USDA Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Pacific Northwest Region | R6- FHP-RO-2020-02 | Revised June 2021

POST-FIRE ASSESSMENT OF TREE STATUS AND MARKING GUIDELINES FOR CONIFERS IN OREGON AND WASHINGTON

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Post-fire Assessment of Tree Status and Marking Guidelines for Conifers in Oregon and Washington

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OVERVIEW

Predicting post-fire tree mortality is not an exact science, but knowing whether trees will die within 3 years post-fire will help managers and silviculturists responsible for certifying prescriptions determine whether management objectives and desired future conditions can still be achieved (Filip et al. 2007). Management objectives and desired conditions often determine how trees will be marked. Data gathered for several years following fires, both in the Pacific Northwest and throughout the west, have provided significant information to help inform the likelihood of tree death following a fire.

The assessment protocols and marking guidelines in this document provide injury thresholds for predicting the likelihood of tree death within three years after fire at different levels of probability. The assessment portion is based, in part, on Forest Service guidelines for the Southwestern Region (Smith and Cluck 2011) and Northern Region (Hood et al. 2017). This section describes how to determine the levels of fire injury and insect damage that have been shown to be the best indicators of tree mortality. The guidelines use the crown injury indicators “percent crown length scorched” or “percent crown volume scorched” alone, or in combination with DBH, bark char or cambium injury, and/or the presence or absence of beetle activity indicators to predict mortality. They incorporate data collected from Oregon and Washington and include documented associations among fire-caused crown and bole injury indicators and subsequent tree mortality for a variety of conifer species growing in the Pacific Northwest. They are a compilation of the latest research on predicting post-fire mortality.

Two different assessment and marking guidelines have been developed which vary in the amount of background information and decision criteria provided to the user:

1. A simplified post-fire rubric that is a stream-lined, more field-oriented guide to evaluate trees for fire-caused injuries and estimate whether a tree is likely to die within 3 years after a fire.

2. Full marking guidelines that provide injury thresholds to determine if a tree will die within three years with a range of probabilities and more specific indicators.

Usage Notes:

- This document should <u>not</u> be used as hazard or danger tree guidelines. It does not account for the probability of tree failure after fire, only the likelihood of death. The topic of trees rendered hazardous or dangerous by fire is outside the scope of this guide and addressed by several relevant publications (Filip et al. 2014, 2016). However, monitoring has shown high levels of decay developing in fire-injured white fir where significant cambium kill occurred at the root collar and on the bole. A portion of these decayed trees failed during the five-year period post-fire while still retaining green foliage. Land managers should be aware that even though true firs with high levels of cambium kill have a high probability of survival, they may become hazards to people or property (Cluck 2005).

- It is recommended that these guidelines be used only through the second post-fire winter. After that crown injuries become less apparent, making assessments more difficult and these guidelines are not applicable.

- The guidelines provide high flexibility to tailor fire salvage prescriptions to individual project needs. We recommend that land managers carefully document the rationale used to make probability of mortality (Pm) level selections for future reference.

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CHAPTER 1: ASSESSING TREE INJURY AFTER FIRE

This Chapter describes the indicators used to assess if a tree will likely die after fire. If the thresholds provided are exceeded, then the tree is likely to die.

The likelihood of a tree dying after fire can be assessed by the following indicators:

1. Crown Condition: the percentage of the live crown volume or length that is remaining,
2. Cambium Injury: the cambium mortality at the root collar,
3. Beetle Activity: mass attack or simple presence of bark beetles and wood boring beetles.

The probability that a tree will die after fire depends upon the magnitude of severity of all three factors. Users wanting a more detailed review of fire-caused tree mortality are encouraged to see Filip et al. (2007) and Hood et al. (2018).

ASSESSING LIVE VERSUS DEAD CROWN

The amount of live crown remaining post-fire is important for the tree's ability to photosynthesize. Crown condition is readily observable and is the most reliable single indicator of post-fire mortality for most species. Tree crowns in the process of fading, where all unburned foliage is transitioning uniformly from green to yellow to red/orange, are considered dead. Otherwise, the degree to which tree foliage is green (unaffected), orange (heat-killed needles), or black (burned or entirely consumed needles) determines live/dead status. Species differ in the amount of crown loss they can survive.

Crown scorch includes both scorched needles (needles present but brown or orange) and consumed needles (blackened needles or only needle fascicles remain; branches blackened). Crown scorch is **not** an estimate of live crown ratio[1]. Rather it is an estimate of how much of the pre-fire living crown was killed by fire. For all species, except ponderosa pine and western larch, it is assumed that any areas with scorched or consumed needles will also have dead buds and branches.

Crown scorch is visually estimated as either a percentage of the pre-fire crown volume or crown length impacted by fire. Both volume and length estimates are accurate, but not interchangeable, and the variable used depends on the data collected in studies of post-fire tree mortality.

Percent crown volume scorch (**PCVS**) is the percentage of the pre-fire crown volume that is scorched from fire. It is determined by first estimating the pre-fire live crown volume, based on remaining live crown, residual scorched foliage, residual burned foliage, and residual

[1] Crown ratio is the percentage of total tree height that has live foliage. It is used when determining if a live tree has enough crown to respond to thinning. The percentage of green crown remaining after fire-injury is not the same. i.e. a tree with a 30% crown ratio may or may not respond to thinning but it may remain alive; a tree with 70% crown scorch and 30% live crown remaining will likely die.

branches that have burned but likely had live needles prior to the fire. After estimating what the pre-fire live crown looked like, next estimate the percentage of the crown by volume that is scorched. It can help to break the estimated pre-fire crown into halves – is the scorch higher or lower than the 50% estimation? You can then divide the halves again to further estimate 25% or 75%. Doing this allows you to quickly hone in on a ballpark estimate, which can be further refined to a final estimate of crown volume scorch.

The following formula applies:

$$\mathbf{PCVS} = \frac{\text{percentage volume of live crown scorched from fire}}{\text{prefire crown volume (always 100\%)}}$$

Percent crown length scorch (**PCLS**) is the percentage of the pre-fire crown length that is scorched from fire. It is determined by first visually estimating the pre-fire live crown base height using remaining live crown, residual scorched foliage, residual burned foliage, and residual branches that have burned but likely had live needles prior to the fire. Next, estimate the average height of the impacted crown. The final crown length scorched estimate can be obtained by either visually estimating the percentage of pre-fire crown length that is scorched or by using a hypsometer or clinometer to measure the estimated pre-fire crown length and average scorch length.

The following formula applies:

$$\mathbf{PCLS} = \frac{\text{length of crown scorched from fire}}{\text{prefire crown length}} \times 100$$

When assessing scorched and consumed crowns, consider these tips (Hood et al., 2007a):

- It is difficult to determine crown scorch when the sky is gray; accuracy will decrease because the greens and oranges are hard to distinguish.
- Reconstruct what was living before the fire based on fine branch structure and remaining needles.
- Estimate the scorch amount based on the part of the crown that was living pre-fire.
- Stand back away from a tree, preferably with the sun to your back to determine crown damage levels. Assessment cannot be done while standing at the tree base. You may need to look at the crown from several different angles.
- For asymmetrical crowns, mentally “move” lower branches around the crown base to symmetrically compact the tree’s crown.

Species Differences

Ponderosa pine (PIPO) and western larch (LAOC) are assessed in a different manner than other tree species because areas of the crown with scorched needles could have buds and branches that survived.

PIPO can potentially survive fairly high crown scorch levels if the fire caused minimal bud kill or crown consumption (Fowler et al. 2010, Hood et al. 2010). The likelihood of a PIPO dying from fire is high if any of the three conditions are met:

- > 85% pre-fire crown volume is scorched (needles present but brown or orange)
- > 40% pre-fire crown volume is consumed (blackened needles or only needle fascicles remain; branches blackened)
- > 5 and ≤ 40% pre-fire crown volume is consumed, combined with > 50% crown scorch

LAOC crown injury must be assessed either before needles drop in the fall of the year of the fire, or after bud break the following year post-fire. The method for determining the likelihood of a LAOC dying from fire changes depending on whether the assessment occurs during the growing season or dormant season. During the growing season when the needles are on, the tree will likely die if crown length scorch is ≥ 80%. If the assessment is done during the dormant season when needles are not present, then bark char height can be used to determine if a tree is alive or dead. If the average height of char observed on the bole is ≥ 70% of the total height of the tree, then it is considered dead.

It is easier to assess PIPO and LAOC crown injury post-bud break the first season after fire. At that time, it will be apparent if the buds survived the fire even if the surrounding needles were scorched by looking for new green growth at branch tips for PIPO and along branches for LAOC.

Figure 1 shows how to assess crown scorch in Douglas-fir. Figure 2 demonstrates how to evaluate and classify crown scorch and dead crown in ponderosa pine. Figure 3 shows a crown with all needles consumed or scorched. Figure 4 is a schematic showing how to estimate crown damage and bark char.

