

One-Year Postfire Mortality of Large Trees in Low- and Moderate-Severity Portions of the Star Fire in the Sierra Nevada¹

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Abstract

Following the Star Fire, 287 trees greater than or equal to 75 cm diameter at breast height (DBH), were tracked for post-fire mortality. The Star Fire, located in the western Sierra Nevada, burned mostly at low to moderate intensity during late summer of 2001. The mixed conifer forest was dominated by *Psuedotsuga menziesii* (Douglas-fir), *Abies concolor* (white fir), *Pinus labertiana* (sugar pine), and *Libocedrus decurrens* (incense cedar). Several *Pinus jeffreyi* (Jeffrey pine) and *P. ponderosa* (ponderosa pine) were also sampled. Trees were measured for crown length, height of crown scorch, live crown height, and bole scorch within several weeks of the fire in the fall 2001. Species, DBH, and location of each tree were recorded. After 1 yr, 92 percent of the trees were still alive, although 8 percent appeared in poor condition. Four percent had died and were standing and a little over 1 percent had died and fallen. Two percent were cut as hazard trees. These mortality rates were compared with those predicted in the U.S. Department of Agriculture (USDA), Forest Service's fire model, First Order Fire Effects Model (FOFEM). Logistic regression was used to develop models to predict probability of mortality. Independent variables were DBH, percent live crown height, percent live crown volume, and species. For all species, percent live crown height was the best predictor of mortality. Results for individual species varied. Percent live crown height was the best predictor of mortality for Douglas fir, live crown height was the best predictor of mortality for white fir, and percent live crown volume was the best predictor of mortality for Sugar pine.

Introduction

In order to plan post-fire management after both wildfires and prescribed burns, managers need to be able to predict fire-induced tree mortality rates. Past research has demonstrated strong relationships between fire mortality and tree characteristics such as proportion of live crown killed or scorched by fire (Ryan 1982, Ryan and others 1988, and Peterson 1985). Bark thickness has also been found to be an important correlate with fire-induced mortality (Ryan and Reinhardt 1988). Mortality rates can vary among species and among regions. Pacific Northwest conifer species have been ranked according to their fire resistance based on differences in bark thickness, rooting depth, and crown form and development (Brown and Davis 1973, Minore 1979).

California sites and species are underrepresented in commonly used models that predict fire mortality. There is great interest in mortality of large and old trees from wildfires and prescribed burns due to their importance to key wildlife species and old growth forests, yet few studies have focused on these trees. The Star Fire burned

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16,800 ac on the Tahoe and Eldorado National Forests in California (*fig. 1*), within the western Sierra Nevada Mountain Range, late summer of 2001. Fire intensities ranged from high to moderate and low. The objectives of this study are to 1) determine post-fire mortality rates in large trees (≥ 76 cm diameter at breast height-DBH) in areas burned at low to moderate intensity; and 2) develop statistical models to predict post-fire mortality from fire damage to crown, species, and diameter.

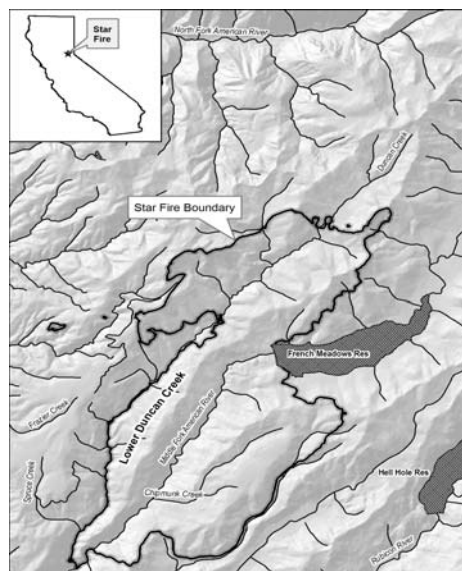


Figure 1—Project Location in California.

Methods

We made a complete census of large trees (≥ 76 cm DBH) across a portion of the Star Fire. The lower portion of Duncan Canyon, which burned primarily at moderate to low intensities, was the focus landscape area (*fig. 1*). In early fall 2001, shortly after the fire, 287 trees were tagged, mapped (using Global Positioning System (GPS)), and crown damage, species, and size of trees recorded. The mixed conifer forest is located west of Lake Tahoe and was dominated by *Psuedotsuga menziesii* (Douglas-fir), *Abies concolor* (white fir), *Pinus labertiana* (sugar pine), and *Libocedrus decurrens* (incense cedar). Only two *Pinus jeffreyi* (Jeffrey pine) and three *P. ponderosa* (ponderosa pines) were sampled; therefore, these individuals were only included in the analysis that addressed all species. Mortality rates of other species were considered both together and separately.

Initially, we measured crown length, height of crown scorch, and bole scorch using an Impulse Laser apparatus. Species, DBH, and location of each tree were recorded. One year later, we visited each tree again and recorded its status as dead or alive.

