Running Head: Postfire conifer survival and flushing

Postfire survival and flushing in three Sierra Nevada conifers with high initial crown scorch

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Abstract. With growing debate over the impacts of postfire salvage logging in conifer forests of the western U.S., managers need accurate assessments of tree survival when significant proportions of the crown have been scorched. The accuracy of fire severity measurements will be affected if trees that initially appear to be fire killed prove to be viable after longer observation. Our goal was to quantify the extent to which three common Sierra Nevada conifer species may "flush" (produce new foliage in the year following a fire from scorched portions of the crown) and survive after fire, and to identify tree or burn characteristics associated with survival. We found that, among ponderosa pines (*Pinus ponderosa* Dougl. ex. Laws) and Jeffrey pines (*Pinus jeffreyi* Grev. & Balf) with 100% initial crown scorch (no green foliage following the fire), the majority of mature trees flushed, and survived. Red fir (*Abies magnifica* A. Murr.) with high crown scorch (mean = 90%) also flushed, and most large trees survived. Our results indicate that, if flushing is not taken into account, fire severity assessments will tend to overestimate mortality and postfire salvage could remove many large trees that appear dead but are not.

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Introduction

In recent years, controversy has grown over the effects of postfire salvage logging in western U.S. conifer forests (Karr *et al.* 2004, Donato *et al.* 2006, Hutto 2006, Noss *et al.* 2006). Managers need accurate assessments of tree survival where high levels of crown scorch occur. If trees that initially appear to be dead prove to be viable after longer observation, the accuracy of fire severity estimates will be affected. This could lead managers to overestimate the amount of habitat available for wildlife species associated with high-severity fire effects (Smucker *et al.* 2005, Hutto 2006, Hanson and North 2008). Moreover, potential seed sources for natural postfire conifer regeneration could be removed, affecting and impeding successional processes (Lindenmayer *et al.* 2004, Noss *et al.* 2006).

Following wildfire, rapid assessments of various fire effects are made by inter-agency Burned Area Emergency Rehabilitation (BAER) teams using remotely sensed data and field visits, often within several weeks of a fire (USDA 1995). Assessments that attempt to estimate conifer stand mortality may gather data immediately postfire or during the following year. Depending on timing, the assessment may occur before postfire flushing from surviving terminal buds is complete in mid- or late summer of the year after the fire in montane forests (Thode 2005, Miller and Thode 2007). Many trees in high-intensity burns have extensive crown scorch, yet there are few studies that have followed these trees through several growing seasons, especially for large, mature conifers.

Rules for identifying postfire dead or dying trees are largely based upon data sets using smaller trees (generally ≤50 cm in diameter at breast height (dbh)) (see, e.g., Stephens and Finney 2002, Hull Sieg *et al.* 2006) and destructive cambial sampling (Hood *et al.* 2007). One recent study of postfire survival among ponderosa pine (*Pinus ponderosa* Dougl. ex. Laws) in Arizona involved mature trees (McHugh and Kolb 2003), but there are few studies examining factors influencing postfire survival among large conifers in the Sierra Nevada. The importance or frequency of postfire flushing in the year following a fire has not been studied for conifers with high or complete initial crown scorch. Trees with complete crown scorch (no green foliage immediately postfire) are often excluded from postfire conifer survival studies or assumed dead (Kobziar *et al.* 2006). However, a recent study in the Sierra Nevada found high survival in moderate and high-intensity burn patches for one species, white fir (*Abies concolor* (Gord. & Glend.) Lindl.), when trees were >50 cm in diameter (Hanson and North 2006). Flushing was not apparent until the second or third growing season following fire, and was the result of epicormic branching. If flushing does occur, fire severity assessments will tend to overestimate mortality and postfire salvage could remove large trees that appear dead but are not.

