Restoration of Whitebark Pine Forests in the Northern Rocky Mountains, USA

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Extended Abstract

Abstract—Whitebark pine (*Pinus albicaulis*) has been declining across much of its range in North America because of the combined effects of mountain pine beetle epidemics, fire exclusion policies, and widespread exotic blister rust infections. Whitebark pine seed is dispersed by a bird, the Clark's nutcracker, which caches seed in open, pattern-rich landscapes created by fire. This study was initiated in 1993 to investigate the effects of various restoration treatments on tree populations, fuel dynamics, and vascular plant cover on five sites in the U.S. northern Rocky Mountains. The objective of this study was to restore whitebark pine ecosystems using treatments that emulate the native fire regime—primarily combinations of prescribed fire, silvicultural cuttings, and fuel enhancement cuttings. The main effects assessed included tree mortality, fuel consumption, and vegetation response measured just prior to the treatment, 1 year after the treatment(s), and 5 years post-treatment. We found that, while all treatments that included prescribed fire created suitable nutcracker caching habitat with many birds observed caching seed in the burned areas, there has yet to be significant regeneration in whitebark pine. All burn treatments resulted in high mortality in both whitebark pine and subalpine fir (>40 percent). Fine woody fuel loadings marginally decreased after fire but coarse woody debris more than doubled because of falling snags. Vascular species decreased in cover by 20 to 80percent and remained low for five years. While the treatments were successful in creating conditions that favor whitebark pine regeneration, the high level of blister rust mortality in surrounding seed sources has reduced available seed which then forced the nutcracker to reclaim most of the cached seed. Manual planting of whitebark pine seedlings is required to adequately restore these sites. A set of management guidelines is presented to guide restoration efforts.

Introduction

Whitebark pine (*Pinus albicaulis*) forests are declining across most of the species range in North America (Arno 1986; Kendall and Keane 2001) due to three factors: (1) recent and historical major mountain pine beetle (*Dendroctonus ponderosae*) outbreaks that have killed many cone-bearing whitebark pine trees (Arno 1986; Tomback and others 2001; Waring and Six 2005), (2) fire exclusion management policies that have reduced the area burned in whitebark pine forests resulting in a decrease of suitable conditions for whitebark pine regeneration (Keane and Arno 1993; Kendall and Keane 2001), and (3) the introduction of the exotic fungus white pine blister rust (*Cronarium ribicola*) to the western U.S. (circa 1910) that has killed many whitebark pine trees (Hoff and others 1980; Murray and others 1995; Kendall and Keane 2001). The cumulative effects of these three agents have resulted in a rapid decrease in mature whitebark pine, especially in the more mesic parts of its range (Keane and Arno 1993). What's worse is that predicted changes in northern Rocky Mountain climate brought about by global warming could further exacerbate whitebark pine decline by increasing the frequency and duration of beetles epidemics, blister rust infections, and severe wildfires (Logan and Powell 2001; Blaustein and Dobson 2006; Running 2006). How can society restore these invaluable ecosystems to their historical dominance?

In this paper, the results of an extensive, long-term study, called Restoring Whitebark Pine Ecosystems, are presented where the effects of several types of ecosystem restoration treatments implemented on five high elevation sites in the northern Rocky Mountains, USA are investigated. This paper is a summary of the Keane and Parsons (2010b) results presented as a comparison of treatment effects for seven major treatment types across the five sites. There is a companion report (Keane and Parsons 2010a) that presents detailed pictorial, anecdotal, and statistical summaries of all measurements and observations for each treatment unit at each time interval to serve as a guide to land management.

Whitebark Pine Ecology

Whitebark pine is a long-lived, seral tree of moderate shade tolerance (Minore 1979). It can live well over 400 years (one tree is more than 1300 years old), but on many sites it is eventually replaced, in the absence of fire, by the shade-tolerant subalpine fir (*Abies lasiocarpa*), and also by spruce (*Picea engelmannii*), and mountain hemlock (*Tsuga mertensiana*) in the mesic parts of its range (Arno and Hoff 1990; Keane 2001). Lodgepole pine (*Pinus contorta*) can outcompete whitebark pine during early successional stages in some subalpine forests, but both species often share dominance in upper subalpine forests (Day 1967; Mattson and Reinhart 1990).

The Clark's nutcracker (*Nucifraga columbiana*) plays a critical role in the dispersal of whitebark pine's heavy, wingless seed (Tomback 1982; Lorenz and others 2008). The bird harvests seed from purple cones during late summer and early fall, then carries these seeds, up to 100 of them in a sublingual pouch, to sites up to 10 km away, where it buries up to 15 seeds in a cache 2-3 cm below the ground surface (Tomback 1998; Lorenz and others 2008). Many of these

In: Keane, Robert E.; Tomback, Diana F.; Murray, Michael P.; and Smith, Cyndi M., eds. 2011. **The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium.** 28-30 June 2010; Missoula, MT. Proceedings RMRS-P-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 376 p. Online at http://www.fs.fed.us/rm/pubs/rmrs_p063.html

caches are reclaimed during the following months but those seeds that remain unclaimed eventually germinate and grow into whitebark pine seedlings (Tomback 2005). Nutcrackers appear to prefer to cache in open areas where the ground is visible from above and they appear to cache near objects on the ground, such as rocks, logs, and snags, because it reclaims seed from caches by pattern recognition (Hutchins and Lanner 1982; Lanner 1996; Tomback and others 1993). Open areas with complex patterns that occur in high mountain settings are often created by wildland fire (Morgan and Bunting 1990).

