2C.3 MONITORING FUEL CONSUMPTION AND MORTALITY FROM PRESCRIBED BURNING IN OLD-GROWTH PONDEROSA PINE STANDS IN EASTERN OREGON

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1. ABSTRACT

Mortality of large ponderosa pines was monitored as part of a series of experiments designed to quantify fuel consumption during prescribed fires in eastern Oregon. Operational prescribed burn units with old-growth characteristics (i.e., presence of >50 cm diameter at breast height ponderosa pine trees with basal accumulations of needle and bark litter and duff) were inventoried to quantify consumption of woody and forest floor fuels. Fuel conditions and consumption around the bases of 10-20 large ponderosa pine trees were monitored specifically to explore potential links between reduction of basal accumulation by fire and tree mortality. Prescribed fires occurred in the spring of 1994 and 1995, and in the fall of 1997 and 1998. Post-fire monitoring occurred in the fall of 1998 and again in the summer of 2000. Fuel consumption was varied throughout many of the units, however, consumption was considerable and approached 100 percent at the bases of many of the monitored trees. Mortality of the monitored trees was as high as 25 percent (5 of 20 trees for a 1994 spring-burn unit) in 1998 and 30 percent (3 of 10 trees for a 1997 fall-burn unit) for a different unit in 2000; there was no mortality of monitored trees in the years following fire for 6 of 14 burn units. Three out of ten burn units showed increased mortality from 1998 to 2000. Preliminary qualitative analysis did not reveal a relationship between basal fuel consumption and tree mortality. Other measures of fire intensity/severity and more rigorous and intensive sampling may be required to adequately evaluate old-growth ponderosa pine mortality during prescribed fires.

Keywords: eastern Oregon, fuel consumption, old-growth, ponderosa pine, prescribed fire, tree mortality

2. INTRODUCTION

Prescribed fire has been used throughout the range of ponderosa pine to manage hazardous fuels, and to maintain and restore historical forest structure and composition. Frequent, low intensity surface fires () maintained open, park-like stands of large ponderosa pine with only small amounts of surface fuel (woody debris, needle and bark litter, duff) prior to European American settlement (Agee 1993, Cooper 1960, Hall 1977, Heyerdahl 1997, Heyerdahl et al. 1995, Weaver 1943, Wright and Agee in press, etc.). Forest management, fire exclusion and aggressive fire suppression activities throughout the twentieth century led to changes in stand structure, species composition and fire regime in these dry forest types throughout the West (e.g., Heyerdahl et al. 2001, Maruoka 1994, Parsons and DeBenedetti 1979, Wright 1996). Extended periods without fire (i.e., several missed fire return intervals) allowed woody material and needle and bark litter to build up, and shade-tolerant trees to reproduce and mature altering the fire regime from one of low to one of moderate or even high intensity and severity (Agee 1994).

Fire managers have re-introduced fire in recent years in an effort to decrease the density of the ingrowth of fire-sensitive, shade-tolerant species (e.g., Douglas-fir, grand fir, white fir), and to reduce fuel levels in ponderosa pine-dominated forests. Fire has been used as a restoration tool in forests that still possess a significant large, old-tree component (see, for example, Fulé et al. 2002, Kilgore and Taylor 1979, Sackett 1980, etc.). Because of their size and age, many believed that, having survived numerous past fires, the large old-growth pines were at little risk of mortality from prescribed fire. Mortality has occurred following prescribed fires where it was not initially expected, however. As most prescribed fires in natural fuels (i.e., not activity fuels) are carried out with a goal of preserving the old-growth components of these forest types (i.e., the large, old trees) it is desirable to understand the mechanisms that may potentially contribute to mortality of the trees that are targeted for preservation.

Tree size, crown scorch, species, basal fuel consumption, bole and root injury, and season of burn have all been proposed as factors contributing to tree mortality following prescribed fires in dry forest types in the western United States (Agee 2003, Harrington 1987, McHugh and Kolb 2003, Swezy and Agee 1991, Peterson and Arbaugh 1989, Ryan and Frandsen 1991, Stephens and Finney 2002, Thomas and Agee 1986). Fire severity (fuel consumption, crown scorch, bole heating, root heating) is an important determinant of tree mortality. The intensity (heat release per unit area) and duration of a fire at a point on the landscape in conjunction with the structure and composition of the vegetation will determine the severity of the effects. Fires of greater intensity and longer duration have more

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severe effects on the existing vegetation, although these effects may not necessarily be undesirable when considered in light of management objectives.

