Post-fire Tree Mortality:

Assessing the Probability of Fire-damaged Tree Death and Potential for Bark Beetle Outbreaks After Fire

Beth Willhite
USFS Forest Health Protection
Westside Insect and Disease Service Center, Sandy, OR
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Two timings of tree mortality are associated with fire injury

Immediate – tree killed during the fire

Delayed – tree dies after the fire

Delayed Tree Mortality – may result from:

Extensive damage to cambium or roots absent lethal crown damage

Interaction of fire injury with other agents and stressors, particularly bark beetles

Fire-associated tree mortality depends on what happens before, during, and after fire

Pre-fire

Drought, competition - increases vulnerability to fire

- Increases plant stress, decreases resiliency
- Affects the physical fire environment
- Influences fire intensity

During fire

Fire injury type, severity, timing affects likelihood of tree mortality

- Lethal injuries
- Sublethal injuries
- Fire timing relative to seasonal tree growth, bark beetle flight season

After fire

Tree mortality outcomes determined by interactions among damaged trees, beetles, weather, etc.

- Interactions are complex and variable, influenced by many factors

Objective - Provide information on two common insect-related questions:

?

Which injured trees will die?

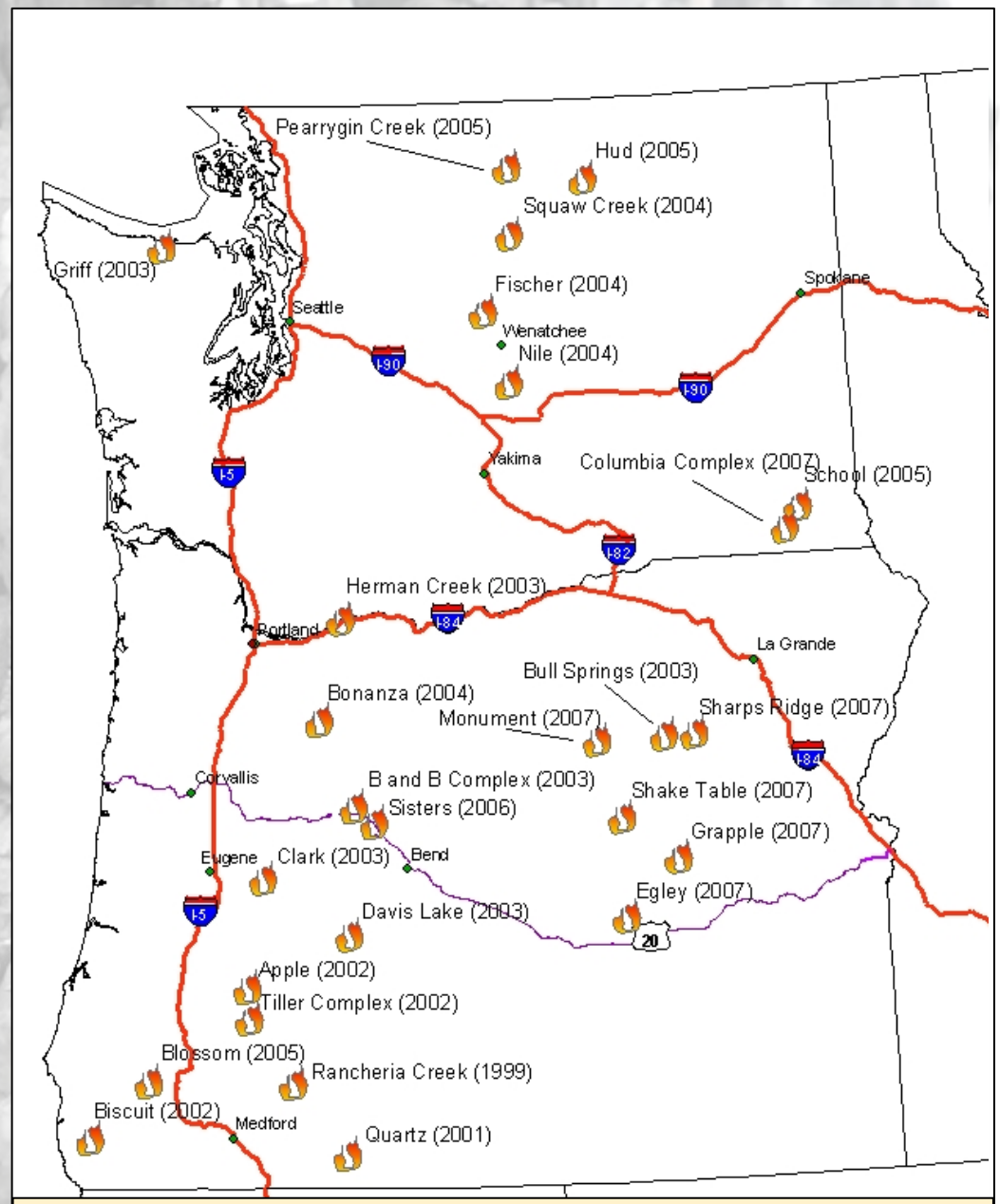
Will this fire cause a bark beetle outbreak?

Which injured trees will die?

Individual Tree Assessment

PNW Post-Fire Mortality Study

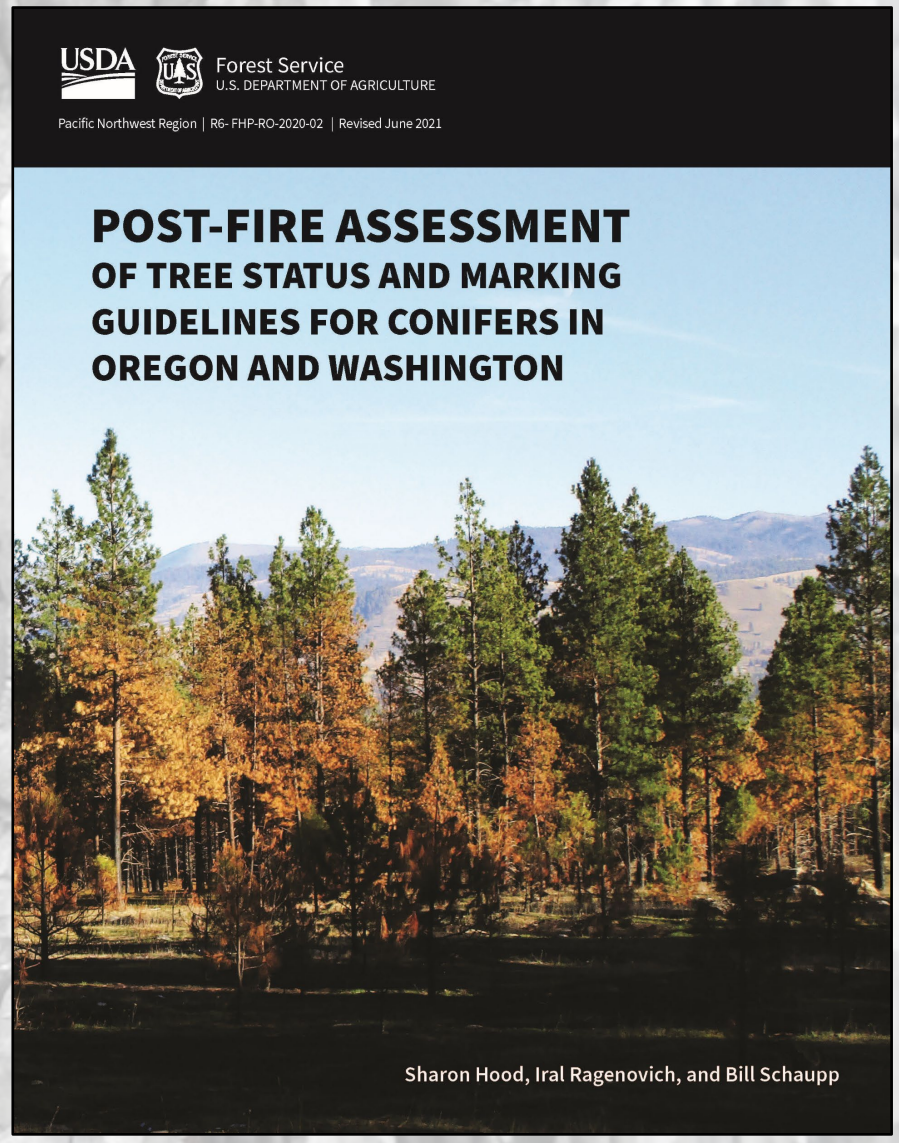
- Initiated in 2003 by Rob Progar, PNW Research Entomologist
- 26 fires
- 19 tree species
- Over 11,000 trees monitored for survival for 3-5 years following fire
- Data used to help develop probability models and tree assessment guidelines for predicting post-fire tree mortality in the Pacific Northwest



Post-fire monitoring data from 26 fires in Oregon and Washington were used to develop region-specific models for predicting the likelihood of post-fire tree mortality.

