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Restoration of Northern Rocky Mountain Moist Forests: Integrating Fuel Treatments From the Site to the Landscape

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ABSTRACT

Restoration and fuel treatments in the moist forests of the northern Rocky Mountains are complex and far different from those applicable to the dry ponderosa pine forests. In the moist forests, clearcuts are the favored method to use for growing early-seral western white pine and western larch. Nevertheless, clearcuts and their associated roads often affect wildlife habitat, water and soil resources, and scenic values. To address this issue, we are applying and quantifying integrative silvicultural methods and systems that are applicable for regenerating and growing these, and other early seral species, while maintaining forest characteristics that are relevant to many contemporary forest management objectives. The silvicultural options we developed maintain multiple tree densities, a variety of canopy cover, and enhance old-forest attributes and most importantly, the harvesting, mastication, grapple piling, and prescribed fire treatments we applied will modify both wildfire intensity and burn severity. We found that the heterogeneous forest structures we created, even with small openings (average size 2.6 ha) and the minor proportion of the landscape (3 percent) treated, would alter a wildfire's progression, flame length, and fire type, according to FlamMap and FARSITE wildfire simulations. This analysis showed the placement, juxtaposition, and location of treatments within the landscape would disrupt a hypothetical wildfire's progression under weather conditions that occurred during one of the worst fire seasons (1967) in the northern Rocky Mountains. We found that masticating fuels after harvest in these multi-species and highly variable forest conditions was as cost effective as grapple piling the fuels and offered additional benefits.

Keywords: silviculture, uneven-aged management, site preparation, wildfire simulation

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INTRODUCTION

The forests of the Inland West have changed significantly in the last 100 years. Fire exclusion, timber harvest, and the introduction of white pine blister rust (***Cronartium ribicola*** Frisch.) have altered forest composition and structure from conditions that occurred historically (pre 1900) (Covington et al. 1994, Jain and Graham 2005, Neuenschwander et al. 1999, Steele et al. 1986). Forests once dominated by shade-intolerant and fire-tolerant species such as western white pine (***Pinus monticola*** (Dougl. *ex* D. Don), western larch (***Larix occidentalis*** Nutt.), and ponderosa pine (***Pinus ponderosa*** P. & C. Lawson) have been replaced by shade-tolerant and fire-intolerant species such as grand fir (***Abies grandis*** (Dougl. *ex* D. Don) Lindl.), western hemlock (***Tsuga heterophylla*** (Raf.) Sarg.), and western redcedar (***Thuja plicata*** Donn *ex* D. Don) (Jain and Graham 2005, Neuenschwander et al. 1999). Likewise, in many areas once dominated by ponderosa pine, fire suppression and timber harvest have created dense multi-storied stands of Douglas-fir (***Pseudotsuga menziesii*** (Mirbel) Franco) and grand fir (Covington et al. 1994, Steele et al. 1986).

Historically in the moist forests, insects and diseases collectively with wind, ice, and snow interacted with fire to regenerate and regulate the development of these forests (Jain and Graham 2005). In concert, these disturbances and the resulting regeneration, development, and mortality created and maintained highly heterogeneous forests occurring at a variety of mosaics over time and space. As such, old-forests did not occur continuously across the landscape and a series of disturbances was required at the appropriate time and place for them to develop (Camp et al. 1997, Franklin et al. 2002). Nevertheless, before 1900 there were many expanses containing abundant and old western white pine, western larch, ponderosa pine, and Douglas-fir trees that fueled the timber based economies of the northern Rocky Mountains (Graham 1990, Hann et al. 1997, Jain and Graham 2005). These historic conditions create the desire of many to restore these forests to the grandeur they once had before the days of intensive timber management (Fins et al. 2001, Graham and Jain 2005, Neuenschwander et al. 1999).

In the Inland Northwest of the United States, clearcutting provided a way to remove the large amount of residual defective trees (e.g., grand fir, western hemlock) through burning and to eradicate Ribes (the alternate host of blister rust) (Davis and Moss 1940, Matthews and Hutchison 1948). This regeneration method used for the production of western white pine became the norm even after Ribes control ceased (Fins et al. 2001) and scientific evidence indicated that western white pine does not need full sunlight to regenerate and develop (Graham et al. 1983, Haig et al. 1941, Jain et al. 2004). Although economically sound, applying clearcut methods and other historical harvesting systems that require short skidding distances (e.g. Idaho Jammer) and high road densities can affect wildlife habitat, soil and water quality, and other characteristics that society values (Bliss 2000, Harris 1984). Given these circumstances, to restore these forests, we designed a selection system to manage western white pine and other early seral species. This system, which we call the free selection silvicultural system (Graham and Jain 2005, Graham et al. 2007), was designed to create environments similar to those created by fine-scale disturbances (e.g. insect, disease, weather, surface fires) that removed single to small patches of trees.

Site preparation and surface fuels reduction

The preparation of sites for seed germination, seedling establishment, or planting is fundamental to all silvicultural systems because it helps define future forest composition and subsequent development (Eramian and Neuenschwander 1989, Graham et al. 1989, Graham et al. 2005, Haig et al. 1941, Nyland 2002). The use of fire is becoming increasingly difficult to apply due to concerns over air quality from smoke, the risk of fire escape, and the increased presence of structures in the urban wildland interface (Berry and Hesseln 2004, Shindler and Reed 1996). Grapple machines are a common technique for piling debris, which offers more latitude for treating debris yet protects the soil resource. In addition, these machines are able to work in complex forest structures and on relatively steep slopes (≈ 40 to 50 percent) (Graham et al. 2005). A new immerging treatment for site preparation and treating harvest debris is machine mastication. These machines chunk, shred, grind, break, or in other ways reduce the size and character of standing and down material. As with grapple piling these machines can work in complex forest structures and on relatively steep slopes and leave a variety of forest floor conditions. There is a need to evaluate the economical and ecological effects of mechanical (grapple and mastication) and prescribed fire methods as to their efficacy in favoring heterogeneity in the future development of vegetation while decreasing fire hazard.

