# The Use of Silviculture and Prescribed Fire to Manage Stand Structure and Fuel Profiles in a Multi-aged Lodgepole Pine Forest

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***Abstract**—This paper presents several components of a multi-disciplinary project designed to evaluate the ecological and biological effects of two innovative silvicultural treatments coupled with prescribed fire in an attempt to both manage fuel profiles and create two-aged stand structures in lodgepole pine. Two shelterwood silvicultural treatments were designed to replicate as well as enhance the existing multi-aged stand structure on the Tenderfoot Creek Experimental Forest in central Montana: the first, with reserve trees evenly distributed; the second, with reserves contained within small (1/10-1/4 acre) groups. Retention of reserve trees was targeted at 50%, without regard to diameter or species. Eight even distribution and eight group-retention treatments were applied on 16 units totaling 649 acres. Half of the units were broadcast burned following harvest using a common burn prescription on all units. Allowable overstory mortality specified in the prescribed fire plan was 50%. Plot-based fuel inventories and fire effects observations were performed at permanent plot locations prior to and following harvest, and after burning. Fuel moisture samples were acquired immediately prior to ignition. Data from four prescribed-burned treatment units were evaluated for this paper: two even-retention units and two grouped retention units. Harvest activities resulted in significant increases in fine-fuel loading (1-, 10-, and 100-hour fuel), which was subsequently reduced by prescribed fire to near pre-harvest levels. Consumption of large woody fuel was similar for both treatment types. The fire-induced mortality of overstory trees was greater in the even distribution than in the grouped distribution. Despite careful execution of a relatively conservative burn plan, mortality in the even treatments exceeded the prescription threshold of 50% by an additional 28%. Additional data collected at the plots include trees per acre, residual tree mortality, residual tree growth, regeneration, windthrow, hydrologic responses, soil impacts, and beetle activity. A comprehensive summary of the treatments will follow subsequent monitoring scheduled to occur five and ten years after burning.*

## Introduction

The Tenderfoot Research Project is a multi-disciplinary effort designed to evaluate and quantify the ecological and biological effects of innovative restoration treatments in an attempt to both manage fuelbed profiles and create two-aged stand structures in lodgepole pine. The suite of sixteen fire and silvicultural treatments were implemented on the Tenderfoot Creek Experimental Forest (TCEF) in the Little Belt Mountains of central Montana (fig. 1). Although the USDA Forest Service has established seventy-seven experimental forests and ranges, the TCEF is the only reserve dominated by the lodgepole pine forest type (Adams and others 2004). The research presented here was guided by the Tenderfoot Creek Research Project mission (USDA Forest Service 1997):

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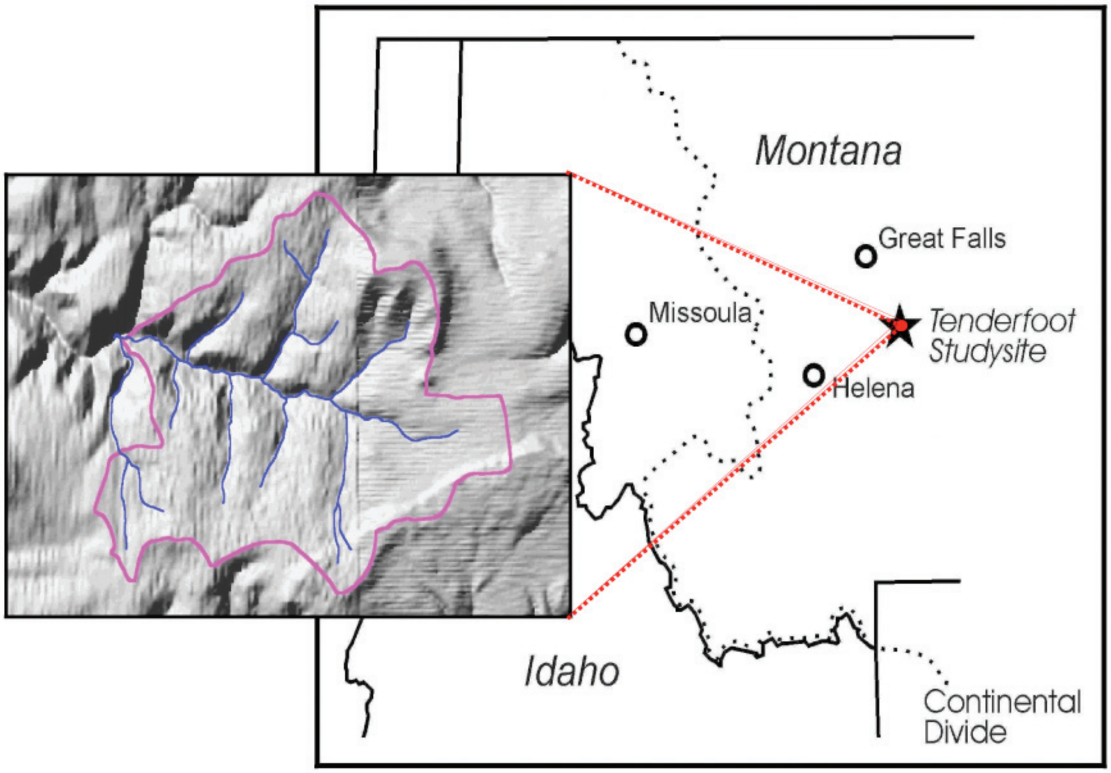


**Figure 1**—The Tenderfoot Creek Experimental Forest is a 9,125 acre watershed located in Central Montana.

> *"Test an array of management treatments for regenerating and restoring healthy lodgepole pine forests through emulation of natural disturbance processes, but avoiding catastrophic-scale disturbances."*

This paper documents a preliminary exploration of selected results following completion of all phases of treatment activities. It is our intent to follow this paper with a comprehensive compilation of results that synthesize all aspects of the multi-disciplinary efforts.

