Management Guide to Ecosystem Restoration Treatments:

Two-Aged Lodgepole Pine Forests of Central Montana, USA

United States Department of Agriculture
Forest Service
Rocky Mountain Research Station
General Technical Report
RMRS-GTR-294

September 2012

Sharon M. Hood
Helen Y. Smith
David K. Wright
Lance S. Glasgow

Hood, Sharon M.; Smith, Helen Y.; Wright, David K.; Glasgow, Lance S. 2012. **Management guide to ecosystem restoration treatments: two-aged lodgepole pine forests of central Montana, USA.** Gen. Tech. Rep. RMRS-GTR-294 Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 126 p.

Abstract

Lodgepole pine is one of the most widely distributed conifers in North America, with a mixed-severity rather than stand-replacement fire regime throughout much of its range. These lodgepole pine forests are patchy and often two-aged. Fire exclusion can reduce two-aged lodgepole pine heterogeneity. This management guide summarizes the effects of thinning and prescribed burning treatments in an effort to restore two-aged lodgepole pine stands on the Tenderfoot Creek Experimental Forest, Montana. We report changes in tree density and fuel loading following thinning and prescribed burning. Results are organized by unit to help users best match a study unit stand condition and treatment to his/her own stand and proposed treatment to estimate potential treatment effects.

Keywords: lodgepole pine, mixed severity, prescribed fire, harvest, shelterwood, uneven-aged management, two-aged

You may order additional copies of this publication by sending your mailing information in label form through one of the following media. Please specify the publication title and series number.

Publishing Services

Telephone (970) 498-1392
FAX (970) 498-1122
E-mail rschneider@fs.fed.us
Web site http://www.fs.fed.us/rm/publications
Mailing address Publications Distribution
Rocky Mountain Research Station
240 West Prospect Road
Fort Collins, CO 80526

The Authors

Sharon M. Hood is an Ecologist with the Fire, Fuel, and Smoke Science Program located at the USDA Forest Service, Rocky Mountain Research Station's Fire Sciences Laboratory in Missoula, Montana. She completed a B.S. degree in Forestry from Mississippi State University, a M.S. degree in Forestry from Virginia Polytechnic Institute and State University, and is pursuing a Ph.D. in Biology at the University of Montana.

Helen Y. Smith is an Ecologist with the Fire, Fuel, and Smoke Science Program located at the Rocky Mountain Research Station's Fire Sciences Laboratory in Missoula, Montana. She completed an A.A.S. degree at Flathead Valley Community College in Kalispell, Montana, and a B.S. degree in Wildlife Biology and M.S. degree in Resource Conservation, both from the University of Montana, Missoula.

David K. Wright is an Ecologist with the Forest and Woodland Ecosystems Program located at the Rocky Mountain Research Station's Forestry Sciences Laboratory in Missoula, Montana. David completed a B.S. degree in Wildlife Science at Purdue University and a M.S. degree in Forestry at Virginia Polytechnic Institute and State University.

Lance S. Glasgow is a Forestry Technician with the Fire, Fuel, and Smoke Science Program located at the Rocky Mountain Research Station's Fire Sciences Laboratory in Missoula, Montana. During the preparation of this report he worked for the Forest Woodland Ecosystems Program at the Rocky Mountain Research Station's Forestry Sciences Laboratory in Missoula, Montana. Lance completed a B.S. degree in Environmental Biology at the University of Southern Mississippi and a M.S. degree in Environmental and Plant Biology at Ohio University.

Acknowledgments

We thank the Lewis and Clark National Forest personnel who implemented the treatments and made this study possible, particularly Steve Zachary, Jess Secrest, and Steve Martin. Ward McCaughey, Glenda Scott, and Carl Fielder designed the silvicultural prescriptions. Colin Hardy and Steve Zachary designed the burn prescriptions, and Darrell Schulte modeled expected fire behavior. Numerous technicians collected data for this project: Leon Theroux, Jack Schmidt, Cassandra Koerner, Virginia Arensberg, Myron Holland, Brenda Yankoviak, Courtney Couch, Signe Leirfallom, Violet Holley, Greg Cohn, Megan Delaurentis, Brian Izbicki, Duncan Lutes, Connie Flores, Ben McShan, Robert Ahl, Karen Stockman, and Matt Witherspoon; we thank them for their hard work and attention to detail. Emily Schembra created the photopoint pages. We also thank Colin Hardy, Tanya Murphy, and Glenda Scott for technical reviews and Scott Baggett for statistical review. The Bitterroot Ecosystem Management Research Project, Rocky Mountain Research Station Fire, Fuel, and Smoke Research Program and Forest and Woodlands Ecosystem Program, and USDA Forest Service, Forest Health Protection, Evaluation Monitoring Proposal #INT-EM-F-11-03 each funded portions of this project.

The Management Guide Series

This report is second in a series of publications that detail restoration, fuel reduction, and silvicultural treatment effects on ecosystems (Keane and Parsons 2010). It presents statistical summaries, treatment descriptions, and photographs by treatment unit at each time interval. This guide is intended as a reference to identify possible impacts of a restoration treatment at a fine scale by matching a proposed treatment for a stand to the most similar treatment unit presented in this report based on vegetation conditions, fire intensity, and geographic area. This guide differs from most other reports in that it presents results at the individual treatment unit level; there are no analyses of differences across treatment units or across research sites. This guide is intended to help plan and design ecosystem restoration treatments by informing managers of possible effects of thinning and prescribed burning treatments on trees and fuels.

How to Use This Management Guide

To use this guide, the manager matches the conditions of the proposed treatment and site to similar stratifications within this guide. First, select the proposed treatment (no action, group shelterwood, even shelterwood, group shelterwood and burn, and even shelterwood and burn). Next, match the local site to the one most similar to the study site within the chosen treatment. The manager can then reference the effects of the treatments detailed in this guide to craft cutting and/or prescribed burning prescriptions to achieve management objectives. The following is a set of steps that provide an example of how this guide can be used for lodgepole pine (*Pinus contorta* Douglas ex Louden var. *latifolia* Engelm. ex S. Watson) restoration in central Montana:

Step 1—Select site. Select a site or area for possible ecosystem restoration treatment.

Step 2—Identify the characteristics. Estimate the dominate fire regime (non-lethal surface fire, mixed-severity fire, or stand-replacement fire), topographic setting (aspect, slope, and elevation), geographic area, habitat type, and dominant vegetation.

Step 3—Develop a proposed treatment. Choose a treatment to emulate and use it to craft a specific prescription.

Step 4—Match local pretreatment site conditions and proposed treatment to a similar treatment study unit within this guide. Within the chosen treatment (no action, group shelterwood, even shelterwood, group shelterwood and burn, and even shelterwood and burn), select one that most closely resembles the proposed local treatment area based on pretreatment tree density, fuel loadings, and vegetation conditions.

Step 5—Use the treatment unit effects described in this guide to inform management action. Data from posttreatment monitoring help to:

- estimate effects of proposed treatment for planning and National Environmental Policy Act (NEPA) analysis;
- design cutting and burning prescriptions to meet management objectives;
- prioritize areas for treatments; and
- fine-tune proposed local treatments to achieve desired effects.

Contents

Introduction

Lodgepole pine (*Pinus contorta* Douglas ex Louden var. *latifolia* Engelm. ex S. Watson)-dominated forest covers an estimated 15 million acres (6 million ha) in the western United States and 50 million acres (20 million ha) in Canada (Lotan and Critchfield 1990). Its latitudinal range extends from Baja, Mexico (35° latitude) to the Yukon, Canada (65° latitude), and longitudinally from the Pacific coast to the Black Hills of South Dakota, USA. 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).

These studies are 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 the most economical and efficient method for 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 mixed-severity wildfires. One negative effect from leaving patches or individual uncut trees in lodgepole pine forests is the vulnerability of the species to windthrow (Alexander 1986). 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 (Hardy and others 2000) have led to continued efforts toward more ecologically based management of lodgepole pine. In this report, we present unit-level treatment results specifically related to fuel management to improve understanding of how other two-aged lodgepole pine stands in the Interior West may respond to different thinning and burning prescriptions.

Lodgepole Pine Ecology

Lodgepole pine has one of the widest ranges of environmental tolerance of all North American conifers, growing from the Yukon Territory, Canada, south to Baja California, Mexico (Lotan and Critchfield 1990). In the Northern Rocky Mountains, lodgepole pine grows under minimum temperatures of -70 °F (-57 °C) to over 100 °F (38 °C), with average daily lows in July frequently below freezing at high elevations. It can survive frost pockets where other tree species do not (Lotan and Critchfield 1990). Nearly pure stands of lodgepole pine in the Northern Rockies occur between the upper limit of the Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *glauca* [Beissn.] Franco) series and the lower limit of the subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) series. In Montana, these stands are especially well developed on the broad ridges and high valleys near and east of the Continental Divide (Arno 1980).

Because of its wide ecological amplitude (both in latitude and elevation), lodgepole pine grows from nearly pure stands to stands of mixed-conifer with many associated species. Lodgepole pine is a minor seral species in warm, moist habitats and a dominant seral species in cool, dry habitats (Lotan and Critchfield 1990). It occurs in some places as even-aged, single storied stands where fire, cones, and climatic conditions combined to produce large numbers of seed at one time. Elsewhere, it grows as two-aged, multistoried stands (Anderson 2003). Lotan and Critchfield (1990) described four lodgepole pine successional roles.

1. Minor Seral—A component of the even-aged stands rapidly being replaced by shade-tolerant associates in 50 to 200 years.
2. Dominant Seral—The dominant cover type of even-aged stands with a vigorous understory of shade-tolerant species that will replace lodgepole pine in 100 to 200 years.
3. Persistent—The dominant cover type of even-aged stands with little evidence of replacement by shade-tolerant species.
4. Climax—The only tree species capable of growing in a particular environment; lodgepole pine is self-perpetuating.

Lodgepole pine produces seed as early as 5 to 10 years of age. Cones can be serotinous or nonserotinous depending on location and associated fire regime (Anderson 2003) and possibly tree age and elevation (Critchfield 1978). Serotiny is common in lodgepole pine in the Northern Rockies, although many stands have less than 50 percent serotinous cones. Serotinous cones are persistent and accumulate viable seed for decades (Lotan and Critchfield 1990).

Lodgepole pine is widely considered a fire-maintained subclimax type. Overstory trees are easily killed by fire because of thin bark; however, a new stand of lodgepole pine quickly develops because fire opens serotinous cones and creates bare mineral soil and high light conditions favorable for seed germination and growth (Lotan and Critchfield 1990). Mixed-severity fires often kill a sufficient number of trees to allow establishment and growth of seedlings, even though lodgepole pine is shade intolerant (Anderson 2003).

Lodgepole pine is susceptible to attacks by mountain pine beetle (*Dendroctonus ponderosae*), which can cause heavy tree mortality in stands during epidemics. At lower populations, beetles favor larger-diameter lodgepole pine, effectively thinning the stand from above and leaving smaller-diameter trees and younger cohorts (Anderson 2003).

Fire regimes in lodgepole pine forests are typically characterized in one of two ways: (1) mixed-severity fire that ranges from non-lethal surface fire to stand-replacement fire, and (2) stand-replacement fire (Barrett and others 1991). Historically, fire was more frequent and less intense in areas with dry summers. Low- to moderate-intensity surface fires with an average mean fire return interval of 25 to 50 years were common in many areas (Arno 1980). Arno and others (1993) found pre-1900 fires in lodgepole pine/subalpine fir forests near Hamilton, Montana, were relatively frequent and patchy, creating a fine-grained mosaic of young and mixed-age lodgepole pine communities. In contrast, large, stand-replacing fires were more common in areas with moist summers. This same fire regime pattern of patchy, mixed-severity burns in drier climates and large, stand-replacement burns in moist climates was repeated in Glacier National Park, Montana (Barrett and others 1991). Poor growing sites, such as in Yellowstone National Park, may require 300 to 400 years to accumulate enough fuel to burn and often burn as stand-replacement crown fires (Romme 1982). Areas with previous history of stand-replacing fires or mountain pine beetle epidemics have heavy fuel accumulations that support future high-intensity, stand-replacing fires (Arno 1980; Stewart 1996).

Methods

Study Description

The Tenderfoot Creek Research Project was designed to evaluate and quantify the ecological and biological effects of restoration treatments in an attempt to both manage fuelbed profiles and create two-aged stand structures in lodgepole pine (Hardy and others 2006). A suite of five fire and silvicultural treatments was implemented between 1999 and 2003 on the Tenderfoot Creek Experimental Forest (TCEF) in central Montana to test how to best maintain a lodgepole pine overstory while also establishing a new cohort of lodgepole pine regeneration. The research was guided by the Tenderfoot Creek Research Project mission (USDA Forest Service 1997):

> *"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."*

The specific research objectives for the Tenderfoot Creek Research Project (Flora and McCaughey 1998) were:

1. Evaluate and quantify the ecological and biological effects of alternative silviculture treatments and prescribed fire in lodgepole pine forests by creating reserve structures that emulate those created by natural disturbance.
2. Evaluate damage to reserve trees relative to alternative stand densities and structures, and examine regeneration and understory vegetation changes over time associated with alternative silviculture treatments.
3. Develop linkages between vegetation management activities and hydrologic responses in order to test and verify hydrologic models.
4. Manage and integrate the knowledge gained from the variety of studies at TCEF to improve ecosystem-based management in lodgepole pine forests.
5. Develop demonstration sites at TCEF for education of the general public, students, professionals, and researchers.
6. Test and verify vegetation models and evaluate harvest costs and product recovery values associated with alternative silviculture prescriptions and harvest systems.
7. Contribute to scientific knowledge through publication of results in appropriate outlets.
8. Integrate knowledge gained from TCEF studies into ecosystem management guidelines that enhance the function and sustainability of lodgepole pine forests in the Northern Rockies through a variety of technology transfer products.

Study Site

The 9125-acre (3693-ha) TCEF was established in 1961 and is representative of the vast expanses of lodgepole pine found east of the Continental Divide in Montana, southwest Alberta, and Wyoming (fig. 1). It encompasses the headwaters of Tenderfoot Creek in the Little Belt Mountains on the Lewis and Clark National Forest in Meagher County, Montana. Lodgepole pine dominates the experimental forest to form a mosaic typical of the fire-prone forests at moderate to high altitudes in the Northern Rocky Mountains. Wet meadows cover 311 acres (125 ha), and drier grass and scree slopes make up another 133 acres (54 ha). TCEF lodgepole stands are classified as both one-aged (47 percent of the forested area) and two-aged (53 percent of the forested area), created by past stand-replacement and mixed-severity fires. Lodgepole pine at TCEF is a mix of dominant seral and persistent, with gradual succession to shade-tolerant species in the absence of fire over much of the area. Pure lodgepole pine stands and mixed stands of lodgepole pine, Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir, and whitebark pine (*Pinus albicaulis* Engelm.) occupy about 8681 acres (3514 ha). Elevations range from 6035 to 7941 ft (1840 to 2421 m).

The study area climate is generally continental with occasional influence of the Pacific maritime climate along the Continental Divide from Marias Pass south. Annual precipitation averages 34.6 inches (88.0 cm) and ranges from 23.4 to 41.3 inches (59.4 to 105.0 cm) from the lowest to highest elevations. Monthly precipitation generally peaks in December or January at 4.0 to 5.0 inches (approximately 10.0 to 12.5 cm) per month and declines to 2 to 2.4 inches (approximately 5.0 to 6.0 cm) per month from late July through October. About 70 percent of the annual precipitation falls during the November through May period, usually as snow. Temperatures range from a minimum of about -16 °F (-27 °C) in the winter to a maximum of about

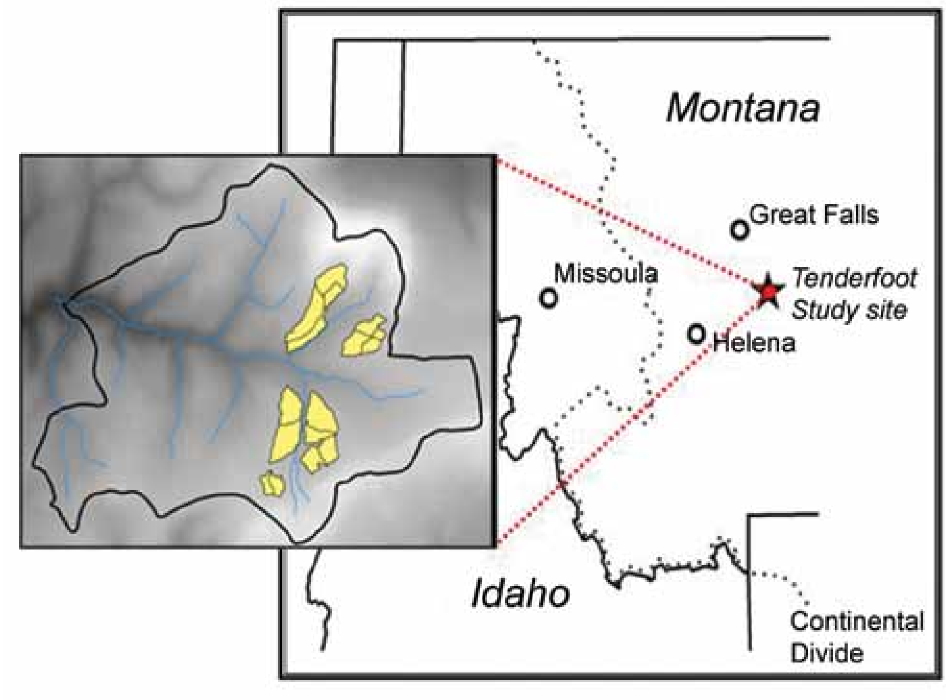


Figure 1. The Tenderfoot Creek Experimental Forest is a 9125-acre (3693-ha) watershed located on the Lewis and Clark National Forest in central Montana.

90 °F (32 °C) in the summer (Onion Park SNOTEL [Natural Resources Conservation Service]). Mean January temperature is about 15 °F (-9 °C) and mean July temperature is about 62 °F (17 °C). Mean length of the growing season ranges between 30 and 75 days, depending upon elevation and exposure.

The historical fire regime at TCEF appears to be markedly different from the large, infrequent, stand-replacing fires in lodgepole pine in Yellowstone National Park where lodgepole pine is the climax successional species (Barrett 1993). 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. Mean fire return interval (MFI) for all fires was 38 years between 1580 and 1992 and 103 years for fires larger than 600 acres (243 ha). The last major fire occurred in 1902. Two-aged stands cover about half the area at TCEF, ranging in size from a few acres to about 1000 acres (405 ha) (fig. 2B). Experimental treatments at TCEF were designed to reflect these historical disturbance patterns and establish a mosaic of small, two-aged stands.

Treatment Descriptions

Treatments were implemented on two sub-watersheds of the Tenderfoot Creek watershed: Spring Park Creek and Sun Creek. Two adjacent sub-watersheds were left as untreated controls: Bubbling Creek and Stringer Creek (table 1, fig. 3). Treatment units averaged 43 acres (17 ha), ranging in size from 16 to 77 acres (6 to 30 ha). Two variable retention treatments were applied: (1) even shelterwood with reserves and (2) group shelterwood with reserves (fig. 4). Treatments were developed and proposed in 1998 (Flora and McCaughey 1998) and harvest began in 1999 (Tables 2 and 3). The harvest treatments were designed to establish a two-aged structure by encouraging lodgepole regeneration under the residual reserve trees (Hardy and others 2006; Hardy and McGaughey 1997). Specific harvest goals included: (1) retain 40 to 60 percent of the basal area (even shelterwood) and 40 to 60 of unit area (group shelterwood), (2) retain 9 to 15 snags per acre, (3) limit basal damage of leave trees to less than 30 percent, (4) create 20 to 30 percent site scarification for regeneration, and (5) promote seedling stocking levels of approximately 100 to 200 trees per acre.

The even shelterwood treatment was designed to remove approximately 40 to 60 percent of basal area, with leave trees evenly distributed throughout the unit. Leave trees 6 inches (15 cm) diameter at breast height (DBH) and greater that represented the general preharvest unit population in species and size were marked by U.S. Forest Service personnel before harvest. Leave trees could be evenly spaced or in small groups of 3 to 5 trees, but no corridors or definite patches were created. Leave trees were healthy, windfirm, free of insect and disease, and preferably not forked. In addition to marking green leave trees, 9 to 15 existing snags or trees with broken or dead tops 9 inches (23 cm) or greater DBH per acre were marked for retention. Species other than lodgepole pine and greater than 15 ft (4.5 m) in height were targeted for snag retention. Some trees less than 6 inches DBH were slashed during harvest to further reduce tree density and facilitate movement of harvest equipment, but small trees and saplings were not slashed after thinning or specifically targeted for removal.

The group shelterwood treatment was designed to remove approximately 40 to 60 percent of the unit area by

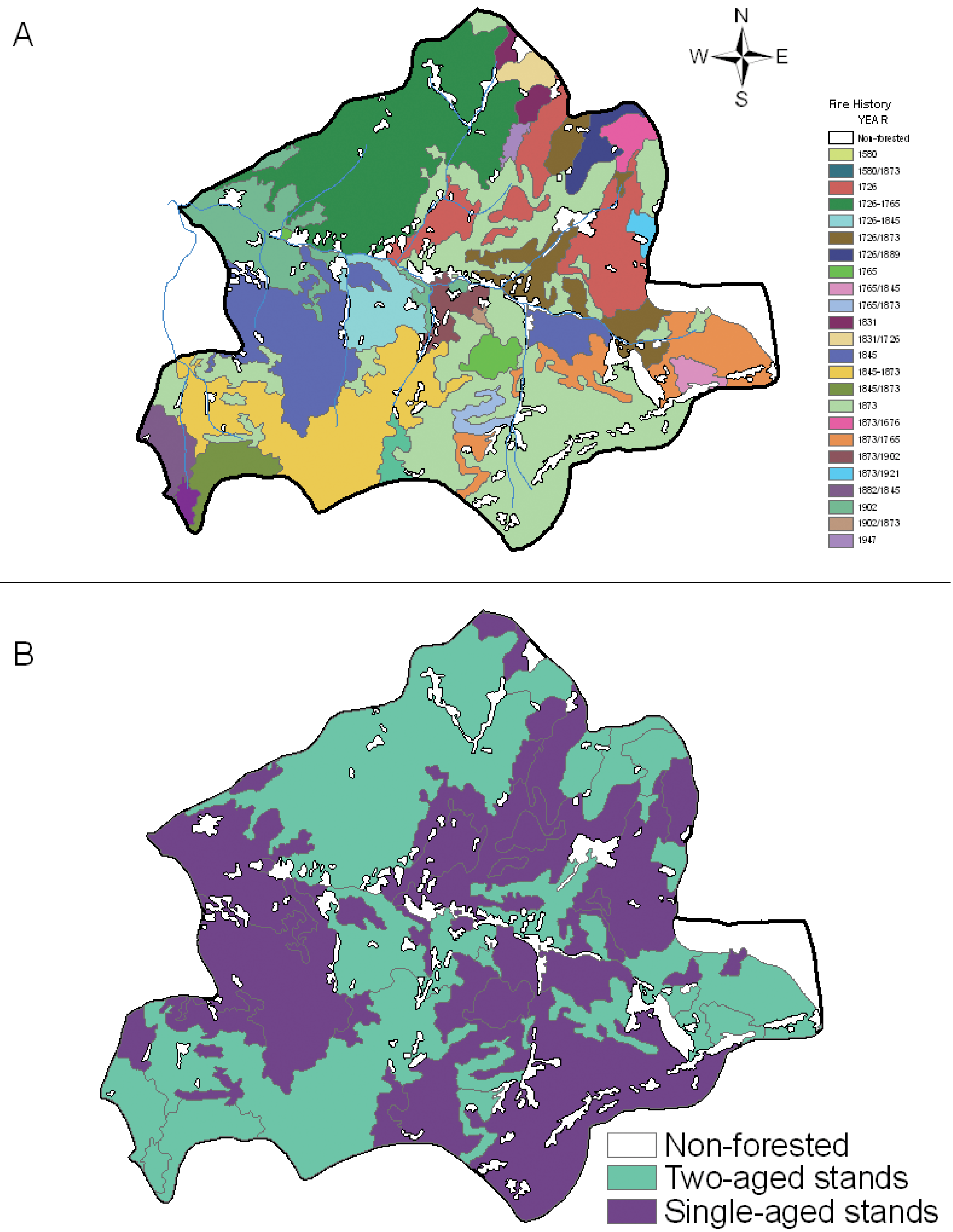


Figure 2. (A) Fire history of the TCEF documenting a complex mosaic of fires dating from 1580 to 1947 (from Barrett 1993). (B) Approximately 50 percent of the Experimental Forest is two-aged resulting from low- to mixed-severity wildfires.

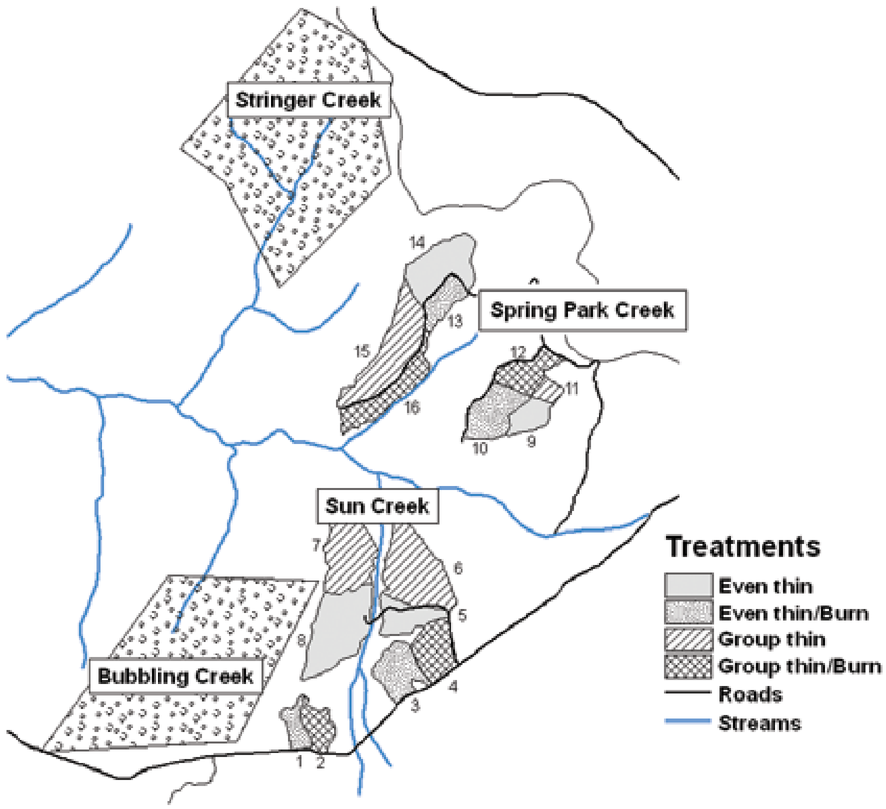


Figure 3. Treatment units are located in four sub-watersheds of Tenderfoot Creek. The harvested and prescribed burn units are located within the Spring Park and Sun Creek sub-watersheds. The control units are located within the Bubbling and Stringer sub-watersheds.

Table 1. Descriptions of treatments implemented in the Tenderfoot Creek Research Project located on the TCEF, Montana.

Treatment	Description
Control	No action
Shelterwood	
Even	40% to 60% of basal area removed with even spacing throughout unit
Group	40% to 60% of basal area removed by retaining unharvested patches and clearcutting corridors around patches
Shelterwood and burn	
Even	Even shelterwood followed by low-intensity, mixed-severity prescribed burn
Group	Group shelterwood followed by low-intensity, mixed-severity prescribed burn

harvesting all trees in corridors around unharvested patches throughout the units, which was assumed to correlate to an equivalent retention of basal area. This treatment resembled a clearcut with reserve patches. Leave patch boundaries of 0.25 to 1.5 acre (0.1 to 0.6 ha) and covering 40 to 60 of the treatment unit area were marked. Leave patch design and location represented preharvest stand condition. Boundaries between leave patches were irregular but wide enough to allow for harvest and skidding in the corridors. All trees greater than or equal to 6 inches (15 cm) outside the leave patches were designated for harvest. However, nearly all trees smaller than 6 inches (15 cm) in the corridors were also cut to facilitate logging. Snag retention targets were met within the leave patches.

All treatment units were harvested using an excavator-mounted "hot-saw" and whole-tree skidded to landings over less than 12 inches (30 cm) of snow. Trees were then delimbed and decked for transport at centralized locations. All unutilized material was piled and burned at the centralized locations. No machinery was allowed within 50 ft (15 m) of stream channels, as these were delineated as streamside management zones.

One-half of the harvested units in the Spring Park Creek and Sun Creek sub-watersheds were subsequently prescribed burned with low-intensity to mixed-severity surface fire. Objectives for prescribed burning were to: (1) reduce activity fuels created during the thinning treatments to mitigate surface fire hazard, (2) expose 20 to 30 percent mineral soil for natural regeneration, (3) maintain at least 50 percent of postharvest or 25 percent of preharvest overstory trees greater than 6 inches (15.2 cm) DBH, and (4) maintain 12 to 15 tons per acre (2.7 to 3.4 kg m^{-2}) of coarse woody debris for nutrient cycling and small mammal habitat.

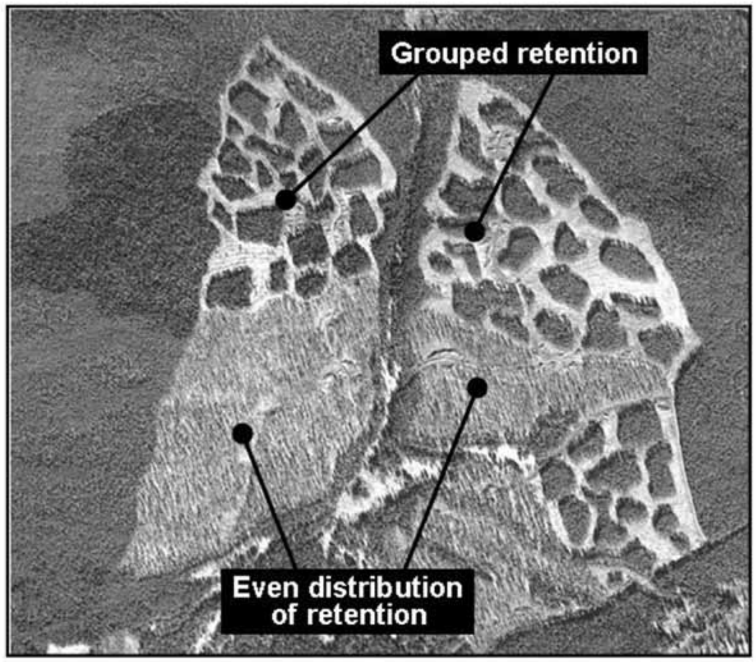


Figure 4. The Sun Creek sub-watershed of Tenderfoot Creek even shelterwood and group shelterwood treatments in 2000 shown in an IKONOS® satellite image.

Table 2. Treatment descriptions and dates by sub-watershed and unit in the Tenderfoot Research Project located on the Tenderfoot Creek Experimental Forest, Montana. N.A. = not applicable.

Sub-watershed	Unit	Treatment	Harvest date	Burn date
Bubbling Creek	C1	Control for Sun Creek	N.A.	N.A.
Stringer Creek	C2	Control for Spring Park Creek	N.A.	N.A.
Sun Creek	1	Even shelterwood & burn	1999/2000	Oct. 1, 2003
	2	Group shelterwood & burn	1999/2000	Oct. 1, 2003
	3	Even shelterwood & burn	1999/2000	Sept. 16, 2002
	4	Group shelterwood & burn	1999/2000	Sept. 16, 2002
	5	Even shelterwood	2000	N.A.
	6	Group shelterwood	2000	N.A.
	7	Group shelterwood	2000	N.A.
	8	Even shelterwood	2000	N.A.
	9	Even shelterwood	2000	N.A.
Spring Park Creek	10	Even shelterwood & burn	2000	Sept. 11, 2002
	11	Group shelterwood	2000	N.A.
	12	Group shelterwood & burn	2000	Sept. 11, 2002
	13	Even shelterwood & burn	2000	Sept. 12, 2002
	14	Even shelterwood	2000	N.A.
	15	Group shelterwood	2000	N.A.
	16	Group shelterwood & burn	2000	Sept. 12, 2002

To meet these objectives, units were hand ignited using strip head fires during fall conditions (specific burning conditions are reported in each unit). The specific prescribed burning window was:

- temperatures between 35 and 75 ^{o}F (2 and 24 ^{o}C),
- relative humidity between 15 and 45 percent,
- mid-flame wind speed between 0 and 7 miles per hour (0 and 11 km per hour),
- dead 10-hr fuel moisture between 6 and 14 percent, and
- flame lengths between 1 and 4 ft (0.3 and 0.6 m).

Sampling Methods

We established approximately one permanent plot per 1.3 acres (0.5 ha) per unit. At each plot, we installed variable radius plots using either a 20 or 40 ft^2/acre basal area factor prism. We permanently marked plot centers with a metal stake and painted an assigned number on overstory trees. For each tree, we recorded species, DBH, tree height, and crown base height. Saplings were greater than 4.5 ft (1.4 m) tall and less than 4.0 inches (10 cm) DBH; seedlings were less than 4.5 ft (1.4 m) tall. We recorded total number of saplings by species on 1/50-acre (1/125-ha) fixed-area plots. We measured seedlings on 1/300-acre (1/1000-ha) plots pre-harvest

Table 3. General stand characteristics by sub-watershed and unit in the Tenderfoot Research Project.

Sub-watershed	Unit	Treatment[1]	Slope (%)	Main aspect(s)	Elevation range (ft)	Primary habitat type[2]	Approximate stand age	Percent single-aged[3]	Percent two-aged	Range of stand age	Average overstory DBH (inches) Pre-harvest[4]	Average overstory DBH (inches) Post-harvest[5]
Bubbling Creek	C1	C	8	N/W	7150-7450	732	127	46	54	127-157	9.3	8
Stringer Creek	C2	C	15	W/S	7160-7480	732, 733	127	10	82	170-274	10.5	9
Sun Creek	1	ES/B	4	N	7440-7520	733	127	47	53	127-235	9.2	8.5
	2	GS/B	7	N	7440-7520	733	127	71	29	127-235	9.3	7.2
	3	ES/B	6	W	7320-7440	733	127	100	0	NA	9.8	8.7
	4	GS/B	6	W	7360-7440	733	127	100	0	NA	9.8	7.8
	5	ES	14	W	7240-7400	732	127	100	0	NA	9.6	9.1
	6	GS	12	W	7200-7400	732	127	61	39	127-235	9.3	8.4
	7	GS	13	E	7120-7300	732	127 or 274	100	0	NA	9	7.6
	8	ES	10	E	7200-7420	732	127	53	47	127-235	9.7	8.7
Spring Park Creek	9	ES	10	W	7360-7480	732	274	97	0	NA	12.2	9.8
	10	ES/B	6	W	7280-7360	732	127 or 274	100	0	NA	10.9	8.5
	11	GS	13	W/N	7380-7480	732	274	100	0	NA	11.6	8.9
	12	GS/B	9	W/N	7280-7380	732	274	87	13	79-127	11	8.4
	13	ES/B	16	S	7200-7340	732	127	66	34	111-274	8.6	7.9
	14	ES	24	S	7320-7560	730	127 or 274	46	46	111-274	8.2	7.4
	15	GS	15	S	7160-7400	733	127 or 274	72	28	127-274	8.3	6.6
	16	GS/B	12	S	7040-7200	732,733	127	49	51	127-274	8.5	7.5

[1] C = Control; ES = Even shelterwood; ES/B = Even shelterwood & burn; GS = Group shelterwood; GS/B = Group shelterwood & burn
[2] 730 = ABILAS\VACSCO; 732 = ABILAS\VACSCO\VACSCO; 733 = ABILAS\VACSCO\THAOCC (Pfister and others 1977)
[3] Percent area in single and two-aged stands is for forested portion of the unit only.
[4] Data based on variable radius plots.
[5] Data based on fixed area plots.

and in 2004 and on 1/1000-acre (1/10,000-ha) plots in 2003. Ideally, sampling methodology would be consistent throughout a long-term study. However, this was not always possible due to funding and staffing issues. Fortunately, the change in sampling only affected the seedling plots.

We collected fuel data on one-half of the permanent plots by installing two, 75-ft (22.86-m) planar-intercept fuel transects radiating from plot center to estimate fuel loadings (mass per unit area) of all fuel components (Brown 1974). We measured duff and litter depths at two locations per transect, 1000-hr fuels along 65-ft (19.8-m) sections, 100-hr fuels along 10-ft (3-m) sections, and 1- and 10-hr fuels along 6-ft (1.8-m) sections. Due to staffing limitations we were unable to collect preharvest fuel data in the Sun Creek sub-watershed before harvest began in the winter of 1999.

We installed fixed-area circular tree plots at each fuel plot in the burned units within one year postfire (2003 and 2004) and on approximately one-half of the fuel plots in the unburned and control units in 2006. We used the same plot center as the variable radius plot. Plot size was 1/15 acre (1/33 ha) in the group shelterwood units and 1/10 acre (1/25 ha) in the even shelterwood units. We added the fixed-area plots to increase sample size of the overstory trees, which was very low after thinning.

We tagged all trees greater than or equal to 4 inches (10.2 cm) DBH that were alive before the fire. For each tree, we recorded DBH, scorch height, status (live or dead), percent volume crown scorched, cambium kill, percent circumference of basal char, and bark beetle attacks. Percent volume crown scorch was the estimated prefire crown volume that was killed by fire and included both scorched and consumed needles. Cambium kill was determined at four points per tree by dividing the tree into quadrants oriented to uphill, downhill, and side-slope. At the center of each quadrant, we used an axe to remove a small portion of bark at ground line and visually determined if the cambium was alive or dead. We coded cambium as alive if it felt moist, soft, and spongy, with a light, peachy shade. We coded cambium as dead if it was hardened with a darker appearance or resin-impregnated. Following burning, we assessed tree status and bark beetle attacks 1, 2, 3, 4, and 6 years postfire.

Data Analysis

We calculated fuel loading (tons acre $^{-1}$; kg m^{-2}) using the methods described in Brown (1974). Postfire fuel loadings included recently fallen trees due to fire and wind; therefore, 1000-hr loadings reflect the combined effect of consumption and addition of new logs. We summed the number of dead cambium samples per tree to calculate a cambium kill rating between 0 and 4. We calculated mean and median crown scorch, mean basal char, and mean cambium kill rating for each burned unit to correlate with fire-caused mortality from the fixed-area plots established 1 year postfire. Cumulative average tree (≥4 inches [10.2 cm] DBH) mortality was calculated for 1, 2, 3, 4 and 6 years postfire in the burned units to observe trends in delayed tree mortality by species. Mortality could have been a result of fire, beetle attacks, or a combination of these factors.

We calculated mean live lodgepole pine, Engelmann spruce, and subalpine fir overstory tree (≥4 inches [10.2 cm] DBH) density using the data collected from the variable-radius plots installed prior to harvest and mean sapling and seedling density using the fixed-area plot data. Temporal sampling varied slightly due to limited suitable prescribed burning conditions in 2002.

We used a repeated measures analysis with post-hoc comparisons adjusted for multiplicity using Sidak's method (Games 1977) based on a lognormal distribution of x+1 to detect differences in preharvest and postharvest/postfire fuel loading and tree, sapling, and seeding density by species. We considered p-values less than or equal to 0.05 to be statistically significant. Because of the two different tree plots used, there are discrepancies in postfire mortality between the trees per acre bar graphs and the percent mortality line graphs. Fire-caused mortality is most accurate in the percent mortality line graphs due to higher sample sizes and more frequent sampling.

