TREE NOTES

CALIFORNIA DEPARTMENT OF FORESTRY AND FIRE PROTECTION

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Survival of Fire-Injured Conifers in California

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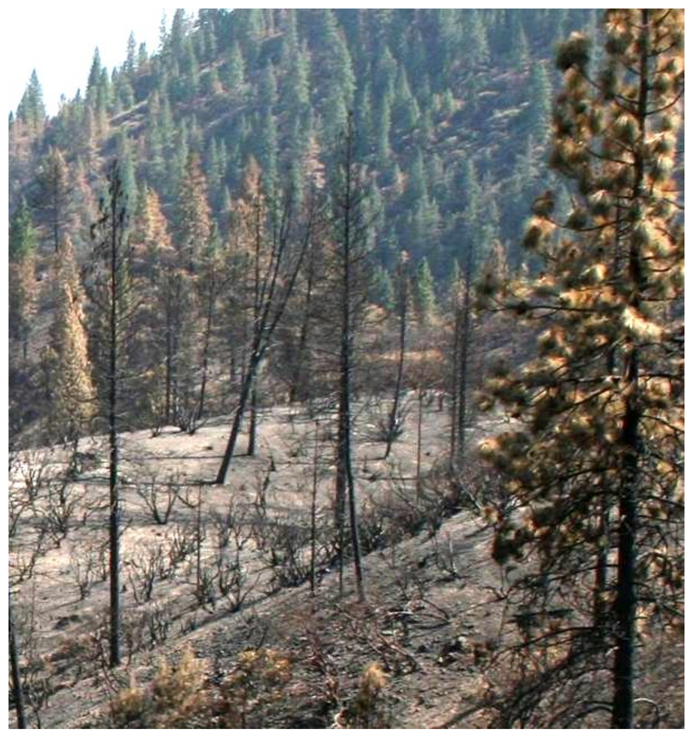
The intensity of wildfire and the injury it causes to trees varies considerably across a landscape. Conifers are killed outright when all foliage in the crown is consumed by flames or killed by extreme heat. Trees may also sustain lesser injuries to the crown, stem and roots and survive. These trees, however, may die prematurely if the injuries are severe. How well a tree survives fire injury is influenced by a variety of factors, including:

- Tree species
- Tree age, size, and vigor
- Extent and location of injury on the tree



Fire impacts trees by heating and killing tissues such as foliage, buds, inner bark and cambium. In extreme cases, foliage, twigs, bark and decayed wood are consumed. Even though severe fire intensity can kill trees directly, the wood in larger sound roots, branches and trunks is typically not degraded until pest organisms invade the tree.

Fire-injured trees may have a reduced probability of survival depending on the level of injury. Most tree mortality takes place within five years post-fire, with the highest levels occurring within the first two years. Fire injuries can also have longer lasting impacts on tree health and may contribute to mortality beyond this time frame, such as if root disease or decay gains entrance to the tree as a result of the injury.

Insects in the families Buprestidae, Cerambycidae, and Siricidae are principal colonizers of fire-killed or severely fire-injured trees. Some of these insects are attracted by smoke and will lay eggs on trees that are still smoldering; because they colonize trees that are dead or dying from fire injury, they are not considered a direct threat to tree survival. Bark beetles (primarily *Dendroctonus* species), in contrast, are more likely to colonize trees that are lightly to moderately fire injured and may kill some trees that might otherwise have survived. Bark beetle activity typically increases and may persist for several years in burned areas, but rarely spills over into healthy, uninjured trees or trees in adjacent unburned areas.

Pioneering research on estimating the survival of fire-injured trees in California was published by forest pathologist Willis Wagener (1961). Subsequent research has been conducted both in California and other parts of the western US that expanded upon and refined our understanding of tree survival (see references). While all of this information is valuable, it also has limitations and complexities that influence effective application by land managers. Using this research, the Forest Health Protection group within the USDA Forest Service has developed and tested guidelines for evaluating tree survival across a range of landscapes, tree species, and fire conditions in California. The report **Marking Guidelines for Fire-Injured Trees in California** (Smith and Cluck 2011) is the result.

This **Tree Note** does not attempt to duplicate the USFS Guidelines, but rather serves as an introduction to fire injury and tree survival, and presents a basic version of the Guidelines. Land managers desiring more information should consult the USFS Guidelines and other references.