The overall objective of the various burning experiments was to quantify fuel consumption in ponderosa pine types during prescribed fires. The portion of the study reported here attempts to determine what, if any, connections exist between basal fuel consumption and old-growth ponderosa pine mortality. We hypothesized that trees that died after the application of fire experienced greater consumption at their bases than trees that did not die.

3. STUDY AREA

A series of experiments designed to quantify fuel consumption during prescribed fire were carried out in central and northeastern Oregon in the spring of 1994 and 1995, and in the fall of 1997 and 1998 (Figure 1). The study sites are mixed-conifer forests composed of ponderosa pine, Douglas-fir, and grand fir in the Blue Mountains and High Lava Plains physiographic provinces (Franklin and Dyrness 1988). All of the stands reported in this study were selected for their old-growth characteristics, primarily the presence of large (>50 cm diameter at breast height) ponderosa pines.

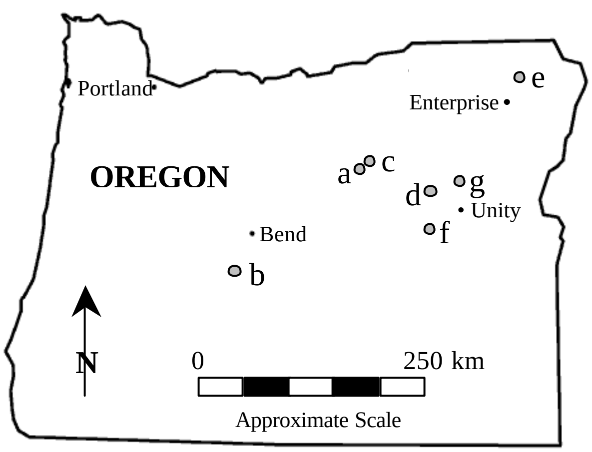

Figure 1. Approximate study site locations. Four burns occurred at (a) Three Troughs, one burn occurred at (b) Pringle Falls, one burn occurred at (c) East End, two burns occurred at (d) Old Growth, two burns occurred at (e) Wapiti, two burns occurred at (f) Cottonwood, and two burns occurred at (g) Maggie Springs. See Table 1 for dates and sample sizes.

Weather patterns in central and eastern Oregon are strongly influenced by the Cascade Range; the study sites were all in areas that receive between 25 and 50 cm of precipitation annually, with more than half falling during the winter months (USDA-NRCS 1999). Lightning activity in and around the study areas was historically relatively high for the interior west (3-6+ storms annually; Morris 1934). Lightning activity supplemented by human-caused ignitions produced a regime of relatively frequent fire (see Heyerdahl et al. 1995, Heyerdahl 1997, Maruoka 1994, Olson 2000). Depending on geographic position, exposure, and vegetation type, a 10-30 year fire return interval was historically typical in these dry forest types dominated by ponderosa pine (Agee 1993, Heyerdahl et al. 1995).

4. METHODS

All sampling was performed within the boundaries of operational prescribed fires. Ten to twenty live “old-growth” ponderosa pines were selected in each unit prior to burning. Each tree was referenced, tagged and measured (diameter at breast height, total height and height to live crown).

Burning operations were carried out by local USDA Forest Service personnel. Ignition was typically by hand with drip torches or aerially with exothermic spheres (“ping pong balls”). Fire behavior and intensity were not uniform within or among units. Some areas within units burned with greater intensity than others, and, in general, some units burned more intensely than others. Data that could be used to evaluate the intensity of a particular prescribed fire (e.g., fire behavior observations, measurements of scorch height or char height, thermal time series, etc.) were inconsistently collected among units. In general, all units burned as surface fires under relatively mild burning conditions (i.e., moderate temperature, relative humidity, windspeed, and fuel moisture), and did not experience any extreme fire behavior.

Four to sixteen steel spikes (steel gutter nails or welding rods) were arranged systematically around the base of each tree in the accumulated needle and bark litter and duff and driven into the ground until they were embedded in mineral soil and set flush with the top of the organic layer. The spikes were typically within ~25 cm of the bole of the tree. Before the fire, the depth of the litter layer was measured at each spike (not done at all locations). After the fire, measurements were made from the top of the spike to the top of the remaining organic material (i.e., the consumption) and from the top of the spike to the mineral soil. It was possible to calculate the depth of the litter layer, the depth of the duff layer (or the total depth of the organic forest floor layer if litter measurements were not taken before each fire) and the amount of each layer consumed by the fire from these measurements.