Results

Guide Organization

This section contains a comprehensive summary of the measured effects for each treatment unit in the study and is organized by treatment (table 1):

- control (no action)
- even shelterwood
- group shelterwood
- even shelterwood and prescribed burn
- group shelterwood and prescribed burn

Each treatment unit summary has a static format of treatment summaries, photographs, figures, and tables presented in the same order. This management guide is organized in this fashion so that managers can match conditions within a proposed treatment site (prescribed fire intensity, geographic area, pretreatment conditions, and habitat type) to a treatment unit in this study to approximate potential effects of the proposed treatment. Each unit contains:

- a brief description of treatment(s) and management recommendations,
- photographs taken at established photopoints for each of the measurement intervals to show general unit characteristics over time, and
- figures and tabular summaries of tree density and fuel loading for each interval.

The photopoints page contains pictures of two representative plots in the unit at the time intervals of preharvest, postharvest, 1 year postfire, and 6 years postfire. The control units are arranged with the same headings even though no action occurred because the photographs were taken at the same intervals as the treated units.

The tree data page contains figures of overstory tree density (DBH≥4.0inches, 10.2 cm) by species and status (live or dead) and live sapling (DBH<4.0 inches, 10.2 cm) and seedling density (<4.5 ft, 1.37 m) for each measurement interval. Burned units contain a second tree data page of postfire overstory tree mortality by species and a summary of fire-related tree injury. These figures report the percent mortality that occurred after fire of all trees sampled in the unit.

The fuel loading page has three figures for each point in time. The left graph reports total forest floor (litter and duff) depth in inches. The middle graph reports fine woody fuels (1-hr: 0 to 0.25 inches [0 to 0.6 cm] and 10-hr: 0.25 to 1 inch [0.6 to 2.54 cm]) and small branchwood (100-hr: 1 to 3 inches [2.54 to 7.62 cm]) in tons per acre. The right graph reports surface fuel loading of logs (1000-hr: >3 inches [7.62 cm] diameter) in tons per acre. The 1000-hr fuel loading includes all decay classes. Within each unit, the scale of the three bar graphs is consistent across all intervals to help compare loadings over time.

The last page presents a tabular statistical summary of live tree density and surface fuel loadings collected for each treatment unit for each interval. We report overstory density, sapling density, and seedling density. Four tree species are included: lodgepole pine (LP), Engelmann spruce (ES), subalpine fir (SF), and whitebark pine (WP). The number in parentheses after each entry indicates standard error of the mean for each time period. For prescribed burn units where preharvest and postharvest/preburn data are available, the fuel loading tables compare the percent change between preharvest and postharvest and also between postharvest and postfire. An asterisk denotes if these percents are statistically significant from the pretreatment condition ($p \leq 0.05$).

Control Units

Treatment: No action

Management planning: No management actions were planned for these units to observe forest succession in the absence of disturbance.

Study site: Bubbling Creek–Control

Unit description: The Bubbling Creek unit serves as the control sub-watershed for Sun Creek. This unit is dominated by lodgepole pine (57 percent of tree density) but has a large component of subalpine fir (42 percent of tree density) in the overstory. Four years after initial measurements, overstory composition changed minimally. Live lodgepole pine tree density dropped from 413 to 344 trees per acre (167 to 139 trees ha^{-1}) and basal area declined from 115 to 106 ft^2 $acre^{-1}$ (26 to 24 m^2 ha^{-1}).

In the initial sampling, subalpine fir comprised the majority of the seedling (97 percent) and sapling (75 percent) layers. Subalpine fir seedling density dropped significantly between sampling periods but it remains dominant. Without disturbance, we expect lodgepole pine to decline in dominance and subalpine fir and Engelmann spruce to increase.

Fuel loading is relatively low, mostly in the form of 1000-hr fuels. Fuels changed little between the 2001 and 2010 measurements.

Management implications: The majority of the unit is dominant seral lodgepole pine, with an understory of shade-tolerant subalpine fir and Engelmann spruce. Subalpine fir seedling density is extremely high and, without disturbance, we expect lodgepole pine abundance will decrease in the overstory and be replaced by these shade-tolerant species. A minor portion of the unit is persistent lodgepole pine, with little shade-tolerant species in the understory. In these areas, we expect lodgepole pine to remain the dominant overstory species. If maintenance of the lodgepole pine overstory component is desirable, we recommend either cutting large patches of the unit or leaving patches and cutting around them, similar to the group shelterwood treatment described later in this report. This would aid in lodgepole pine regeneration and reduce fire intensity in the event of a wildfire. Use of low-intensity prescribed fire under current stand conditions would be difficult without prior silvicultural entry.

SITE: Bubbling Creek
TREATMENT: Control (no action)

PREHARVEST

POSTHARVEST

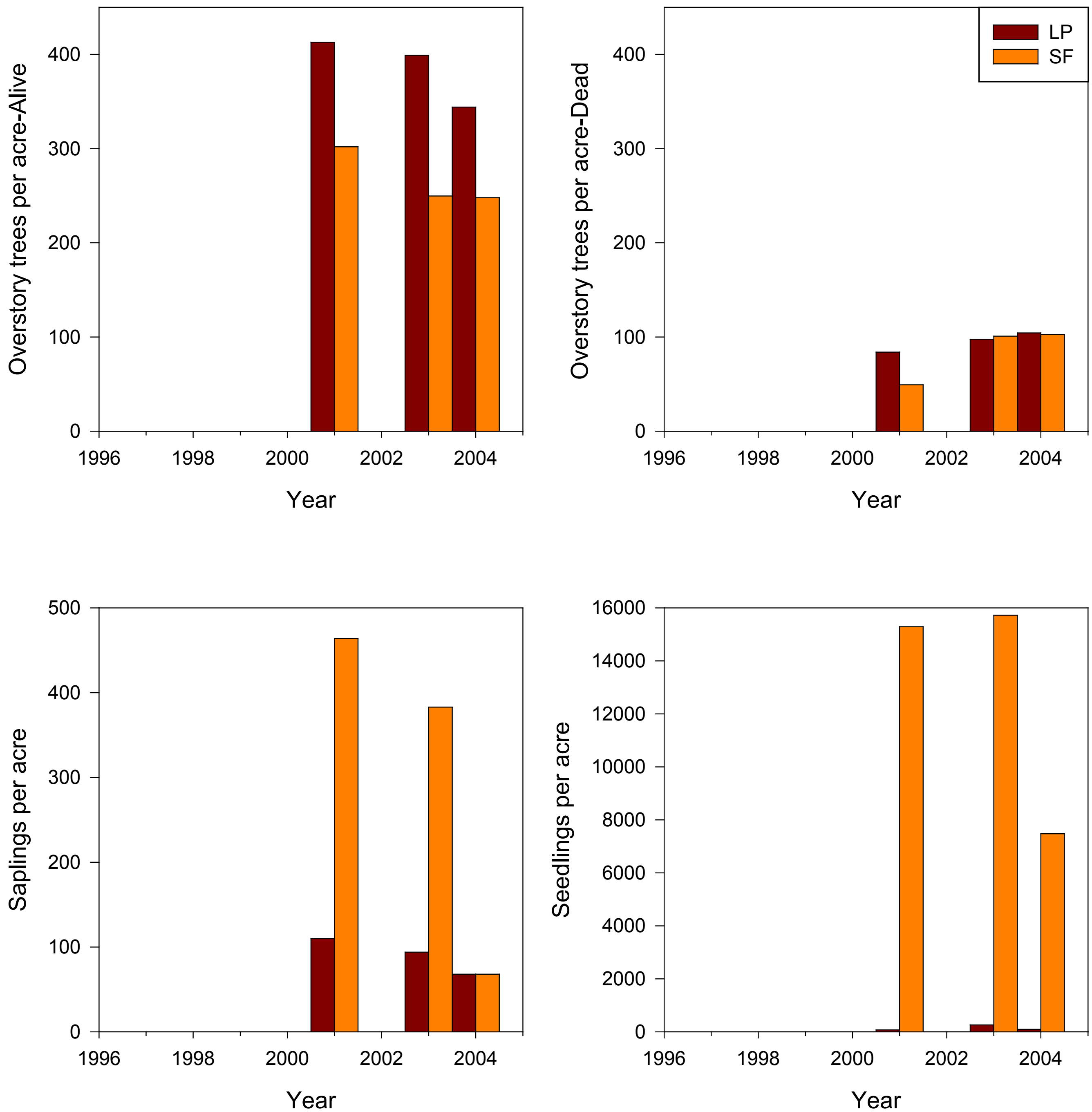
No data collected

POSTFIRE-1

No data collected

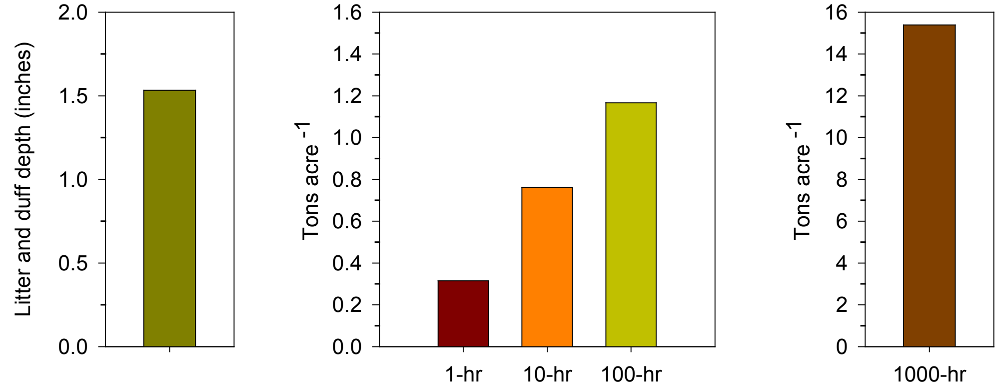
POSTFIRE-6

SITE: Bubbling Creek
TREATMENT: Control (no action)



SITE: Bubbling Creek
TREATMENT: Control (no action)

PREHARVEST



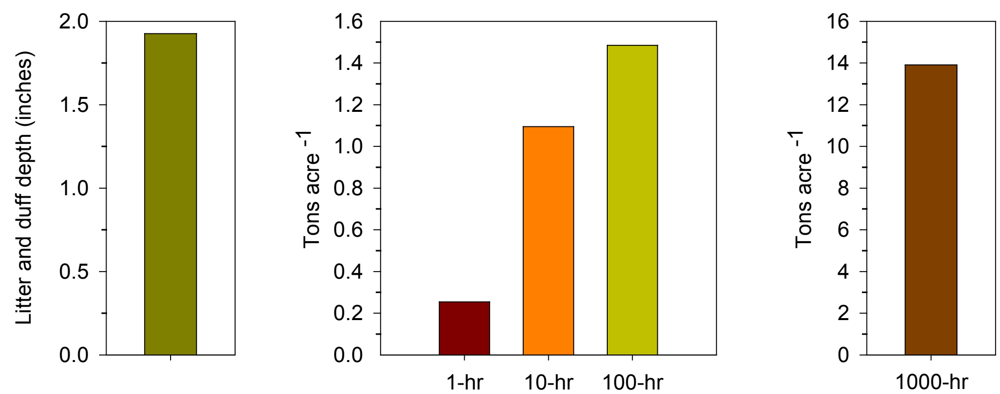
POSTHARVEST

No data collected

POSTFIRE-1

No data collected

POSTFIRE-6



SITE: Bubbling Creek
TREATMENT: Control (no action)

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. Asterisk (*) denotes change between initial 2001 tree density/fuel loading and subsequent measurement year is significant at p<0.05. Dash indicates timestep where no sampling was done.

	# Plots	2001 (Std. Err.)	2003 (Std. Err.)	2004 (Std. Err.)	2010 (Std. Err.)
Overstory density (trees acre^{-1})					
LP	50	412.8 (85.9)	399.0 (84.6)	344.1 (79.6)	—
ES	50	9.7 (4.4)	9.7 (4.4)	9.7 (4.4)	—
SF	50	301.8 (87.2)	249.6 (74.0)	247.8* (74.1)	—
Overstory basal area (ft^{2} acre^{-1})					
LP	50	115.2 (12.6)	112.8 (12.4)	105.6 (12.1)	—
ES	50	4 (1.7)	4 (1.7)	4 (1.7)	—
SF	50	46.4 (9.9)	36 (7.5)	34.4* (7.3)	—
Sapling density (trees acre^{-1})					
LP	50	110.0 (27.5)	94.0 (23.2)	68.0 (16.9)	—
ES	50	17.0 (9.1)	34.0 (15.8)	26.0 (10.4)	—
SF	50	464.0 (75.8)	383.0 (57.1)	343.0 (53.5)	—
WB	50	9.0 (8.0)	0 (0)	1.0 (1.0)	—
Seedling density (trees acre^{-1})					
LP	50	72.0 (42.5)	260.0 (93.9)	96.0 (62.1)	—
ES	50	168.0 (76.7)	280.0 (185.3)	24.0 (18.9)	—
SF	50	15288.0 (3180.7)	15720.0 (3295.5)	7476.0 (1136.6)	—
WB	50	30.0 (174.1)	0 (0)	114.0 (108.0)	—
Surface fuels					
Duff and litter depth (in)	24	1.53 (0.12)	—	—	1.93 (0.11)
1 hour fuel load (tons acre^{-1})	24	0.31 (0.02)	—	—	0.25 (0.02)
10 hour fuel load (tons acre^{-1})	24	0.76 (0.08)	—	—	1.09 (0.18)
100 hour fuel load (tons acre^{-1})	24	1.17 (1.15)	—	—	1.48 (0.21)
1000 hour fuel load (tons acre^{-1})	24	15.39 (1.16)	—	—	13.91 (1.02)

Study site: Stringer Creek–Control

Unit description: The Stringer Creek unit serves as the control sub-watershed for Spring Park Creek. The overstory is dominated by lodgepole pine (74 percent of tree density) with a minor component of subalpine fir (25 percent) and Engelmann spruce (0.7 percent). Four years after initial measurements, composition changed minimally. Live lodgepole pine tree density dropped from 382 to 376 trees acre^{-1} (155 to 152 trees ha^{-1}) and basal area declined from 120 to 116 ft^2 acre^{-1} (28 to 27 m^2 ha^{-1}).

In the initial sampling, the recruitment layer was dominated by subalpine fir in both the seedling (82 percent) and sapling (60 percent) layers. Lodgepole pine comprised about 33 percent of the sapling layer and about 9 percent of the seedling layer. Four years later, the relative proportions of these species remained the same in both the seedling and sapling layers. Without disturbance, we expect lodgepole pine to decline in dominance and subalpine fir and Engelmann spruce to increase.

Fuel loading is relatively low, mostly in the form of 1000-hr fuels. Fuels changed little between the 2001 and 2010 measurements.

Management implications: The unit consists of approximately equal portions of persistent and dominant seral lodgepole pine. There are patches of shade-tolerant regeneration, and in these areas, we expect that lodgepole pine abundance will decrease in the overstory and gradually be replaced by shade-tolerant species. If maintenance of the lodgepole pine overstory component is desirable, we recommend either cutting large patches of the unit or leaving patches and cutting around them, similar to the group shelterwood treatment described later in this report. This would aid in lodgepole pine regeneration and reduce fire intensity in the event of a wildfire. Low-intensity prescribed fire could be implemented in portions of this unit without initial entry.

SITE: Stringer Creek
TREATMENT: Control (no action)

PREHARVEST

POSTHARVEST

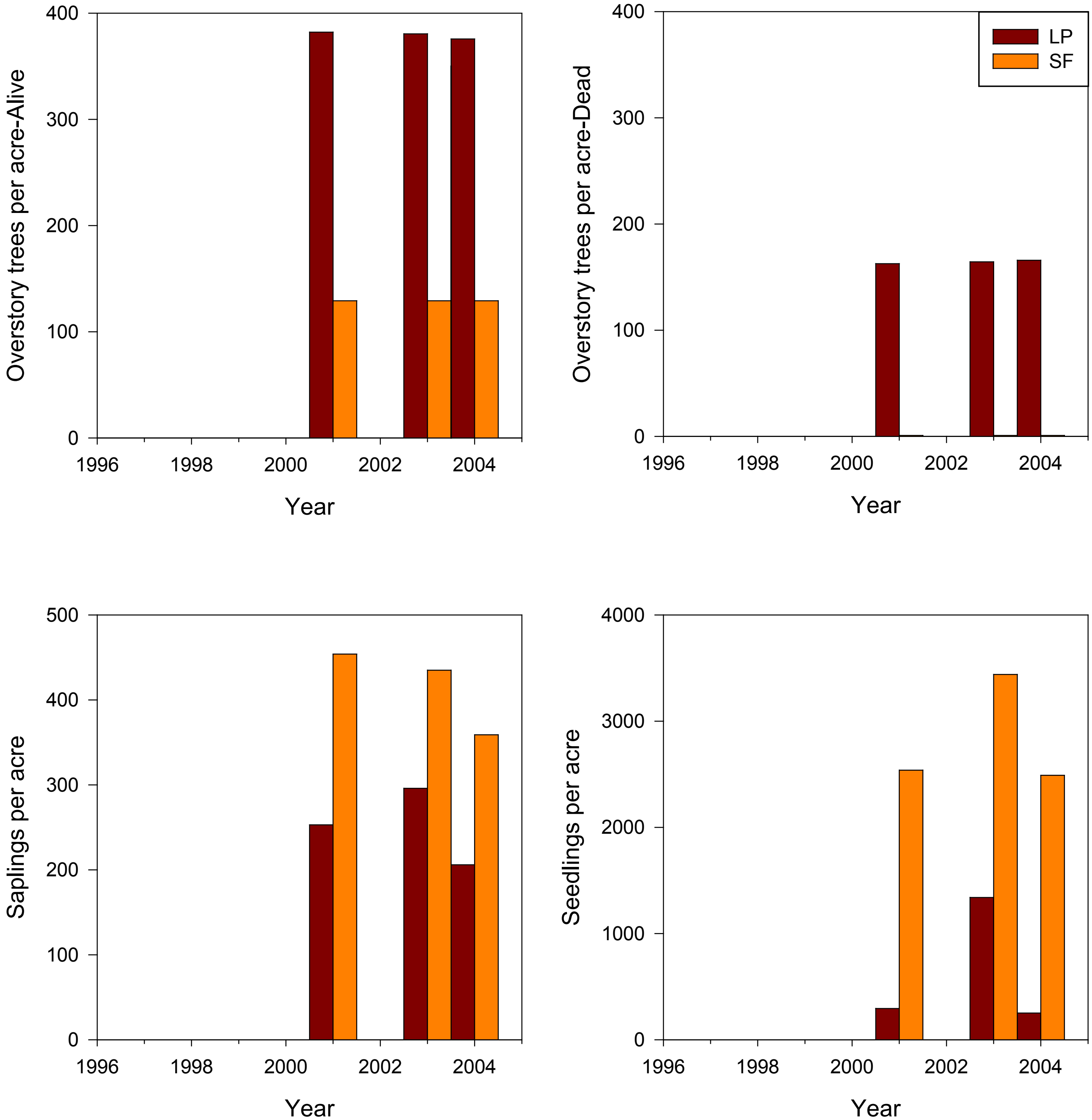
No data collected

POSTFIRE-1

No data collected

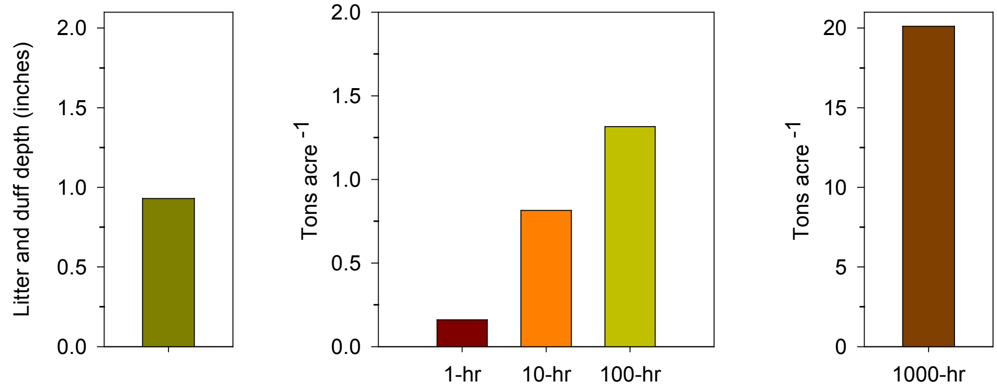
POSTFIRE-6

SITE: Stringer Creek
TREATMENT: Control (no action)



SITE: Stringer Creek
TREATMENT: Control (no action)

PREHARVEST



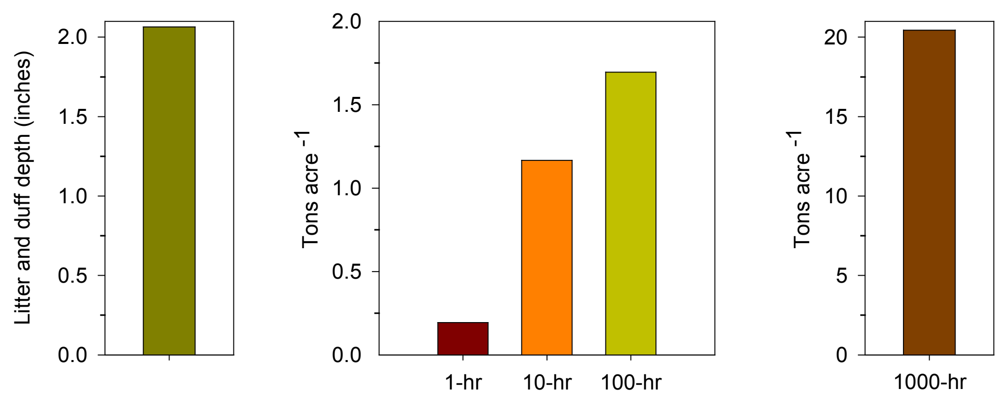
POSTHARVEST

No data collected

POSTFIRE-1

No data collected

POSTFIRE-6



SITE: Stringer Creek
TREATMENT: Control (no action)

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. Asterisk (*) denotes change between initial 2001 tree density/fuel loading and subsequent measurement year is significant at $p<0.05$. Dash indicates timestep where no sampling was done. **Pines not identified to species level.

	# Plots	2001 (Std. Err.)	2003 (Std. Err.)	2004 (Std. Err.)	2010 (Std. Err.)
Overstory density (trees acre^{-1})					
LP	48	382.1 (76.5)	380.4 (76.5)	375.6 (76.7)	—
ES	48	3.5 (2.7)	3.5 (2.7)	3.5 (2.7)	—
SF	48	129.1 (77.4)	129.1 (77.4)	129.1 (77.4)	—
Overstory basal area (ft^2 acre^{-1})					
LP	48	120.0 (9.7)	118.3 (9.6)	115.8 (9.6)	—
ES	48	1.7 (1.2)	1.7 (1.2)	1.7 (1.2)	—
SF	48	10.0 (3.5)	10.0 (3.5)	10.0 (3.5)	—
Sapling density (trees acre^{-1})					
LP	48	253.0 (36.8)	**	206.0 (33.8)	—
SF	48	454.0 (130.5)	435.0 (125.7)	359.0 (117.4)	—
WB	48	54.0 (16.7)	**	45.0 (18.9)	—
Seedling density (trees acre^{-1})					
LP	48	294.0 (76.9)	**	252.0 (60.2)	—
ES	48	6.0 (6.0)	40.0 (40.0)	12.0 (8.4)	—
SF	48	2538.0 (3545.6)	3440.0 (5831.5)	2490.0 (447.3)	—
WB	48	276.0 (85.2)	**	174.0 (54.3)	—
Surface fuels					
Duff and litter depth (in)	25	0.93 (0.06)	—	—	2.06 (0.16)
1 hour fuel load (tons acre^{-1})	25	0.16 (0.02)	—	—	0.19 (0.02)
10 hour fuel load (tons acre^{-1})	25	0.81 (0.06)	—	—	1.17 (0.13)
100 hour fuel load (tons acre^{-1})	25	1.32 (0.20)	—	—	1.70 (0.27)
1000 hour fuel load (tons acre^{-1})	25	20.12 (1.09)	—	—	20.44 (0.99)

Even Shelterwood Treatment Units

Treatment: Even-spaced shelterwood

Management planning: The units were harvested with the objective to reduce the overstory by 40 to 60 percent basal area or trees per acre. Trees were harvested to create approximately equal spacing between reserve trees. Felled trees were whole-tree skidded to centralized processing locations for delimbing and decking for transport. All unutilized materials were piled and burned at the centralized locations. A detailed harvest prescription is provided in the "Treatment Descriptions" section.

Study site: Sun Creek Unit 5–Even Shelterwood

Unit description: The 30-acre (12-ha) unit was harvested in 2000. Before treatment, the overstory consisted entirely of lodgepole pine. Harvesting significantly reduced the average number of live lodgepole pine from approximately 540 to 39 trees per acre (219 to 16 trees ha^{-1}) and basal area from 189 to 23 ft^2 $acre^{-1}$ (43 to 5 m^2 ha^{-1}).

Lodgepole pine also was the dominant species in the preharvest seedling and sapling layers. Four years postharvest, lodgepole sapling density was significantly reduced while seedling density was significantly increased.

Preharvest fuel loading was not measured. Forest floor depth and 1-hr fuel increased significantly between 3 and 10 years following harvest. All other fuel components remained unchanged.

Management implications: The goal of reducing the overstory basal area by 40 to 60 percent through harvest was not met in this unit. In actuality, harvesting removed 88 percent of overstory trees, resulting in very few leave trees scattered throughout the unit. Increased light resulting from the even harvest treatment favored lodgepole pine regeneration.

SITE: Sun Creek Unit 5
TREATMENT: Even Shelterwood / Unburned

PREHARVEST

No data collected

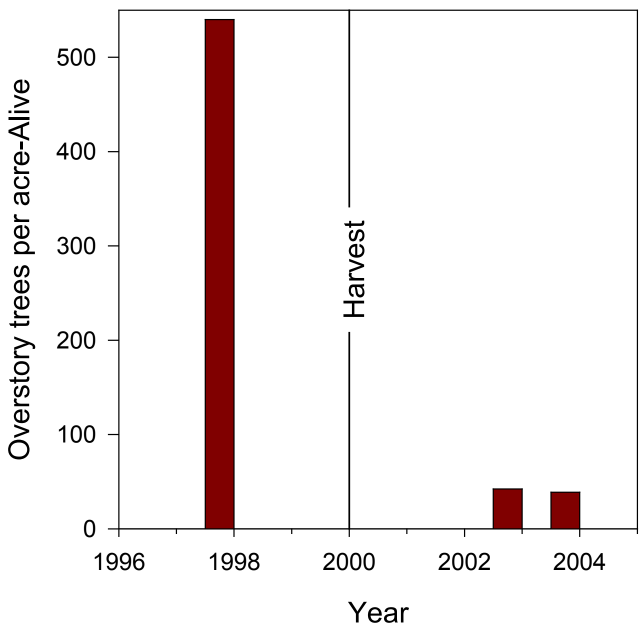
POSTHARVEST

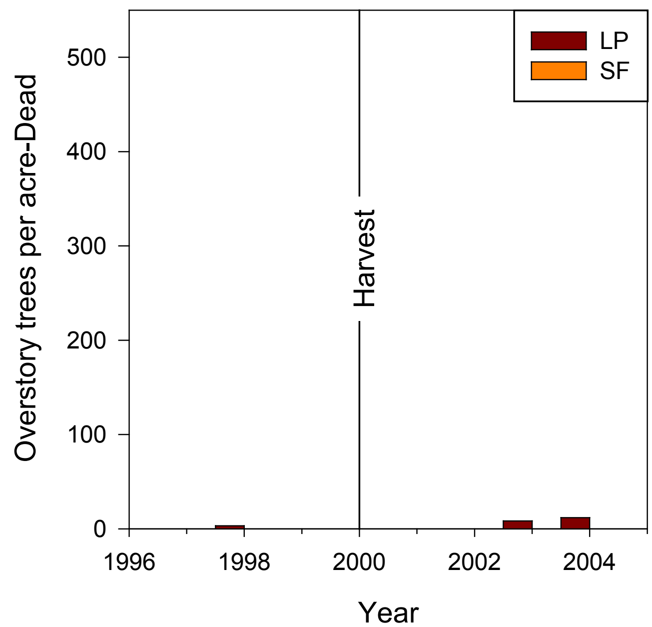
POSTFIRE-1

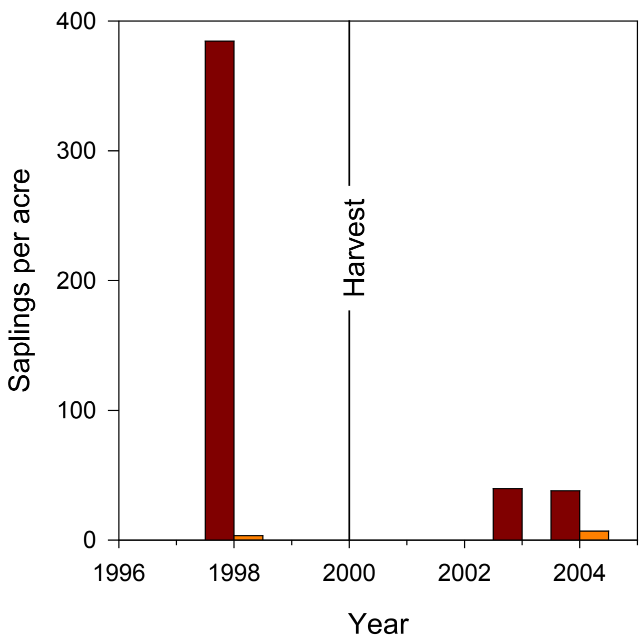
No data collected

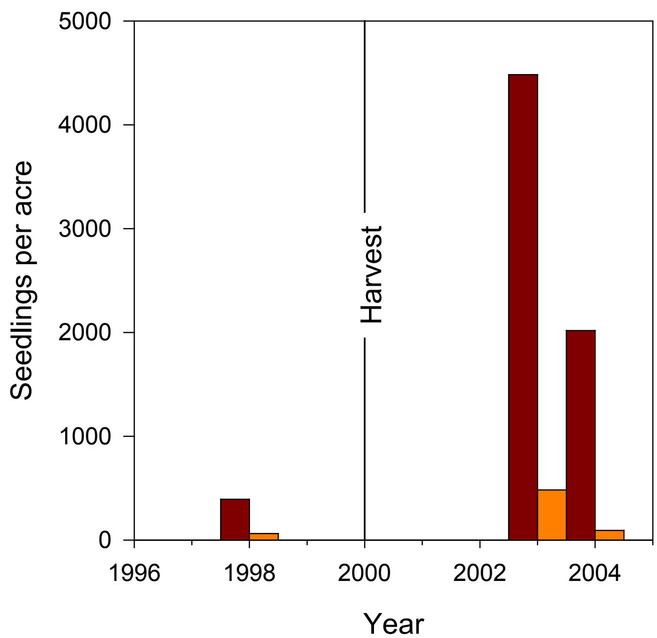
POSTFIRE-6

SITE: Sun Creek Unit 5
TREATMENT: Even Shelterwood / Unburned







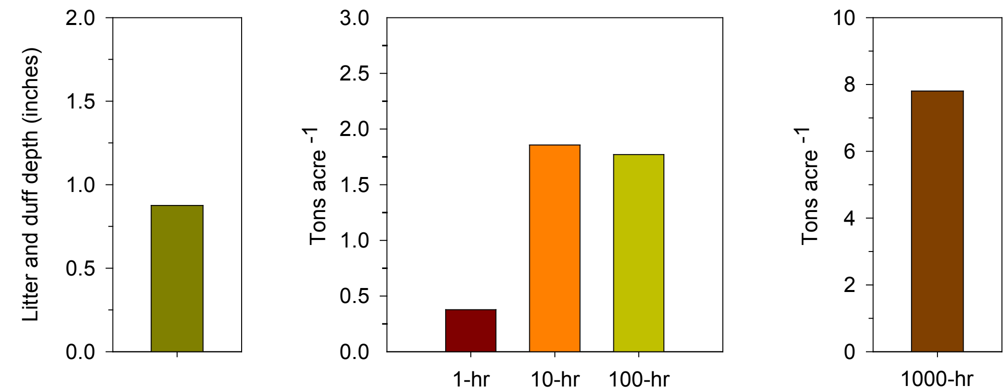


SITE: Sun Creek Unit 5
TREATMENT: Even Shelterwood / Unburned

PREHARVEST

No data collected

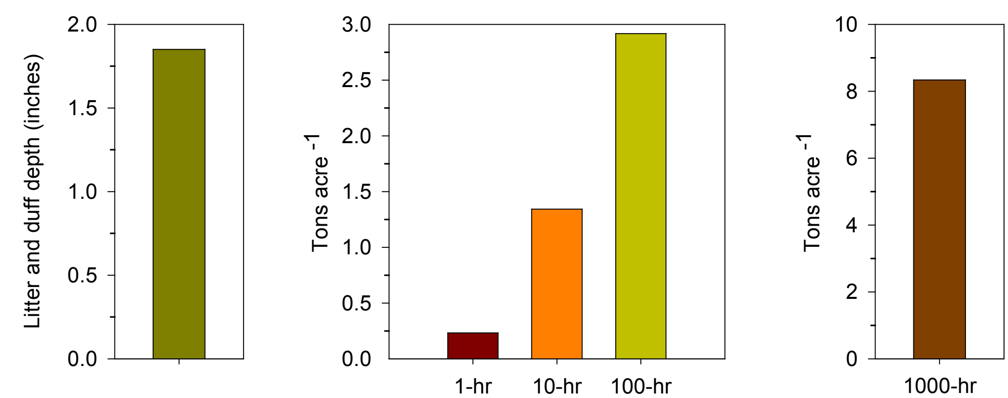
POSTHARVEST



POSTFIRE-1

No data collected

POSTFIRE-6



SITE: Sun Creek Unit 5
TREATMENT: Even Shelterwood / Unburned

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at $p<0.05$. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	3 Years Postharvest (Std. Err.)	4 Years Postharvest (Std. Err.)	10 Years Postharvest (Std. Err.)
Overstory density (trees acre^{-1})					
LP	29	540.0 (66.8)	42.3* (12.1)	38.8* (12.0)	—
Overstory basal area (ft^2 acre^{-1})					
LP	29	189 (12.8)	24.8* (5.4)	23.4* (5.4)	—
Sapling density (trees acre^{-1})					
LP	29	384.5 (45.2)	39.7* (10.0)	37.9* (10.7)	—
SF	29	3.4 (2.4)	0 (0)	6.9 (4.1)	—
Seedling density (trees acre^{-1})					
LP	29	393.1 (164.5)	4482.8* (945.1)	2017.2* (379.9)	—
ES	29	31.0 (17.3)	137.9 (137.9)	0 (0)	—
SF	29	62.1 (23.0)	482.8 (127.7)	93.1 (33.6)	—
WB	29	248.3 (150.4)	0* (0)	103.4 (56.3)	—
Surface fuels					
Duff and litter depth (in)	14	—	0.88 (0.12)	—	1.85* (0.26)
1 hour fuel load (tons acre^{-1})	14	—	0.38 (0.05)	—	0.23* (0.03)
10 hour fuel load (tons acre^{-1})	14	—	1.86 (0.27)	—	1.34 (0.11)
100 hour fuel load (tons acre^{-1})	14	—	1.77 (0.28)	—	2.92* (0.48)
1000 hour fuel load (tons acre^{-1})	14	—	7.80 (2.13)	—	8.34 (2.18)

Study site: Sun Creek Unit 8–Even Shelterwood

Unit description: The 77-acre (31-ha) unit was harvested in 2000. Before treatment, the unit overstory was dominated by lodgepole pine (97 percent of tree density). A significant wind event following harvest blew down a large number of leave trees. Harvesting combined with the wind event reduced the average number of live lodgepole pine from approximately 468 to 41 trees per acre (190 to 17 trees ha^{-1}) and basal area from 164 to 20 ft^2 $acre^{-1}$ (38 to 5 m^2 ha^{-1}).

The sapling layer was largely lodgepole pine and subalpine fir pretreatment, while the majority of seedlings were subalpine fir. Four years after harvest, lodgepole pine sapling density was significantly reduced to levels equal to subalpine fir. Seedling dominance shifted from subalpine fir to lodgepole pine, with only lodgepole pine having a significant increase.

Preharvest fuel loading was not measured. The 1-hr and 10-hr fuel components decreased significantly between 3 and 10 years following harvest. All other fuel components remained unchanged.

Management implications: The goal of reducing the overstory basal area by 40 to 60 percent through harvest was not met in this unit. Harvesting combined with windthrow removed 88 percent of overstory trees and left very few leave trees scattered throughout the unit. Increased light resulting from the even shelterwood harvest treatment favored lodgepole pine regeneration. Even though subalpine fir seedlings and saplings were reduced by harvest, they remained a prominent component in the unit. Additional treatments may be necessary to reduce subalpine fir competition if lodgepole pine regeneration is desired.