Because of the complex forest structures and forest floor conditions left after the above-mentioned silvicultural treatments, the traditional regular spacing of planted trees described in planting contracts may not be appropriate. Regular spacing of seedlings at 3 by 3 m or 4 by 4 m intervals is common for achieving timber management objectives and easily translated into contracts (Graham et al. 2005). However, naturally regenerated trees seldom occur with regular spacing and the historical fine-scale disturbances that regulated the structures and compositions of moist forests rarely maintained uniform forest conditions; rather, trees would grow in small groups with interlocking crowns and often with one or more species in a group. To foster the development of these heterogeneous forest structures and compositions, it is more appropriate to plant trees in groups and clumps of more than one species. Furthermore, if there is a wide variety of overstory densities and compositions combined with a mosaic of forest floor conditions, regularity in planting is impossible. Incorporating attributes such as variation in species and density based on forest floor and overstory conditions into language suitable for planting contracts requires innovative thinking to insure regeneration goals are accomplished.

Fire hazard and fuel treatments

Canopy bulk density, canopy base height, and amount and condition of surface and ladder fuels influence both fire intensity and burn severity (what remains after a fire). Their influence is important in all forests but appears to be most prominent or at least most recognized in the dry forests (Graham et al. 2004). In the moist forests, these metrics are also important but because the sites are productive, large amounts of surface, ladder, and crown fuels develop quickly after harvesting or other disturbances. Jain and Graham (2007) and Jain et al. (2006) recognized the potential for short longevity in fuel treatments in these forests and identified thresholds and estimates of uncertainty associated with forest characteristics such as forest developmental stage, canopy base height, and tree density and their influence on burn severity in moist forests after wildfires. Even though some of these forest characteristics have not been included when designing and implementing silvicultural systems and prescriptions, they are relevant for creating and maintaining forests resilient and resistant to wildfires and damaging burn severities.

Another component when managing forests for wildfire fuel is to disrupt or alter fire progression and provide or enhance suppression opportunities. Finney (2001) provides a conceptual way of placing fuel treatments within landscapes and shows the proportion of the landscape needing treatment to alter fire progression. Similar to the forest metrics that influence burn severity, the location and juxtaposition of fuel treatments can also be important for planning and executing silvicultural systems. FARSITE and FlamMap, two fire simulation tools, offer opportunities to evaluate the effectiveness of fuel treatments for disruption of a wildfire's progress within a landscape (Finney 1998, 2006).

The practice of silviculture, being an integrative discipline, is the proper construct to incorporate and evaluate objectives such as forest restoration and the creation and maintenance of old-forests, heterogeneous and complex forest structures and compositions, and fire resilient forests into an operational silvicultural system. These objectives are values important to many stakeholders. Integral to such an evaluation is disclosing the costs and logistics of implementing such a silvicultural system, which many would consider extremely complex and difficult to apply. Therefore, we designed this study to implement and evaluate silvicultural methods potentially valuable for restoring moist forests. The salient components of the study reflected in the previous discussion are to:

1) create forests with canopy openings that reflect fine-scale disturbances, but leave a high proportion of forest cover;
2) create forest conditions that would alter both fire intensity, spread, and burn severity if a wildfire were to occur;
3) evaluate different techniques applicable for treating slash and preparing planting and germination sites in highly complex and diverse forests; and
4) evaluate the logistics and costs of implementing such integrative and complex silvicultural systems using National Forest Systems procedures and contracts.

METHODS

Study area

The study is located on the Priest River Experimental Forest (PREF) on the west slope of the Selkirk Mountains in northern Idaho (fig. 1a). PREF (2573 ha) contains upland slope angles range from 20 to 60 percent and is dominated (two-thirds) by mixed conifer (e.g., western hemlock,