The goal of our research was to identify fire damage and tree characteristics useful for modeling postfire flushing for three common species of Sierran conifers: ponderosa pine; Jeffrey pine; and red fir. We focused on areas where crown scorch was complete (100% [no green foliage]; pines) or nearly so (≥85%; red fir). We did not include trees in areas affected by crown fire (generally, trees that had most or all of their crown foliage consumed [i.e., incinerated by flames, as opposed to foliage being killed by radiant heat from high-intensity surface fire]) because there are no studies of which we are aware that have found survival when a tree crown is consumed. The objectives of our study were to evaluate the following: 1) of the trees presumed dead upon initial postfire evaluation (i.e., 100% crown scorch for pines, ≥85% crown scorch for red fir), what proportion flush and remain alive at 3-4 years postfire? and 2) which tree or fire characteristics (diameter, bole char, crown scorch or kill, crown consumption) most effectively predict a tree's postfire status (flushed and alive versus dead)? The accuracy of stand- and landscape-level fire severity assessments may be improved if crown and bole characteristics associated with postfire conifer flushing and survival can be identified.

Methods

Study Sites

We sampled trees in two study areas: the 2003 Tuolumne fire in Yosemite National Park (approximately 1,500 ha) in the central Sierra Nevada, and the 2002 McNally fire in Sequoia National Forest (60,750 ha) in the southern Sierra Nevada (Figure 1). Both fires occurred during the summer, and were of mixed severity, with high-severity (high or complete tree mortality) patches in a mosaic of low- and moderate-severity effects.

The two study sites (one ponderosa pine site and one Jeffrey pine site) within the McNally fire were limited to a section of roadway along which initial crown scorch (prior to flushing) was assessed by the U.S. Forest Service. Their assessment focused on identifying roadside hazard trees using a criteria of 100% initial crown scorch (no green foliage) for trees located within approximately 50 m of the road. All such trees were marked for removal by agency staff. Along this section of road, all areas dominated by ponderosa pine or Jeffrey pine with 100% initial crown scorch (no green foliage) and trees >25 cm dbh were included in this study. The study sites, which totaled approximately 80 ha, experienced high-intensity surface fire. We included all trees >25 cm dbh with 100% crown scorch. No red fir sites were located in the McNally fire.

In the Tuolumne fire area, prior to the first postfire growing season, we identified red fir with high (≥85%) to complete initial crown scorch. Matching our selection criteria in the McNally fire, we did not include areas with low- or moderate-intensity surface fire, which were dominated by trees with high levels of remaining green crown, or sites that experienced crown fire, which were dominated by trees with complete consumption of crown foliage. Within the site, which totaled approximately 45 ha, we included all trees >25 cm dbh with crown scorch of 85% or greater.

Measurements

We tagged trees in each study site and monitored them for three or four years postfire.

We measured the following variables as potential predictors of postfire survival based upon previous research in western U.S. conifer forests (Peterson and Ryan 1986, Ryan and Reinhardt 1988, Stephens and Finney 2002, McHugh and Kolb 2003, van Mantgem *et al.* 2003):

1) Diameter at breast height (dbh) (cm): Diameter at breast height was measured (to the nearest .5 cm) for each tree. We analyzed dbh as a continuous variable in logistic regression.

2) Percent crown volume killed ("crown kill"): Crown kill, as defined in this study, includes the portion of the pre-fire crown that is killed by fire (brown needles killed by radiant heat, with no surviving buds) and the portion consumed (black needles directly affected by flames). This variable is difficult to measure with precision, and usually is determined visually. Estimates must be made at least one year postfire to account for any flushing of foliage (from surviving terminal buds) occurring in the first growing season following the fire. In an effort to standardize estimates, our procedure was to visually estimate the number of times the remaining green crown volume would fit within the killed portion of the crown volume, then placing each tree into the appropriate crown kill category (e.g., 60-69.9, 70-79.9, 80-89.9, 90-94.9, 95-99.9, and 100% crown kill). For example, if the green crown volume would spatially "fit" within the killed crown volume approximately three times, the tree had 70-79.9% crown kill, since the green crown was approximately one-fourth of the total crown volume. We made visual estimates on both sides of each tree to improve accuracy. We assigned trees on the boundary between two crown kill categories to the lower category.

3) Percent crown volume scorch ("crown scorch"): We used the same method to estimate crown scorch as described above for crown kill. We measured crown scorch before the first season of foliage production after a fire to determine the difference in green crown volume between

pre- and post-flushing. As defined in this study, crown scorch includes the portion of the crown in which foliage was killed (brown needles) but not terminal buds, the portion of the crown in which foliage and terminal buds were killed by radiant heat (brown needles), and the portion consumed (black needles, no surviving terminal buds) (Fig. 2). For the purposes of logistic regression analysis, we used the midpoint of each category (e.g., 75% for the category 70-79.9%).