SITE: Sun Creek Unit 8
TREATMENT: Even Shelterwood / Unburned

PREHARVEST

No data collected

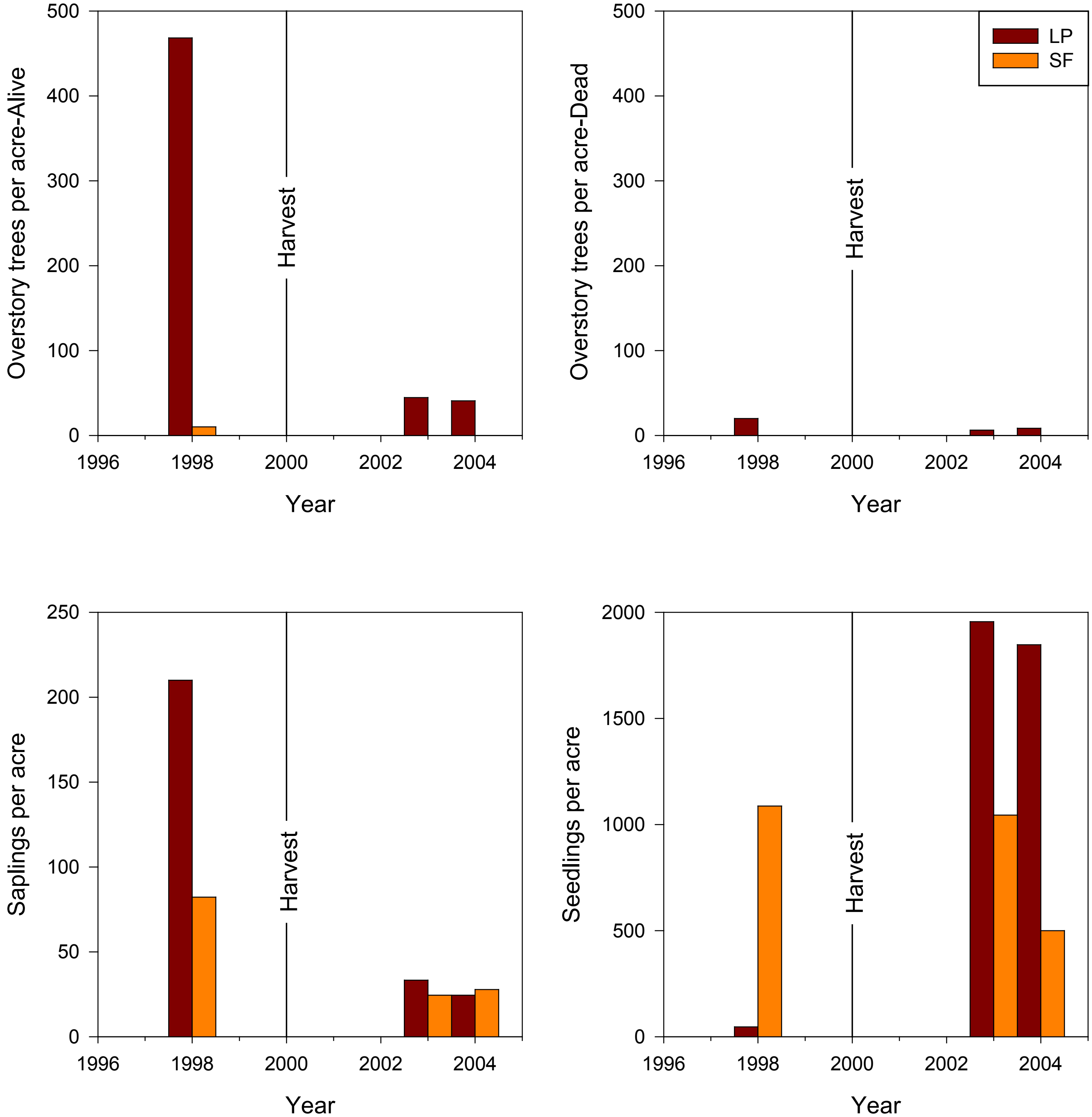
POSTHARVEST

POSTFIRE-1

No data collected

POSTFIRE-6

SITE: Sun Creek Unit 8
TREATMENT: Even Shelterwood / Unburned

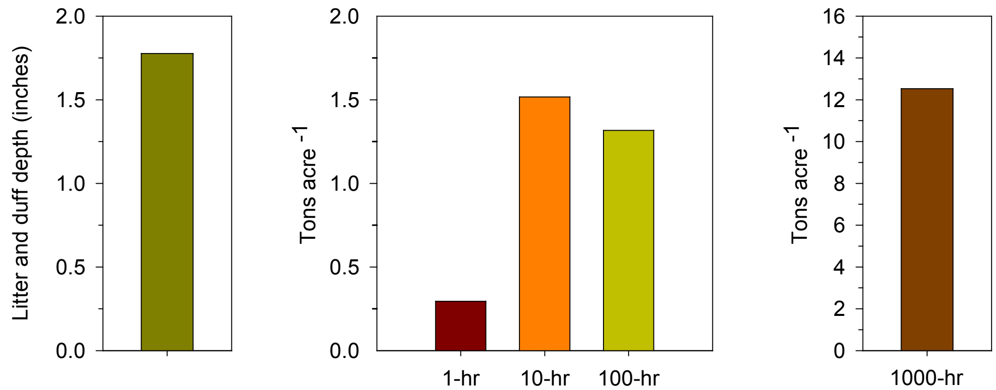


SITE: Sun Creek Unit 8
TREATMENT: Even Shelterwood / Unburned

PREHARVEST

No data collected

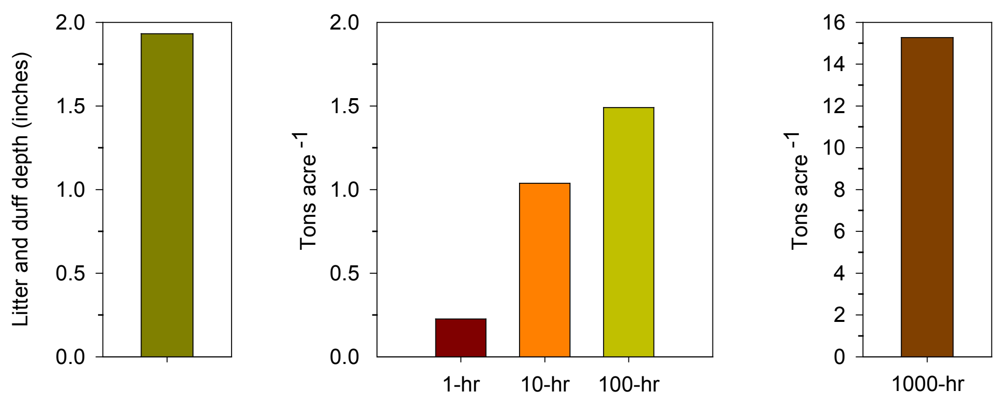
POSTHARVEST



POSTFIRE-1

No data collected

POSTFIRE-6



SITE: Sun Creek Unit 8
TREATMENT: Even Shelterwood / Unburned

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at $p<0.05$. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	3 Years Postharvest (Std. Err.)	4 Years Postharvest (Std. Err.)	10 Years Postharvest (Std. Err.)
Overstory density (trees acre^{-1})					
LP	45	468.2 (61.2)	44.6* (9.7)	40.7* (9.6)	—
ES	45	5.1 (3.7)	0 (0)	0 (0)	—
SF	45	10.0 (7.0)	0 (0)	0 (0)	—
Overstory basal area (ft^2 acre^{-1})					
LP	45	163.6 (10.3)	23.1* (4.5)	20.4* (4.3)	—
ES	45	1.8 (1.2)	0 (0)	0 (0)	—
SF	45	1.8 (1.2)	0 (0)	0 (0)	—
Sapling density (trees acre^{-1})					
LP	45	210.0 (38.2)	33.3* (9.9)	24.4* (8.5)	—
ES	45	4.4 (2.1)	0* (0)	0* (0)	—
SF	45	82.2 (25.8)	24.4* (15.7)	27.8* (19.0)	—
Seedling density (trees acre^{-1})					
LP	45	46.7 (21.2)	1955.6* (487.2)	1846.7* (366.2)	—
ES	45	40.0 (24.5)	0 (0)	40.0 (33.8)	—
SF	45	1086.7 (350.8)	1044.4* (349.5)	500.0* (162.9)	—
WB	45	80.0 (43.1)	0* (0)	0* (0)	—
Surface fuels					
Duff and litter depth (in)	21	—	1.78 (0.19)	—	1.93 (0.24)
1 hour fuel load (tons acre^{-1})	21	—	0.29 (0.02)	—	0.23* (0.02)
10 hour fuel load (tons acre^{-1})	21	—	1.52 (0.12)	—	1.04* (0.12)
100 hour fuel load (tons acre^{-1})	21	—	1.32 (0.24)	—	1.49 (0.25)
1000 hour fuel load (tons acre^{-1})	21	—	12.53 (1.54)	—	15.27* (2.33)

Study site: Spring Park Creek Unit 9–Even Shelterwood

Unit description: The 21-acre (8.5-ha) unit was harvested in 2000. Before treatment, lodgepole pine (47 percent of tree density) and subalpine fir (49 percent) codominated the overstory. Harvesting reduced the average number of live lodgepole pine from approximately 226 to 71 trees per acre (92 to 29 trees ha^{-1}) and basal area from 135 to 37 ft^2 $acre^{-1}$ (31 to 8 m^2 ha^{-1}). Harvesting significantly reduced subalpine fir to 20 percent of the residual overstory.

The pretreatment seedling and sapling layers were comprised almost entirely of subalpine fir. Four years postharvest, there was a significant decrease in subalpine fir density in the sapling and seedling layers. Lodgepole pine seedlings increased significantly, but subalpine fir still dominated the recruitment layer four years postharvest.

Preharvest fuel loading was approximately 18 tons $acre^{-1}$ (4 kg m^{-2}). Harvest significantly increased forest floor depth and 1000-hr fuels but decreased fine fuels.

Management implications: The goal of reducing the overstory basal area by 40 to 60 percent through harvest was not met in this unit. In actuality, harvest removed 88 percent of overstory trees and left very few leave trees scattered throughout the unit. Increased light resulting from the even shelterwood harvest treatment favored lodgepole pine regeneration. Even though subalpine fir seedlings and saplings were reduced by the harvest, they remained dominant components in the unit. Additional treatments may be necessary to reduce subalpine fir competition if lodgepole pine regeneration is desired.

SITE: Spring Park Unit 9
TREATMENT: Even Shelterwood / Unburned

PREHARVEST

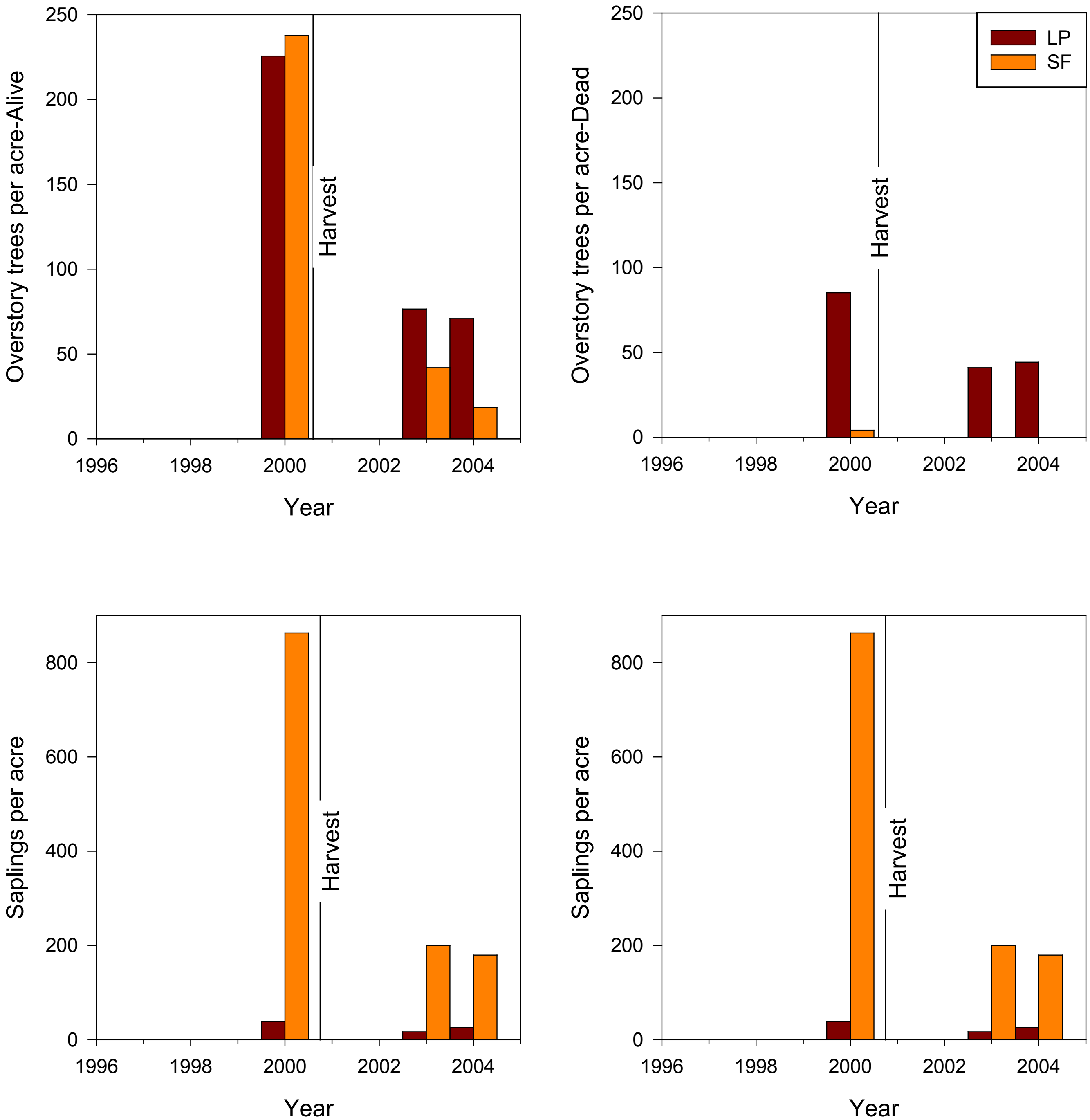
POSTHARVEST

POSTFIRE-1

No data collected

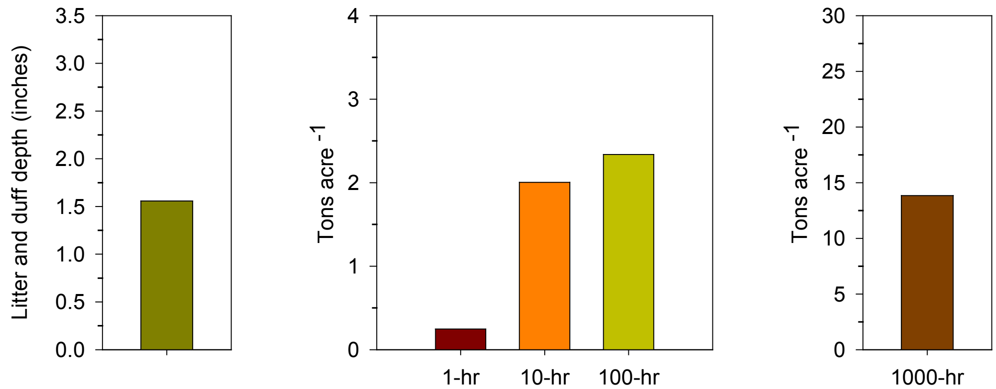
POSTFIRE-6

SITE: Spring Park Unit 9
TREATMENT: Even Shelterwood / Unburned

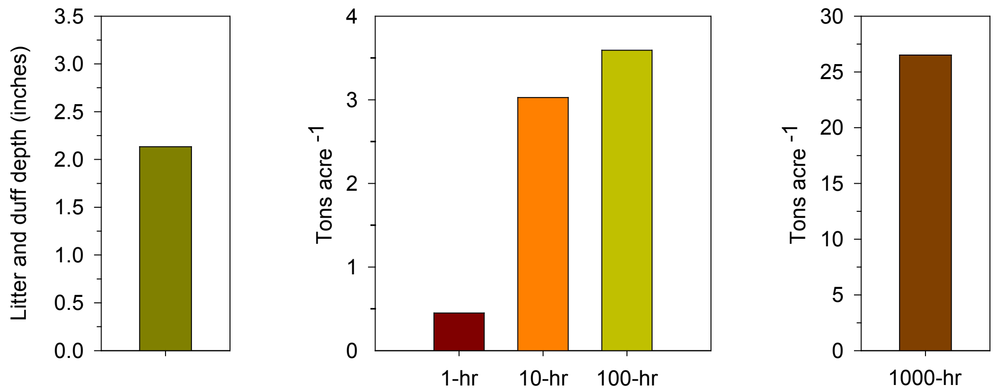


SITE: Spring Park Unit 9
TREATMENT: Even Shelterwood / Unburned

PREHARVEST



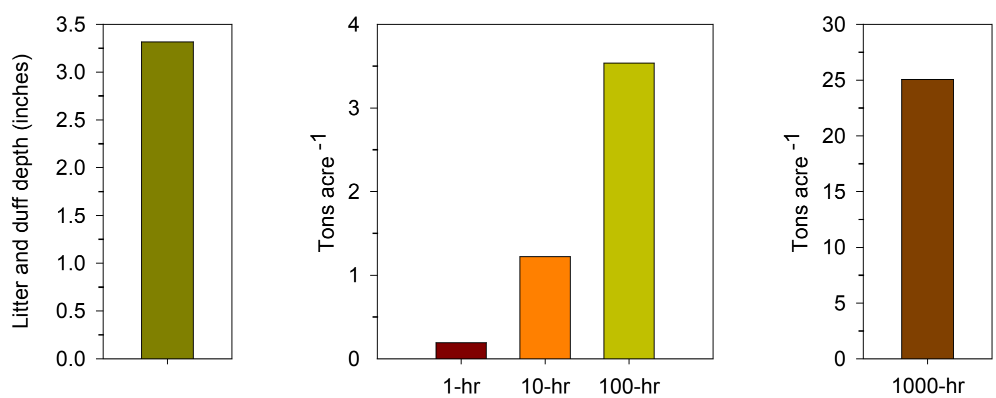
POSTHARVEST



POSTFIRE-1

No data collected

POSTFIRE-6



SITE: Spring Park Creek Unit 9
TREATMENT: Even Shelterwood / Unburned

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at $p<0.05$. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	3 Years Postharvest (Std. Err.)	4 Years Postharvest (Std. Err.)	10 Years Postharvest (Std. Err.)
Overstory density (trees acre^{-1})					
LP	27	225.5 (34.2)	76.4* (22.0)	70.8* (21.7)	—
ES	27	14.3 (6.7)	1.2* (1.2)	1.2* (1.2)	—
SF	27	237.7 (86.5)	41.9* (34.9)	18.4* (13.0)	—
WB	27	5.9 (5.9)	0 (0)	0 (0)	
Overstory basal area (ft^2 acre^{-1})					
LP	27	134.8 (13.2)	43.0* (7.4)	37.0* (7.4)	—
ES	27	16.3 (7.5)	1.5* (1.5)	1.5* (1.5)	—
SF	27	22.2 (5.4)	5.9* (4.6)	4.4* (3.3)	—
WB	27	1.5 (1.5)	0 (0)	0 (0)	—
Sapling density (trees acre^{-1})					
LP	27	38.9 (11.1)	16.7 (7.5)	25.9 (20.4)	—
ES	27	5.6 (21.2)	0 (0)	0 (0)	—
SF	27	863.0 (133.1)	200.0* (64.8)	179.6* (53.0)	—
WB	27	9.3 (5.4)	1.9 (1.9)	0 (0)	—
Seedling density (trees acre^{-1})					
LP	27	0 (0)	111.1 (61.6)	200.0 (81.7)	—
ES	27	300.0 (245.0)	37.0 (37.0)	11.1 (11.1)	—
SF	27	27300.0 (4172.4)	6814.8* (1459.9)	2544.4* (559.2)	—
WB	27	177.8 (101.6)	148.2 (115.8)	33.3 (18.5)	—
Surface fuels					
Duff and litter depth (in)	14	1.56 (0.25)	2.13* (0.35)	—	3.32* (0.36)
1 hour fuel load (tons acre^{-1})	14	0.25 (0.05)	0.45* (0.06)	—	0.19* (0.02)
10 hour fuel load (tons acre^{-1})	14	2.0 (0.56)	3.03* (0.48)	—	1.22* (0.19)
100 hour fuel load (tons acre^{-1})	14	2.34 (0.77)	3.59 (0.60)	—	3.54 (0.73)
1000 hour fuel load (tons acre^{-1})	14	13.84 (2.94)	26.5* (3.62)	—	25.04 (3.80)

Study site: Spring Park Creek Unit 14–Even Shelterwood

Unit description: The 54-acre (22-ha) unit was harvested in 2000. Preharvest, the overstory was dominated almost entirely by lodgepole pine (98 percent of tree density). Harvesting reduced the average number of live lodgepole pine from approximately 890 to 228 trees per acre (360 to 92 trees ha^{-1}) and basal area from 214 to 64 ft^2 $acre^{-1}$ (49 to 15 m^2 ha^{-1}).

Saplings consisted primarily of lodgepole pine with a secondary component of subalpine fir pretreatment. Almost all seedlings were subalpine fir pretreatment. Four years postharvest, sapling density for all species was reduced. In the seedling layer, a significant increase in lodgepole pine seedlings combined with a significant decrease in subalpine fir resulted in approximately equal seedling density for lodgepole pine and subalpine fir four years postharvest.

Pretreatment fuel loading was approximately 13 tons $acre^{-1}$ (3 kg m^{-2}). Fuel loading increased significantly after harvest because many of the saplings had to be cut to access overstory trees for harvest. These cut saplings were then left scattered throughout the unit, resulting in a high level of surface fuel following harvest, so the decision was made to pile the material using a machine with a grapple hook and burn it. This modification of the original prescription affected surface fuel distribution on about 60 percent of the unit. Piling and burning resulted in a mix of areas with high activity fuel loading and areas with almost no activity fuels present.

Management implications: The goal of reducing the overstory basal area by 40 to 60 percent through harvest was not met in this unit. Harvesting removed 74 percent of overstory trees. Increased light resulting from the even shelterwood harvest favored lodgepole pine regeneration. Even though subalpine fir seedlings and saplings were reduced by harvest-related activities, they remained prominent components in the unit. Additional treatments may be necessary to reduce subalpine fir competition if lodgepole pine regeneration is desired.

SITE: Spring Park Unit 14
TREATMENT: Even Shelterwood / Unburned

PREHARVEST

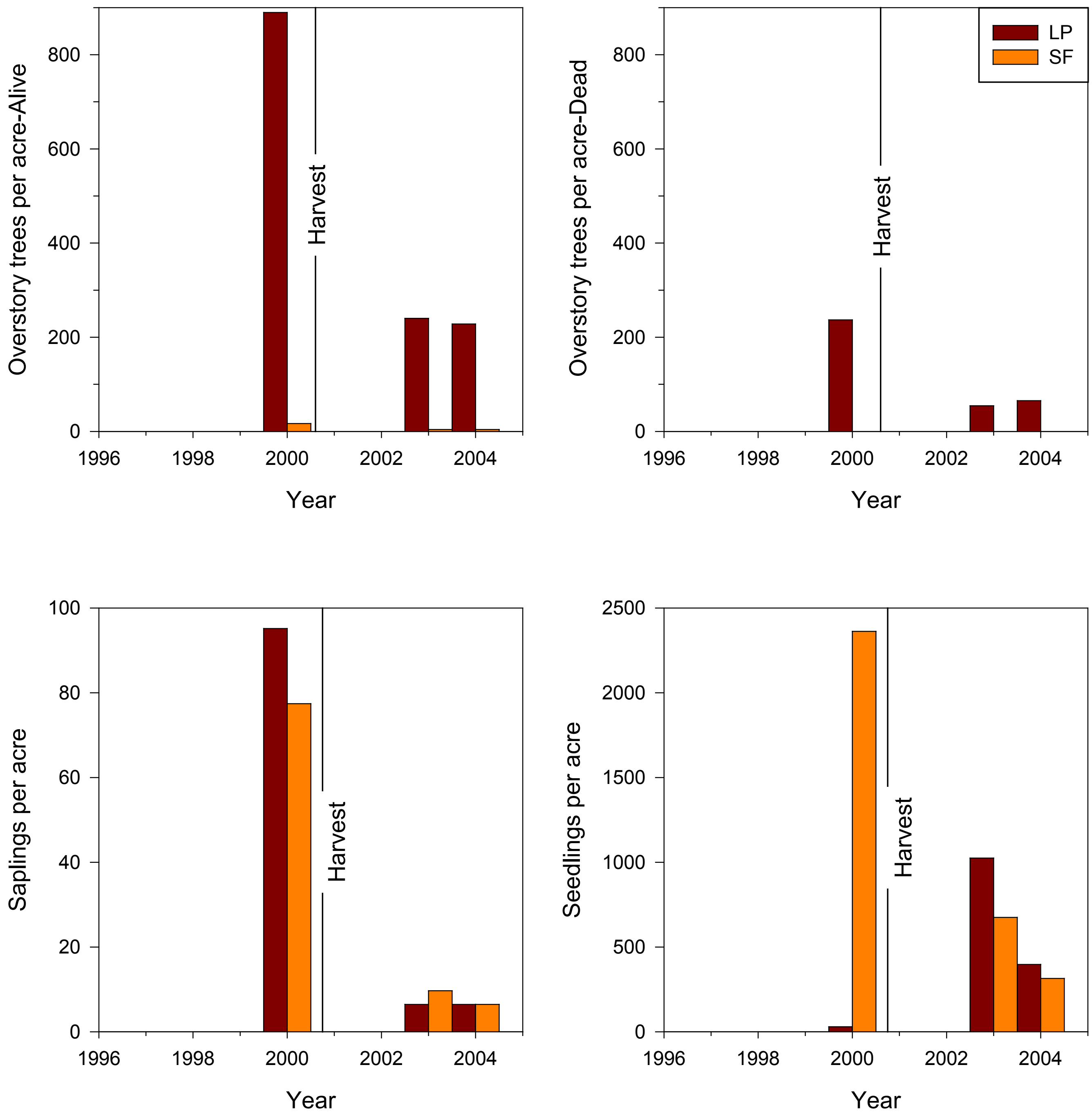
POSTHARVEST

POSTFIRE-1

No data collected

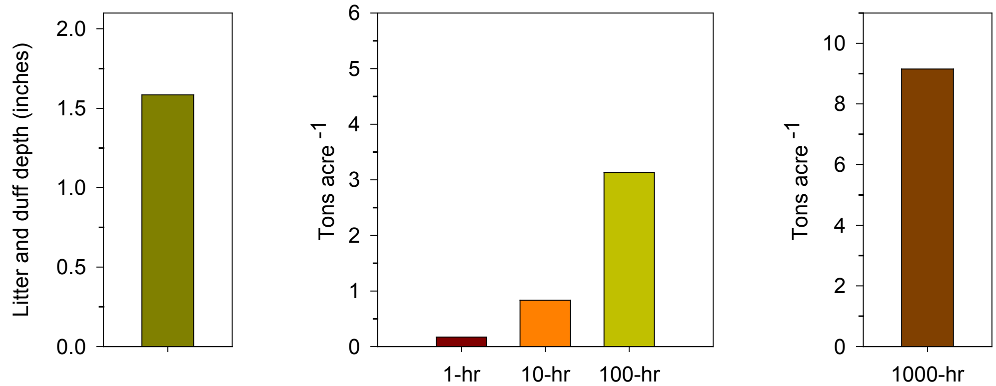
POSTFIRE-6

SITE: Spring Park Unit 14
TREATMENT: Even Shelterwood / Unburned

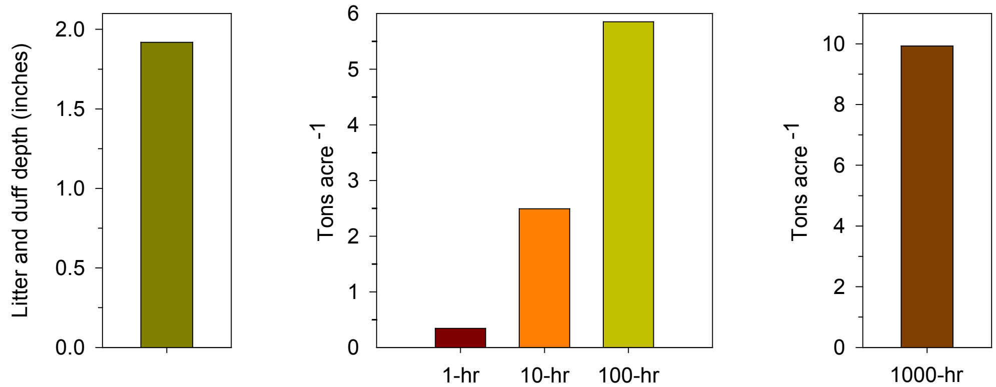


SITE: Spring Park Unit 14
TREATMENT: Even Shelterwood / Unburned

PREHARVEST



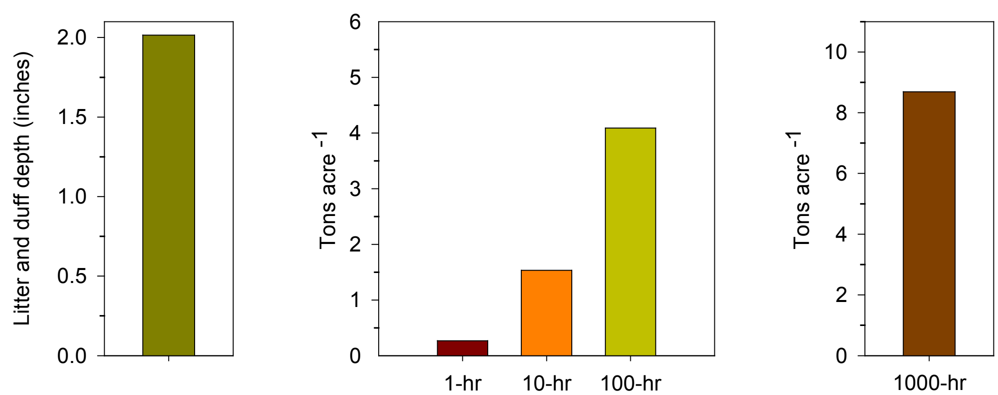
POSTHARVEST



POSTFIRE-1

No data collected

POSTFIRE-6



SITE: Spring Park Creek Unit 14
TREATMENT: Even Shelterwood / Unburned

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at $p < 0.05$. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	3 Years Postharvest (Std. Err.)	4 Years Postharvest (Std. Err.)	10 Years Postharvest (Std. Err.)
Overstory density (trees acre^{-1})					
LP	40	889.6 (82.1)	240.1* (57.3)	228.1* (57.6)	—
SF	40	16.7 (7.2)	4.2* (3.0)	4.2* (3.0)	—
Overstory basal area (ft^2 acre^{-1})					
LP	40	214.0 (11.2)	68.0* (11.2)	64.0* (11.2)	—
SF	40	9.0 (4.4)	5.0* (4.1)	5.0* (4.1)	—
Sapling density (trees acre^{-1})					
LP	40	235.0 (33.1)	23.8* (6.7)	25.0* (6.7)	—
ES	40	3.8 (2.8)	0 (0)	0 (0)	—
SF	40	95.0 (40.0)	66.3 (26.7)	43.8 (17.7)	—
WB	40	20.0 (10.3)	3.8 (2.8)	0* (0)	—
Seedling density (trees acre^{-1})					
LP	40	30.0 (18.0)	1025.0* (366.0)	397.5* (86.9)	—
ES	40	15.0 (10.5)	25.0 (25.0)	22.5 (16.6)	—
SF	40	2362.5 (693.3)	675.0* (221.8)	315.0* (114.2)	—
WB	40	412.5 (92.2)	0* (0)	0* (0)	—
Surface fuels					
Duff and litter depth (in)	20	1.58 (0.15)	1.92 (0.2)	—	2.01 (0.22)
1 hour fuel load (tons acre^{-1})	20	0.17 (0.02)	0.34* (0.05)	—	0.27 (0.07)
10 hour fuel load (tons acre^{-1})	20	0.83 (0.15)	2.49* (0.24)	—	1.53* (0.26)
100 hour fuel load (tons acre^{-1})	20	3.13 (0.63)	5.85* (0.74)	—	4.09 (0.58)
1000 hour fuel load (tons acre^{-1})	20	9.15 (2.92)	9.93* (1.47)	—	8.69 (1.26)

Group Shelterwood Treatment Units

Treatment: Group shelterwood

Management planning: The units were harvested with the objective to reduce the overstory by 40 to 60 percent. All trees were cut in corridors that surrounded unharvested patches of leave trees. Felled trees were whole-tree skidded to centralized processing locations for delimbing and decking for transport. All unutilized materials were piled and burned at the centralized locations. A detailed harvest prescription is provided in the "Treatment Descriptions" section.

Study site: Sun Creek Unit 6–Group Shelterwood

Unit description: The 78-acre (32-ha) unit was harvested in 2000. Lodgepole pine dominated (93 percent of tree density) the overstory prior to treatment. Harvesting reduced the average number of live lodgepole pine from approximately 515 to 218 trees per acre (209 to 88 trees ha^{-1}) and basal area from 182 to 83 ft^2 $acre^{-1}$ (42 to 19 m^2 ha^{-1}).

Pretreatment, the majority of saplings were lodgepole pine, while most seedlings were subalpine fir. Four years postharvest, lodgepole pine sapling density was significantly reduced and lodgepole pine seedling density significantly increased to become the dominant understory species. The reduction in tree and sapling density occurred in the harvested corridors, with overstory and sapling structure remaining relatively unchanged in the uncut leave patches.

Preharvest fuel loading was not measured. Fuel loading did not change between 3 and 10 years postharvest.

Management implications: The goal of reducing the overstory basal area by 40 to 60 percent through harvest was met in this unit, with an actual 58 percent reduction in overstory trees. Increased light resulting from the group shelterwood treatment favored lodgepole pine regeneration; however, most lodgepole pine regeneration occurred in the cut corridors where there was less vegetative competition and more light. Even though lodgepole pine saplings were reduced by the harvest, higher average densities remained in the group shelterwood harvest units compared to the even shelterwood units due to islands of uncut vegetation.

SITE: Sun Creek Unit 6
TREATMENT: Group Shelterwood / Unburned

PREHARVEST

No data collected

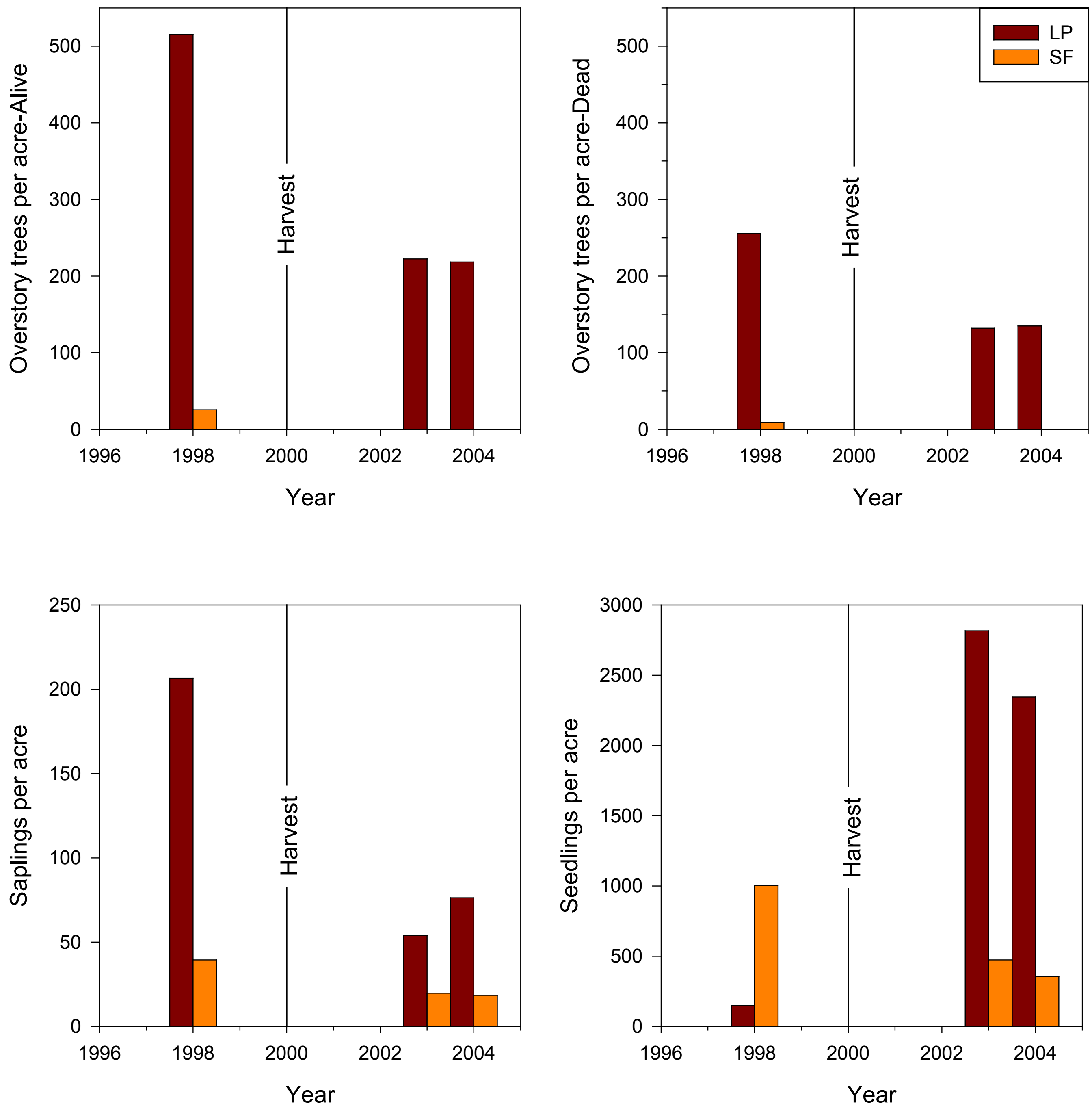
POSTHARVEST

POSTFIRE-1

No data collected

POSTFIRE-6

SITE: Sun Creek Unit 6
TREATMENT: Group Shelterwood / Unburned

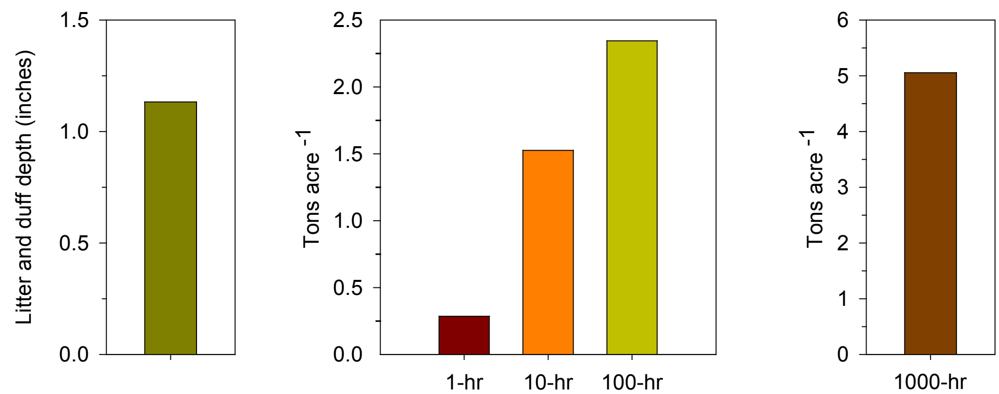


SITE: Sun Creek Unit 6
TREATMENT: Group Shelterwood / Unburned

PREHARVEST

No data collected

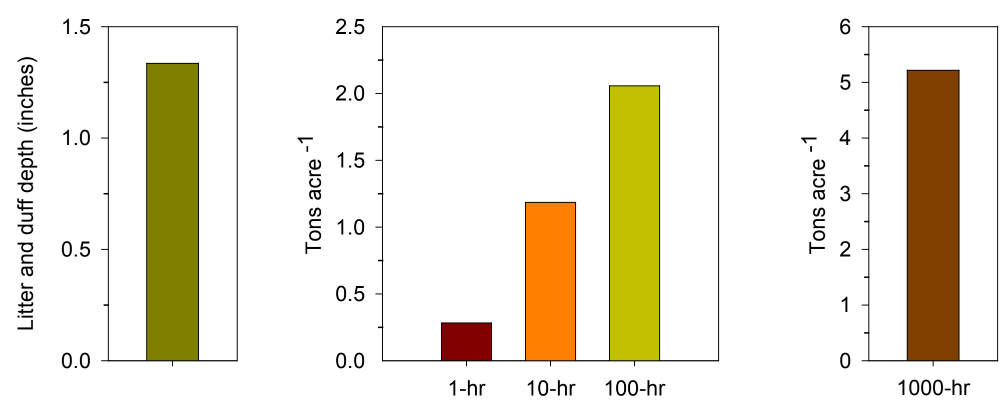
POSTHARVEST



POSTFIRE-1

No data collected

POSTFIRE-6



SITE: Sun Creek Unit 6
TREATMENT: Group Shelterwood / Unburned

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at $p<0.05$. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	3 Years Postharvest (Std. Err.)	4 Years Postharvest (Std. Err.)	10 Years Postharvest (Std. Err.)
Overstory density (trees acre^{-1})					
LP	38	515.4 (66.9)	222.3* (58.0)	218.3* (58.3)	—
ES	38	11.6 (8.2)	6.4 (6.4)	6.4 (6.4)	—
SF	38	25.4 (12.7)	0* (0)	0* (0)	—
Overstory basal area (ft^2 acre^{-1})					
LP	38	182.1 (13.8)	86.3* (19.2)	83.2* (19.3)	—
ES	38	3.2 (2.3)	1.1 (1.1)	1.1 (1.1)	—
SF	38	6.3 (3.2)	0* (0)	0* (0)	—
Sapling density (trees acre^{-1})					
LP	38	206.6 (42.3)	53.9* (17.8)	76.3* (23.2)	—
ES	38	23.7 (9.6)	3.9* (2.2)	3.9* (2.2)	—
SF	38	39.5 (20.6)	19.7 (7.4)	18.4 (7.2)	—
Seedling density (trees acre^{-1})					
LP	38	150.0 (60.7)	2815.8* (989.9)	2344.7* (606.7)	—
ES	38	0 (0)	0 (0)	47.4* (26.6)	—
SF	38	1002.6 (342.9)	473.7* (175.8)	355.3* (108.4)	—
WB	38	418.4 (106.5)	0* (0)	0* (0)	—
Surface fuels					
Duff and litter depth (in)	18	—	1.13 (0.22)	—	1.34 (0.19)
1 hour fuel load (tons acre^{-1})	18	—	0.29 (0.03)	—	0.28 (0.04)
10 hour fuel load (tons acre^{-1})	18	—	1.53 (0.23)	—	1.18 (0.25)
100 hour fuel load (tons acre^{-1})	18	—	2.34 (0.62)	—	2.06 (0.56)
1000 hour fuel load (tons acre^{-1})	18	—	5.05 (1.01)	—	5.22 (1.05)

Study site: Sun Creek Unit 7–Group Shelterwood

Unit description: The 61-acre (25-ha) unit was harvested in 2000. Lodgepole pine (45 percent of tree density) and subalpine fir (52 percent) dominated the overstory prior to treatment. Harvesting reduced the average number of live lodgepole pine trees per acre from approximately 321 to 105 (130 to 43 trees ha^{-1}) and basal area from 119 to 37 ft^2 $acre^{-1}$ (27 to 8 m^2 ha^{-1}). Subalpine fir density was significantly reduced and now comprises approximately 30 percent of the overstory.