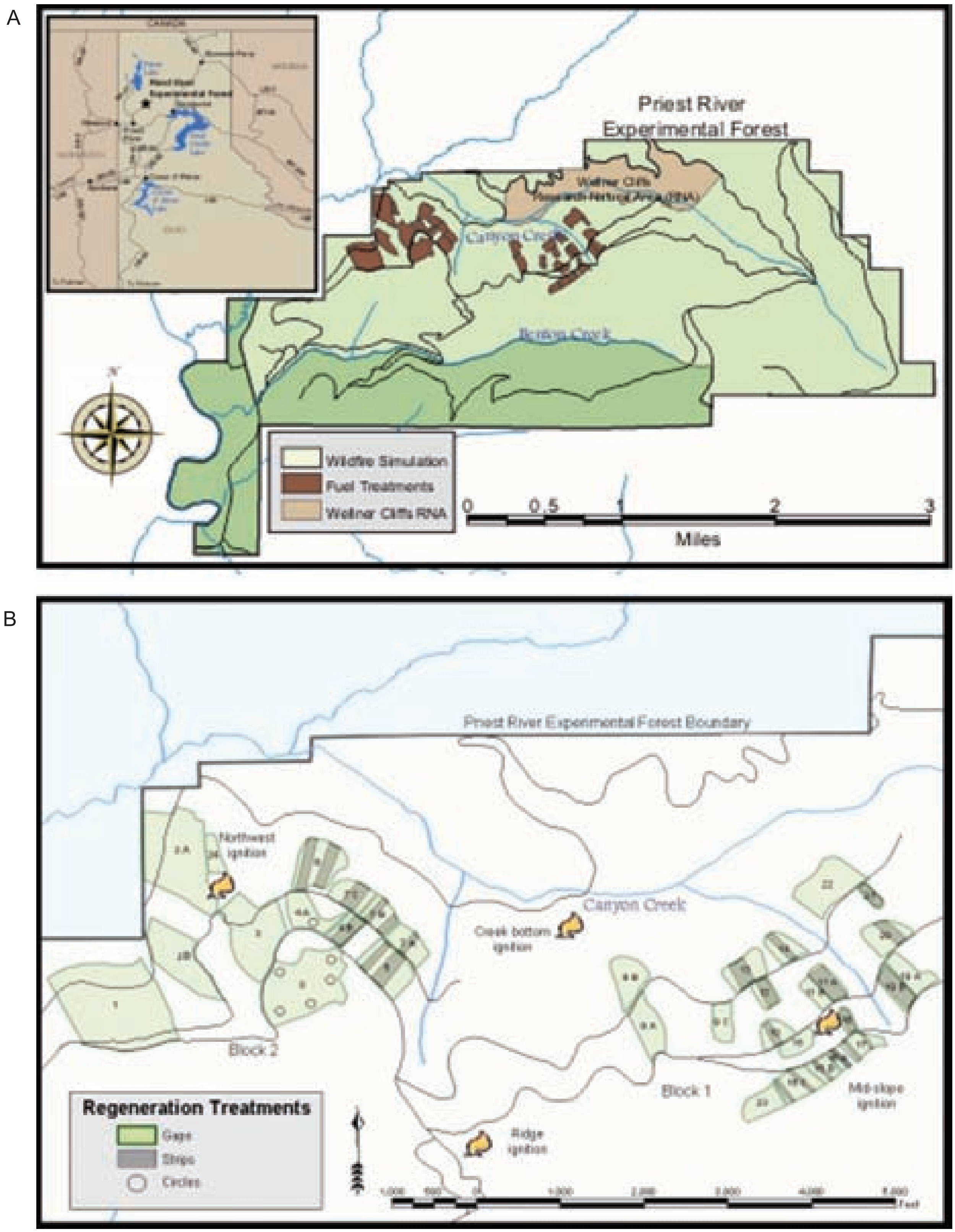


Figure 1— The study area is within the Canyon Creek drainage at Priest River Experimental Forest (a). We used a combination of different width strips and opening sizes to create diversity in forest structure within and among the harvested sites (b). To evaluate efficacy of treatment juxtapositions, we conducted a wildfire simulation using FARSITE and FlamMap within the area bordered by Benton Creek to the south and in the Canyon Creek drainage (light green area on 1a). Locations of orange flames indicate the four ignition points we used in the wildfire simulation: stream bottom, mid-slope, ridge, and northwest (b).

western redcedar, Douglas-fir, ponderosa pine, western white pine, grand fir) forest, ranging in age between 130 and 150-years old (resulting from a fire ca. 1860), with small portions having trees over 200 years old (Wellner 1976). Three primary drainages (Benton Creek, Canyon Creek, and Fox Creek) dissect PREF east to west, which drain into Priest River at 655 m in elevation (fig. 1a). As a result, primary topography faces north and south with small tributaries further dissecting slopes, creating a diversity of aspects with some areas facing east and west. The study area lies within the Canyon Creek drainage (fig. 1b).

The climate of PREF is transitional between the Pacific Coastal and Continental types. The Pacific climate favors moderate winter temperatures with January being the coldest (-4°C, 25°F), with the lowest temperature recorded since 1911 was -38° C (-36° F). Summers at PREF are sunny and dry with July being the warmest (18°C, 64°F) and the highest temperature ever recorded was 40° C (103° F) (Finklin 1983). Annual precipitation averages 817 mm with the majority (60 percent) in the form of snow in fall and winter, with accumulations in the valley bottoms averaging 49 cm. At high elevations (1455 m), precipitation averages 925 mm, with snowfall accounting for more than 50 percent of the total and snow accumulations averaging 132 cm. This snow pack can occasionally remain well into June.

SILVICULTURAL PRESCRIPTIONS

Management objectives and vision

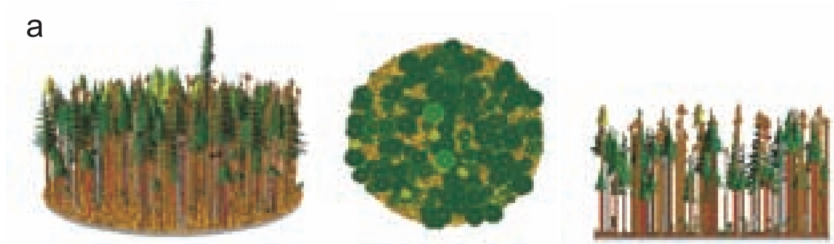
The objectives and vision of the treatments were to create or begin developing forest compositions and structures that would enhance current and future research opportunities at PREF utilizing a variety of silvicultural methods. In addition, we wanted to create forest conditions resilient to insect, disease, wildfire, and climate change. To increase resilience, we wanted high amounts of early- and mid-seral tree species (e.g. western white pine, western larch, ponderosa pine), while simultaneously reducing the current abundance of grand fir, western hemlock, and Douglas-fir, without clearcutting (Everett et al. 1994, Hann et al. 1997, Harvey et al. 1999, Jain and Graham 2005). Because there is always wildfire potential at PREF, we wanted to modify the fire behavior and burn severity if a wildfire were to burn through Canyon Creek. To alter the potential fire behavior and the burn severity a wildfire could cause, we wanted to introduce heterogeneity within the vegetation (e.g., vegetation composition and structure, surface and ground fuel composition, structure, and distribution). Before treatment, Canyon Creek had areas of vegetation uniformity, coupled with pockets of high amounts of tree disease, and lacked the plurality of early seral species.

Current condition

The east-west orientation of the Canyon Creek drainage allows north- and south-facing aspects to dominate the topography (fig. 1a). Western hemlock habitat types, consisting of dense and continuous tree canopies, prevail on the northerly aspects. The southerly aspects, where western redcedar and grand fir habitat types dominate, are drier and the tree canopy cover tends to be more discontinuous compared to cover on the northerly aspects, (Cooper et al. 1991). The forests in Canyon Creek originated from a major wildfire that occurred nearly 160 years ago and historically contained a diverse mixture of conifers, with an abundance of western white pine. However, during the last century white pine blister rust killed many white pines (fig. 2). Western larch, the other historically dominant species, is present throughout the drainage, yet tends to be small in diameter (< 50 cm) and nearly all larch crowns in the drainage are heavily infected with dwarf mistletoe (***Arceuthobium laricis*** Piper). Douglas-fir is also well represented in all canopy layers (fig. 2c), with the Douglas-fir beetle (***Dendroctonus pseudotsugae*** Hopkins) especially active on southerly aspects. Dominant and co-dominant western hemlock, grand fir, and western redcedar trees are intermingled through the stands (figs. 2a, b, and d), especially on the northerly aspects, with the mid and low canopy layers containing dense (1000's to 10's of thousands of trees/ha) assemblages of all three of these species, often occupying small canopy gaps. The root diseases ***Phellinus weirii*** and ***Armillaria spp.*** are very prevalent throughout the area and Indian paint fungus (***Echinodontium tinctorium***) is very common in the boles of western hemlock and grand fir. The moderate to high amount of insect and disease activity in Canyon Creek, along with isolated wind and ice damage has contributed to moderate (37-74 Mg/ha) amounts of coarse woody debris dispersed across the forest floor and canopy gaps that have been readily occupied by regeneration of late seral species.