# Background

The subalpine lodgepole pine forest type is estimated to cover about 15 million acres in the western United States and a much larger area (nearly 50 million acres) in western Canada (Lotan and Critchfield 1990). Its latitudinal range extends from Baja (35° latitude) to the Yukon (65° latitude), and longitudinally from the Pacific coast to the Black Hills of South Dakota. In the Rocky Mountains of the Interior West, lodgepole pine is the third most extensive forest type. The adaptations of lodgepole pine to severe, stand replacement fire—in particular its serotinous cones—have long been acknowledged (Lotan and Perry 1983). Less well-known is that lodgepole pine forests also burn in low- to mixed-severity fire, often creating two-aged stands and variable patterns across the landscape (Agee 1993; Arno 1980; Barrett and others 1991). Numerous studies in the interior Northwest have documented the intricate mosaic patterns of historical fires in lodgepole pine forests (Arno and others 1993; Barrett 1993; Barrett and others 1991). Newer studies are looking more closely at the details of these patterns and their implications for management (Hardy and others 2000; Stewart 1996). These studies are being used as a basis for designing and refining silvicultural and prescribed fire treatments in National Forests of the Northern Rocky Mountains.

Historically, clearcutting and broadcast burning of lodgepole pine forests was considered to be economically efficient and conducive to regeneration. These treatments roughly mimic effects of natural, stand-replacement fires. More recently, foresters have recognized that burning irregularly shaped cutting units containing patches of uncut trees, while also creating snags, would far more effectively simulate effects of historical fires. One negative effect from leaving patches or individual uncut trees in lodgepole pine forests is the vulnerability of the species to windthrow. However, recognition of the extent of the mixed-severity fire regime in lodgepole pine, and the recent success and experience gained from other pilot projects have led to continued efforts toward more ecologically-based management of lodgepole pine.

Paired watersheds at TCEF have been monitored for several years and serve as a basis for comparison of water quantity and quality under different cutting and burning treatments. A detailed fire history study and map completed by Barrett (1993) documents a sequence of stand replacement and mixed-severity fires extending back to 1580 (fig. 2A). Stand-replacing burns occurred at intervals of 100 to over 300 years, with low- or mixed-severity burns often occurring within these intervals. Two-aged stands cover about half the area at TCEF, ranging in size from a few acres to about 1,000 acres (fig. 2B). Experimental treatments at TCEF were designed to reflect these historical disturbance patterns. The study design for TCEF integrates observations of on-site treatment response with water yield and water quality data from paired, experimental sub-watersheds that have monitoring flumes.

In this paper we present new research and preliminary results specifically related to fuel management that may lead to more complete knowledge and innovative techniques to manage lodgepole pine forests in the Interior West.

# Methods

## *Timeline for Planning and Execution*

The timeline for execution of the study is given in table 1. The Tenderfoot Creek Experimental Forest is administered by the Rocky Mountain Research Station (RMRS) in collaboration with the Lewis and Clark and National Forest. Research is proposed and planned by RMRS and timber sales on the EF are conducted and administered by the National Forest. Implementation of any research on the Experimental forest requires close and continuous cooperation between research and National Forest personnel.

Planning for this extensive study was initiated by Forest Service Research in 1995, and an interdisciplinary planning team was assembled by the Lewis and Clark National Forest to accomplish the Environmental Assessment (EA) process required for the project. The EA was completed in 1998 and a final decision notice was issued in early 1999. Construction of approximately 2 ½ miles of roads was accomplished in 1999, with harvesting completed in 2000. Prescribed burning operations were executed in 2002 and 2003.