Before treatment, the seedling and sapling layers consisted almost entirely of subalpine fir. Four years postharvest, subalpine fir seedlings and saplings were significantly reduced while lodgepole pine seedlings significantly increased. While the treatment favored lodgepole pine regeneration, subalpine fir continued to dominate the recruitment layer. The reduction in tree and sapling density occurred in the harvested corridors, with overstory and sapling structure remaining relatively unchanged in the uncut leave patches.

Preharvest fuel loading was not measured. Fuel loading did not change between 3 and 10 years postharvest.

Management implications: The goal of reducing the overstory by 40 to 60 percent basal area through harvest was not met in this unit. In actuality, harvesting removed 78 percent of overstory trees. Increased light resulting from the group shelterwood treatment favored lodgepole pine regeneration; however, most lodgepole pine regeneration occurred in the cut corridors where there was less vegetative competition and more light. Even though lodgepole pine saplings were reduced by the harvest, higher average densities remained in the group shelterwood units than in the even shelterwood units due to islands of uncut vegetation. Additional treatments may be necessary to reduce competing subalpine fir seedlings if lodgepole pine recruitment is desired.

SITE: Sun Creek Unit 7
TREATMENT: Group Shelterwood / Unburned

PREHARVEST

No data collected

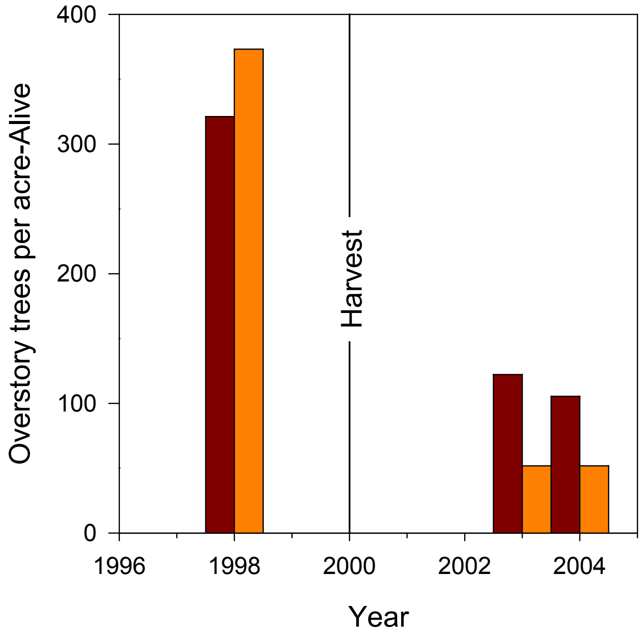
POSTHARVEST

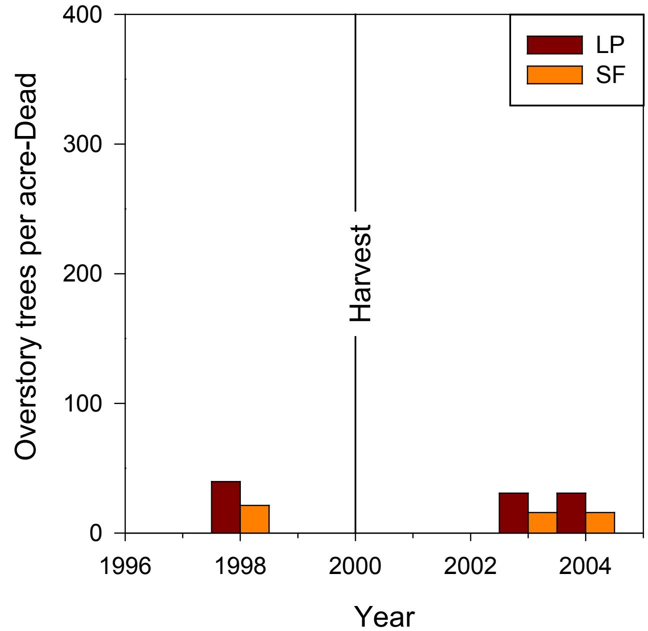

POSTFIRE-1

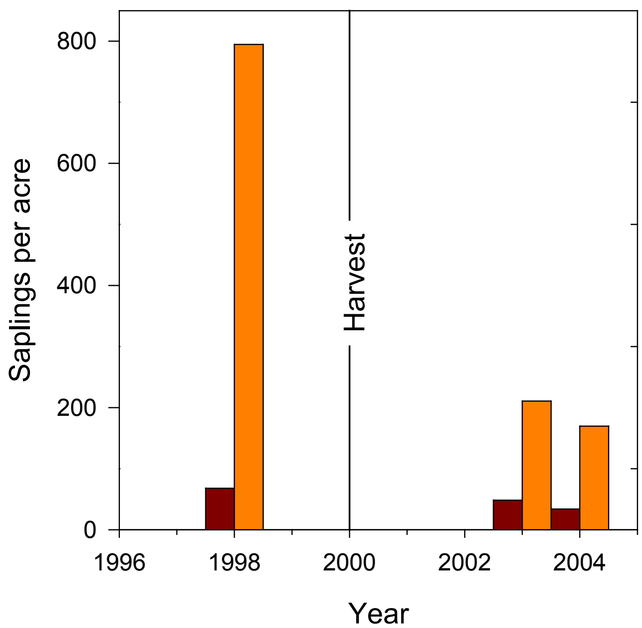
No data collected

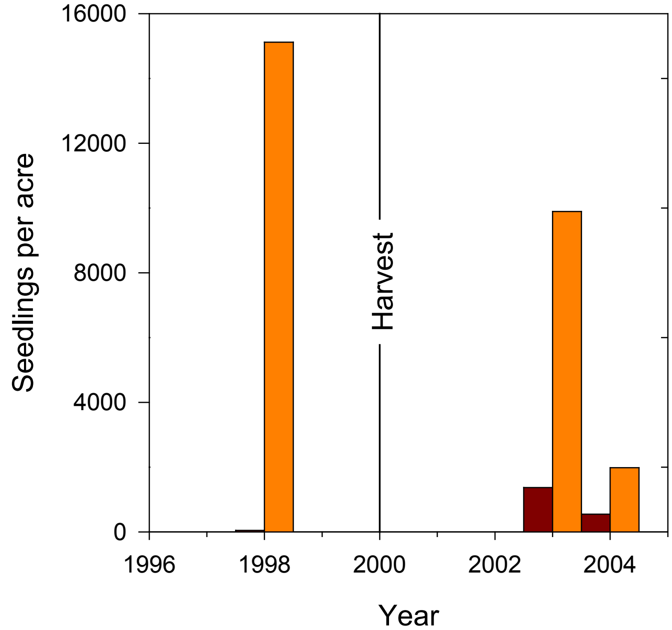
POSTFIRE-6


SITE: Sun Creek Unit 7
TREATMENT: Group Shelterwood / Unburned







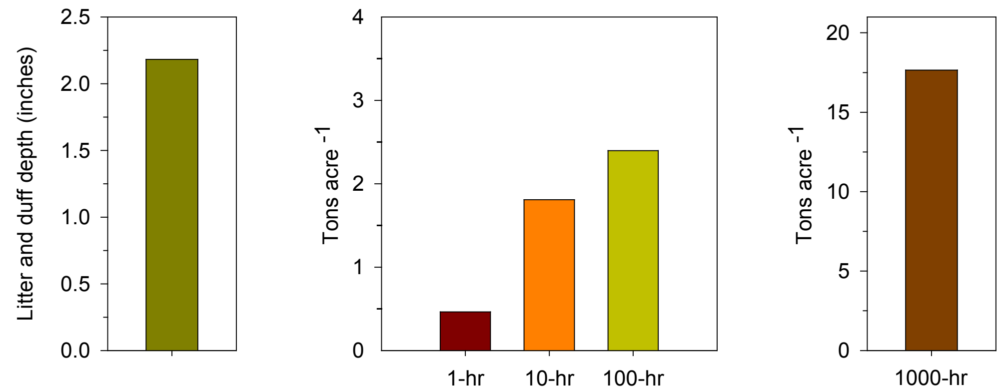


SITE: Sun Creek Unit 7
TREATMENT: Group Shelterwood / Unburned

PREHARVEST

No data collected

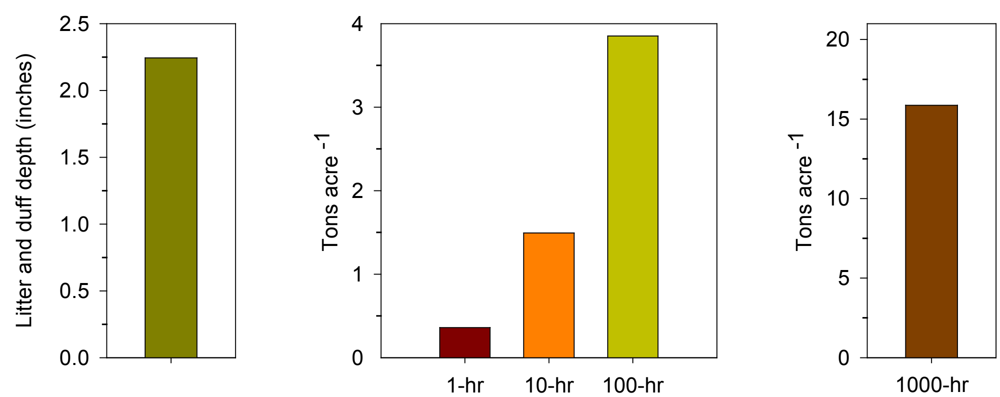
POSTHARVEST



POSTFIRE-1

No data collected

POSTFIRE-6



SITE: Sun Creek Unit 7
TREATMENT: Group Shelterwood / Unburned

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at $p<0.05$. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	3 Years Postharvest (Std. Err.)	4 Years Postharvest (Std. Err.)	10 Years Postharvest (Std. Err.)
Overstory density (trees acre^{-1})					
LP	28	321.1 (67.5)	122.2* (49.3)	105.4* (47.8)	—
ES	28	10.2 (8.1)	0* (0)	0* (0)	—
SF	28	373.2 (130.5)	51.8* (34.3)	51.8* (34.3)	—
WB	28	9.7 (9.7)	0 (0)	0 (0)	—
Overstory basal area (ft^2 acre^{-1})					
LP	28	118.6 (18.2)	44.3* (14.5)	37.1* (13.3)	—
ES	28	8.6 (5.9)	0* (0)	0* (0)	—
SF	28	44.3 (12.1)	5.7* (3.4)	5.7* (3.4)	—
WB	28	1.4 (1.4)	0 (0)	0 (0)	—
Sapling density (trees acre^{-1})					
LP	28	67.9 (18.8)	48.2* (21.7)	33.9* (12.6)	—
ES	28	19.6 (8.7)	0* (0)	0* (0)	—
SF	28	794.6 (98.5)	210.7* (65.2)	169.6* (50.9)	—
WB	28	3.6 (2.5)	0 (0)	0(0)	—
Seedling density (trees acre^{-1})					
LP	27	42.9 (42.9)	1370.4* (474.9)	566.7* (168.2)	—
ES	27	42.9 (25.4)	37.0 (37.0)	11.1 (11.1)	—
SF	27	15117.9 (2948.8)	9888.9* (5558.6)	2055.6* (582.6)	—
WB	27	10.7 (10.7)	111.1 (111.1)	88.9 (63.7)	—
Surface fuels					
Duff and litter depth (in)	14	—	2.18 (0.37)	—	2.24 (0.40)
1 hour fuel load (tons acre^{-1})	14	—	0.46 (0.08)	—	0.36* (0.10)
10 hour fuel load (tons acre^{-1})	14	—	1.81 (0.40)	—	1.49 (0.29)
100 hour fuel load (tons acre^{-1})	14	—	2.40 (0.49)	—	3.85 (0.89)
1000 hour fuel load (tons acre^{-1})	14	—	17.66 (3.82)	—	15.86 (2.84)

Study site: Spring Park Creek Unit 11–Group Shelterwood

Unit description: The 9-acre (4-ha) unit was harvested in 2000. Prior to harvest, subalpine fir dominated the overstory (43 percent of tree density), while lodgepole pine comprised approximately 30 percent. Harvesting significantly reduced overstory tree density and shifted dominance from subalpine fir to lodgepole pine. The average number of live lodgepole pine was reduced from approximately 136 to 55 trees per acre (55 to 22 trees ha^{-1}) and basal area from 83 to 33 ft^2 $acre^{-1}$ (19 to 7 m^2 ha^{-1}).

Regeneration consisted almost entirely of subalpine fir prior to harvest. Four years postharvest, sapling density for all species was reduced. In the seedling layer, lodgepole pine seedling regeneration increased, though subalpine fir still dominated. The reduction in tree and sapling density occurred in the harvested corridors, with overstory and sapling structure remaining relatively unchanged in the uncut leave patches.

Preharvest fuel loading was approximately 13 tons per acre (3 kg m^{-2}). Fine and 100-hr fuels significantly increased after harvest but declined to preharvest levels within 10 years.

Management implications: The goal of reducing the overstory basal area by 40 to 60 percent through harvest was not met in this unit. Harvesting removed 79 percent of overstory trees. Increased light resulting from the group shelterwood treatment favored lodgepole pine regeneration; however, most lodgepole pine regeneration occurred in the cut corridors where there was less vegetative competition and more light. Even though lodgepole pine saplings were reduced by the harvest, higher average densities remained in the group shelterwood units than in the even shelterwood units due to islands of uncut vegetation. Additional treatments may be necessary to reduce competing subalpine fir seedlings if lodgepole pine recruitment is desired.

SITE: Spring Park Unit 11
TREATMENT: Group Shelterwood / Unburned

PREHARVEST

No data collected

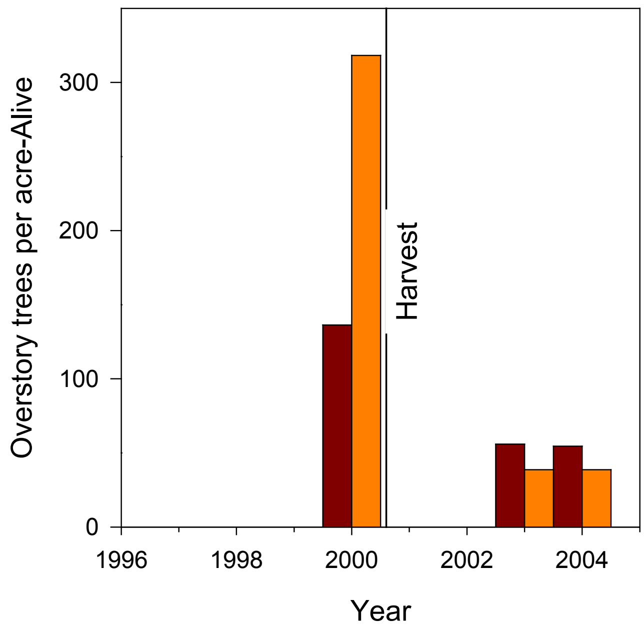
POSTHARVEST

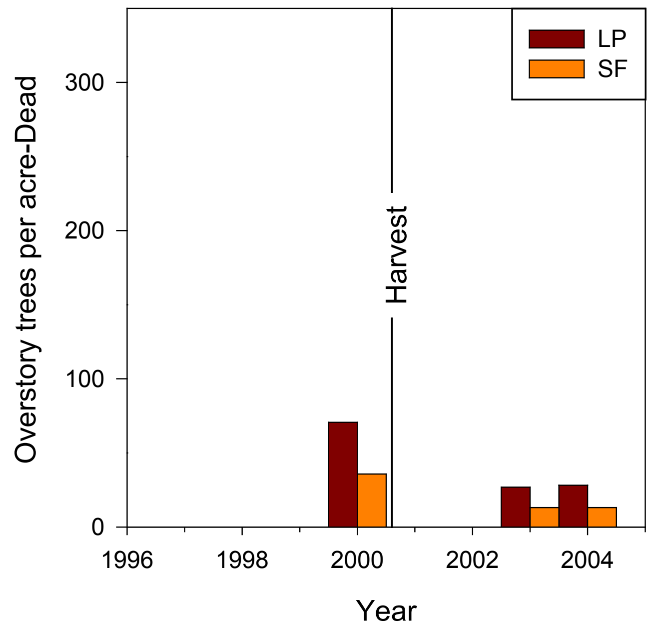
POSTFIRE-1

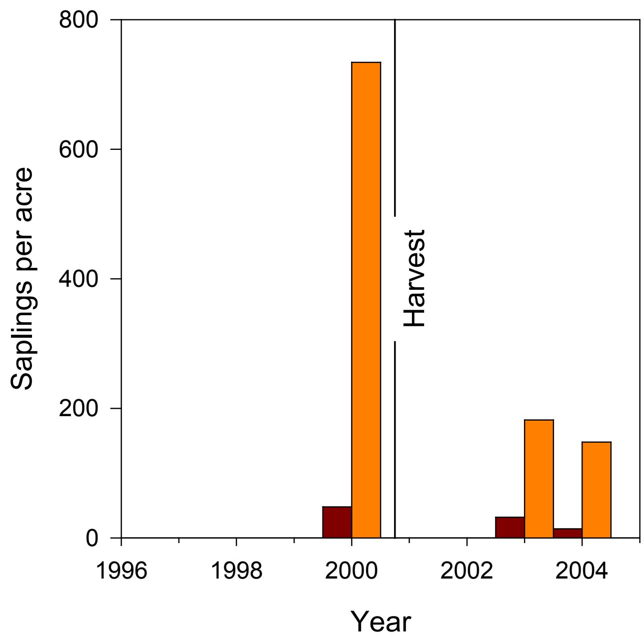
No data collected

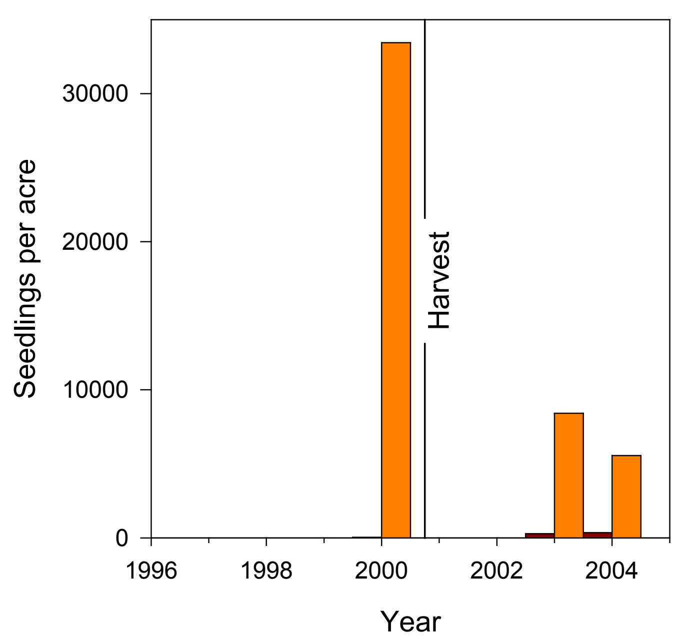
POSTFIRE-6

SITE: Spring Park Unit 11
TREATMENT: Group Shelterwood / Unburned



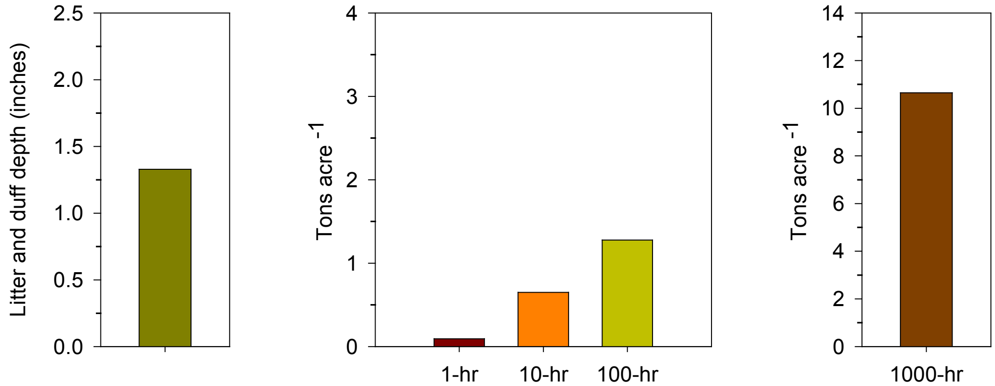




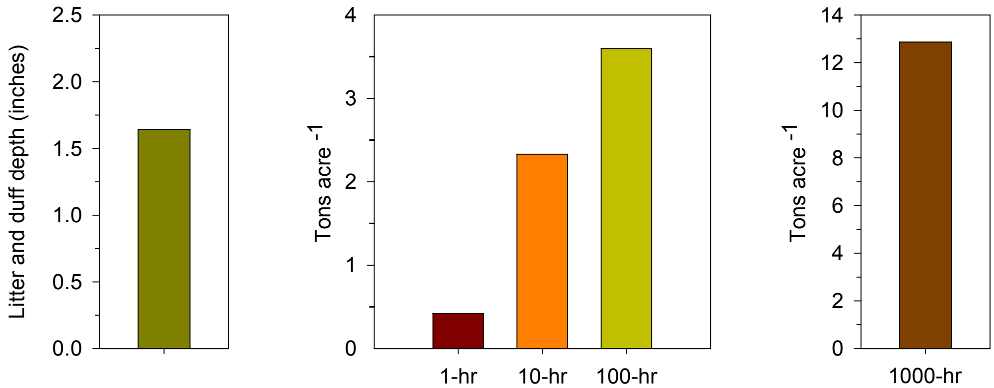


SITE: Spring Park Unit 11
TREATMENT: Group Shelterwood / Unburned

PREHARVEST



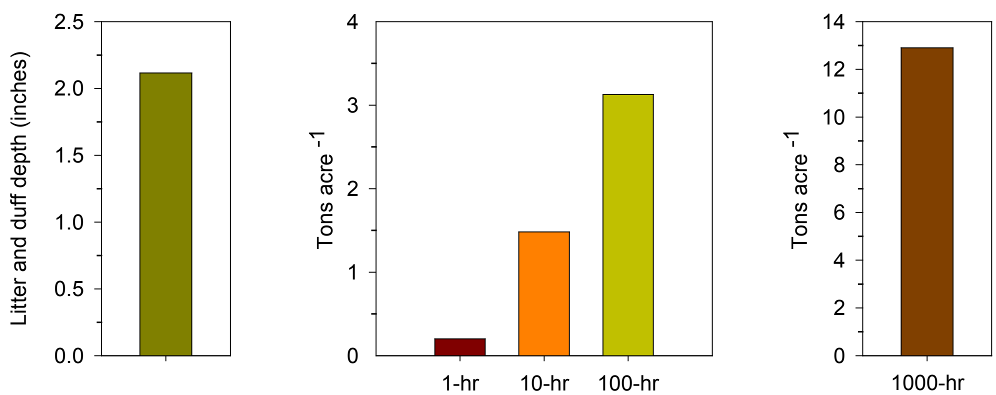
POSTHARVEST



POSTFIRE-1

No data collected

POSTFIRE-6



SITE: Spring Park Creek Unit 11
TREATMENT: Group Shelterwood / Unburned

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at p<0.05. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	3 Years Postharvest (Std. Err.)	4 Years Postharvest (Std. Err.)	10 Years Postharvest (Std. Err.)
Overstory density (trees acre^{-1})					
LP	25	136.3 (27.4)	56.0* (23.1)	54.5* (23.1)	—
ES	25	5.4 (3.2)	2.4 (2.4)	2.4 (2.4)	—
SF	25	318.2 (107.4)	38.7* (28.1)	38.7* (28.1)	—
Overstory basal area (ft^{2} acre^{-1})					
LP	25	83.2 (10.8)	33.6* (11.0)	32.0* (10.8)	—
ES	25	4.8 (2.7)	1.6 (1.6)	1.6 (1.6)	—
SF	25	43.2 (8.3)	3.2* (2.2)	3.2* (2.2)	—
Sapling density (trees acre^{-1})					—
LP	25	48.0 (13.1)	32.0* (14.4)	14.0* (7.4)	—
ES	25	12.0 (7.2)	0 (0)	2.0 (2.0)	—
SF	25	734.0 (142.4)	182.0* (53.0)	148.0* (44.6)	—
WB	25	8.0 (3.7)	0 (0)	8.0 (3.7)	—
Seedling density (trees acre^{-1})					
LP	24	36.0 (19.9)	291.7 (140.9)	375.0 (181.7)	—
ES	24	108.0 (96.3)	166.7 (130.0)	125.0 (86.5)	—
SF	24	33444.0 (4768.4)	8416.7* (1861.0)	5787.5* (1220.5)	—
WB	24	348.0 (175.5)	0* (0)	62.5 (25.4)	—
Surface fuels					
Duff and litter depth (in)	12	1.33 (0.16)	1.64 (0.22)	—	2.12 (0.26)
1 hour fuel load (tons acre^{-1})	12	0.09 (0.03)	0.42 (0.07)	—	0.20* (0.03)
10 hour fuel load (tons acre^{-1})	12	0.65 (0.13)	2.33* (0.57)	—	1.48 (0.31)
100 hour fuel load (tons acre^{-1})	12	1.28 (0.47)	3.6* (0.71)	—	3.13 (0.56)
1000 hour fuel load (tons acre^{-1})	12	10.65 (2.23)	12.86 (1.81)	—	12.90 (1.77)

Study site: Spring Park Creek Unit 15–Group Shelterwood

Unit description: The 73-acre (30-ha) unit was harvested in 2000. Lodgepole pine dominated (98 percent of tree density) the overstory prior to treatment. Harvesting reduced the average number of live lodgepole pine from approximately 766 to 257 trees per acre (310 to 104 trees ha^{-1}) and basal area from 193 to 71 ft^2 $acre^{-1}$ (44 to 16 m^2 ha^{-1}).

Preharvest, saplings consisted primarily of lodgepole pine, while the seedling layer was composed of lodgepole pine, subalpine fir, and whitebark pine. Four years postharvest, lodgepole pine sapling density was greatly reduced but remained dominant. In the seedling layer, lodgepole pine significantly increased, while subalpine fir significantly decreased and whitebark pine was not detected. The reduction in tree and sapling density occurred in the harvested corridors, with overstory and sapling structure remaining relatively unchanged in the uncut leave patches.

Preharvest fuel loading was approximately 9 tons per acre (2 kg m^{-2}). Cut saplings and sub-merchantable trees in the corridors were left scattered throughout the unit, resulting in a high level of surface fuel following harvest. Therefore, the original prescription was modified such that material was mechanically grapple-piled and burned throughout the unit. Surface fuel distribution was affected on approximately 40 percent of the unit from the additional burn treatment. This resulted in a mix of areas with high levels of activity fuels and areas with almost no activity fuels present.

Management implications: The goal of reducing the overstory basal area by 40 to 60 percent through harvest was not met in this unit. Harvesting removed 65 percent of overstory trees. Increased light resulting from the group shelterwood treatment favored lodgepole pine regeneration; however, most lodgepole pine regeneration occurred in the cut corridors where there was less vegetative competition and more light. Even though lodgepole pine saplings were reduced by the harvest, higher average densities remained in the group shelterwood units compared to the even shelterwood units due to islands of uncut vegetation.

SITE: Spring Park Unit 15
TREATMENT: Group Shelterwood / Unburned

PREHARVEST

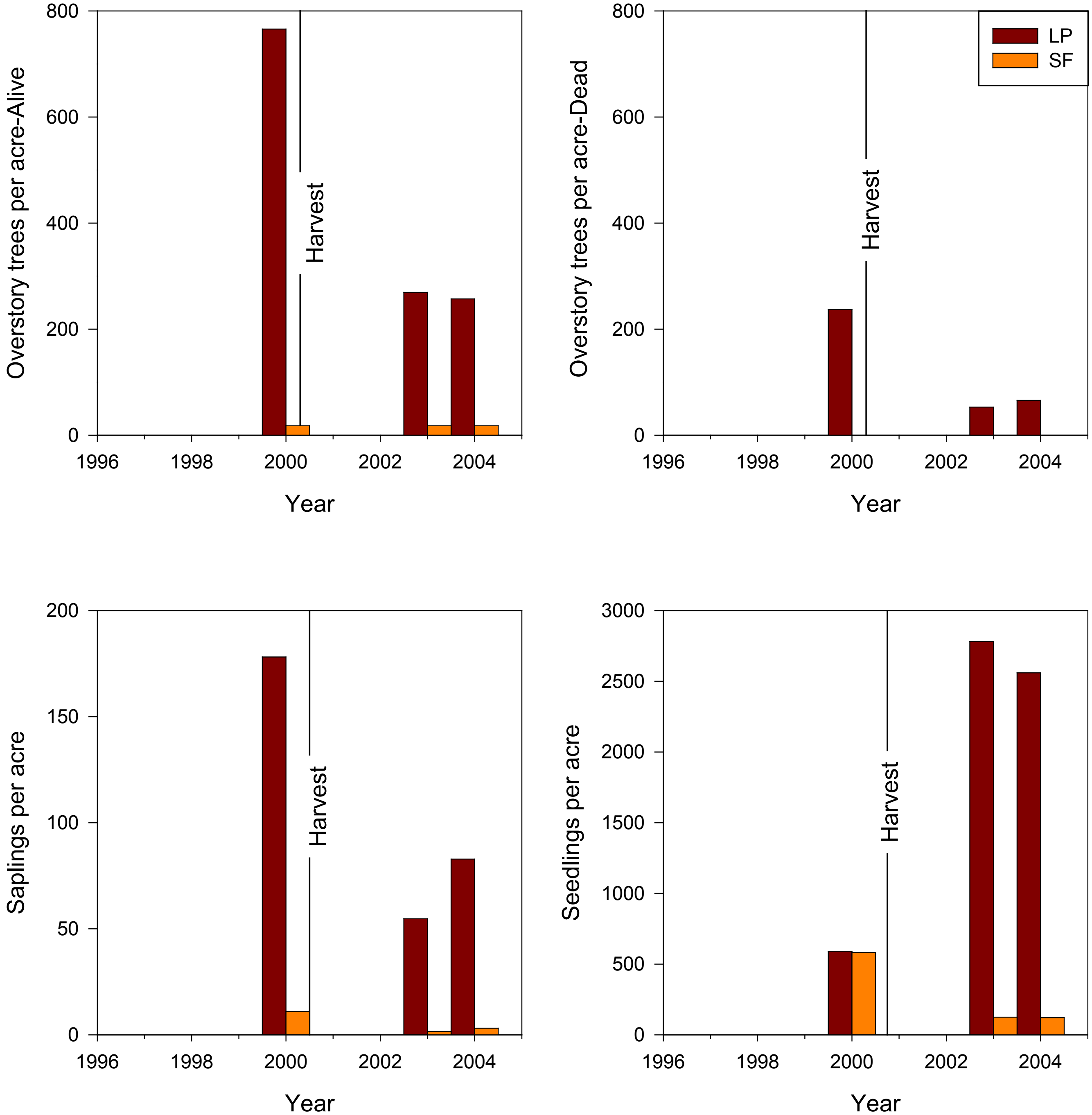
POSTHARVEST

POSTFIRE-1

No data collected

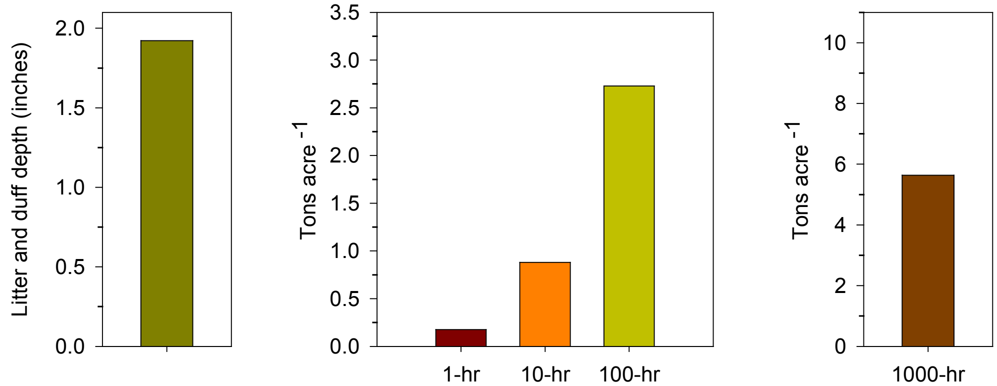
POSTFIRE-6

SITE: Spring Park Unit 15
TREATMENT: Group Shelterwood / Unburned

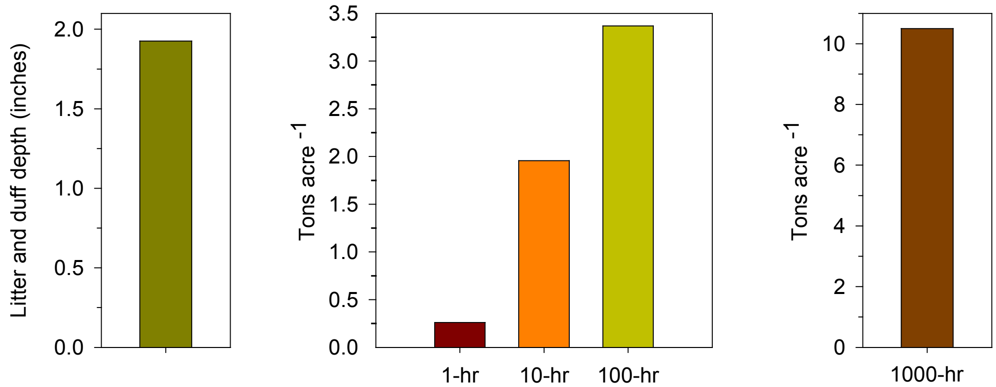


SITE: Spring Park Unit 15
TREATMENT: Group Shelterwood / Unburned

PREHARVEST



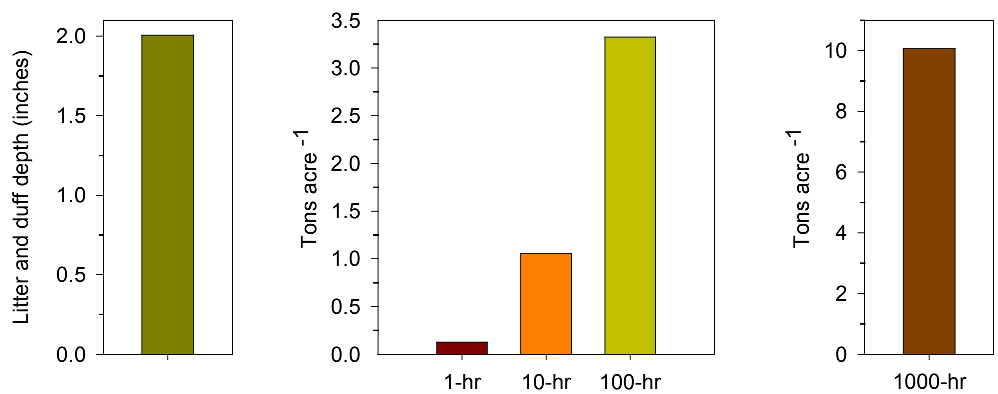
POSTHARVEST



POSTFIRE-1

No data collected

POSTFIRE-6



SITE: Spring Park Creek Unit 15
TREATMENT: Group Shelterwood / Unburned

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at $p < 0.05$. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	3 Years Postharvest (Std. Err.)	4 Years Postharvest (Std. Err.)	10 Years Postharvest (Std. Err.)
Overstory density (trees acre^{-1})					
LP	32	765.7 (98.3)	269.3* (73.3)	256.8* (70.8)	—
SF	32	17.7 (17.7)	17.7 (17.7)	17.7 (17.7)	—
Overstory basal area (ft^2 acre^{-1})					
LP	32	192.5 (11.6)	73.8* (17.5)	71.3* (17.1)	—
SF	32	1.3 (1.3)	1.3 (1.3)	1.3 (1.3)	—
Sapling density (trees acre^{-1})					
LP	32	178.1 (32.6)	54.7* (20.1)	82.8* (30.0)	—
SF	32	10.9 (3.7)	1.6* (1.6)	3.1* (2.2)	—
Seedling density (trees acre^{-1})					
LP	32	590.6 (213.2)	2781.3 (794.1)	2559.4* (677.6)	—
ES	32	46.9 (38.4)	0 (0)	9.4 (9.4)	—
SF	32	581.3 (176.1)	125.0* (97.9)	121.9* (37.8)	—
WB	32	356.3 (87.8)	0* (0)	0* (0)	—
Surface fuels					
Duff and litter depth (in)	16	1.92 (0.43)	1.93 (0.27)	—	2.01 (0.30)
1 hour fuel load (tons acre^{-1})	16	0.18 (0.02)	0.26 (0.03)	—	0.13* (0.02)
10 hour fuel load (tons acre^{-1})	16	0.88 (0.10)	1.96* (0.29)	—	1.06* (0.16)
100 hour fuel load (tons acre^{-1})	16	2.73 (0.95)	3.37* (0.71)	—	3.32 (0.58)
1000 hour fuel load (tons acre^{-1})	16	5.64 (0.98)	10.5* (1.88)	—	10.06 (1.40)

Even Shelterwood and Prescribed Burn Treatment Units

Treatment: Even-spaced shelterwood followed by a low-intensity, mixed-severity prescribed burn

Management planning: The units were harvested with the objective to reduce the overstory by 40 to 60 percent during harvest. Trees were harvested to create approximately equal spacing between reserve trees. Felled trees were whole-tree skidded to centralized processing locations for delimbing and decking for transport. All unutilized materials were piled and burned at the centralized locations. The prescribed burn treatment was designed to reduce activity fuels created from the harvest operation and to prepare a seed bed for natural regeneration while limiting overstory postharvest mortality to 50 percent. After harvest and prescribed burning, the target tree density was retention of at least 25 percent of preharvest overstory tree density. A detailed harvest prescription is provided in the "Treatment Descriptions" section.

Study site: Sun Creek Unit 1–Even Shelterwood and Burn

Unit description: This 16-acre (6-ha) unit is typically very wet due to a shallow water table, so it was harvested during the winter of 1999/2000 over frozen ground and/or snow to reduce soil disturbance. Prior to harvest, the overstory was dominated by lodgepole pine (54 percent of tree density) and subalpine fir (34 percent). A wind event following harvest blew down a large number of residual trees leaving lodgepole pine as the dominant species. Unfortunately, we were not able to measure postharvest tree density before the wind event. Following harvest and the wind event, the average number of live lodgepole pine was dramatically reduced from approximately 318 to 24 trees per acre (129 to 10 trees ha^{-1}) and basal area from 119 to 14 ft^2 $acre^{-1}$ (27 to 3 m^2 ha^{-1}).

The seedling and sapling layer consisted mostly of subalpine fir prior to harvest. One year postfire, subalpine fir and lodgepole pine sapling density was significantly lower. Although the combined treatments favored lodgepole pine regeneration, subalpine fir still comprised approximately 50 percent of the seedling layer 1 year postfire.

Fuel loading was not measured prior to harvest. Fuel model 11 (Anderson 1981) best described the unit after harvest. The unit was prescribed burned on October 3, 2003. Mean fuel moisture by size class was: 16 percent for 1-hr, 14 percent for 10-hr, 16 percent for 100-hr, 24 percent for 1000-hr, and 44 percent for duff. Temperatures ranged from 60 to 68 ^{o}F (16 to 20 ^{o}C). Relative humidity ranged from 7 to 18 percent, with average wind speed between 1 and 6 mph (0.5 to 3 m sec^{-1}). Crown scorch was low throughout most of the unit, with an average of 15 percent and a median of 0 percent. Average basal bark char was 47 percent (median = 50 percent). Fire-caused mortality resulted in an additional 52 percent mortality of lodgepole pine trees greater than 4 inches (10.2 cm) DBH, with mortality stabilizing within 3 years after the burn. While the fire reduced forest floor and fine fuel loading, very little consumption of the 1000-hr fuels occurred. Six years postfire, the forest floor depth and fine fuel load were significantly lower than postharvest levels.