Three types of fires describe the diverse array of fire regimes in whitebark pine forests (Morgan and Bunting 1990; Morgan and others 1994). Some high elevation whitebark pine stands experience non-lethal surface fires (called underburns in this study) because sparse fuel loadings foster low intensity fires (Keane and others 1994). The more common, mixed-severity fire regime is characterized by fires of mixed severities in space and time that create complex mosaics of tree survival and mortality on the landscape. Mixed severity fires can occur at 60- to 300-year intervals in patches that are often 1 to 100 ha, depending on topography and fuels, and these openings provide important caching habitat for the Clark's nutcracker (Morgan and Bunting 1990; Arno and others 2000; Norment 1991; Tomback and others 1993). Many whitebark pine forests in northwestern Montana, northern Idaho and western Washington originated from large, stand-replacement fires that occurred at long time intervals (greater than 250 years) (Keane and others 1994; Murray 1996).

Whitebark pine benefits from wildland fire because it is better adapted to surviving and regenerating after fire than its associated shade-tolerant trees (Arno and Hoff 1990). Whitebark pine can survive low severity fires better than its competitors can because it has thicker bark, thinner crowns, and deeper roots (Arno and Hoff 1990). It also readily colonizes large, stand-replacement burns because nutcrackers transport the seed great distances (Lorenz and others 2008; Tomback 2005). Nutcrackers can disperse whitebark pine seeds up to 100 times farther (over 10 km) than wind can disperse seeds of its competitors (McCaughey and others 1985; Tomback and others 1993). It is on open, burned sites where whitebark pine can successfully grow and mature to healthy cone producing trees in the absence of competition (Arno and Hoff 1990).

The critical assumption of this study is that whitebark pine ecosystems can be restored from the damaging effects of blister rust, mountain pine beetles, and fire exclusion by implementing treatments that emulate wildland fire regimes to remove competitors and create habitat suitable for nutcracker caching. The primary objective of these treatments was to increase whitebark pine regeneration to provide for future whitebark pine cone crops. We hypothesized that those living, cone-producing whitebark pine seed sources at or near the restoration sites will possess some degree of blister rust-resistance because they have already survived decades of rust infection (Arno and others 2001).

Methods

This study was implemented on five sites in the northern Rocky Mountains of the United States (figure 1, table 1). Whitebark pine is experiencing heavy rust mortality on all sites except for the Blackbird Mountain site. All sites are in the *Abies lasiocarpa/Luzula hitchcockii* (ABLA/LUHI) habitat type with most sites in the *Vaccinium scoparium* phase, but some in the *Menziesia ferruginea* phase (Pfister and others 1977). Prior to treatment, the overstory of most sites consisted of 200 to 400 year old overstory whitebark pine and lodgepole pine with encroaching subalpine fir and scattered large Engelmann spruce (table 1).

Each site was divided into treatment areas and each treatment area was further divided into treatment units (figure 2; example from the Beaver Ridge site). The treatment area is described by the major treatment implemented within the area, and the treatment unit is defined as a sub-area within the treatment area within which a secondary or minor treatment was implemented. We tried to replicate treatment units within a site to satisfy statistical requirements for analysis of variance but found that replication was nearly impossible due to the limited extent of most study sites (most were confined by ridgetop settings), the diversity of biophysical characteristics within each site (complex aspect, slope, drainage, and species composition conditions), pseudo-replication issue (Hurlbert 1984), and a consistent lack of accessible homogeneous areas. Each study site always included a control unit adjacent to the treatment units.

Two broad types of treatments were investigated in this study (table 2), both designed to reduce subalpine

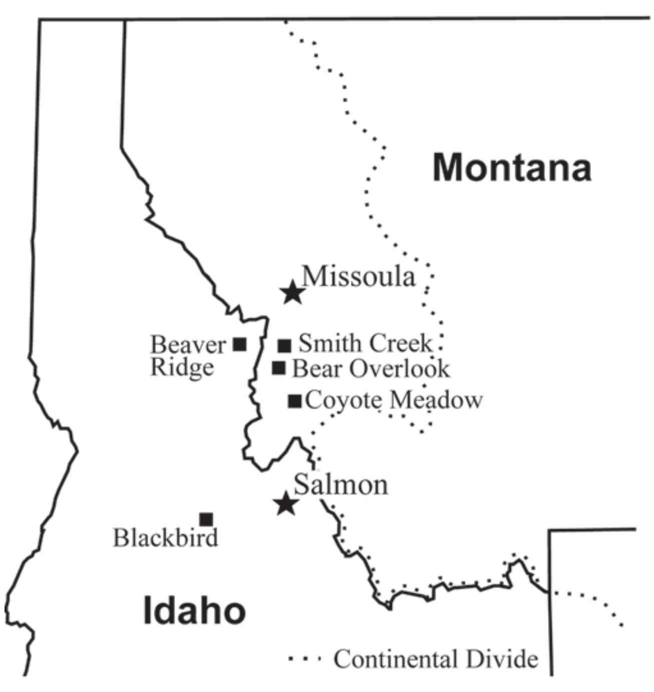

Figure 1. Study sites in the Restoring Whitebark Pine Ecosystems study.

