The Post-Burning Response of Bark Beetles to Prescribed Burning Treatments

David J. Ganz[1], Donald L. Dahlsten[1], and Patrick J. Shea[2]

Abstract—*Ecologists and fire scientists have recommended reintroducing fire in fire-dependent ecosystems to achieve the twin goals of restoring pre-settlement forest conditions and reducing catastrophic fire risk (McKelvey 1996, Parsons 1995). Early work by forest entomologists (Miller 1927, Miller 1960; Rasmussen et al. 1996, Salman 1934) established a direct relationship between fire injury and subsequent insect attack in burned-over areas. Initial concern has centered on the primary tree killers* Dendroctonus *spp. and* Scolytus ventralis *LeConte. This research is also finding that* Dendroctonus valens *and* Ips pini *are causing tree mortality with both fall and spring prescribed burns. Post-burning bark beetle induced mortality can be quite significant as demonstrated by two case studies presented here from Lassen Volcanic National Park and Spooner Summit, Lake Tahoe Basin Management Unit. From these two sites, inferences are made on the effect of seasonality for predisposing trees to particular bark beetles. In comparing these two populations, there was no significant difference in the mean number of trees killed by insects in each seasonal window. As case studies, not enough replicates existed to merit a more rigorous analysis. As such, management implications of post-burning bark beetle response are discussed given the information available on fire-insect interactions during these two seasonal windows.*

Introduction

Bark beetles are recognized as a significant factor in California forest ecosystems (Bradley and Tueller 2001, Mutch 1994). Susceptibility of forest stands to bark beetle attack has increased through combined effects of climate change, past forest management, fire suppression, drought, and other pests. The accelerated use of prescribed fire in California ecosystems may or may not alleviate these conditions. Hence, an increased comprehension of fire-insect interactions is necessary for more effective science-based management of forest ecosystems (McCullogh et al. 1998).

Fire may increase the risk of tree mortality from bark beetles by compromising tree defenses against beetles (Geiszler et al. 1984). Charring of the lower bole may damage the tree's vascular cambium, and provide large areas for bark beetle attack by rupturing the resin ducts that help defend pines from attack. Bark beetles, which bore through the tree's outer bark to feed and reproduce within the phloem, are inhibited by oleoresin, resulting in negative relationships between resin production and beetle attack success (Coyne and Lott 1976). Oleoresin is produced by specialized epithelial cells within the xylem and stored within vertical resin ducts in the xylem and in bark resin canals. As a result of heat trauma to these tissues, oleoresin production and defense may be reduced in the lower bole. Alternatively, it has been suggested that some trees which have a long evolutionary history of interactions with fire and bark beetles respond to fire with increases in resin flow to counteract the increased risk of bark beetles (Feeney et al. 1998). Contrary to earlier

[1]Department of Environmental Science, Policy and Management, University of California, Berkeley, CA.
[2]USDA Forest Service, Pacific Southwest Research Station, Davis, CA.

works, it has been reported that increased resin flow does not necessarily result in a decrease in insect activity following fire (Santoro et al. 2001).

Prescribed fire treatments applied in the spring and fall in immature ponderosa pine stands have resulted in significantly different mortality (Harrington 1993). Fires were ignited in the late spring, midsummer, and autumn. Mortality of trees scorched in the spring and summer was about 2.5 times greater than the autumn for similar crown damage. Most trees greater than 18 cm diameter at breast height (dbh) survived injury even with greater than 90% crown scorch. Following spring and summer injury, trees smaller than 10 cm dbh with greater than 50% crown scorching died, but about 90% crown scorch was required to kill large trees. Differences in mortality within the two seasonal windows are likely due to contrasts in physiological activity and to carbohydrate storage (Harrington 1993). Physiological activity was greatly reduced at the time of autumn burns in response to short day lengths, cool air, and cool soil temperatures (Fritts 1976, Kozlowski et al. 1991). Dormant protected buds are likely to survive within scorched crowns and will produce new foliage the following spring (Ryan 1990).

The best indicator of crown injury appears to be the proportion of the crown scorched or killed by fire (Peterson 1985, Ryan 1982, Ryan et al. 1988, Ryan and Reinhardt 1988, Wagener 1961). Empirical evidence has shown that over a wide range of conditions, mortality increases with the square of the fraction of the crown killed (Ryan 1990). Other factors that can be used in mortality prediction modeling include dbh, species, scorch height, bark char height, and local fuel consumption.

Objectives of Study

The Forest Service is looking to use prescribed fire as a tool to reduce the fire hazard and improve the physiological condition of the ecosystem. Jack Ward Thomas, former Chief of the USDA Forest Service, asked the agency to "increase mechanical and prescribed fire treatments to 3,000,000 acres per year in fire dependent ecosystems by the year 2005" (Thomas 1995). The National Fire Plan has since stated that Federal agencies will "jointly develop programs to plan, fund, and implement an expanded program of prescribed fire in fire-dependent ecosystems."[1] This policy has led to a significant scientific commitment to understanding the impacts of prescribed fire operations.

The purpose of this paper is to compare the extent of tree mortality and bark beetle-induced mortality from two different prescribed fires used in the fall and spring burning windows. The goal is to provide forest managers in this region with an idea of the severity of tree mortality associated with prescribed fires burned under two cases with some similarities in environmental and fuel conditions. In addition, management implications of post-burning bark beetle response are discussed given the information available on fire-insect interactions during these two seasonal windows.

Study Sites

Lassen Volcanic National Park Roadside Unit Spring Burn

The Lassen Volcanic National Park Roadside burn is located 18 km from Manzanita Lake, about 100 m from Lost Creek Campground. The exact

[1] National Fire Plan Website http://www.fireplan.gov/.

location within the park is T. 31 N., R. 4 E., Sec. 10, NE ° (figure 1). The Roadside burn is 102 acres and includes all aspects at elevations of 1725-1798 m (5660-5900 ft).

The objectives of the spring burn were to reduce hazard fuels, monitor fire effects, and restore fire as a natural process. In addition, the hope was to kill a large number of white firs to eventually initiate more pine regeneration. Two permanent square plots were set up using fuels sampling protocol in Western Region Fire Monitoring Handbook (1992). One plot is located in the white fir-dominated portion and the other in ponderosa pine-dominated portion of the spring burn. A total of 93 trees with permanent tags were revisited over the three years since 1999. In the fir-dominated plot, white fir represents at least 60% of the composition of overstory species. Other dominant trees are ponderosa pine, Jeffrey pine, and incense cedar. Sugar pine snags are located in the burn but only in small numbers and do not show up in overstory sampling. In the pine-dominated plot, the overstory species is predominantly ponderosa pine, and together with white fir, these two comprise 80% of the overstory with the remaining component incense cedar and Jeffrey pine.