Management implications: The goal of reducing the overstory basal area by 40 to 60 percent through harvest was not met in this unit. Harvesting combined with the wind event removed 96 percent of overstory trees, resulting in very few leave trees scattered throughout the unit. The prescribed burn killed approximately 50 percent of the remaining overstory lodgepole pine and reduced activity fuels created during harvest. While this was within the mortality limits set for the prescribed burn, the overstory retention target of 25 percent of preharvest trees was not met due to overharvesting combined with the wind event. Harvest followed by fire reduced litter and duff depth and created light conditions favorable for lodgepole pine regeneration. Additional treatments may be necessary to reduce competing subalpine fir seedlings if further lodgepole pine recruitment is desired. Because lodgepole pine has such thin bark, it is very susceptible to fire regardless of flame length. If the majority (>75 percent) of the tree base is blackened, lodgepole pine will likely die. Therefore, prescribed burns that leave patches of unburned vegetation are critical for limiting lodgepole pine mortality, especially in units with activity fuel on the ground.

SITE: Sun Creek Unit 1
TREATMENT: Even Shelterwood & Prescribed Burn

PREHARVEST

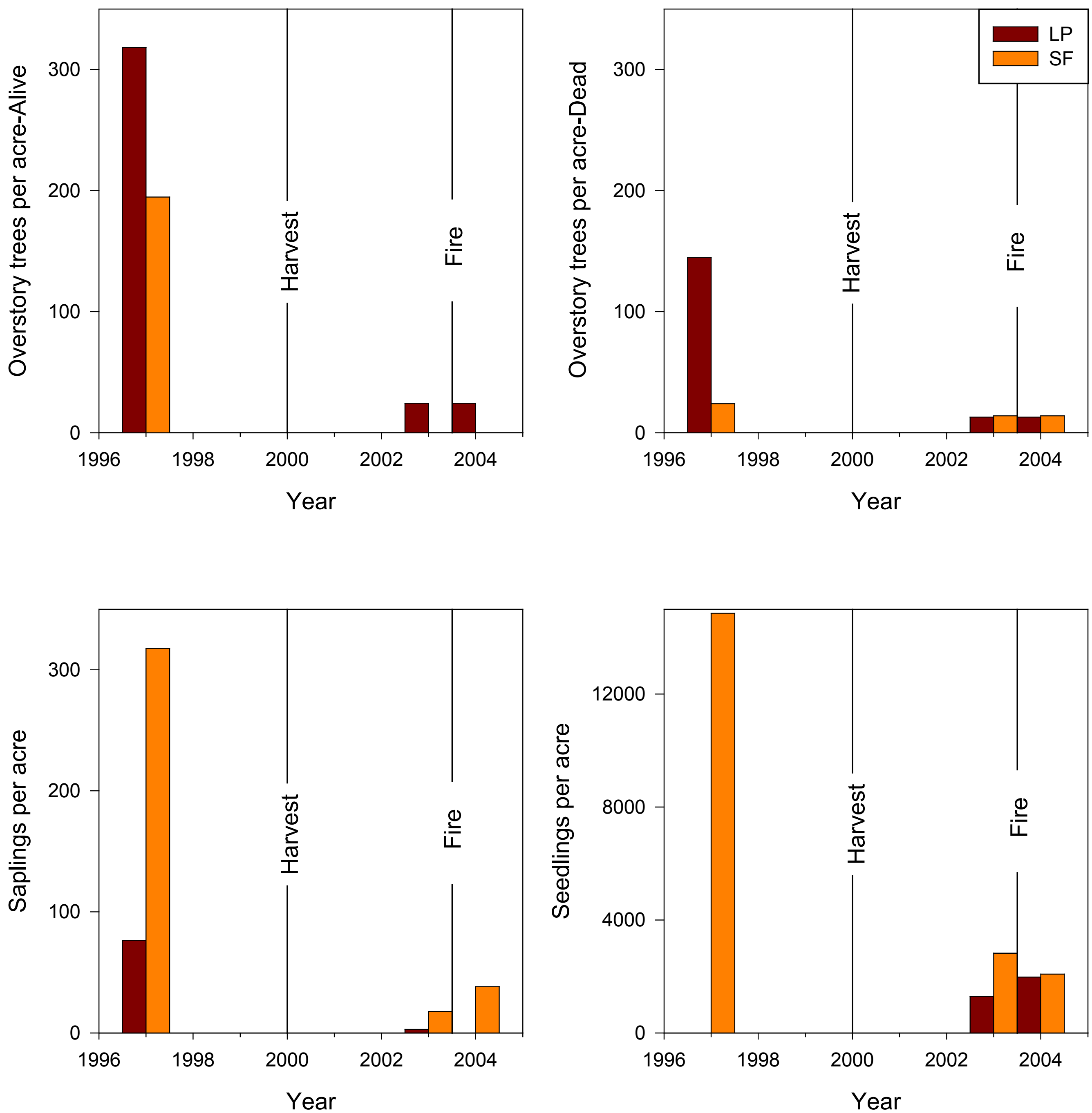
No data collected

POSTHARVEST

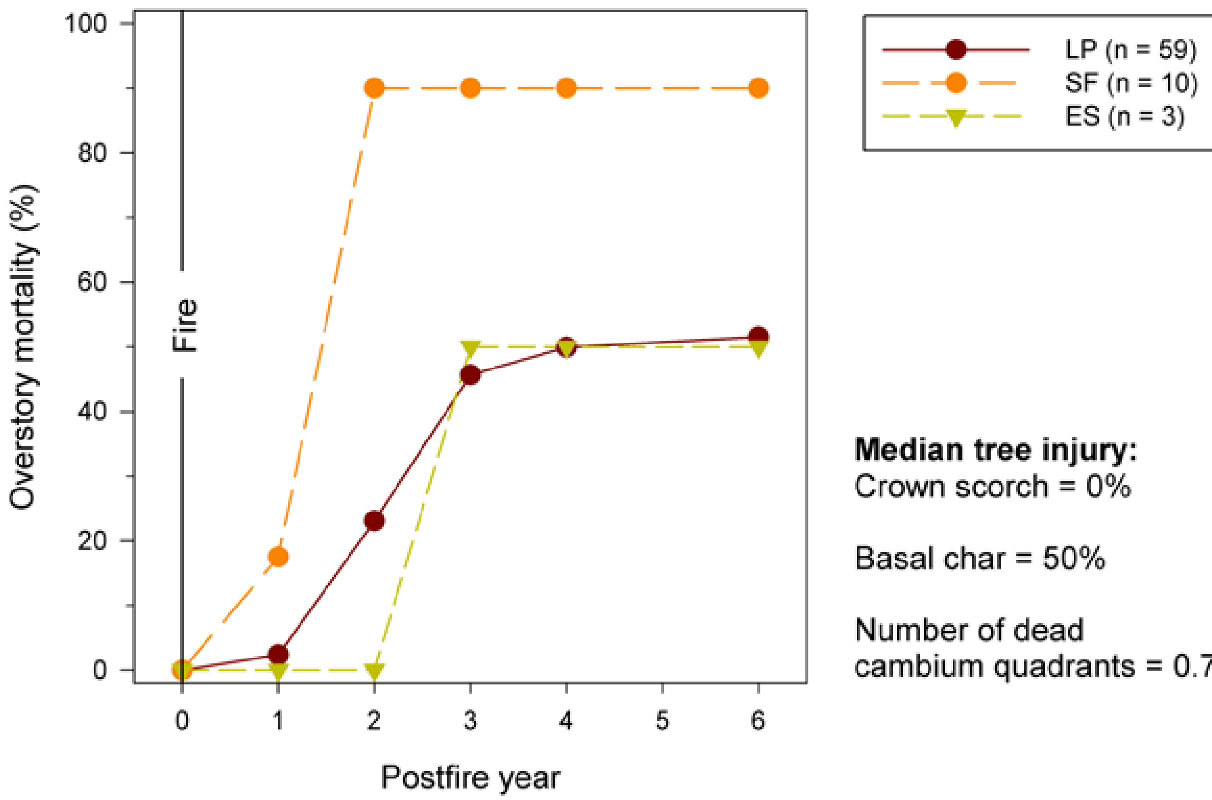
POSTFIRE-1

POSTFIRE-6

SITE: Sun Creek Unit 1
TREATMENT: Even Shelterwood & Prescribed Burn



SITE: Sun Creek Unit 1
TREATMENT: Even Shelterwood & Prescribed Burn



Median tree injury:
Crown scorch = 0%

Basal char = 50%

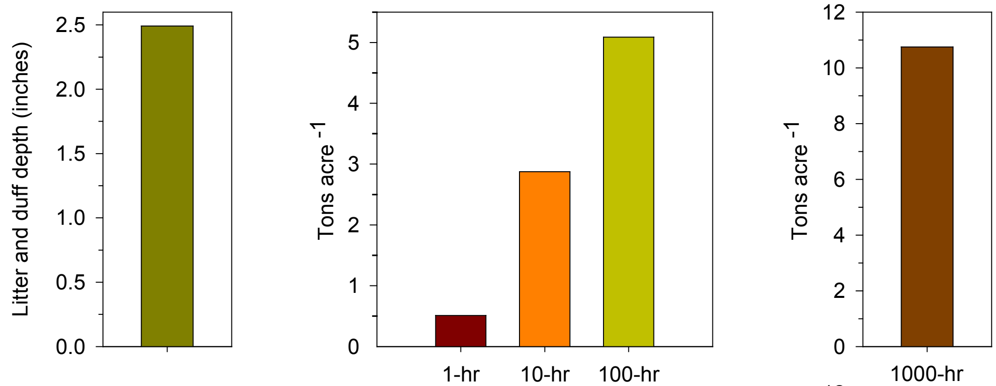
Number of dead
cambium quadrants = 0.75

SITE: Sun Creek Unit 1
TREATMENT: Even Shelterwood & Prescribed Burn

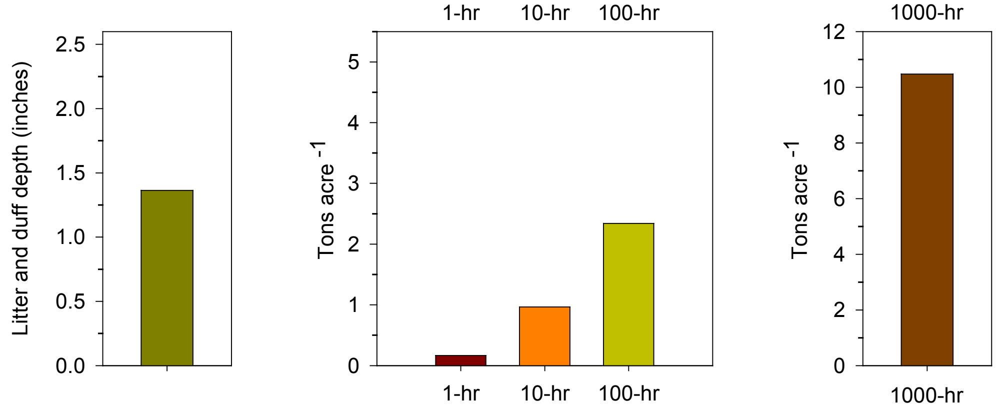
PREHARVEST

No data collected

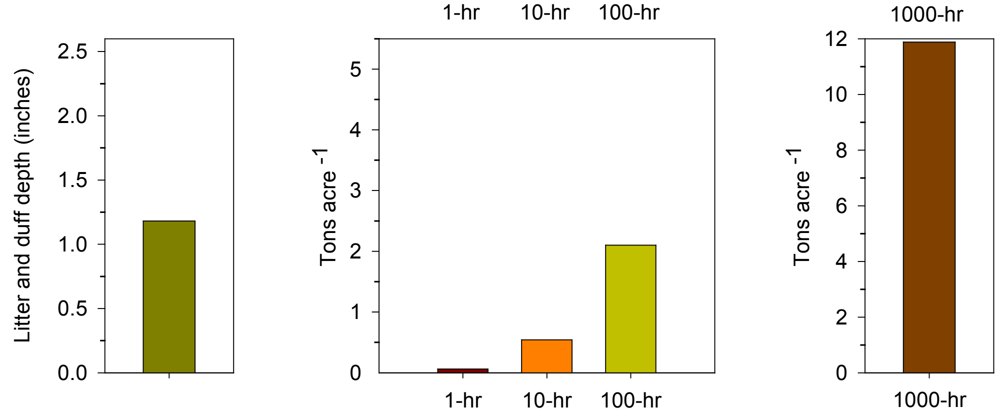
POSTHARVEST



POSTFIRE-1



POSTFIRE-6



SITE: Sun Creek Unit 1
TREATMENT: Even Shelterwood & Prescribed burn

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at p<0.05. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. An asterisk by postburn measurement denotes change between postharvest loading and postburn loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	3 Years Postharvest (Std. Err.)	1 Year Postburn (Std. Err.)	6 Years Postburn (Std. Err.)
Overstory density (trees acre^{-1})					
LP	17	318.2 (75.5)	24.3* (10.2)	24.3* (10.2)	—
ES	17	66.4 (31.0)	1.3* (1.3)	1.3* (1.3)	—
SF	17	194.7 (106.6)	0* (0)	0* (0)	—
Overstory basal area (ft^2 acre^{-1})					
LP	17	118.8 (17.7)	14.1* (4.5)	14.1* (4.5)	—
ES	17	17.6 (7.5)	1.2* (1.2)	1.2* (1.2)	—
SF	17	18.8 (9.6)	0* (0)	0* (0)	—
Sapling density (trees acre^{-1})					
LP	17	76.5 (25.4)	2.9* (2.9)	0* (0)	—
ES	17	11.8 (6.8)	0 (0)	2.9 (2.9)	—
SF	17	317.6 (39.3)	17.6* (7.4)	38.2* (18.9)	—
Seedling density (trees acre^{-1})					
LP	17	0 (0)	1294.1 (1059.8)	1976.5* (1021.9)	—
ES	17	123.5 (45.0)	58.8* (58.8)	0* (0)	—
SF	17	14858.8 (4201.8)	2823.5* (1243.3)	2082.4* (915.5)	—
WB	17	35.3 (35.3)	0 (0)	0 (0)	—
Surface fuels					
Duff and litter depth (in)	9	—	2.49 (0.28)	1.36* (0.24)	1.18* (0.20)
1 hour fuel load (tons acre^{-1})	9	—	0.51 (0.08)	0.17* (0.05)	0.06* (0.01)
10 hour fuel load (tons acre^{-1})	9	—	2.88 (0.33)	0.96* (0.28)	0.54* (0.11)
100 hour fuel load (tons acre^{-1})	9	—	5.09 (0.83)	2.34* (0.55)	2.10* (0.26)
1000 hour fuel load (tons acre^{-1})	9	—	10.75 (2.53)	10.47 (2.37)	11.88 (2.61)

Study site: Sun Creek Unit 3–Even Shelterwood and Burn

Unit description: Because this 36-acre (15-ha) unit is often fairly wet, it was harvested during the winter of 1999/2000 over frozen ground and/or snow to reduce soil disturbance. The overstory was dominated by lodgepole pine (94 percent of tree density) prior to harvest. Harvest and fire reduced the average number of live lodgepole pine from approximately 683 to 92 trees per acre (277 to 37 trees ha^{-1}) and basal area from 188 to 37 ft^2 $acre^{-1}$ (43 to 8 m^2 ha^{-1}).

Pretreatment sapling density was mostly lodgepole pine with some subalpine fir. Seedling density was predominantly subalpine fir. Two years postfire, sapling density was greatly reduced for all species and codominated by lodgepole pine and subalpine fir, while lodgepole pine seedlings had significantly increased.

Preharvest fuel loading was not measured in this unit. After harvest, fuel model 11 (Anderson 1981) best described the unit with fuel loading approximately 14 tons per acre (3 kg m^{-2}). The unit was prescribed burned on September 16, 2002, between 1400 and 1800. Mean fuel moisture by size class was: 7 percent for 1-hr, 8 percent for 10-hr, 13 percent for 100-hr, and 25 percent for 1000-hr. Temperatures ranged from 66 to 73 ^oF (19 to 23 ^oC). Relative humidity ranged from 15 to 25 percent, with average wind speed between 4 and 8 mph (2 to 4 m sec^{-1}). Crown scorch was low throughout most of the unit, with an average of 30 percent and a median of 8 percent. Average basal bark char was 52 percent (median = 85 percent). Fire-caused mortality resulted in an additional 58 percent mortality of lodgepole pine trees greater than 4 inches (10.2 cm) DBH, with mortality stabilizing within 2 years after the burn. While the fire reduced forest floor depth and fine fuel loading, very little consumption of the 1000-hr fuels occurred.

Management implications: We did not sample tree plots postharvest in this unit; therefore, we do not know the reduction in tree density from harvest alone. Harvest and fire reduced overstory tree density by 84 percent. The goal of reducing the overstory basal area by 40 to 60 percent through harvest was likely close to target, but the prescribed burn killed more trees than the intended goal of no more than 50 percent of the residual trees. The prescribed fire was effective in significantly reducing fine fuel created by the logging but not the 1000-hr fuel component.

Harvest followed by fire reduced litter and duff depth and created light conditions favorable for lodgepole pine regeneration. Additional treatments may be necessary to reduce competing subalpine fir seedlings if further lodgepole pine recruitment is desired. Because lodgepole pine has such thin bark, it is very susceptible to fire regardless of flame length. If the majority (>75 percent) of the tree base is blackened, lodgepole pine will likely die. Therefore, prescribed burns that leave patches of unburned vegetation are critical for limiting lodgepole pine mortality, especially in units with activity fuel on the ground.

SITE: Sun Creek Unit 3
TREATMENT: Even Shelterwood & Prescribed Burn

PREHARVEST

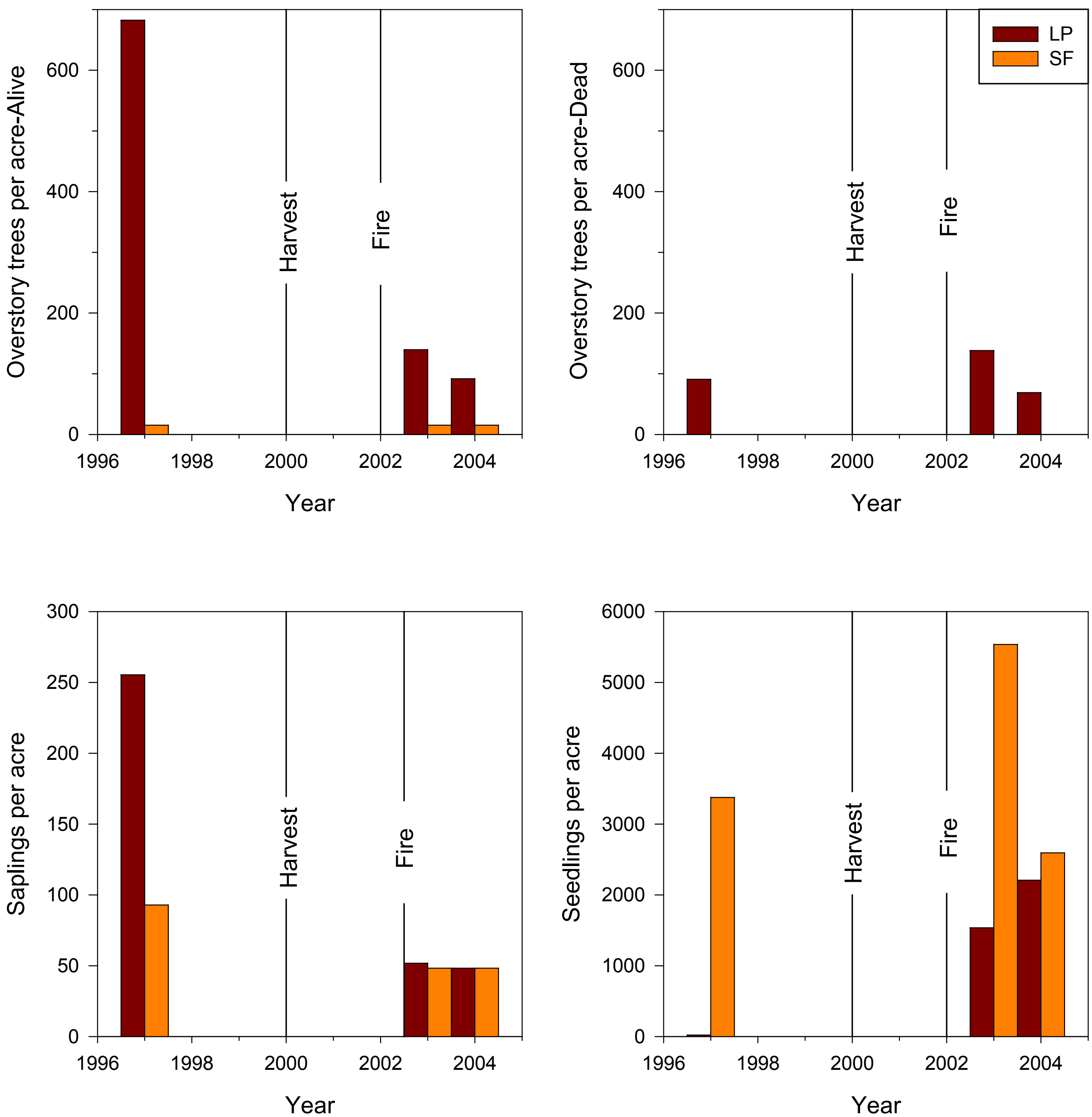
No data collected

POSTHARVEST

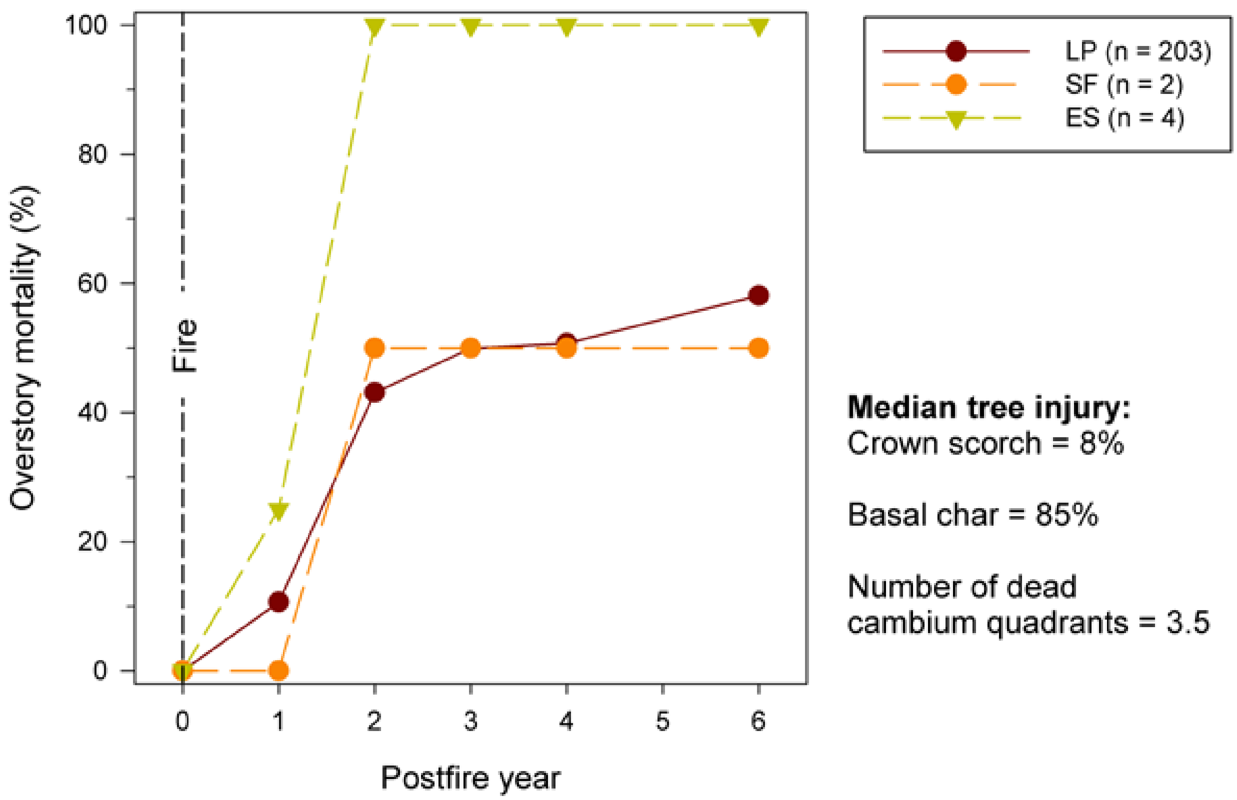
POSTFIRE-1

POSTFIRE-6

SITE: Sun Creek Unit 3
TREATMENT: Even Shelterwood & Prescribed Burn



SITE: Sun Creek Unit 3
TREATMENT: Even Shelterwood & Prescribed Burn



Median tree injury:
Crown scorch = 8%

Basal char = 85%

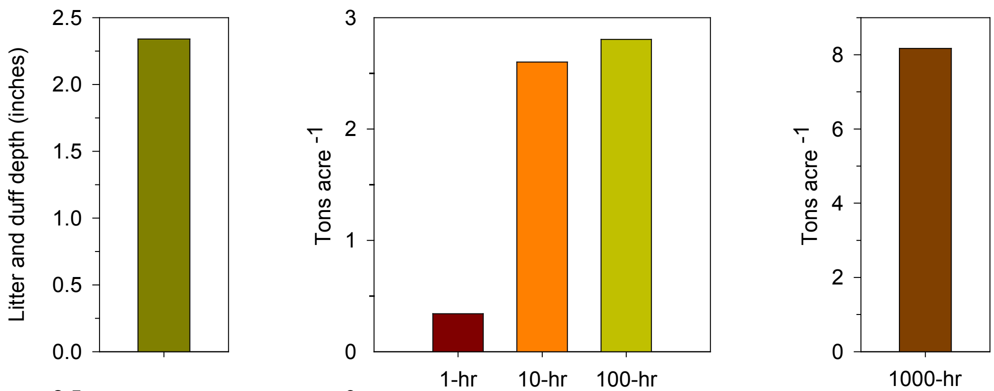
Number of dead
cambium quadrants = 3.5

SITE: Sun Creek Unit 3
TREATMENT: Even Shelterwood & Prescribed Burn

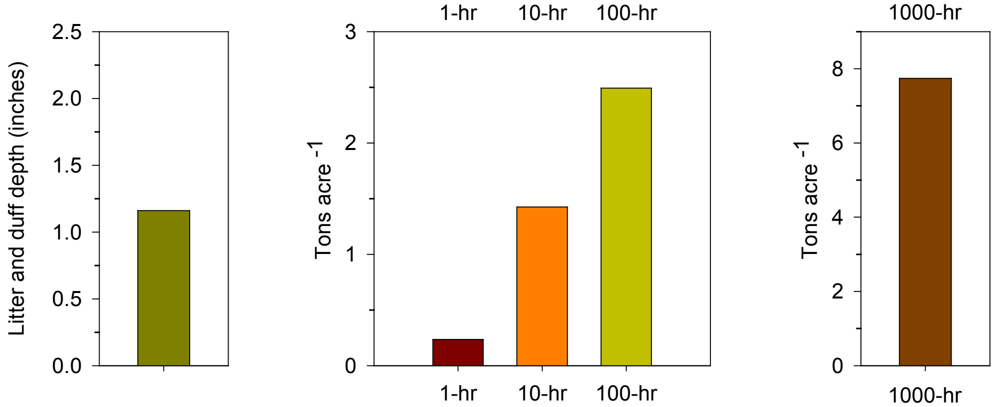
PREHARVEST

No data collected

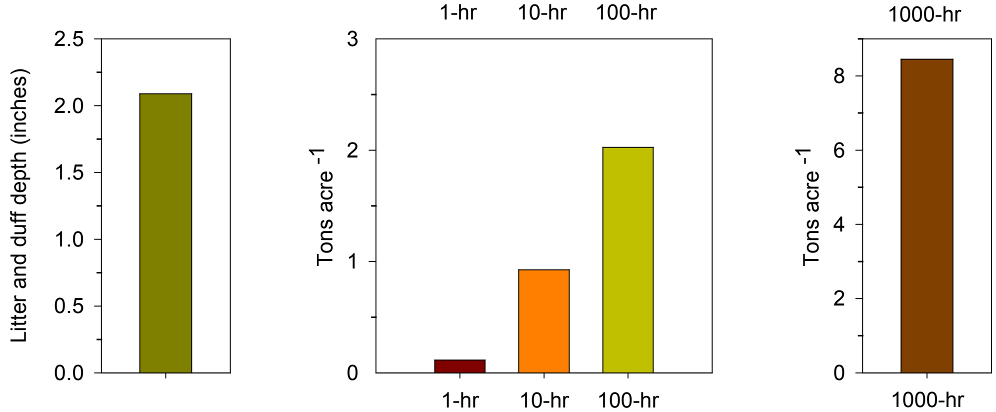
POSTHARVEST



POSTFIRE-1



POSTFIRE-6



SITE: Sun Creek Unit 3
TREATMENT: Even Shelterwood & Prescribed burn

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at $p<0.05$. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. An asterisk by postburn measurement denotes change between postharvest loading and postburn loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	Postharvest (Std. Err.)	1 Year Postburn (Std. Err.)	2 Years Postburn (Std. Err.)	6 Years Postburn (Std. Err.)
Overstory density (trees acre^{-1})						
LP	28	682.5 (125.0)	—	139.5* (27.1)	91.8* (28.6)	—
ES	28	21.2 (10.2)	—	11.4 (8.5)	10.3* (8.5)	—
SF	28	15.2 (11.5)	—	15.2 (11.5)	15.2 (11.5)	—
WB	28	6.0 (6.0)	—	0 (0)	0 (0)	—
Overstory basal area (ft^2 acre^{-1})						
LP	28	187.9 (12.1)	—	58.6* (9.1)	37.1* (8.8)	—
ES	28	8.6 (3.2)	—	4.3 (2.4)	2.9 (2.0)	—
SF	28	2.1 (1.6)	—	2.1 (1.6)	2.1 (1.6)	—
WB	28	1.4 (1.4)	—	0 (0)	0 (0)	—
Sapling density (trees acre^{-1})						
LP	28	255.4 (54.8)	—	51.8* (25.0)	48.2* (24.6)	—
ES	28	5.4 (3.0)	—	1.8 (1.8)	3.6 (2.5)	—
SF	28	92.9 (16.4)	—	48.2* (20.2)	48.2* (20.7)	—
Seedling density (trees acre^{-1})						
LP	28	21.4 (14.9)	—	1535.7* (603.1)	2207.1* (717.3)	—
ES	28	139.3 (44.9)	—	71.4* (49.6)	75.0 (47.9)	—
SF	28	3375.0 (1298.8)	—	5535.7* (4276.0)	2592.9 (1041.4)	—
WB	28	182.1 (71.3)	—	35.7* (35.7)	0* (0)	—
Surface fuels						
Duff and litter depth (in)	14	—	2.34 (0.25)	1.16* (0.25)	—	2.09 (0.17)
1 hour fuel load (tons acre^{-1})	14	—	0.34 (0.05)	0.24 (0.05)	—	0.12* (0.03)
10 hour fuel load (tons acre^{-1})	14	—	2.6 (0.42)	1.43 (0.17)	—	0.92* (0.19)
100 hour fuel load (tons acre^{-1})	14	—	2.8 (0.49)	2.49 (0.45)	—	2.02 (0.41)
1000 hour fuel load (tons acre^{-1})	14	—	8.17 (1.2)	7.74 (1.38)	—	8.45 (1.45)

Study site: Spring Park Creek Unit 10–Even Shelterwood and Burn

Unit description: The 42-acre (17-ha) unit was harvested during the summer of 2000. Prior to harvest, lodgepole pine (49 percent of tree density) and subalpine fir (45 percent) codominated the overstory. Harvest and prescribed burning reduced the average number of live lodgepole pine from approximately 171 to 12 trees per acre (69 to 5 trees ha^{-1}) and basal area from 98 to 6 ft^2 $acre^{-1}$ (22 to 1 m^2 ha^{-1}).

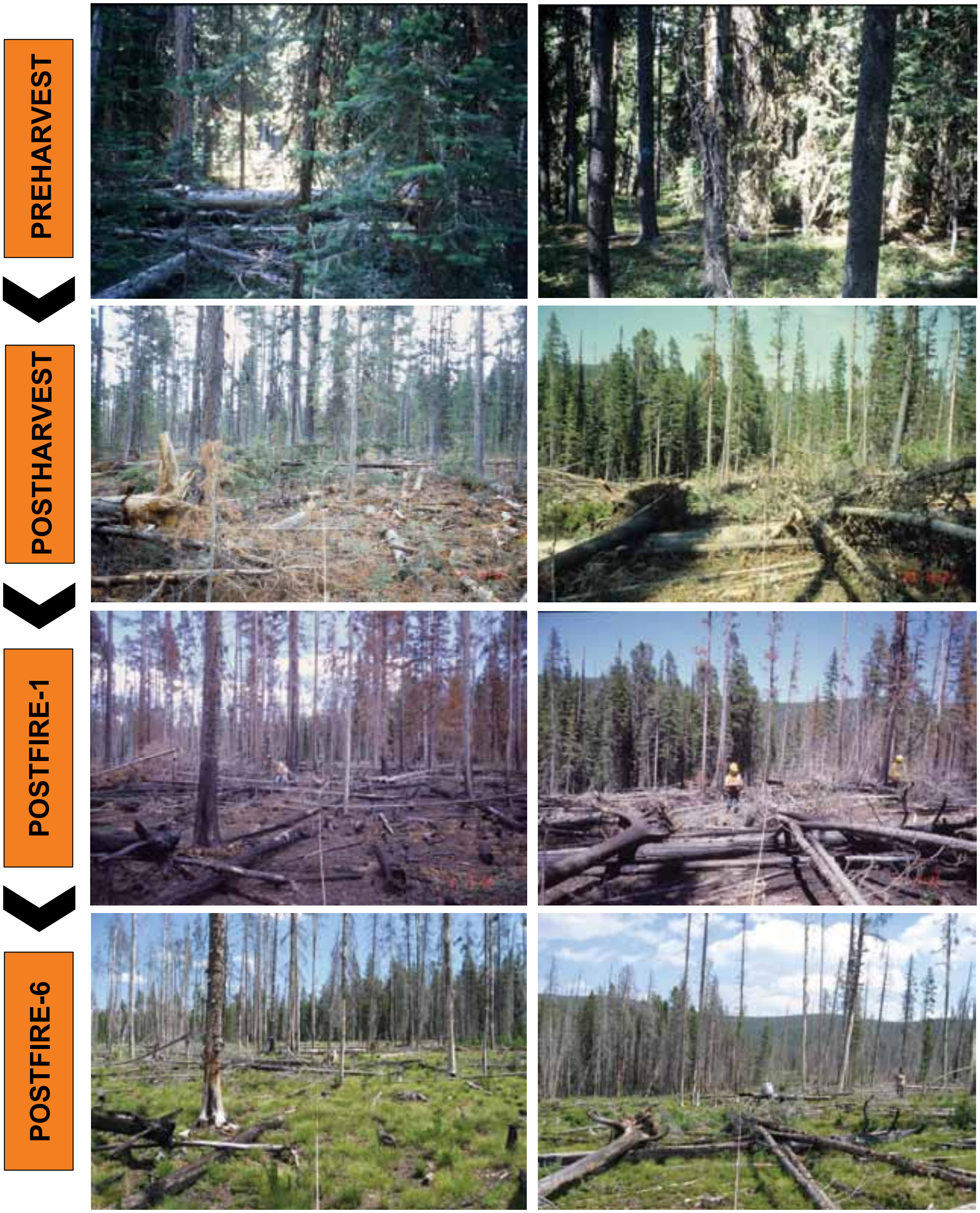
The seedling and sapling layers consisted almost entirely of subalpine fir prior to harvest. Sapling density was significantly reduced 2 years postfire. Lodgepole pine seedling density significantly increased for 2 years postfire; however, subalpine fir was still the most common species in this layer.

Before harvest, most fuels were in the 1000-hr class. Fuel model 12 (Anderson 1981) best described the unit after harvest due to significantly increased fuel loading in all classes. The unit was prescribed burned on September 11, 2002, between 1300 and 1600. Mean fuel moisture by size class was: 13 percent for 1-hr, 14 percent for 10-hr, 20 percent for 100-hr, and 41 percent for 1000-hr. Temperatures ranged from 66 to 68 ^oF (19 to 20 ^oC). Relative humidity ranged from 31 to 32 percent, with average wind speed between 3 and 6 mph (1 to 3 m sec^{-1}). Crown scorch was fairly high throughout most of the unit with an average of 67 percent and a median of 90 percent. Average basal bark char was 85 percent (median = 100 percent). Fire-caused mortality resulted in an additional 90 percent mortality of lodgepole pine trees greater than 4 inches (10.2 cm) DBH, with mortality stabilizing within 2 years after the burn. While the fire reduced forest floor depth and fine fuel loading, very little consumption of the 1000-hr fuels occurred.

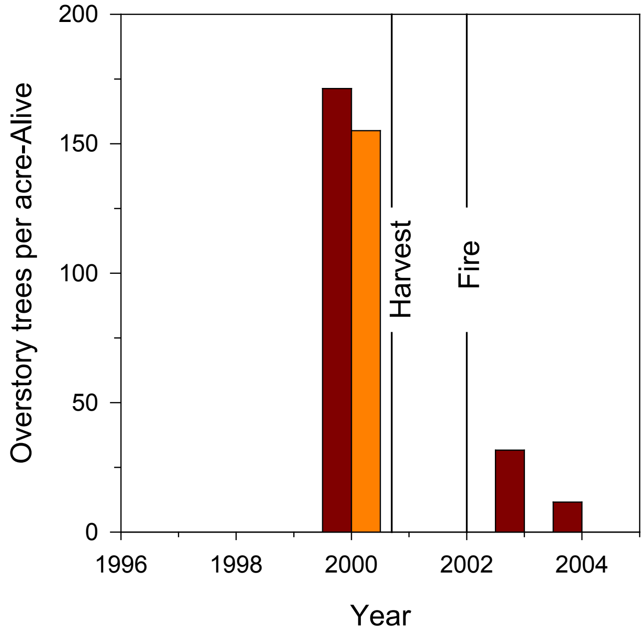
Management implications: We did not sample tree plots postharvest in this unit; therefore, we do not know the reduction in tree density from harvest alone. Harvest and fire reduced overstory tree density by 97 percent. The prescribed burn killed approximately 90 percent of the residual lodgepole pine, much more than the intended goal of 20 to 50 percent. The prescribed fire was effective in significantly reducing fine fuel created by the logging but not 1000-hr fuels. Because of the high 1000-hr fuel load prior to harvest (20 tons $acre^{-1}$ [4.5 kg m^{-2})], the fuels in this unit were heavier than most of the other prescribed burn units.

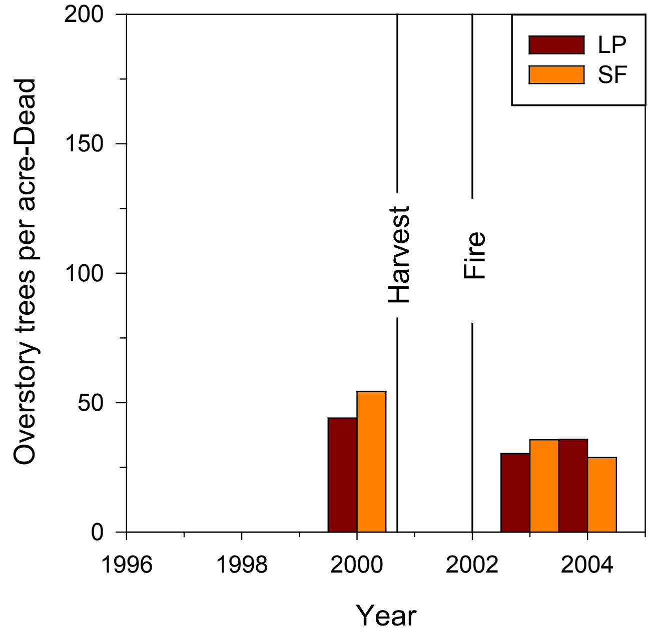
Harvest followed by fire reduced litter and duff depth and created higher light conditions favorable for lodgepole pine regeneration. Additional treatments may be necessary to reduce competing subalpine fir seedlings if further lodgepole pine recruitment is desired. Because lodgepole pine has such thin bark, it is very susceptible to fire regardless of flame length. If the majority (>75 percent) of the tree base is blackened, lodgepole pine will likely die. Therefore, when burning in lodgepole pine with heavy activity fuels, it is important to leave patches of unburned vegetation in order to limit lodgepole pine mortality.