MEASURING INJURY

For all conifer species studied, fire injury to the crown is the most important variable influencing survival. Another important variable is injury to the inner bark and cambium at the base of the main stem. Bark beetle attacks in response to injury can be an additional predictor of mortality. The USFS Guidelines include evaluation protocols that range from basic to complex. The basic level of evaluation requires an estimate of crown injury and stem diameter. Additional measures, such as cambial kill and bark beetle activity may improve predictions of survival. Because most fire-related mortality takes place within 5 years following the fire, this is the time frame for which survival estimates have been developed.

Crown Injury

Crown injury is defined as the percentage of the tree's pre-fire live crown (all branches supporting green needles) killed by fire. For most conifer species, this can be estimated by measuring the percentage of foliage that was consumed or killed by the fire. For ponderosa and Jeffrey pines, due to more fire resistant buds and twigs, the percentage of foliage killed is typically much greater than the percentage of crown killed. An accurate measurement of crown kill for ponderosa and Jeffrey pines usually requires waiting until new foliage is produced the following spring. If waiting to evaluate crown kill for ponderosa and Jeffrey pine is not practical, the Guidelines also provide a survival prediction based on fire-killed foliage alone (Table 1a), before the level of crown kill can be determined.

Obtaining a full view of the crown under good light conditions is important when estimating injury. Overcast skies and shade can make it difficult to distinguish green (live) from brown (dead) needles. Ideal lighting is direct sunlight coming from behind the observer with the sunlit crown viewed against a clear sky. Injury is often heavier on one side of the crown, so the best estimate takes this variation into account (Figure 1).

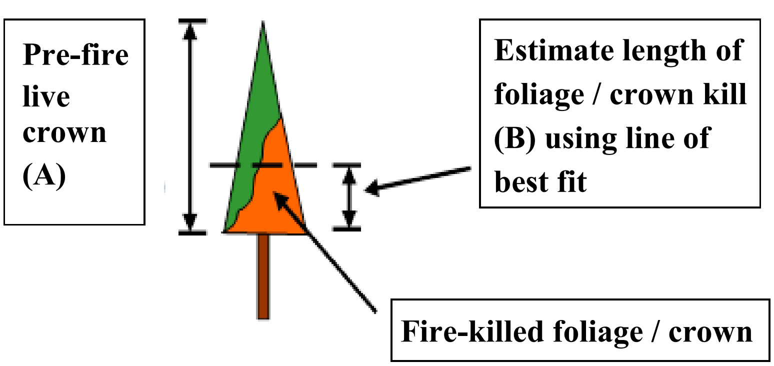


Figure 1.
Percentage of foliage or crown killed by fire = B/A x 100

Measurement of crown kill requires an estimate of the live crown before the fire occurred. The pre-fire live crown is defined as all branches with needles, both green (live) and brown (fire-killed), as well as any branches whose needles were consumed by the fire. If a branch has <u>fine</u> <u>blackened</u> <u>twigs</u> but no needles, the observer should assume it had needles before the fire. Over time, loss of fire-killed needles will reduce the ability to estimate the pre-fire live crown. Therefore, the appropriate timeframe for using the Guidelines is after the fire through fall of the following year (a 12- to 17-month post-fire timeframe). If an evaluation is done during the second growing season following the fire, be sure that the new year's (spring) growth is apparent before evaluating crown kill. Any branch with new growth is part of the live crown.

Cambial Injury

The vascular cambium is a cylinder of actively dividing cells within the stem that produces phloem (inner bark) to the outside and xylem (wood) to the inside. The outer, corky layer of bark helps prevent injury, but its ability to do so varies with tree species, age, and characteristics of the fire. If the cambium is killed, the adjacent phloem and xylem die and become non-functional. Cambium at the base of the tree's stem is particularly susceptible to injury. When the amount of cambium killed at the base of the stem is 25% of the circumference or less, this is likely to be inconsequential to tree survival. As this percentage increases, the loss of vascular tissues becomes critical and at some point the tree is effectively girdled. Non-lethal cambial wounds can be healed by the tree over time. Larger wounds provide an entryway to pathogens that cause root disease and wood decay, and may never heal completely.