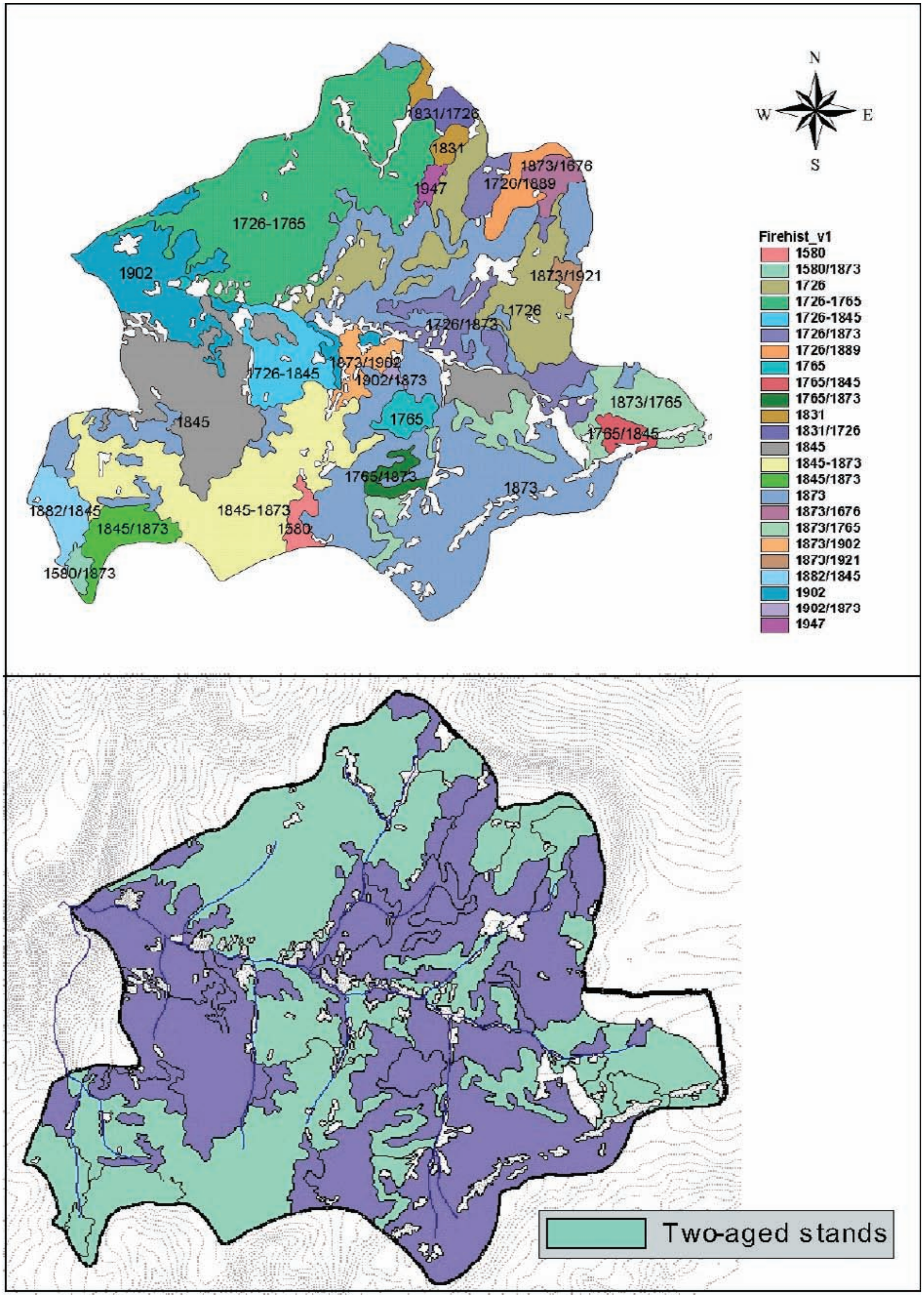


**Figure 2**—An extensive fire history study done at TCEF in 1986 documented a complex mosaic of fires dating back to 1580 (top), and determined that about half of TCEF is comprised of two-aged stands resulting from low- to mixed-severity fire(s).

**Table 1**—Timeline of activities, from project proposal to post-burn assessments.

| Date(s) | Activity |
|---|---|
| 1995 – 1997 | Draft Research Proposal<br>MOU between FS Research and L&C Nat'l Forest |
| 1997 – 1998 | Planning with L&C Nat'l Forest<br>Scoping/public comment |
| Spring 1999 | Environmental Assessment |
| 1999 – 2000 | Establish treatment units<br>Sale administration<br>Road installation<br>Pre-harvest sampling<br>Harvest activities<br>Prepare burn prescriptions |
| Autumn 2001 | Burn all piles and windrows |
| Summer 2002 | Post-harvest sampling |
| 2002 – 2003 | Burn treatments |
| 2003 – 2005 | Post-burn sampling and assessments |

## *Treatment Descriptions and Locations*

The large-scale set of treatments were implemented on two sub-watersheds within the 9,125-acre Experimental Forest, with two adjacent sub-watersheds left as untreated controls. The two treatment sub-watersheds are Spring Park Creek (north of Tenderfoot Creek) and Sun Creek (south of Tenderfoot Creek) (fig. 3). The silvicultural system used was a two-aged system termed "shelterwood with reserves," with two forms of leave tree retention: one with leave trees evenly distributed, and the other with leave trees retained in unharvested retention groups distributed across the treatment units in a noticeably uneven pattern. The harvest system utilized in all units included felling by excavator-mounted "hot saws" and whole-tree skidding to centralized processing locations where the trees were de-limbed and decked for transport. All unutilized materials were piled and burned on site. About 50 percent of the basal area and stems were removed in both treatment types, with low intensity underburns in one-half of the treatment units. One objective for low intensity underburns was mitigation of surface fire hazard exacerbated by high loadings of harvesting debris (slash). The fuelbed components most relevant to a hazard reduction objective are the fine fuels: 1-hour, 10-hour, and 100-hour timelag fuelbed components. It is these fuel particles that contribute most significantly to surface fire behavior, and a reduction in loading of these fuelbed components was a principle objective in the treatment prescription. The sum of these three fuelbed components is hereafter referred to as "fine-fuel loading."

The treatment labels and descriptions are summarized in table 2, and a satellite (IKONOS®) image of the two Sun Creek treatments is shown in figure 4.

