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Probability of Tree Mortality as Related to Fire-Caused Crown Scorch[1]

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INTRODUCTION

Information presented below was developed during post-fire planning and ecosystem analysis activities initiated following Bull, Summit, Tower, and Wheeler Point wildfires in 1996. It provides probabilities, expressed as a percent, of trees of various species and diameter being killed as a result of varying proportions of crown scorch volume.

Note that tree mortality probabilities are based on one damage factor only – crown scorch volume – and do not account for other factors such as stem or root damage.

A separate table is provided for each of eight tree species: ponderosa pine, interior Douglas-fir, western larch, grand fir, lodgepole pine, Engelmann spruce, subalpine fir, and western white pine (tables 3-10).

Mortality probability tables, by tree species, presented in this white paper were also used in a cooperative extension bulletin entitled "After the burn: Assessing and managing your forestland after a wildfire" (Barkley 2006).

Probability calculations were based on an equation from Reinhardt and Ryan (1989); bark thickness factors were taken from Keane et al. (1989 or 1996) (table 1).

Calculation procedures are described in Steele and others (1996). Probability values for each combination of tree size (diameter) and crown scorch volume, as stratified by tree species, were calculated by using a Microsoft Excel® spreadsheet.

[1] White papers are internal reports; they receive only limited review. Viewpoints expressed in this paper are those of the author – they may not represent positions of USDA Forest Service.

Table 1: Bark thickness factors for tree species included in this tree mortality protocol.

Tree Species	Bark Thickness Factor	Equation Based on Diameter Outside Bark
Ponderosa pine	.070 × DOB	-.0376 + (.0584 × DOB)
Interior Douglas-fir	.065 × DOB	.065 × DOB
Western larch	.069 × DOB	-.045 + (.0629 × DOB)
Grand fir	.033 × DOB	.043 × DOB
Lodgepole pine	.014 × DOB	.0271 + (.0143 × DOB)
Engelmann spruce	.022 × DOB	.126 + (.025 × DOB)
Subalpine fir	.015 × DOB	.015 × DOB
Western white pine	.014 × DOB	.054 + (.025 × DOB)

Sources/Notes: Column 2 is from Keane et al. (1989 or 1996); column 3 is from Ryan (1982). Note that "DOB" in columns 2 and 3 refers to diameter outside bark (and DOB is assumed to be the same as DBH for most forestry data sets). When making probability calculations displayed in tables 3-10, bark thickness factors from column 2 were used with Steele et al. (1996) equations.

TREE SUSCEPTIBILITY

Whether a tree is killed or damaged by fire depends on a variety of factors: fire resistance characteristics varying by plant species, fire intensity, fire duration, when a fire occurs during the growing season, and amounts of direct damage (referred to as first-order fire effects) to a tree's foliage (crown), stem (bole), and roots.

Perhaps the most effective indicator of crown injury is a proportion of the crown scorched or killed by fire (Peterson 1985, Ryan 1982, Ryan et al. 1988, Ryan and Reinhardt 1988, Wagener 1961).

Response of immature ponderosa pine and many other conifers to crown scorch has been found to vary depending on when a fire occurs during the growing season – mortality of immature ponderosa pines scorched in spring or early summer was about 2.5 times greater than for pines scorched in autumn (when compared for similar levels of crown damage) (Harrington 1993).

The same study (Harrington 1993) showed that most ponderosa pines greater than 7 inches DBH survived fire injury, even after sustaining more than 90% crown scorch. Following spring or early summer injury, ponderosa pines smaller than 4 inches DBH and with greater than 50% crown scorch typically died.

It was suggested that differences in ponderosa pine mortality for these two seasonal windows (spring-early summer versus late summer-autumn) are likely due to contrasts in physiological activity and to carbohydrate storage (Harrington 1993).

Less fire-caused damage occurs in late summer or autumn because tree growth has slowed, terminal buds have formed, and root reserves have accumulated. For the same reasons, crown scorch in very early spring, before or immediately after bud burst, also results in minimal tree damage (Crane and Fischer 1986).

Although some research has found stem injury to be a less important factor than crown scorch when predicting tree mortality from fire-caused damage (Peterson and Arbaugh 1986, Peterson and Ryan 1986), bark thickness still influences tree survival – thin-barked species have a greater probability of dying within a year of being damaged than thick-barked species.