The precipitation at Lassen Volcanic National Park falls primarily during November through May in the form of snow and rain. Annual air temperatures have an average 14˚C as the daily high and as the low as 0˚C. Annual

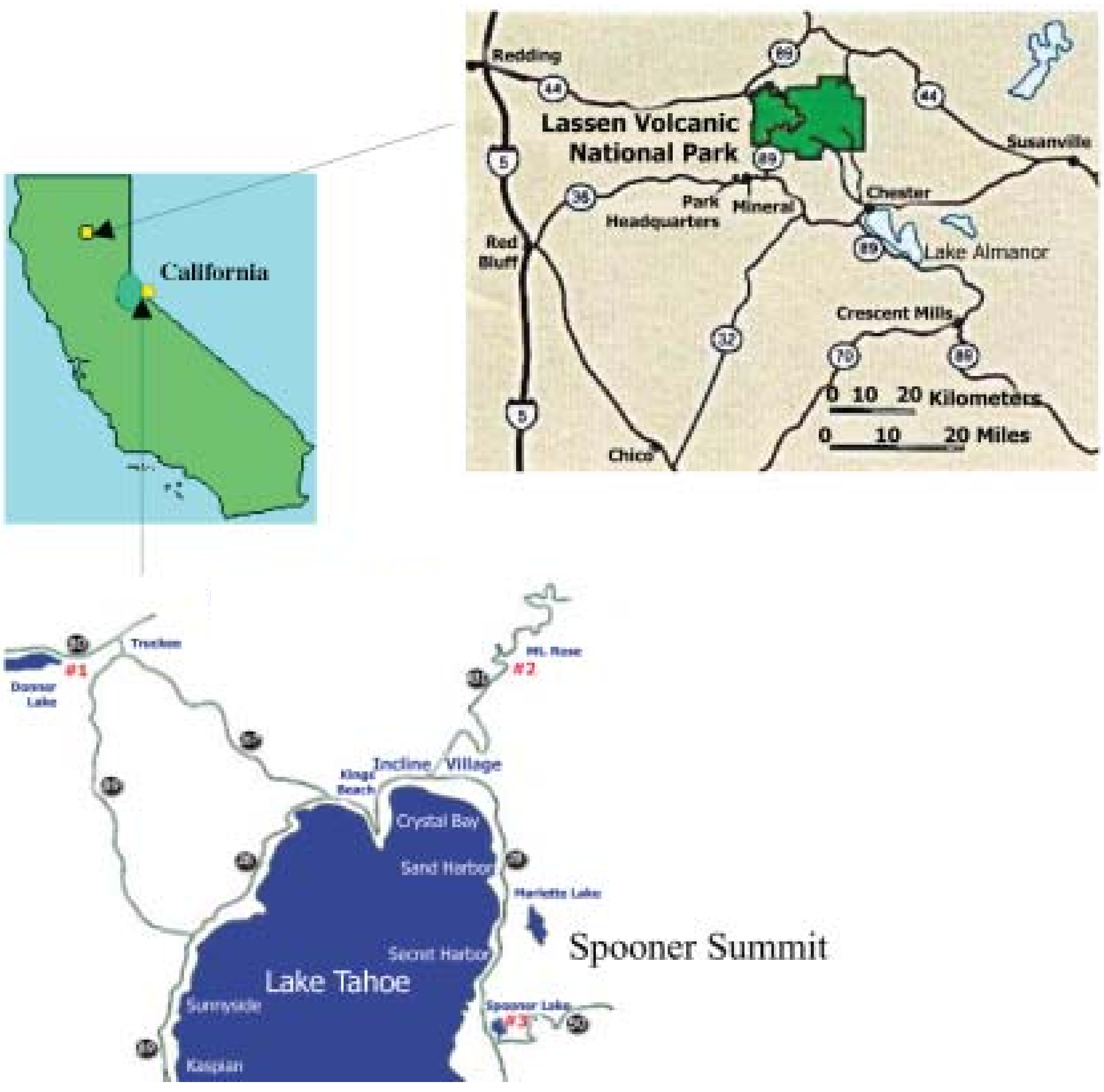

Figure 1—Site Locations within California.

total precipitation averages 1067 mm (42 in) per year and snowfall 4800 mm (188 in) per year (Manzanita Lake Weather Station 1949-2002). Relative humidity is fairly high in the spring (during the burning window), ranging from 25% to 85%.

Spooner Summit

Spooner Summit is located in the Lake Tahoe Basin Management Unit, approximately 35 km northeast of South Lake Tahoe (figure 1). Spooner Summit is a steep montane environment covering 50.6 hectares (125 acres) and ranging from 1981 to 2176 meters (6500-7140 ft). Spooner Summit makes up part of the Lake Tahoe's forests that were last cut 140 years ago to supply fuel and timbers for mining the Comstock Lode near Virginia City, Nevada (Taylor 1998). In the early 1900s, fire eradication on federal land became mandatory with state government following suit with the enactment of the California Forest Protection Act in 1905. The regrown forests are now 120 years old and are two to 10 times denser than the original forests (Taylor 1998). These trees now compete intensely for resources, especially water. Drought, combined with the absence of fire which thins forests, has predisposed the trees to bark beetle attack. Under such a scenario, thinning and the reintroduction of fire have been suggested.

In 1992, Forest Pest Management (of Region 5 of the Forest Service) initiated a study to evaluate the effectiveness of Jeffrey pine beetle suppression by comparing the number of trees killed by Jeffrey pine beetle in areas where infested trees were removed annually (treated areas) with the number of beetle-killed trees in areas where the infested trees were not removed (untreated areas). A summary of preliminary results to date indicate that, for selected areas in Lake Tahoe Management Unit between 1993 and 1995, mortality was reduced by 87% in the treated areas, and mortality in the untreated areas increased 182% (table 1). These findings led to the helicopter logging of Spooner Summit in 1996 down to densities averaging 222 trees per hectare (90 per acre).

Table 1—USDA Forest Service Forest Pest Management study on bark beetle infested Jeffrey pines in the Lake Tahoe Basin Management Unit, 1992–1995.[1]

Status and location	1992-93	1993-94	1994-95	Increase/decrease
Treated				
Nevada Beach and Zephyr Cover	909 trees	240 trees	121 trees	-87%
Untreated				
Spooner Summit	1213 trees	1966 trees	2213 trees	+182%

[1]Forest Pest Management website: http://www.r5.fed.us/fpm/fh_94-95/m261e.htm.