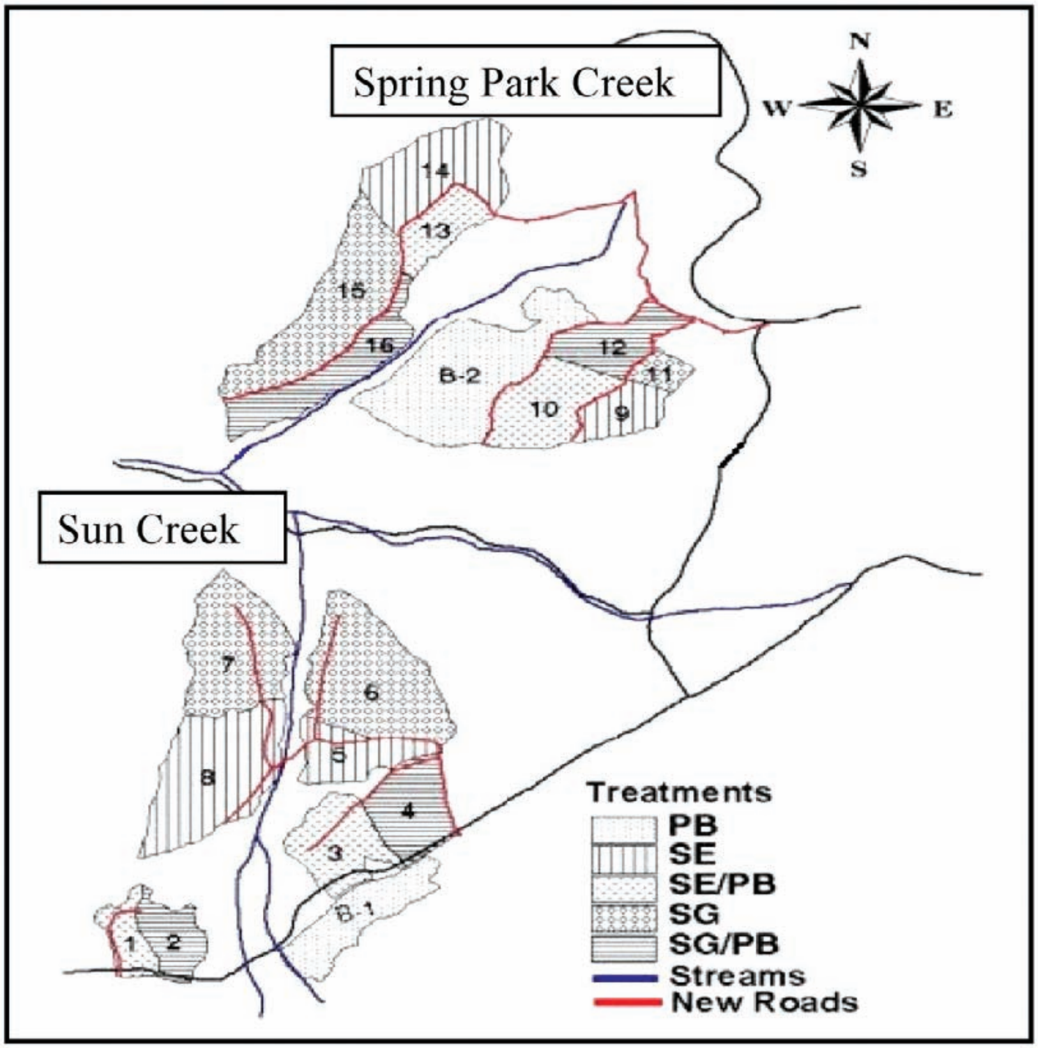


**Figure 3**—Treatment units were located in two sub-watersheds of Tenderfoot Creek: Spring Park Creek (south aspect, north of Tenderfoot Creek), and Sun Creek (north aspect, south of Tenderfoot Creek).

**Table 2**—Treatment labels and descriptions.

| Treatment label | Distribution of retention trees | Prescribed fire |
|---|---|---|
| SE | Evenly distributed | None |
| SEB | Evenly distributed | Burned (B) |
| SG | Group-retention | None |
| SGB | Group-retention | Burned (B) |