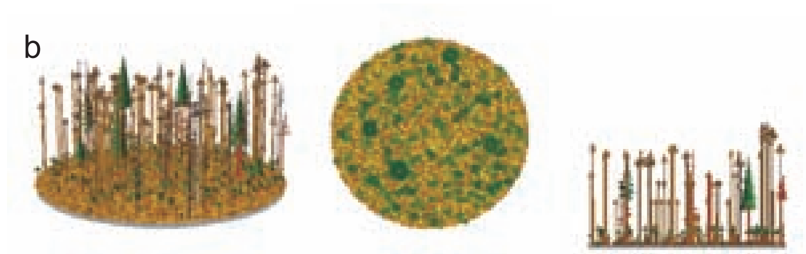
Desired future condition

The desired forest condition within Canyon Creek is to insure there is a representation of all the potential forest species and structures, with an emphasis on increasing western a



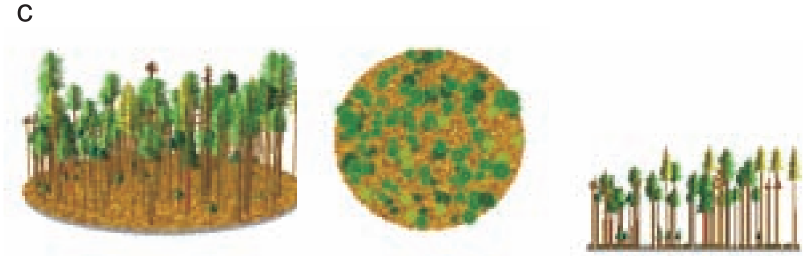
Trees per ha	Basal area m^2/ha (ft^2/ac)	Bulk density (kg/m^3)	Canopy cover (%)	25th percentile cbh (m)	Mean cbh (m)	Species
7188	43 (186)	0.07	77	1.4	4	50% WH, 48% WRC, 2% GF

b



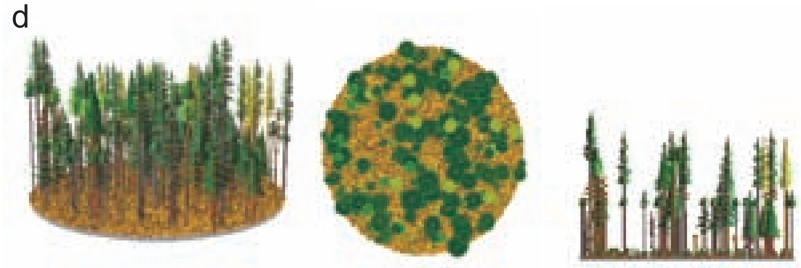
Trees per ha	Basal area m^2/ha (ft^2/ac)	Bulk density (kg/m^3)	Canopy cover (%)	25th percentile cbh (m)	Mean cbh (m)	Species
4552	5 (22)	0.02	28	2.0	4	44% WH, 26% WRC, 11% GF

c



Trees per ha	Basal area m^2/ha (ft^2/ac)	Bulk density (kg/m^3)	Canopy cover (%)	25th percentile cbh (m)	Mean cbh (m)	Species
2451	29 (124)	0.10	43	0.4	4	81% DF, 10% GF, 5% WRC, 4% PP

d



Trees per ha	Basal area m^2/ha (ft^2/ac)	Bulk density (kg/m^3)	Canopy cover (%)	25th percentile cbh (m)	Mean cbh (m)	Species
3269	28 (120)	0.05	53	0.4	3	42% WRC, 30% WH, 17% GF, 10% WP

Figure 2— Before treatment variation in forest structure and composition. Western hemlock (WH) and western redcedar (WRC) dominated north-facing aspects with small amounts of grand fir (GF) and western white pine (WP) (a, b, d). Douglas-fir, grand fir, and a few ponderosa pine dominated west-facing aspects (c). The table provides forest structure characteristics shown in figure. All sites contained a diversity of canopy cover (28 to 77%), basal area (5 to 43 m^2/ha), trees per ha (2400 to 7200), and canopy bulk densities (bulk density) (0.02 to 0.10 kg/m^3). Average canopy base height (cbh) was 4 m; however, at least 25 percent of the observations on some sites had a cbh equal to or less than 1 m.

white pine abundance so that it becomes the primary cover type (defined as sites that contain a plurality of white pine) (Eyre 1980). The desired multi-species compositions and complex forest structures will provide abundant research opportunities not found in other areas of PREF, created by traditional even-aged management. By decreasing the abundance of suppressed and diseased trees and featuring dominant western white pine, western larch, and ponderosa pine where they occur, the resilience and resistance of the vegetation on PREF to native and introduced disturbances will increase (Hoff et al. 1976, Jain and Graham 2005). Also desired is the presence of large and old trees on PREF in addition to old–forest characteristics, which includes large trees, snags, and down logs. In all structural and compositional conditions, it is our goal to have high heterogeneity at all scales, from 0.01-12 ha.

Experimental design

Canopy dynamics (e.g., opening and gap creation along with tree and canopy growth) and forest floor conditions determine how a forest regenerates and develops. For regeneration treatments, we used a randomized complete block design. The design contained two blocks and within each block, six regeneration treatments were replicated a minimum of 3 times (table 1, fig. 1b). We were unable to cross all regeneration methods and slash treatments, because the overstory composition prevented us from using prescribed fire for treating the slash in several treatment units. For example, in areas where our free selection system created small (< 0.2 ha) canopy gaps among western hemlock and western redcedar, a prescribed fire would likely kill these fire intolerant trees. On such sites, we either grapple piled, masticated, or in some isolated areas, jackpot burned the surface fuels (table 1). Therefore, for slash treatments we used a second independent randomized complete block design. The design contained two blocks and four slash treatments and an untreated control, which were independently placed within the regeneration methods and each slash treatment was replicated 2 to 14 times (table 1). We recognize the combination of size and slash treatment influences forest regeneration and development. However, this interaction occurs at a far smaller spatial extent than a large regeneration harvest (Jain et al., 2002). Therefore, testing the interaction between canopy opening and slash treatment will be micro-site specific, using fisheye photography to quantify canopy cover and forest floor characteristics. Because of the forest conditions present in Canyon Creek, we have only one site where we used free selection to enhance the old-forest characteristics of the site (site 22) (table 1 fig. 1b). We will evaluate this as a case study to determine if we create conditions that reflect old-forest structure.