Perusing tables 3-10, particularly the proportion of each table that is black (black areas depict relatively high susceptibility[2] to fire-caused mortality) versus white (indicating relatively low susceptibility to fire-caused mortality), clearly shows the effect of bark thickness on tree mortality, and plainly illustrates how this life history trait varies between tree species (Ryan 1982).

FIRE-RELATED INSECT SUSCEPTIBILITY

During post-fire planning activities, an important issue is increased susceptibility of fire-damaged trees to insect attack (McCullough et al. 1998, Miller and Patterson 1927). First-order fire effects reflect direct damage to a tree's living tissues; second-order fire effects involve insects and other organisms that opportunistically attack stressed trees exhibiting symptoms of low vigor (and the high stress/low vigor levels experienced by these trees are commonly related to their first-order fire effects).

Charring the lower stem may damage a tree's vascular cambium, and reduce its resistance to bark beetle attack, by rupturing resin ducts used to defend against bark beetle invasion of the cambium layer.

[***Tree physiology note***: Although defined somewhat differently in different sources, cambium is a relatively thin layer of living cells that completely encircles a tree stem and is located between a tree's outer bark and its sapwood layer.

Sapwood is the outer portion of a tree's wood column – it is usually lighter in color and, depending on species and tree age, it generally comprises about ¼ to 1/3 of a tree's total wood column.

Cambium reactivates in spring, following winter dormancy, by becoming rehydrated, and this 'slimy' period results in a well-known spring phenomenon called bark slippage, when bark is easily peeled (slipped) from a log.

Native Americans were well aware of this spring 'slippage' period, when they would peel bark from large-diameter ponderosa pines and harvest the moist cambium as a sweet treat. Some large, old ponderosa pines across the western US still bear scars from this early bark-peeling activity (Hart and Moore 1992).

When cell divisions occur, cambium differentiates into two types of cells – differentiation creates thick-walled, lignified wood cells (a xylem zone) toward the inside (wood side) of a tree. Xylem adds wood to a tree's sapwood layer and, in conifers, some of this sapwood remains functional (alive) for many years.

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[2] For this protocol, high susceptibility to fire-caused tree mortality is defined as probabilities greater than or equal to 50 percent; low susceptibility includes probabilities less than 50 percent.

Sapwood is important for water movement in a tree – after roots pick up water, it moves upward through a tree's sapwood in response to a vapor-pressure gradient. The steepness (strength) of a vapor-pressure gradient is influenced by transpiration (evaporation of water) at the foliage, and water availability in the soil.

A possible model for this vapor-pressure gradient is a typical 'drinking straw' – on one end, foliage is losing (evaporating) water to the atmosphere, and this is producing 'pull' or suction force on the straw (water column). The straw itself is a long column of xylem (sapwood) tissue running the full length (height) of the tree. On the other end of the straw, suction force produced by transpiration results in water being absorbed by roots.

Cambial differentiation also creates thin-walled 'inner-bark' cells (a phloem zone) toward the outside (bark side) of a tree. As new phloem cells are created, old phloem cells are 'crushed' and become inactivated bark tissue.

Material in this physiology note was adapted from Daniel et al. 1979, especially chapters 5 (Ecophysiology of Tree Growth) and 6 (Stem Cambium Development).]

Bark beetles bore through a tree's corky outer bark to feed and reproduce in phloem, a moist inner-bark zone. When beetles invade phloem, trees inhibit their activity by using a substance called oleoresin. Oleoresin, produced by specialized epithelial cells in the xylem, is stored in vertical resin ducts in xylem and bark resin canals (Ganz et al. 2003).

It has been suggested that some tree species have a long evolutionary history of interactions with fire and bark beetles, and these species are adept at responding to fire-caused bole damage with increased resin flow to counteract increased risk of post-fire bark beetle attack (Feeney et al. 1998, McCullough et al. 1998).

For ponderosa pine, western pine beetle (*Dendroctonus brevicomis*) preferentially attacks old, thick-barked ponderosa pine (Miller and Keen 1960). But because much old-growth ponderosa pine has been harvested, or has died for other reasons, western pine beetle (WPB) outbreaks now tend to occur most frequently after wildfire (Mitchell and Martin 1980) – this is in contrast to an historical pattern of WPB being associated almost exclusively with slow-growing, old-growth stands.

Old ponderosa pines scorched or wounded by fire are weakened and less resistant to western pine beetle attack (McCullough et al. 1998). Risk of western pine beetle attack varies in direct proportion to the amount of crown lost from fire scorch, as demonstrated by table 2 below.