4) Crown consumption: This is defined by the percent of total tree height with incinerated foliage (needles and small twigs consumed, blackened branches), and is expressed as the total tree height divided by the maximum height of complete foliage incineration (0-19, 20-39, 40-59, 60-79, or 80-100% of total tree height). For the purposes of logistic regression analysis, we used the midpoint of each category.

5) Bole char: This is a composite of the amount and severity of bole char. Trees were categorized as having low bole char if they had <0.2 cm char depth (where char includes only blackened material, not discolored or "cooked" bark or cambium underneath the char) completely around the tree circumference, or a mixture of <0.2 cm and 0.2-1.0 cm char depth around the tree circumference. Trees were defined as having medium bole char if they had 0.2-1.0 cm char depth completely around the tree circumference, or >1.0 cm char depth on >50% of tree circumference. Trees had high bole char if char depth was >1.0 cm around the entire tree circumference. We took bole char measurements in each of four quadrants on each tree at a height of approximately 1 m. We measured char depth by using a knife to scrape away the char, after which we measured the depth of the cut required to find no more char.

For the purposes of logistic regression analysis, we assigned the values 1, 2, and 3 to low, medium, and high bole char, respectively.

Data analysis

To analyze whether dbh category was associated with survival of pines with 100% initial crown scorch, we used a Chi-square test of independence. We used logistic regression to analyze all other conifer survival data, with live/dead as the dependent variable. We used model selection and Akaike's Information Criteria (AIC) (Burnham and Anderson 2002) to identify predictor variables to include in the logistic regression analysis. All independent variables and their interactions were added to the model, and then terms were dropped if their C_p statistic (the likelihood version of AIC in S-PLUS) was lower than the C_p statistic for the null model. We used the Hosmer-Lemeshow goodness of fit test to assess the fit of final models to the data, where a good fit is indicated by non-significance ($P > .05$) (van Mantgem *et al*. 2003, Thies *et al.* 2006). We evaluated each model using a jackknife procedure to determine the percentage of correct live/dead classifications. We used S-Plus (S-Plus 2001) for all data analyses.

Ponderosa and Jeffrey pine

In the ponderosa and Jeffrey pine study sites within the McNally fire area, the U.S. Forest Service had marked, adjacent to roads, all trees with 100% initial crown scorch a few months after the fire occurred, prior to the first postfire growing season. Trees so marked were scheduled for removal as roadside hazard trees, but actual felling and removal did not occur until after the first postfire growing season in the year after the fire. Trees that flushed, producing new green foliage, were un-marked prior to hazard tree operations, and were not felled. Our study site identification and data collection did not begin until several weeks after hazard tree felling. For felled trees, we estimated diameter at breast height by measuring stump diameter and subtracting 10%, based upon our observations in the study area of the ratio of diameter at breast height and diameter at stump height, similar to common U.S. Forest Service tree marking protocols in the Sierra Nevada. We monitored trees for four years postfire (Table 1).

We first analyzed four-year survival of all ponderosa and Jeffrey pine with 100% initial crown scorch (n = 354). Since this included trees which did not flush, and which were therefore felled and removed prior to data collection, the only variable that could be used was diameter at breast height. We used a Chi-square test of independence to determine whether dbh was a significant factor in determining survival of trees with 100% crown scorch, using dbh categories that track existing ones used by land managers in the Sierra Nevada for postfire salvage marking guidelines (25-49, 50-75, and >75 cm dbh).

We next analyzed four-year survival of the ponderosa and Jeffrey pine that not only had 100% initial crown scorch, but which also flushed in the year after the fire (n = 142). We analyzed the following independent variables: dbh; crown kill; crown consumption; and bole char. Three pines flushed, and were therefore not felled, but died in the brief period between felling and data collection, precluding an estimate of the extent of flushing. We excluded these trees from this analysis.