Spooner Summit's climate varies from average high temperatures in July of 26 ˚C to lows of 2 ˚C in January. Annual rainfall is very low with an average of 212 mm and average annual snowfall is 5500 cm (216 in). Slopes are very steep, ranging from 10% to 50%. Soils are rocky with shale-like volcanic parent material. A total of 235 trees were tagged and measured. Average tree dbh is 33.6 cm (SD =17.5, CI (95%) = .08) and average tree height is 12.8 m (SD= 4.2, CI (95%) = .09). Pre-fire fuel loads averaged 79 tons / hectare. *Ceanothus prostratus* dominates the foliar cover of the understory.

Site Differences

Two distinctive sampling units, using the Park's Fire Monitoring system, stratified the Roadside burn as Pine and Fir units. Although the species composition, precipitation, location, and management histories are quite distinct, the elevation, size of burn, and forest structure of Pine unit was similar to Spooner Summit making the Roadside spring burn a suitable comparison (table 2). These environmental factors may play a stronger role than seasonality; therefore, in comparing these two cases, only inferences can be made as to why these populations (and their fire-insect interactions) differ.

Table 2—Comparison of metadata from Lake Tahoe Basin Management Unit's Spooner Summit Fall Burn and Lassen Volcanic National Park's Roadside Unit Spring Burn. Preburn data collected in 1996 for Spooner and 1997 for Roadside.

	Spooner Summit	**Roadside Unit, LNP**
Size of burn	50.6 ha	41.3 ha
Month and year of burn	October 1996	June 1999
Elevation	1981-2176 m	1725-1798 m
Avg. temperature (high)	26 ˚C	14˚C
Avg. temperature (low)	2 ˚C	0˚C
Snowfall	5500 cm	480 cm
Precipitation	212 mm	1067 mm
Pre-fire stocking	222 trees/ ha	300 trees/ ha
Average DBH	33.6 cm	37.3 cm
Species composition	98% Jeffrey pine	Fir - 60% *Abies concolor* Pine - 73% *Pinus ponderosa*

Methods

Fire Effects Monitoring

Pre-burn surface fuel loads at Lake Tahoe Basin Management's Spooner Summit were determined using a grid of 28 plots. Plot centers were placed systematically on 4 transects that were installed directly upslope in the Spooner Summit fall prescribed fire unit. At each of the 28 plot centers, surface fuels were inventoried using three Brown (1974) transects at random azimuths (total of 84 transects installed). One and 10 hour fuels were sampled from 0-2 meters, 100 hour fuels from 0-3 meters, and 1000 hour fuels from 0-10 meters. At 10 randomly located grid points, all trees greater than 5.9 inches (15 cm) dbh within a one acre circular plot were tagged, identified to species and dbh and heights measured (dbh to the nearest 0.1 cm and height to the nearest 0.1 m).

Plot locations at Lassen Volcanic National Park's Roadside were selected utilizing a stratified random sampling design. Data were collected within two 20 m × 50 m plots pre-fire, immediately post-fire, and 1- and 2-years post-fire. All overstory trees ≥5.9 inches (15 cm) dbh were recorded within these two plot areas while pole trees between 1.0-5.9 inches (2.5-15 cm) dbh were sampled within one 10 m × 25 m quarter of the plot. All sampled trees were tagged, mapped, identified to species, and recorded as live or dead in accordance with Western Region Fire Monitoring Handbook protocols (1992). Fuel load was measured along four 15.2 m (50 ft) transects per plot using the planar intercept method (Brown 1974). Woody fuel load includes: 1-hour (0-0.24 inches or 0-0.63 cm in diameter), 10-hour (0.25-0.99 inches or 0.64-2.53 cm) 100-hour (1.0-2.99 inches or 2.54-7.61 cm), and 1000-hr (≥3 inches or ≥7.62 cm) fuels. Total fuel load also includes duff, which consists of the layer of partially decomposed, consolidated organic matter below the litter layer. Litter, which is defined as the freshly cast organic matter still retaining its morphological characteristics, was measured but is not included in the total fuel load calculation. Data were analyzed utilizing the Fire Monitoring Software version 3.0. This software provides a platform for data entry and storage while also performing functions including minimum plot calculations and analyses of change over time.

At both of these prescribed burning locations, four duff pins were placed (using the four cardinal directions) around the boles of randomly chosen trees at 30.5 cm (1 ft) from the main stem. Three to five trees were chosen at randomly chosen distances and azimuths (from grid point centers) using a table of random numbers. These trees were thus geo-referenced to plot centers for post-fire visits. Duff stakes were driven flush with the top of the duff and then the fine fuels consumed were measured following the burn. These marked trees served as a subsample of the population for a closer analysis of associated damage to the root collar and *D. valens* LeConte concentrations around the injuries.

The maximum height of bark charring was recorded on all trees greater than 5.9 inches (15 cm). Ocular estimates of three codes of bark char were recorded to the nearest 0.1 of a meter. The maximum height of each charring code was measured on the highest fire-charred side and then again on the opposite side of the tree. If the bark was uncharred, then a zero was recorded. The three levels of charring, designed for use with a similar study at Blacks Mountain Experimental Forest, Lassen County, are defined as follows (Oliver 2000):

- Code 1-Bark is black but not consumed and the bark fissures are not black.
- Code 2–The entire bark including the bark fissures is black, but the bark has not been consumed by fire.
- Code 3–The entire bark is black including the fissures and a significant degree of bark consumption is evident. Bark consumption often is indicated by a “smoothing” of the original bark profile of ridges and fissures.

Four crown measurements were taken to determine the percentage of live crown scorched. These four measurements are defined as follows:

- Measure the height above ground to the base of the living crown if the crown is unscorched or to the base of the crown that was living before the burn but is now dead, in the case of crown-scorched trees.
- Measure the height above ground to the base of the crown that had scorched needles but is still living.
- Measure the height above ground to the base of the unscorched portion of the crown.
- Measure the crown width.

Using these four measurements, the overall percentage of scorched crown was estimated. Overall crown surface area (C^a) is calculated assuming the crown is a solid geometric shape with a measured crown depth (L) and crown width (D). In this study, the amount of crown scorched assumed that the crown resembled a conoid shape. The equation used for crown surface area is as follows:

$$C_a = \frac{\pi D}{2} * \sqrt{L^2 + (\frac{D}{2})^2}$$

For a comparison of burning effects on tree mortality compared to non-burned splits, a paired T-test was used to evaluate the two normally distributed populations. This statistical test was also used to compare a difference in means, in this case the difference of mean mortality between burned and non-burned populations, or between spring and fall burning treatments. It assumes the following hypothesis:

$$H_O : \mu d = 0 \quad \text{and} \quad H_A : \mu d \neq 0 \quad \text{or also expressed} \quad H_A : \mu d \neq \mu o$$

It was particularly useful in these two cases where there was not adequate replication in the design although inferences were made through comparing the two populations.