Table 2: Relationship between crown scorch and tree mortality caused by western pine beetle for ponderosa pine.

Percent Scorch (Defoliation)	Percent of Trees Killed by Beetles
0-25	0-15
25-50	13-14
50-75	19-42
75-100	45-87

Sources/Notes: Adapted from Crane and Fischer (1986), and based on data from Stevens and Hall (1960).

Table 3: Probability of fire-induced mortality for ponderosa pine *(Pinus ponderosa)*.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
5	49%	53%	60%	68%	78%	86%	93%	97%	99%	99%
6	42%	46%	53%	62%	72%	83%	90%	95%	98%	99%
7	36%	40%	46%	55%	67%	78%	88%	94%	98%	99%
8	30%	34%	40%	49%	61%	74%	85%	93%	97%	99%
9	25%	28%	34%	43%	55%	69%	82%	91%	96%	99%
10	21%	24%	29%	37%	49%	64%	78%	89%	95%	98%
12	15%	17%	21%	28%	39%	53%	69%	84%	93%	97%
14	11%	12%	10%	21%	30%	43%	61%	77%	90%	96%
16	8%	9%	7%	16%	23%	35%	52%	71%	86%	94%
18	6%	7%	6%	12%	18%	29%	45%	65%	82%	93%
20	5%	5%	4%	10%	15%	24%	39%	59%	78%	91%
22	4%	4%	4%	8%	13%	21%	34%	54%	74%	89%
24	3%	4%	3%	7%	11%	18%	31%	50%	71%	87%
26	3%	3%	3%	6%	10%	16%	28%	47%	69%	86%
28	3%	3%	3%	6%	9%	15%	27%	45%	67%	85%
30	3%	3%	3%	6%	9%	15%	26%	44%	67%	85%

Sources/Notes: These values are probabilities, expressed as a percent, of ponderosa pines of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). Steele et al. (1996) describes the calculation methodology. White values on a black background denote combinations of crown scorch and DBH with a tree mortality probability ≥ 50%; black values on a white background show tree mortality probability < 50%.

Table 4: Probability of fire-induced mortality for Douglas-fir *(Pseudotsuga menziesii glauca)*.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
5	52%	56%	62%	70%	79%	87%	93%	97%	99%	100%
6	45%	49%	56%	65%	75%	84%	91%	96%	98%	99%
7	39%	43%	49%	59%	70%	81%	89%	95%	98%	99%
8	33%	37%	43%	53%	64%	76%	87%	94%	97%	99%
9	28%	32%	38%	47%	59%	72%	84%	92%	97%	99%
10	24%	27%	33%	41%	53%	67%	80%	90%	96%	98%
12	17%	20%	24%	32%	43%	58%	73%	86%	94%	98%
14	12%	14%	18%	24%	34%	48%	65%	81%	91%	97%
16	9%	11%	13%	18%	27%	40%	57%	75%	88%	95%
18	7%	8%	10%	14%	21%	33%	50%	69%	84%	94%
20	5%	6%	8%	11%	17%	27%	43%	63%	81%	92%
22	4%	5%	7%	9%	14%	23%	38%	57%	77%	90%
24	4%	4%	6%	8%	12%	20%	34%	53%	74%	89%
26	3%	4%	5%	7%	11%	18%	30%	49%	71%	87%
28	3%	3%	4%	6%	10%	16%	28%	47%	69%	86%
30	3%	3%	4%	6%	9%	16%	27%	45%	67%	85%

Sources/Notes: These values are probabilities, expressed as a percent, of Douglas-firs of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). Steele et al. (1996) describes the calculation methodology. White values on a black background denote combinations of crown scorch and DBH with a tree mortality probability ≥ 50%; black values on a white background show tree mortality probability < 50%.