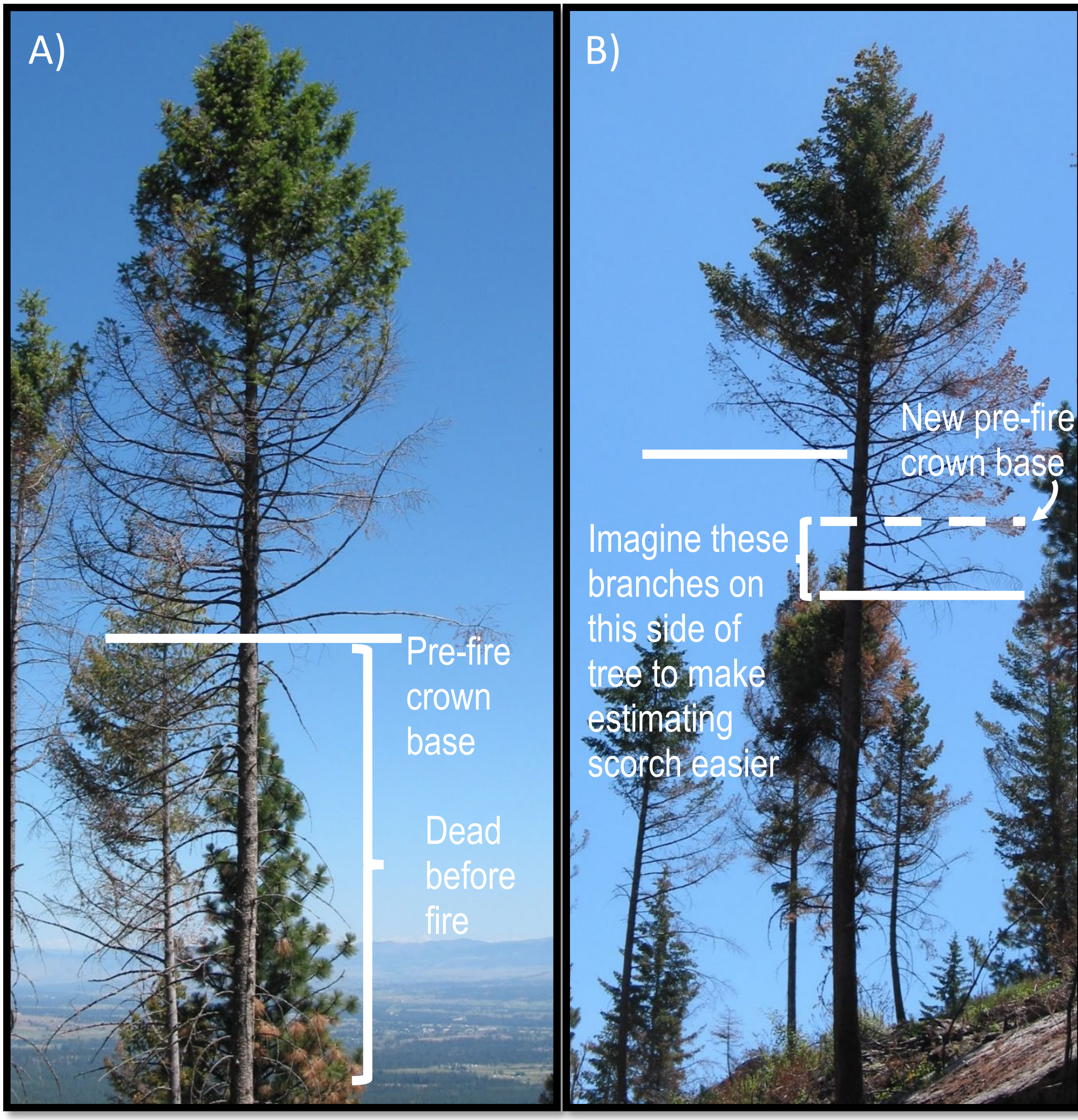

Figure 1. Assessing crown scorch (Hood et al., 2007a). Two examples of Douglas-fir with 50 percent crown volume scorched. A) The short, lower branches of this tree were dead before the fire and should not be included when determining crown scorch. Branches that were dead before the fire will not have any fine twigs and will often be broken off.
B) Trees often have asymmetrical crown bases as seen in this photo. A trick to determining crown scorch for these trees is to "move" some of the lower branches to the other side of the crown to symmetrically even out the crown bases. Next, estimate crown scorch based on this new crown shape.

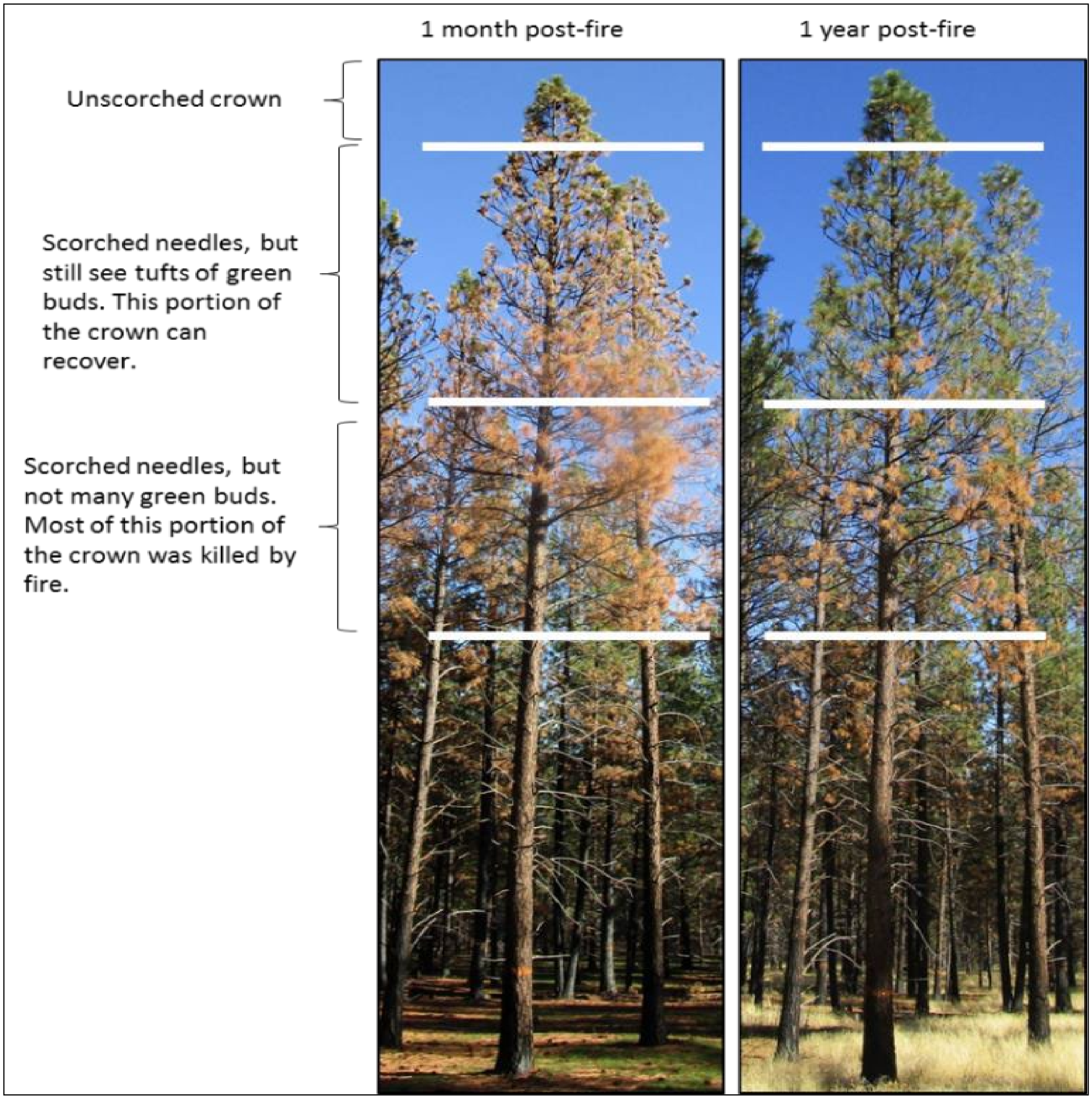

Figure 2. Example of ponderosa pine dead crown assessment. Ponderosa pine with 85% pre-fire crown volume scorched but little-to-no (i.e. < 10%) needles blackened or consumed. The buds in a large portion of the crown survived the fire, allowing the tree's crown to recover the following year. Within a couple months after a fire, areas with living buds will start to appear thin, as the scorched needles fall off. Areas with dead buds will retain scorched needles for much longer (right photo).

Figure 3. A) An example of a tree crown where most of the needles were consumed by fire and the remaining needles are scorched. B) Tree crown where most of the needles were scorched and have fallen off. The buds survived the fire and flushed the first year after fire, but the tree died the second-year post-fire.

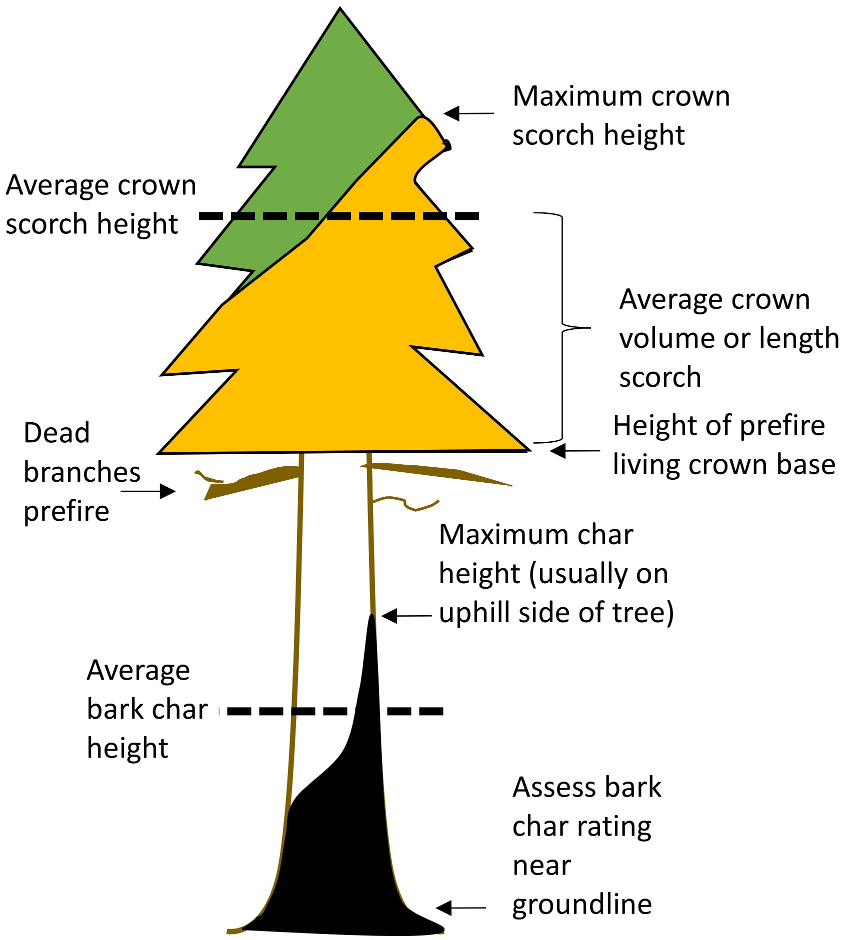

Figure 4. Example of how to assess crown scorch and bark char.

ASSESSING CAMBIUM INJURY AND BARK CHAR SEVERITY

The condition of the cambium determines whether a tree will be able to continue to transport nutrients to roots. Bark insulates cambium from heat during a fire. For thick-barked species, such as ponderosa pine, incense cedar, Douglas-fir, and western larch, the potential for cambium kill is minimized because thick bark quickly develops as tree diameter increases. For thick-barked species, high levels of crown injury (needle consumption or scorch) are typically required to cause tree mortality because the cambium is so well insulated. The cambium at the base of thin-barked species, such as lodgepole pine, Engelmann spruce, and some firs, is easily killed by fire even without any crown damage. Trees with high amounts of dead cambium, but with little crown injury, may take several years to die because the trees can still photosynthesize and transport water up through the xylem, but the connection between the crown and roots is severed. Over time, fine roots die without photosynthates, causing a decline in the tree's ability to transport water to the crown and photosynthesize and eventually the tree dies (Hood et al. 2018). Root injury is not included as a mortality risk factor in the salvage guidelines in this document because it is very difficult to assess. If a fire consumed deep duff (>5 inches) that had accumulated around the bases of trees, and root injury is a concern, we direct readers to Hood (2010).