It is desirable to monitor litter and duff separately because they typically have different physical properties (moisture content, density) and, as a result, combust differently. For the purposes of this study, litter is defined as unbroken needles and undecomposed bark flakes, and duff is considered partially or fully decomposed needle and bark litter. In general, litter is usually consumed quickly by flaming combustion, whereas duff typically consumes more slowly by smoldering combustion (Ryan and Frandsen 1991, Sackett 1988). Neither the duration nor the intensity of fire at the bases of our sample trees was monitored directly.

Occasionally, trees burned through at the base and fell during or immediately after the fires, but in most cases, trees were not immediately killed by the fire. Post-fire tree mortality was monitored in 1998 and 2000 by revisiting each tree (Table 1).

5. RESULTS AND DISCUSSION

Mortality of monitored ponderosa pines varied among burns, but was generally low. No data were collected on adjacent unburned stands as controls so it is not possible to discern whether, or by how much, observed levels of mortality exceed background levels for old-growth trees at the various study sites. Similarly, it is impossible to know how the levels of mortality observed in this study compare to historical levels. Future monitoring efforts should include an unburned control group for each burn unit to account for other external factors that could be contributing to tree mortality (non fire-related insect activity, old age, drought, wind, other pathogens, etc.).

Despite the lack of experimental controls in this study however, it is suspected that at least a portion of the mortality observed was a first- or second-order effect of the fires. That is, fire either killed the trees directly by causing sufficient damage to living tissue through heating or actual combustion to halt critical physiological processes or to fell trees (first-order effect), or fire killed the trees by causing harm to living tissues that reduced vigor and increased susceptibility to successful insect and other pathogens colonization that ultimately led to mortality (second-order effect). Of the burns conducted in the spring of 1994 and 1995, only two of the five units experienced any mortality by 1998; no additional monitored trees died on these plots between 1998 and 2000 (Table 1). In contrast, of the burns conducted in the fall of 1997, all five units experienced some mortality (5-10% of monitored trees) by 1998, and three of five units showed additional mortality between 1998 and 2000. Two trees (one each at Old Growth #2 and Wapiti #1) burned through at their bases and were killed during the fires. Of the four burns conducted in the fall of 1998, only one unit experienced any mortality by 2000. Additional monitoring is tentatively scheduled for fall 2003.

Seasonal and multi-year drought is a potential contributor to tree mortality. Trees that do not receive an adequate supply of water and nutrients during the growing season may die as a result, or can show reduced vigor and increased susceptibility to insect- or disease-caused mortality. External factors, such as those that could be caused by fire or other disturbances, that affect the ability of a tree to perform physiological processes (e.g., loss of root mass, photosynthetic mass, or cambium) could compound the effects of drought, or conversely, drought conditions following a fire could amplify negative fire-caused impacts.

Table 1. Sampling dates and tree mortality observations.

Site	Burn Year	Pre-burn No. of trees	Fall 1998 Observation No. dead	Fall 1998 Observation % dead	Fall 2000 Observation No. dead	Fall 2000 Observation % dead
Three Troughs 1	Spring 1994	20	0	0	0	0
Three Troughs 2	Spring 1994	20	5	25	5	25
Three Troughs 3	Spring 1994	19	0	0	0	0
Three Troughs 4	Spring 1994	19	0	0	0	0
Pringle Falls 2	Spring 1995	14	1	7	1	7
Subtotal	Spring	92	6	7	6	7
East End 2	Fall 1997	20	1	5	5	25
Old Growth 1	Fall 1997	20	1	5	1	5
Old Growth 2	Fall 1997	20	2	10	4	20
Wapiti 1	Fall 1997	10	1	10	1	10
Wapiti 2	Fall 1997	10	1	10	3	30
Cottonwood 1A	Fall 1998	9	0 of 9[2]	--	0	0
Cottonwood 1B	Fall 1998	13	0 of 13[2]	--	0	0
Maggie Springs 1	Fall 1998	18	0 of 18[2]	--	2	11
Maggie Springs 2	Fall 1998	15	0 of 15[2]	--	0	0
Subtotal	Fall	135	6	4	16	12
Grand Total	Spring+Fall	227	12	5	22	10

[1]Number of trees ignited at their base.