Cambial kill at the base of a tree's stem can be roughly estimated by examining the outer bark. Assume the cambium is alive beneath portions of the bark that are not blackened. At the other extreme, assume the cambium is dead beneath bark that is completely blackened and eroded (consumed) to the point where its structure is no longer discernable. The bark may even be eroded and cracked to the point where the wood beneath is visible. Heavy pitch flow concentrated on a portion of the bark is also a good indication that the cambium beneath has been killed. When the condition of the outer bark falls between these extremes, i.e. the bark is blackened but has little or no pitching or loss of structure, it is best to inspect the cambium directly to determine its condition.

The protocol for directly estimating cambial kill is to use an axe to sample a small portion (about 1 square inch or less) of the inner bark / cambium at 4 equally spaced locations around the circumference of the stem, a few inches above ground line (Figure 2). Live inner bark and cambium is cream-colored and moist, often with a tinge of pink. Dead tissue dries and darkens with time and may be resinous. Brown, shrunken tissue is unequivocally dead. Cambial injury is rated as 0 to 4 based on the number of samples with dead cambium. For most trees, a cambial injury rating of 2 to 4 will increase the probability of mortality. Although the Guidelines do not require an evaluation of cambial injury, it is still a good idea to quickly inspect the lower stem for injuries that may significantly influence survival. A review of the Guidelines will help determine the value of assessing cambial injury to improve survival estimates.

Figure 2. Cambial sample

Non-lethal cambial injury can have a negative impact on tree health during and beyond the five years post-fire for which these guidelines apply. When wound-invading wood decay or root disease pathogens gain entrance to a tree, this can lead to hazardous conditions due to stem or root failure. While white and red firs are particularly prone to this, any tree with significant wounding has the potential to become a safety risk. Likewise, if a tree's vascular system has been significantly impaired by wounding and decay, the tree will have slower growth and may have a higher probability of dying, especially during periods of drought.

Insect Attack

While a variety of factors may contribute to tree mortality, a common feature of tree dieback and death is colonization of the cambial region by insects and associated microorganisms. In some instances, colonizing insects and fungi cause tissue death, while in other instances, the invaders are simply colonizing dying tissue. When colonization completely encircles the stem, this is a sure sign the tree is dead.

Recognizing successful colonization by insects can enable you to determine if a tree is dead or dying, regardless of crown and cambial injury. External evidence of bark beetle attack occurs in the form of pitch tubes, pitch streaming (which also occurs due to fire injury), pitch granules, and boring dust. Release of pitch is a defensive response of conifers and is a sign that the tree is successfully defending itself against beetle attack. “Dry” boring dust (i.e., with little or no pitch) in bark crevices indicates that tissues beneath are dead and being successfully colonized by insects. White dust is produced by ambrosia beetles that bore directly into the sapwood, while yellow-brown or red-brown dust is produced by bark beetles. Successful insect attack can be confirmed by cutting into the bark at or near spots where boring dust has accumulated and looking for live beetles (adults, eggs, or larvae) and their tunnels. When successful attacks encircle the stem, the tree is dying.

The red turpentine beetle (RTB) is one of the first bark beetles to attack fire-injured ponderosa, Jeffrey, and sugar pines. Its main flight period is in the spring, and this is typically when RTB becomes active in recently burned areas. RTB pitch tubes at the base of the stem can provide additional information for estimating tree survival.

Dead or dying trees (all foliage consumed or killed) will quickly be colonized by wood-boring insects and associated fungi that cause wood stain and decay. Evidence of colonization may not be apparent immediately after the fire but will increase over time as coarse woody shavings are expelled by developing beetle larvae.

BASIC GUIDELINES (Abbreviated form of the USFS Guidelines – Smith and Cluck 2011)

The Guidelines are based on probabilities, i.e. what is the likelihood that this tree will die from its fire injuries within 5 years? Table 1a uses percentage of foliage killed and Tables 1b to 7 use percentage of crown killed to determine probability of tree mortality, irrespective of cambial injury or insect attack. Measuring only foliage or crown kill is the quickest and easiest way to determine probability of mortality. Listed beneath some of the tables is information on how cambial injury and RTB pitch tubes modify the probability of mortality.

Little information exists on the impacts of fire injury on long-term tree health, but we know that such impacts occur. These impacts occur because the vascular system or structural integrity of the tree has been impaired. Disease organisms are often involved. How to address long-term impacts depends upon management goals for the property. Tree hazard needs to be addressed when there is a risk to life or property. Tree growth and longevity are important considerations for lands being managed for timber.

Tables for determining probability of mortality begin on the next page.