Red fir

All red fir (n = 57) were located within the Tuolumne fire (Table 1). Initial data was gathered in the year following the fire, but prior to flushing. We analyzed three-year survival of red fir, using the following independent variables: dbh; crown scorch; crown consumption; and bole char. We were able to analyze crown scorch for red fir because, unlike our data for ponderosa and Jeffrey pine, there was variance in crown scorch for red fir (all ponderosa and Jeffrey pine had 100% crown scorch).

Results

Ponderosa and Jeffrey pine

The C_p statistic for species, between ponderosa pine (n = 310) and Jeffrey pine (n = 44) with 100% initial crown scorch, was lower than the C_p statistic for the null model, and a Chi-square test found no significant difference in survival between the two species ($\chi^2_1 = 0.12$, $P = .722$). Accordingly, we analyzed these species together. In the McNally fire area, four-year postfire survival of ponderosa and Jeffrey pines with 100% initial crown scorch (n = 354) was 22% (47 of 215), 47% (51 of 108), and 58% (18 of 31) for trees 25-49, 50-75, and >75 cm dbh, respectively. Diameter at breast height was a significant predictor of survival ($\chi^2_2 = 32.41$, $P < .001$), with the larger trees surviving at higher rates.

Among ponderosa and Jeffrey pine with 100% initial crown scorch, and which flushed in the year following the fire (142 of the 354 analyzed above), 82% survived and were alive at four years postfire. The average extent of flushing among surviving pines was 30 percentage points (i.e., 0% green foliage initially to 30% green crown volume after flushing). The final model to predict survival of these trees included crown kill, crown consumption, and bole char (Table 2) (Hosmer-Lemeshow test, $\chi^2 = 7.42$, $P = .386$ [P-values >.05 indicate good model fit]). The C_p statistic for dbh was lower than the C_p statistic for the null model, so we did not include dbh in the logistic regression analysis. The final model had a max-rescaled R^2 value of .549. The model correctly predicted 88% of observed mortality.

Red fir

For red fir (n = 57), mean crown scorch was 90%, and overall survival was 44% at three years postfire. Trees >50 cm dbh had a mean crown scorch of 90%, and survival rate of 56% (22 of 39) at three years postfire. The average extent of flushing among surviving trees was 23% (Fig. 3). The final model to predict survival included dbh and bole char (Table 3) (Hosmer-Lemeshow test, $\chi^2 = 6.70$, $P = .461$). The C_p statistic for crown scorch was lower than the C_p statistic for the null model, so we did not include crown scorch in the logistic regression analysis. Crown consumption was included in the logistic regression analysis, but was not significant ($P = .998$). The final model had a max-rescaled R^2 value of .618. The model correctly predicted 83% of observed mortality.

Discussion

Postfire flushing was widespread among ponderosa pine, Jeffrey pine, and red fir, and survival was high, especially among larger trees. The majority of the large pines that had no green foliage after fire, and which appeared dead, nevertheless flushed and survived. Our results have important implications for postfire salvage logging. If land managers do not wait to determine the extent of postfire flushing in mid- or late summer of the year following the fire, intermediate and large trees that might otherwise survive could be felled because they appear to be dead. Moreover, if postfire flushing is not taken into account, the accuracy of fire severity estimates (both field-based and remote sensing) will be diminished. Assessments made prior to flushing will tend to overestimate the extent of high-severity effects.

Our findings are consistent with another study pertaining to flushing and survival of ponderosa pines with 100% crown scorch in Colorado (Harrington 1987). They are also consistent with survival estimates (~42%) for ponderosa pine approximately 50 cm dbh with 100% crown scorch in the Sierra Nevada (Stephens and Finney 2002). Neither of these studies, however, included large trees.

Hood *et al.* (2007) predicted far lower rates of survival for ponderosa and Jeffrey pine with 100% initial crown scorch; overall predicted survival of such trees was ~12%, and the range was ~5% to approximately ~37%, depending upon the level of cambial damage. This discrepancy could be in part due to destructive cambial sampling used by Hood *et al.* (2007), which may have influenced mortality. Although we found higher survival than Hood *et al.* (2007) there are several limitations to our design that may influence our results. We had a relatively small sample size from only two locations and sampling was restricted to a narrow subset of trees (e.g., ponderosa and Jeffrey pine with 100% scorch and red fir with 85% or greater scorch). We also did not sample in high-severity crown fire areas where foliage consumption is high. Future investigations with larger samples in other locations will facilitate more precise estimates of flushing and survival. Nevertheless, our results represent the first data on postfire flushing and survival of the large ponderosa and Jeffrey pines that can dominate overstory structure, and the first data on postfire flushing of red fir of any size.