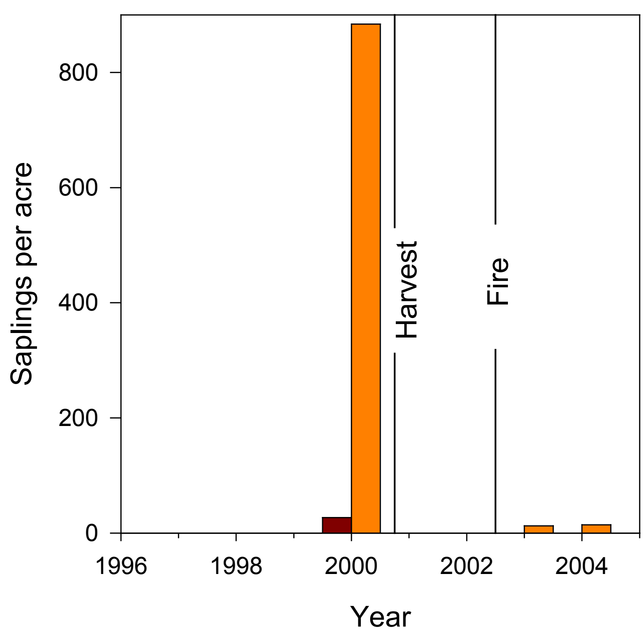
SITE: Spring Park Unit 10
TREATMENT: Even Shelterwood & Prescribed Burn

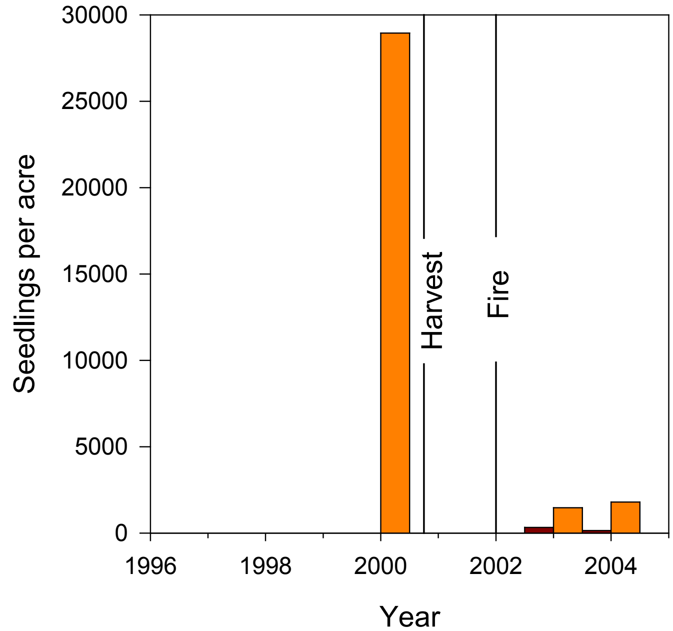


SITE: Spring Park Unit 10
TREATMENT: Even Shelterwood & Prescribed Burn

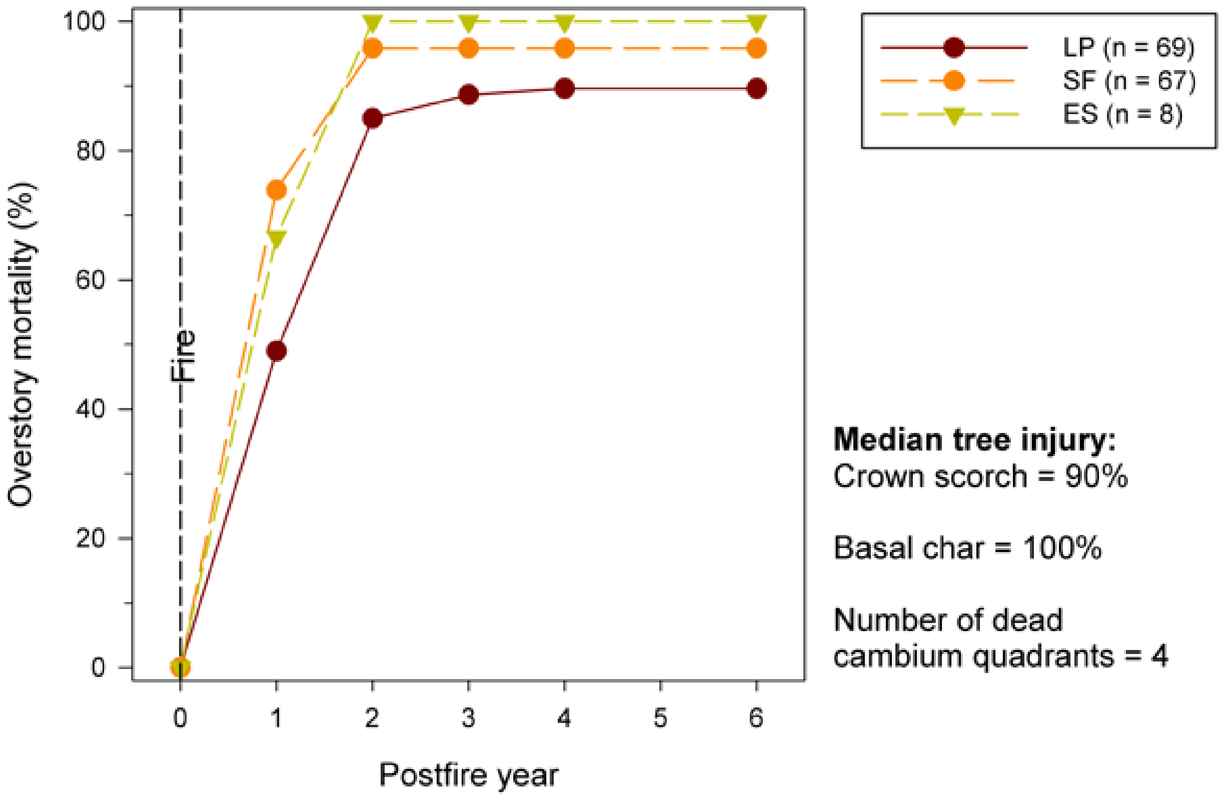








SITE: Spring Park Unit 10
TREATMENT: Even Shelterwood & Prescribed Burn

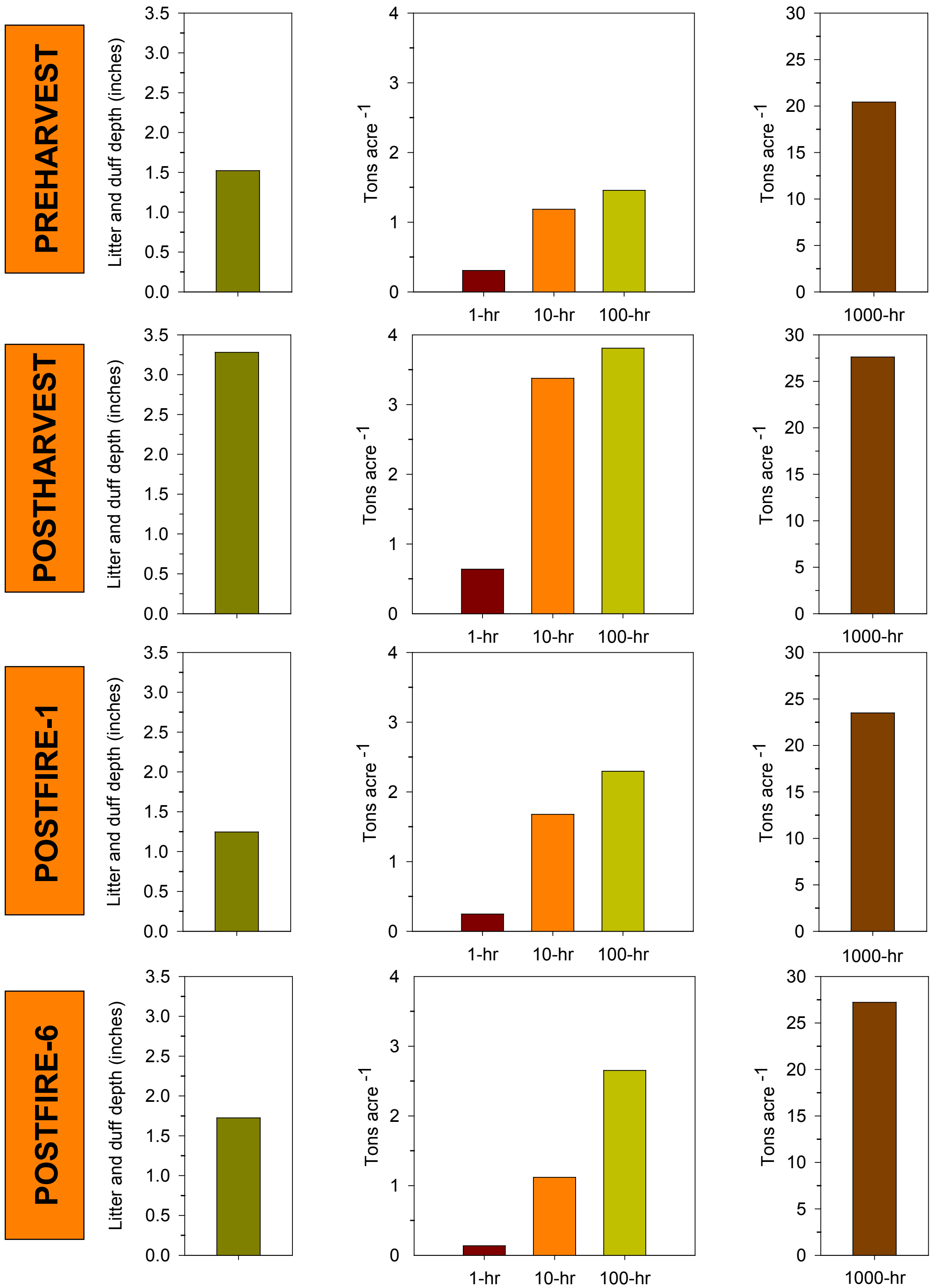


Median tree injury:
Crown scorch = 90%

Basal char = 100%

Number of dead
cambium quadrants = 4

SITE: Spring Park Unit 10
TREATMENT: Even Shelterwood & Prescribed Burn



SITE: Spring Park Creek Unit 10
TREATMENT: Even Shelterwood & Prescribed burn

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at p<0.05. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. An asterisk by postburn measurement denotes change between postharvest loading and postburn loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	Postharvest (Std. Err.)	1 Year Postburn (Std. Err.)	2 Years Postburn (Std. Err.)	6 Years Postburn (Std. Err.)
Overstory density (trees acre^{-1})						
LP	28	165.2 (39.3)	—	30.5* (15.1)	11.2* (9.3)	—
ES	28	19.9 (9.7)	—	0* (0)	0* (0)	—
SF	28	149.5 (40.1)	—	0* (0)	0* (0)	—
Overstory basal area (ft^2 acre^{-1})						
LP	28	94.3 (13.7)	—	18.6* (7.6)	5.7* (4.5)	—
ES	28	10.0 (3.9)	—	1.4* (1.4)	0* (0)	—
SF	28	37.1 (7.7)	—	0* (0)	0* (0)	—
Sapling density (trees acre^{-1})						
LP	28	26.8 (12.2)	—	0* (0)	0* (0)	—
ES	28	8.9 (4.5)	—	0* (0)	0* (0)	—
SF	28	883.9 (110.9)	—	12.5* (7.6)	14.3* (9.9)	—
Seedling density (trees acre^{-1})						
LP	28	0 (0)	—	321.4* (126.6)	150.0* (52.3)	—
ES	28	42.9 (42.9)	—	0 (0)	85.7 (55.5)	—
SF	28	28950.0 (4387.6)	—	1464.3* (1284.3)	1800.0* (1319.8)	—
WB	28	85.7 (85.7)	—	0 (0)	342.9* (94.8)	—
Surface fuels						
Duff and litter depth (in)	14	1.52 (0.19)	3.28* (0.36)	1.25* (0.19)	—	1.72* (0.41)
1 hour fuel load (tons acre^{-1})	14	0.31 (0.03)	0.64* (0.07)	0.25* (0.07)	—	0.14* (0.04)
10 hour fuel load (tons acre^{-1})	14	1.19 (0.18)	3.38* (0.53)	1.68* (0.38)	—	1.12* (0.20)
100 hour fuel load (tons acre^{-1})	14	1.46 (0.32)	3.81* (0.65)	2.3 (0.38)	—	2.65 (0.48)
1000 hour fuel load (tons acre^{-1})	14	20.42 (3.69)	27.62* (3.29)	23.49 (2.87)	—	27.22 (3.98)

Study site: Spring Park Creek Unit 13–Even Shelterwood and Burn

Unit description: The 21-acre (8-ha) unit was harvested during the summer of 2000. Prior to harvest, lodgepole pine dominated the overstory (92 percent of tree density). Harvest and prescribed fire reduced the average number of live lodgepole pine from approximately 636 to 62 trees per acre (258 to 25 trees ha^{-1}) and basal area from 186 to 23 ft^2 $acre^{-1}$ (43 to 5 m^2 ha^{-1}).

Sapling density was evenly distributed between lodgepole pine and subalpine fir prior to harvest, while seedlings were primarily subalpine fir. Two years postfire, sapling density was greatly reduced for all species, while lodgepole pine seedling density had significantly increased and comprised the majority of regeneration.

Preharvest fuel loading was low (14 ton $acre^{-1}$ [3 kg m^{-2}]) and consisted primarily of 1000-hr fuels. Fuel model 11 (Anderson 1981) best described the unit after harvest due to a significant increase in fine fuel loading. The unit was prescribed burned on September 12, 2002, between 1330 and 1530. Mean fuel moisture by size class was: 12 percent for 1-hr, 12 percent for 10-hr, 16 percent for 100-hr, and 36 percent for 1000-hr. Temperatures ranged from 68 to 69 °F (20 to 21 °C). Relative humidity ranged from 23 to 26 percent, with average wind speed between 4 and 5 mph (2 m sec^{-1}). Crown scorch was low throughout most of the unit with an average of 38 percent and a median of 5 percent. Average basal bark char was 69 percent (median = 100 percent). Fire-caused mortality resulted in an additional 79 percent mortality of lodgepole pine trees greater than 4 inches (10.2 cm) DBH, with mortality stabilizing within 2 years after the burn. While the fire reduced fine fuel loading, very little consumption of the 1000-hr fuels occurred.

Management implications: We did not sample postharvest tree plots in this unit; therefore, we do not know the reduction in tree density from harvest alone. Harvest and fire reduced the tree density by 91 percent. The prescribed burn killed approximately 80 percent of the residual lodgepole pine, much more than the intended goal of no more than 20 to 50 percent. The prescribed fire was effective in significantly reducing 1- and 10-hr fine fuel created by the logging but not 100- or 1000-hr fuel. Harvest followed by fire reduced litter and duff depth and created light conditions favorable for lodgepole pine regeneration. Because lodgepole pine has such thin bark, it is very susceptible to fire regardless of flame length. If the majority (>75 percent) of the tree base is blackened, lodgepole pine will likely die. Therefore, prescribed burns that leave patches of unburned vegetation are critical for limiting lodgepole pine mortality, especially in units with activity fuel on the ground.

SITE: Spring Park Unit 13
TREATMENT: Even Shelterwood & Prescribed Burn

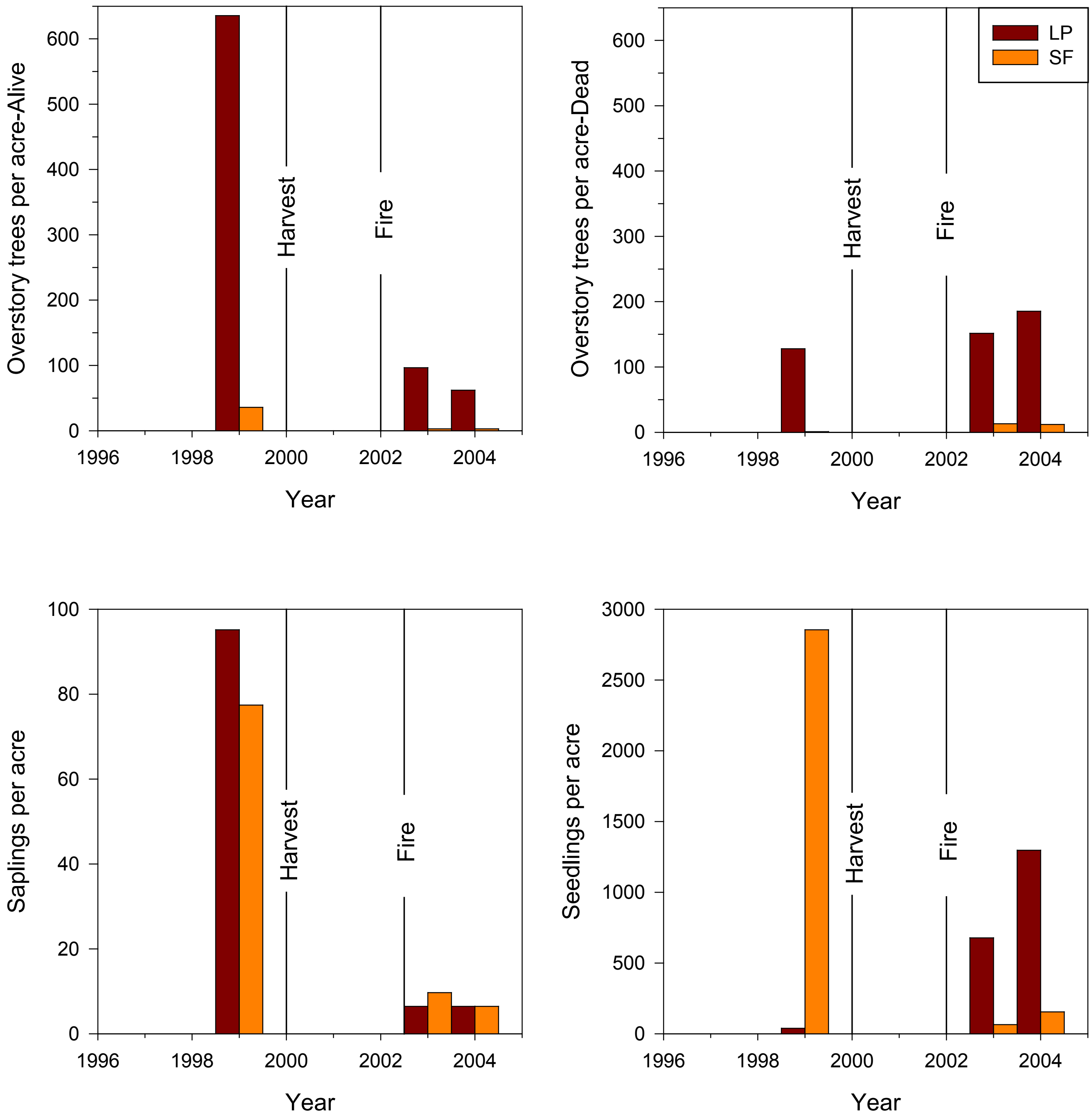
PREHARVEST

POSTHARVEST

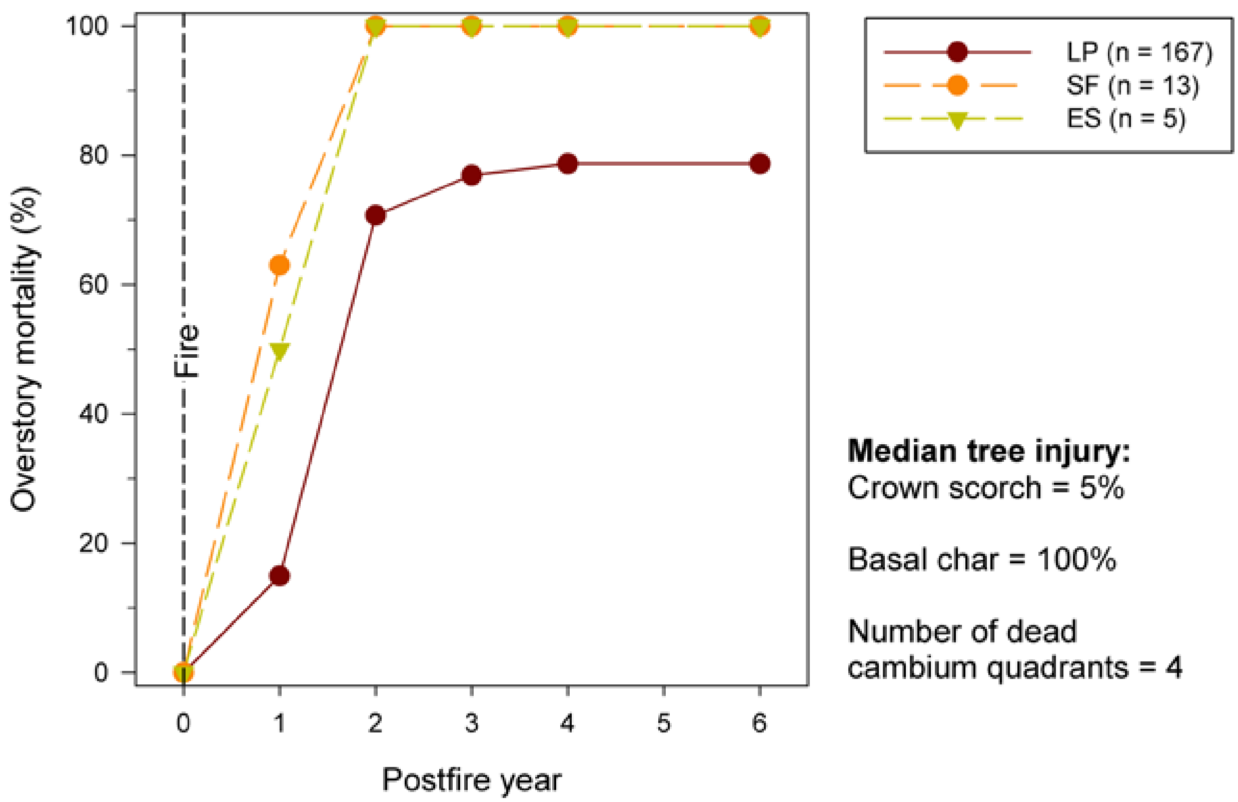
POSTFIRE-1

POSTFIRE-6

SITE: Spring Park Unit 13
TREATMENT: Even Shelterwood & Prescribed Burn



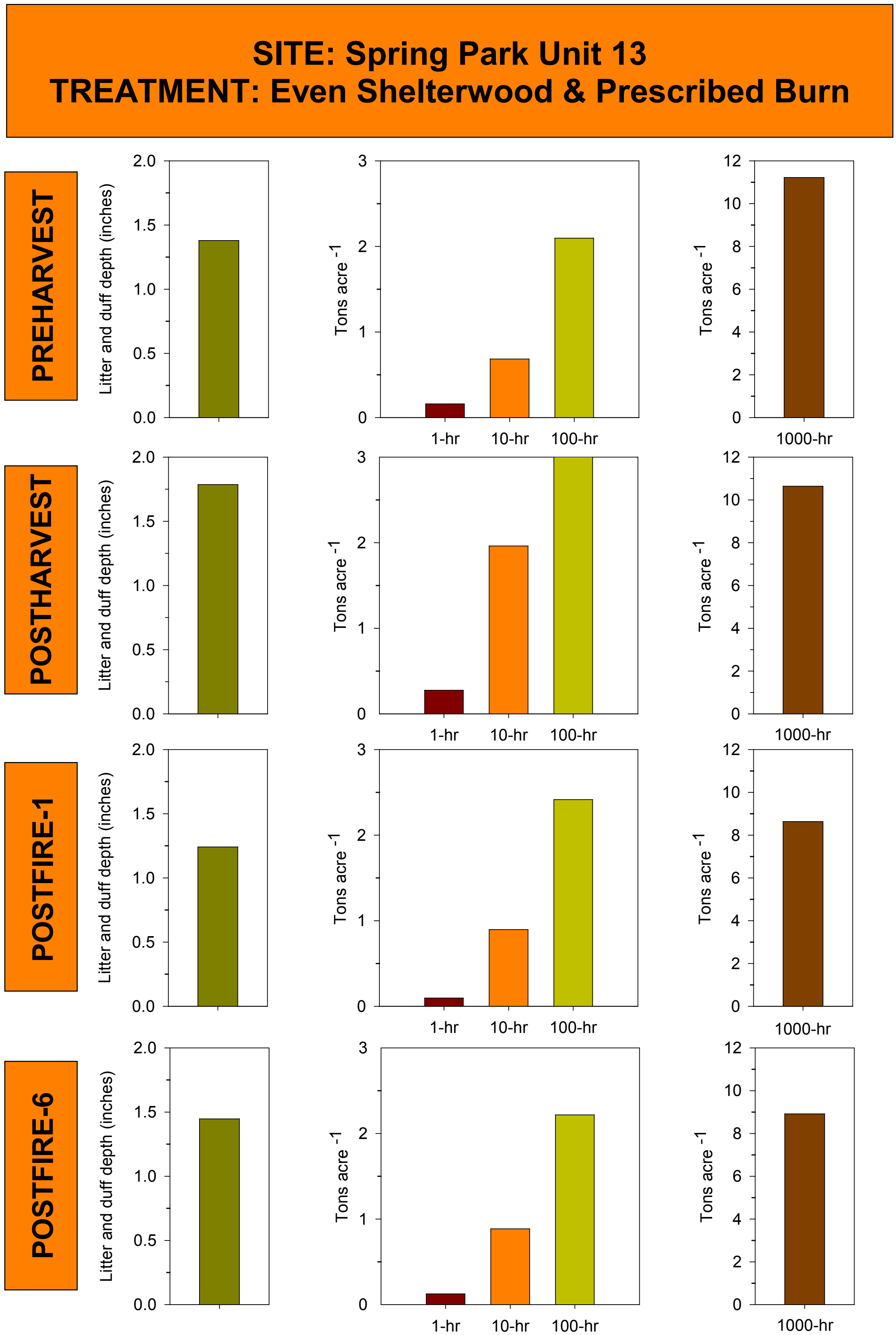
SITE: Spring Park Unit 13
TREATMENT: Even Shelterwood & Prescribed Burn



Median tree injury:
Crown scorch = 5%

Basal char = 100%

Number of dead cambium quadrants = 4



SITE: Spring Park Unit 13
TREATMENT: Even Shelterwood & Prescribed Burn
PREHARVEST
POSTHARVEST
POSTFIRE-1
POSTFIRE-6
Litter and duff depth (inches)
Tons acre -1
1-hr
10-hr
100-hr
1000-hr

SITE: Spring Park Creek Unit 13
TREATMENT: Even Shelterwood & Prescribed burn

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at p<0.05. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. An asterisk by postburn measurement denotes change between postharvest loading and postburn loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	Postharvest (Std. Err.)	1 Year Postburn (Std. Err.)	2 Years Postburn (Std. Err.)	7 Years Postburn (Std. Err.)
Overstory density (trees acre^{-1})						
LP	31	635.6 (114.7)	—	96.5* (34.3)	62.0* (28.9)	—
ES	31	19.0 (10.7)	—	0* (0)	0* (0)	—
SF	31	35.9 (20.0)	—	2.8* (2.8)	2.8* (2.8)	—
Overstory basal area (ft^2 acre^{-1})						
LP	31	185.8 (16.9)	—	36.1* (10.9)	23.2* (9.0)	—
ES	31	7.7 (4.7)	—	0* (0)	0* (0)	—
SF	31	10.3 (4.9)	—	2.6* (2.6)	2.6* (2.6)	—
Sapling density (trees acre^{-1})						
LP	31	95.2 (18.9)	—	6.5* (5.0)	6.5* (3.1)	—
ES	31	3.2 (2.2)	—	1.6 (1.6)	0 (0)	—
SF	31	77.4 (28.8)	—	9.7* (7.1)	6.5* (3.8)	—
WB	31	1.6 (1.6)	—	0 (0)	0 (0)	—
Seedling density (trees acre^{-1})						
LP	31	38.7 (38.7)	—	677.4 (394.6)	1296.8* (603.9)	—
ES	31	77.4 (50.1)	—	161.3 (161.3)	0 (0)	—
SF	31	2854.8 (696.7)	—	64.5* (64.5)	154.8* (78.5)	—
WB	31	348.4 (129.8)	—	0* (0)	38.7* (26.9)	—
Surface fuels						
Duff and litter depth (in)	15	1.38 (0.24)	1.79 (0.24)	1.24 (0.18)	—	1.45 (0.16)
1 hour fuel load (tons acre^{-1})	15	0.16 (0.02)	0.27* (0.04)	0.1* (0.02)	—	0.13* (0.02)
10 hour fuel load (tons acre^{-1})	15	0.68 (0.08)	1.96* (0.13)	0.9* (0.17)	—	0.89* (0.13)
100 hour fuel load (tons acre^{-1})	15	2.1 (0.44)	3.02 (0.74)	2.42 (0.44)	—	2.22 (0.60)
1000 hour fuel load (tons acre^{-1})	15	11.22 (2.97)	10.64 (2.31)	8.63 (1.45)	—	8.92 (1.31)

Group Shelterwood and Prescribed Burn Treatment Units

Treatment: Group shelterwood followed by a low-intensity, mixed-severity prescribed burn

Management planning: These units were harvested with the objective to reduce the overstory by 40 to 60 percent. The group shelterwood treatment left islands of residual trees on 40 to 60 percent of the unit area, with the remaining areas resembling clearcuts. All trees were cut in corridors that surrounded unharvested patches of leave trees. Felled trees were whole-tree skidded to centralized processing locations for delimbing and decking for transport. All unutilized materials were piled and burned at the centralized locations. The prescribed burn treatment was designed to reduce activity fuels created from the harvest operation and to prepare a seed bed for natural regeneration while limiting overstory postharvest mortality to 50 percent. After harvest and prescribed burning, the target tree density was retention of at least 25 percent of preharvest overstory tree density. A detailed harvest prescription is provided in the "Treatment Descriptions" section.

Study site: Sun Creek Unit 2–Group Shelterwood and Burn

Unit description: This 22-acre (9-ha) unit is typically very wet, so it was harvested during the winter of 1999/2000 over frozen ground and/or snow to reduce soil disturbance. Prior to harvest, the overstory was dominated by lodgepole pine (57 percent of tree density) with a large component of subalpine fir (36 percent). Harvesting reduced average number of live lodgepole pine from approximately 570 to 222 trees per acre (231 to 90 trees ha^{-1}) and basal area from 170 to 82 ft^2 $acre^{-1}$ (39 to 19 m^2 ha^{-1}). Prescribed burning further reduced density to 202 trees per acre (82 trees ha^{-1}) and basal area to 74 ft^2 $acre^{-1}$ (17 m^2 ha^{-1}).

The seedling and sapling layers consisted primarily of subalpine fir prior to harvest. One year postfire, sapling density was greatly reduced, with subalpine fir remaining the dominant species. In the seedling layer, lodgepole pine increased significantly, although subalpine fir remained the dominant species 1 year postfire.

We did not measure fuel loading prior to harvest. Fuel model 11 (Anderson 1981) best described the unit after harvest. The unit was prescribed burned on October 1, 2003. Mean fuel moisture by size class in the uncut groups was: 16 percent for 1-hr, 20 percent for 10-hr, 22 percent for 100-hr, 23 percent for 1000-hr, and 51 percent for duff. Mean fuel moisture by size class in the clearcut areas was: 12 percent for 1-hr and 10-hr, 16 percent for 100-hr, 23 percent for 1000-hr, and 43 percent for duff. Temperatures ranged from 60 to 68 °F (16 to 20 °C). Relative humidity ranged from 7 to 18 percent, with average wind speed between 1 and 6 mph (0.5 to 3 m sec^{-1}). Crown scorch was low throughout most of the unit with an average of 7 percent and a median of 0 percent. Average basal bark char was 20 percent (median = 0 percent). Fire-caused mortality resulted in an additional 26 percent mortality of lodgepole pine trees greater than 4 inches (10.2 cm) DBH, with mortality stabilizing within 3 years after the burn. While the fire reduced litter and duff depth and fine fuel loading, very little consumption of the 1000-hr fuels occurred.

Management implications: Harvest reduced tree density and basal area by approximately 50 percent, within the goal of 40 to 60 percent. The prescribed burn also met the objectives of maintaining at least 25 percent of the preharvest overstory and reducing logging slash. The burn in this unit generally carried through the logging slash in the clearcut corridors but did not carry through most of the uncut leave islands. The understory in the leave islands consisted primarily of grouse whortleberry (*Vaccinium scoparium* Leiberg ex Coville), which did not burn well. Compared to the even shelterwood treatment, the group shelterwood created a stand structure that was less susceptible to windthrow and fire-caused mortality while reducing activity fuel loads. The group shelterwood treatment also created a more heterogeneous mosaic on the landscape. Increased light resulting from the group shelterwood harvest favored lodgepole pine regeneration. However, most lodgepole pine regeneration occurred in the cut patches where there was less vegetative competition and more light. Even though harvest reduced the lodgepole pine sapling component, higher average densities remained in the group shelterwood units than in the even shelterwood units due to islands of uncut vegetation. Additional treatments may be necessary to reduce competing subalpine fir seedlings if further lodgepole pine recruitment is desired.

SITE: Sun Creek Unit 2
TREATMENT: Group Shelterwood & Prescribed Burn

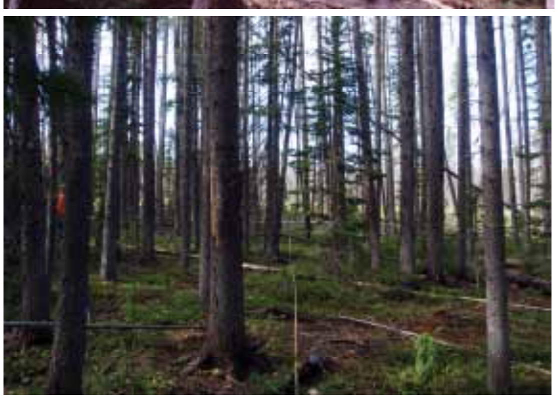
PREHARVEST

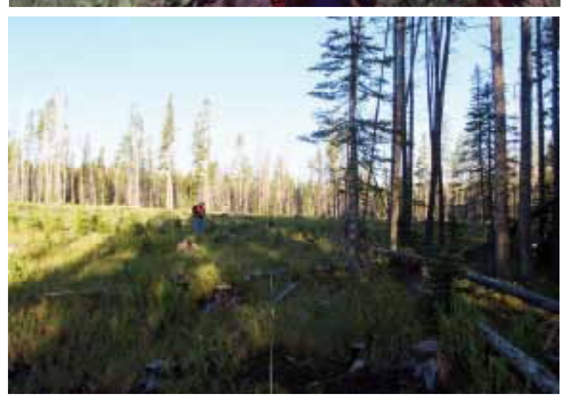
No data collected

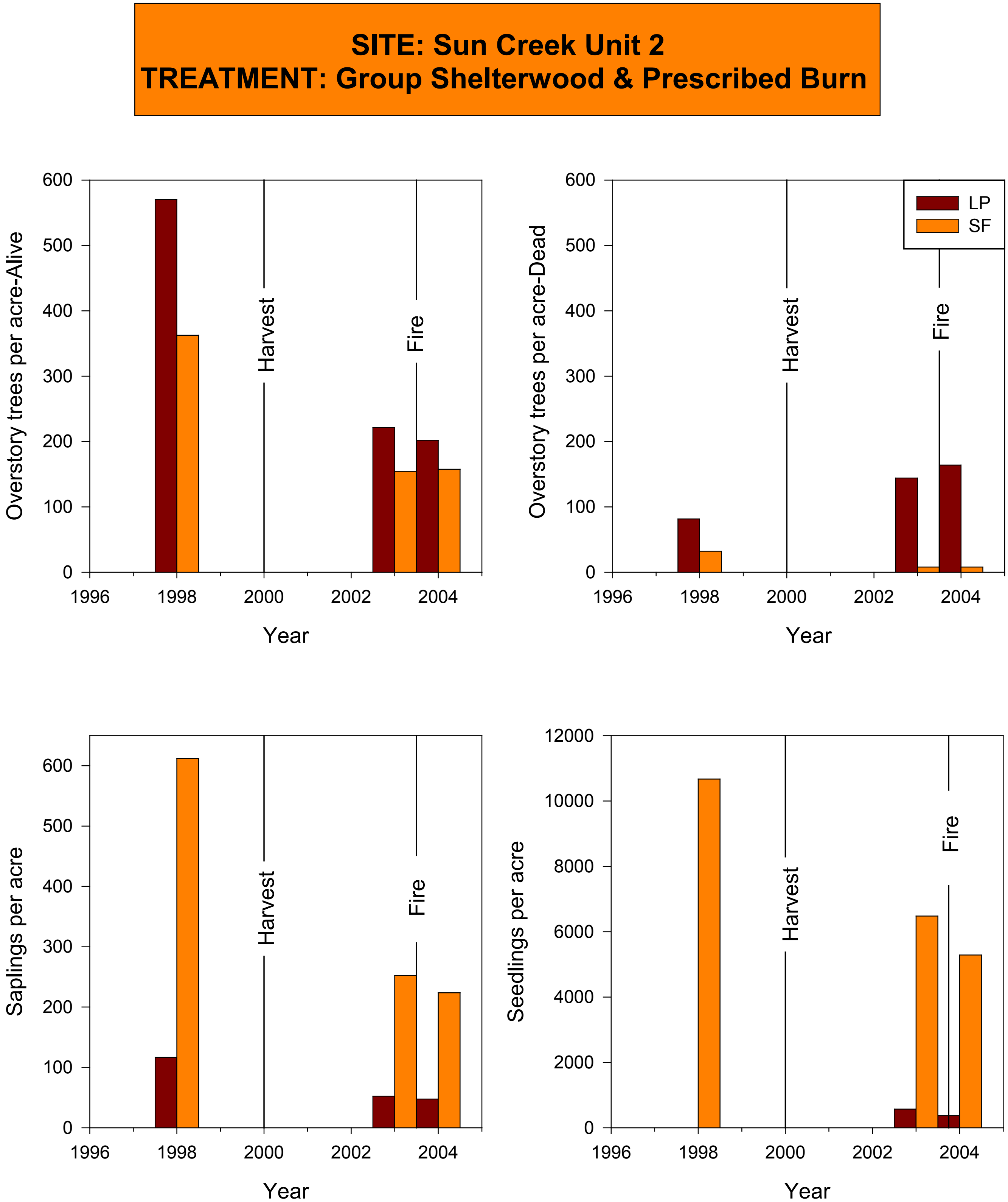
POSTHARVEST

POSTFIRE-1

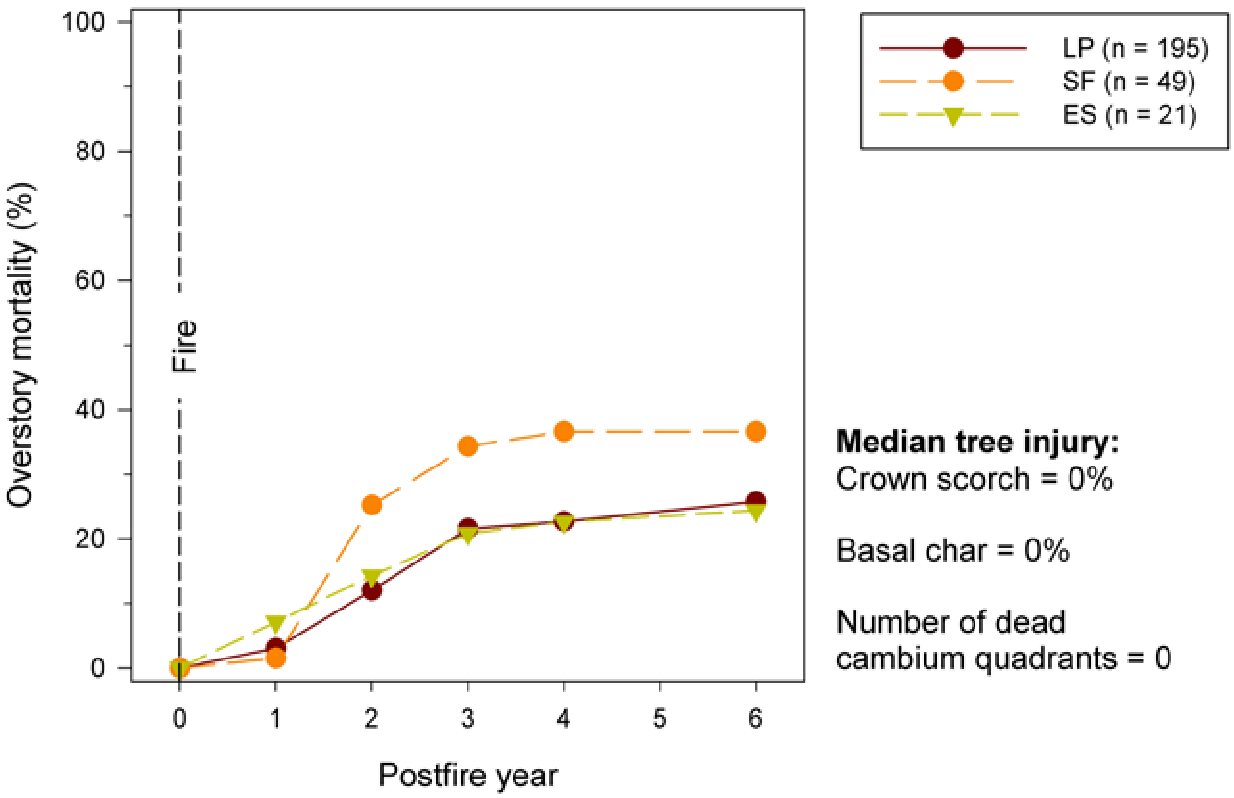
POSTFIRE-6






SITE: Sun Creek Unit 2
TREATMENT: Group Shelterwood & Prescribed Burn
Overstory trees per acre-Alive
Overstory trees per acre-Dead
Saplings per acre
Seedlings per acre
Year
Harvest
Fire
LP
SF
0
100
200
300
400
500
600
2000
4000
6000
8000
10000
12000
1996
1998
2000
2002
2004