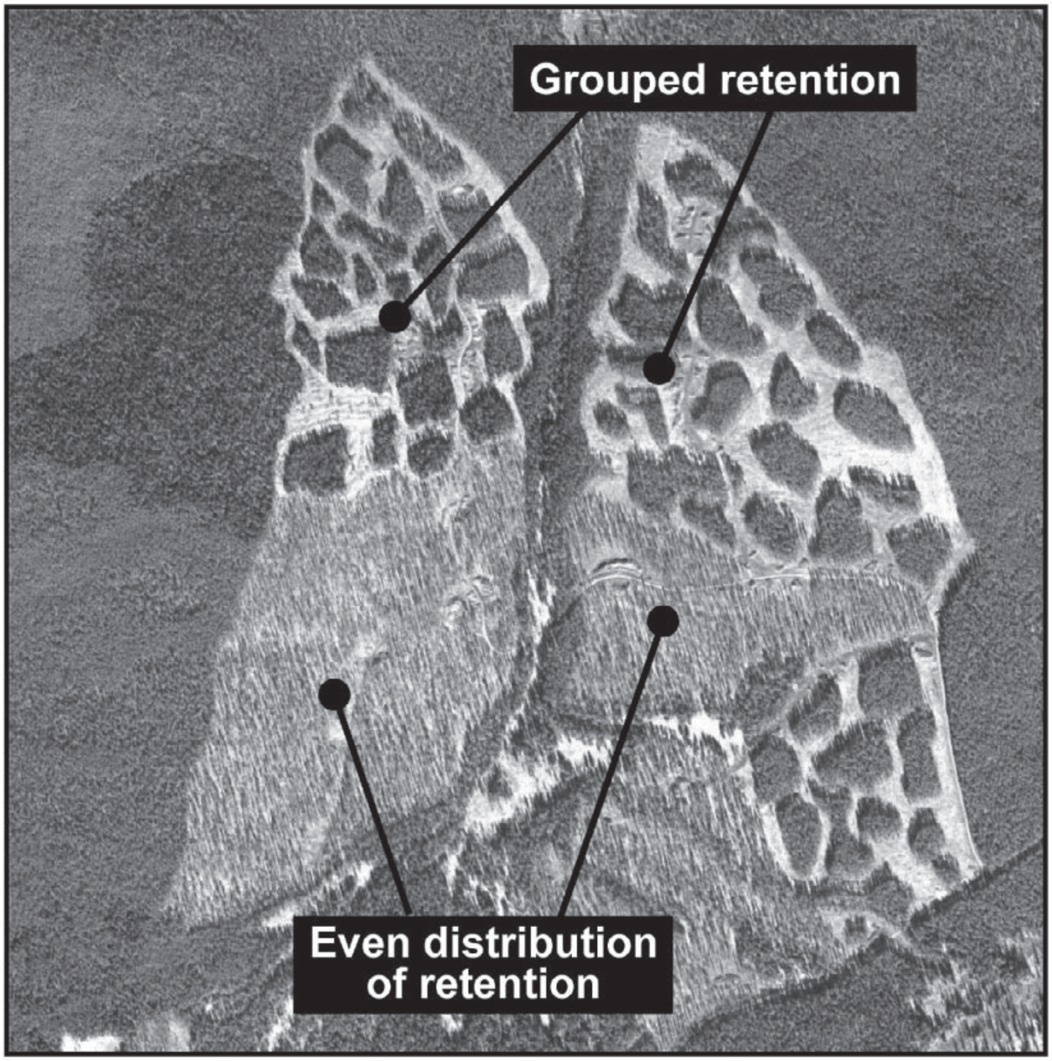


**Figure 4**—An IKONOS® satellite image showing the two types of "shelterwood with reserves" silvicultural treatments.

## *Field Sampling*

The average size per treatment unit was 43 acres. An average of 32 sampling plots per unit (about one plot per 1.3 acres) were permanently located to facilitate multiple-year sampling at each plot—pre-harvest, post-harvest, and post-burning. In addition to a comprehensive assessment of vegetation and stand characteristics, fuelbed data were collected on one-half of the plots, where two 75' line-intercept fuel transects were installed and permanently located at each plot. Fuel loadings (mass per unit area) of all fuel components along each transect were then estimated per Brown (1974). This allows the generation of summary statistics and analyses that can be calculated at multiple levels—plot, unit, and treatment type (pooled-unit).

The consumption by prescribed burning of large woody fuel was determined by measuring the reduction in diameter of sampled logs using wires installed prior to burning. Following burning, the wires were tightened, and the difference in wire length was used to determine reduction in diameter and associated mass.

Following burning, annual assessments will continue for several years to document windthrow (a problem common to lodgepole pine) and both fire- and insect-caused tree mortality. The burn prescription for both the *Even* and *Grouped* treatment type specified a maximum target overstory tree mortality of fifty percent. Data from three years of post-burn mortality sampling are available for the present analysis.

## Analysis

Although the study included treatment units in both Spring Park Creek and Sun Creek sub-watersheds, we did not obtain pre-harvest sample data from the Sun Creek Units. Therefore, fire- and fuels-related data spanning all phases of the study (pre-harvest, post-harvest, and post-burn) are only available for Spring Park Creek.

The fuels analysis in his paper is focused on the four treatment units within Spring Park Creek that included prescribed burning following harvest (SEB and SGB). This selection constraint for the current analysis provides two pairs of treatment units: one pair of *Even* distribution with burning (SEB—units 10 and 13), and one pair of *Grouped* retention with burning (SGB—units 12 and 16). The Spring Park Creek units are illustrated in figure 5.

Prior to pooling the fine-fuel loading data from pairs of units, we evaluated the individual unit statistics to ensure similarity of variances and central tendencies between units within a pooled pair. This analysis was done for each of pre-harvest, post-harvest, and post-burn fine-fuel loading data. The box-and-whisker plots given in figure 6 present median values and interquartile ranges (expressed as tons per acre), and also illustrate the 0.05 *Student's t* statistic. We can conclude from the plots in figure 6 that no significant difference existed in fine-fuel loading between pairs of units in either the *Even* retention pool (fig. 6A) or *Grouped* retention pool (fig. 6B). Therefore, results will be presented with respect to the pooled classes.