Tables 1a & b. Mortality of **Fire-Injured Ponderosa and Jeffrey pines** (based on Hood *et al.* 2010)

Table 1a. Evaluation made before the next growing season

*** Percentage of foliage killed by fire**

Probability the tree will die ⇨	**30%**	**50%**	**70%**
DBH (diameter of stem at breast height)			
10 to < 30”	**70 ***	**80**	**90**
30 to 40”	**35**	**45**	**60**
> 40”	**15**	**30**	**40**

* length of crown with dead (brown) + consumed foliage ÷ length of entire crown (all foliage) × 100

Modifications to Table 1a based on Cambial Injury Rating

trees 10 to < 30” DBH

- Rating of 0 or 1 reduces the probability of mortality by 20-30%
- Rating of 2 causes no change
- Rating of 3 or 4 increases the probability of mortality by 5-30%

trees ≥ 30” DBH

- Rating of 0 or 1 reduces the probability of mortality by 0-10%
- Rating of 2 increases the probability of mortality by 10%
- Rating of 3 or 4 increases the probability of mortality by 10-30%

For fires that occur before pine foliage has fully elongated (May and much of June): shoots and fire-scorched needles may continue to grow, producing brown needles with green bases (post-fire growth). When this occurs, consider portions of the crown with these needles as alive and utilize Table 1b to rate probability of mortality.

Table 1b. Evaluation made during the growing season following the fire (one winter has passed and the new year’s growth is apparent; any branch with new growth is part of the live crown)

*** Percentage of live crown killed by fire**

Probability the tree will die ⇨	**30%**	**50%**	**70%**
DBH (diameter of stem at breast height)			
10 to < 30”	**40 ***	**50**	**60**
30 to 40”	**10**	**25**	**40**
> 40 to 50”	**--**	**10**	**25**

* length of killed crown (branches with only brown or consumed foliage) ÷ length of entire crown (all foliage) × 100

Modifications to Table 1b based on Cambial Injury Rating

trees 10 to < 30” DBH

- Rating of 0 or 1 reduces the probability of mortality by 10%
- Rating of 2 causes no change
- Rating of 3 or 4 increases the probability of mortality by 15-20%

trees ≥ 30” DBH

- Rating of 0 or 1 reduces the probability of mortality by 5-10%
- Rating of 2 causes no change
- Rating of 3 or 4 increases the probability of mortality by 5-10%

Red Turpentine Beetle

- When pitch tubes are absent, probability of mortality remains the same or decreases slightly (up to 10%)
- When pitch tubes are present on trees10 to < 30” DBH, probability of mortality increases slightly (up to 10%)
- When pitch tubes are present on trees ≥ 30” DBH, probability of mortality increases significantly (up to 40%)

Table 2. Mortality of **<u>Fire-Injured Sugar Pine</u>** (based on Hood *et al.* 2010)

*** Percentage of live crown killed by fire**

Probability the tree will die ⇨	**30%**	**50%**	**70%**
<u>DBH</u> (diameter of stem at breast height)			
10 to 60"	**40 ***	**50**	**60**

* length of killed crown (brown + consumed foliage) ÷ length of entire crown (all foliage) × 100

Modifications to Table 2 based on Cambial Injury Rating
- Rating of 0 to 3 reduces the probability of mortality 5-15%
- Rating of 4 increases the probability of mortality by 40%

Red Turpentine Beetle
- When pitch tubes are absent, probability of mortality decreases a moderate amount (10-20%)
- When pitch tubes are present, probability of mortality increases a moderate amount (10-20%)

Table 3. Mortality of **<u>Fire-Injured Lodgepole Pine</u>** (based on Ryan and Reinhardt. 1988)

*** Percentage of live crown killed by fire** (the guidelines for lodgepole pine use volume of crown killed rather than length)

Probability the tree will die ⇨	**40%**	**60%**	**80%**
<u>DBH</u> (diameter of stem at breast height)			
≤ 10"	**--**	**5**	**40**
> 10 to 15"	**--**	**35**	**55**
> 15 to 20"	**25 ***	**40**	**60**

* volume of killed crown (brown + consumed foliage) ÷ vol. of entire crown (all foliage) × 100

No other variables are recommended; however, lodgepole pine has relatively thin bark and significant bark charring around the entire stem (cambial injury rating of 4) is likely to lead to mortality.