PNW Post-fire Tree Assessment Guidelines

- First version published online in 2020, available online at: https://digital.osl.state.or.us/islandora/object/osl:957682
- Revised hardcopy version published in June, 2021, available at USFS FHP Offices in Oregon and Washington. Soon to be available online.
- Predicts the likelihood of tree mortality within 3 years after fire
- 3 damage indicators: crown damage, cambial injury, beetle activity; criteria values may vary by diameter class
- Major sections:
  1. How to assess trees
  2. Marking guidelines
     1. Rubric
     2. Full Marking Guidelines
  3. Example of marking guidelines development



Revised version, published June 2021

Hood, S.M., I. Ragenovich, and B. Schaupp. 2021. Post-fire assessment of tree status and marking guidelines for conifers in Oregon and Washington. Rev. ed. R6-FHP-RO-2020-02. 57 p.

Assessing for mortality: when and how?

All trees should be evaluated <u>before the beginning of the second post-fire winter</u>, but preferably within the first post-fire year.

Two options:

1. “Rubric” Guidelines = streamlined, user has less design flexibility
2. “Full Marking Guidelines” = comprehensive, user has more design flexibility

The two options are based on the same datasets but use different types of analyses

Rubric: Simplification of model predictions. Synthesis of Oregon and Washington post-fire mortality data analysis, published research, and expert knowledge.

Full Marking Guidelines: Contain the actual best-fit linear regression and threshold model output values derived from the Oregon and Washington and other applicable fire mortality datasets.

Predetermined Threshold = tree is more likely to die than to live

Threshold values range from 0.10 to 0.90 Pm*

Species	Criteria	DBH 5-11.9"	DBH 12-20.9"	DBH 21"+
Douglas-fir	Crown Scorch	> 65% volume		
	Bark Char	> 50% deep char	> 75% deep char	
Western Hemlock	Crown Scorch	> 20% volume		
	Bark Char	> 90% any char		

Example of simplified predictions

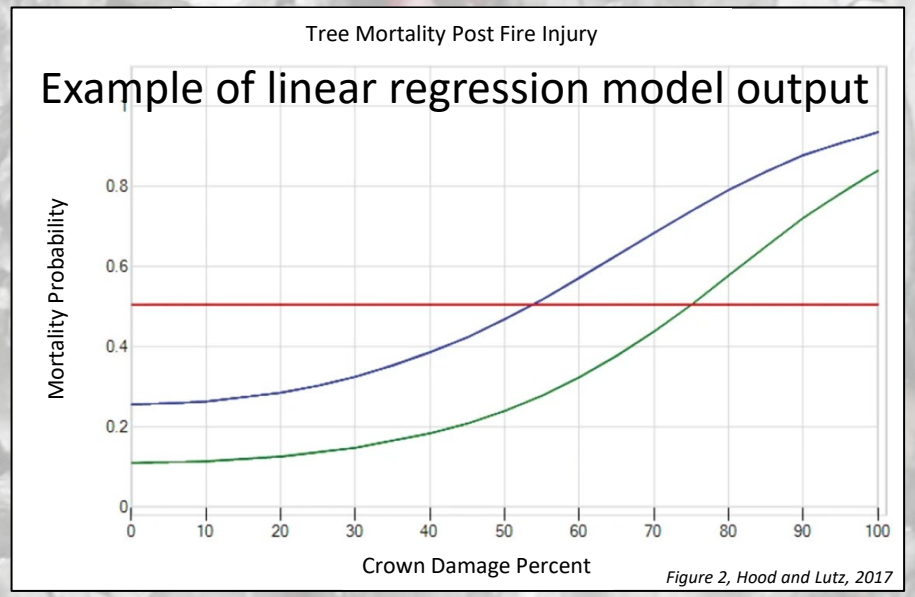


Figure 2, Hood and Lutz, 2017

Table 2a. PONDEROSA & JEFFREY PINE: percent crown volume scorched **(PCVS), CKR,** and **beetles PRESENT** ***(use post-fire, pre-bud break)*** [Hood and Lutes 2017 - post-fire CVS model – beetles present]

Probability of mortality (Pm)	.10	.20	.30	.40	.50	.60	.70	.80	.90
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

Example of model output table

*Pm = Probability of Mortality

Full Marking Guidelines

aggressive ← → conservative

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

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

Rubric

Post-fire Tree Mortality Assessment Rubric

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: 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: Ponderosa 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.

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Full Marking Guidelines

1 Criterion: Crown

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

2 or 3 Criteria: Crown and Cambium Kill and/or Douglas-fir beetle

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

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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

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	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.

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Full Marking Guidelines

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
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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

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Pros and Cons of Guidelines Options

Rubric

Pros

- Relatively fast and easy to use. Mostly consistent measures (e.g., crown length vs. volume). Consistent criteria options.
  - Uses only "Bark Char" to assess cambial damage, which is faster than assessing "Cambium Kill."
- More tree species covered than the full marking guidelines.

Cons

- Limited to a single mortality threshold = "tree is more likely to die than to live within 3 years of the fire."
- Limited other options for custom design.

Full Marking Guidelines

Pros

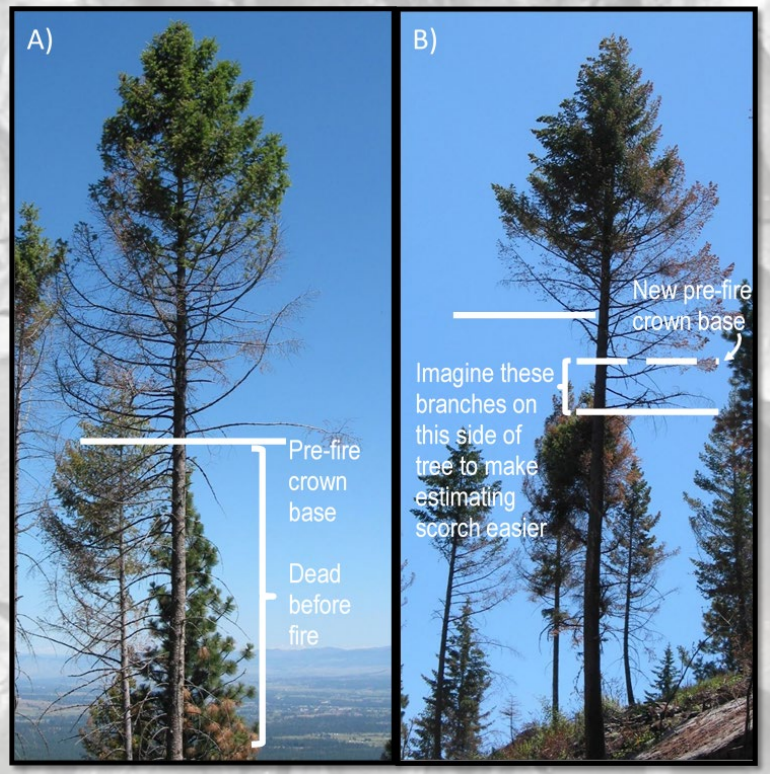
- Affords many options and choices for custom design – allows the manager to select from a range of mortality thresholds to implement a more conservative or aggressive mark.
- Most accurate assessment available when all damage criteria including "Cambium Kill" are used.

Cons

- Can be much more time consuming to apply than the rubric.
- More complicated to use than the rubric. Inconsistent measures among tree species due to use of different models and model inputs.
- Fewer tree species (14) covered than the rubric (19). However, for user convenience, tables displaying the rubric thresholds for tree species without Pm models have been incorporated into the set of Pm tables.