Table 1. Description of the five sites included in the study Restoring Whitebark Pine Ecosystems (RWPE) study. All sites experienced a 1930-1934 mountain pine beetle epidemic and all but Blackbird Mountain had evidence of the 1910 fire.

Study Site Attribute	Smith Creek (SC)	Bear Overlook (BO)	Coyote Meadows (CM)	Blackbird Mountain (BM)	Beaver Ridge (BR)
National Forest	Bitterroot	Bitterroot	Bitterroot	Salmon	Clearwater
Elevation (m MSL)	2,100-2,250	2,070-2,250	2,340-2,425	2,400-2,460	2,010-2,250
Aspect	Southeast	Southeast	Northwest	South	South
Habitat type[a]	ABLA/LUHI	ABLA/LUHI	ABLA/LUHI, ABLA/MEFE	ABLA/LUHI	ABLA/LUHI
Cover type[b]	WP-LP	WP-LP	WP-SF	WP-SF	WP-LP
Overstory whitebark pine density (ha^{-1})	158	96	47	115	30
Overstory subalpine fir density (ha^{-1})	195	80	93	337	156
Historical fire regime	Mixed severity	Mixed Severity	Mixed Severity	Stand-replacement	Stand-replacement
Rust infection (%)[c]	85	70	90	<1	51
Rust mortality (%)[c]	95	93	91	<1	88
Number and type of treatment units[d]	3 MO, MN, LO	2 LO, LF	5 LO, MO, MF, HO, HF	2 HO, HF	6 LO, MO, MF, MN, HO, HF
Pre-treatment measurement year	1995	1996	1993, again in1996	1997	1997
Prescribed burn year(s)	1996	1999	2000	1999	1999, 2000, 2002
Plots compromised by wildfire[e]	20 (5)	0 (0)	44 (30)	6 (6)	28 (0)

[a] Habitat type is taken from Pfister and others (1977) where ABLA is *Abies lasiocarpa*, LUHI is *Luzula hitchcockii*, MEFE-*Menziesia ferruginea*
[b] Cover type acronyms are WP-whitebark pine, SF-subalpine fir, LP-lodgepole pine
[c] Infection and mortality levels were estimated from the tree data collected on the plots.
[d] Treatment unit codes are defined in table 2.
[e] A number of sites were burned by unplanned wildfires that burned some but not all of the plots. Number of control plots lost is in parentheses.

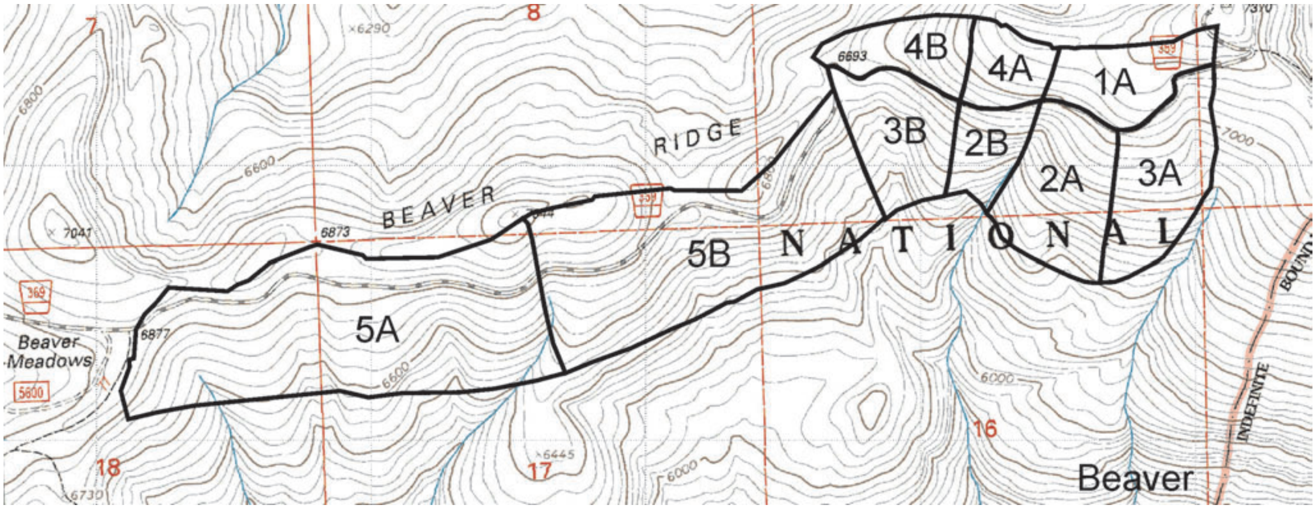

Figure 2. Treatment unit design for the Beaver Ridge study site where 1A is the control, 2A and 2B are nutcracker openings and no burning with and without tree planting, 3A and 3B are nutcracker openings with prescribed burning with and without tree planting, 4A and 4B are low severity prescribed burns with and without fuel enhancement, and 5A and 5B are high severity prescribed burns with and without fuel enhancement.