Cambium death, caused by high or sustained heating of the tree bole or root collar, is an influential factor in tree mortality following fire. Ryan (1982) states that, in the absence of significant crown injury, most trees survive up to 25% basal girdling, but few trees survive more than 75% girdling. Extensive root collar damage on thin-bark species will most likely result in death, regardless of percent of pre-fire live crown remaining (Hood 2010).

Assessing cambium injury directly

Determine the extent of the cambium injury by directly sampling the cambium. Minimize wounding by sampling in as small an area as possible on the four quadrants of the tree bole within 3" of the ground line (Figures 5 and 6). Use a hatchet or bark punch to cut through the bark and expose a small window of the cambium.

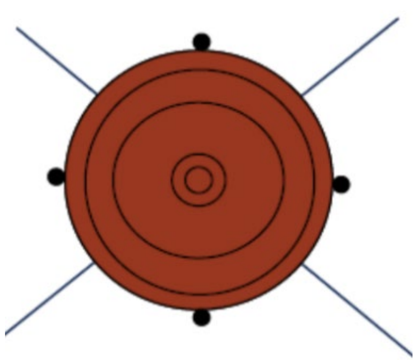

Figure 5: Sample cambium at four quadrants.

Figure 6. Sampling cambium with a small hatchet.

Inspect the samples for the color and condition of the vascular tissue (Figure 7). The cambium is the portion of the tree that creates new bark and xylem (i.e. wood) cells. It is a very thin layer underlying the moist, thicker phloem layer. When assessing if the cambium is dead, we lump cambium and phloem together because it is easier to see the thicker phloem layer, but just refer to cambium for simplicity. Live cambium is lighter in color, as well as moist and pliable. Live phloem and cambium typically separate from the wood as a distinct layer between the bark and wood (Ryan, 1982). Dead cambium is darker in color, often resin soaked and hard, stringy, or gummy, or sometimes dry, in texture. Dead cambium cells lose their plasticity, which may allow the bark and wood to separate more easily with no distinct layer between them. Sampling unburned trees can give a good sense of what live cambium looks and feels like for different tree species.

Add the total number of dead samples (0 to 4) to determine the cambium kill rating **(CKR)**. When both live and dead cambium occurs in the same sample, classify the sample according to the dominant condition of the sample (i.e. if half or more of the cambium is dead, count the sample as dead).

For the most accuracy in assessing cambium kill for thick-barked species, such as ponderosa pine, Douglas-fir and western larch, use this direct sampling method.

Figure 7. An example of dead cambium (left) and cambium that is alive (right).

Bark char as a substitute for direct sampling of cambium injury

The severity and extent of bark char at the root collar (Table 1) can be used as a surrogate for direct cambium sampling (Ryan, 1982). Estimating bark char to determine if a tree is fire-killed is much faster, however, the accuracy varies by species and not all species have been evaluated (Hood et al. 2008). Bark char on thin-bark species is a reliable indicator of cambium death but is not as reliable on species with thick bark. Table 2 provides a crosswalk of bark char codes to the likelihood of whether cambium is alive or dead by species. If direct cambium sampling is not feasible, this crosswalk can be used to estimate CKR to use the tables in Appendix B by assessing bark char on four sides of the tree to determine cambium status.

Another option is to spend some time in the burned area of interest looking at bark char severity and directly sampling the cambium under that bark for a range of species and tree sizes to develop a better eye of what level of bark char is needed to cause cambium death.

The extent of bark char is based on the percentage of the tree stem circumference near the root collar that is charred, not the overall height of the char severity (Figures 8, 9, and 10). The circumference charred is a general estimate and includes areas with fluted roots, but not roots extending out along the soil surface. Moderate bark char is typically the most common severity rating.

Table 1. Bark char severity and descriptions.

Bark char severity	Bark Appearance
Unburned	No char
Light	Evidence of light scorching; can still identify species based on bark characteristics; bark is not completely blackened; edges of bark plates charred
Moderate	Bark is uniformly black except possibly some inner fissures; species bark characteristics still discernable
Deep	Bark has been burned into, but not necessarily to the wood; outer bark species characteristics are lost; bark looks smoothed because all ridges are gone

Table 2. Crosswalk of bark char code to probable status of cambium by species. To estimate cambium kill rating (CKR), evaluate bark char on four sides of tree near groundline and sum the quadrants that likely have dead cambium according to the table.

Species	Light	Moderate	Deep
ABAM: Pacific silver fir	Dead	Dead	Dead
ABCO: white fir or hybrids	Alive	Alive	Dead
ABGR: grand fir	Dead if < 12” DBH; Alive if ≥ 12” DBH	Dead	Dead
ABLA: subalpine fir	Dead	Dead	Dead
ABMA: Shasta red fir	Alive	Alive	Dead
CADE: Incense cedar	Alive	Alive	Dead
LAOC: Western larch	Alive	Alive	Dead if < 12” DBH; Alive if ≥ 12” DBH
PIEN: Engelmann spruce	Dead	Dead	Dead
PISI: Sitka spruce	Dead	Dead	Dead
PICO: Lodgepole pine	Dead	Dead	Dead
PIAL: Whitebark pine	Dead	Dead	Dead
PILA: Sugar pine	Alive	Dead	Dead
PIMO: Western white pine	Dead	Dead	Dead
PIPO/PIJE: Ponderosa and Jeffrey pine	Alive	Alive	Dead
PSME: Douglas-fir	Alive	Alive	Dead
THPL: Western redcedar	Dead	Dead	Dead
TSHE: Western hemlock	Dead	Dead	Dead
TSME: Mountain hemlock	Dead	Dead	Dead

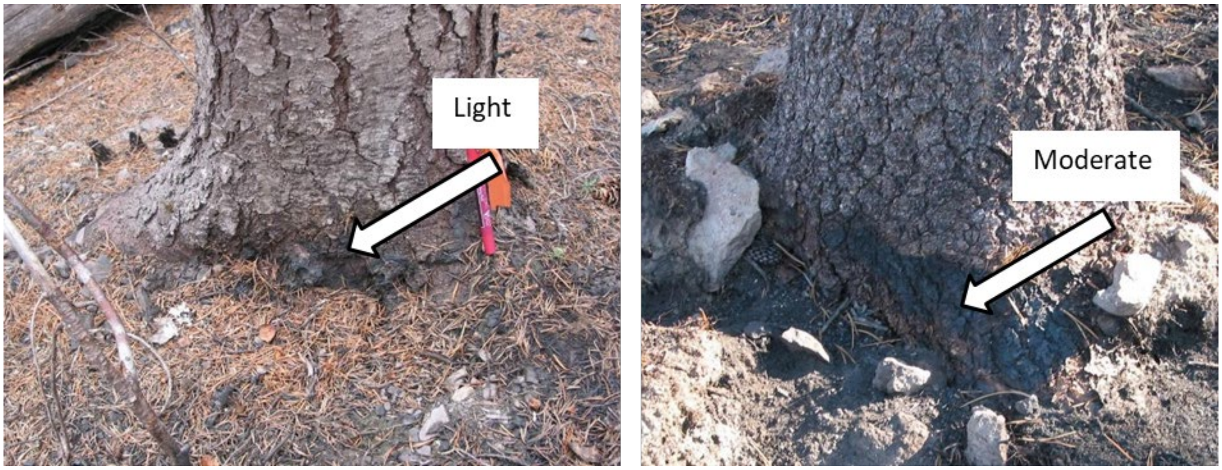

Figure 8. Assess bark char severity at the base of the tree near the root collar. Bark charring may only occur very low on the bole, but if the underlying cambium is killed then the nutrient translocation is still severed from the crown to the roots.

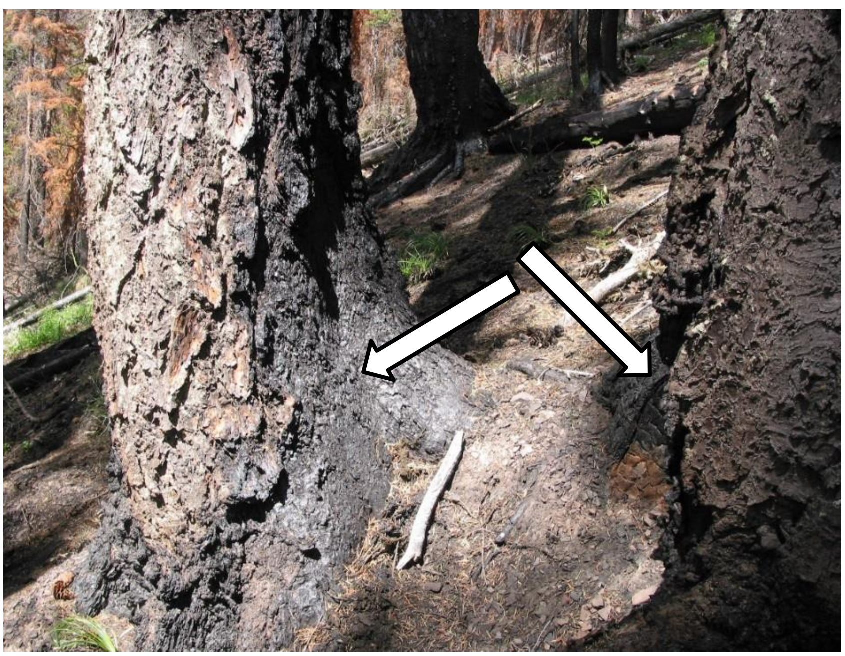

Figure 9. Deep char on Douglas-fir where outer bark species characteristics are lost (left arrow) and completely burned away to expose wood (right arrow).

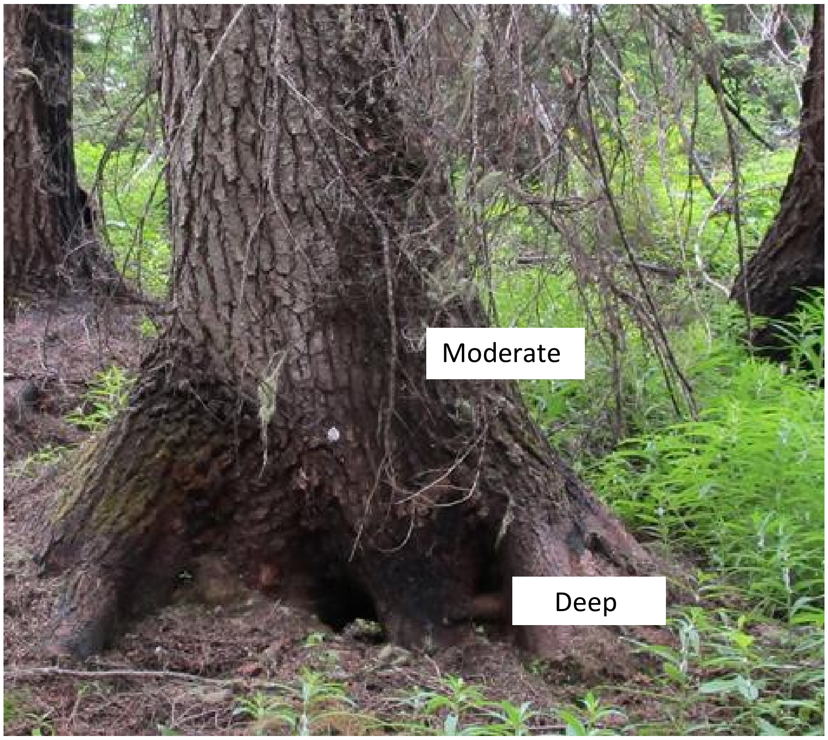

Figure 10. Moderate and deep bark char on western hemlock. Moderate charring has bark that is uniformly black except possibly some inner fissures and species bark characteristics are still discernable. Species bark characteristics are lost with deep charring.