[2]Immediately post-fire

Moderate to mild drought conditions occurred during the growing seasons of 1994, 1995, and 1996, with slightly more extreme drought in 2000. Drought conditions were absent during the growing seasons of 1997-1999. Lack of mortality during drought years at 3 of 5 spring 1994 and 1995 burn units (Three Troughs, Pringle Falls), and limited mortality at all five fall 1997 burn units by 1998 does not point to a strong compounding influence of drought on old-growth tree mortality during those years (Table 1, Figure 2). More severe drought conditions in 2000 may have contributed to increases in mortality among units burned during the fall of 1997 and 1998. Without 1999 observations however, it is impossible to know whether tree death occurred coincident with more extreme drought conditions in the vicinity of the study areas in 2000 or before. Drought conditions in the mid-1990s may have been too mild to negatively effect the study trees, while slightly drier conditions in 2000 may have worked synergistically with the fires to increase mortality rates by 2000.

Swezy and Agee (1991) speculated that fire-induced loss of fine root mass, and therefore, water and nutrient translocation ability, resulting from the combustion of the basal build-up of forest floor material may contribute to tree mortality. They speculated that loss of annually-grown fine roots during spring burns may have exacerbated summer drought stress. This study did not observe spring-burned units to experience greater mortality than fall-burned units, although this could be explained by differences in individual burn intensities.

Trees with a greater accumulation of litter and duff at their bases may also have greater fine root mass invested within this material. The average pre-burn basal accumulation depth (litter + duff) of dead trees exceeded that of live trees for 5 of 7 units showing mortality by 1998 following the spring burns of 1994 and 1995 and the fall burns of 1997 (Figure 3). Considering additional units burned in 1998, 5 of 8 units that showed mortality by 2000 had greater pre-burn forest floor depth for dead trees.

The average depth of forest floor consumption showed a wide range for live and dead trees, and was actually less for dead trees than for live trees at several units (heavy black overlay bar in Figure 3). Although dead trees had more forest floor on average for some units it was not found that they always experienced greater consumption. Twenty four percent of the trees in the overall sample set (55 of 227 trees) experienced total consumption of the litter and duff at their bases, but only 15 percent of those died by 2000 (8 of 55 trees). This compares to the eight percent mortality found for all other trees. High levels of fuel consumption at the bases of old-growth ponderosa pines may be leading to elevated levels of mortality, however, the limited data from this study suggest only a very weak connection, if any.

Fuel consumption at the bases of the sampled trees was not uniform within or among units. Ryan and Frandsen (1991) observed total litter and duff