Table 5: Probability of fire-induced mortality for western larch *(Larix occidentalis)*.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
5	49%	**53%**	**60%**	**69%**	**78%**	**86%**	**93%**	**97%**	**99%**	**99%**
6	43%	47%	**53%**	**62%**	**73%**	**83%**	**91%**	**96%**	**98%**	**99%**
7	36%	40%	47%	**56%**	**67%**	**79%**	**88%**	**94%**	**98%**	**99%**
8	31%	34%	41%	**50%**	**62%**	**74%**	**85%**	**93%**	**97%**	**99%**
9	26%	29%	35%	44%	**56%**	**69%**	**82%**	**91%**	**96%**	**99%**
10	22%	25%	30%	38%	**50%**	**64%**	**78%**	**89%**	**95%**	**98%**
12	15%	17%	22%	29%	39%	**54%**	**70%**	**84%**	**93%**	**97%**
14	11%	13%	16%	21%	31%	44%	**62%**	**78%**	**90%**	**96%**
16	8%	9%	12%	16%	24%	36%	**53%**	**72%**	**86%**	**95%**
18	6%	7%	9%	13%	19%	30%	46%	**65%**	**82%**	**93%**
20	5%	6%	7%	10%	15%	25%	40%	**59%**	**78%**	**91%**
22	4%	5%	6%	8%	13%	21%	35%	**54%**	**75%**	**89%**
24	3%	4%	5%	7%	11%	18%	31%	**50%**	**71%**	**87%**
26	3%	3%	5%	6%	10%	17%	29%	47%	**69%**	**86%**
28	3%	3%	4%	6%	9%	16%	27%	45%	**67%**	**85%**
30	3%	3%	4%	6%	9%	15%	26%	44%	**67%**	**85%**

Sources/Notes: These values are probabilities, expressed as a percent, of western larches of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). Steele et al. (1996) describes the calculation methodology. White values on a black background denote combinations of crown scorch and DBH with a tree mortality probability ≥ 50%; black values on a white background show tree mortality probability < 50%.

Table 6: Probability of fire-induced mortality for grand fir *(Abies grandis)*.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
5	**68%**	**71%**	**76%**	**83%**	**88%**	**93%**	**96%**	**98%**	**99%**	**100%**
6	**65%**	**68%**	**74%**	**80%**	**87%**	**92%**	**96%**	**98%**	**99%**	**100%**
7	**61%**	**65%**	**71%**	**78%**	**85%**	**91%**	**95%**	**98%**	**99%**	**100%**
8	**58%**	**62%**	**68%**	**75%**	**83%**	**90%**	**95%**	**98%**	**99%**	**100%**
9	**54%**	**58%**	**65%**	**73%**	**81%**	**89%**	**94%**	**97%**	**99%**	**100%**
10	**51%**	**55%**	**62%**	**70%**	**79%**	**87%**	**93%**	**97%**	**99%**	**100%**
12	44%	48%	**55%**	**64%**	**74%**	**84%**	**91%**	**96%**	**98%**	**99%**
14	38%	42%	49%	**58%**	**69%**	**80%**	**89%**	**95%**	**98%**	**99%**
16	33%	36%	43%	**52%**	**64%**	**76%**	**86%**	**93%**	**97%**	**99%**
18	28%	31%	37%	46%	**58%**	**71%**	**83%**	**92%**	**97%**	**99%**
20	23%	26%	32%	41%	**52%**	**67%**	**80%**	**90%**	**96%**	**98%**
22	20%	22%	27%	35%	47%	**62%**	**76%**	**88%**	**95%**	**98%**
24	17%	19%	24%	31%	42%	**57%**	**72%**	**85%**	**94%**	**98%**
26	14%	16%	20%	27%	37%	**52%**	**68%**	**83%**	**92%**	**97%**
28	12%	14%	17%	23%	33%	47%	**64%**	**80%**	**91%**	**96%**
30	10%	12%	15%	20%	29%	43%	**60%**	**77%**	**89%**	**96%**

Sources/Notes: These values are probabilities, expressed as a percent, of grand firs of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). Steele et al. (1996) describes the calculation methodology. White values on a black background denote combinations of crown scorch and DBH with a tree mortality probability ≥ 50%; black values on a white background show tree mortality probability < 50%.

Table 7: Probability of fire-induced mortality for lodgepole pine *(Pinus contorta)*.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
5	77%	79%	83%	88%	92%	96%	98%	99%	100%	100%
6	75%	78%	82%	87%	92%	95%	98%	99%	100%	100%
7	74%	77%	81%	86%	91%	95%	97%	99%	100%	100%
8	73%	76%	80%	86%	91%	95%	97%	99%	99%	100%
9	72%	75%	79%	85%	90%	94%	97%	99%	99%	100%
10	70%	74%	78%	84%	90%	94%	97%	99%	99%	100%
12	68%	71%	76%	82%	88%	93%	96%	98%	99%	100%
14	65%	68%	74%	80%	87%	92%	96%	98%	99%	100%
16	62%	66%	71%	78%	85%	91%	96%	98%	99%	100%
18	59%	63%	69%	76%	84%	90%	95%	98%	99%	100%
20	56%	60%	66%	74%	82%	89%	94%	97%	99%	100%
22	53%	57%	64%	72%	80%	88%	94%	97%	99%	100%
24	50%	54%	61%	69%	79%	87%	93%	97%	99%	100%
26	48%	52%	58%	67%	77%	86%	92%	96%	98%	99%
28	45%	49%	55%	64%	75%	84%	91%	96%	98%	99%
30	42%	46%	53%	62%	72%	83%	90%	95%	98%	99%