ASSESSING BARK BEETLE AND WOOD BORING BEETLE INFESTATION STATUS

Trees heavily infested by bark and/or wood boring beetles are predicted to die. This is either due directly to the impact of bark beetle infestation and/or indirectly due to trees being so significantly injured that they have become infested by wood boring or ambrosia beetles that only feed in dying and recently dead hosts.

Bark beetle and wood boring beetle infestations within fire-injured trees are common following wildfire events. Trees may be mass-attacked by aggressive bark beetles and/or colonized by secondary bark and wood boring beetles opportunistically taking advantage of dying host. Fire-injured trees create a pulse resource of habitat suitable for insect colonization that typically lasts 2-3 years following fire-injury (Davis et al. 2012). Multiple studies have documented that the presence of bark beetle and wood-boring beetle infestations within fire-injured trees substantially increases the probability of mortality (DeNitto et al. 2000; Weatherby et al. 2001; Hood and Bentz 2007; Hood et al. 2010; Oblinger, 2017).

The amount of bark beetle and wood boring beetle infestation will determine the potential for mortality even if the tree is not predicted to die based on other injury variables. Some types of beetle attack can indicate a tree may, in fact, already be dead or dying while still appearing alive. Beetle infestation is typically indicated by the presence of pitch tubes or boring dust on the bole or around the base of a tree.

Pitch tubes may be present in infested pine and spruce trees, but will not occur within Douglas-fir, true fir, or other species. Mass attack pitch tubes are pea to popcorn-sized globs of resin ranging from white/tan to reddish/pink in coloration (Figure 11).

Figure 11. Example of popcorn-sized pitch tubes scattered over the bole that are caused by bark beetle attacks on pines and are diagnostic of tree mortality.

Large pitch tubes near the base of pines caused by red turpentine beetles (RTB) do not signify mass-attacks that will directly cause mortality and, in most cases, should be ignored when looking for evidence of significant beetle activity on the bole. RTB pitch tubes are typically larger than a quarter, are deep-red, and found in the lower 3-feet of a tree's bole (Figure 12). Very occasionally, RTB attacks aggressively and when this kind of significant activity occurs it should not be ignored, but rather the RTB should be assessed like other bark beetles for mass attack. FHP personnel can assist with this determination.

Pitch streamers may occur on true fir, Douglas-fir, spruce, and occasionally other hosts but are not specific enough for a beetle attack diagnosis (Figure 13). When observed, look for additional evidence of beetle activity on the tree bole. Consider beetles as present only if boring dust is also encountered. On spruce, small pitch tubes may be present instead of boring dust. Boring dust with reddish-brown or white coloration found within bark furrows and in the upper root collar area of a tree's lower bole is diagnostic for beetle attack within all tree species (Figure 14 and 15).

Figure 12. Large pitch tubes at the base of the tree caused by red turpentine beetle (RTB) are generally not diagnostic of tree mortality and usually should be ignored when determining bark beetle mass-attack status, except when using the tables in Appendix B for ponderosa and Jeffrey pine.

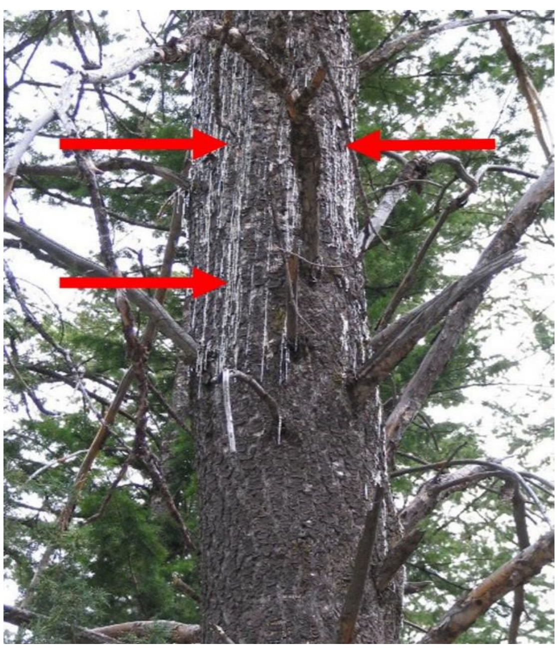

Figure 13. Pitch streamers that are not diagnostic of beetle mass-attack. Presence should trigger further investigations to detect diagnostic insect boring dust.

Figure 14. Boring dust is diagnostic of mass beetle attack on Douglas-fir.

Figure 15. White boring dust from ambrosia beetles is an indication that the tree is already dead.

Infestations can be classified as having no bark beetle or wood boring beetle activity, unsuccessful-attacks, strip- attacks, or mass-attacks, depending on the density and arrangement of indicators. Only mass-attacked trees are used when designating tree mortality status. Beetle mass-attacks that indicate tree mortality are designated by presence of pitch tubes and/or boring dust around > 50% of the circumference of the lower bole of a tree (Hagle et al. 2003).

How to assess beetle mass-attack and beetle presence
Inspect the bole of the tree for randomly arranged popcorn- or smaller-sized pitch tubes (pines and spruces), whitish to reddish brown boring dust (all species), pouch fungus, or woodpecker activity associated with mass attacks or beetles.
If present, assess the percentage of bole circumference with beetle activity indicators. Exclude red turpentine beetle (RTB) pitch tubes from this assessment unless significant activity is present. Trees are considered mass attacked when boring dust, pitch tubes, or other indicators predicting beetle-associated tree mortality are present on ≥50% of the bole circumference.
Inspect the boles of ponderosa, Jeffrey, and sugar pines for RTB pitch tubes or boring dust. If present, use the **RTB beetles present** table for the respective tree species to assess the probability of mortality according to crown scorch and/or cambium variables. If no RTB pitch tubes or boring dust are present, use the **RTB beetles absent** tables. Inspect the boles of white fir, western hemlock, or Douglas-fir for boring dust. If present, use the beetles present tables for the respective tree species. If no boring dust is present, use the beetles absent tables.

Further information about diagnostics of bark beetle symptoms and attack characteristics can be found in Forest Health Protection’s "Field Guide to the Common Diseases and Insect Pests of Washington and Oregon Conifers" (Goheen and Willhite, 2021).

CHAPTER 2: DETERMINING DEAD AND DYING TREES

We provide two different methods for determining dead and dying trees after fire. The methods draw on the same research but apply the mortality models differently. Most post-fire tree mortality research uses logistic regression to develop models predicting tree death after fire. A tree is considered either alive or dead, but the model outputs values as a continuous probability of death between 0 (alive) and 1 (dead). Therefore, users must decide a threshold above which trees will be considered dead. This can complicate applying the models, but it also allows users flexibility to choose the threshold that works best for their management objectives. Some researchers have developed basic thresholds for when a tree is likely to die as an alternative to logistic regression. These are simple to use, but do not provide the same flexibility as logistic regression models.

The methods to assess the likelihood of tree mortality are:

1. Tree assessment rubric (Appendix A): A one-page field guide that can be used as a stand-alone document in the field. Individual trees are considered dead if they are likely to die within three years post-fire in order to capture delayed tree mortality.

2. Full marking guidelines (Appendix B): The guidelines provide injury thresholds to determine if a tree will die within three years after fire over a range of probabilities and requires more specific evaluation criteria.

The methods were developed with different applications in mind. The rubric and full marking guidelines are not directly comparable, as different methods were used. The rubric uses the logistic regression and threshold model output more generally (i.e., not a specific probability of mortality level), together with expert opinion to make a simplified guide to determine which trees are likely to die within 3 years post-fire. The full guidelines report actual logistic regression and threshold model output. <u>When deciding whether to use the rubric or full guidelines, it is important to document your reasons for choosing that method. If the full marking guidelines are used, it is also important to document your reasoning for the threshold level chosen.</u>

Readers are encouraged to use the rubric and full marking guidelines in field training sessions in consultation with fire ecologists and entomologists.

<u>TREE ASSESSMENT RUBRIC</u>

In this assessment, trees are considered dead if they are likely to die within 3 years post-fire to capture delayed tree mortality. Trees exceeding the listed thresholds are considered dead, even if they have green needles, because they will likely die within 3 years.

The rubric shows mortality thresholds using percent crown scorched (either as a percentage of volume or length), circumference and severity of bark char at the root collar, and the bole circumference infested by bark beetles or wood boring beetles. For the rubric, bark char severity is used instead of cambium kill. A tree is considered dead if **any** criterion is met.

The rubric can be used to:

- Provide a fast estimation for determining if a stand would meet salvage requirements. For example, in a large burn, you may want to first identify potential areas that have enough volume of dead and dying trees before moving to more specific marking guidelines. A few plots using the rubric would provide an estimate of expected stand-level mortality by species.
- Determine a change in designation. For example, the rubric allows a fast way to evaluate if a stand no longer meets old-growth conditions or specific habitat conditions for wildlife. Individual stands can be examined spatially to determine anticipated cumulative mortality for a watershed.
- Provide marking guidelines to remove or leave trees for harvesting operations.

The advantage of the rubric is that it is simple to apply; the disadvantage is that there is not much discretion to change the thresholds to account for other factors. Thresholds are based only on if the tree is likely to die within three years post-fire. See Appendix A for the rubric.

FULL MARKING GUIDELINES

The marking guidelines (Appendix B) provide injury thresholds to determine if a tree will die within three years after fire over a range of probabilities. The guidelines allow for using only percent crown length or volume scorched or killed, or crown injury in combination with DBH, cambium kill rating, and/or the presence or absence of bark beetle activity. The marking guidelines are more detailed and provide users with a wider range of options based on land management objectives and site conditions to develop specific marking guidelines for a given area. An example of a marking guideline is provided in Appendix C.

Determining what variables to use when marking trees for removal

Identify the tree species to be evaluated when marking. Decide whether the cambium injury or beetle presence variables will be included in mortality assessments. Evaluation of a cambium injury variable (cambium kill rating or bark char) is an option for most tree species. Use of the beetle presence variable is an option when assessing the mortality probabilities of ponderosa pine, Jeffrey pine, sugar pine, white fir, western hemlock, and Douglas-fir.