In our results, postfire flushing was not limited to ponderosa and Jeffrey pine. Red fir with high crown scorch also flushed, and survival of such trees was high in the largest size class. We have not found any previous reports of postfire flushing in red fir with high levels of crown scorch in the scientific literature. In the Sierra Nevada, postfire crown reiteration through epicormic branching on the scorched portion of the bole has been found in white fir (Hanson and North 2006), though there are no reports of postfire flushing (i.e., new growth from surviving terminal buds in the scorched portion of the crown) among white fir. Conversely, while there are no reports of epicormic branching in red fir, the red fir in this study did exhibit flushing, reflecting different physiological responses to fire by these two fir species.

Diameter and bole char were generally significant factors associated with the survival of trees with high or complete crown scorch. Other studies, sampling trees with <100% initial crown scorch, have also found these factors to be significantly associated with postfire conifer survival (Stephens and Finney 2002, McHugh and Kolb 2003, Hull Sieg *et al.* 2006). Larger diameter trees have thicker, more fire-resistant bark, making them more resistant to cambial damage, which may minimize postfire stress (Peterson and Ryan 1986, Wyant *et al.* 1986). Larger diameter is also correlated with taller tree height, often providing a greater separation between surface fire and live crown base. A small tree would experience a greater proportion of crown loss compared to a large tree with a larger and longer pre-fire crown for an equivalent scorch height (Wyant *et al.* 1983, Wyant *et al.* 1986).

Tree diameter, however, was not associated with ponderosa and Jeffrey pine survival once trees flushed. Following flushing, percent crown kill, bole char, and crown consumption were significant predictive variables. These variables, or very similar ones, have been found to be important in other postfire conifer survival studies, with crown damage affecting a tree's capacity to produce photosynthate, and bole char potentially affecting the living cambial tissue needed to transport nutrients to support root structure (Peterson and Ryan 1986, Stephens and Finney 2002, McHugh and Kolb 2003). The significance of crown consumption may result from the effects of radiant or convection heating, where greater levels of heat reach the upper crown, killing not only needles but also terminal buds and increasing crown incineration (Peterson and Ryan 1986). We can only speculate as to why tree diameter was not a significant factor following flushing. We hypothesize that higher levels of stored photosynthate in larger trees may confer greater vigor, allowing more large trees to flush. Flushed tree survival, however, may be influenced by the future amount of photosynthate that can be produced from the remaining crown foliage and transported to the roots.

Management implications

Many of the pines in our study, which initially appeared to be dead (0% green foliage), flushed and survived. This may occur because foliage succumbs to radiant heat more readily than do protected terminal buds (Methven 1971, Peterson and Ryan 1986). Moreover, photosynthate production per unit area of crown foliage in the uppermost portion of the crown is about twice that of the lower crown (Helms 1970). This suggests pines can survive and flush even if all of the crown foliage is killed, as long as the terminal buds in the upper crown remain viable. In such an event, water demand will be reduced due to loss of lower and middle crown structure, while photosynthate production will see relatively smaller declines due to the survival of the most productive tissues (Wyant 1981, Stephens and Finney 2002).

The ability of large red fir, and ponderosa and Jeffrey pines, to flush and survive high or complete levels of crown scorch implies a need for caution in making early estimates of fire effects in large-diameter stands. To avoid overestimating high-severity effects, our study suggests remote sensing and field-based assessments of fire severity should be conducted after flushing is completed in the late summer of the year following the fire. Similarly, where managers seek to remove roadside hazard trees along popular recreation roads, as was the case in our McNally fire study sites, early severity estimates (i.e., before completion of the following year's growing season) may lead to needless felling of many large, old trees based upon the erroneous assumption that they are dead. Our data strongly suggest assessments of postfire mortality be postponed until the passage of one postfire growing season. Additional study is needed to more completely determine the degree of flushing and survival in a variety of site conditions for ponderosa and Jeffrey pines, and red fir.