Sources/Notes: These values are probabilities, expressed as a percent, of lodgepole pines of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). Steele et al. (1996) describes the calculation methodology. White values on a black background denote combinations of crown scorch and DBH with a tree mortality probability ≥ 50%; black values on a white background show tree mortality probability < 50%.

Table 8: Probability of fire-induced mortality for Engelmann spruce *(Picea engelmannii)*.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
5	73%	76%	81%	86%	91%	95%	97%	99%	99%	100%
6	71%	74%	79%	85%	90%	94%	97%	99%	99%	100%
7	69%	72%	77%	83%	89%	94%	97%	98%	99%	100%
8	67%	70%	76%	82%	88%	93%	96%	98%	99%	100%
9	65%	68%	74%	80%	87%	92%	96%	98%	99%	100%
10	62%	66%	72%	79%	86%	92%	96%	98%	99%	100%
12	58%	62%	68%	75%	83%	90%	95%	98%	99%	100%
14	53%	57%	64%	72%	80%	88%	94%	97%	99%	100%
16	49%	53%	59%	68%	77%	86%	93%	97%	99%	99%
18	44%	48%	55%	64%	74%	84%	91%	96%	98%	99%
20	40%	44%	51%	60%	71%	81%	90%	95%	98%	99%
22	36%	40%	47%	56%	67%	79%	88%	94%	98%	99%
24	33%	36%	43%	52%	64%	76%	86%	93%	97%	99%
26	29%	33%	39%	48%	60%	73%	84%	92%	97%	99%
28	26%	29%	35%	44%	56%	70%	82%	91%	96%	99%
30	23%	26%	32%	41%	52%	67%	80%	90%	96%	98%

Sources/Notes: These values are probabilities, expressed as a percent, of Engelmann spruces of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). Steele et al. (1996) describes the calculation methodology. White values on a black background denote combinations of crown scorch and DBH with a tree mortality probability ≥ 50%; black values on a white background show tree mortality probability < 50%.

Table 9: Probability of fire-induced mortality for subalpine fir *(Abies lasiocarpa)*.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
5	76%	79%	83%	88%	92%	95%	98%	99%	100%	100%
6	75%	78%	82%	87%	91%	95%	97%	99%	100%	100%
7	74%	77%	81%	86%	91%	95%	97%	99%	100%	100%
8	72%	75%	80%	85%	90%	94%	97%	99%	99%	100%
9	71%	74%	79%	84%	90%	94%	97%	99%	99%	100%
10	69%	73%	78%	83%	89%	94%	97%	99%	99%	100%
12	66%	70%	75%	82%	88%	93%	96%	98%	99%	100%
14	63%	67%	73%	79%	86%	92%	96%	98%	99%	100%
16	60%	64%	70%	77%	85%	91%	95%	98%	99%	100%
18	57%	61%	67%	75%	83%	90%	95%	97%	99%	100%
20	54%	58%	64%	72%	81%	88%	94%	97%	99%	100%
22	51%	55%	62%	70%	79%	87%	93%	97%	99%	100%
24	48%	52%	59%	67%	77%	86%	92%	96%	99%	99%
26	45%	49%	56%	65%	75%	84%	91%	96%	98%	99%
28	42%	46%	53%	62%	72%	83%	90%	95%	98%	99%
30	39%	43%	50%	59%	70%	81%	89%	95%	98%	99%

Sources/Notes: These values are probabilities, expressed as a percent, of subalpine firs of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1989). Steele et al. (1996) describes the calculation methodology. White values on a black background denote combinations of crown scorch and DBH with a tree mortality probability ≥ 50%; black values on a white background show tree mortality probability < 50%.

Table 10: Probability of fire-induced mortality for western white pine *(Pinus monticola)*.