Table 4. Mortality of **<u>Fire-Injured White Fir</u>** (based on Hood *et al.* 2010)

*** Percentage of live crown killed by fire**

Probability the tree will die ⇨	**30%**	**50%**	**70%**
<u>DBH</u> (diameter of stem at breast height)			
10 to 35"	**65 ***	**75**	**80**
> 35"	**45**	**60**	**70**

* length of killed crown (brown + consumed foliage) ÷ length of entire crown (all foliage) × 100

Modifications to Table 4 based on Cambial Injury Rating:
- Rating of 0 causes no change in the probability of mortality
- Rating of 1 or 2 increases the probability of mortality by 10-20%
- Rating of 3 or 4 increases the probability of mortality by 15-30%

Hazard Tree Alert: white firs have a high probability of stem failure due to cambial kill and subsequent wood decay.

Table 5. Mortality of **Fire-Injured Red Fir** (based on Hood *et al.* 2007a)

*** Percentage of live crown killed by fire**

Probability the tree will die ⇨	**30%**	**50%**	**70%**
DBH (diameter of stem at breast height) 6 to 40”	**45 ***	**70**	**80**

* length of killed crown (brown + consumed foliage) ÷ length of entire crown (all foliage) × 100

No other variables are recommended.

Hazard Tree Alert: red firs have a high probability of stem failure due to cambial kill and subsequent wood decay.

Table 6. Mortality of **Fire-Injured Douglas-fir** (based on Hood 2008)

*** Percentage of live crown killed by fire**

Probability the tree will die ⇨	**30%**	**50%**	**70%**
DBH (diameter of stem at breast height) 4 to 40”	**25 ***	**65**	**75**

* length of killed crown (brown + consumed foliage) ÷ length of entire crown (all foliage) × 100

Modifications to Table 6 based on Cambial Injury Rating:

- Rating of 0 to 2 causes little change in the probability of mortality
- Rating of 3 or 4 increases the probability of mortality by 15-30%

Table 7. Mortality of **Fire-injured Incense Cedar** (based on Hood *et al.* 2010)

*** Percentage of live crown killed by fire**

Probability the tree will die ⇨	**30%**	**50%**	**70%**
DBH (diameter of stem at breast height) 10 to 60”	**75 ***	**85**	**90**

* length of killed crown (brown + consumed foliage) ÷ length of entire crown (all foliage) × 100

No other variables are recommended.

References

Angwin, P. A., D.R. Cluck, P.J. Zambino, B.W. Oblinger and W.C. Woodruff. 2012. Hazard tree guidelines for forest service facilities and roads in the Pacific Southwest Region. USDA Forest Service, Region 5, Forest Health Protection. Report # RO-12-01. 27 p. (available on the internet from Region 5 Forest Health Protection)

Hood, SM, SL Smith, and DR Cluck. 2010. Predicting mortality for five California conifers following wildfire. Forest Ecology and Management. 260: 750-762.

Hood, SM. 2008. Delayed tree mortality following fire in western conifers. USDA Forest Service, Rocky Mtn Research Station. JFSP Final Report 05-2-1-105. 35p.

Hood, SM, DR Cluck, SL Smith, and KC Ryan. 2008. Using bark char codes to predict post-fire cambium mortality. Fire Ecology. 4(1): 57-73.

Hood, SM, SL Smith, and DR Cluck. 2007a. Delayed conifer mortality following fire in California. p. 261-83 *IN* USDA Forest Service Gen Tech Rep, PSW-GTR-203.

Hood, S, B Bentz, K Gibson, K Ryan, and G DeNitto 2007b. Assessing post-fire Douglas-fir mortality and Douglas-fir beetle attacks in the northern Rocky Mountains. USDA Forest Service Gen Tech Rep, RMRS-GTR-199. 31p. Includes Supplement.

Owen, DR, SL Smith, and SJ Seybold. 2010. Red Turpentine Beetle. USDA Forest Service Forest Insect and Disease Leaflet 55. 8p.

Ryan, KC and ED Reinhardt. 1988. Predicting post fire mortality of seven western conifers. Can J For Res. 18: 1291-1297.

Smith, S.L. and D.R. Cluck. 2011. Marking guidelines for fire-injured trees in CA. USDA Forest Service, Region 5, Forest Health Protection. Report # RO-11-01. 11 p. (available on the internet from Region 5 Forest Health Protection)

Wagener, WW. 1961. Guidelines for estimating the survival of fire-damaged trees in California. USDA Forest Service PSW Exp Sta, Misc Pap No 60. 11p.