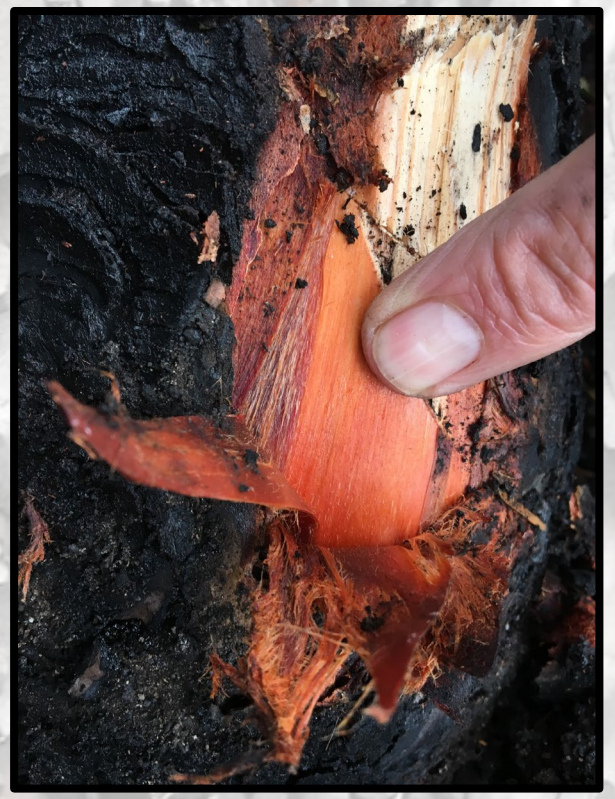
Tree Injury Indicators

Crown Condition



Crown Scorch
Volume or Length (%)

Cambium Injury



Cambium Kill (rating 0-4) or **Bark Char** (unburned, light, moderate, deep) at the root collar

Beetle Activity

Mass attack: Beetle signs ≥ 50% of bole circumference (exclude red turpentine beetle)
Presence/absence of indicator beetles for ponderosa, Jeffrey, and sugar pines, white fir, Douglas-fir, and western hemlock.

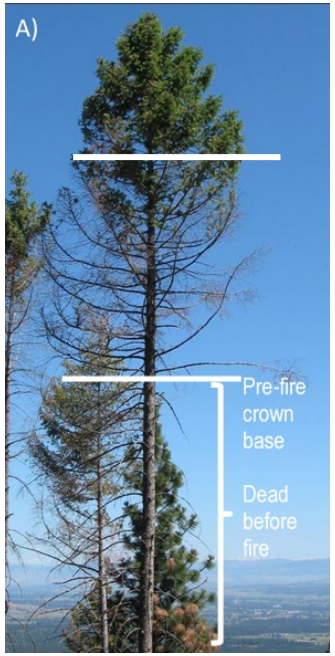
Relative importance of the three assessment factors

- Crown injury is the most important variable to predict tree injury after fire. It is the minimum assessment needed for predicting the likelihood of mortality.
- Assessing cambium injury provides a slight increase in accuracy.
- For some species, assessing the presence or absence of indicator beetle species provides a slight increase in accuracy.[1]
- The slight increases in accuracy are additive. The most accurate marking guidelines assess all defined criteria.

[1]For western hemlock, the presence/absence of ambrosia beetles plays a large role in predictive accuracy.

Crown Scorch

% Volume (Douglas-fir)



Unburned (green)

Percent Crown Volume Scorched = 70%

Crown base

% Length (White fir)

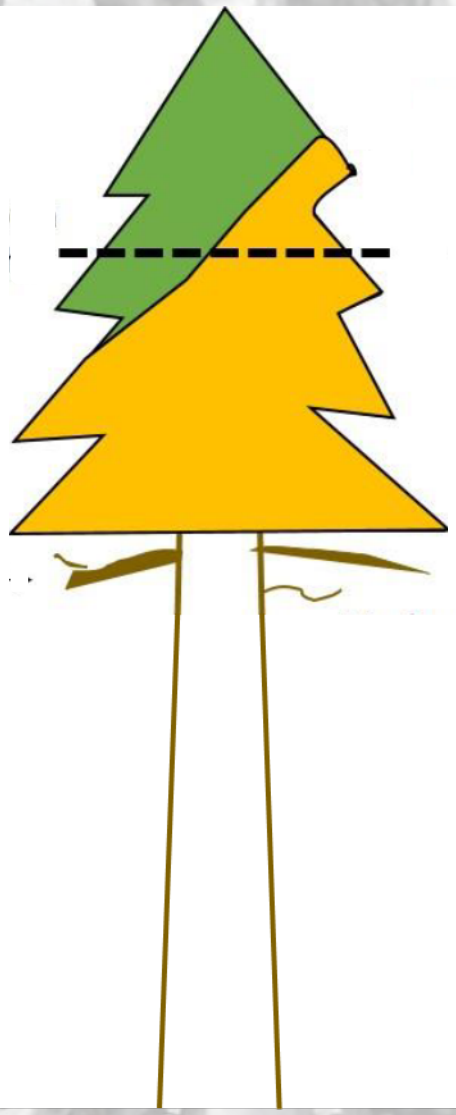
Unburned (green)

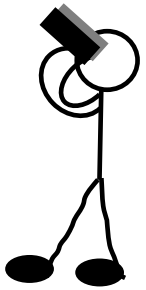
Percent Crown Length Killed = 80%

Crown base

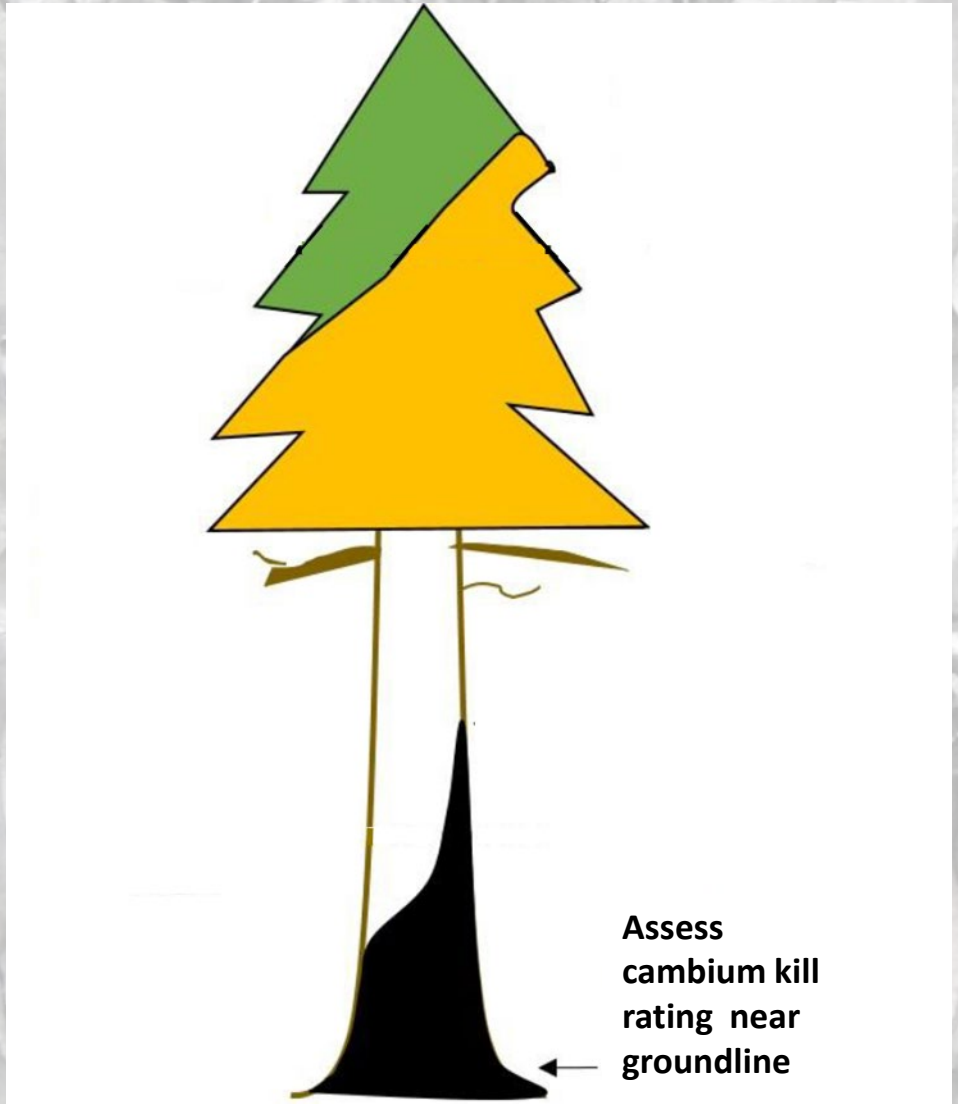
Crown Scorch

- Includes both scorched needles and consumed needles (blackened needles or missing needles on branches that were alive pre-fire).
- Visually estimated as a percentage of pre-fire crown volume or crown length. Volume and length are not interchangeable, as the variable used depends on the data collected in the studies of post-fire mortality.
- Ponderosa pine and western larch are assessed a little differently because areas of the crown with scorched needles could have buds and branches that survived the fire. Easiest to assess after bud break the first year after the fire.