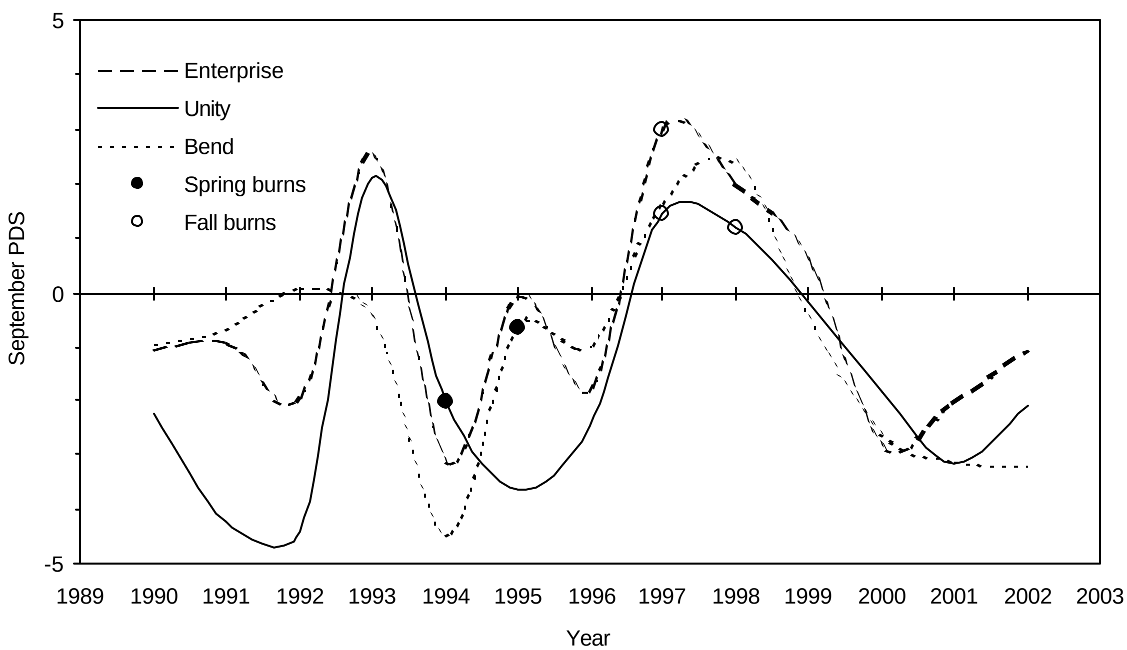

Figure 2. September Palmer Drought Severity Index (PDSI) for locations in the vicinity of the experimental burns. See figure 1 for locations.