Insect Activity Monitoring

Post-burn visits to each plot were performed in the late fall of each year following the burn to determine bark beetle-induced mortality. Spooner Summit performed in 1996 was revisited from 1997 to 2001 and Roadside spring burn performed in 1999 was visited from 1999 to 2001. At both locations, permanent control plots were set up in non-burned areas to compare the effect of burning itself on insect activity. For this comparison, 112 unburned trees, 50 at Roadside and 62 at Spooner Summit, were monitored for the duration of the study.

For the spring burn, multiple visits throughout the growing season were performed to determine the insect invasion pattern for *D. valens*. For this insect, the number of attacks as evidenced by large red pitch tubes and / or granular frass at the root collar was counted and woodpecker foraging noted. The presence of frass, gallery patterns and / or woodpecker activity was used to determine activity of other *Dendroctonus* beetles, mainly Jeffrey pine beetle (*D. jeffreyi* Hopkins), mountain pine beetle (*D. ponderosae* Hopkins), and western pine beetle (*D. brevicomis* LeConte). Woodpeckers working on trees infested by *D. brevicomis* shave the bark to a more or less uniform thickness (Otvos 1965). This enables a visual identification decipherable from the other *Dendroctonus* species. Other insects like the pine engraver (*Ips pini* Say) as well as the California flatheaded borer, *Melanophila californica* Van Dyke, have a pronounced role in mortality after fire (Lyon 1970) and these insects were identified by intrusive sampling (bark removal) of the bole when outside verification was not feasible. The role of these insects and other typical secondary infestation beetles were documented in this project. *Scolytus ventralis* LeConte activity was indicated by white fir pitch streamers and top kill. Within white fir, mortality from *Tetropium abietis* Fall was also documented. A major assumption of this study is that phloem-feeding insects will not infest trees with no viable cambium. Therefore a distinction is made by those trees killed by fire and those predisposed by fire and subsequently killed by insects.

Results

Fire Monitoring

Although burned in different seasons, both Spooner Summit and Lassen Volcanic National Park Roadside prescribed burns have shown similar pre-fire

Table 3—Summary of fire monitoring for Lake Tahoe Basin Management Unit's Spooner Summit Fall Burn and Lassen Volcanic National Park's Roadside Unit Spring Burn. Pre-fire data collected in 1996 for Spooner and 1997 for Roadside.

	Spooner Summit	LNP Roadside Burn
Season of prescribed burn	Fall	Spring
Pre-burn fuel loading	5.13 tons/acre (SD = 6.8)	7.9 tons/acre (SD = 6.5)
Post-burn fuel loading	4.87 tons/acre (SD = 5.3)	4.74 tons/acre (SD = 5.5)
Fine fuels consumed	5.48 cm (SD = 2.3)	3.95 cm (SD = 2.9)
Bark char front code 1	4.25 m (SD = 3.7)	3.77 m (SD = 3.9)
Bark char front code 2	1.77 m (SD = 1.9)	1.86 m (SD = 2.1)
Bark char front code 3	0.55 m (SD = 0.6)	0.70 m (SD = 0.8)
% live crown scorch	60	56

fuel loads and standard deviations (table 3). In comparing the averages from the 235 burned trees of Spooner Summit and the 88 burned trees of Roadside, the fire severity measures of bark char and crown scorch are remarkably similar (table 3). Although the standard deviations for all of these averages are quite large, the ranges follow a similar trend in both burns.

The Lassen Volcanic National Park Roadside Unit has two monitoring plots: one within a white fir-dominated area and the other within a ponderosa pine-dominated area. The white fir-dominated portion of this prescribed burn suffered only mild fire severities with scorching averaging 36% of live crown and bark char (Code 1) reaching heights of 2 m on the high side and .75 m on the low side. Unlike with the pine species, bark char is probably a better severity measure than crown scorch for predicting mortality in white fir.

The ponderosa pine-dominated portion of the Roadside prescribed burn had slightly more severe fire effects due to higher fuel loadings (some fuel loadings were 80 tons/acre). As a result, bark char heights averaged 7 m on the front side and 3 m on the backside. Scorch heights were higher averaging 76% of live crowns scorched. Prior to prescribed burning, many of the ponderosa pines had the needle cast, *Elytroderma dispars*, which may have contributed to higher live crown scorch measures.

At Spooner Summit, 26 trees with complete crown scorch had significant green bud break one year after the fall fire season of 1996. Only one tree was blatantly killed by fire with 100% crown scorch and complete bark char (Code 3) down to the cambium. Bark char heights averaged 7 m on the front side and 3 m on the backside. Live crown scorch heights were a bit higher than the Roadside spring burn averaging 60% of live crown scorched. Using a simple paired T-test to compare fire severity measures at both sites, the difference in bark char codes for the back of the tree and the percentage live crown were significant with a 95% confidence interval. All three front bark char codes were not significantly different in these two populations. Different weather conditions and ignition patterns alone may have caused these differences in back bark char codes and percentage live crown scorched.

Insect Activity Monitoring

After the Spooner Summit fall burn, 31% of the Jeffrey pines were hit by *Ips pini* and *D. valens* in the first year. *D. valens*, with a range of 1-25 attacks per tree, hit 53% of the Jeffrey pines (125 trees). The trees hit by *D. valens* averaged 30.2 cm in dbh (SD of 16) and six *D. valens* attacks per tree (SD of 5) while those plots outside the burn only had one incident of a tree attacked by *D. valens*. Fifty-nine percent of the burned trees attacked by *D. valens* (73 trees) were also hit by *Ips pini*. Only 12 trees were hit by *Ips pini* without the presence of *D. valens*. These 12 trees were hit by *Ips pini* without the presence of *D. valens* (representing only 13% of the *Ips pini* activity). This might indicate some type of predisposal or chemical attractants with *D. valens*.

In this Lassen Roadside Unit spring burn, six trees of the total sample (87) were initially killed by the fire. In year one, 13 were outright killed by *Ips pini* (15%), one by *D. jeffreyii* and 11 by *S. ventralis*. Twenty-three trees were hit by *D. valens*, averaging 16 attacks per tree. By 2001, 50 trees had been killed by one of these four insects. Eight trees within the white fir-dominated area had *S. ventralis* and *T. abietis*, all of which shared extremely high severity measures with crown scorch of 0-90% and bark char heights shown of 5 m front side and 1.75 m backside for Code 1 and 1.6 m front side and 0.73 m backside for Code 3.