Prescription implementation

Prior to implementing free selection in Canyon Creek, we conducted a thorough reconnaissance of the area to identify places containing high levels of disease, presence of western white pine, or containing or potentially containing old-forest structures. We identified operational constraints (access, slope angles), and limitations and preferences for different slash treatments. Using this information, we located 40 treatment units predicated by slope angles, current forest conditions, and access. Even though free selection and the vision guiding it framed the treatments we applied, we used strips of different widths (16-62 m) and circles (0.4 ha) to delineate areas (areas of disease, insect attack) where we ensured openings greater than a canopy gap were created (≥ 0.4 ha) (table 1) (Jain et al. 2004). As such, throughout the study area (271 ha) we created a wide variety of canopy openings and forest floor conditions (table 1).

Marking guide

In general western white pine, western larch, and ponderosa pine were the preferred species to favor in all settings and in particular near or within gaps and canopy openings (strips and circles) intended for regeneration (Jain et al. 2004). Heterogeneity, groups, and clumps of trees were preferred and tree marking was to have minimal impact on the inherent clumps of trees that often contained multiple species and even snags. Dominant or co-dominant trees ≥40 percent crown were favored; however, we also left western white pines with <40 percent crown, even those with dead tops. We removed intermediate and suppressed western white pines, depending on what the current condition presented, particularly if they had minimal seed potential. Large western larches (>46 cm) with full and mistletoe free crowns were preferred and larches ≥61 cm in diameter were often left, even with poor (<20 percent) crowns, for snag recruitment. Douglas-fir, grand fir, western redcedar, and western hemlock trees were frequently favored if their crowns were full (>40 percent), they were co-dominant or dominant trees, and when western white pine, ponderosa pine or western larch could not fulfill the desired conditions outlined in the objectives and vision for Canyon Creek. Trees of all species were eligible to become potential snags and subsequent large log recruitment, with western redcedar having the highest priority, followed by

Table 1. Regeneration and slash treatment summary. The experimental design included two blocks and within each block three replications of different width strips and circles. The objective, current condition, and the use of western white pine (WP) management thresholds determined opening size. Western white pine thresholds for regeneration establishment is between 25 and 54 percent canopy opening, competitive advantage (comp. adv.) begins at 55 percent, and free-to-grow begins at 92 percent. Favored species are western white pine (WP), western larch (WL), ponderosa pine (PP) and western redcedar (WRC). Slash treatments were replicated a minimum of five times across the entire study area and include grapple pile (grapple), prescribed fire (pres. fire), mastication (mast.), jackpot burn, and no treatment (NT).

Block	Unit no.	Regeneration treatment	Unit size (ha)	Strip or circle (ha)	Rep.	WP threshold (+ is above threshold)	Canopy opening (%)	Tree species planted	Slash treatment
1	17_1	16.0 m strip	1.0	0.10	1	Comp. adv.	55	WP, WL	Grapple
1	17_2	16.0 m strip	1.0	0.14	2	Comp. adv.	55	WP, WL	Grapple
1	16c1	16.0 m strip	1.1	0.15	3	Comp. adv.	55	WP, WL	Grapple
1	18	31.0 m strip	0.4	0.26	1	Comp. adv. +	70	WP, WL	Pres. fire
1	10	31.0 m strip	1.0	0.27	2	Comp. adv. +	70	WP, WL	Mast.
1	14	31.0 m strip	1.1	0.33	3	Comp. adv. +	70	WP, WL	Mast.
1	20	47.0 m strip	1.6	0.48	1	Comp. adv. +	85	WP, WL	Grapple
1	12	47.0 m strip	0.8	0.46	2	Comp. adv. +	85	WP, WL	Mast
1	21	47.0 m strip	0.4	0.34	3	Comp. adv. +	85	WP, WL	Grapple
1	19	62.0 m strip	1.2	0.94	1	Free-to-grow +	100	WP, WL	Pres. fire
1	11a	62 .0 m strip	1.1	0.83	2	Free-to-grow +	100	WP, WL	Pres. fire
1	13	62 .0 m strip	1.6	0.64	3	Free-to-grow +	100	WP, WL	Grapple
1	8_1	0.4 ha circle	6.6	0.40	1	Free-to-grow	92	WP, WL, PP	Mast.
1	8_2	0.4 ha circle	6.6	0.40	2	Free-to-grow	92	WP, WL, PP	Mast.
1	8_3	0.4 ha circle	6.6	0.40	3	Free-to-grow	92	WP, WL, PP	Mast.
1	23	<0.2 ha gap	1.3	<0.20	1	Establishment	25 - 40	WRC, WP	Mast.
1	15	<0.2 ha gap	0.9	<0.20	3	Establishment	25 - 40	WRC, WP	Mast.
1	9a	<0.2 ha gap	2.0	<0.20	4	Establishment	25 - 40	WRC, WP	Mast.
1	9b	<0.2 ha gap	1.8	<0.20	4	Establishment	25 - 40	WRC, WP	Jackpot
1	9c	<0.2 ha gap	1.1	<0.20	5	Establishment	25 - 40	WRC, WP	Mast.
1	22	<0.2 ha gap	3.3	<0.20	6	Old forest	20 - 30	WRC, WP	Grapple
2	16a	16.0 m strip	0.2	0.15	1	Comp. adv.	55	WP, WL	Mast.
2	16b	16.0 m strip	1.4	0.14	2	Comp. adv.	55	WP, WL	NT
2	16c2	16.0 m strip	1.1	0.21	3	Comp. adv.	55	WP, WL	Grapple
2	5_1	31.0 m strip	2.8	0.34	1	Comp. adv. +	70	WP, WL	Pres. fire
2	7a	31.0 m strip	1.4	0.21	2	Comp. adv. +	70	WP, WL	Mast.
2	7b1	31.0 m strip	1.3	0.28	3	Comp. adv. +	70	WP, WL	Mast.
2	7b2	47.0 m strip	1.3	0.24	1	Comp. adv. +	85	WP, WL	Grapple
2	6_1	47.0 m strip	2.8	0.70	2	Comp. adv. +	85	WP, WL, PP	Pres. fire
2	6_2	47.0 m strip	2.8	0.68	3	Comp. adv. +	85	WP, WL, PP	Pres. fire
2	5_2	62.0 m strip	2.8	0.74	1	Free-to-grow +	100	WP, WL	Mast.
2	4b	62.0 m strip	0.9	0.67	2	Free-to-grow +	100	WP, WL	Mast.
2	7c	62.0 m strip	1.4	0.58	3	Free-to-grow +	100	WP, WL	Pres. fire
2	4a	0.4 ha circle	1.7	0.40	1	Free-to-grow	92	WP, WL	Mast.
2	8_4	0.4 ha circle	6.6	0.40	2	Free-to-grow	92	WP, WL, PP	Mast.
2	8_5	0.4 ha circle	6.6	0.40	3	Free-to-grow	92	WP, WL, PP	Mast.
2	1	<0.2 ha gap	11.9	<0.20	1	Establishment	25 - 40	WRC, WP	Grapple
2	2a	<0.2 ha gap	7.7	<0.20	2	Establishment	25 - 40	WP, PP	NT
2	2b	<0.2 ha gap	3.9	<0.20	3	Establishment	25 - 40	WP, PP	NT
2	3	<0.2 ha gap	5.1	<0.20	4	Establishment	25 - 40	WRC, WP	Jackpot