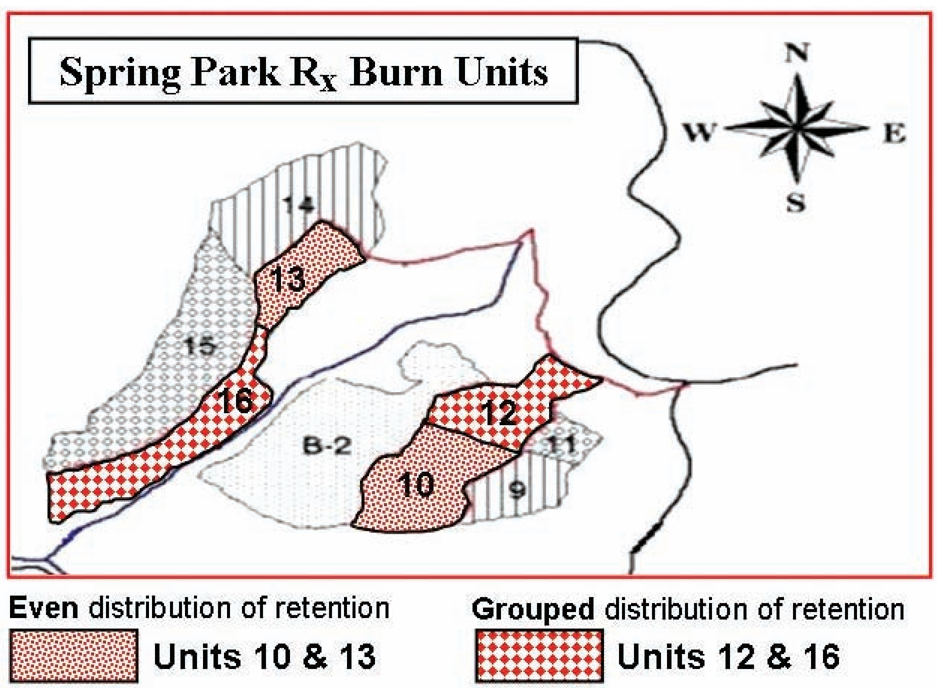


**Figure 5**—Two pairs of units in Spring Park were selected for analysis: SEB (units 10 & 13), and SGB (units 12 & 16).

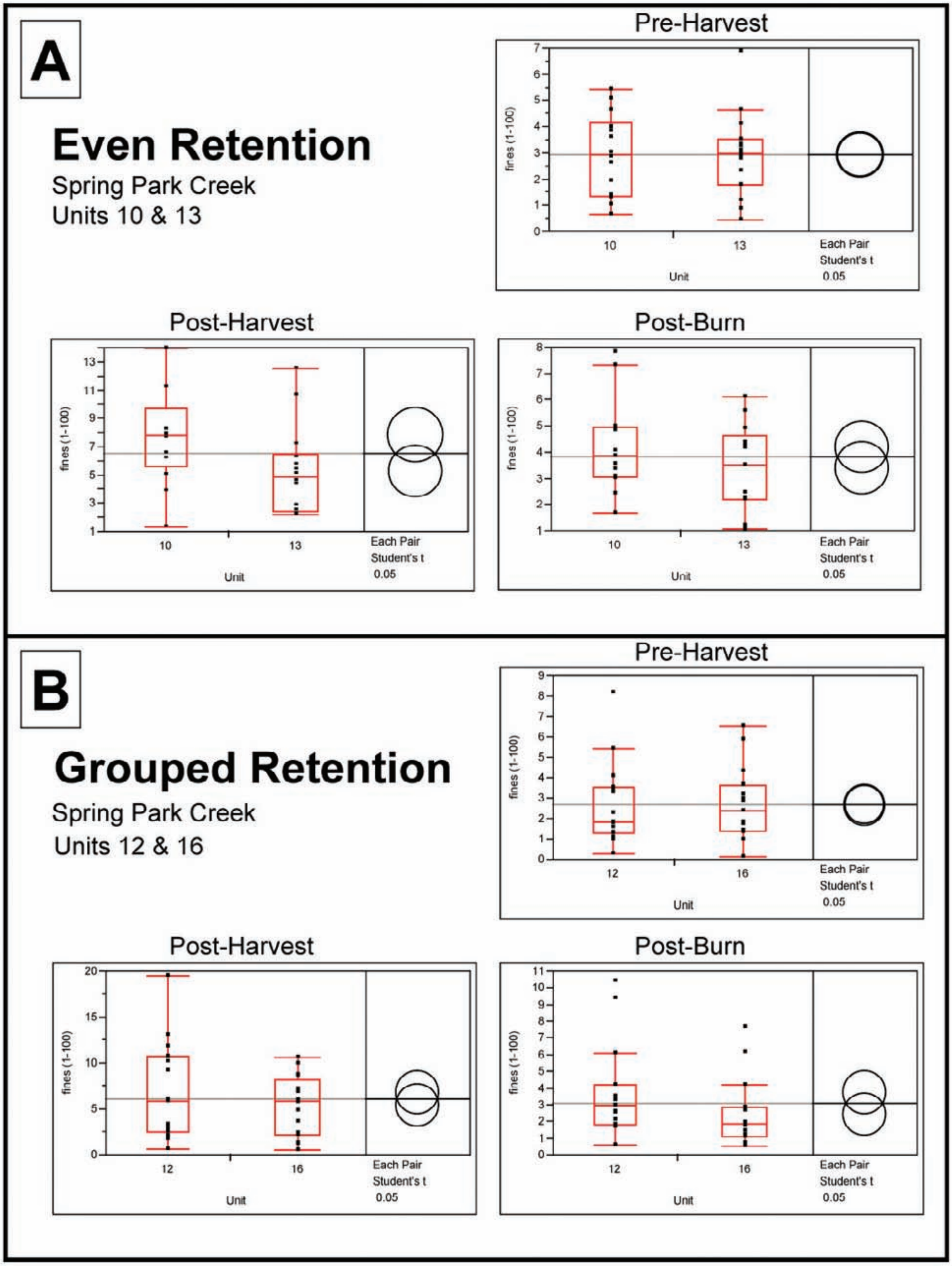


**Figure 6**—Median values, interquartile ranges, and the 0.05 *Student's t* statistic (expressed as tons per acre) presented as confirmation that fine-fuel loadings in the pooled units are not significantly different for either the Even (6A) or Grouped (6B) treatments.

# Results

We present results of preliminary analyses by comparing pre-harvest, post-harvest and post-burn conditions between the two harvest-and-burn treatments on Spring Park Creek. As described above in methods, two treatment units are pooled for each of the two treatment types—SEB and SGB. Results presented here are limited to fine-fuel loading, large-woody fuel loading, and fire-caused overstory tree mortality.

**Fine-Fuel Loading**—Harvesting activities contributed approximately 3.5 tons per acre of fine fuels in both the *Even* and *Grouped* treatments, as illustrated in figure 7 by the mean values of all plots within the pooled units for each treatment type—this is roughly a one hundred percent increase from pre-harvest conditions (fig. 7). The prescribed burning treatment following harvest reduced the fine-fuel loading to near pre-harvest conditions in both treatment types; reductions were 2.7 tons per acre and 3.0 tons per acre for the *Even* and *Grouped* treatments, respectively. While the post-harvest fine-fuel loadings were significantly higher ($\alpha=0.05$) than either the pre-harvest or post-burn loadings for both treatment types, the differences between pre-harvest and post-burn fine-fuel loadings were not statistically significant ($\alpha=0.05$) for either treatment type. In summary, the harvesting activities resulted in significant increases in fine-fuel loadings, and post-harvest prescribed burning effectively reduced the fine-fuel loadings to pre-harvest levels.