Sampling for the first season shows 35% of pines hit with *D. valens* and 24% with *Ips pini* by late-August. Each tree hit by *D. valens* more than 20 times was also subsequently hit by *Ips pini* in this first sampling season. Trees hit by *D. valens* averaged 20 attacks per tree, ranging from 2 to 131 pitch tubes. Although not the intent of this study to document the timing and duration of insect activity, field observations noted two distinct time periods when newly injured trees are susceptible to *D. valens* attack: first early in the summer and then again at the end of the summer months.

Trees at the Lassen Volcanic National Park's Roadside spring burn had steady increases in the number of *D. valens* attacks throughout the first season (figure 2). Here, initial tree attack took place on June 23 (24 hours after the

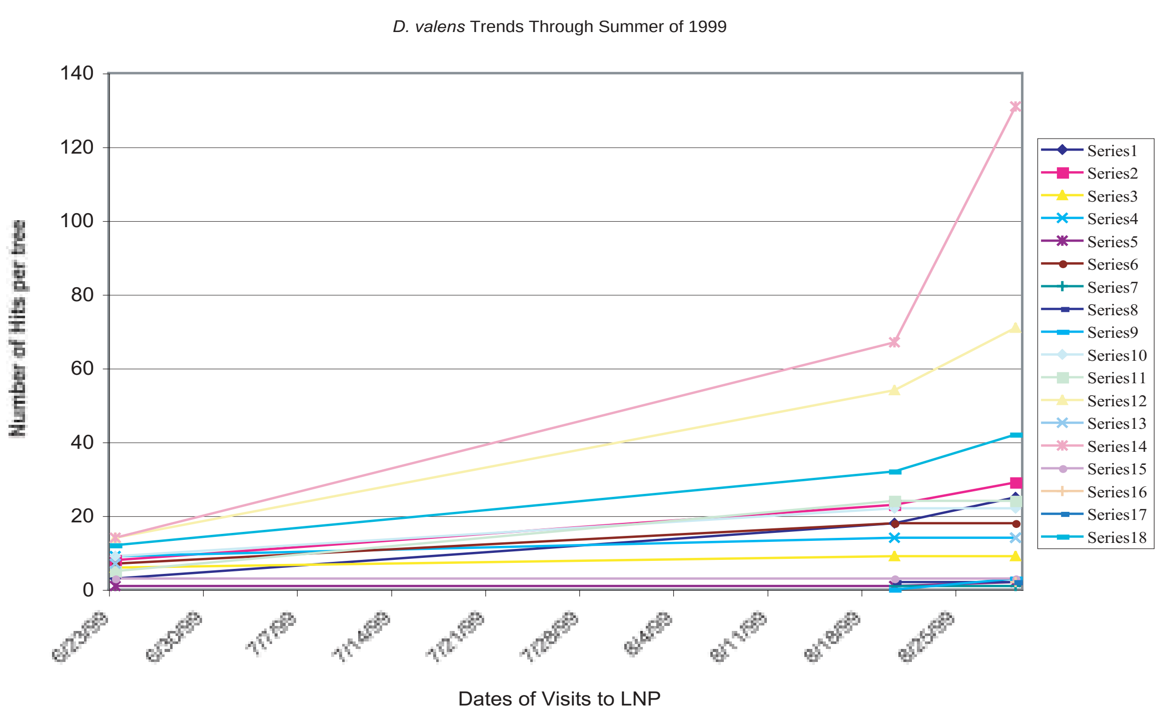

Figure 2—Red turpentine beetle activity during the summer months of 1999 after spring prescribed burning within Roadside Unit, Lassen Volcanic National Park. Initial tree attack, denoted by series, took place on June 23 (24 hours after the burn) and subsequently no new trees were infested until the last sampling on August.

burn) and subsequently no new trees were infested until the last sampling period on August 25 (figure 2). At Blodgett Research Forest in El Dorado County, Owen (1985) found that the largest pulse of *D. valens* took place in the first three weeks of May when daily temperatures had increased. The Roadside spring burn is at higher elevations with a range of 1725-1798 m (5660-5900 ft) compared with that of Blodgett Forest at 1200-1550 m (3900-4800 ft) and therefore the *D. valens* pulse may be delayed due to cooler temperatures. Other environmental factors may be playing a role in determining when such a *D. valens* is likely to occur in a given year. As this is a poorly studied insect in California, more work on the flight periodicity of *D. valens* is needed.

For a comparison of burning effects on insect-induced tree mortality, a paired T-test was used to evaluate the populations of burned and non-burned trees at Spooner Summit and Lassen Volcanic National Park (comparing 323 burned trees with 112 unburned trees outside of the two prescribed burns). The null hypothesis for this test is there is no difference between means of those trees killed by insects (KBI) between burned and unburned populations. The test rejected the null with 95% confidence and a T-value of 8.58 with 433 degrees of freedom and a P of 0. There is a significant difference between the two population means, which in this case, is the proportion of 1's since KBI is binary (0 = alive, 1 = dead). Since it is the proportion or rates of mortality that is of interest to this study, this is a suitable test to run. Ordinarily with such binary data, a nonparametric test that can be applied to two independent sets of sample data would be used (like a Z-test). This Z-test was thus applied to this data. The Z-distribution is a standard normal distribution and the Z-test statistic is calculated by Z=(X-mean of X) / (standard deviation of X), i.e., number of standard deviations away from the mean for any normal data, X. Using this test, the Z-value for KBI is significant with Z = 8.5033 and P = 0.

For a comparison of seasonal effects on insect-induced tree mortality, a paired T-test was used to evaluate the populations of those trees killed by insects in both fall and spring populations of Spooner Summit and Roadside prescribed burns. The null hypothesis for this test is there is no difference between means of those trees killed by insects (KBI) between fall and spring populations. The test accepted the null with 95% confidence and a T-value of -1.6384 with 321 degrees of freedom and P = 0.1023. There is a no significant difference between the two population means, which in this case, are the percentages of trees killed per seasonal window.