Managers should determine how much time is available for assessing each tree. The most accurate marking guidelines require the most time and assess crown injury and cambium injury, and, when applicable, red turpentine beetle (RTB) activity. At a minimum, a crown injury assessment is required for all species. Assessing cambium injury and/or RTB activity (for the ponderosa, Jeffrey, and sugar pines) requires additional time, however, it does provide some increase in accuracy for white fir, sugar pine and ponderosa and Jeffry pines. In general, if managers choose to only assess crown injury, and the fire resulted in cambium kill ratings > 2 on most trees, mortality will be under predicted. The opposite is true if the fire resulted in cambium kill ratings of ≤ 2 on most trees, as mortality will then be over predicted (this varies by tree species). Mortality for ponderosa and sugar pines could also be under or over predicted if RTB activity is not assessed depending on the level of post-fire RTB activity. Knowledge of fire behavior, pre-fire fuel conditions and post-fire RTB activity will help to determine the value of assessing for these variables.

Selecting the predicted probability of mortality (Pm) level that will meet land management objectives

The probability of mortality (Pm) levels incorporated into the guidelines are thresholds where all trees meeting or exceeding a selected Pm level are marked for removal. Providing a range of Pm levels afford land managers more options to meet post-fire management objectives. The number of trees removed from a project area will generally vary with different Pm levels; fewer trees will be marked at higher Pm levels (a more conservative mark) and more trees will be marked at lower Pm levels (a less conservative mark) as per the example below. The exact amount of difference in the mark between Pm levels depends on the population of fire-injured trees within the project area. For example, if the project consists primarily of high severity burn areas, the number of trees marked for removal will not significantly change with different Pm levels.

Probability of Mortality (Pm)								
0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Use lower probability thresholds when it is important to prevent leaving trees that may die

Use higher probability thresholds when it is important to prevent taking trees that may live

The selection of the Pm level should take into consideration the following factors:

- The population of fire-injured trees within the project area (can be based on vegetation burn severity maps showing low, moderate, and high burn severity – see Fire RAVG map in Appendix C)
- Management objectives and desired future conditions
- Number of harvest entries allowed
- Post-salvage fuels objectives
- Snag requirements
- Method of harvest: tractor, helicopter, cable, etc.
- Economics and logistics (availability of marking crews and operators, timber values, length of contracts, etc.)
- Reforestation plans: planting and/or natural regeneration
- NEPA process
- Hazard/Danger trees and whether the risk of leaving trees that likely would die later, and therefore a pose a hazard/danger, is acceptable or not
- Environmental conditions (drought, stand density, severity of dwarf mistletoes, presence of root diseases and beetle activity)

After identifying project-specific objectives, conditions, and requirements, land managers should be able to determine which Pm level, or levels (more than one may be selected), will best meet their needs. Different Pm levels could also be considered for certain trees compared to others depending on management objectives. Consultation with Forest Health Protection staff and other land managers that have implemented projects using these guidelines can greatly assist in making a Pm selection. It is also recommended that land managers document the rationale used to make Pm level selections for future reference.

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APPENDIX A: TREE MORTALITY ASSESSMENT RUBRIC

This rubric can be used to assess the likelihood of tree mortality after fire (see chapter 2). Trees meeting the conditions in the rubric are likely to die within three years of a fire. The species included in the rubric are ones for which accurate post-fire mortality models exist. If a species is not listed, either no post-fire tree mortality data exist or the existing evaluated models performed very poorly. The rubric draws on published research of post-fire tree mortality (Ryan and Reinhardt 1988; Cluck 2005; Thies et al. 2006; Hood and Bentz 2007; Hood et.al. 2007b; Hood et al. 2008; Fowler et al. 2010; Hood et al. 2010; Smith and Cluck 2011; Grayson et al. 2017; Hood and Lutes 2017).

All trees should be evaluated before the beginning of the second post-fire winter, preferably within the first post-fire year. These criteria are a simplification of statistical model predictions.

Use this rubric to meet post-fire management objectives by deciding how many of the criteria are used in the marking decision.

- **If a species is host to beetles or wood borers and there is boring dust and attack signs around > 50% of the bole circumference, the tree will die regardless of fire injury**. This does not include red turpentine beetle (RTB).
- For a less conservative mark, where more trees will be marked to be salvaged, or felled and left, if **any** criterion is met, the tree is predicted to die within 3 years post-fire.
- For a more conservative mark, where fewer trees will be marked to be salvaged, or felled and left, if **both crown scorch and bark char** criteria are met, the tree is predicted to die within 3 years post-fire.
- For the thin-barked species indicated by shaded boxes in the table, it is uncommon for trees to have lower levels of crown scorch (15-40%), with little to no bark char. This combination of fire injury can occur, but generally not over large areas. If a thin-barked tree has a crown scorch value that is around the threshold level, and there is concern that too many trees will be marked to cut, managers have the flexibility to add additional criteria, such as stating that bark char must be present on at least 25% of the bole circumference.

Crown scorch = % length or volume scorched

Bark char = % circumference of bole near groundline

Beetle/wood borer activity = % circumference of bole with signs of attack

Species	Criteria	Diameter Class		
		5 – 11.9"	12 – 20.9"	21"+
ABAM: Pacific silver fir	Crown scorch	> 30% volume		> 40% volume
	Bark char	≥ 50% any char		
ABCO: white fir or hybrids	Crown scorch	≥ 70% volume		
	Bark char	≥ 75% deep char		
ABGR: grand fir	Crown scorch	≥ 60% volume		
	Bark char	≥ 50% any char	≥ 75% moderate or deep char	
ABLA: subalpine fir	Crown scorch	> 30% volume		> 40% volume
	Bark char	> 50% any char		
ABMA: Shasta red fir	Crown scorch	≥ 70% volume		
	Bark char	> 75% deep char		
CADE: Incense cedar	Crown scorch	≥ 85% volume		
	Bark char	> 75% deep char		
LAOC: Western larch	Crown scorch	If needles on: ≥ 80% crown length If needles off: average char height over entire tree length > 70%		
	Bark char	> 75% deep char	Bark char not a predictive injury indicator	
PIEN: Engelmann spruce	Crown scorch	≥ 75% volume		
	Bark char	> 75% any char		
PISI: Sitka spruce	Crown scorch	≥ 75% volume		
	Bark char	> 75% any char		
PICO: Lodgepole pine	Crown scorch	≥ 40% volume		
	Bark char	≥ 75% any char		
PIAL: Whitebark pine	Crown scorch	≥ 40% volume		
	Bark char	≥ 75% any char		
PILA: Sugar pine	Crown scorch	≥ 70% volume		
	Bark char	> 90% moderate or deep char		
PIMO: Western white pine	Crown scorch	> 30% volume		
	Bark char	≥ 90% any char		
PIPO/PIJE: Ponderosa and Jeffrey pine	Crown scorch	Pre-bud break (volume): • ≥ 85% needles scorched OR • ≥ 40% needles consumed/blackened OR • ≥ 5% and ≤ 40% needles consumed/blackened combined with >50% needles scorched Post-bud break (volume): > 70% crown volume killed (no new growth)		
	Bark char	> 90% deep char		
PSME: Douglas-fir	Crown scorch	> 65% crown volume		
	Bark char	> 50% deep char	> 75% deep char	
THPL: Western red cedar	Crown scorch	> 20% crown volume	> 40% crown volume	> 60% crown volume
	Bark char	> 50% any char		> 75% any char
TSHE: Western hemlock	Crown scorch	≥ 20% crown volume		
	Bark char	≥ 90% any char		
TSME: Mountain hemlock	Crown scorch	≥ 20% crown volume		
	Bark char	≥ 90% any char		

Note: If a species is host to bark beetles or wood borers and there is boring dust and attack signs that are not RTB around > 50% of the bole circumference, the tree will die regardless of fire injury.

APPENDIX B: FULL MARKING GUIDELINES

The guidelines report actual logistic regression and threshold model output and cite the publication where the model is reported (see chapter 2).

***Step 1*. Look for evidence of significant bark and/or wood boring beetle activity (Cluck 2008). <u>Any tree meeting the following criteria is predicted to die and no further assessment is required</u>:**

Mortality is predicted if any of the following factors are present over 50% or more of the bole circumference:

1) pitch tubes with associated pink or reddish boring dust, but <u>not</u> clear pitch streamers;
2) boring dust or frass in bark crevices, in webbing along the bole, or that has accumulated at the base of the trees from bark beetles and/or wood borers. The boring dust may be white, gray, or reddish orange in color. Even though the presence of red turpentine beetle (RTB; *Dendroctonus valens*) pitch tubes is used as criterion in some pine guidelines, it should not be used exclusively to mark trees for removal. Basal attacks by RTB on all pines is indicated by large resinous or granular pitch tubes associated with coarse boring dust and is generally restricted to the lower 3 feet of bole;
3) pouch fungus conks;
4) current woodpecker activity indicated by holes into the sapwood and/or bark flaking, excluding woodpecker activity restricted to the lower 3 feet of the bole, injury caused by sapsucker feeding, or when the above indicators are associated exclusively with wounds or old fire scars.

***Step 2*. Use the following probability of mortality (Pm) tables for various tree species in accordance with your preselected assessment factors (crown scorch, cambium injury, beetle attacks, and DBH) to evaluate trees not predicted to die using the Step 1 criteria. Species are listed in alphabetical order by Latin name. Acronyms used in the Pm tables are defined as follows:**

DBH = Diameter at breast height. The diameter ranges in each table represent the actual range of diameters from the data but diameters outside of those ranges can be treated similarly.

PCVS = Percent crown volume scorched

PCVK = Percent crown volume killed

PCLS = Percent crown length scorched

CKR = Cambium kill rating - number of dead cambium samples from checking four sides of the tree at groundline (values of 0 to 4). For some thin barked species as noted in the tables, bark char can be used instead of cambium samples; bark char provides an inaccurate measure for thick-barked species and cambium samples must be used for accuracy.

— = not applicable; the mortality curves do not reach the Pm level for any level of crown injury.

ABIES AMABILIS

PACIFIC SILVER FIR (ABAM)

Data for Pacific silver fir are limited. The threshold model performed better than the existing species-specific models for Pacific silver fir in Grayson et al. (2017); therefore, estimates for Pacific silver fir are the same as in the simple rubric.

Table 1: PACIFIC SILVER FIR: PCVS, bark char, and DBH [Grayson et al. 2017 model]

Criteria	Diameter Class		
	5 – 11.9”	**12 – 20.9”**	**21”+**
PCVS	≥ 30% volume		> 40% volume
Bark char	≥ 50% any char		

ABIES CONCOLOR

WHITE FIR AND HYBRIDS (ABCO)

Since grand fir and white fir hybridize in Oregon, selecting the tree species most applicable to your project area is needed when evaluating post-fire tree survival.