western larch, ponderosa pine, western white pine, and western hemlock.

When we encountered favored species with short crowns or heavily infected with disease, openings most often were created within the range of competitive advantage (55 percent) and free-to-grow (92 percent) thresholds and, if available, dominant western white pine and disease and mistletoe-free western larch were featured (Jain et al. 2004). In some locales within Canyon Creek, because of slope steepness (>40 percent), we applied free selection in strips to accommodate skyline yarding systems. Nevertheless, these strips contained different canopy densities and had a variety of widths; while still addressing the canopy opening thresholds identified by Jain et al. (2004). However, strip placement had to fall within the context of the current forest conditions (areas where a strip could be located without removing favored species and composition) and within the context of fulfilling the short- and long-term conditions outlined in the vision. We ensured that near the strips, we increased tree density slowly (e.g., feathering of the edges) to minimize any artificial appearance of the forest (straight boundaries). Single species to multiple species groups and clumps (or both) of trees tend to occur naturally in the moist forests as do single trees. We maintained this character in the forest by avoiding the creation of geometrically uniform openings (e.g. squares or rectangles), even when canopy openings were of sufficient size for western white pine to grow freely (>0.4 ha).

Harvesting

We used both ground based and skyline yarding systems, depending on the slope angle and residual tree densities (figs. 3a and b). We used the skyline system on slopes exceeding 40 percent, and contrary to normal sets, where yarding follows the slope profile, we yarded diagonal to the slope. This yarding technique yields different forest and forest floor conditions than yarding following the slope profile. As such, the visual impacts were minimal. In addition, this corridor configuration readily created residual tree spacing and an appearance very compatible with our application and conditions we wanted to create using free selection. On slopes <40 percent we used both conventional rubber tired skidders and processors (cut-to-length) to do the harvesting. The operator made the choice of machines, with residual tree density influencing the decision.

Slash treatments

There were three slash treatments, grapple pile followed by pile burning, mastication, and prescribed fire. Prior to grapple piling the slash, hand crews cut undesirable standing trees and cut down long material in smaller pieces (slashing). Two mid-sized excavators equipped with hydraulic thumbs, at $82.50/hr, piled the material after slashing on 10 treatment units (table 1, fig. 3c). The piling occurred during July and crews burned the piles in fall of 2006. During the pile burning and especially in the area in which we used free selection to enhance old-forest character (site 22), we

Figure 3— Various equipment and yarding techniques used to harvest sites and conduct slash treatments. The topographic relief required two yarding techniques: (a) ground based equipment included skidders (pictured), processors, and forwarders; (b) we used a slack skyline to harvest the steeper (40%) slopes. We used (c) grapple and (d) mastication equipment for mechanical fuel treatments in addition to prescribed fire (broadcast and jackpot).

Table 2. Weather from August 26 through September 2, 1967. During the FARSITE and FlamMap simulations we used minimum and maximum temperature, and minimum and maximum relative humidity during the Sundance wildfire of 1967 from the Priest River weather station. Dead fuel conditioning period occurred from August 26 until September 1, prior to ignition, and the burn period was from 0400 on September 1 through 2300 on September 2.

Month	Day	Minimum temperature hour	Minimum temperature C⁰ (F⁰)	Minimum relative humidity (%)	Maximum temperature hour	Maximum temperature C⁰ (F⁰)	Maximum relative humidity (%)
				Conditioning period			
August	26	0500	0 (32)	16	1600	31 (87)	98
	27	0400	10 (50)	34	1600	23 (74)	94
	28	0500	3 (38)	23	1400	32 (89)	98
	29	0600	6 (42)	14	1400	34 (94)	99
	30	0400	7 (45)	16	1500	34 (94)	99
	31	0500	6 (41)	12	1600	37 (98)	99
				Burn period			
September	1	0500	6 (42)	13	1400	33 (92)	98
	2	2300	7 (44)	30	1400	26 (78)	97

allowed the fires to creep, creating a mosaic of soil burn severities. To treat the slash through mastication, we used a large (≈ 36 364 kg) excavator with a rotary mastication head, that cost $300/hr. Hand slashing was not necessary because the machine treated both standing and down material (18 units) (table 1, fig. 3d). Even though the machine was large it had the capacity to operate on steep (45 percent) slopes and its ground pressure was light (4 g/cm^2). There was minimal soil displacement and compaction as it only traversed a 21 m wide strip once while masticating. With this machine we tried to create a variety of piece sizes with the smallest being the size of a basketball or football so as to maintain the wood integrity (outer bark, inner bark, cambium, sapwood, and heartwood) in contact with the forest floor enhancing the decomposition of these materials (Graham and Jain 2007).