Table 2. The seven treatment type combinations (prescribed burn and tree cutting treatment) summarized in this study. Not all combinations could be reported because a majority of the study sites were burned in unplanned wildfires and uncontrolled prescribed burns (see table 1).

Prescribed burn treatment	Tree cutting treatment	Study Sites	Code
Low intensity, low severity underburn (Low)	Burn only, no cutting	BR, BO, CM, SC	LO
	Fuel enhancement	BR, BO	LF
Moderate intensity, mixed severity (Moderate)	Burn only, no cutting	BR, CM	MO
Nutcracker Openings	BR, SC	MN	
	Fuel enhancement	BR, CM	MF
High intensity, stand replacement (High)	Burn only, no cutting	CM, BM	HO
	Fuel enhancement	CM, BM	HF
No Fire (None)[a]	Nutcracker Openings	BR	N/A

[a] This treatment unit was burned by a wildfire and an uncontrolled prescribed burn so it's results are not reported here.

fir competition and to create desirable nutcracker caching habitat. The primary treatment was prescribed fire and it was implemented at three intensity levels to mimic the three types of fire regimes common in whitebark pine. A high intensity prescribed fire was used to mimic stand-replacement fire where more than 90 percent of the overstory was targeted to be killed by fire, while the moderate severity prescribed fire simulated effects from a mixed severity fire where patches of stand-replacement fire are mixed with varying severities of non-lethal surface fires (10-90 percent overstory mortality). The underburn fire was emulated with a low intensity prescribed fire. Silvicultural tree cuttings, the second type of treatment, were implemented at various levels of species selection and intensity to achieve stated objectives (table 2). First, we created cutting treatments called "Nutcracker Openings" where all trees except whitebark pine trees were cut within near-circular areas of 1 to 3 ha to entice the nutcrackers to cache seeds there. Between the nutcracker openings, but within the major treatment unit, we used group selection cuttings to remove all subalpine fir and spruce and leave all lodgepole and whitebark pine trees. A cutting treatment called *fuel enhancement* was also used to enhance the effectiveness of prescribed burning by cutting small and large fir and spruce trees and positioning them in areas with low fuel loadings. Fuel enhancement increased fuel loadings by 0.3 to 2.8 kg m^{-2} depending on the level and distribution of natural fuels.

Sampling Methods

We installed 10 plots within each treatment unit to record changes in ecological conditions. We systematically located these plots across the treatment units using a random start because attempts to randomly establish plots failed due to odd treatment unit shapes, variable fuel conditions, and concerns about finding plots in later years.

Sampling methods are described in detail in Keane and Parsons (2010a). In general, circular 0.04 ha plots were permanently located in all treatment units with all trees above 12 cm DBH (diameter at breast height) being tagged and measured for species, DBH (diameter breast height), height, crown height, and rust damage (Lutes and others 2006). The same measurements were taken on all live trees less than 12 cm DBH and greater than 1.37 meters tall (saplings), except that DBH was estimated to 2.5 cm diameter classes. Tree seedlings (trees less than 1.37 m in height) were counted by 0.3 m height classes on a 125 m^2 circular plot nested within the 0.04 ha plot. Surface fuels were measured using Lutes and other (2006) techniques on two 15.2 m transects that originated at plot center and extended in opposite directions (figure 3). Vertically projected foliar cover and heights of each vascular plant species was visually estimated within each of four, 1 m^2 microplots at each plot (figure 3) using the Lutes and others (2006) cover classes. Ground covers for rock, bare soil, wood, duff/litter, and moss were also estimated in each microplot using the same cover class categories.

Tree, fuel, and undergrowth plant species measurements were taken prior to the treatment, one year after each treatment, and five years after each treatment. Some units received two or more treatments (table 2) and we measured after each treatment type, but this report only summarizes the measurements after the last treatment was implemented. Photographs of each plot were taken in two directions at each of the measurement times.