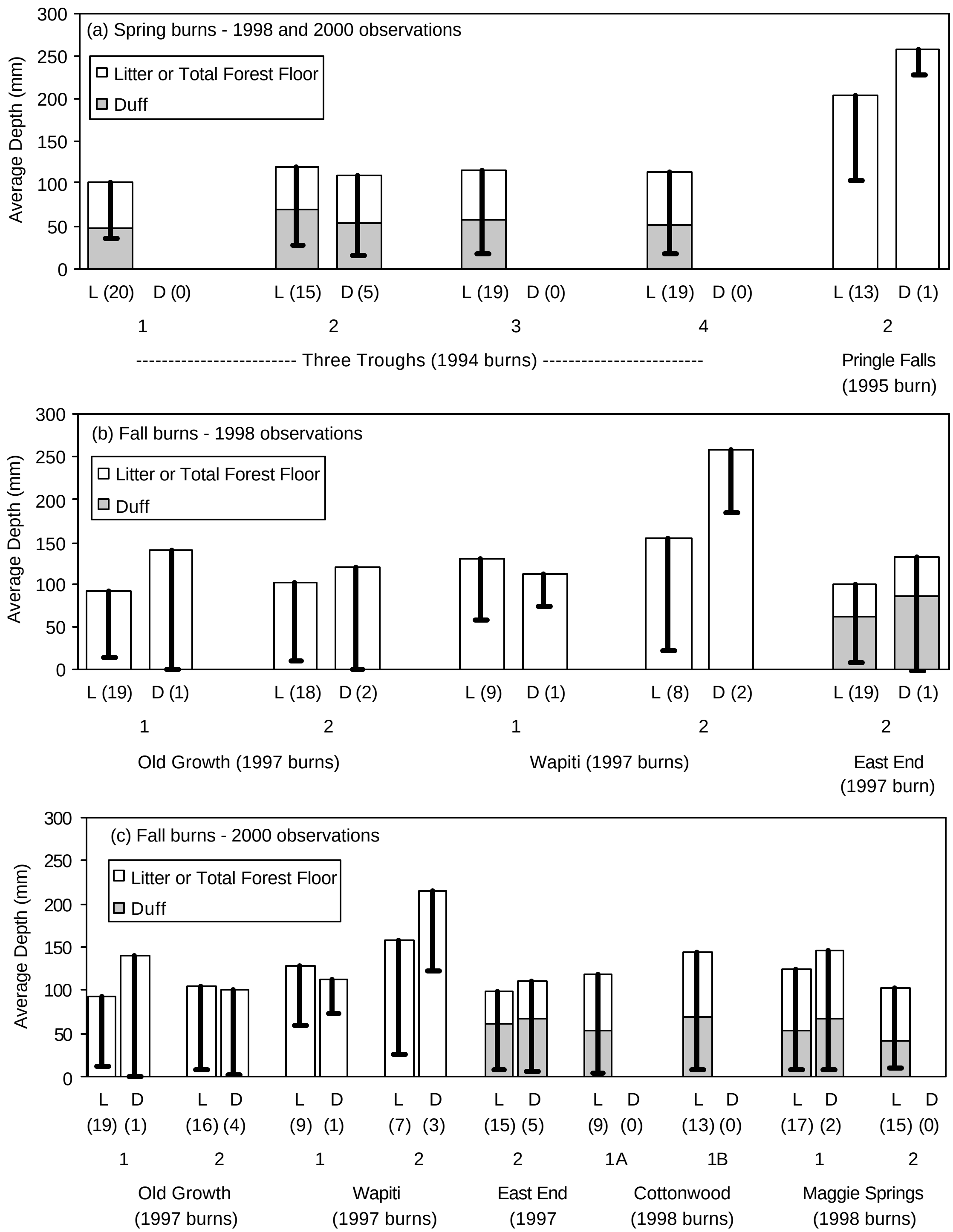

Figure 3. Average forest floor depth for live (L) and dead (D) trees (open and hatched bars), and forest floor consumption (black line) for units burned in the spring (a) and fall fall (b-c). Values in parentheses indicate the number of live and dead trees at each location during each observation year.

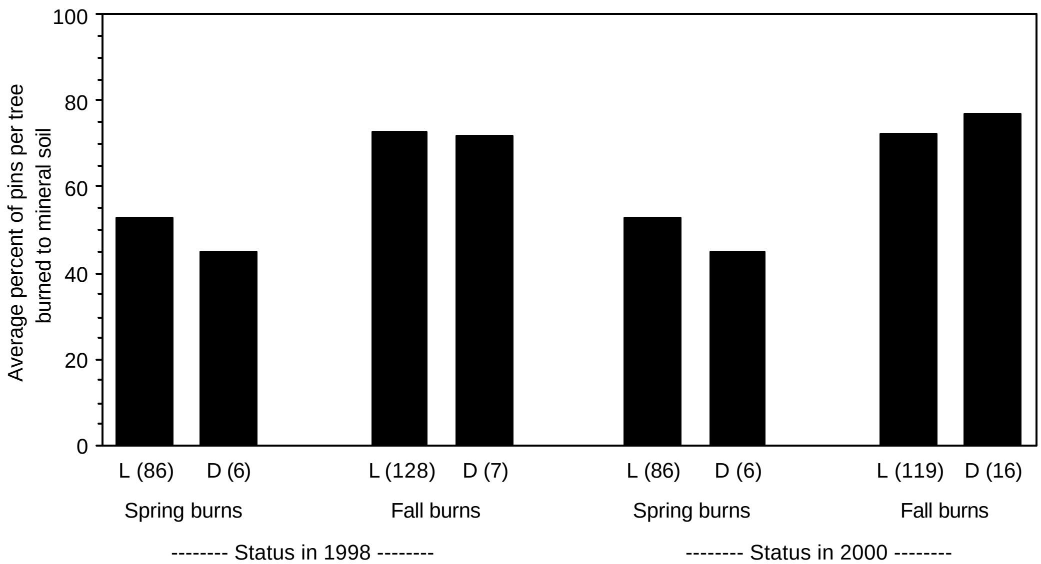

Figure 4. Average amount of the circumference of the bole impacted by total fuel consumption as measured by the average of the percentage of the pins placed around the base of each tree that burned to mineral soil. Burns are split into spring and fall burn units with observations in 1998 and 2000. Values in parentheses indicate the number of live and dead trees in each category. Spring burn units did not change from 1998 to 2000.

consumption around nearly all of their trees. In contrast, on average, the litter and duff fuels around a smaller proportion of the circumference of each tree in this study consumed completely (Figure 4). Only small differences in the amount of the circumference burned to mineral soil were observed between live and dead trees for either spring or fall burns. More of the circumference was found to burn to mineral soil for fall burns than for spring burns. In 1998, mortality was lower for fall burns than for spring burns (4 percent mortality in fall versus 7 percent mortality in spring), despite the observation that trees burned in the fall had greater consumption to mineral soil at their bases. However, by 2000 the trend had reversed (12 percent mortality in fall versus 7 percent mortality in spring) confusing any potential relationship between the amount of total consumption and tree mortality.