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References

Burnham KP, Anderson DR (2002) Model selection and inference: A practical information-theoretic approach. Springer-Verlag, New York, NY.

Donato DC, Fontaine JB, Campbell JL, Robinson WD, Kauffman JB, Law BE (2006) Post-wildfire logging hinders regeneration and increases fire risk. *Science* **311**, 352.

Harrington MG (1987) Ponderosa pine mortality from spring, summer, and fall crown scorching. *Western Journal of Applied Forestry* **2**, 14-16.

Hanson CT, North MP (2006) Post-fire epicormic branching in Sierra Nevada *Abies concolor* (white fir). *International Journal of Wildland Fire* **15**, 31-35.

Hanson CT, North MP (2008) Postfire woodpecker foraging in salvage-logged and unlogged forests of the Sierra Nevada. *The Condor* **110**, 777-782.

Helms JA (1970) Summer photosynthesis of ponderosa pine in its natural habitat. *Photosynthetica* **4**, 234-253.

Hood SM, Smith SL, Cluck DR (2007) Delayed conifer tree mortality following fire in California. U.S. Forest Service, General Technical Report PSW-GTR-203.

Hull Sieg C, McMillin JD, Fowler JF, Allen KA, Negron JF, Wadleigh LL, Anhold JA, Gibson KE (2006) Best predictors for postfire mortality of ponderosa pines trees in the intermountain west. *Forest Science* **52**, 718-728.

Hutto RL (2006) Toward meaningful snag-management guidelines for postfire salvage logging in North American conifer forests. *Conservation Biology* **20**, 984–993.

Karr JR, Rhodes JJ, Minshall GW, Hauer FR, Beschta RL, Frissell CA, Perry DA (2004). Postfire salvage logging's effects on aquatic ecosystems in the American West. *BioScience* **54**,1029-1033.

Kobziar L, Moghaddas J, Stephens S (2006) Tree mortality patterns following prescribed fires in a mixed conifer forest. *Canadian Journal of Forest Research* **36**, 3222-3238.

Lindenmayer DB, Foster DR, Franklin JF, Hunter ML, Noss RF, Schmeigelow FA, Perry D (2004) Salvage harvesting policies after natural disturbance. *Science* **303**,1303.

McHugh CW, Kolb TE (2003) Ponderosa pine mortality following fire in northern Arizona. *International Journal of Wildland Fire* **12**, 7-22.

Methven IR (1971) Prescribed fire, crown scorch and mortality: field and laboratory studies on red and white pine. Canadian Forestry Service Information Report PS-X-31. Petawawa Forest Experiment Station, Chalk River, Ontario.

Miller JD, Thode AE (2007) Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). *Remote Sensing of Environment* **109**, 66-80.

Noss RF, Franklin JF, Baker WL, Schoennagel T, Moyle PB (2006) Managing fire-prone forests in the western United States. *Frontiers in Ecology and Environment* **4**, 481–487.

Peterson DL, Ryan KC (1986) Modeling postfire conifer mortality for long-range planning. *Environmental Management* **10**, 797-808.

Ryan KC, Reinhardt ED (1988) Predicting postfire mortality of seven western conifers. *Canadian Journal of Forest Research* **18**, 1291-1297.

S-Plus (2001) S-Plus 6 for Windows. Insightful Corporation. Seattle, WA.

Smucker KM, Hutto RL, Steele BM (2005) Changes in bird abundance after wildfire: importance of fire severity and time since fire. *Ecological Applications* **15**, 1535-1549.

Stephens SL, Finney MA (2002) Prescribed fire mortality of Sierra Nevada mixed conifer tree species: effects of crown damage and forest floor combustion. *Forest Ecology and Management* **162**, 261-271.

Thies WG, Westlind DJ, Loewen M, Brenner G (2006) Prediction of delayed mortality of fire-damaged ponderosa pine following prescribed fires in eastern Oregon, USA. *International Journal of Wildland Fire* **15**, 19-29.

Thode AE (2005) Quantifying the fire regime attributes of severity and spatial complexity using field and imagery data. Ph.D. Dissertation. Davis (CA): University of California.