Discussion

At the Roadside Unit, the white fir component experienced considerable mortality in the smaller size classes (5-10 cm) while the ponderosa pine component experienced mortality in the larger size classes (five size classes from 20-70 cm). Bark beetles are contributing to most of this pine mortality with only six trees killed by the prescribed fire outright. Given the remaining live overstory component (figure 3), it is probable that white fir will retain dominance over the growing space of the site. It will probably take two to three more fires of this intensity to restore the pre-fire species composition as indicated by the pine snags in the area. In the pine-dominated area of the burn, the higher mortality rate is most likely attributed to a high water table. Old Park Service maps show this area as a grassy opening or a high elevation meadow. Under a more frequent fire regime, this area is likely to revert back to a high

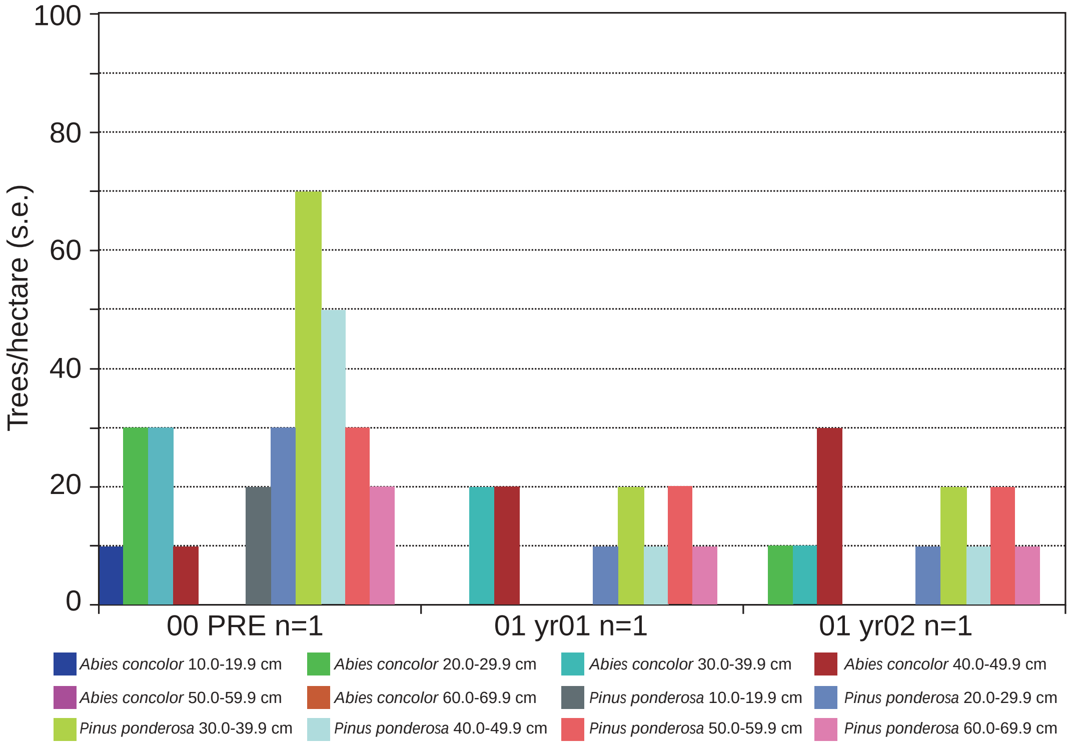

Figure 3—Live overstory tree density by species and size classes within the Lassen Park Roadside spring prescribed burn, Lassen Volcanic National Park, Lassen County, CA. Pre-burn data sampled in 1997, post-burn in 1999-2000.

elevation meadow. With fire suppression, pines have established themselves but not with high vigor. This assessment was made by looking at live crown ratios which are remarkably low for this aspect exposure. A general rule of thumb is that trees living in an open, relative flat environment, such as the one at Roadside, would be expected to have at least 30% of its height in vigorous green growth[2]. However, the trees inspected had only 20% of their total height in a yellowish crown that was riddled with *Elytroderma dispars*. It is speculated that these trees were going to die with or without prescribed burning but at a slower time scale. Therefore, the increased mortality rates from this spring burn can be potentially seen as speeding up succession back towards a meadow landscape.

Historically, *D. valens*, otherwise known as the red turpentine beetle, has not been considered a primary mortality agent in ponderosa pine and Jeffrey pine (Jenkinson 1990). As a lower bole specialist, this insect has been prolific in cutover stumps and predisposed trees but never of much concern to forest managers. Only under rare conditions was it seen overwhelming trees (Smith 1961), usually with exotic introductions and / or other human interventions such as overwatering, fertilizing, soil displacement around root systems, etc. Fire-scorched trees frequently have had sizable populations of this beetle (Eaton and Lara 1967). Mitchell and Martin (1980) speculated that a program of systematic prescribed burning could stimulate a population of *D. valens* to levels where it could overwhelm trees or predispose trees to other mortality agents. Owen (1985) observed a spring prescribed burn at Blodgett Forest, El Dorado County, where 80-90 scorched trees were heavily attacked by *D. valens*. On a wildfire 16 km east of Blodgett Forest in the Rubicon River drainage, Owen again observed unusually high attack rates with 80% of *Pinus ponderosa* and *Pinus lambertiana* attacked (Owen 1985). Ferrell (1996) goes

[2] Monitoring Tree Health on Private Woodlands, University of Idaho Extension Website http: / www.ets.uidaho..edu / extforest / .

further in identifying the probable increase in *D. valens* in the Sierras following the increased use of controlled burning.

In the case of the Spooner Summit fall burn, Lake Tahoe Basin Management Unit, 31% of the Jeffrey pines were attacked by *Ips pini* and *D. valens*. These results are comparable with another study in the Tahoe Basin which found 23% of its sampled trees attacked within the first two sampling seasons (Bradley and Tueller 2001). In another study on the Harvey Mountain spring burn, Lassen County, large open grown trees with high fire severity measures had large lower branches 15.2 cm (6 in) in diameter infested with pronounced *Ips pini* and *D. valens* activity on the lower bole (Ganz 2002). It could be that fire-injured small diameter material is creating a reservoir for both of these species but especially for *Ips pini*, which usually attacks slash piles and tops of trees (Furniss and Carolin 1977).

High variability in fire effects to trees was observed throughout the two prescribed burning study areas, consistent with the range of thermal effects mentioned by Schmidt (1996). *D. valens* and *Ips pini* activity at both sites was particularly high, perhaps due to the high intensity of burns and a stressful environment. Spooner Summit has a southwestern exposure, shallow soils, steep slope, and heavy winds. Beetle-induced mortality was already evident as early as July 9 when plot layout was performed. As previously mentioned, a high water table is speculated to play a role in the Roadside pine-dominated area. Regardless of these two site's predisposition to bark beetle attack, there needs to be a re-evaluation of traditional perceptions of *Ips pini* and *D. valens* and their ecological niches in forested ecosystems following the disturbance of fire. *Ips pini* and *D. valens* are contributing to high levels of pine mortality.