Analysis Methods

Tree mortality was computed as percent of trees killed by species for three size classes: seedlings, saplings, and overstory trees. All ten plots within each treatment unit were used in the tree mortality calculations. We also included an assessment of snags (dead trees above 11 cm DBH) by comparing pre- and post-disturbance densities. Downed woody fuel loadings were computed from planar intercept counts using the protocols in FIREMON (Lutes and others 2006). Fuel consumption was computed as the difference in loading from pre-treatment and post-treatment measurements calculated as an average across all 20 transects in the treatment unit. We used the 60 observations of duff plus litter depth (three measurements on each of two transects for 10 plots) to

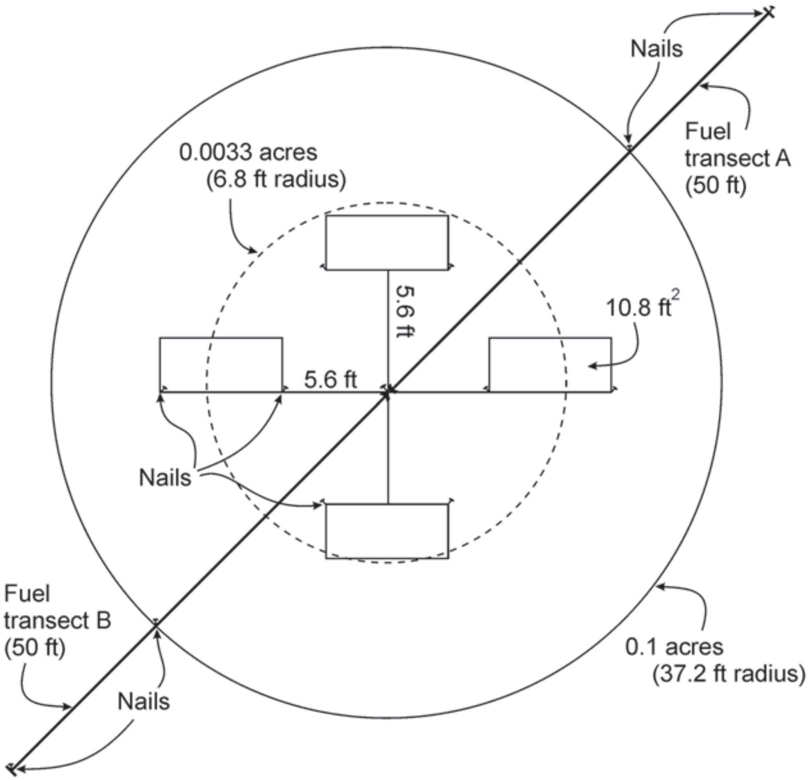

Figure 3. Diagram of the sample plot design used in the study.

calculate duff and litter consumption. Duff and litter depth was converted to loading using a bulk density of 31 kg m^{-3} (Brown 1981). We used all 40 microplots (four at each of ten plots) within each treatment unit as observations in the calculation of plant species cover response and ground cover changes (wood, rock, bare soil, duff/litter). For brevity and simplicity, seven major treatment combinations are used to present results of this restoration study. Combinations were developed by combining treatment units into similar groups across sites based on the prescribed burn intensity and the secondary cutting treatment (table 2).

Results

Summarized study results for the seven treatment type combinations across all sites are presented in table 3. Tree mortality was highest (55 to 88 percent) in treatment units with moderate to high intensity prescribed burns (HO, HF in table 3), and on any treatment with a fuel enhancement cutting (LF, MF, HF). Mortality for whitebark pine was comparable to that for subalpine fir for nearly all treatment combinations. Fire-caused mortality was highest for mature trees of both species on sites with high burn coverage (>60 percent of area burned). Moderate intensity prescribed fire (MO, MN, MF) had the greatest range of mortality across all species and size classes (19 to 88 percent) because of the patchy nature of the fires and the great diversity of site conditions across the five sites (Keane and Parsons 2010a). Most importantly, there were no detectable increases in seedling whitebark pine or subalpine fir after five years (except for the LO treatment; table 3). Whitebark pine snag densities did not change significantly after five years (except for 78 percent reduction in MF treatment) because fallen snags were replaced by fire-killed trees, but the overall trend was a 10 to 40 percent decrease in number of snags. In contrast, subalpine fir snags increased significantly for most treatments mainly because there were few fir snags prior to treatment.

New whitebark pine regeneration was rarely detected on any of the treatment units and only one site (Blackbird Mountain) had significant whitebark seedlings, probably because this site was in an area of few blister rust infections (Keane and Parsons 2010a). Some whitebark pine seedlings were survivors of the cutting and burning treatments and had marginal vigor. It is unknown whether the residual regeneration will have the capacity to release and grow into mature trees (Keane and others 2007). Subalpine fir trees were twice as plentiful as whitebark pine trees before and after all treatments for both trees and seedlings. Post-treatment fir densities are highest on sites that were burned without fuel enhancement and they tended to decrease over the five years.

Major changes in fuel loadings were detected in nearly all treatments but the direction of this change differed by woody size class (table 3, 4). Fine woody fuels (1, 10, 100 hr) marginally decreased in all treatment combinations except for LO because of extensive fuel consumption by the prescribed fires. Fine fuels were mostly unconsumed in the LO treatment because of the low coverage of the prescribed burn (<31 percent of area burned). However, logs increased significantly in all seven treatment combinations and, in some cases, this increase was striking (two to eight times greater) (tables 5, 6). Even though there was significant log consumption (10 to 50 percent) for most fires, especially in rotten logs, the

Table 3. Treatment effects for tree, fuel, and ground cover measurements averaged across all units within each of the seven treatment types (see table 2) expressed as percent change after five years from pre-treatment condition. Numbers in bold indicate statistically significant difference (p<0.05) between pre- and five year post-treatment measurements.