After hand slashing the unwanted standing material, District crews conducted spring prescribed fires in seven of the treatment units starting in 2007. These fires tended to be very low intensity with short (<1.0 m) flame lengths and were conducted when the lower duff moisture contents exceeded 100 percent. At these moisture contents, forest floor organic material consumption is minimal, preserving the microbial and nutrients intrinsic to them, yet providing a burned over surface ideal for conifer seed germination (Graham et al. 2005, Haig et al. 1941). In addition to the spring prescribed fires, jackpot burns will remove concentrations of slash in the fall (2007) after wetting rains in two units. These units are inaccessible for machine piling and grapple piling and inappropriate for using prescribed fire because western redcedar and western hemlock dominate the residual trees (figs. 2a, b, and d). In the units where Douglas-fir, western larch, or ponderosa pine are dominant, we used prescribed fire (fig 2c).

Wildfire simulation

To determine effects of created stand structures and our increase in fuel heterogeneity, we simulated several wildfires using FARSITE and FLAMMAP (Finney 1995, 1998, 2006, Stratton 2004). FARSITE models fire progression and rate of spread while FlamMap predicts whether a particular site will favor a particular fire behavior such as

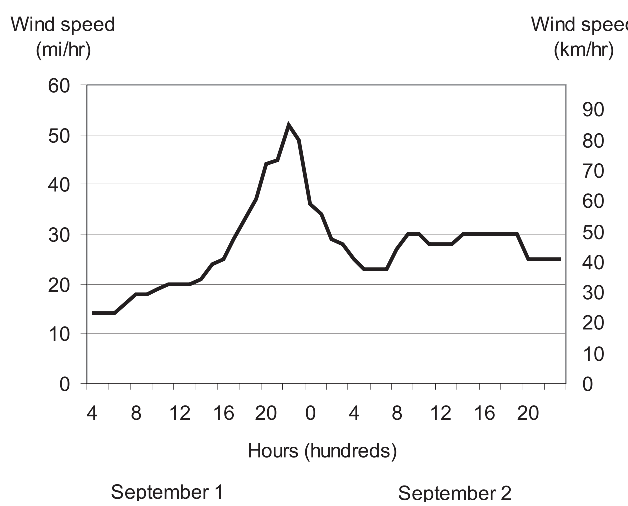


Figure 4— Wind speeds used during the FARSITE simulation. We used wind speeds from September 1 and 2, 1967, which was the same period when the Sundance wildfire had the fastest rate of spread. In the FlamMap simulation, we used a wind speed of 82 km/hour.

Table 3. FARSITE simulation parameters and fire behavior options used to test the effectiveness of treatments for altering fire behavior.

Model input/output parameter	Parameter selected	Fire behavior options	Option selected
Time step (min)	30	Enable crown fire (Finney method)	Yes
Visible step (hrs)	4	Embers from torching trees	Yes
Perimeter resolution (m)	30	Enable spot fire growth	No
Distance resolution (m)	15	Ignition frequency	1.00
Units	metric	Ignition delay	0

a surface, passive crown, or active crown fire. The wildfires we simulated burned a large portion of PREF including the southern aspects in Benton Creek and the entire Canyon Creek drainage (fig. 1a). To populate this landscape with the appropriate data, we used a combination of LiDAR (light detection and ranging), stand exams, and research plot data. These data included canopy cover (percent), tree height, canopy base height, canopy bulk density, elevation, aspect, slope, and fuel model. The research staff familiar with PREF assigned the appropriate fuel model to each stand using descriptions from Anderson (1982) and Scott and Burgan (2005). LIDAR, remotely sensed data, was adjusted using plot data in regressions; thus the LIDAR data ultimately populated the area (each stand) with the appropriate information needed to conduct the FARSITE and FlamMap analysis.

Using long-term weather records from PREF (since 1911), we identified an extreme weather event out of several years (1919, 1926, 1939, 1967, 1991, and 2003) to use in the FARSITE and FlamMap simulations (table 2). We selected August 26 through September 2, 1967 which was hot (23-36° C, 74-98° F) dry (relative humidity, 12-34 percent), and windy (6 m wind speeds were > 81 km/hr) and coincided with the period when the Sundance fire burned near PREF (Anderson 1968, Finklin 1983) (table 2, fig. 4). The fire burned over 22 662 ha and on September 1, 1967, moving sometimes at a speed 10 km/hr. Selecting the period of the Sundance fire gave us a realistic and extreme condition to evaluate our free selection system in influencing wildfire intensity and burn severity. In addition to the input data, we selected parameters and fire behavior options in FARSITE and FlamMap when running the simulations (table 3).

The distance between the forest surface and the canopy base height is a major forest characteristic manageable with fuel treatments. This characteristic also tends to be very sensitive for predicting crown fire potential. In addition, this attribute is highly variable and is typically calibrated using expert knowledge when using FARSITE. For example, when simulating wildfires using FARSITE and the results do not reflect a probable outcome (crown fire), canopy base height is often "tweaked" to produce expected results. To avoid this subjective modification of canopy base heights, we used four different canopy base heights (CBH) in our FARSITE simulations. Rather than using, one CBH value in our simulations we arrayed the data and used the 1st and 3rd quartiles values along with the median CBH obtained from the FFE-FVS tree list (Dixon 2002). We also used a CBH calculated with FFE -FVS where the program defines CBH as the height where canopy bulk density exceeds 0.011 kg/m^3 (Reinhardt and Crookston 2003). Because there are so many trees < 0.3 m in Canyon Creek, we used this value rather than the default of 2 m for calculating CBH. These stand level measurements of CBH combined with the LIDAR data allowed us to estimate for the entire area these four CBH values.

To evaluate how the juxtaposition of fuel treatments may influence a fire's behavior and progression we used four different and realistic ignition points in our simulations and selected these points prior to locating them in relation to the treatments we applied in Canyon Creek (fig. 1b). We chose one ignition point near the bottom of Canyon Creek and one in the northwest corner of PREF. We chose a mid-slope ignition point near a well-traveled road, as well as a ridge ignition point. By establishing this range of ignition points, we ensured a variety of simulated fires (e.g., head, backing, or flanking) would encounter the treatments we established.