SITE: Sun Creek Unit 2
TREATMENT: Group Shelterwood & Prescribed Burn



Median tree injury:
Crown scorch = 0%

Basal char = 0%

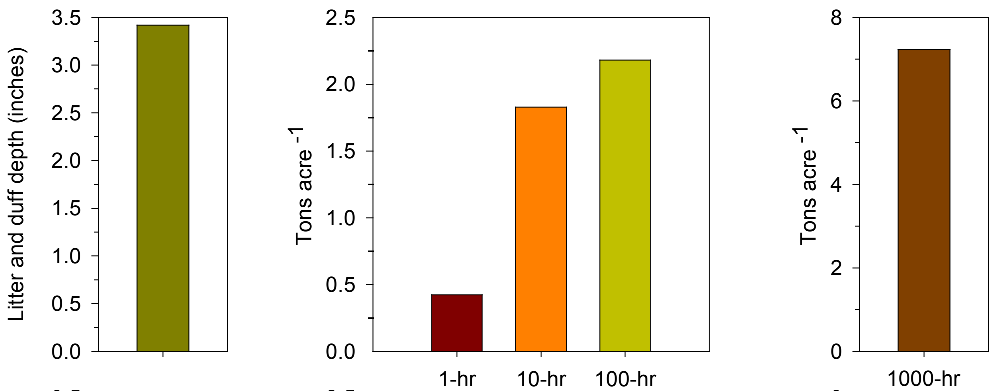
Number of dead cambium quadrants = 0

SITE: Sun Creek Unit 2
TREATMENT: Group Shelterwood & Prescribed Burn

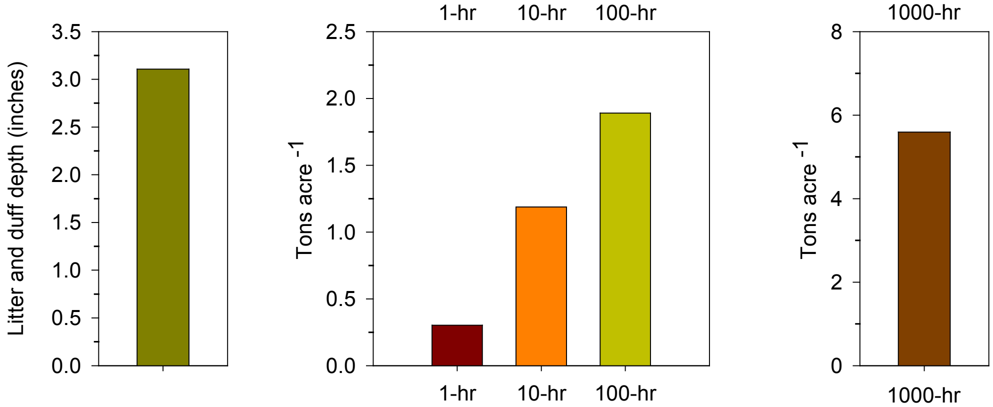
PREHARVEST

No data collected

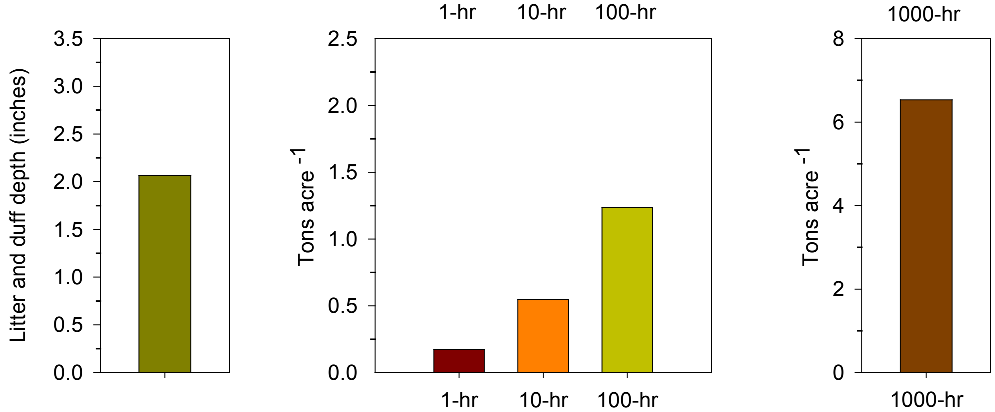
POSTHARVEST



POSTFIRE-1



POSTFIRE-6



SITE: Sun Creek Unit 2
TREATMENT: Group Shelterwood & Prescribed burn

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at p<0.05. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. An asterisk by postburn measurement denotes change between postharvest loading and postburn loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	3 Years Postharvest (Std. Err.)	1 Year Postburn (Std. Err.)	6 Years Postburn (Std. Err.)
Overstory density (trees acre^{-1})					
LP	21	570.3 (127.6)	221.5* (76.6)	201.9* (74.6)	—
ES	21	73.3 (48.2)	61.9 (48.3)	59.9 (48.4)	—
SF	21	362.5 (155.4)	154.2* (121.6)	157.5* (121.8)	—
Overstory basal area (ft^2 acre^{-1})					
LP	21	169.5 (24.7)	81.9* (21.3)	74.3* (20.5)	—
ES	21	15.2 (6.5)	11.4 (6.3)	9.5 (6.1)	—
SF	21	26.7 (10.8)	5.7* (3.1)	7.6* (4.5)	—
Sapling density (trees acre^{-1})					
LP	21	116.7 (32.6)	52.4* (17.8)	47.6* (16.7)	—
ES	21	107.1 (36.1)	26.2* (10.1)	19.0* (12.7)	—
SF	21	611.9 (114.6)	252.4* (52.9)	223.8* (57.9)	—
Seedling density (trees acre^{-1})					
LP	21	0 (0)	571.4 (280.9)	371.4* (134.0)	—
ES	21	228.6 (87.6)	285.7 (140.5)	14.3* (14.3)	—
SF	21	10671.4 (1884.2)	6476.2* (2064.0)	5285.7* (1200.8)	—
WB	21	42.9 (31.3)	0 (0)	0 (0)	—
Surface fuels					
Duff and litter depth (in)	10	—	3.42 (0.47)	3.11 (0.42)	2.07* (0.38)
1 hour fuel load (tons acre^{-1})	10	—	0.42 (0.07)	0.3 (0.05)	0.17* (0.04)
10 hour fuel load (tons acre^{-1})	10	—	1.83 (0.37)	1.19 (0.30)	0.55* (0.11)
100 hour fuel load (tons acre^{-1})	10	—	2.18 (0.68)	1.89 (0.60)	1.24 (0.42)
1000 hour fuel load (tons acre^{-1})	10	—	7.23 (1.8)	5.59* (1.35)	6.53 (1.27)

Study site: Sun Creek Unit 4–Group Shelterwood and Burn

Unit description: Because this 36-acre (15-ha) unit is typically moderately wet in places, it was harvested during the winter of 1999/2000 over frozen ground and/or snow to reduce soil disturbance. Lodgepole pine dominated the overstory (99 percent of tree density) prior to harvest. Harvest and prescribed burning reduced the average number of live lodgepole pine trees per acre from approximately 914 to 387 (370 to 157 trees ha^{-1}) and basal area from 214 to 93 ft^2 acre-1 (49 to 21 m^2 ha^{-1}).

Preharvest, almost all saplings were lodgepole pine, while the seedlings were a mix of mainly lodgepole pine and subalpine fir. Two years postfire, sapling density was greatly reduced, with lodgepole pine remaining the most common species. Lodgepole pine seedling density was significantly higher and comprised approximately 90 percent of regeneration 2 years postfire.

We did not measure fuel loading prior to harvest. Fuel model 11 (Anderson 1981) best described the unit after harvest. The unit was prescribed burned on September 16, 2002, between 1100 and 1400. Mean fuel moisture by size class in the uncut groups was: 9 percent for 1-hr and 10-hr, 14 percent for 100-hr, and 17 percent for 1000-hr. Mean fuel moisture by size class in the clearcut areas was: 6 percent for 1-hr, 7 percent for 10-hr, 14 percent for 100-hr, and 25 percent for 1000-hr. Temperatures ranged from 61 to 75 ^{o}F (17 to 24 ^{o}C). Relative humidity ranged from 14 to 29 percent, with average wind speed between 2 and 8 mph (1 to 4 m sec^{-1}). Crown scorch was low throughout most of the unit with an average of 28 percent and a median of 5 percent. Average basal bark char was 41 percent (median = 10 percent). Fire-caused mortality resulted in an additional 39 percent mortality of lodgepole pine trees greater than 4 inches (10.2 cm) DBH, with mortality stabilizing within 3 years after the burn. While the fire reduced forest floor depth and fine fuel loading, very little consumption of the 1000-hr fuels occurred.

Management implications: We did not sample postharvest tree plots in this unit; therefore, we do not know the reduction in tree density from harvest alone. Harvest and fire reduced tree density by 68 percent, within the tree retention goal. The fire killed approximately 40 percent of the leave trees based on the estimates from the postfire mortality assessment, which was within the goal of limiting mortality from fire to 50 percent. The goal of reducing logging slash was not met immediately, but by 6 years postfire, the fine fuels were significantly lower than preburn levels. The burn in this unit generally carried through the logging slash in the clearcut corridors but did not carry through most of the uncut leave islands. In the leave islands, the understory consisted primarily of grouse whortleberry, which did not burn well. Compared to the even shelterwood treatment, the group shelterwood created a stand structure that was less susceptible to windthrow and fire-caused mortality, while reducing activity fuel loads. The group shelterwood treatment also created a more heterogeneous mosaic on the landscape. Increased light resulting from the group shelterwood treatment favored lodgepole pine regeneration; however, most lodgepole pine regeneration occurred in the cut patches where there was less vegetative competition and more light. Even though harvest and burning reduced the lodgepole pine sapling component, higher average densities remained in the group shelterwood units than in the even shelterwood units due to islands of uncut vegetation.

SITE: Sun Creek Unit 4
TREATMENT: Group Shelterwood & Prescribed Burn

PREHARVEST

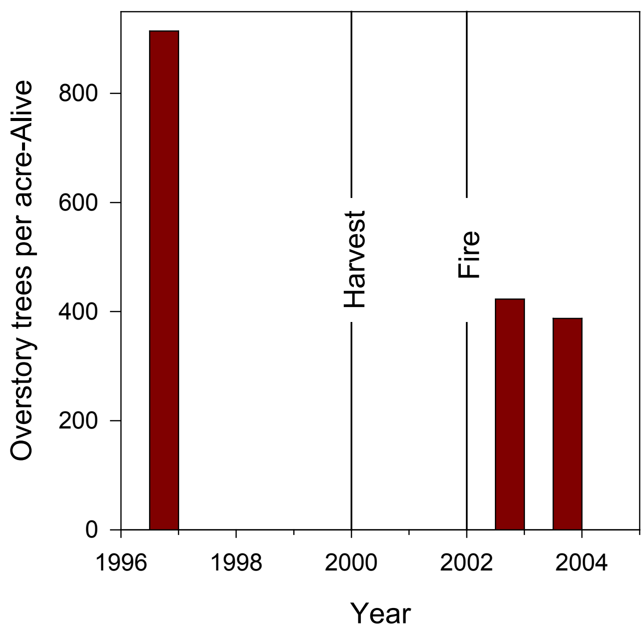
No data collected

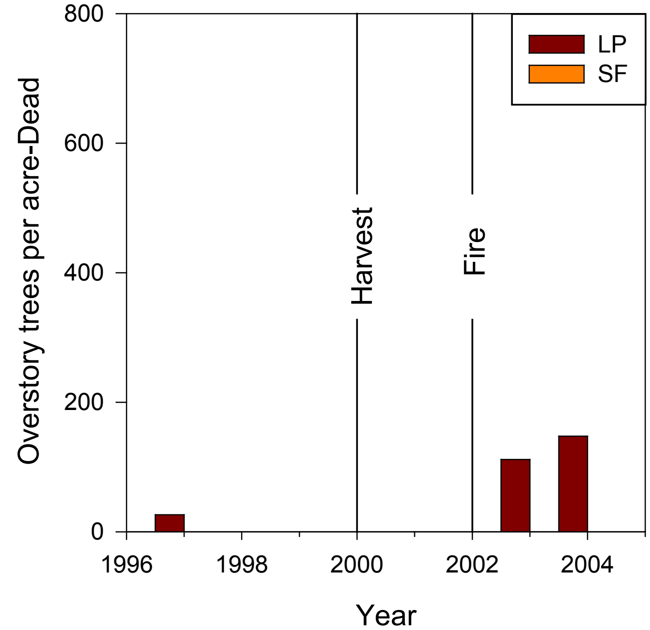
POSTHARVEST

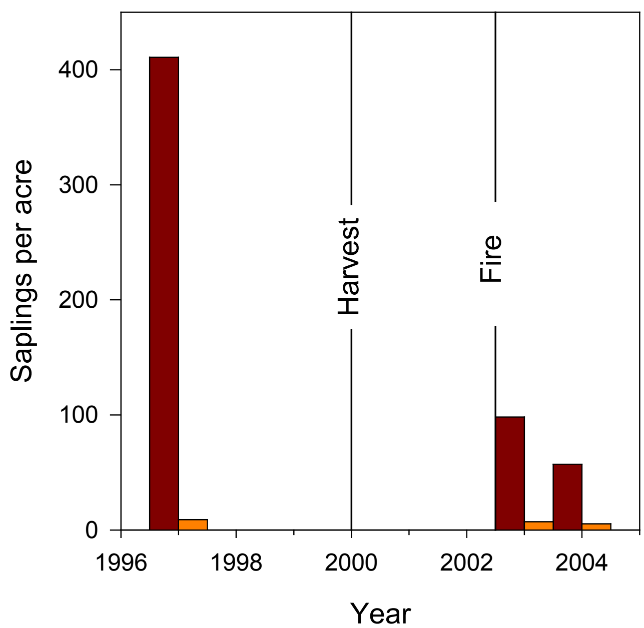
POSTFIRE-1

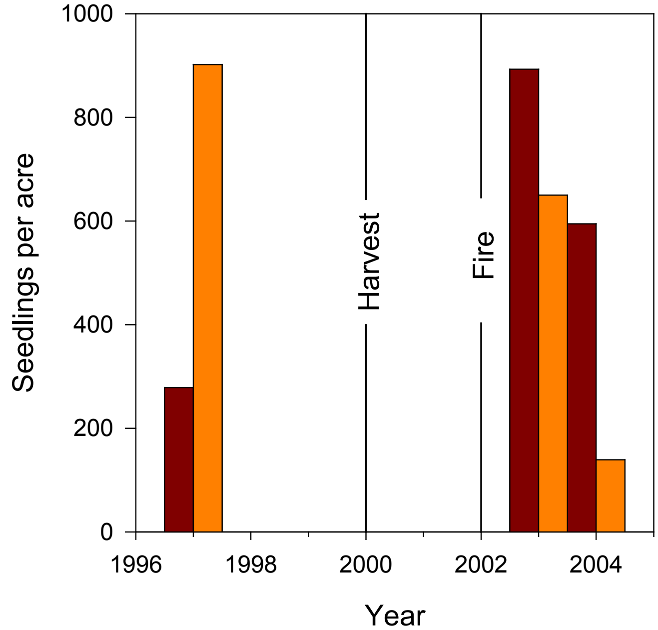
POSTFIRE-6

SITE: Sun Creek Unit 4
TREATMENT: Group Shelterwood & Prescribed Burn

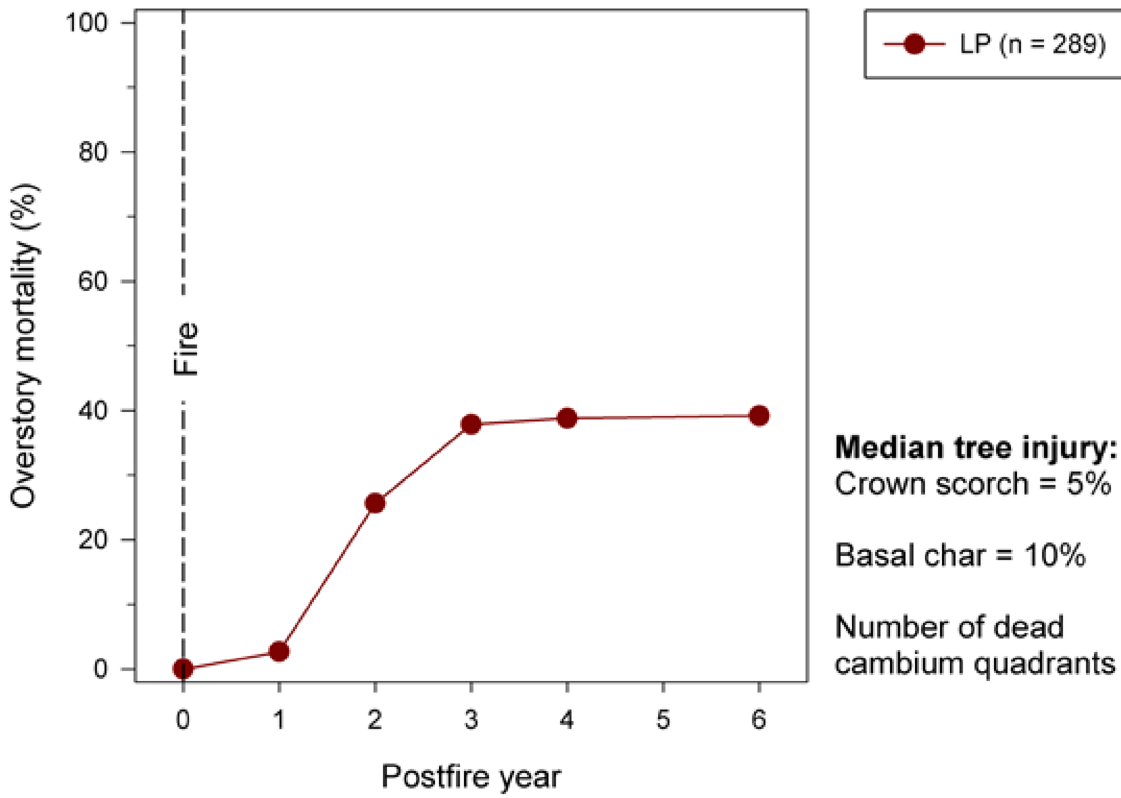








SITE: Sun Creek Unit 4
TREATMENT: Group Shelterwood & Prescribed Burn



Median tree injury:
Crown scorch = 5%

Basal char = 10%

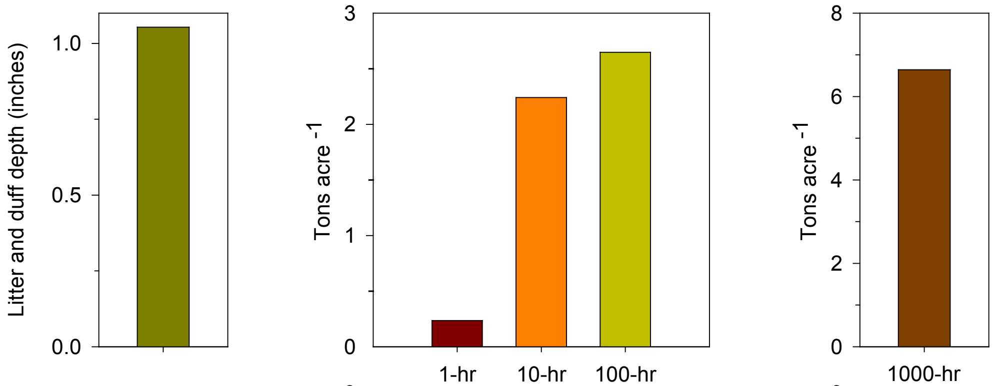
Number of dead
cambium quadrants = 0

SITE: Sun Creek Unit 4
TREATMENT: Group Shelterwood & Prescribed Burn

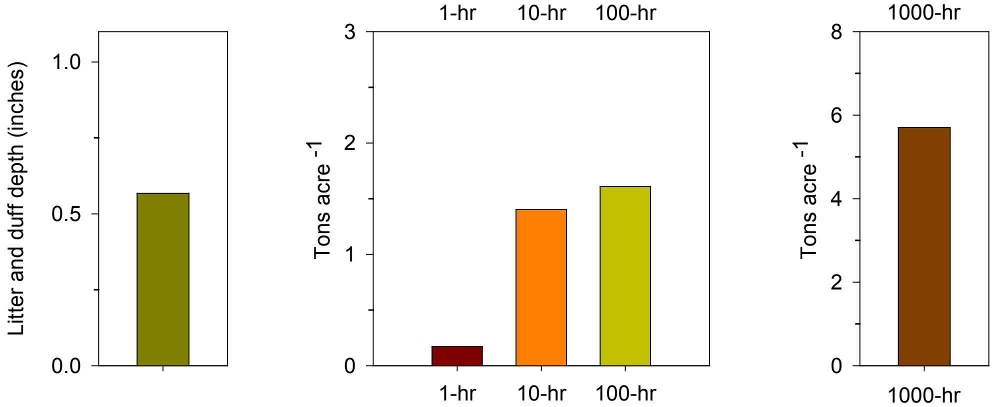
PREHARVEST

No data collected

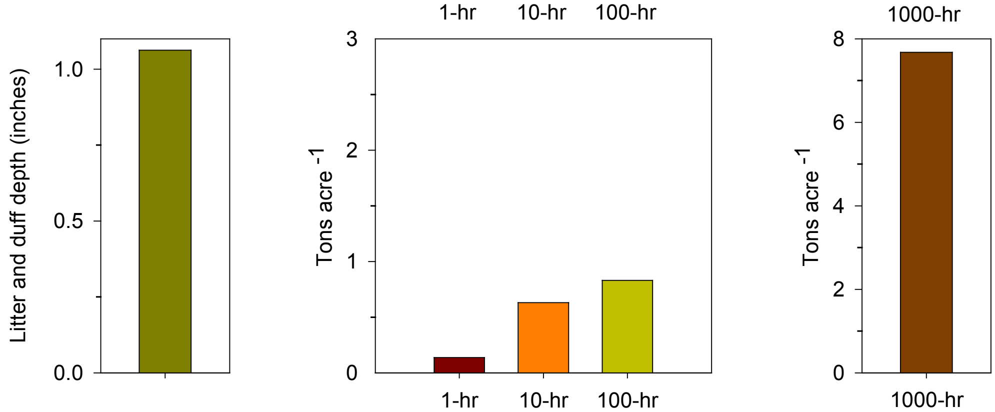
POSTHARVEST



POSTFIRE-1



POSTFIRE-6



SITE: Sun Creek Unit 4
TREATMENT: Group Shelterwood & Prescribed burn

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at p<0.05. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. An asterisk by postburn measurement denotes change between postharvest loading and postburn loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	Postharvest (Std. Err.)	1 Year Postburn (Std. Err.)	2 Years Postburn (Std. Err.)	6 Years Postburn (Std. Err.)
Overstory density (trees acre^{-1})						
LP	28	914.2 (143.4)	—	422.9* (129.1)	387.3* (125.9)	—
ES	28	0.9 (0.9)	—	0.9 (0.9)	0.9 (0.9)	—
Overstory basal area (ft^2 acre^{-1})						
LP	28	213.6 (10.2)	—	104.3* (19.4)	92.9* (18.6)	—
ES	28	0.7 (0.7)	—	0.7 (0.7)	0.7 (0.7)	—
Sapling density (trees acre^{-1})						
LP	28	410.7 (45.7)	—	98.2* (33.9)	57.1* (20.5)	—
SF	28	8.9 (5.2)	—	7.1 (3.4)	5.4 (3.9)	—
Seedling density (trees acre^{-1})						
LP	28	289.3 (102.9)	—	1535.7 (550.3)	1050.0 (295.0)	—
ES	28	21.4 (14.9)	—	0 (0)	0 (0)	—
SF	28	267.9 (58.4)	—	250.0* (132.4)	139.3* (47.5)	—
WB	28	128.6 (60.6)	—	0* (0)	0* (0)	—
Surface fuels						
Duff and litter depth (in)	14	—	1.05 (0.11)	0.57* (0.09)	—	1.06 (0.22)
1 hour fuel load (tons acre^{-1})	14	—	0.24 (0.03)	0.17 (0.03)	—	0.14* (0.03)
10 hour fuel load (tons acre^{-1})	14	—	2.24 (0.45)	1.4 (0.41)	—	0.63* (0.15)
100 hour fuel load (tons acre^{-1})	14	—	2.65 (0.71)	1.61* (0.41)	—	0.83* (0.17)
1000 hour fuel load (tons acre^{-1})	14	—	6.64 (1.49)	5.71 (1.23)	—	7.68 (2.21)

Study site: Spring Park Creek Unit 12–Group Shelterwood and Burn

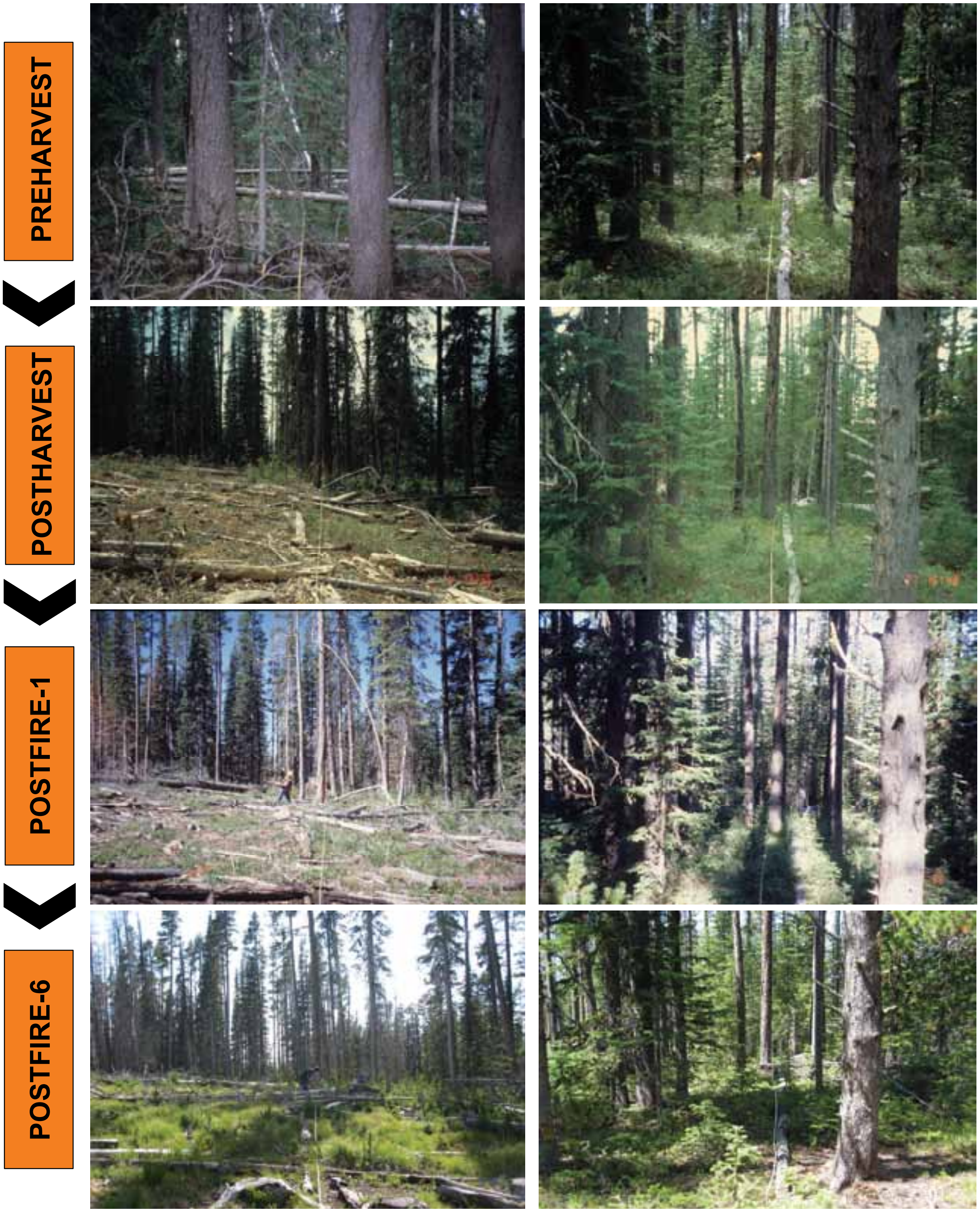
Unit description: The 30-acre (12-ha) unit was harvested during the summer of 2000. Prior to harvest, lodgepole pine (45 percent of tree density) and subalpine fir (47 percent) codominated the overstory. Harvest and prescribed burning reduced the average number of live lodgepole pine trees per acre from approximately 215 to 60 (87 to 24 trees ha^{-1}) and basal area from 121 to 41 ft^2 $acre^{-1}$ (28 to 9 m^2 ha^{-1}). Subalpine fir remained the most common overstory species (52 percent) 2 years postfire.

Prior to harvest, the seedling and sapling layers were predominantly subalpine fir. Two years postfire, sapling density was significantly reduced for all species, with subalpine fir still the dominant species. In addition, lodgepole pine seedlings had increased after fire, but subalpine fir remained the dominant species, comprising 98 percent of the regeneration.

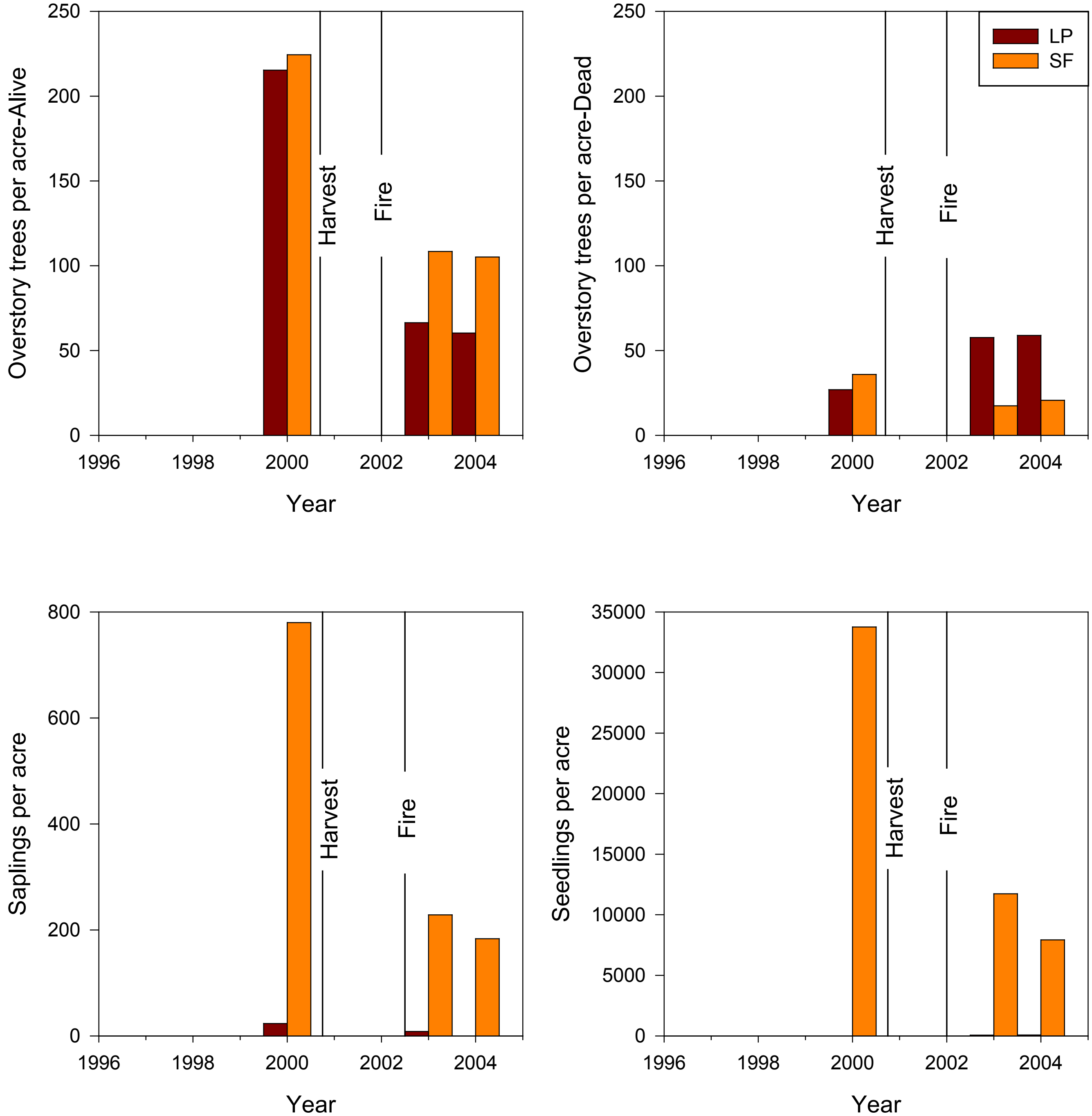
After harvest, fuel model 12 (Anderson 1981) best described the unit and forest floor depths, and fine fuel loading were significantly higher. The unit was prescribed burned on September 11, 2002, between 1600 and 1930. Mean fuel moisture by size class in the uncut groups was: 13 percent for 1-hr, 18 percent for 10-hr, 33 percent for 100-hr, and 28 percent for 1000-hr. Mean fuel moisture by size class in the clearcut areas was: 12 percent for 1-hr, 11 percent for 10-hr, 19 percent for 100-hr, and 21 percent for 1000-hr. Temperatures ranged from 59 to 68 ^{o}F (15 to 20 ^{o}C). Relative humidity ranged from 34 to 42 percent, with average wind speed between 2 and 8 mph (1 to 4 m sec^{-1}). Crown scorch was low throughout most of the unit with an average of 30 percent and a median of 0 percent. Average basal bark char was 30 percent (median = 14 percent). Fire-caused mortality resulted in an additional 22 percent mortality of lodgepole pine trees greater than 4 inches (10.2 cm) DBH, with mortality stabilizing within 3 years after the burn. While the fire reduced forest floor depth and fine fuel loading, little consumption of 1000-hr fuels occurred.

Management implications: We did not sample postharvest tree plots in this unit; therefore, we do not know the reduction in tree density from harvest alone. Harvest and fire reduced tree density by 67 percent, which met the tree retention goal. The burn significantly reduced 1-hr and 10-hr fuel loads and duff and litter depths but not 100-hr or 1000-hr fuel loads. The burn in this unit generally carried through the logging slash in the clearcut corridors but did not carry through most of the uncut leave islands. In the leave islands, the understory consisted primarily of grouse whortleberry, which did not burn well. Compared to the even shelterwood treatment, the group shelterwood created a stand structure that was less susceptible to windthrow and fire-caused mortality, while reducing activity fuel loads. The group shelterwood treatment also created a more heterogeneous mosaic on the landscape. Increased light resulting from the group shelterwood harvest favored lodgepole pine regeneration; however, most lodgepole pine regeneration likely occurred in the cut patches where there was less vegetative competition and more light available. Even though lodgepole pine saplings were reduced by harvesting and burning, higher average densities remained in the group shelterwood units than in the even shelterwood units due to islands of uncut vegetation.