	CROWN SCORCH VOLUME (PERCENT)									
DBH	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
5	77%	79%	83%	88%	92%	96%	98%	99%	100%	100%
6	75%	78%	82%	87%	92%	95%	98%	99%	100%	100%
7	74%	77%	81%	86%	91%	95%	97%	99%	100%	100%
8	73%	76%	80%	86%	91%	95%	97%	99%	99%	100%
9	72%	75%	79%	85%	90%	94%	97%	99%	99%	100%
10	70%	74%	78%	84%	90%	94%	97%	99%	99%	100%
12	68%	71%	76%	82%	88%	93%	96%	98%	99%	100%
14	65%	68%	74%	80%	87%	92%	96%	98%	99%	100%
16	62%	66%	71%	78%	85%	91%	96%	98%	99%	100%
18	59%	63%	69%	76%	84%	90%	95%	98%	99%	100%
20	56%	60%	66%	74%	82%	89%	94%	97%	99%	100%
22	53%	57%	64%	72%	80%	88%	94%	97%	99%	100%
24	50%	54%	61%	69%	79%	87%	93%	97%	99%	100%
26	48%	52%	58%	67%	77%	86%	92%	96%	98%	99%
28	45%	49%	55%	64%	75%	84%	91%	96%	98%	99%
30	42%	46%	53%	62%	72%	83%	90%	95%	98%	99%

Sources/Notes: These values are probabilities, expressed as a percent, of white pines of various diameters being killed by fire. They are based on an equation from Reinhardt and Ryan (1989) and a bark thickness factor from Keane et al. (1996). Steele et al. (1996) describes the calculation methodology. White values on a black background denote combinations of crown scorch and DBH with a tree mortality probability ≥ 50%; black values on a white background show tree mortality probability < 50%.

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APPENDIX 1: SILVICULTURE WHITE PAPERS

White papers are internal reports, and they are produced with a consistent formatting and numbering scheme – all papers dealing with Silviculture, for example, are placed in a silviculture series (Silv) and numbered sequentially. Generally, white papers receive only limited review and, in some instances pertaining to highly technical or narrowly focused topics, the papers may receive no technical peer review at all. For papers that receive no review, the viewpoints and perspectives expressed in the paper are those of the author only, and do not necessarily represent agency positions of the Umatilla National Forest or the USDA Forest Service.

Large or important papers, such as two papers discussing active management considerations for dry and moist forests (white papers Silv-4 and Silv-7, respectively), receive extensive review comparable to what would occur for a research station general technical report (but they don't receive blind peer review, a process often used for journal articles).

White papers are designed to address a variety of objectives:

(1) They guide how a methodology, model, or procedure is used by practitioners on the Umatilla National Forest (to ensure consistency from one unit, or project, to another).

(2) Papers are often prepared to address ongoing and recurring needs; some papers have existed for more than 20 years and still receive high use, indicating that the need (or issue) has long standing – an example is white paper #1 describing the Forest's big-tree program, which has operated continuously for more than 25 years.

(3) Papers are sometimes prepared to address emerging or controversial issues, such as management of moist forests, elk thermal cover, or aspen forest in the Blue Mountains. These papers help establish a foundation of relevant literature, concepts, and principles, and they continuously evolve as an issue matures, experiencing many iterations (versions) through time. [But also note that some papers have not changed since their initial development, in which case they reflect historical concepts or procedures.]

(4) Papers synthesize science viewed as particularly relevant to geographical and management contexts for the Umatilla National Forest. This is considered to be the Forest's self-selected 'best available science' (BAS), realizing that non-agency commenters would generally have a different perception of what constitutes BAS – like beauty, BAS is in the eye of the beholder.

(5) The objective of some papers is to locate and summarize the science germane to a particular topic or issue, including obscure sources such as master's theses or Ph.D. dissertations. In other instances, a paper may be designed to wade through an overwhelming amount of published science (dry-forest management), and then synthesize sources viewed as being most relevant to a local context.

(6) White papers function as a citable literature source for methodologies, models, and procedures used during environmental analysis – by citing a white paper, specialist reports can include less verbiage describing analytical databases, techniques, and so forth, some of which change little (if at all) from one planning effort to another.

(7) White papers are often used to describe how a map, database, or other product was developed. In this situation, the white paper functions as a 'user's guide' for the new product. Examples include papers dealing with historical products: (a) historical fire extents for the Tu-

cannon watershed (WP Silv-21); (b) an 1880s map developed from General Land Office survey notes (WP Silv-41); and (c) a description of historical mapping sources (24 separate items) available from the Forest's history website (WP Silv-23).