Table 2 (1 factor table) is used if only crown injury is considered when evaluating trees.

Table 3 (4 factor table) is used when evaluating trees for crown injury, DBH, CKR, and ambrosia beetle attacks. The output from this model contains two continuous variables (PCLS and DBH). Complete output cannot reasonably be presented in table format. Results from 20” and 40” DBH are presented to represent DBH classes encompassing the variation, although model output within the data range for any specified DBH or range of DBH can be calculated upon request.

Table 2. WHITE FIR: PCLS [Hood and Lutes 2017 – pre-fire model]

Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
DBH	**Percent crown length scorched (PCLS)**								
6”-60”	20	45	60	65	70	75	80	85	90

Table 3. WHITE FIR: PCLS, CKR, DBH, and **ambrosia beetle** activity [Hood and Lutes 2017 – post-fire model]

DBH = 6" – 30"										
Beetles	**Pm**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
Present	**CKR**	**Percent crown length scorched (PCLS)**								
	0	0	45	60	65	70	75	80	85	90
	1	0	40	55	60	65	70	75	80	85
	2	0	25	45	55	60	65	70	75	85
	3	0	0	35	50	60	65	70	75	80
	4	0	0	0	40	55	60	65	70	80
Absent	**CKR**	**Percent crown length scorched (PCLS)**								
	0	40	60	65	70	75	80	85	90	95
	1	25	55	60	65	70	75	80	85	90
	2	0	45	55	65	70	75	80	85	90
	3	0	35	50	60	65	70	75	80	85
	4	0	0	45	55	60	65	70	75	80
DBH = 31" - 60"										
Beetles	**Pm**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
Present	**CKR**	**Percent crown length scorched (PCLS)**								
	0	0	0	35	50	60	65	70	75	80
	1	0	0	0	40	50	55	65	70	80
	2	0	0	0	20	45	55	60	65	75
	3	0	0	0	0	30	45	55	65	75
	4	0	0	0	0	0	35	50	60	70
Absent	**CKR**	**Percent crown length scorched (PCLS)**								
	0	0	35	50	60	65	70	75	80	85
	1	0	0	45	55	60	65	70	75	85
	2	0	0	25	45	55	60	70	75	80
	3	0	0	0	40	50	55	65	70	80
	4	0	0	0	0	40	50	60	65	75

ABIES GRANDIS
GRAND FIR (ABGR)

Although data for grand fir exist, species specific logistic regression models and threshold models for grand fir in Grayson et, al. (2017) performed similarly; therefore, estimates for grand fir are the same as in the simple rubric. Grand fir and white fir are not interchangeable. Since grand and white firs hybridize in Oregon, selecting the tree species most applicable to your project area is needed when evaluating post-fire tree survival.

Table 4: GRAND FIR: PCVS, bark char, and **DBH** [Grayson et al. 2017 model]

Criteria	**Diameter Class**		
	5 – 11.9”	**12 – 20.9”**	**21”+**
PCVS	≥ 60% volume		
Bark char	≥ 50% any char	≥ 75% moderate or deep char	

ABIES LASIOCARPA

SUBALPINE FIR (ABLA)

Due to its very thin bark, accounting for cambium kill by using either CKR or bark char severity improves accuracy in post-fire mortality estimation substantially.

Table 5 (1 factor table) is used if only crown injury is considered when evaluating trees.

Table 6 (2 factor table) is used when evaluating trees for crown injury and CKR.

Table 5. SUBALPINE FIR: PCVS [Hood and Lutes 2017 – pre-fire model]

Pm	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
DBH	**Percent crown volume scorched (PCVS)**								
4” – 30”	0	0	5	5	10	15	20	35	75

Table 6. SUBALPINE FIR: PCVS and **CKR** [Hood and Lutes 2017 – post-fire model]

Pm	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
CKR	**Percent crown volume scorched (PCVS)**								
0	45	65	75	80	85	90	–	–	–
1	0	0	45	55	65	70	75	85	90
2	0	0	0	0	0	35	55	65	75
3	0	0	0	0	0	0	0	0	55
4	0	0	0	0	0	0	0	0	0
All subalpine fir, regardless of diameter, are predicted to die if all bole quadrants have moderate or deep char as defined by Table 1 in the text.									

ABIES MAGNIFICA

SHASTA RED FIR (ABMA)

Table 7 (1 factor table) is used if only crown injury is considered when evaluating trees.

Table 8 (2 factor table) is used when evaluating trees for crown injury and CKR.

Table 7. SHASTA RED FIR: PCLS [Hood and Lutes 2017 – pre-fire model]

Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
DBH	**Percent crown length scorched (PCLS)**								
6” – 41”	25	60	70	80	85	90	95	100	100

Table 8. SHASTA RED FIR: PCLS and **CKR** [Hood and Lutes 2017 – post-fire model]

Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
CKR	**Percent crown length scorched (PCLS)**								
0	75	80	85	90	90	95	95	100	100
1	65	75	80	80	85	90	90	95	100
2	30	60	65	70	75	80	85	90	95
3	0	5	50	55	65	70	75	80	85
4	0	0	0	0	45	55	60	65	75

CALOCEDRUS DECURRENS

INCENSE CEDAR (CADE)

Table 9 (1 factor table) is used if only crown injury is considered when evaluating trees.

Table 10 (2 factor table) is used when evaluating trees for crown injury and CKR.

Table 9. INCENSE CEDAR: PCLS [Hood and Lutes 2017 – pre-fire model**]**

Pm	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
DBH	**Percent crown length scorched (PCLS)**								
10”-66”	65	75	80	80	85	85	90	95	100

Table 10. INCENSE CEDAR: PCLS and **CKR [**Hood and Lutes 2017 – post-fire CKR model**]**

Pm	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
CKR	**Percent crown length scorched (PCLS)**								
0	80	85	85	90	90	95	95	100	–
1	75	80	85	85	90	90	95	95	100
2	70	75	80	80	85	85	90	95	100
3	60	70	75	80	80	85	85	90	95
4	55	65	70	75	75	80	85	90	95

LARIX OCCIDENTALIS

WESTERN LARCH (LAOC)

Table 11 (2 factor table) is used when evaluating trees for crown injury and diameter range.

Table 12 (2 factor table) is used when evaluating trees for crown injury and CKR,

Table 11. WESTERN LARCH: PCVS and **DBH** [Hood and Lutes 2017, pre-fire model]
The model uses two continuous variables (PCVS and DBH). Complete output cannot reasonably be presented in table format. Model output results for 9”, 14”’ 21” and 30” DBH are presented to represent DBH classes encompassing the variation, although model output within the data range for any specified DBH or range of DBH can be calculated upon request.

Pm	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
DBH	**Percent crown volume scorched (PCVS)**								
4” - 9”	15	45	60	70	85	100	–	–	–
10” - 14”	35	60	75	90	100	–	–	–	–
15” – 21”	60	90	–	–	–	–	–	–	–
22” – 35”	95	–	–	–	–	–	–	–	–

Table 12. WESTERN LARCH: PCVS and **CKR** [Hood and Lutes 2017, post-fire model]

Pm	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
CKR	**Percent crown volume scorched (PCVS)**								
0	65	80	85	95	100	–	–	–	–
1	50	70	75	85	90	95	100	–	–
2	30	55	65	75	80	85	95	100	–
3	0	35	55	65	70	75	85	90	100
4	0	20	35	50	60	65	75	85	95

PICEA ENGELMANNII

ENGELMANN SPRUCE (PIEN)

Due to its very thin bark, accounting for cambium kill by using either CKR or bark char severity improves accuracy in post-fire mortality estimation substantially.

Table 13 (1 factor table) is used if only crown injury is considered when evaluating trees.

Table 14 (2 factor table) is used when evaluating trees for crown injury and CKR.

Table 13. ENGELMANN SPRUCE: PCVS [Hood and Lutes 2017 – pre-fire model]

Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
DBH	**Percent crown volume scorched (PCVS)**								
5” – 34”	0	0	0	0	5	10	20	35	50

Table 14. ENGELMANN SPRUCE: PCVS and **CKR** [Hood and Lutes 2017 – post-fire model]

Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
CKR	**Percent crown volume scorched (PCVS)**								
0	20	40	55	65	75	85	95	–	–
1	0	10	25	35	45	55	65	80	100
2	0	0	0	5	15	25	35	50	70
3	0	0	0	0	0	0	10	20	40
4	0	0	0	0	0	0	0	0	10
All spruce, regardless of diameter, are predicted to die if all bole quadrants have moderate or deep char as defined by Table 1 in the text.									

PICEA SITCHENSIS

SITKA SPRUCE (PISI)

Little data exist for Sitka spruce. Therefore, the table for Sitka spruce in the rubric is used and is based on species characteristics and general response to fire reported in the literature.

Table 15. SITKA SPRUCE: PCVS, bark char, and **DBH** [based on literature]

Criteria	Diameter Class		
	5 – 11.9”	**12 – 20.9”**	**21”+**
PCVS	≥ 75% volume		
Bark char	≥ 75% any char		

PINUS CONTORTA AND PINUS ALBICAULIS

LODGEPOLE PINE AND WHITEBARK PINE (PICO/PIAL)

Due to small sample size and no statistical differences in DBH, PCVS, and CKR, lodgepole and whitebark pine data were grouped when modelled [Hood and Lutes 2017].

Due to its very thin bark, accounting for cambium kill by using either CKR or bark char severity improves accuracy in post-fire mortality estimation substantially.

Table 16 (2 factor table) is used when evaluating trees for crown injury and DBH.

Table 17 (3 factor table) is used when evaluating trees for crown injury, DBH, and CKR.

Table 16. LODGEPOLE & WHITEBARK PINES: PCVS and **DBH** [Hood and Lutes 2017 – pre-fire model]

The models use two continuous variables (PCVS and DBH). Complete output cannot reasonably be presented in table format. Model output results for 8”, 13” and 19” DBH are presented to represent DBH classes encompassing the variation, although model output within the data range for any specified DBH or range of DBH can be calculated upon request.

Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
DBH	**Percent crown volume scorched (PCVS)**								
6” - 10”	0	0	0	5	10	15	20	70	95
>10 - 15”	0	0	5	10	15	20	65	80	85
>15 ”+	0	5	10	15	20	65	70	85	90
All lodgepole and whitebark pines, regardless of diameter, are predicted to die if all bole quadrants have moderate or deep char as defined in Table 1 in the text.									