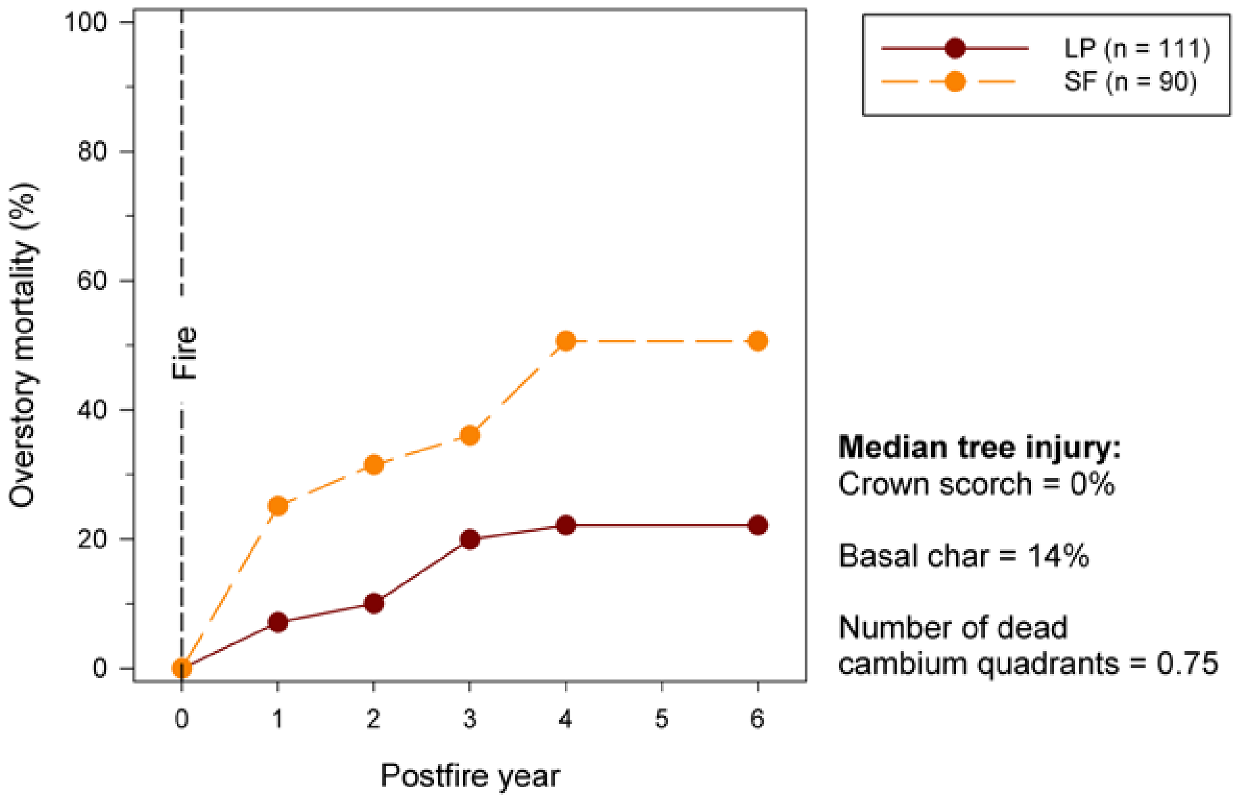
SITE: Spring Park Unit 12
TREATMENT: Group Shelterwood & Prescribed Burn



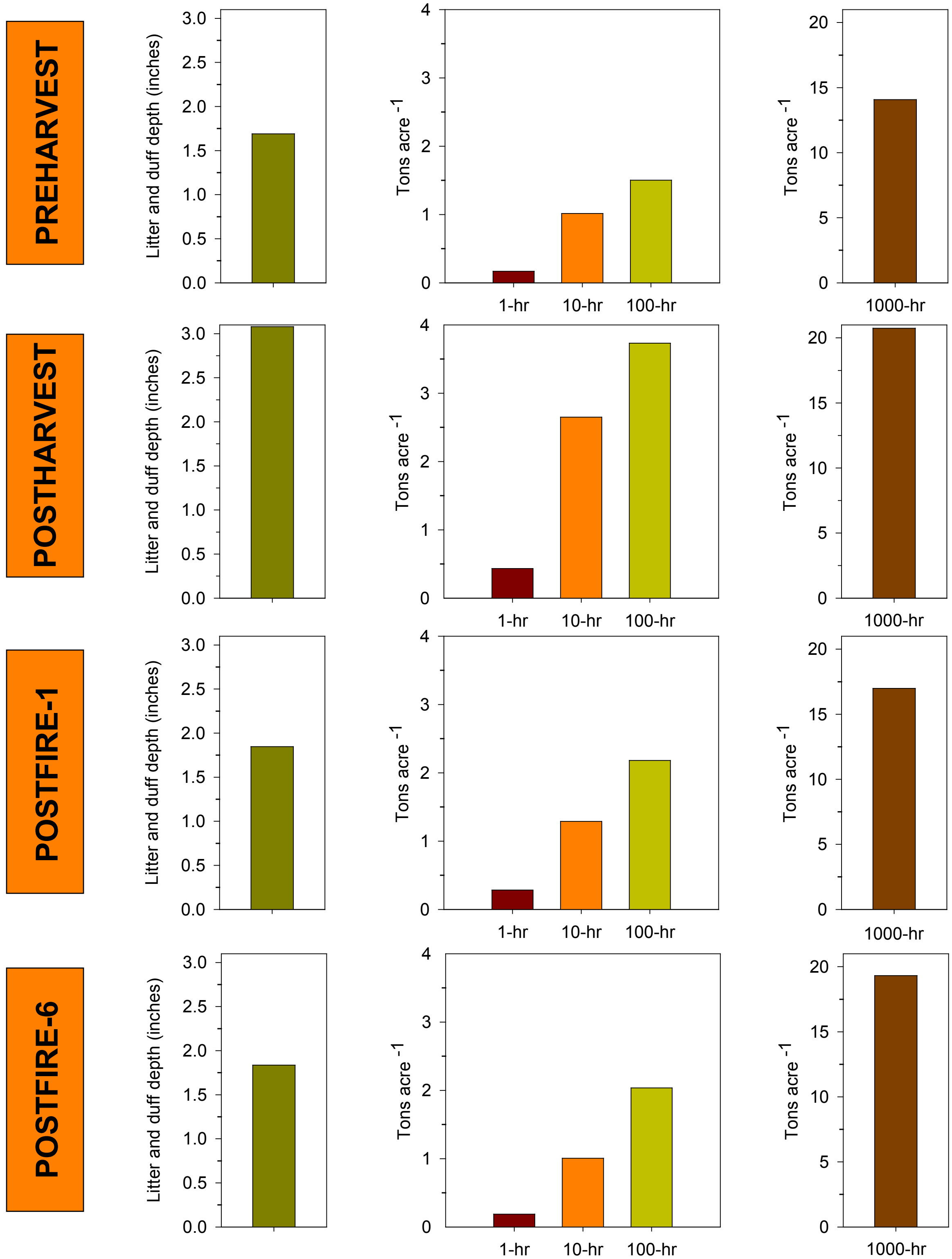
SITE: Spring Park Unit 12
TREATMENT: Group Shelterwood & Prescribed Burn



SITE: Spring Park Unit 12
TREATMENT: Group Shelterwood & Prescribed Burn



SITE: Spring Park Unit 12
TREATMENT: Group Shelterwood & Prescribed Burn



SITE: Spring Park Creek Unit 12
TREATMENT: Group Shelterwood & Prescribed burn

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at $p<0.05$. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. An asterisk by postburn measurement denotes change between postharvest loading and postburn loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	Postharvest (Std. Err.)	1 Year Postburn (Std. Err.)	2 Years Postburn (Std. Err.)	6 Years Postburn (Std. Err.)
Overstory density (trees acre^{-1})						
LP	30	208.1 (32.3)	—	64.2* (18.4)	58.3* (18.4)	—
ES	30	37.3 (27.4)	—	34.3 (27.5)	34.3 (27.5)	—
SF	30	216.9 (56.9)	—	104.8* (44.5)	101.6* (44.7)	—
Overstory basal area (ft^2 acre^{-1})						
LP	30	117.3 (12.4)	—	45.3* (11.8)	40.0* (11.7)	—
ES	30	9.3 (4.6)	—	6.7 (4.3)	6.7 (4.3)	—
SF	30	38.7 (6.5)	—	17.3* (5.3)	16.0* (5.3)	—
Sapling density (trees acre^{-1})						
LP	30	23.3 (10.4)	—	8.3 (5.4)	0* (0)	—
ES	30	23.3 (10.9)	—	6.7 (4.6)	0* (0)	—
SF	30	780.0 (131.6)	—	228.3* (97.0)	183.3*(66.2)	—
WB	30	1.7 (1.7)	—	0 (0)	0 (0)	—
Seedling density (trees acre^{-1})						
LP	30	0 (0)	—	66.7 (46.3)	80.0 (45.3)	—
ES	30	280.0 (212.8)	—	133.3 (133.3)	20.0 (13.9)	—
SF	30	33760.0 (5702.6)	—	11733.3* (3563.5)	7930.0* (2417.2)	—
WB	30	90.0 (56.0)	—	0 (0)	100.0 (48.4)	—
Surface fuels						
Duff and litter depth (in)	15	1.69 (0.29)	3.08* (0.50)	1.85 (0.26)	—	1.84 (0.16)
1 hour fuel load (tons acre^{-1})	15	0.17 (0.03)	0.43* (0.04)	0.28* (0.07)	—	0.19* (0.06)
10 hour fuel load (tons acre^{-1})	15	1.02 (0.17)	2.65* (0.45)	1.29* (0.29)	—	1.01* (0.18)
100 hour fuel load (tons acre^{-1})	15	1.5 (0.39)	3.73 (1.00)	2.18 (0.52)	—	2.04 (0.38)
1000 hour fuel load (tons acre^{-1})	15	14.08 (2.05)	20.74* (3.27)	16.98 (2.24)	—	19.32 (2.72)

Study site: Spring Park Creek Unit 16–Group Shelterwood and Burn

Treatment description: The 42-acre (17-ha) unit was harvested during the summer of 2000. The overstory was pure lodgepole pine prior to harvest. Harvest and prescribed burning reduced the average number of live lodgepole pine trees per acre from approximately 613 to 168 (248 to 68 trees ha^{-1}) and basal area from 180 to 50 ft^2 $acre^{-1}$ (43 to 11 m^2 ha^{-1}).

Prior to harvest, saplings were predominantly lodgepole pine, while the seedling layer was a mix of lodepole pine, Engelmann spruce, subalpine fir, and whitebark pine. Sapling density was greatly reduced 2 years postfire. In the seedling layer, lodgepole pine had significantly increased and was the main species present 2 years postfire.

Fuel loading was low prior to harvest. Harvest increased 10-, 100-, and 1000-hr fuel loading, and fuel model 11 (Anderson 1981) best described the unit after harvest. The unit was prescribed burned on September 12, 2002, between 1530 and 1730. Mean fuel moisture by size class in the uncut groups was: 9 percent for 1-hr, 11 percent for 10-hr, 16 percent for 100-hr, and 26 percent for 1000-hr. Mean fuel moisture by size class in the clearcut areas was: 8 percent for 1-hr, 9 percent for 10-hr, 16 percent for 100-hr, and 26 percent for 1000-hr. Temperatures ranged from 66 to 68 ^{o}F (19 to 20 ^{o}C). Relative humidity ranged from 19 to 22 percent, with average wind speed between 2 and 3 mph (1 to 2 m sec^{-1}). Crown scorch was low throughout most of the unit with an average of 34 percent and a median of 15 percent. Average basal bark char was 48 percent (median = 50 percent). Fire-caused mortality resulted in an additional 60 percent mortality of lodgepole pine trees greater than 4 inches (10.2 cm) DBH, and mortality stabilized within 4 years after the burn. The burned reduced overall fuel load, but it returned to near preharvest levels within 6 years postfire.

Management recommendations: We did not sample postharvest tree plots in this unit; therefore, we do not know the reduction in tree density from harvest alone. Harvest and fire reduced tree density by 72 percent, which met the tree retention goals and significantly reduced activity fuel loads. Like the other group shelterwood and burn units, the prescribed fire in this unit carried through the logging slash in the clearcut corridors. However, fire in this unit burned through more of the uncut islands compared to the other group shelterwood and burn units, killing approximately 60 percent of the leave trees. Compared to the even shelterwood treatment, the group shelterwood created a stand structure that was less susceptible to windthrow and fire-caused mortality, while reducing activity fuel loads. The group shelterwood treatment also created a more heterogeneous mosaic on the landscape. Increased light from treatment favored lodgepole pine regeneration; however, most lodgepole pine regeneration occurred in the cut patches where there was less vegetative competition and more light available. Even though harvest and burning reduced lodgepole pine saplings, higher average densities remained in the group shelterwood units than in the even shelterwood units due to islands of uncut vegetation.

SITE: Spring Park Unit 16
TREATMENT: Group Shelterwood & Prescribed Burn

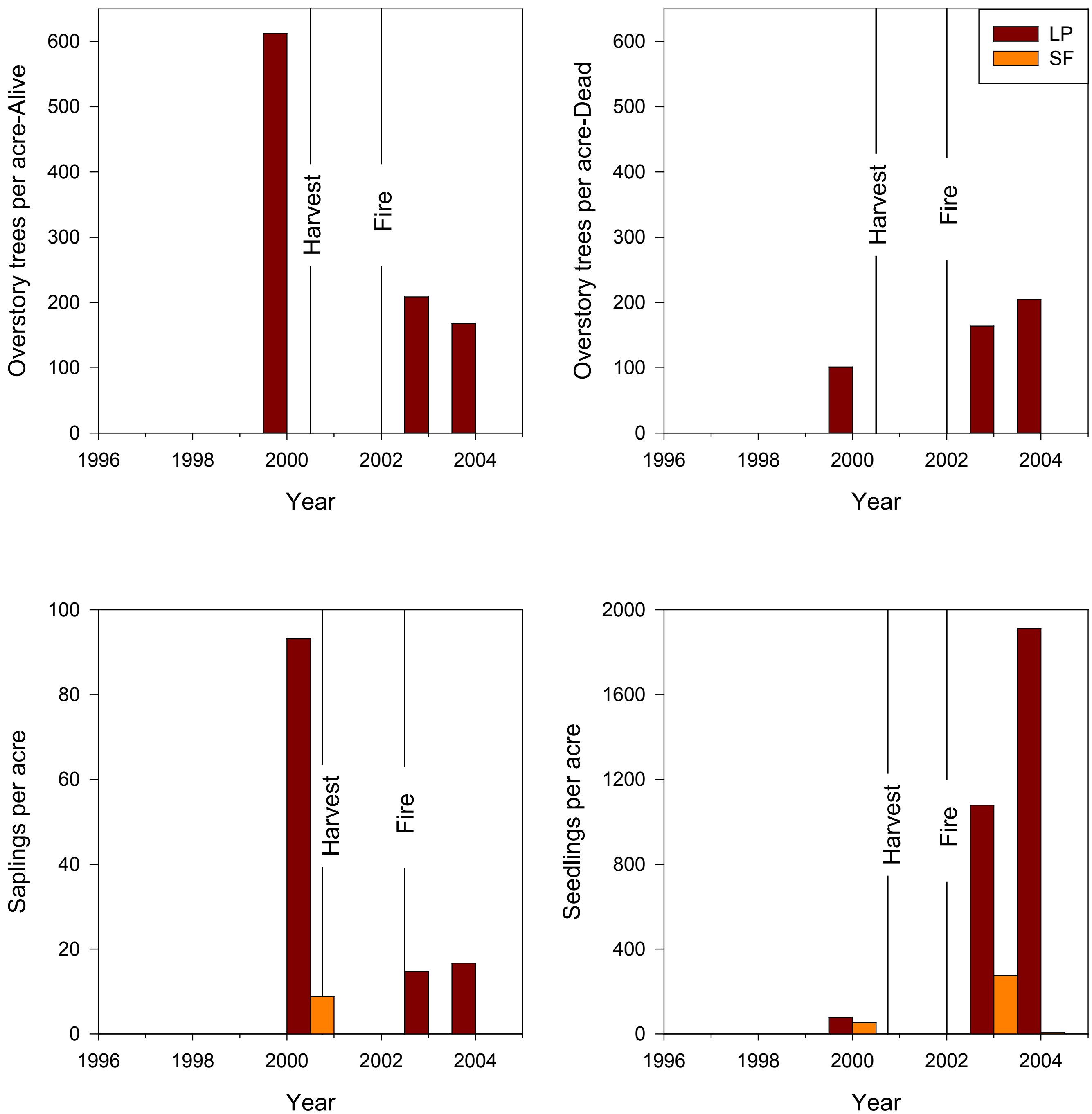
PREHARVEST


POSTHARVEST

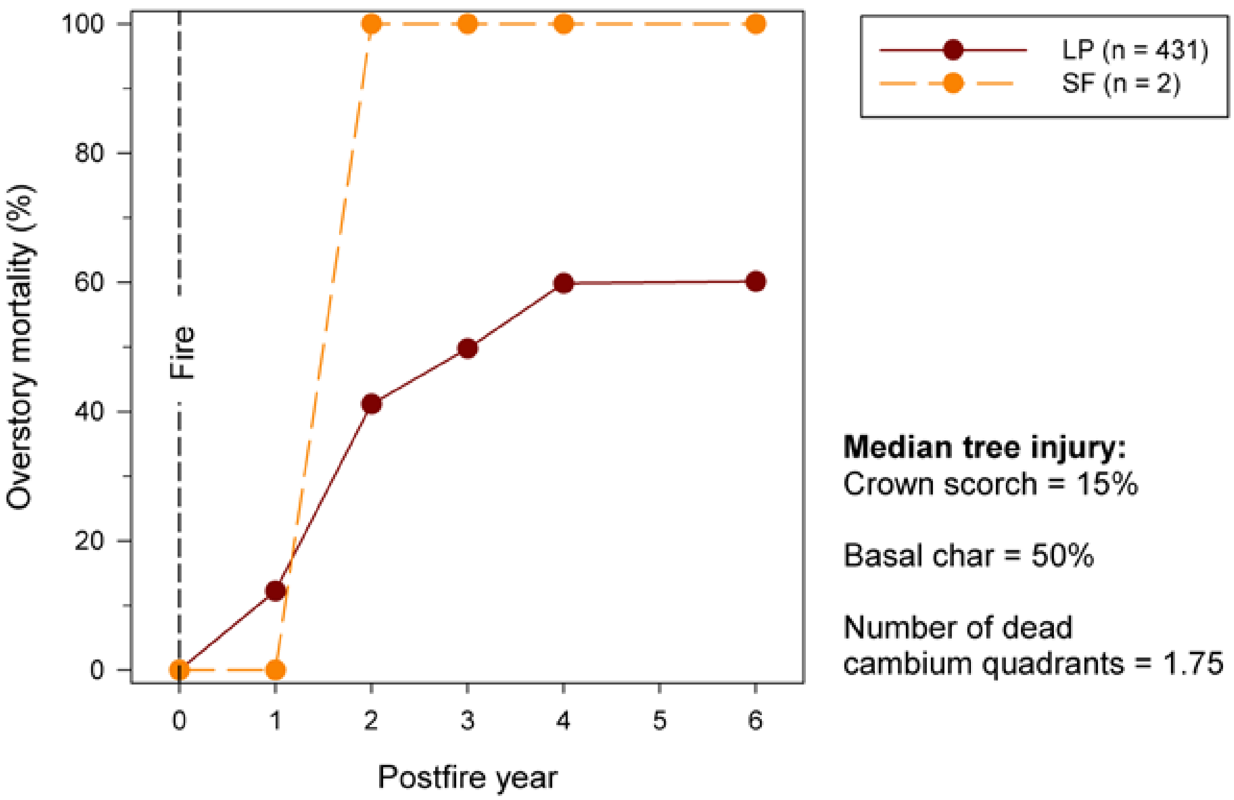

POSTFIRE-1


POSTFIRE-6


SITE: Spring Park Unit 16
TREATMENT: Group Shelterwood & Prescribed Burn



SITE: Spring Park Unit 16
TREATMENT: Group Shelterwood & Prescribed Burn

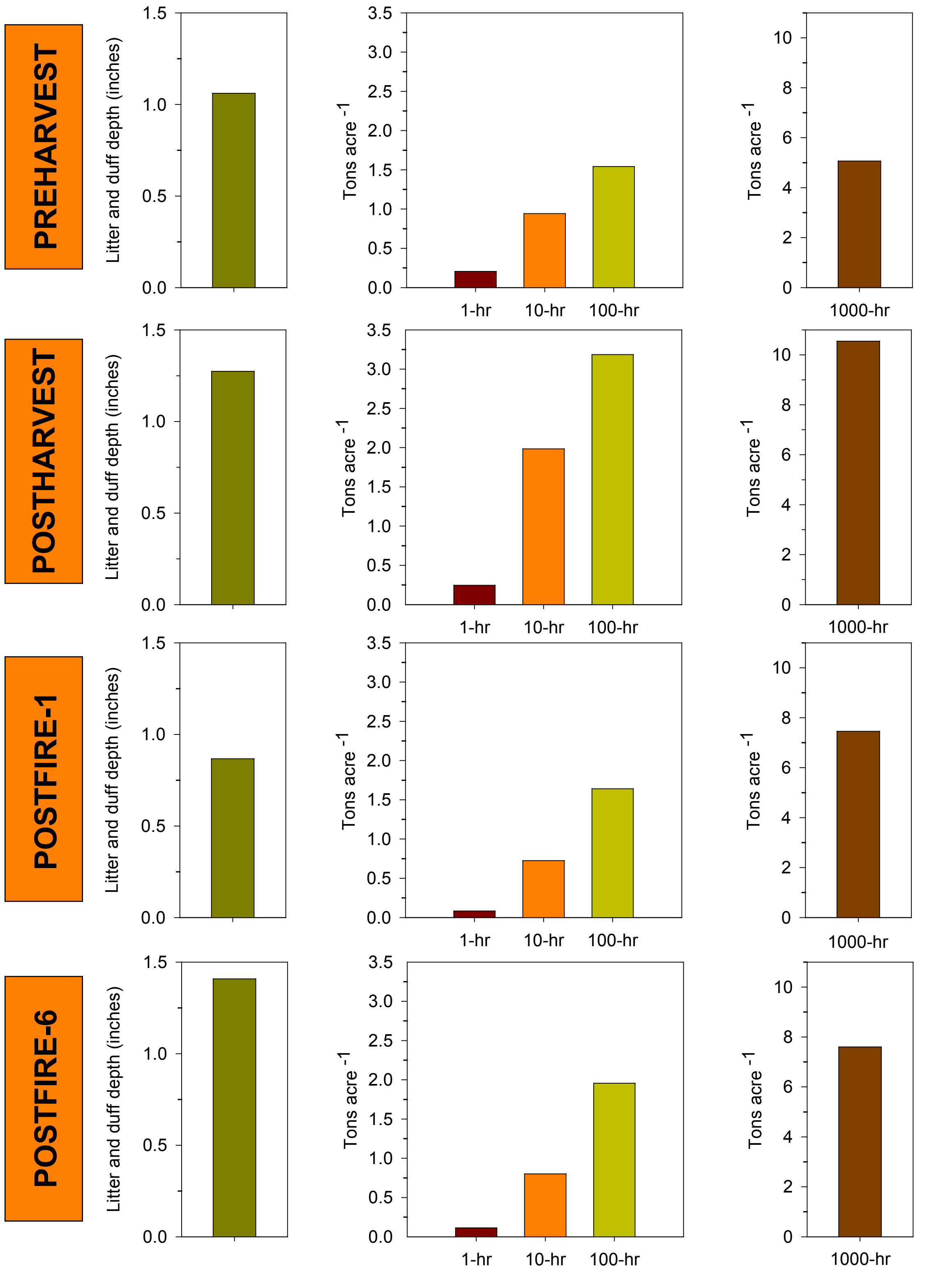


Median tree injury:
Crown scorch = 15%

Basal char = 50%

Number of dead
cambium quadrants = 1.75

SITE: Spring Park Unit 16
TREATMENT: Group Shelterwood & Prescribed Burn



SITE: Spring Park Creek Unit 16
TREATMENT: Group Shelterwood & Prescribed burn

Overstory density and basal area, sapling and seedling density, and fuel loading by measurement year with standard error in parenthesis. For density, asterisk (*) denotes change between preharvest density and subsequent measurement year is significant at $p<0.05$. For fuel loading, an asterisk by postharvest loading denotes change between initial loading and postharvest loading. An asterisk by postburn measurement denotes change between postharvest loading and postburn loading. Dash indicates timestep where no sampling was done.

	# Plots	Preharvest (Std. Err.)	Postharvest (Std. Err.)	1 Year Postburn (Std. Err.)	2 Years Postburn (Std. Err.)	6 Years Postburn (Std. Err.)
Overstory density (trees acre^{-1})						
LP	51	612.7 (63.6)	—	208.5* (44.8)	167.7* (44.4)	—
Overstory basal area (ft^2 acre^{-1})						
LP	51	179.6 (10.3)	—	65.9* (11.2)	50.2* (10.9)	—
Sapling density (trees acre^{-1})						
LP	51	93.1 (13.1)	—	14.7* (4.5)	16.7* (4.6)	—
SF	51	8.8 (2.7)	—	0* (0)	0* (0)	—
WB	51	1.0 (1.0)	—	0 (0)	0 (0)	—
Seedling density (trees acre^{-1})						
LP	51	76.5 (30.1)	—	1078.4 (403.8)	1911.8* (369.3)	—
ES	51	47.1 (22.8)	—	0* (0)	0* (0)	—
SF	51	52.9 (18.2)	—	274.5 (237.8)	5.9* (5.9)	—
WB	51	164.7 (52.7)	—	0* (0)	0* (0)	—
Surface fuels						
Duff and litter depth (in)	17	1.06 (0.08)	1.27 (0.16)	0.87* (0.11)	—	1.41 (0.24)
1 hour fuel load (tons acre^{-1})	17	0.21 (0.02)	0.25 (0.03)	0.08* (0.02)	—	0.11* (0.02)
10 hour fuel load (tons acre^{-1})	17	0.94 (0.12)	1.98* (0.29)	0.73* (0.14)	—	0.80* (0.21)
100 hour fuel load (tons acre^{-1})	17	1.54 (0.40)	3.19* (0.63)	1.64* (0.48)	—	1.96 (0.49)
1000 hour fuel load (tons acre^{-1})	17	5.07 (1.23)	10.55* (1.57)	7.46 (0.88)	—	7.6 (0.75)

Discussion

Little research exists on silvicultural treatments to create two-aged stands of lodgepole pine, with the exception of Alexander (1975; 1986). However, Alexander's research focused on cutting methods designed primarily to maximize timber production and water yield, rather than ones that restore forest structure created by historical mixed-severity fire regimes. Heterogeneous landscapes of small patches of two-aged lodgepole pine were historically common in many parts of lodgepole pine's range (Arno and others 1993; Barrett and others 1991). Over time, fire suppression has lead to more uniform stand structure, which could result in larger fires. The variable retention harvests and prescribed burn treatments implemented on the TCEF were designed to help determine suitable methods for establishing heterogeneous, two-aged lodgepole pine landscapes.

As expected, overstory, sapling, and seedling composition and density in the control units remained relatively unchanged through the study period. Exceptions to this trend occurred in the seedling layer, which exhibited large fluctuations in subalpine fir and lodgepole pine densities between sampling periods. These were most likely attributed to the change in sampling methodology for the 2003 sampling period. As stated in the "Methods" section, the change in sampling only affected the seedling plots. All units except Spring Park Creek unit 12 met the seedling stocking level objective of 100 to 200 seedlings per acre by the most recent sampling period (4 years postharvest or 2 years postburn). Without disturbance, we expect that lodgepole pine abundance will decrease and subalpine fir and Engelmann spruce abundance will increase in the control units over time.

The postharvest overstory retention goal for all unburned units of 40 to 60 percent of the preharvest overstory density was not met. This was likely due to a combination of over-cutting and a wind event that occurred in 2001 soon after harvest was completed. Actual retention values for the even shelterwood treatment ranged from 7 to 26 percent. Group shelterwood treatment units came closer to meeting the retention goals but were still low with only 21 to 41 percent of the overstory retained. Windthrow was especially heavy in the even shelterwood units 1 and 8. In these units, trees were downed throughout the area, with no particular pattern. Unfortunately, we did not collect postharvest data prior to the wind event, so the actual amount of windfall could not be quantified. Stands of dense lodgepole pine are often susceptible to windthrow after thinning (Alexander 1975; Anderson 2003). Therefore, when conducting even thinning harvest operations in lodgepole pine, we recommend prescribing higher postharvest tree densities to allow for potential losses due to wind. Alexander (1986) provides additional information about designing cutting units to limit windthrow.

Over-cutting may have occurred because operators often had to cut trees in order to allow enough spacing for the machinery to pass through. Pretreatment stands were very dense, making it difficult for machinery to maneuver through them. Even-spaced thinning in some stands of extremely dense lodgepole pine may not be feasible due to equipment constraints and windthrow concerns. Also, it was very difficult and time intensive to estimate the appropriate size of leave patches in the group shelterwood treatment. Marking crews flagged patch boundaries with the goal of leaving approximately half of the area in each group shelterwood unit uncut, but this was hard to implement accurately. In addition, future harvest of the leave patches will likely be difficult without damaging the developing regeneration in the cut corridors.

The overstory retention goal in the prescribed burn units was at least 50 of the postharvest overstory, or 25 percent of the preharvest overstory. The group shelterwood and burn treatment units met this goal with 27 to 42 percent retained. However, overstory retention was low in the even shelterwood and burn treatment units with only 3 to 16 percent of the overstory remaining postfire. In general, fires did not carry through the uncut patches in the group shelterwood units. This resulted in higher survival in the group shelterwood units as fire mainly affected trees around the perimeter of the patches. Fire was much more uniform in the even shelterwood and burned units, due in part to the homogeneous distribution of uncompacted activity fuels and higher winds compared to the more sheltered leave patches in the group shelterwood treatment. Fire spread through the grouse whortleberry understory was much more effective with light winds (5 to 7 mph [8 to 11 km hr^{-1}]) and a previous frost. Because of its thin bark, lodgepole pine is easily killed by even low-intensity surface fire (Figure 5) regardless of flame length. A tree will likely die if the majority of its bole circumference is charred (Hood and others 2008). Therefore, if maintenance of a lodgepole pine overstory is desired, a heterogeneous, patchy burn is essential.

The high tree mortality caused from burning highlights the limitations of fire effects modeling when planning prescribed fires. The First Order Fire Effects Model (FOFEM) (Reinhardt and others 1997) was used to develop the burning prescription necessary to meet mortality objectives. However, only crown scorch and DBH were factored into the FOFEM mortality model at that time. For example, when planning the prescribed burns, FOFEM predicted higher mortality for subalpine fir than lodgepole pine due to lower crown base heights that would lead to higher crown scorch. However, because both species have thin bark, high cambium kill resulted in higher mortality of lodgepole pine than was predicted because cambium kill was not considered in FOFEM at the time (Hood and others 2007). FOFEM version 5.7 addresses this issue by allowing the user to include the anticipated level of cambium kill through the "postfire injury" option.

All overstory tree density estimates were calculated from data collected from variable-radius plots. After harvest, many units had very few sample trees remaining. In contrast, the postfire mortality and injury estimates were calculated from fixed-area plots, and sample sizes were much higher and monitored for a longer period compared to the variable-radius plots. Different methods could result in discrepancies when comparing mortality estimates between the bar graphs and line graphs in the Results section, especially when considerable delayed mortality occurred after the fire. We recommend fixed-area plots for monitoring forest structural changes over time to ensure adequate sampling of all tree sizes.

Treatments retained lodgepole pine as the dominant species in the overstory and understory with few exceptions. The even shelterwood and unburned treatment created a high proportion of lodgepole regeneration with some subalpine fir. The treatments

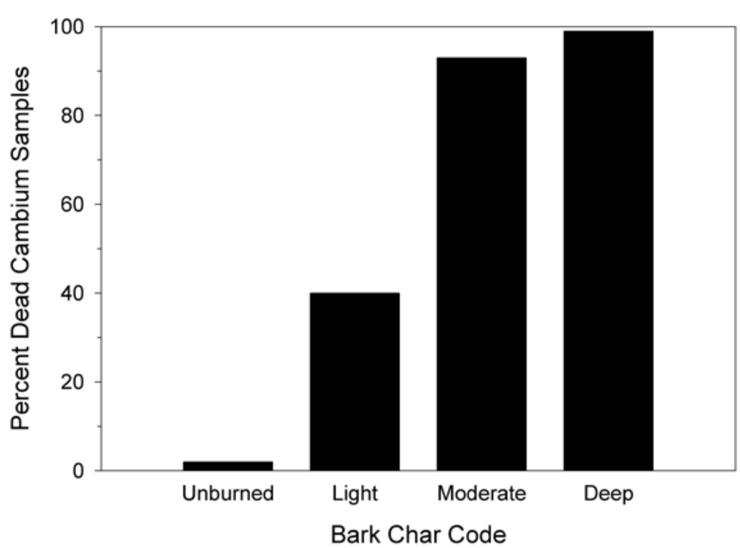


Figure 5. Percent of lodgepole pine bark char quadrants with dead cambium by bark char code. Unburned = no char; Light = bark is not completely blackened and bark species characteristics are discernable; Moderate = bark is uniformly blackened but bark species characteristics are discernable; Deep = outer bark species' characteristics are lost due to complete charring. Adapted from Hood and others (2008).

created an adequate cohort for the development of two-aged stands, provided enough overstory was retained. The group shelterwood and unburned treatment also produced mixed compositions with either high lodgepole pine or subalpine fir regeneration. Not surprisingly, the preharvest composition determined the postharvest composition. The group shelterwood and unburned treatment was less effective at reducing the density of subalpine fir. The stark microenvironments created by this treatment tended to create a different forest structure, though still two-aged, than that created by the even shelterwood and unburned treatment. In the long term, the areas that were the equivalent to a clearcut will likely become dominated by lodgepole pine, while the leave groups will contain progressively higher densities of subalpine fir.

Overstory mortality was much lower in the group shelterwood and burn units compared to the even shelterwood and burn units. In the even shelterwood units, the fire caused significant mortality, due in part to the homogeneous distribution of activity fuels, whereas most of the uncut patches in the group shelterwood did not burn due to very low fuel loading. The continuous strip headfire ignition pattern with narrow spacing between strips used in this study burned almost 100 percent of the area within the even shelterwood units. Excess mortality could possibly be mitigated by burning under moister conditions, creating patchier fuel distribution, or changing ignition patterns (for example, wider spacing between strips or dot firing) in order to create a more patchy burn.

The even shelterwood treatment created more uniform forest structure conditions and composition compared to the group shelterwood. Regeneration predominantly occurred in the cut areas of each unit due to the open canopy conditions and exposed mineral soil, regardless of the treatment. Therefore, in the even shelterwood units, regeneration was fairly uniform across each unit, while regeneration in the group shelterwood only existed in the cut corridors. Because most of the leave patches in the group shelterwood units did not burn, large amounts of subalpine fir regeneration remained where it was a large component in the preharvest overstory and understory. Because lodgepole pine grows faster than subalpine fir in the open-stand conditions, we predict it will be the dominant overstory component in the future. However, in the patches of the group shelterwood units, we predict subalpine fir will continue to increase and be a significant component of the future overstory. In general, when subalpine fir density was low in the preharvest forest, the developing stands were dominated by lodgepole pine regeneration.

Harvesting caused an initial increase in both forest floor depth and total fuel loading. In the unburned units, fuel loading was still above preharvest levels 10 years postharvest. Burning generally reduced both forest floor depth and fuel loading, and 6 years postfire (i.e., 10 years postharvest), loading had returned to near or below preharvest levels.

Bark beetle populations were low preharvest and before prescribed burning. Mountain pine beetle attacked a small number of lodgepole pine trees within 1 year after fire. However, attacks did not produce successful broods, and no additional attacks in subsequent years were observed in the last sampling, 6 years postfire. However, this last sampling occurred in 2008 and 2009 just prior to observed increases in beetle populations in TCEF.

Conclusions and Management Implications

This guide is intended to help managers determine potential effects of harvesting and prescribed burning in lodgepole pine to create two-aged stands. Each unit should be considered a case study and an example of what may occur for a given stand condition and applied treatment.

Our results indicate that even-distribution thinning alone or combined with prescribed fire results in extremely low overstory density. Homogenous prescribed burning of any intensity in lodgepole pine, especially stands with activity fuels present, will almost always result in high mortality and is not recommended if retention of overstory trees is desired. For areas where windthrow is a concern, we recommend variable retention harvests similar to the group shelterwood described in this guide. The group shelterwood fostered lodgepole pine regeneration in the cut corridors while maintaining lodgepole pine in the overstory in the leave patches. This treatment demonstrated that fire does not spread well in lodgepole under typical prescribed fire burning conditions without some type of prior mechanical treatment. With careful marking, it is possible to create a heterogeneous, two-aged lodgepole pine stand using the group shelterwood treatment both alone and in conjunction with prescribed burning.

References

Alexander, R. R. 1975. Partial cutting in old-growth lodgepole pine. Res. Pap. RM-136. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 17 p.

Alexander, R. R. 1986. Silvicultural systems and cutting methods for old-growth lodgepole pine forests in the central Rocky Mountains. Gen. Tech. Rep. GTR-RM-127. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 31 p.

Anderson, H. E. 1981. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Anderson, M. D. I. 2003. *Pinus contorta* var. *latifolia*. Fire Effects Information System [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2011, May 18].

Arno, S. F. 1980. Forest fire history in the Northern Rockies. Journal of Forestry. 78: 460-465.

Arno, S. F.; Reinhardt, E.; Scott, J. H. 1993. Forest structure and landscape patterns in the subalpine lodgepole pine type: A procedure for quantifying past and present conditions. Gen. Tech. Rep. INT-294. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 17 p.

Barrett, S. W.; Arno, S. F.; Key, C. H. 1991. Fire regimes of western larch–lodgepole pine forests in Glacier National Park, Montana. Canadian Journal of Forest Research. 21: 1711-1720.

Barrett, S. W. 1993. Fire history of Tenderfoot Creek Experimental Forest, Lewis and Clark National Forest. Unpublished final report on file at the Missoula Fire Sciences Laboratory. Missoula, Montana: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 23 p.

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

Critchfield, W. B. 1978. The distribution, genetics, and silvics of lodgepole pine. In: Proceedings, International Union of Forestry Research Organizations (IUFRO) joint meeting of working parties. Vol. 1: Background papers and Douglas fir provenances. British Columbia Ministry of Forests, Victoria, BC: 65-94.

Flora, G. F.; McCaughey, W. 1998. Environmental assessment: Tenderfoot Creek Experimental Forest vegetative treatment research project. Kings Hill Ranger District, Lewis and Clark National Forest, Meagher County, Montana. 88 p.

Games, P. A. 1977. An Improved *t* table for simultaneous control on *g* contrasts. Journal of the American Statistical Association. 72: 531-534.

Hardy, C.; Keane, R. E.; Stewart, C. 2000. Ecosystem-based management in the lodgepole pine zone. In: H. Y. Smith, ed. The Bitterroot ecosystem management research project: What we have learned. Proc. RMRS-P-17. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 31-35.

Hardy, C.; Smith, H. Y.; McCaughey, W. 2006. The use of silviculture and prescribed fire to manage stand structure and fuel profiles in a multi-aged lodgepole pine forest. In: P. L. Andrews; B. Butler, eds. Fuels management–How to measure success: Conference Proceedings; 2006, 28-30 March; Portland, OR. Proc. RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 451-464.

Hardy, C. C.; McGaughey, W. W. 1997. Restoring fire in lodgepole pine forests of the Intermountain West. In: Changing ecosystems: Natural and human influences; Supplement to Bulletin of the Ecological Society of America Annual Meeting. Ecological Society of America and The Nature Conservancy: 78(4): 15.

Hood, S. M.; McHugh, C.; Ryan, K. C.; Reinhardt, E.; Smith, S. L. 2007. Evaluation of a post-fire tree mortality model for western US conifers. International Journal of Wildland Fire. 16: 679-689.

Hood, S. M.; Cluck, D. R.; Smith, S. L.; Ryan, K. C. 2008. Using bark char codes to predict post-fire cambium mortality. Fire Ecology. 4: 57-73.

Keane, R. E.; Parsons, R. A. 2010. Management guide to ecosystem restoration treatments: Whitebark pine forests of the northern Rocky Mountains, U.S.A. Gen. Tech. Rep. RMRS-GTR-232. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 133 p.

Lotan, J. E.; Critchfield, W. B. 1990. *Pinus contorta* Dougl. ex. Loud.–lodgepole pine. In: R. M. Burns; B. H. Honkala, eds. Silvics of North America: Volume 1, conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 302-315.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-GTR-34. Ogden, Utah: U.S. Department. of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Reinhardt, E. D.; Keane, R. E.; Brown, J. K. 1997. First Order Fire Effects Model: FOFEM 4.0 user’s guide. Gen. Tech. Rep. INT-GTR-344. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 65 p.

Romme, W. H. 1982. Fire and landscape diversity in subalpine forests of Yellowstone National Park. Ecological Monographs. 52: 199-221.

Stewart, C. 1996. Restoring historic landscape patterns through management: restoring fire mosaics on the landscape. In: C. Hardy; S. F. Arno, eds. The use of fire in forest restoration. Gen. Tech. Rep. INT-GTR-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 49-50.

U.S. Department of Agriculture, Forest Service. 1997. Tenderfoot research project: A proposal for research and demonstration of ecosystem-based treatments in lodgepole pine forests on the Tenderfoot Creek Experimental Forest. [Unpublished report on file]. Missoula, Montana: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 22 p.

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of the National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals. Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

Station Headquarters
Rocky Mountain Research Station
240 W Prospect Road
Fort Collins, CO 80526
(970) 498-1100

Research Locations

Flagstaff, Arizona
Fort Collins, Colorado
Boise, Idaho
Moscow, Idaho
Bozeman, Montana
Missoula, Montana
Reno, Nevada
Albuquerque, New Mexico
Rapid City, South Dakota
Logan, Utah
Ogden, Utah
Provo, Utah

www.fs.fed.us/rmrs

To learn more about RMRS publications or search our online titles:

www.fs.fed.us/rm/publications

www.treesearch.fs.fed.us