extent of historic (~1960s) clearcuts are shown in cross-hatch. Additional species-level samples are marked with an asterisk.

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Appendix 1. AFR 2017 legacy tree fire effects monitoring tree and plot data definitions and field protocol notes.

Metric	**Description**
Tree tag number	unique identifier number on tag nailed at DBH height facing upslope
Species	four letter species code: PIPO, PILA, PSME, ABCO, ARME
Date	date of field observation
Diameter (DBH)	in inches to nearest 0.1", at 4.5' above ground on upslope side of bole
Aspect	slope aspect in degrees, compass bearing
Slope	percent slope, clinometer, average of up and down slope
Crown scorch % volume	percent of pre-burn live crown volume turned brown by heat
Crown scorch % length	percent of pre-burn live crown length turned brown by heat
Crown torch % volume	percent of pre-burn live crown volume turned black or consumed
Bole char height	in feet to nearest foot, height of continuous black char on bole
Cambium kill %	0 - 4 score for fire-killed cambium detections, checked near groundline at upslope or hottest burn location, if detected checked at three more locations at ~90 degree intervals around the bole; does not include dead cambium when obviously from pre-burn fire scar or other pre-burn damage
Fuel model pre-burn	Scott and Burgan (2005) fuel model estimated for pre-burn fuel load in 0.1 ac circular plot around tree base
Moderate soil burn severity % area	% area of moderate severity burn conditions in 0.1 ac circular plot around tree, Parsons et al. (2010) method
High soil burn severity % area	% area of high severity burn conditions in 0.1 ac circular plot around tree, Parsons et al. (2010) method
Basal duff % consumption	0 - 4 score for substantial consumption of duff in contact with tree base with each point equivalent to approximately 25% of basal circumference
Mortality-causing insect attack	1 = yes, 0 = no: evidence of post-burn beetle attack by
MPB	mountain pine beetle
WPB:IPS	western pine beetle / Ips beetle
DFB	Douglas-fir beetle
FFB	flatheaded fir borer
FEG	fir engraver
Stress-indicator insect attack	1 = yes, 0 = no: evidence of post-burn beetle attack by
RTB	red turpentine beetle
AMB	ambrosia wood borer
OWB	other wood borer
Pre-burn basal scar	1 = yes, 0 = no: substantial pre-burn basal scar from prior burn or mechanical
Pre-burn weak crown	1 = yes, 0 = no: evident pre-burn crown die-back or obvious low crown vigor
Pre-burn blister rust	1 = yes, 0 = no: evidence of pre-burn pine blister rust, PILA only
Pre-burn mistletoe	1 = yes, 0 = no: pre-burn mistletoe infestation with a Hawkworth rating $\geq$ 4
Chimney effect?	"yes" if legacy located in canopy gap with surrounding relatively dense lower-height canopy capable of funneling convective heat to tree, else "no"