Tree crown volumes were calculated based on crown height and crown width (measured along two axes). We assumed crown shape was a truncated ellipse (volume= $0.75 \cdot \text{height} \cdot \text{PI} \cdot r^2$) for all species except sugar pine, which we assumed had a general cylinder form (volume= $\text{height} \cdot \text{PI} \cdot r^2$; Van Pelt and North 1996, 1999). Percentage of live crown volume was calculated as the ratio of calculated live over

calculated total crown volume (based on field measurements of total height, scorch height, and radius) times one hundred.

We performed binary logistic regressions to determine the relationship between mortality and the dependent variables percent live crown volume, percent live crown height, species, and DBH. Autocorrelation among variables was tested prior to analyses. A maximum likelihood fitting procedure was applied to estimate coefficients of the linear predictor, and fitted values were back-transformed via the logit link to predict the probability of mortality. Mortality was coded as 1 (dead) or 0 (alive). Statistical Package for the Social Science (SPSS) 10.0 for Microsoft Windows was used for all data analyses.

Results and Discussion

The descriptive statistics for trees greater than or equal to 76 cm DBH were measured shortly after the Star Fire (*table 1*). Data from the trees sampled, by species, were used to calculate group means and standard errors for DBH, meter and percentage of live crown height, and meter and percentage live crown volume. All trees measured were within low to moderate fire intensities from the Star Fire.

Table 1—Descriptive statistics for trees (≥ 76 cm DBH) in the study area within the Star Fire, Tahoe National Forest. Measurements are of group means and standard errors.

| Species | No. of trees | DBH (cm) | Live crown | | Pct live crown | |
|---------------|--------------|-------------|------------|--------------------------|----------------|------------|
| | | | Height (m) | Volume (m ³) | Height | Volume |
| White fir | 81 | 96.1 + 2.2 | 17.7 + 1.1 | 597.4 + 54.6 | 63.2 + 3.4 | 49.1 + 4.0 |
| Incense cedar | 37 | 98.4 + 2.7 | 10.0 + 1.0 | 252.5 + 38.3 | 55.1 + 5.9 | 43.0 + 6.3 |
| Sugar pine | 106 | 117.4 + 2.9 | 17.6 + 0.9 | 1998.2 + 210.8 | 68.1 + 3.2 | 43.0 + 2.9 |
| Douglas fir | 58 | 97.3 + 2.0 | 17.2 + 1.4 | 1067.7 + 128.4 | 67.7 + 4.8 | 59.1 + 5.5 |

Mortality Rates

After one year, most of the trees had survived the low to moderate intensity fire in this portion of the Star Fire (*table 2*). Ninety-two percent of trees were still alive, although 8 percent appeared in poor condition. Four percent had died and were standing and a little more than one percent had died and fallen. Two percent were cut as hazard trees.

Table 2—Mortality numbers and percentages of dead trees ≥ 76 cm DBH 1 yr following low to moderate fire in northern Sierra Nevada mixed conifer forest.

| Species | No. of trees alive (dead) | Pct mortality |
|---------------|---------------------------|---------------|
| White fir | 79 (2) | 2.5 |
| Incense cedar | 34 (3) | 8.1 |
| Sugar pine | 100 (6) | 5.7 |
| Douglas-fir | 54 (4) | 6.9 |

Predictive Mortality Models

Based on the logistic regressions run, significant ($p < 0.05$) models were identified for all species combined and for sugar pine, Douglas-fir, and white fir species independently. None of the variables measured were significantly related to incense cedar mortality. Independent variables with the best fit are presented in *table 3*. Based on the models, percentage of live crown height, crown height, and percentage of live crown volume were the best indicators of tree mortality. Although DBH has been found to be a significant variable by others (e.g., Mutch and Parsons 1998), it was not found to be true in this data set, perhaps due to the restricted range of tree sizes included in this study.

After the Star Fire, remaining live tree crown heights ranged from 0 to 100 percent of total crown height. Predicted probability of mortality never exceeded 40 percent in any of the four models (*fig. 3*), regardless of the amount of remaining live crown. This is a reflection of the very low mortality rates observed in the field for all species one year following the fire. For three of the four species models, live crown height (either percentage of or actual) was used as the independent variable to predict probability of mortality. Similarly, Bevins (1980) used scorch height to predict mortality in Douglas-fir trees following fire. However, few others have reported live crown height as an effective predictor variable for post-fire tree mortality. The sugar pine model was the only one for which live crown volume was the best predictor variable for tree mortality. Others have also found percentage of crown scorch volume to be the best predictor variable (Wagener 1961, Methven 1971, Dieterich 1979, Peterson 1983, Mutch and Parsons 1998). One possible reason for the difference in significant variables among species could be the accuracy of volume estimates among species. Peterson (1985) found that calculated crown volumes were more accurate for species classified as having cylindrical (e.g., sugar pine) rather than paraboloid or cone crown shapes (e.g., the other species in this study).