**Large Woody Fuel Loading**—We compared the consumption (mass reduction measured in tons per acre) of large woody fuel due to prescribed burning between the *Even* and *Group* treatment types. Mean values and 95% confidence intervals representing all plots within the pooled units for each treatment type are presented in figure 8. In both treatment types, less than one ton per acre of large woody fuel was consumed, with no significant difference between the treatment types ($\alpha=0.05$) (fig.8). The percent mass reduction in large woody fuels for the *Even* and *Group* treatment types was

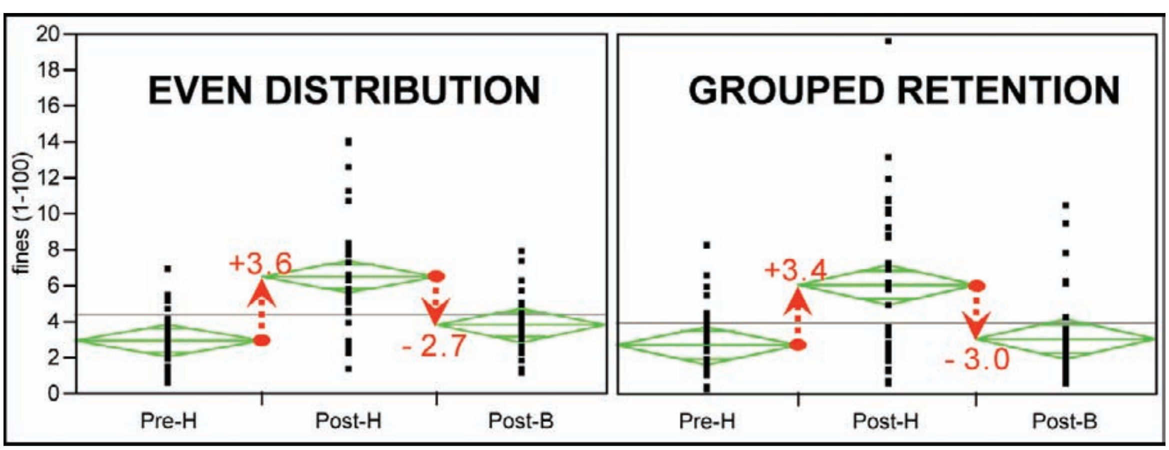


**Figure 7**—Changes in fine-fuel loading (tons/acre) between pre-harvest, post-harvest, and post-burning for pooled *Even* (left) and *Grouped* (right) distribution units.

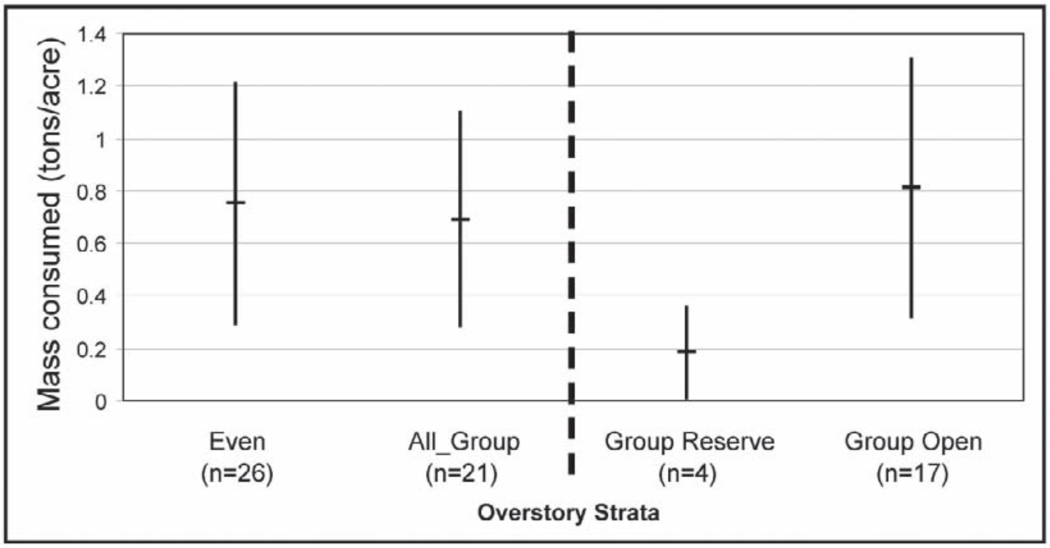


**Figure 8**—Comparison of means and 95% confidence intervals for consumption of large woody fuel (1000-hour) between Even and Grouped (*All_Group*) distributions. The data labeled "*Group Reserve*" are from plots within the grouped retention areas, and data labeled "*Group Open*" are from plots located in the open (harvested) areas between groups.

14.5% and 12.9%, respectively. Within the grouped treatment types are two distinct distributions of overstory: 1. The un-harvested retention groups; and 2. The completely harvested (effectively, "clearcut") open areas between grouped reserves. These two strata are labeled in figure 8 as "*Group Reserve*" and "*Group Open*," respectively. While the total mass consumption of large woody fuel in the *Group Open* plots was somewhat greater than the average for the overall group treatment (labeled "*All_Group*" in figure 8), consumption within the *Group Reserves* was significantly lower than either the *Group Open* or the *Even* distribution ($\alpha$=0.05). In terms of percent mass reduction in large woody fuels within the two *Group* treatment strata, there was a 19.5% reduction in mass for the *Group Open* strata and only a 2.7% reduction for the *Group Reserves* strata.

**Fire-induced Overstory Tree Mortality**—Although most of the results presented here have been confined to the Spring Park treatments, data on fire-induced overstory tree mortality were acquired and analyzed for treatments in both Spring Park Creek and Sun Creek. Mortality data from each of the first three years following burning are presented in figure 9. Within a treatment type (*Even* or *Group*) the three-year trends are similar for both sub-watersheds. However, a general comparison of mortality between the two sub-watersheds indicates higher levels of mortality in the Spring Park units, regardless of treatment type (fig. 9). By the third year following burning, mortality in the *Even* treatments was twenty-three percent and thirty-seven percent higher than for the *Group* treatments in Sun Creek and Spring Park, respectively. The highest mortality, seventy-eight percent, was observed for the *Even* treatment type in Spring Park— twenty-eight percent higher than the maximum prescription target of fifty percent.