	Low Rx Fire		Moderate Rx Fire			High Rx Fire	
Category[a]	No cutting (LO)	Fuel enhance (LF)	No cutting (MO)	Nut-cracker Opening (MN)	Fuel enhance (MF)	No cut (HO)	Fuel enhance (HF)
			Whitebark pine (Pinus albicaulis) tree density percent change				
Seedling	-41.21	-54.35	**-82.87**	**-79.00**	-70.34	29.17	-40.69
Sapling	-31.03	-29.26	-19.44	**-88.52**	-47.85	**-63.39**	**-61.13**
Trees	**-47.20**	-37.84	**-88.37**	**-68.00**	-56.00	**-80.00**	**-86.15**
Snags	16.28	-17.28	-36.00	-8.94	**-78.26**	-25.29	10.00
			Subalpine fir (Abies lasiocarpa) tree density percent change				
Seedling	10.98	16.15	-34.08	**-87.37**	-18.79	-46.55	**-84.31**
Sapling	-17.62	-40.71	-40.52	-43.57	**-84.70**	-32.30	**-69.92**
Tree	**-58.05**	**-47.06**	-40.83	-40.63	**-75.00**	**-84.85**	**-84.73**
Snags	**188.10**	-33.33	19.18	20.69	**126.32**	**276.92**	29.73
			Fuel loading percent change				
Duff+Litter	**868.97**	**241.29**	**119.44**	-27.13	**138.64**	-40.25	-23.81
1 hr	**102.92**	-12.94	49.79	**-65.13**	**218.44**	-50.40	-18.42
10 hr	-16.97	-36.74	-49.76	**-72.07**	42.06	-10.77	-36.83
100 hr	-39.43	-12.00	-39.79	**-68.30**	45.80	-27.55	**-49.63**
1000 hr snd	-17.02	-12.34	**62.30**	**-45.29**	**97.08**	11.12	-22.30
1000 hr rot	**173.82**	143.35	**414.27**	**-30.95**	**778.00**	**342.74**	**398.90**
			Ground cover percent change				
Wood	**5.70**	4.44	**13.73**	-1.81	**12.61**	-1.17	-1.09
Rock	2.64	0.84	3.25	2.00	2.78	**11.06**	**17.66**
Soil	**5.72**	**7.60**	**6.74**	**8.37**	**5.98**	**19.24**	**22.65**
Duff+Litter	**39.32**	**17.63**	**19.69**	-5.85	**16.93**	8.96	-3.96
			Burn cover (%)				
After burn	31	54	56	91	81	61	90

[a] Categories for trees are seedling (tree height < 1.37 m), sapling (DBH<11.5 cm), trees (DBH>11.6 cm), snags (dead trees DBH>11.6); for fuels are 1 hr (dia<0.5 cm), 10hr (dia<2.5cm), 100hr (dia<7.6 cm), 1000hr (dia>7.6 cm); duff+litter refers to both litter and duff layers.

extensive log load increases were a result of prescribed fires weakening the numerous standing dead whitebark pine snags causing them to fall (table 3). Nearly all fallen whitebark pine snags were trees that had been previously killed by mountain pine beetle or blister rust. Duff and litter increased after low intensity prescribed burns (241 to 868 percent) because of the contribution of scorched needles from standing trees. Prescribed fires tended to increase bare soil and rock cover because of the corresponding decrease in duff/litter and woody cover (table 4), but the magnitude and variability of these changes were entirely dictated by the intensity and coverage of the fire. Woody cover increased in some units because of the fallen snags, whereas duff+ litter cover increased because of fallen scorched foliage. Rock and soil cover, however, increased in nearly all treatment combinations with the most significant increases in fuel-enhanced units with high burn cover and intensity. We feel that an increase in rock and bare soil cover creates more fine scale pattern within the unit thereby improving nutcracker caching potential (McCaughey and Weaver 1990; Tomback and others 1993; Tomback 2005).

Most treatment units in this study had low vascular plant diversity with microplots averaging only five species and the sites having only 20 to 25 species (Keane and Parsons 2010b). We selected four common undergrowth plant species that were dominant across all sites and treatment unit combinations, and found that these species declined in cover after treatment (20 to 100 percent) (figure 4). Elk sedge (*Carex geyeri,* CAGE) increased in cover after five years for all but the most severe burn treatments. Grouse whortleberry (*Vaccinum scoparium,* VASC) cover declined the most after nearly all treatments, but most sites recovered at least half pre-burn cover by the fifth year.