Research from Blacks Mountain Experimental Forest (BMEF) has used the same fire severity measures and has found that the bark char measures are useful for deciphering between those trees killed by fire and those killed by insects (Ganz 2002). In this study, the combination of percent live crown and bark char codes greatly increased the ability of models to predict tree mortality, both from the fire itself and from subsequent insect attack. In all models, these two fire severity measures had a positive relationship with increasing probability of tree death. In general, the models for KBI performed better with higher predictability using the fire severity measures than those models for killed by fire (KBF). Also noteworthy from this study was the fact that those models for KBI performed best with the use of Bark Code 2 (front and back) while those models predicting KBF performed better with Bark Code 3. Biologically, this inherently makes sense as insects are less likely to invade material that has no nutritional value (which Code 3 probably indicates). Also relevant to these two cases at Lassen Volcanic National Park and Spooner Summit was the finding that the same fire severity measures performed differently from tree species to tree species and between individual insects within one tree species (Ganz 2002). For instance, the *Ips pini* response model on the BMEF data set performed differently than the *Dendroctonus ponderosae* response model with regard to the emphasis of particular fire severity measures. Given that Lassen Volcanic National Park and Spooner Summit have very distinct forest composition, the insect responses may differ even more than the BMEF results. Differences in years and seasonal windows (although not found in this particular case comparison) are likely to further convolute these results. Interactions with insect parasites, insect predators, and avian predator complexes, which are known to affect bark beetle populations (Berryman et al. 1970), will vary from spring to fall and from year to year. Further work is recommended to determine the role of these interactions, specifically with different pine species and their post-burning mortality rates.

Conclusion

A primary goal of restoration treatments in ponderosa pine forests is to create more open-stand structures, thereby improving tree vigor and reducing vulnerability to insects, disease, and severe fire. Alternatively, the use of prescribed fire has increased the concerns about the detrimental impacts of fire on tree vigor, especially for its potential to predispose large trees to bark beetle attacks. In the same manner that a management tool has the potential to increase tree vigor and site productivity (site quality), it also has the potential to reduce it through misapplication and site degradation. Prescribed fires have been shown to have such a potential. Growth losses on commercial tree species have been reported in response to fire stress. These losses are usually attributed to root, cambial, and crown damage, leading to a decline in the physiological condition or vigor of the tree (Hare 1961). Other potential sources of losses may be attributed to fuel consumption of organic material and topsoil loss through the process of erosion (Agee 1973). This study has documented some of the effects of cambial and crown damage from two different prescribed burning treatments.

Insect-induced mortality following prescribed burning may be further assessed with specific knowledge of the insect's ecology and the post-burning response. Such knowledge intrinsically can add to the value of prescribed burning as a tool for creating heterogeneity in post-burning tree survival and subsequent recruitment. Although not found in this particular two case comparison, insect-induced mortality differences are likely to occur by seasonal windows and by year (especially under drought conditions). The use of prescribed burning with this embedded knowledge of insect-induced mortality will allow managers to change stand densities, size distribution, and community composition. For instance, many low intensity fires have little effect on the relative density of the stand because the average tree size will change little although the density will decrease through the loss of small stems both from the fire itself and the presence of bark beetles specializing in small diameter classes. Alternatively, the opposite may take place with delayed mortality in the larger diameter classes (due to opportunistic bark beetles) having a pronounced impact on relative densities. An increased comprehension of these fire-insect interactions is necessary for more effective science-based management of forest ecosystems (McCullogh et al. 1998). Given these two cases from Lassen Volcanic National Park and the Lake Tahoe Basin, tree mortality from bark beetles can reduce stocking levels of pine trees which, given the management objectives of the prescribed burn, may be desirable or undesirable. Many have claimed the use of prescribed burning as a means to restore the competitive advantage to the pine species by thinning out shade-tolerant, understory white fir trees. This would create the growing space for pine regeneration or allow remnant large pines to retain dominance and vigor with less water stress resulting from the thinning of neighboring competition. But the two study cases indicate otherwise, further demonstrating the need to consider the management implications of post-burning bark beetle responses.

References

Agee, James K. 1973. Prescribed fire effects on physical and hydrologic properties of mixed conifer forest floor and soil. University of California - Berkeley, School of Forestry. Dissertation.129 p.

Berryman, A. A.; Otvos, I. S.; Dahlsten, D. L.; Stark, R. W. 1970. Interactions and effects of the insect parasite, insect predator and avian predator complex. In: Stark, R. W.; Dahlsten, D. L., eds. Studies on the population dynamics of the western pine beetle, *Dendroctonus brevicomis* LeConte. Berkeley: University of California, Division of Agricultural Sciences. 174 p.

Bradley, Tim; Tueller, P. 2001. Effects of fire on bark beetle presence on Jeffrey pine in the Lake Tahoe Basin. Forest Ecology and Management. 142: 205-214.

Brown, James K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Coyne, J. F.; Lott, L. H. 1976. Toxicity of substances in pine oleoresin to southern pine beetles [*Dendroctonus frontalis*]. Georgia Entomological Society, Journal of Entomological Science. 11: 301-305.

Eaton, Charles B; Lara, R. R. 1967. 3-red turpentine beetle, *Dendroctonus valens* LeConte. In: Davidson, A. G.; Prentice, R. M., ed. Important forest insects and diseases of mutual concern to Canada, the United States, and Mexico. Canadian Deartment of Forestry and Rural Development. 248 p.

Feeney, Shelly R.; Kolb, T. E.; Covington, W. W.; Wagner, M. R. 1998. Influence of thinning and burning restoration treatments on presettlement ponderosa pines at the Gus Pearson Natural Area. Canadian Journal of Forest Research. 28: 1295-1306.

Ferrell, George T. 1996. The influence of insects pests and pathogens on Sierra forests, Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. II, Assessments and scientific basis for management options. University of California at Davis, Centers for Water and Wildland Resources: 1117-1192.

Forest Pest Management Web site: http://www.r5.fed.us/fpm/fh_94-95/m261e.htm, Jan.29, 2002.

Fritts, Harold C. 1976. Tree rings and climate. London; New York: Academic Press.

Furniss, Robert L.; Carolin, V. M. 1977. Western forest insects. Misc. Publ. 1339. Washington, DC: U.S. Department of Agriculture, Forest Service. 654 p.

Ganz, David J. 2000. The post burning response of bark beetles to prescribed burning treatments in northern California. University of California, Berkeley, College of Natural Resources, Department of Environmental Science Policy and Management. Dissertation. 198 p.

Geiszler, Daniel R.; Gara, R. I.; Littke, W. R. 1984. Bark beetle infestations of lodgepole pine following a fire in south central Oregon. Zeitschrift fur Angewandte Entomologie. 98(4): 389-394.