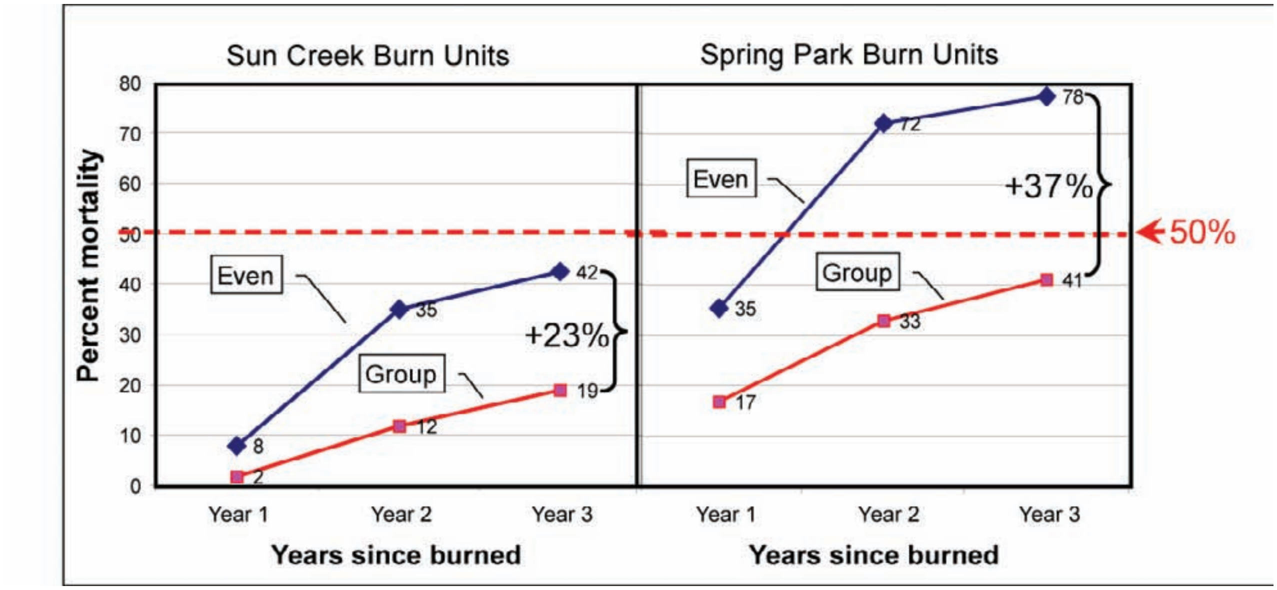


**Figure 9**—Fire-caused mortality was much higher for the Spring Park units than for Sun Creek; mortality for the even distribution was much higher (23%-37%) than for the grouped distribution; and in the even distribution for Spring Park mortality greatly exceeded the prescribed upper limit of 50%.

# Discussion

Specific evidence presented here regarding the consequences related to two of four treatment alternatives is limited to fine-fuel loadings, consumption of large woody fuel, overstory tree mortality, and anecdotal observations. The significant increase in fine-fuel loadings resulting from harvest activities was well mitigated by post-harvest prescribed burning. Although fine-fuel loadings were effectively doubled by harvest activities, the absolute loadings were not particularly high (3.5 tons/acre). In lodgepole pine, however, the vulnerability of the thin-barked species to bole-related mortality is high, relative to most other coniferous species. This makes management of fine-fuel loadings—the principle contributor to surface fire intensity—of paramount importance. Despite very careful execution of a conservative prescribed fire plan, increased levels of fine-fuel loadings caused by the harvesting activities in the *Even* distribution treatment were high enough to cause unacceptable fire-induced mortality. During a typical wildfire season, most fuel and weather conditions would be significantly warmer, drier, and windier than conditions under which the prescribed burning treatments were applied. In such cases, the fine-fuel loadings present following the harvesting activities would lead to dramatic, unacceptable increases in overstory tree mortality. For example, the comparison of mortality between the Sun Creek units and the Spring Park Creek units shown in figure 9 indicates much lower mortality for the Sun Creek units. Despite our desire to burn all units within similar weather and fuel conditions, the relative humidity was considerably higher during the burning operations in Sun Creek, with lower temperatures and wind speeds. Although not considered in the statistical analyses, these conditions provide substantial anecdotal evidence supporting the sensitivity of the lodgepole pine forest type to fire-weather conditions.

In contrast to the prescriptions targeting reductions in fine-fuel loading through prescribed fire treatments, there is neither a fire hazard-related nor ecological advantage to burning of large woody fuel components (there are, in fact, a number of advantages to retaining large woody biomass). When the large woody fuel becomes involved in combustion, there are significant increases in heat flux to the soil and organic surface components, and also production of significantly elevated levels of smoke emissions from combustion of the large woody fuels as well as other biomass associated with the large fuel combustion. There was no significant difference in large woody fuel consumption between the two treatment types, however, so there are no management implications associated with large-woody fuel consumption.

Although there is an on-going field effort to assess and document windthrow in all treatment units, quantitative data are not yet available. However, anecdotal evidence from observations over the short period of time since completion of management activities show significant windthrow in several of the *Even* treatment units. In contrast, windthrow in the Group treatment have been observed to be limited to an occasional tree at the perimeter of the retention groups.

These preliminary results provide a first-look at the relative successes of innovative silvicultural and prescribed fire treatments targeting restoration and maintenance of lodgepole pine forest systems. They are not, however, sufficient enough to support conclusions from which to formulate management direction. The research mission for TCEF directed us to "test an array of management treatments for regenerating and restoring healthy lodgepole pine forests through emulation of natural disturbance processes, but avoiding catastrophic-scale disturbances." Results from further examination of the complete data set from this study will be integrated with results from other Tenderfoot Creek Research Project studies in a comprehensive assessment of the feasibility and consequences of these innovative treatments. More management direction may be provided at that time.

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