Discussion

All high and moderate intensity prescribed fire-cutting treatment combinations were effective at creating desirable nutcracker caching habitat as evidenced by the abundant nutcracker caching observed on nearly all sites (Keane and Parsons 2010a). These treatments were also successful at removing subalpine fir competition thereby creating desirable growing conditions for surviving and newly regenerating whitebark pine. However, the expected whitebark pine regeneration from the observed caching has not yet materialized with nearly all sites having few or no new whitebark pine seedlings (table 3). This is probably a result of several factors:

Table 4. Fuelbed characteristics at pre-treatment, 1 year after treatment, and 5 years after treatment. Rx stands for prescribed fire, and bold numbers indicate statistical significance (p<0.05) from pre-treatment condition

	Low Rx Fire		Moderate Rx Fire			High Rx Fire	
Sample Time	No cutting (LO)	Fuel enhance (LF)	No cutting (MO)	Nut-cracker Opening (MN)	Fuel enhance (MF)	No Cut (HO)	Fuel enhance (HF)
				Fine fuel loadings (kg m^{-2})			
Pre	0.65	0.76	1.05	0.97	0.37	0.71	0.94
1 year	0.39	0.76	0.70	**0.37**	0.47	0.52	0.73
5 year	0.46	0.63	0.64	**0.30**	0.57	0.53	0.50
				Sound log loading (kg m^{-2})			
Pre	2.64	3.94	3.75	11.71	1.72	4.35	4.64
1 year	**7.34**	**8.81**	**21.80**	7.37	**16.77**	**13.40**	**19.65**
5 year	**7.22**	**9.58**	**19.30**	8.09	**15.08**	**19.24**	**23.14**
				Duff and litter loading (kg m^{-2})			
Pre	0.12	0.34	0.55	0.61	0.31	1.04	1.07
1 year	0.37	0.68	0.33	**0.07**	0.35	0.75	**0.68**
5 year	**1.13**	**1.15**	**1.21**	0.45	**0.74**	**0.62**	0.82
				Bare soil cover (%)			
Pre	2.38	4.98	1.68	5.01	6.03	4.50	3.19
1 year	**14.40**	**16.08**	**19.62**	**38.51**	**17.69**	**29.59**	**36.05**
5 year	**8.09**	**12.58**	**8.41**	**13.38**	**12.00**	**23.74**	**25.84**

1. Many of the cached seeds were probably reclaimed by the nutcrackers during the years following caching. The populations of cone-producing whitebark pine at or near our study areas were so low that the nutcrackers are consuming many seeds during caching and reclaiming many cached seeds so it is doubtful that the bird left sufficient seed in the ground to provide for adequate regeneration (McKinney and Tomback 2007).
2. Severe environmental conditions could have killed many emerging seedlings. These steep, high mountain sites experience deep snowpack, especially the Beaver Ridge site, which had over 50 feet in 1997, and the heavy snow tended to creep down slope and pull young seedlings out of the ground.
3. Soils were highly erosive. Spring snowmelts generate abundant water that usually scours the topsoil away from those seedlings that are rooted in it, especially in recently burned sites.
4. The five-year evaluation period was too short for effectively evaluating regeneration dynamics. In these severe sites, a 10 or 20-year measurement might more accurately describe the success of our treatments. Some have identified a lag period of up to 40 years for whitebark pine to become established in upper subalpine zones due to severity of the disturbance and the site (Agee and Smith 1984; Arno and Hoff 1990).

We found that it was difficult to implement prescribed fires to mimic non-lethal surface and mixed severity fires for a number of reasons. First, the shrub and herbaceous fuels on most sites were rarely dry enough to sufficiently carry a fire under our prescriptions (desired conditions of burning) resulting in a light fire with low tree mortality and low burn coverage. In contrast, fire intensities on fuel enhanced sites were sometimes too high resulting in unwanted high whitebark pine mortality and extensive reductions in the stabilizing undergrowth plant community (table 4; figure 4). It takes a delicate balance of sufficient fuels and dry fuel moistures to implement an effective prescribed burn that reduces subalpine fir overstory and understory while allowing survival of mature whitebark pine trees. The lack of experience in burning high elevation ecosystems may have influenced fire crews to implement prescribed burns under wetter than desired moisture conditions thereby achieving lower than desired fire intensity and lower burn coverage across the stand (table 4).

Contrary to the restoration goals, the level of subalpine fir mortality was nearly the same as whitebark pine mortality and many fir trees remained after treatment (table 3). Our objective was to kill the majority of subalpine fir (>80 percent) and leave whitebark pine (>80 percent), yet we seemed to kill both tree species at the same rate regardless of diameter. This could be due to the mentioned inexperienced burn crews, but it is more likely that whitebark pine is not as fire tolerant as the literature would suggest (Ryan and Reinhardt 1988). We also found that many whitebark pine trees were killed by *Ips* spp. (originating from populations in unburned slash) and mountain pine beetle after burning (Baker and Six 2001). Because of this, it may be difficult to keep whitebark pines alive in units treated with prescribed burns so alternative non-burn treatments may be warranted, especially in areas with high beetle populations.