Table 3—Logistic regression parameters for models with all species and individual species. Only parameters that were significant predictors of mortality are included.

| Model | Variable | Estimated regression coefficient | Wald χ^2 | Sig. |
|---------------------|-----------------------|----------------------------------|---------------|--------|
| All species (n=287) | pct live crown height | 0.966 | 18.271 | <0.001 |
| Sugar pine (n=106) | pct live crown height | 1.158 | 4.678 | <0.001 |
| Douglas fir (n=58) | pct live crown height | 0.971 | 4.262 | 0.039 |
| White fir (n=81) | live crown height | 0.787 | 4.813 | 0.028 |

[†]The exp (B) reflects the change in odds of the dependent variable (e.g., tree mortality) for a unit change in the independent variable (e.g., pct live crown height).

The odds ratio (exp (B); Hosmer and Lemeshow 2000) for percentage of live crown volume in the sugar pine model indicates a rapid increase in predicted probability of mortality with every unit decrease in percentage of live crown volume below 20 percent (*table 3, fig. 3b*). The odds ratios for the other models are not as high as that for the sugar pine (*table 3*). Results from the white fir model similarly indicate that a possible threshold exists for the amount of scorch damage a crown can sustain and survive. The predicted probability of mortality for white firs, with less than 10 m of live crown remaining, increases rapidly for every unit decrease in remaining live crown height (*fig. 3d*). The more rapid predicted mortality response in the sugar pine and white fir could reflect these species' greater sensitivity to fire than

Douglas-fir or ponderosa and Jeffrey pine (Minore 1979). Similar thresholds are not indicated from the Douglas-fir model; instead this model suggests a fairly steady increase in predicted probability of mortality for every unit decrease in percentage of live crown height (*fig. 3c*). Data collected on tree mortality on these sites in coming years will be important in determining longer term mortality response.

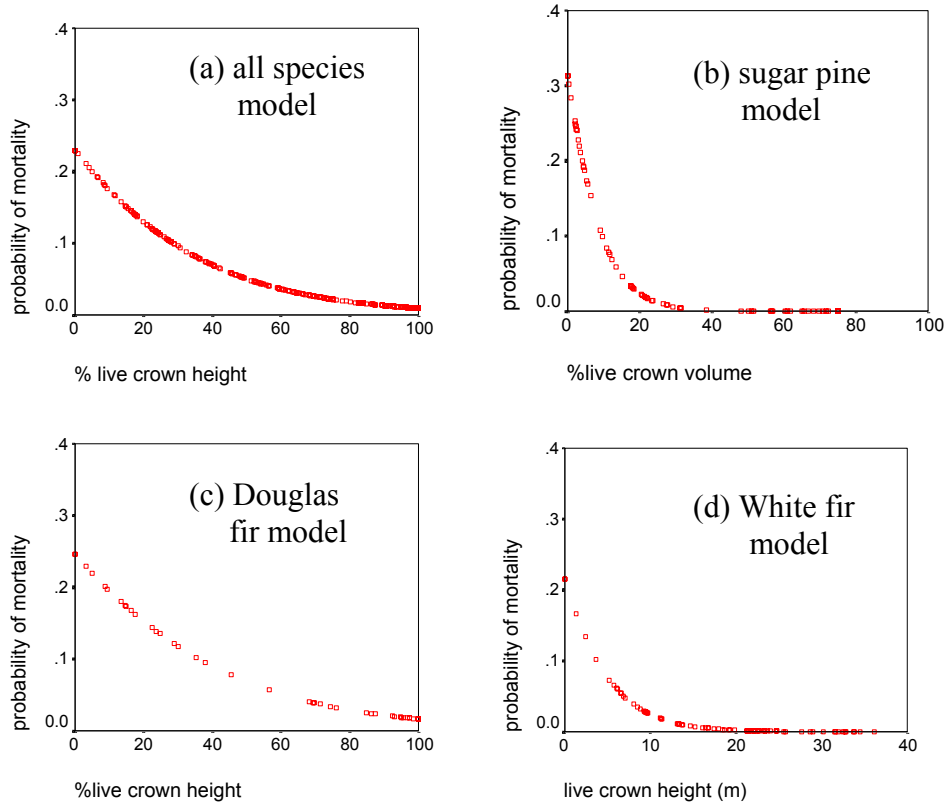


Figure 3—Scatter plots of model-predicted mortality and live crown volume or height. The best predictor variables varied based on which species were included in the model.

Conclusions

Models predicting mortality rates among conifer species in the Sierra Nevada can be used to develop silvicultural prescriptions related to prescribed burns, and can be used to mark high-risk trees for salvage directly after wildfires or prescribed burns. Variations among species and geographic location affect mortality from fires. Empirical data that covers a range of species, sizes, and physical settings should be used to develop models that advise management decisions. In this study, post-fire mortality rates among three conifer species common to mixed conifer forests of the California Sierra Nevada were significantly related to percent live crown height and percent live crown volume.

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