Table 17. LODGEPOLE & WHITEBARK PINES: PCVS, CKR, and **DBH** [Hood and Lutes 2017 – post-fire model]

DBH = 6" – 10"									
Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
CKR	**Percent crown volume scorched (PCVS)**								
0	35	60	70	75	80	85	90	95	100
1	0	55	65	70	80	85	90	95	100
2	0	0	55	60	65	70	80	85	90
3	0	0	0	0	0	35	55	65	75
4	0	0	0	0	0	0	0	0	0
DBH = >10" – 15"									
Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
CKR	**Percent crown volume scorched (PCVS)**								
0	55	70	80	85	90	90	95	100	–
1	45	70	75	80	85	90	95	100	–
2	0	45	60	70	75	80	85	90	95
3	0	0	0	0	45	60	65	75	85
4	0	0	0	0	0	0	0	0	45
DBH = >15" – 22"									
Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
CKR	**Percent crown volume scorched (PCVS)**								
0	70	80	85	90	95	100	–	–	–
1	65	80	85	90	90	90	100	–	–
2	45	65	75	80	85	90	95	100	–
3	0	0	40	55	65	70	75	85	90
4	0	0	0	0	0	0	0	50	70

PINUS LAMBERTIANA

SUGAR PINE (PILA)

Table 18 (1 factor table) is used if only crown injury is considered when evaluating trees.

Table 19 (3 factor table) is used when evaluating trees for crown injury, CKR, and RTB attacks.

Table 18. SUGAR PINE: PCLS [Hood and Lutes 2017 – pre-fire model]

Pm	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
DBH	**Percent crown length scorched (PCLS)**								
10”-74”	5	30	40	45	50	55	60	65	70

Table 19. SUGAR PINE: PCLS, CKR, and **RTB activity** [Hood and Lutes 2017 – post-fire model]

Beetles	Pm	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
Present	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	0	30	40	50	55	60	65	70	80
	1	0	25	40	50	55	60	65	70	80
	2	0	20	35	45	50	55	60	70	75
	3	0	0	0	25	35	45	50	60	70
	4	0	0	0	0	0	0	20	35	50
Absent	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	30	45	55	60	65	70	75	80	90
	1	30	45	55	60	65	70	75	80	90
	2	20	40	50	55	60	65	70	80	85
	3	0	20	35	45	50	60	65	70	80
	4	0	0	0	0	20	35	40	50	60

PINUS MONTICOLA

WESTERN WHITE PINE (PIMO)

Table 20 (1 factor table) is used if only crown injury is considered when evaluating trees.

Table 21 (2 factor table) is used when evaluating trees for crown injury and CKR.

Table 20. WESTERN WHITE PINE: PCVS [model PIMO 3, Grayson et al. 2017]

Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
DBH	**Percent crown volume scorched (PCVS)**								
6”– 32”	0	5	15	25	35	45	55	65	85

Table 21. WESTERN WHITE PINE: PCVS and **CKR** [model PIMO 2, Grayson et al. 2017]

Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
CKR	**Percent crown volume scorched (PCVS)**								
0	35	50	65	75	85	95	—	—	—
1	30	45	60	70	80	90	100	—	—
2	15	30	45	55	65	75	85	95	—
3	0	5	20	30	40	50	60	75	90
4	0	0	0	0	10	15	25	40	55

PINUS PONDEROSA AND PINUS JEFFREYI

PONDEROSA AND JEFFREY PINES (PIPO/PIJE)

Table 22 (1 factor table) is used if only crown injury is considered when evaluating trees.

Table 23 (3 factor table) is used when evaluating trees for crown injury pre-bud break, CKR, and RTB attacks.

Table 24 (3 factor table) is used when evaluating trees for crown injury post-bud break, CKR, and RTB attacks.

Table 22: PONDEROSA & JEFFREY PINE: PCVS [Hood and Lutes 2017 – prefire CVS model]

Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
DBH	**Percent crown volume scorched (PCVS)**								
2”-70”	50	70	75	80	85	90	95	100	–

Table 23. PONDEROSA & JEFFREY PINE: PCVS, CKR, and **RTB activity** for use pre-bud break **[**from Hood and Lutes 2017 - post-fire CVS models]

Beetles	**Pm**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
Present	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	35	55	70	75	85	90	95	100	–
	1	5	45	55	65	75	80	90	95	–
	2	0	25	45	55	65	75	80	90	100
	3	0	0	25	40	55	65	70	80	95
	4	0	0	0	20	40	50	60	70	80
Absent	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	70	85	95	100	–	–	–	–	–
	1	60	80	85	95	100	–	–	–	–
	2	50	70	80	85	90	100	–	–	–
	3	35	60	70	75	85	90	95	100	–
	4	5	45	60	65	75	85	90	95	100

Table 24. PONDEROSA & JEFFREY PINE: PCVK, CKR, and **RTB activity** for use post-bud break **[**Hood and Lutes 2017 - post-fire CVK models]

Beetles	**Pm**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
Present	**CKR**	**Percent crown volume killed (PCVK)**								
	0	0	30	45	55	60	65	70	80	85
	1	0	15	35	45	50	60	65	75	80
	2	0	0	20	35	45	50	60	65	75
	3	0	0	0	20	30	40	50	60	70
	4	0	0	0	0	15	30	40	50	65
Absent	**CKR**	**Percent crown volume killed (PCVK)**								
	0	50	60	70	75	80	85	90	95	100
	1	40	55	65	70	75	80	85	90	95
	2	30	45	55	65	70	75	80	85	95
	3	10	35	50	55	60	70	75	80	90
	4	0	25	40	50	55	60	70	70	85

PSEUDOTSUGA MENZIESII

DOUGLAS-FIR (PSME)

Table 25 (1 factor table) is used if only crown injury is considered when evaluating trees.

Table 26 (4 factor table) is used when evaluating trees for crown injury, DBH, CKR, and Douglas-fir beetle attacks. The output from this model contains two continuous variables (PCVS and DBH). Complete output cannot reasonably be presented in table format. Results from 10”, 20”, and 35” DBH are presented to represent DBH classes encompassing the variation, although model output within the data range for any specified DBH or range of DBH can be calculated upon request.

Table 25. DOUGLAS-FIR: PCVS [Hood and Lutes 2017 – pre-fire model]

Pm	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
DBH	Percent crown volume scorched (PCVS)								
4” – 41”	0	10	25	60	70	75	80	85	90

Table 26. DOUGLAS-FIR: PCVS, CKR, DBH and **Douglas-fir beetle activity** [Hood and Lutes 2017 – post-fire model]

DBH = 4" – 15"										
Beetles	**Pm**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
Present	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	0	25	65	70	75	80	85	90	95
	1	0	5	20	60	70	75	80	85	90
	2	0	0	5	15	55	65	70	80	85
	3	0	0	0	0	10	30	60	70	80
	4	0	0	0	0	0	5	20	60	75
Absent	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	10	60	70	75	80	85	85	90	95
	1	5	15	60	70	75	80	80	85	90
	2	0	0	15	55	65	70	75	80	85
	3	0	0	0	10	40	60	70	75	85
	4	0	0	0	0	5	20	60	70	80
DBH = >15" – 25"										
Beetles	**Pm**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
Present	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	0	5	25	60	70	75	80	85	90
	1	0	0	5	20	55	70	75	80	85
	2	0	0	0	5	15	45	65	75	80
	3	0	0	0	0	0	10	25	60	75
	4	0	0	0	0	0	0	5	20	65
Absent	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	55	75	80	85	85	90	—	—	—
	1	15	65	75	80	80	85	85	90	95
	2	5	30	65	70	75	80	85	90	95
	3	0	5	25	60	70	75	80	85	90
	4	0	0	5	15	55	65	75	80	85

Table 26 continued. DOUGLAS-FIR: PCVS, CKR, DBH and **Douglas-fir beetle activity**
[Hood and Lutes 2017 – post-fire model]

DBH = >25" – 41"										
Beetles	**Pm**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
Present	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	0	0	5	15	50	65	75	80	85
	1	0	0	0	0	10	25	60	70	80
	2	0	0	0	0	0	5	15	60	75
	3	0	0	0	0	0	0	5	15	65
	4	0	0	0	0	0	0	0	0	25
Absent	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	75	85	85	90	90	95	95	100	–
	1	70	80	85	85	90	90	95	95	100
	2	60	75	80	80	85	90	90	95	100
	3	15	65	75	80	80	85	85	90	95
	4	0	35	65	70	75	80	85	90	95

THUJA PLICATA

WESTERN REDCEDAR (THPL)

Table 27 (2 factor table) is used when evaluating trees for crown injury and diameter range.

Table 27. WESTERN REDCEDAR: PCVS [Ryan and Amman 1994; Ryan and Reinhardt 1988]

Pm	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
DBH	**Percent crown volume scorched (PCVS)**								
5” – 11.9”	0	0	0	0	0	15	30	45	60
12”– 20.9”	0	0	0	30	40	50	55	65	75
21”– 34.9”	0	35	45	55	60	65	75	80	90
35” – 50”+	35	55	65	70	75	80	85	90	98

TSUGA HETEROPHYLLA

WESTERN HEMLOCK (TSHE)

No univariate logistic model specific to western hemlock is available when evaluating trees using only crown injury.

Due to its very thin bark, accounting for cambium kill by using either CKR or bark char severity improves accuracy in post-fire mortality estimation substantially.

The data used to create the PCVS+CKR model had very few trees with PCVS values >20% combined with CKR values <2. The model should be used with caution for trees with this condition.

Table 28 (4 factor table) is used when evaluating trees for PCVS, DBH, and CKR, and ambrosia beetle activity. The models use two continuous variables (PCVS and DBH). Complete output cannot reasonably be presented in table format. Model output results for 9”, 21” and 35” DBH are presented to represent DBH classes encompassing the variation, although model output within the data range for any specified DBH or range of DBH can be calculated upon request.

Table 28. WESTERN HEMLOCK: PCVS, CKR, DBH, and ambrosia beetle activity
[Model TSHE3, Grayson et al. 2017]

DBH = 5” – 13”										
Beetles	**Pm**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
Present	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	0	0	0	15	35	55	75	100	–
	1	0	0	0	5	25	45	65	90	–
	2	0	0	0	0	0	15	40	65	95
	3	0	0	0	0	0	0	0	15	55
	4	0	0	0	0	0	0	0	0	0
Absent	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	10	50	75	95	–	–	–	–	–
	1	0	40	65	90	–	–	–	–	–
	2	0	10	40	60	80	100	–	–	–
	3	0	0	0	10	30	55	75	100	–
	4	0	0	0	0	0	0	5	35	75

Table 28 continued. WESTERN HEMLOCK: PCVS, CKR, DBH, and ambrosia beetle activity [Model TSHE3, Grayson et al. 2017]

DBH = 14" – 28"										
Beetles	**Pm**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
Present	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	0	10	35	60	80	100	–	–	–
	1	0	0	25	50	70	90	–	–	–
	2	0	0	0	20	40	60	80	–	–
	3	0	0	0	0	0	10	35	60	–
	4	0	0	0	0	0	0	0	0	30
Absent	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	50	95	–	–	–	–	–	–	–
	1	40	85	–	–	–	–	–	–	–
	2	15	55	85	–	–	–	–	–	–
	3	0	10	35	55	75	95	–	–	–
	4	0	0	0	0	10	30	55	80	–
DBH = 29" – 52"										
Beetles	**Pm**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
Present	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	25	65	90	–	–	–	–	–	–
	1	15	55	80	100	–	–	–	–	–
	2	0	25	50	70	90	–	–	–	–
	3	0	0	0	25	45	65	85	–	–
	4	0	0	0	0	0	0	20	45	80
Absent	**CKR**	**Percent crown volume scorched (PCVS)**								
	0	100	–	–	–	–	–	–	–	–
	1	95	–	–	–	–	–	–	–	–
	2	65	–	–	–	–	–	–	–	–
	3	20	60	85	–	–	–	–	–	–
	4	0	0	20	40	60	80	100	–	–
All western hemlock, regardless of diameter, are predicted to die if all bole quadrants have moderate or deep char as defined by Table 1 in the text.										