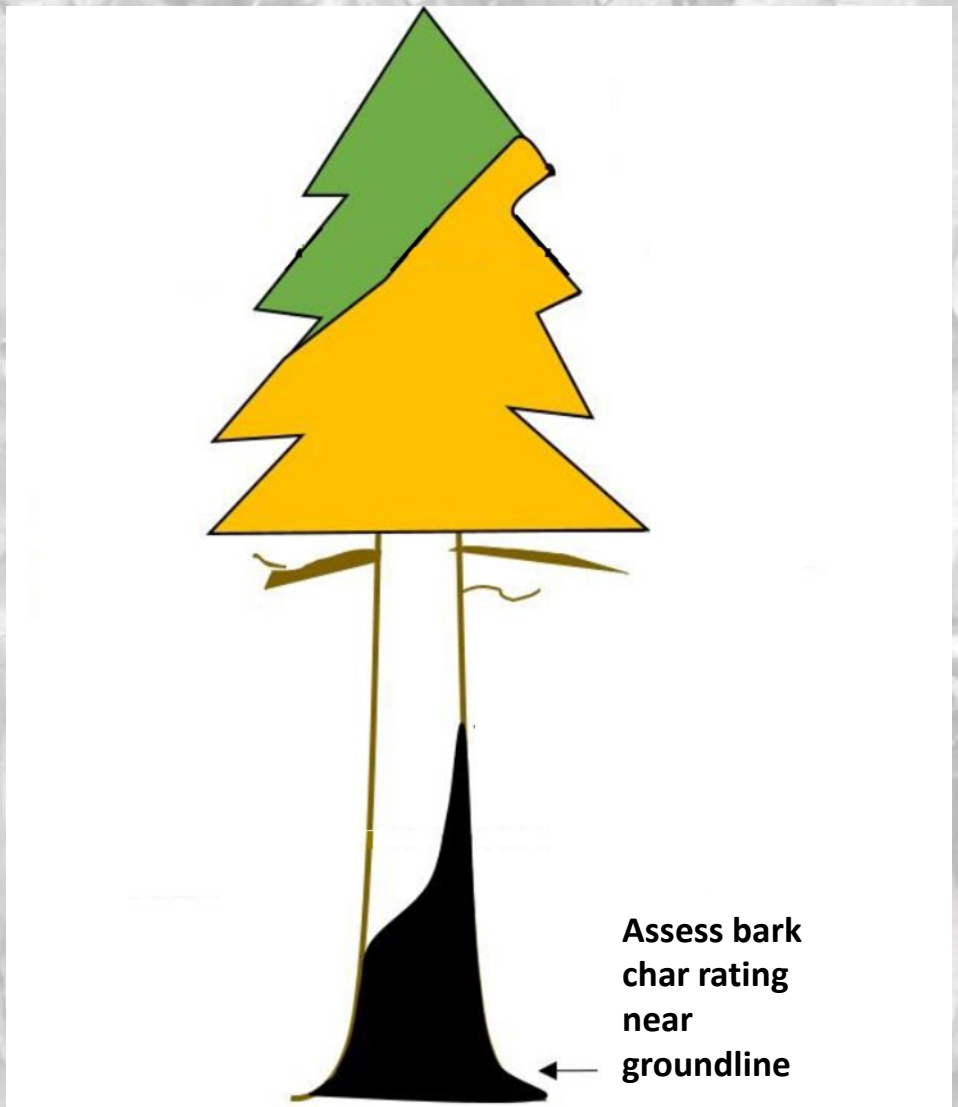
Cambium Kill

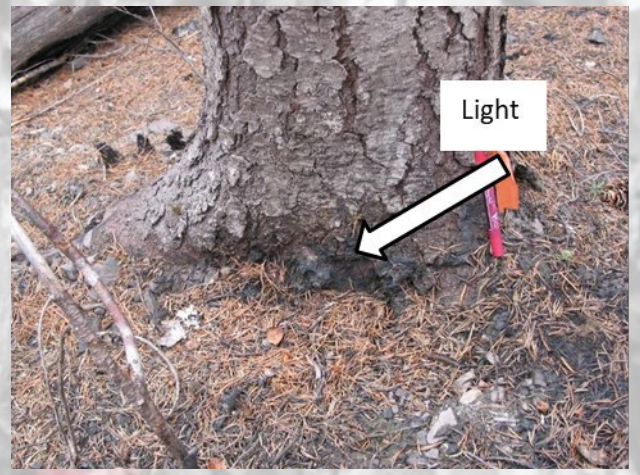


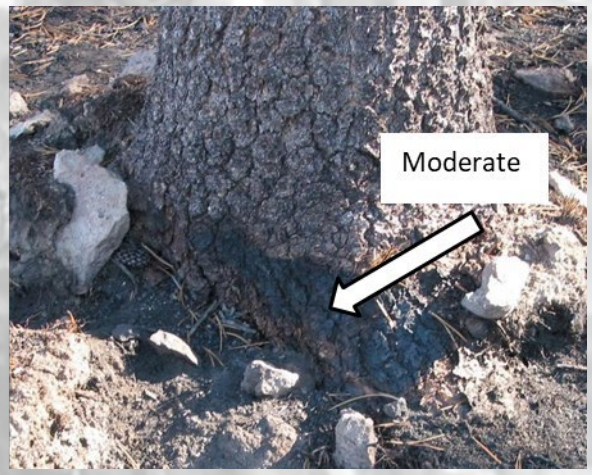
<u>Cambium Kill Rating</u>

Sum of the number of dead quadrants = 0-4

Bark Char







<u>Bark Char Rating (select one)</u>

- **Unburned**
- **Light**
- **Moderate (most common rating)**
- **Deep**

Assessed as a % of bole circumference near the groundline

Most reliable for thin-barked species

Beetle Signs

(When evaluating mass attack, exclude red turpentine beetle pitch tubes) 

Pitch tubes
Pine beetles, spruce beetle

Brown boring dust
(Douglas-fir beetle,
other bark beetles, wood borers)

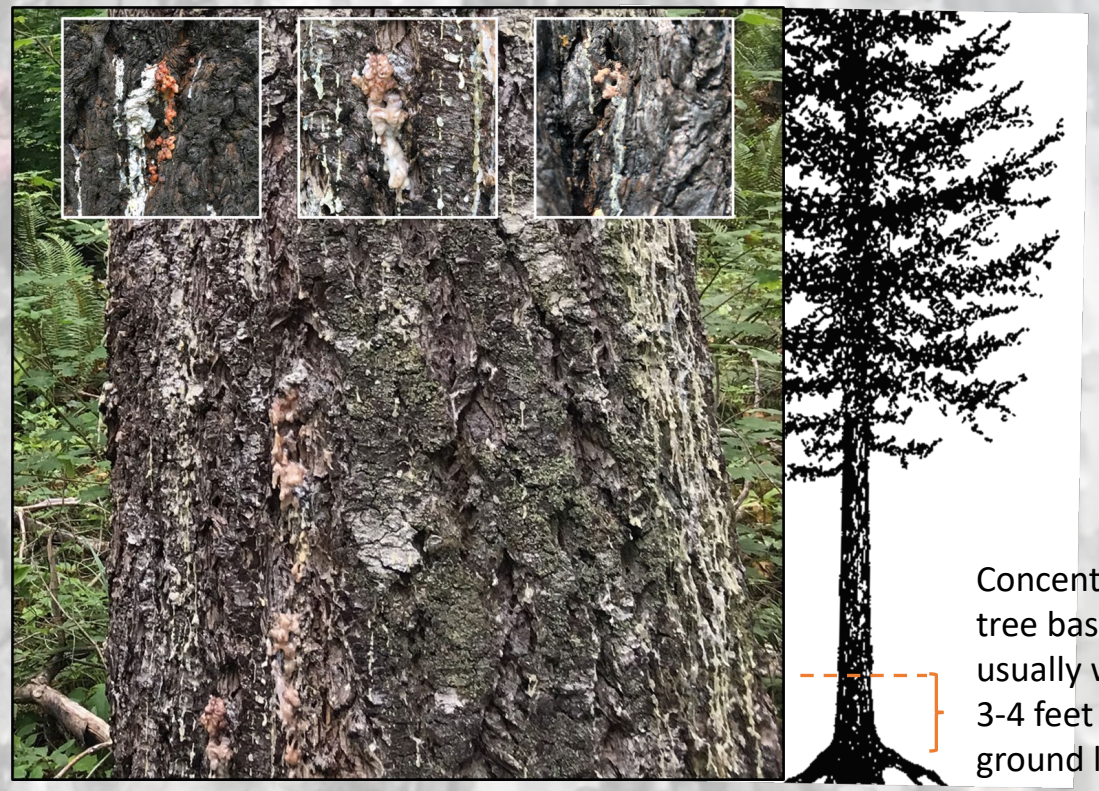
Yellow boring dust
(ambrosia beetles)