Ryan and Frandsen (1991) also note a correlation between tree size and basal accumulation where bigger trees accumulate more litter and duff at their bases. In 1998, average size (both diameter and height) were greater for live trees than for dead trees (Figure 5). By 2000, however, this pattern had reversed as eight additional trees averaging 73 cm dbh died making the average size of dead trees greater than live trees. This seems to suggest that larger trees may experience more delayed mortality. Agee (2003) noted that the average size of trees that died increased as the time since fire interval got longer, but was careful to note that the effects of drought and insect activity could not be separated from the effects of fire. Lack of yearly monitoring makes it impossible to examine potential

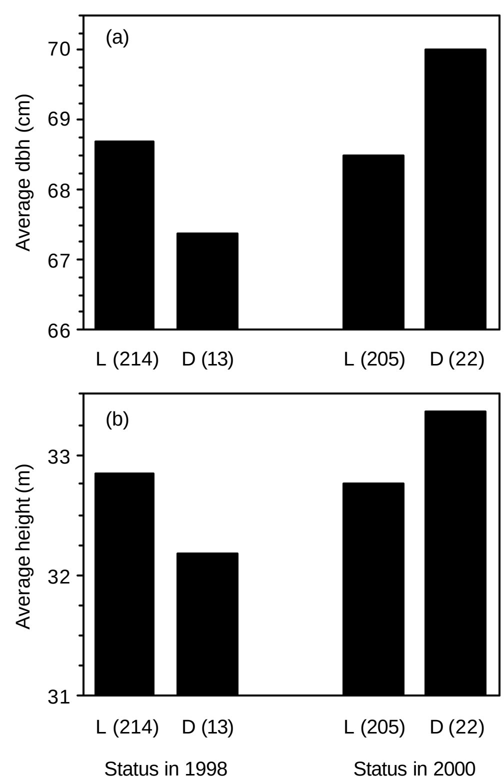

Figure 5. Average diameter at breast height (dbh; a) and average height (b) of live and dead trees in 1998 and 2000. Values in parentheses indicate the number of live and dead trees in each for each observation year.

effects of seasonal and annual drought on mortality. Without unburned controls, it is also impossible to distinguish background levels of mortality from those that might be fire-influenced. Exactly how long a fire's effects last with respect to individual tree mortality is a question that requires further investigation.

As of 2000, mortality did not exceed 30% (3 of 10 trees) on any burn unit, and averaged 10% for all units combined (22 of 227 trees). Three units (East End #2, Old Growth #2, and Wapiti #2) experienced additional mortality between 1998 and 2000. This additional mortality could be the result of drought conditions in 2000, relatively more intense fires, or the delayed expression of negative fire-effects, or a combination.

Many factors contribute to the deaths of large, old-growth ponderosa pines in the dry forests of the West. Insects, disease, drought, competition, wind and fire all affect an individual tree's chances for survival. Concerning fire, whether season of burn, consumption of litter and duff, size of tree, or pre-burn litter and duff depth play a significant role in tree mortality is not clear from this study. A high degree of variability of fire effects between live and dead trees, and among units suggests that future research into old-growth ponderosa pine mortality should incorporate multiple burns to fully evaluate the effects of prescribed fire on old-growth tree mortality.

5.1 Recommendations for future sampling

Understanding what factors influence old-growth ponderosa pine mortality will allow fire managers to apply prescribed fire in such a way as to preserve desirable structural elements (i.e., the large old trees) and move forests toward desired future conditions. While this study had value as a first step toward understanding, additional research should develop and test a whole suite of hypotheses concerning the potential causes of old-growth tree mortality. More thorough documentation of pre-burn conditions (*sensu* Swezy and Agee 1991) of individual trees (e.g., vigor, insect activity, presence of exposed fire scars, etc.), and establishment of unburned controls would allow for more confident assumptions as to causes of mortality. Similarly, post-fire documentation and testing of tree injury and vigor (*sensu* Ryan and Frandsen 1991, Swezy and Agee 1991) would shed light on the nature of tree injuries from fire. Experimentation to document thermal regimes (Swezy and Agee 1991, Ryan and Frandsen 1991, Sackett 1988), both as an impact on boles and roots would also likely shed light on the potential mechanisms for tree injury and death. Fire behavior measurements, and post-burn measurements of heat release (i.e., scorch or char height) and fuel consumption will also be important as these are critical elements in prescribed fire planning and execution. Long-term post-fire monitoring should occur on an annual schedule to determine the duration of the fire effect and any possible synergistic influences on mortality of climate or other disturbances. If fire managers are to successfully use prescribed fire simultaneously as a hazard reduction and a restoration tool, they must understand the ramifications of applying fire under a variety of conditions.

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