USDA (1995) Forest Service Handbook 2509. USDA Forest Service, Washington, D.C.

van Mantgem PJ, Stephenson NL, Mutch LS, Johnson VG, Esperanza AM, Parsons DJ (2003) Growth rate predicts mortality of *Abies concolor* in both burned and unburned stands. *Canadian Journal of Forest Research* **33**, 1029-1038.

Wyant JG (1981) Fire effects on tree growth and mortality in a ponderosa pine-Douglas-fir ecosystem. M.S. Thesis, Colorado State University, Fort Collins.

Wyant JG, Laven RD, Omi PN (1983) Fire effects on shoot growth characteristics of ponderosa pine in Colorado. *Canadian Journal of Forest Research* **13**, 620-625.

Wyant JG, Omi PN, Laven RD (1986) Fire induced tree mortality in a Colorado ponderosa pine/Douglas-fir stand. *Forest Science* **32**, 49-59.

Figure Captions

Figure 1. The McNally fire and Tuolumne fire study areas.

Figure 2. Crown scorch, crown kill, and crown incineration.

Figure 3. Red fir (Tuolumne fire) pre-flush (A) and post-flush (B).

Tables

Table 1. Characteristics of study trees in the McNally and Tuolumne fire areas (values in parentheses are standard deviations).

Species[A]	dbh category (cm)	n	Number flushed[B]	Number survived[C]	Mean dbh (cm)	Mean crown scorch	Mean crown kill[D]	Mean crown consump.	Mean bole char
PIPO (n=310)	25-49	190	54	41	40.9 (5.8)	100 (0)	80.1 (17.4)	24.4 (15.7)	2.6 (0.5)
	50-75	95	50	44	61.0 (5.7)	100 (0)	67.2 (19.1)	21.6 (11.5)	2.7 (0.5)
	>75	25	16	15	86.4 (8.8)	100 (0)	56.3 (24.5)	22.5 (12.4)	2.4 (0.7)
PIJE (n=44)	25-49	25	11	6	40.1 (6.2)	100 (0)	94.1 (2.3)	20.9 (10.4)	2.3 (0.5)
	50-75	13	8	7	58.6 (6.7)	100 (0)	85.3 (7.3)	17.5 (10.4)	2.1 (0.4)
	>75	6	3	3	100.3 (12.1)	100 (0)	75.0 (10.0)	10.0 (0)	2.0 (0)
ABMA (n=57)	25-49	18	2	3	40.7 (6.0)	90.4 (5.6)	67.5 (21.7)	15.6 (9.2)	2.3 (0.8)
	50-75	17	7	8	61.9 (6.8)	89.4 (5.3)	63.8 (16.4)	12.4 (6.6)	2.4 (0.8)
	>75	22	13	14	97.8 (17.2)	89.8 (4.9)	67.1 (15.3)	19.1 (18.2)	2.5 (0.7)

[A] PIPO = ponderosa pine, PIJE = Jeffrey pine, and ABMA = red fir.
[B] For red fir, we gathered pre-flush data in 2004 and post-flush data in 2006, but were unable to gather data in 2005. Thus, the total number of red fir that flushed is unknown, since some may have flushed in the summer of 2004 (after our initial data collection) but could have died in 2005.
[C] For red fir, in each of the three dbh categories all of the surviving trees flushed except one.
[D] For red fir, crown kill data pertains only to trees alive as of 2006, since no data was gathered in 2005 for this species.

Table 2. Logistic regression summary for survival of ponderosa and Jeffrey pines >25 cm dbh that flushed after having 100% initial crown scorch, McNally fire (n = 142).

Variable	Coefficient	SE	*P*-value
crown kill	-0.166	0.044	$P < .001$
bole char	-2.239	0.773	$P = .004$
crown consumption	-0.061	0.023	$P = .008$
intercept	23.082	5.035	$P < .001$

Table 3. Logistic regression summary for survival of red fir >25 cm dbh with ≥85% crown scorch (mean crown scorch = 90%), Tuolumne fire (n = 57).

Variable	Coefficient	SE	*P*-value
bole char	-2.869	.779	P < .001
dbh	0.056	0.018	P = .002
intercept	2.744	1.648	P = .096