Red Turpentine Beetle Pitch Tubes (RTB)

Presence: Ponderosa, Jeffrey, Sugar pine Do not include in mass attack evaluations

On Ponderosa Pine

On Douglas-fir



Concentrated at tree base, usually within 3-4 feet above ground level

Project Logistics

- **Recon project area** – collect information on tree species, burn severity (crown scorch and bark char) and beetle signs/activity (if applicable).
- **Consider** management objectives, resources, and constraints.
- **Select** guidelines and criteria to use, create customized marking prescription. Can mix and match Rubric and Full Marking Guidelines when marking a mix of species. A sequential flow approach for tree assessment criteria is effective, e.g., 1) are there any live needles, 2) does it meet scorch threshold, 3) does it meet bark char threshold, 4) is it mass attacked? Stop and mark if any are yes, if all no, then don't mark.
- **Document** the guidelines used for future reference.

Will this fire cause a bark beetle outbreak?

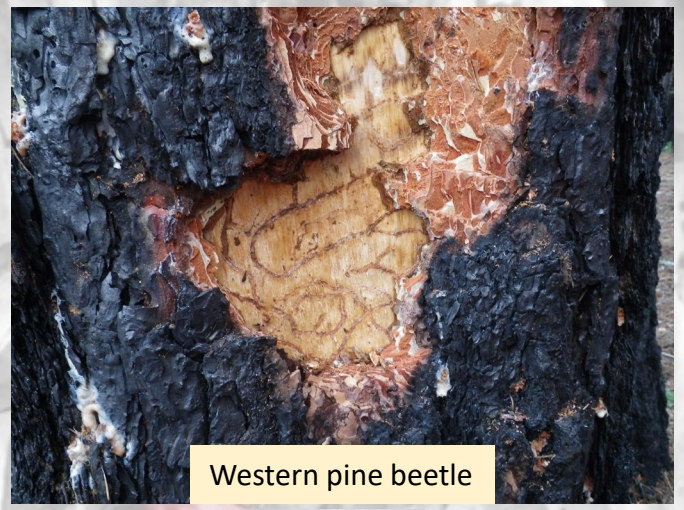
Evaluating risk to surviving and nearby stands

Increased Beetle Activity is Common After a Fire

Often aggressive after fire: Western pine beetle, Douglas-fir beetle, Ips beetles

Sometimes aggressive: Mountain pine beetle, fir engraver, spruce beetle, flatheaded fir borer?

Active in stressed, dying or fire-killed trees but secondary: Red turpentine beetle, other bark beetles, wood borers, ambrosia beetles

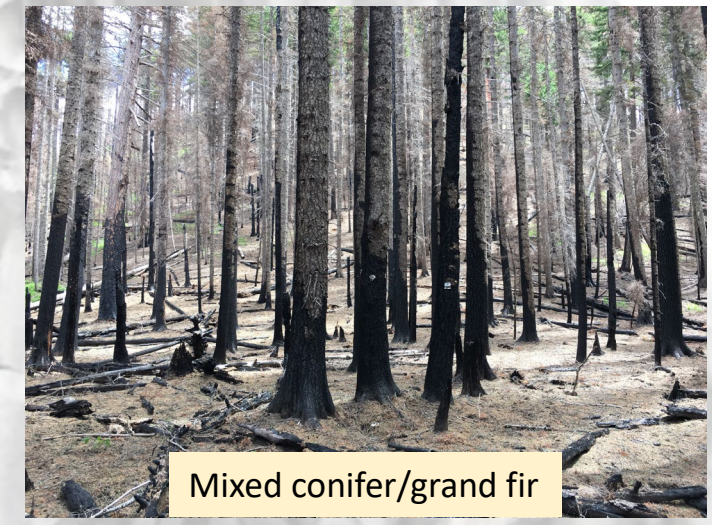

Western pine beetle


Douglas-fir beetle


Ips beetles


Ponderosa pine

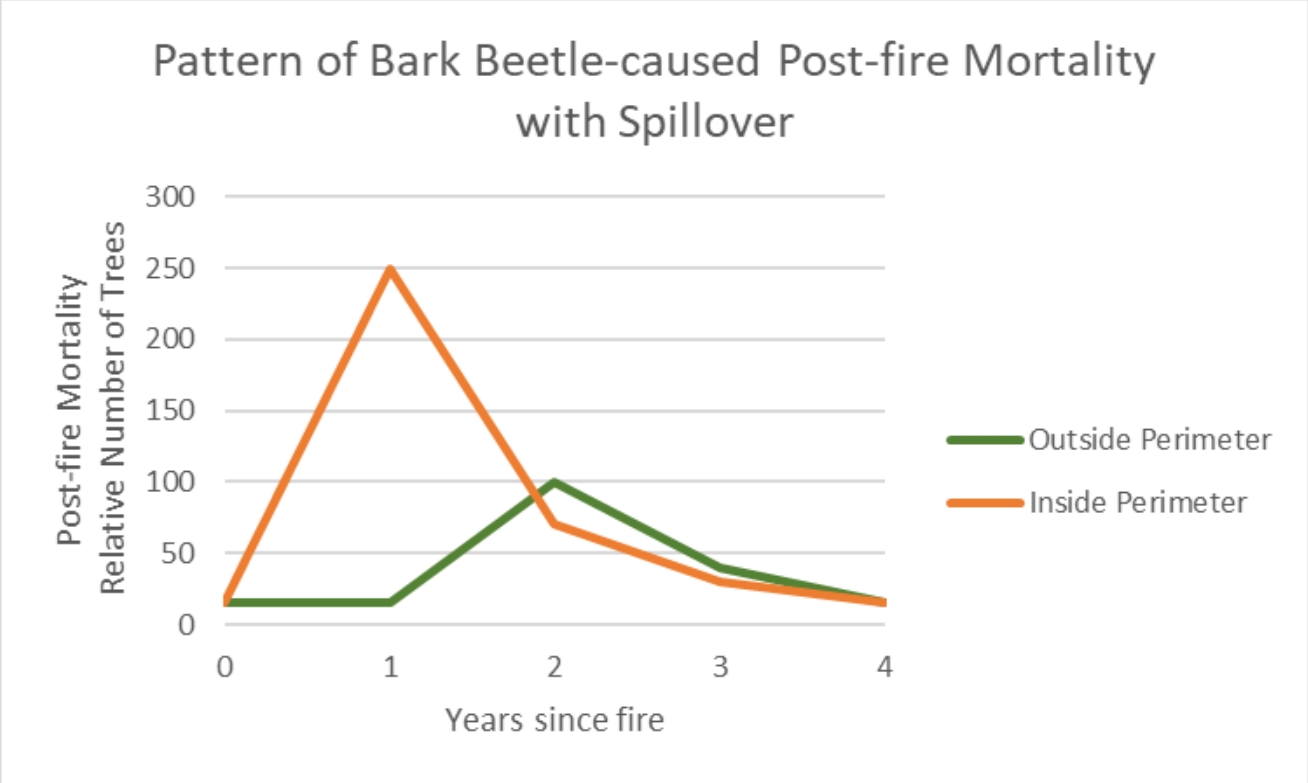

Douglas-fir


Mixed conifer/grand fir

What do we know?[1]

- Most post-fire bark beetle attacks (75-90%) occur during the first season following a fire, and these <u>attacks are concentrated in moderately injured trees.</u>
- Bark beetle populations may increase to high levels in fire-injured trees.
- Uninjured green trees may be attacked within the fire perimeter during the second or third year post-fire.
- Occasionally, small spillover attacks in adjacent green unburned stands may occur during the second or third year post-fire, mostly commonly with western pine beetle.
- Beetle brood survival in fire-injured trees is sometimes much reduced over that observed in unburned areas.
- Bark beetle populations within the fire perimeter decline two to four years post-fire.
- It is rare for a fire to cause a significant bark beetle outbreak in adjacent, unburned areas.
- Fires do not cause widespread epidemics.