These papers are available from the Forest's website: Silviculture White Papers

Paper #	Title
1	Big tree program
2	Description of composite vegetation database
3	Range of variation recommendations for dry, moist, and cold forests
4	Active management of Blue Mountains dry forests: Silvicultural considerations
5	Site productivity estimates for upland forest plant associations of Blue and Ochoco Mountains
6	Blue Mountains fire regimes
7	Active management of Blue Mountains moist forests: Silvicultural considerations
8	Keys for identifying forest series and plant associations of Blue and Ochoco Mountains
9	Is elk thermal cover ecologically sustainable?
10	A stage is a stage is a stage…or is it? Successional stages, structural stages, seral stages
11	Blue Mountains vegetation chronology
12	Calculated values of basal area and board-foot timber volume for existing (known) values of canopy cover
13	Created opening, minimum stocking, and reforestation standards from Umatilla National Forest Land and Resource Management Plan
14	Description of EVG-PI database
15	Determining green-tree replacements for snags: A process paper
16	Douglas-fir tussock moth: A briefing paper
17	Fact sheet: Forest Service trust funds
18	Fire regime condition class queries
19	Forest health notes for an Interior Columbia Basin Ecosystem Management Project field trip on July 30, 1998 (handout)
20	Height-diameter equations for tree species of Blue and Wallowa Mountains
21	Historical fires in headwaters portion of Tucannon River watershed
22	Range of variation recommendations for insect and disease susceptibility
23	Historical vegetation mapping
24	How to measure a big tree
25	Important Blue Mountains insects and diseases
26	Is this stand overstocked? An environmental education activity
27	Mechanized timber harvest: Some ecosystem management considerations
28	Common plants of south-central Blue Mountains (Malheur National Forest)
29	Potential natural vegetation of Umatilla National Forest
30	Potential vegetation mapping chronology
31	Probability of tree mortality as related to fire-caused crown scorch

Paper #	Title
32	Review of “Integrated scientific assessment for ecosystem management in the interior Columbia basin, and portions of the Klamath and Great basins” – Forest vegetation
33	Silviculture facts
34	Silvicultural activities: Description and terminology
35	Site potential tree height estimates for Pomeroy and Walla Walla Ranger Districts
36	Stand density protocol for mid-scale assessments
37	Stand density thresholds as related to crown-fire susceptibility
38	Umatilla National Forest Land and Resource Management Plan: Forestry direction
39	Updates of maximum stand density index and site index for Blue Mountains variant of Forest Vegetation Simulator
40	Competing vegetation analysis for southern portion of Tower Fire area
41	Using General Land Office survey notes to characterize historical vegetation conditions for Umatilla National Forest
42	Life history traits for common Blue Mountains conifer trees
43	Timber volume reductions associated with green-tree snag replacements
44	Density management field exercise
45	Climate change and carbon sequestration: Vegetation management considerations
46	Knutson-Vandenberg (K-V) program
47	Active management of quaking aspen plant communities in northern Blue Mountains: Regeneration ecology and silvicultural considerations
48	Tower Fire…then and now. Using camera points to monitor postfire recovery
49	How to prepare a silvicultural prescription for uneven-aged management
50	Stand density conditions for Umatilla National Forest: A range of variation analysis
51	Restoration opportunities for upland forest environments of Umatilla National Forest
52	New perspectives in riparian management: Why might we want to consider active management for certain portions of riparian habitat conservation areas?
53	Eastside Screens chronology
54	Using mathematics in forestry: An environmental education activity
55	Silviculture certification: Tips, tools, and trip-ups
56	Vegetation polygon mapping and classification standards: Malheur, Umatilla, and Wallowa-Whitman National Forests
57	State of vegetation databases for Malheur, Umatilla, and Wallowa-Whitman National Forests
58	Seral status for tree species of Blue and Ochoco Mountains

REVISION HISTORY

November 2012: First version of this white paper was prepared in late autumn of 1996 in response to four large forest fires occurring the previous summer. In autumn of 1996 and spring of 1997, it was used when marking salvage sales for Wheeler Point Fire at Heppner Ranger District.

It was revised in November 2012 by making minor formatting and editing changes, and to describe a silviculture white-paper system, including a list of available white papers.