Hare, Robert C. 1961. Heat effects on living plants. Occasional Pap. 183. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Experiment Station.

Harrington, Michael. G. 1993. Predicting *Pinus ponderosa* mortality from dormant season and growing season fire injury. International Journal of Wildland Fire. 3: 65-72.

Jenkinson, James L. 1990. Jeffrey pine. In: Burns, Russell M.; Honkala, B. H., ed. Silvics of North America. Agic. Handb. 654 Washington, DC: U.S. Department of Agriculture, Forest Service.

Kozlowski, Theodore T.; Kramer, P. J.; Pallardy, S. G. 1991. Physiological ecology the Physiological Ecology of Woody Plants. Academic Press. San Diego, New York. xix + 657 p.

Lyon, Robert L. 1970. California flatheaded borer. Forest Pest Leaflet 24. Washington, DC: U.S. Department of Agriculture. 8 p.

McCullogh, Deborah.G.; Werner, R. A.; Neuman, D. 1998. Fire and insects in northern and boreal forest ecosystems of North America. Annual Review of Entomology. 43: 107–127.

McKelvey, Kevin.S.; Skinner, C. S; Chang, C.; Erman, D. C.; Husari, S. J.; Parsons, D. J.; van Wagtendonk, J. W.; Weatherspoon, C. P. 1996. An overview of fire in the Sierra Nevada. Sierra Nevada Ecosystem Report. Davis: University of California, Wildland Resources Center. II: 1033-1040.

Miller, John M.; Keen, F. P. 1960. Biology and control of western pine beetle. Misc. Publ. 800. Washington, DC: U.S. Department of Agriculture. 381 p. plus illustrations.

Miller, John M.; Patterson, J. E. 1927. Preliminary studies on the relation of fire injury to bark beetle attack in western yellow pine. Journal of Agricultural Research. 34: 597-613.

Mitchell, Robert G.; Martin, R. E. 1980. Fire and insects in western pine culture in the Pacific Northwest. In: Sixth conference on fire and forest meteorology; 1980 April 22-24. Society of American Foresters: 182-190.

Mutch, Robert W. 1994. Fighting fire with prescribed fire—a return to ecosystem health. Journal of Forestry. 92: 31-33.

National Fire Plan Web site http: / /www.fireplan.gov, January 14, 2002.

Oliver, William W. 2000. Ecological research at the Blacks Mountain Experimental Forest in northeastern California. Gen. Tech. Rep. PSW-GTR-179. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 66 p.

Otvos, Imre S. 1965. Studies on avian predators of *Dendroctonus brevicomis* LeConte (Coleoptera: Scolytidae), with special reference to Picidae. Canadian Entomology. 97: 1184-1199.

Owen, Donald R. 1985. The role of *Dendroctonus valens* and its vectored fungi in the mortality of ponderosa pine. University of California, Berkeley, Department of Entomological Sciences. Dissertation. 64 p.

Parsons, David J. 1995. Restoring fire to the giant sequoia groves: what have we learned in 25 years. In: Brown, James K.; Mutch, Robert W.; Spoon, Charles W.; Wakimoto, Ronald H., eds. Proceedings—symposium on fire in wilderness and park management. Gen. Tech. Rep. INT-GTR-320. Ogden, UT. U.S. Department of Agriculture, Forest Service, Intermountain Research Station. INT-GTR-320: 256-258.

Peterson, David L. 1985. Crown scorch volume and scorch height: estimates of post-fire tree condition. Canadian Journal of Forest Research. 15: 596-598.

Rasmussen, Lynn. A.; Amman, G. D.; Vandygriff, J. C.; Oakes, R. D.; Munson, A. S.; Gibson, K. E. 1996. Bark beetle and wood borer infestation in the Greater Yellowstone area during four postfire years. Gen. Tech. Rep. INT-GTR-487. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 10 p.

Ryan, Kevin C. 1982. Evaluating potential tree mortality from prescribed burning. In: Proceedings of symposium on site preparation and fuels management on steep terrain; February 15-17, 1982; Spokane, WA. Pullman: Washington State University, Cooperative Extension Service. 167-178

Ryan, Kevin C.; Steele, B. M. 1990. Cambium mortality resulting from broadcast burning in mixed conifer shelterwoods. In: Proceedings of the 10th conference on fire and forest meteorology; April 17-21, 1989; Ottawa, Canada. Ottawa, Canada: Forestry Canada: 108-116

Ryan, Kevin C.; Peterson, D. L.; Reinhart, E. D. 1988. Modeling long-term fire caused mortality of Douglas-fir. Forest Science. 34: 190-199.

Ryan, Kevin C.; Reinhardt, E. D. 1988. Predicting postfire mortality of seven western conifers. Canadian Journal of Forest Research. 18: 1291-1297.

Salman, K. A. 1934. Entomological factors affect salvaging of fire injured trees. Journal of Forestry. 32: 1016-1017.

Santoro, Alyson E.; Lombardero, M. J.; Ayres, M. P.; Ruel, J. J. 2001. Interactions between fire and bark beetles in an old growth pine forest. Forest Ecology and Management. 144: 245-254.

Schmidt, R. Gordon. 1996. Can we restore the fire process? What awaits us if we don't. In: Hardy, C. C.; Arno, S. F., ed. Use of fire in forest restoration; Seattle, WA, September 14-16, 1995. Gen. Tech. Rep. GTR-INT-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 86 p.

Smith, Robert H. 1961. Red turpentine beetle. Forest Pest Leaflet 55. Washington, DC. U.S. Department of Agriculture. 8 p.

Taylor, Alan H. 1998. Reconstruction of Pre-European forest structure, composition and fire history in the Carson Range, Lake Tahoe Basin Management Unit. Final Report for Cooperative Agreement 0024-CA-95. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 27 p.

Thomas, Jack W. 1995. USDA Forest Service "Course to the Future: Positioning Fire and Aviation Management." In: USDA Forest Service Position Statement. Washington DC. Statement before House Agriculture and Natural Resources Committees, Oversight Hearing.

University of Idaho Extension Web site http://www.ets.uidaho.edu/extforest/Aug,99.htm, January 16, 2002.

Wagener, Willis. 1961. Guidelines for estimating the survival of fire damaged trees in California. Berkeley, CA: U.S Department of Agriculture, Forest Service, Pacific Southwest Research Station. 11 p.

Western Region Fire Monitoring Handbook. 1992. Prepared by the Western Region Prescribed Natural Fire Monitoring Task Force. San Francisco, CA: U.S. Department of the Interior, National Park Service, Western Region. 134 p.