[1]Cunningham et al. 2005, Davis et al. 2012, Eglitis 2006, Fettig et al. 2010, Furniss 1965, Hood and Bentz 2007, Lerch et al. 2016, Miller and Keen 1960, Miller and Patterson 1927, Powell et al 2012, Rasmussen et al. 1996, Ryan and Amman 1994, Weatherby et al. 1994



Typical Post-fire Mortality Progression:
The exact pattern varies among fires and is influenced by a variety of factors.
Year 0: Fire
Year 1: Bark beetles attack and build up numbers in moderately injured trees during the first flight season after the fire.
Years 2 and 3: Bark beetles forced to move into less severely injured trees and sometimes uninjured trees in the second and third season, causing populations to decline.
Year 4: Populations return to pre-fire levels in the absence of other disturbance.
Note: Tree mortality may not be apparent/recorded until the year following attack because trees killed by bark beetles often take one year to turn red.

Mosquito Burn, October 31, 1917

Post-fire mortality study of western pine beetle in ponderosa pine

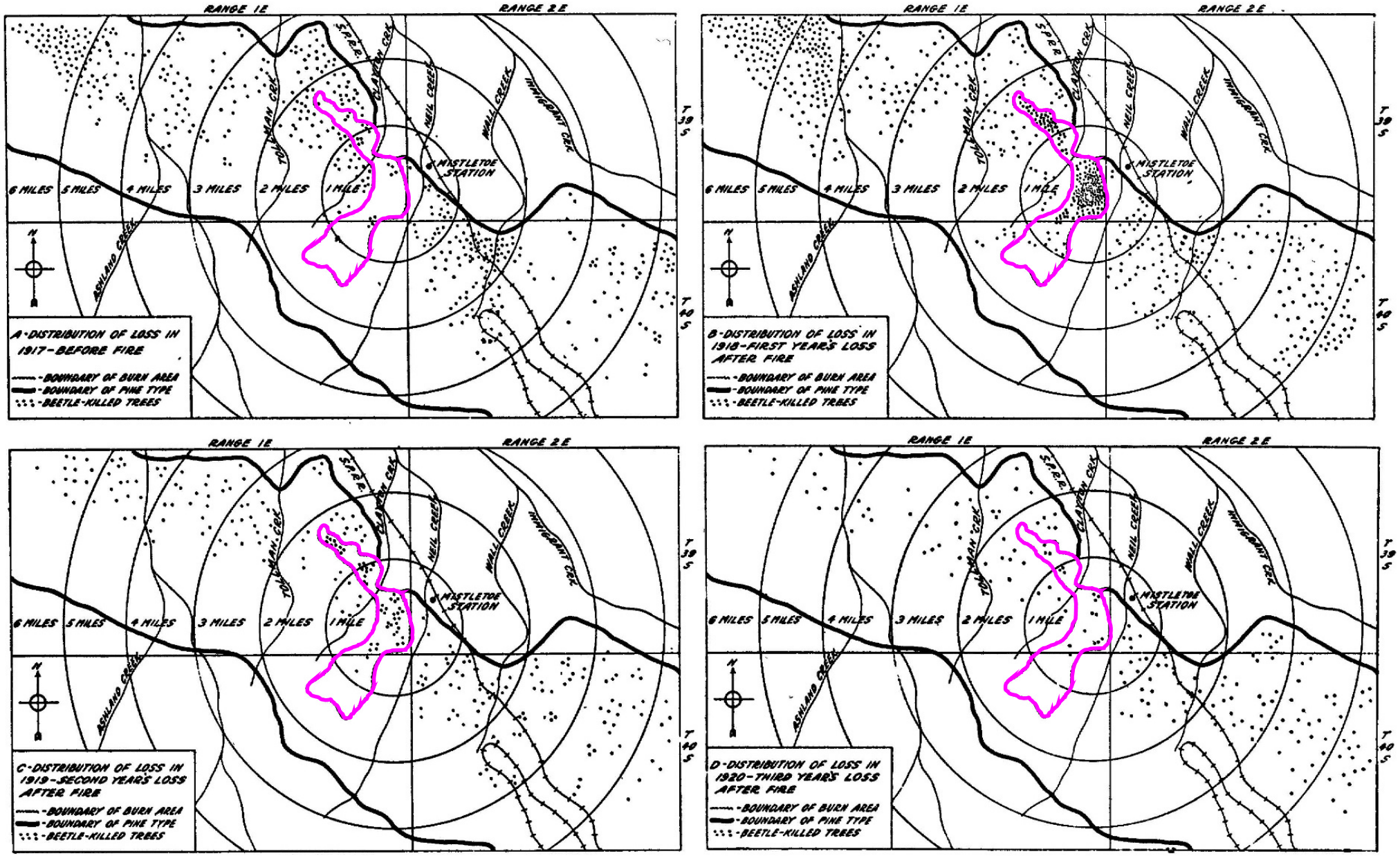
-800 acres
-SW Oregon, Siskiyou Mountains
-7 miles SE of Ashland, OR
-Forest composition: Ponderosa pine (44%), Douglas-fir (52%), sugar pine (3%)
-A large western pine beetle control study initiated in 1914 included the fire area
-Post-fire morality study, 1917-1920 (Miller and Patterson 1927):

- 100 percent sample and mapping of ponderosa pine mortality extending 6 miles from the burned area, sampled annually pre-fire through 3 years post-fire
- Ponderosa pine: western pine beetle
- Douglas-fir: <u>the only insects that attacked Douglas-fir were wood borers; attacks limited to fire-killed trees</u>, so excluded from study
- Sugar pine: scarce, so excluded from study

Miller and Patterson. 1927. Preliminary studies on the relation of fire injury to bark-beetle attack in western yellow pine. Journal of Agricultural Research 34: 597-614.

1917 – Before Fire

1918 – First Year

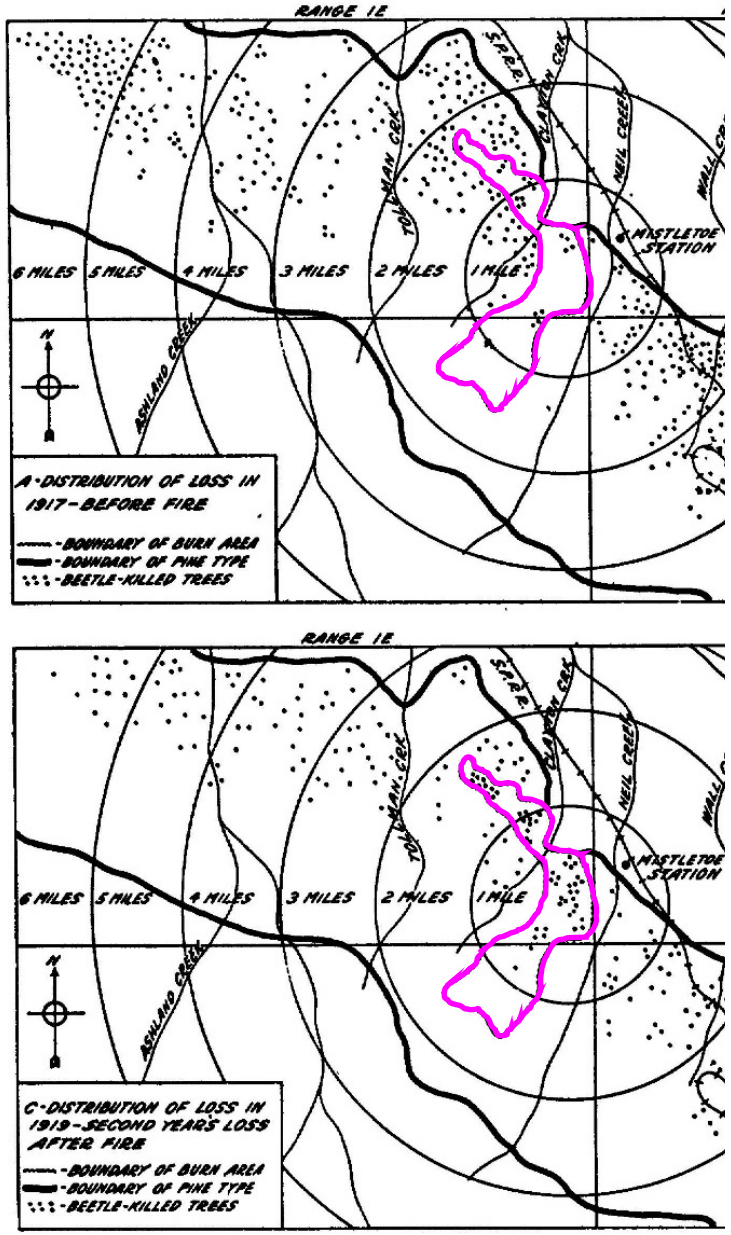


1919 – Second Year

1920 – Third Year

FIG. 1.—Distribution of trees killed by bark beetles (*Dendroctonus brevicomis*) in the Mistletoe burn and in the surrounding zones one year before and three years after the fire