TSUGA MERTENSIANA

MOUNTAIN HEMLOCK (TSME)

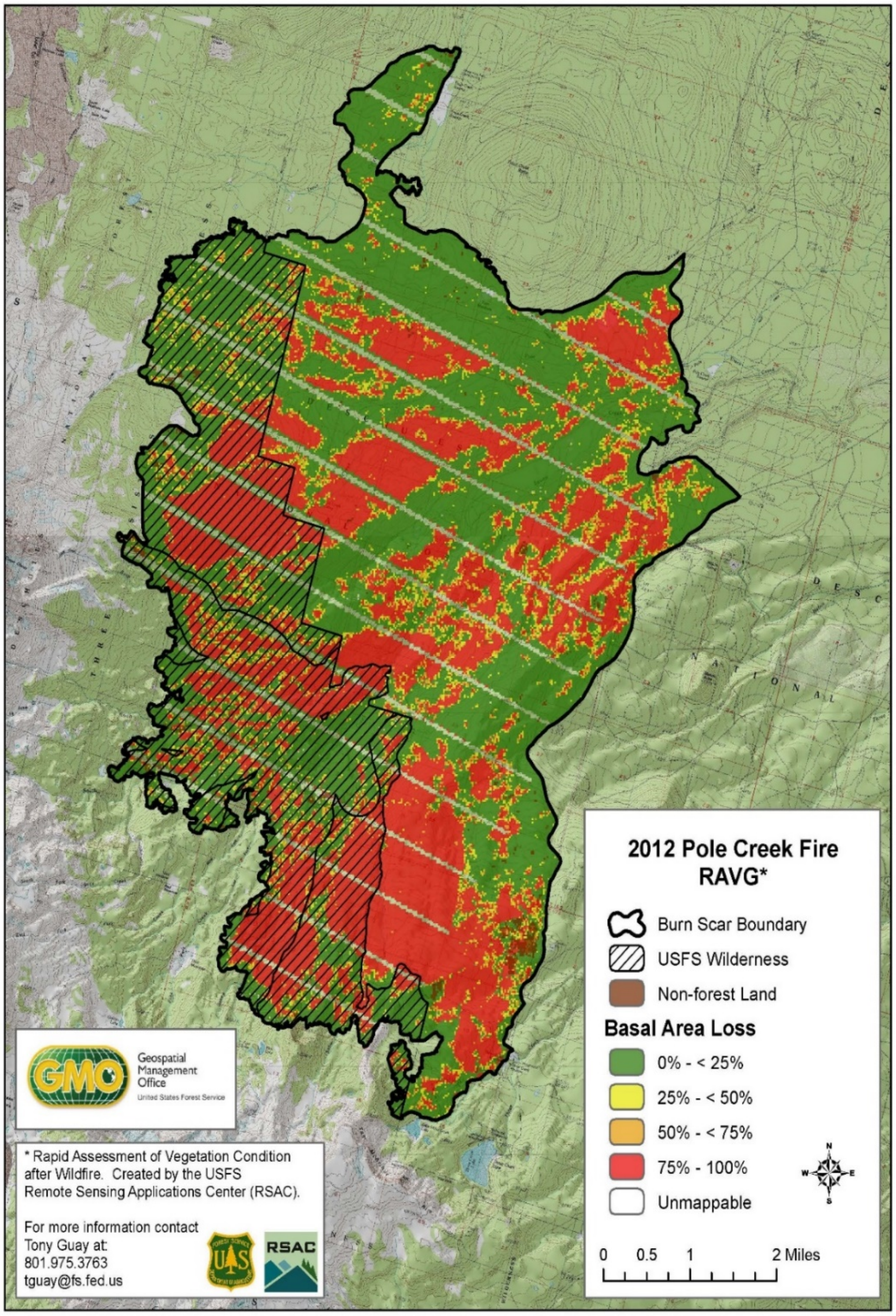
Very little data for mountain hemlock exist. Therefore, the table for mountain hemlock in the rubric is used and is based on species characteristics and general response to fire reported in the literature.

Table 29: MOUNTAIN HEMLOCK: PCVS, bark char, and **DBH** [based on literature]

Criteria	5 – 11.9"	12 – 20.9"	21"+
PCVS	≥ 20% volume		
Bark char	≥ 90% any char		

APPENDIX C: EXAMPLE OF MARKING GUIDELINES

Pole Creek Vegetation Burn Severity Map showing low, moderate, and high severity on the Sisters RD, Deschutes NF. This example was created to demonstrate the use of selecting a probability and developing subsequent guidelines, and does not represent the actual marking guidelines that may have been used on the Pole Creek Fire.



Guideline Objectives: *These guidelines will provide a means to identify and remove trees that were killed or severely injured from fire and/or insect attack within the Pole Creek Fire, Deschutes NF*

The Pole Creek Fire burned in September into October. Trees were primarily ponderosa pine and lodgepole pine with some mixed conifer, primarily grand-fir, some Douglas-fir, and a small amount of Engelmann spruce.

These guidelines are based on the fire injured tree marking guidelines developed for Region 6. The guideline criteria (#3) for delayed conifer tree mortality are based on the **pre-bud** break model (i.e. the trees are being marked in late winter early spring before bud-break and before DFB flight). A probability of mortality of 0.7 (Pm=0.7) was selected for this project to meet the management objectives of: 1) removing trees that were killed or that have a high probability of mortality to recover their economic value; and 2) retaining those trees that have a moderate to high probability of survival to provide forest cover as a seed source for natural regeneration and wildlife habitat. **All trees >26" DBH, regardless of condition, will be retained to provide for wildlife except when they pose a hazard to people or property.**

Note: There are two examples for marking guidelines. Table 1 consists of marking guidelines using percent crown volume scorch only and Table 2 has marking guidelines that include PCVS and CKR for increased accuracy. Cambium sampling or a crosswalk (Table 2 of main document) is used for thick-barked species; bark char is substituted for cambium sampling for thin-barked species.

Mark for removal any tree that meets the following criteria:

1. Any tree with no green needles (does not include those designated for snag retention).
2. For all species, trees should be marked for removal if any combination of boring dust or frass (in bark crevices, webbing along the bole, or that accumulates at the base of the trees), pitch tubes with pink or reddish boring dust associated with them, pouch fungus conks and/or current woodpecker activity (holes into the sapwood and/or bark flaking, specifically excludes injury caused by sapsucker feeding) is present over at least 1/2 of the bole circumference. This specifically excludes basal attacks by the red turpentine beetle on yellow pines (large pitch tubes associated with coarse boring dust generally restricted to the lower 2 to 4 feet of the bole or woodpecker activity restricted to this area) and when the above indicators are only associated with wounds, old fire scars, etc. The presence or absence of red turpentine beetle pitch tubes will be accounted for in criteria #3.
3. Any tree that meets or exceeds the following fire-injured conifer mortality guidelines (Table 1) at the Pm = 0.7 level. This assessment will be made by visually estimating the percent of the original pre-fire crown length that was killed (ponderosa pine and white fir), the presence or absence of red turpentine beetle pitch tubes (ponderosa pine) and tree diameter (ponderosa pine and white fir).

Table 1: Criteria for marking fire-injured tree at the Pm=0.7 level for the Pole Creek Fire using only PCVS as a factor.

Ponderosa Pine	
DBH	**Minimum Percent Crown Volume Scorched (PCVS)**
2” – 70”	**95**
Lodgepole Pine	
DBH	**Minimum PCVS**
6” – 10”	**20**
>10” - 15”	**65**
>15”+	**70**
Grand Fir	
DBH	**Minimum PCVS**
6” – 21”+”	**60**
Douglas-fir	
DBH	**Minimum PCVS**
4” – 41”	**80**
Engelmann Spruce	
DBH	**Minimum PCVS**
5” – 34”	**20**

Table 2: **Specific criteria for marking fire-injured trees at the Pm = 0.7 level for the Pole Creek Fire using both crown scorch and cambium kill rating for slightly increased accuracy.**

Ponderosa Pine – RTB activity absent – post-fire, pre-budbreak		
DBH	**Cambium Kill Rating (CKR)**	**% Crown Volume Scorched (PCVS)**
2" – 70"	0	---
	1	---
	2	---
	3	90
	4	95

Ponderosa Pine –RTB activity present – post-fire, pre-budbreak		
DBH	**Cambium Kill Rating (CKR)**	**% Crown Volume Scorched (PCVS)**
2" –70"	0	95
	1	90
	2	80
	3	70
	4	60

Lodgepole Pine*		
DBH	**Cambium Kill Rating (CKR)**	**% Crown Volume Scorched (PCVS)**
6"-10"	0	90
	1	90
	2	80
	3	55
	4	0
>10"-15"	0	95
	1	95
	2	85
	3	65
	4	0
>15"-22"	0	--
	1	100
	2	95
	3	75
	4	0

Douglas-fir – Douglas-fir beetles absent		
DBH	**Cambium Kill Rating (CKR)**	**% Crown Volume Scorched (PCVS)**
4"-15"	0	95
	1	90
	2	80
	3	70
	4	60
>5"–25"	0	--
	1	85
	2	85
	3	80
	4	75
>25"–41"	0	95
	1	95
	2	85
	3	85
	4	80

*All lodgepole, regardless of diameter, are predicted to die if all bole quadrants have moderate or deep char. Bark char is based on the severity of char on 4 quadrants of circumference, not length of bole char

Engelmann Spruce*		
DBH	**Cambium Kill Rating (CKR)**	**% Crown Volume Scorched (PCVS)**
5"- 34"	0	95
	1	65
	2	35
	3	10
	4	0

Grand fir			
DBH	**5" – 11.9"**	**12" – 20.9"**	**21+"**
Crown Scorch	≥ 60% volume		
Bark Char	≥ 50% any char	≥ 75% moderate or deep char	

*All spruce, regardless of diameter, are predicted to die if all quadrants have moderate or deep char

U.S. Forest Service, Pacific Northwest Region
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