Management Implications

Based on the findings of this study, we recommend the following in designing and implementing whitebark pine restoration activities:

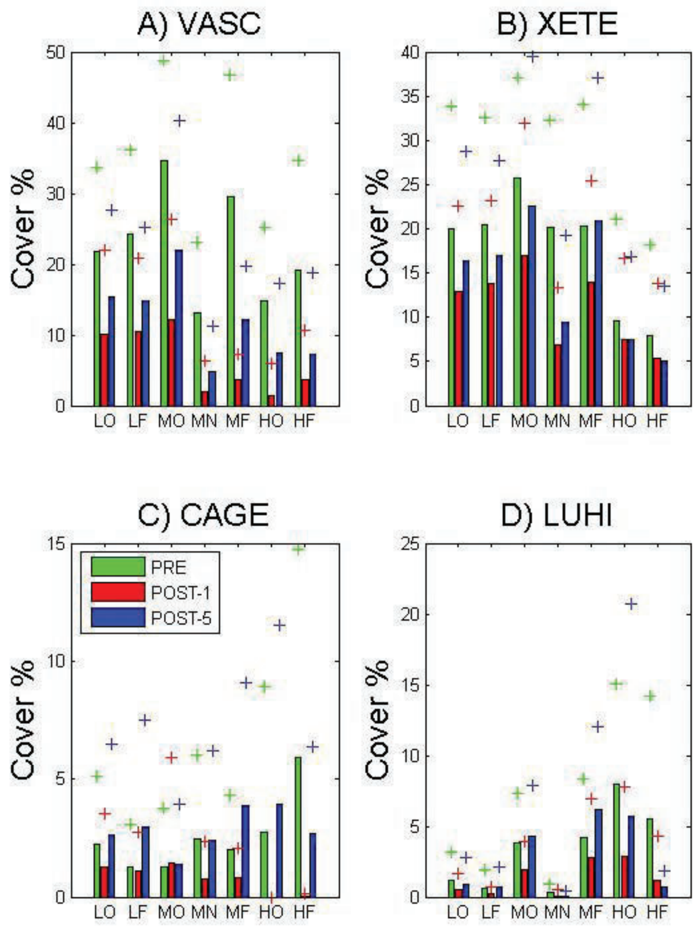

Figure 4. Changes canopy cover of the four dominant undergrowth plant species across each of the treatment combinations – a) *Vaccinium scoparium* (VASC), b) *Xerophyllum tenax* (XETE), c) *Carex geyeri* (CAGE), and d) *Luzula hitchcockii* (LUHI). Treatment combination codes are described in table 2. The symbol + represent standard error of the data.

- **Emulate historical fire regime**. Use the observed fire regime for a potential treatment site to guide design of the whitebark pine restoration treatment. Craft treatment specifics around the native fire regime effects.
- **Use prescribed burning**. Try to use prescribed burning as one of the restoration tools if economically possible. Prescribed burning can be enhanced by the following.
  - *Augmenting fuelbeds*. Fuel enhancement cuttings should be implemented one year prior to a prescribed burn to ensure burn objectives are fully realized. The addition of cured slash to discontinuous fuelbeds facilitates burn effectivness by providing additional fine fuel to 1) aid fire spread into all areas of the stand and 2) augment quickly drying fine fuel levels so the burn can be implemented in moister conditions.
  - *Burning under appropriate conditions*. Wait until the first hard frost in late summer or early fall before implementing a prescribed burn because we found shrub and herbaceous fuels were much drier after the first hard frost.
- **Use wildland fire use**. Pro-active, controlled management-ignited prescribed burns, such as those used in this study, many not always be possible due to access, cost, and risk considerations. Wildland fire use (letting lightning fires burn under acceptable conditions) may have a wider use in land management.
- **Plant, plant, plant**. Sites experiencing high whitebark pine blister rust-caused mortality (above 20 percent) and high rust infection (above 50 percent) or sites experiencing high beetle mortality should be planted with potentially rust-resistant seedlings after treatment, including wildland fire use. Potentially rust resistant seeds can be collected from surviving whitebark pine trees (Hoff and others 2001).
- **Monitor results**. There is a lack of comprehensive studies investigating effects of restoration treatment in whitebark pine. It is critical to monitor treatment effects to ensure future restoration success for others.

Acknowledgements

We thank the large number of skilled ecological technicians that participated in this project since 1993: Todd Carlson, Courtney Couch, Daniel Covington, Laura Dickinson, Janice Garner, Myron Holland, Violet Holley, Curtis Johnson, Cat Maxwell, Ben McShan, Jim Menakis, Scott Mincemoyer, Kirsten Schmidt, Virginia Arensberg, Dennis LeMond, Nadev Kaufman, Cassandra Koerner, and Wayne Lyngholm of the USDA Forest Service Rocky Mountain Research Station Missoula Fire Sciences Laboratory. We also thank the people who participated in the study: Joe Scott, Eva Karau, Alisa Keyser, Mick Harrington, Lisa Holsinger, Helen Smith of the Rocky Mountain Research Station Missoula Fire Sciences Laboratory; and last we would like to thank the people from the National Forests that made the study possible: Karen Harvey, Steve Munson, Bob Lippincott, Jon Weston, Chris Ourada, Vicki Edwards of the Clearwater National Forest; Barbara Levesque, Breck Hudson, Diana Schuldt, Terry Black of the Salmon-Challis National Forest, Leslie Anderson, Cathy Stewart, Bruce "Buster" Windhorst, of the Bitterroot National Forest. We also thank Cyndi Smith, Parks Canada, Waterton Lakes National Park, Waterton Park for an excellent editorial review.

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