1917 – Before Fire



1919 – Second Year

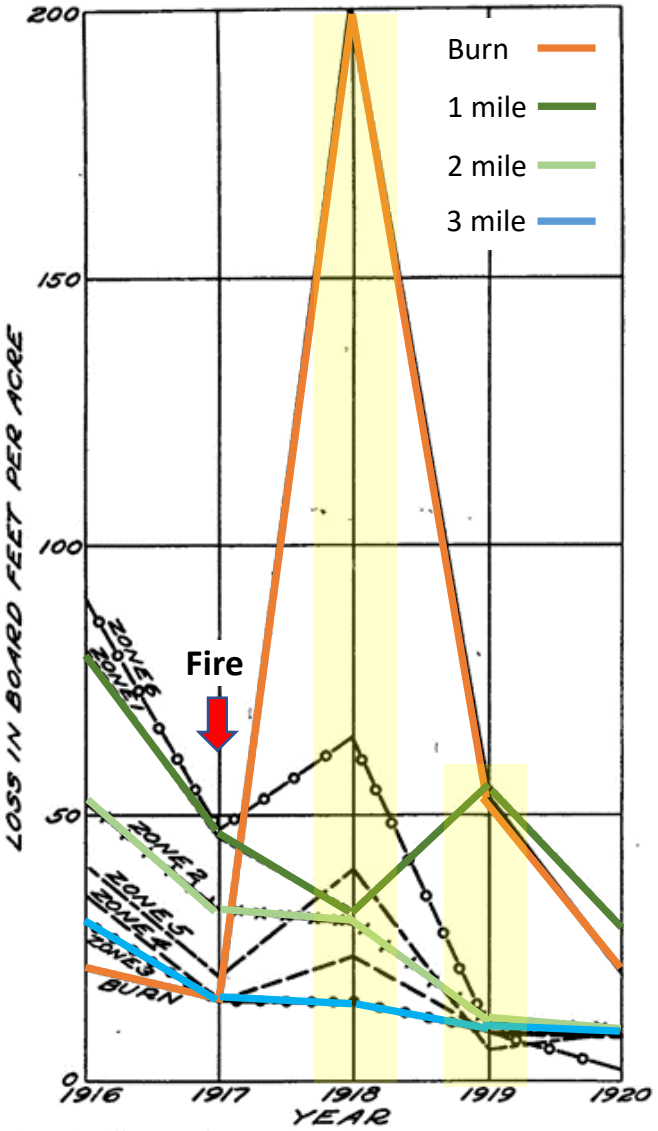
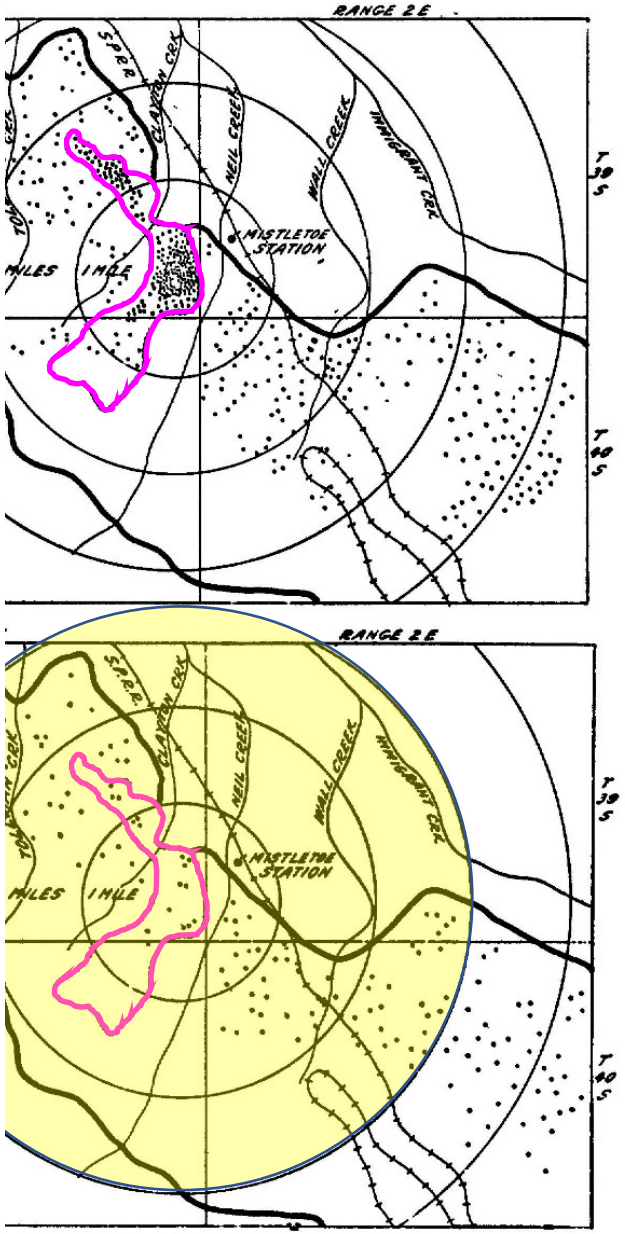


FIG. 4.—Comparative rates of loss, in board feet per acre, of timber killed by bark beetles on burned area and on each of the surrounding zones during the season preceding the fire and for three seasons subsequent to it (Mistletoe burn)

1918 – First Year

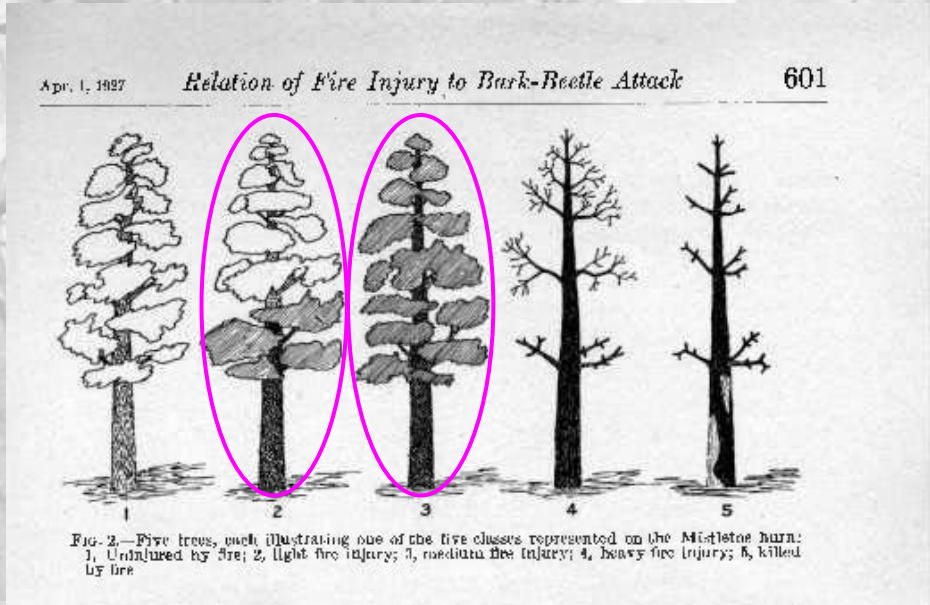


1920 – Third Year

FIG. 1.—Distribution of trees killed by bark beetles (*Dendroctonus brevicomis*) in the Mistletoe burn and in the surrounding zones one year before and three years after the fire

Mosquito Burn, October 31, 1917

Post-fire mortality study findings



Trees in the light to moderate fire-injury classes were most frequently attacked and killed by western pine beetle. Over 80% of the trees in Classes 2 and 3 (light or moderate damage class) were attacked the first season after the fire. 67% of Class 4 trees were attacked the first season after fire and none were attacked the second season, but the unattacked trees in Class 4 all died anyway from fire injury. [1]

Bark beetle brood mortality was high in many of the fire-injured trees due to extremely moist condition in the inner bark (aka "sour sap"). Fewer beetles were produced in these trees than in trees successfully attacked outside the burn.[1]

"This concentration of beetles within the burn did not cause an epidemic infestation that continued to increase within the burn or to spread to surrounding areas." [1]

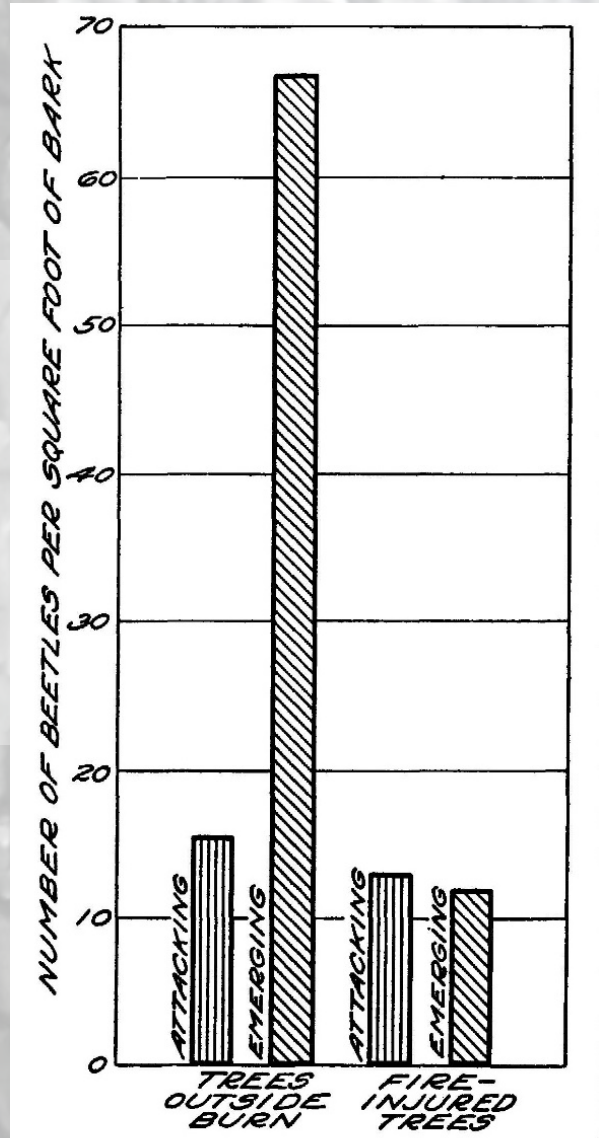


FIG. 7.—Comparison of brood development in trees under normal conditions adjacent to Mistletoe burn and in fire-injured trees

[1]Miller and Patterson. 1927. Preliminary studies on the relation of fire injury to bark-beetle attack in western yellow pine. Journal of Agricultural Research 34: 597-614.

Tillamook Burn, August 14, 1933

-244,706 acres
-Coast Range, NW Oregon
-Mostly crown fire; some large patches of unburned green forest remained inside the fire perimeter
-Forest composition: Douglas-fir (~78%), hemlock and other species (22%) [1]
-Other conditions of note:

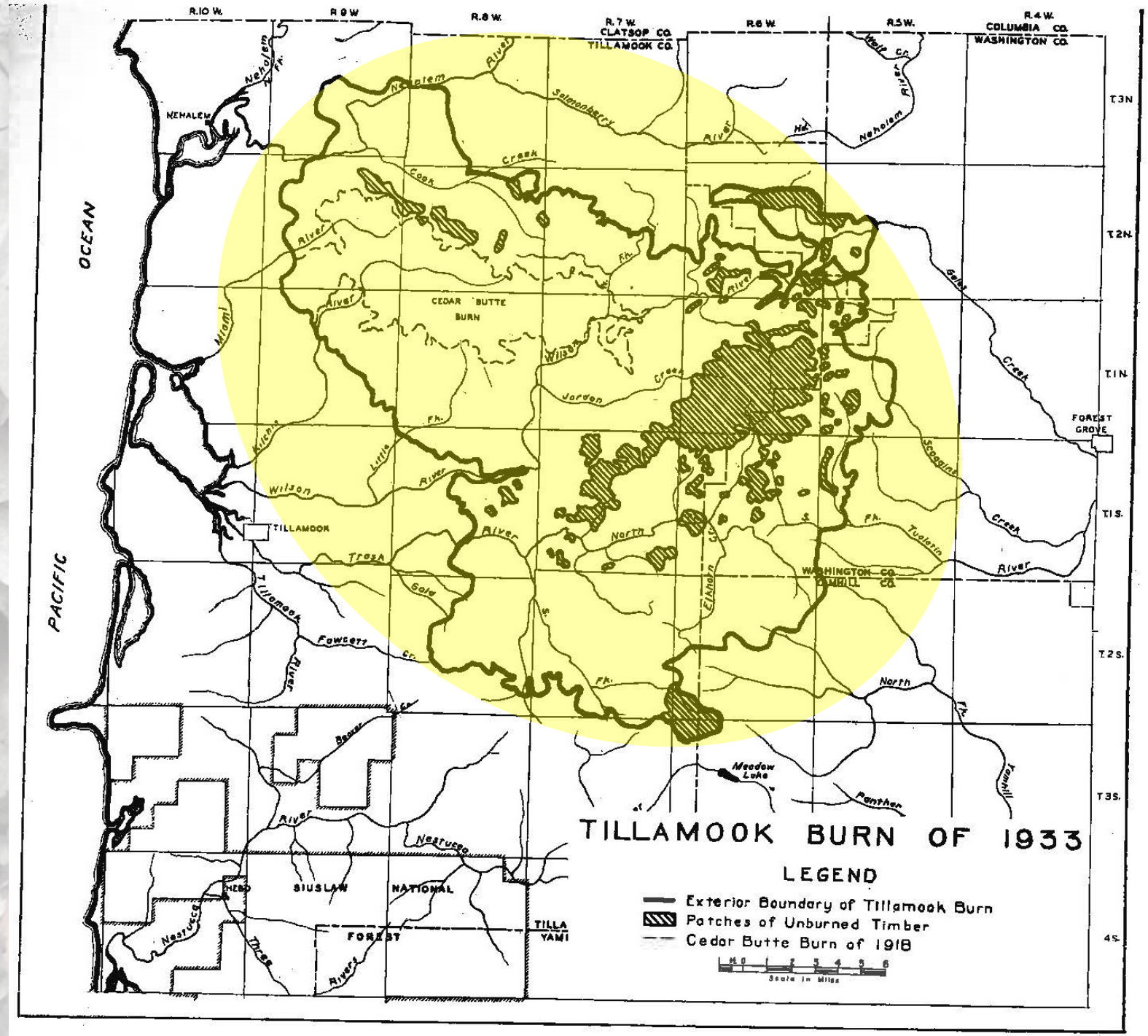
- Severe, prolonged drought during the 1920s and 1930s
- Pre-fire population levels of Douglas-fir beetle were high due to a yearly succession of large fires in the Tillamook area from 1929 to 1933[2]

[1]Unknown. 1939. Tillamook Fires 1933-1939: History of disasters and present condition of area to be visited on Congress field trip. Logger's Daily, Pacific Logging Congress, Portland, October 11-14, 1939. p. 36-42, 59.
[2]Furniss, R.L. 1936. Bark beetles active following Tillamook Fire. The Timberman. January, 1936. p. 21-22.

“An aftermath of the Tillamook blaze…was an outbreak of the Douglas-fir beetle... This bark beetle built up to large numbers in the burned trees. Then in the years 1935-1937 the beetles attacked and killed about two hundred million board feet of green Douglas-fir in and about the burn.”

Timeline:
1933: Tillamook Fire
1934: Douglas-fir beetle infested fire-injured trees
1935: Douglas-fir beetle attacked groups of healthy trees in green tree islands within the burn and also outside the burn up to several miles. This type of damage was general around other burns in that vicinity.
1936-1937: Douglas-fir beetle activity continued but declined each year. The beetle-caused mortality occurred in five Oregon counties, namely Clatsop, Tillamook, Columbia, Washington, and Yamhill.

An anomaly? Since this event, no similar outbreak outside of fire perimeters has been documented.



Assessing the Likelihood of Beetle Outbreak Post-fire

The risk of significant post-fire beetle-caused mortality in green, unburned stands outside of a fire perimeter is thought to be low in today's landscapes, and likely requires several concurrent predisposing conditions:

- High pre-fire beetle populations in the vicinity.
- Green host stands within a mile of the fire that are susceptible (having risk factors) to attack by the beetle species of concern, e.g., host species, preferred diameter, overly dense, abundant root disease, etc.
- Conducive pre- and post-fire weather, e.g., prolonged drought or other significant stressors.

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