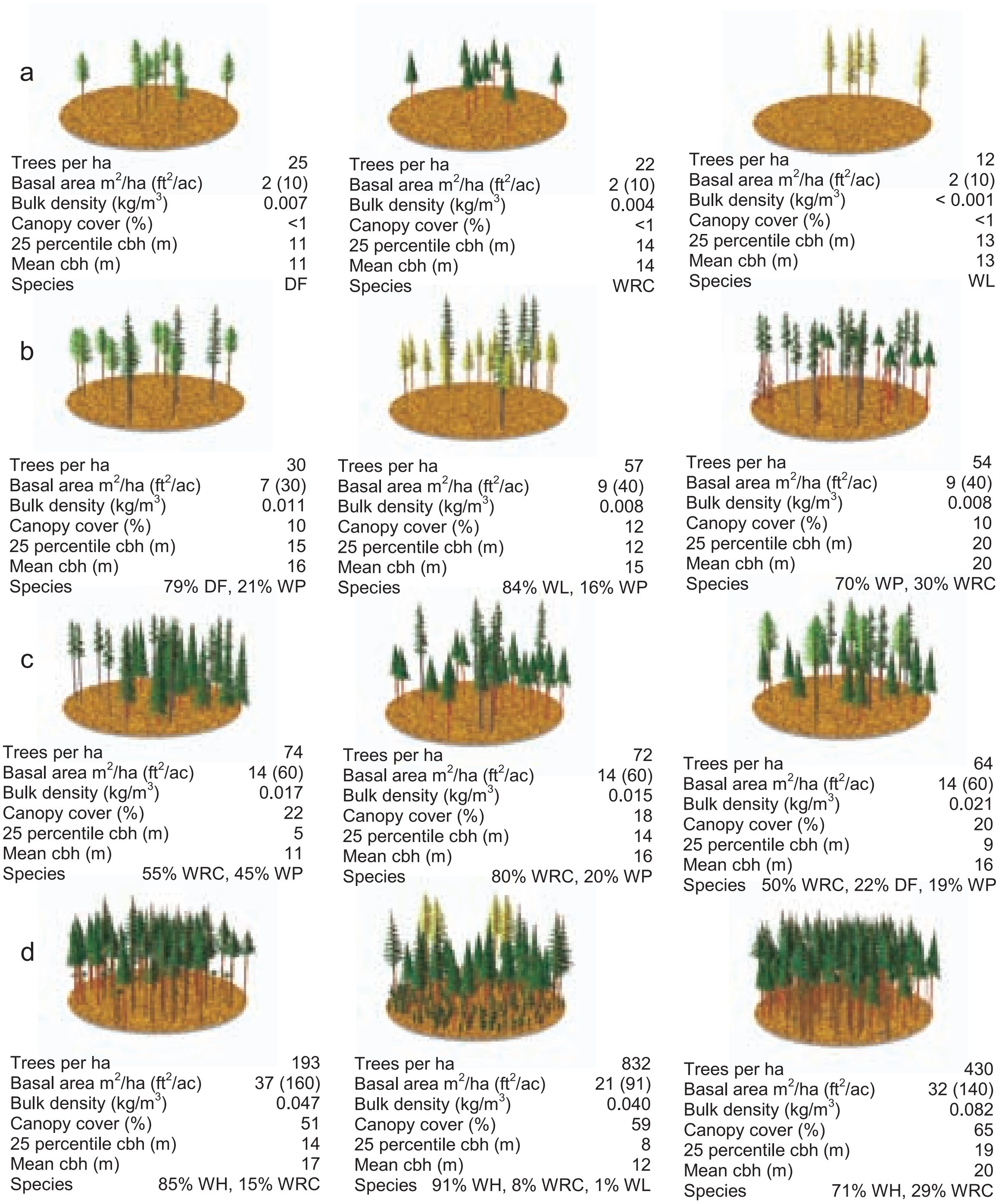


Figure 5— After treatment variation in forest structure and composition. Each series of examples reflect observations that occurred within the (a) 25th, (b) 50th, (c) 75th, and (d) 100th quartile in canopy cover. The treatments maintained considerable variation in canopy cover and species composition while favoring the abundance of western white pine (WP), western larch (WL), western redcedar (WRC), and Douglas-fir (DF) (a, b, and c). Only the sites that contained the highest densities favored western hemlock (WH) as the primary species (d). In all cases, we increased canopy base height to disfavor the potential for crown fire.

Table 4. Slash treatment costs for grapple piling. Approximately 17 ha were grapple piled on 9 units. Costs included actual work (hand slashing and grapple piling), administration (admin.) costs, and pile burning (not in table). Pile burning cost an average of $106.00/ha bringing total average cost to $1877/ha. Variation in cost and productivity (prod.) was due to number of trees needing slashing, steepness of slope, and avoiding residual trees.

			Debris distribution			Costs/ha (US dollars)				
Unit Number	Area treated (ha)	Slope (%)	Before (Mg/ha)	After (Mg/ha)	Change (%)	Hand slash	Grapple pile	Admin.	Total	Prod. (ha/hr)
7b1	1.3	32	137	63	-54	312	532	65	909	0.92
5_1	2.8	35	90	38	-57	517	696	53	1,267	0.70
20	1.6	31	72	54	-25	128	1,047	128	1,303	0.46
13	1.6	32	148	99	-33	495	805	70	1,370	0.60
1	6.1	55	N.d.[a]	N.d.	N.d.	786	694	104	1,583	0.70
22	0.8	26	117	109	-7	290	1,346	244	1,880	0.36
21	0.4	28	114	74	-35	732	1,088	133	1,953	0.44
16	1.1	41	80	94	18[b]	766	1,341	508	2,615	0.36
17	1.1	43	N.d.	N.d.	N.d.	3,377	1,073	459	4,909	0.46
Mean (ha)	1.8	36	108	76	-30	768	852	151	1771[c]	0.10[d]

[a] N.d. indicates no fuels information available for these units.
[b] Woody debris increased because of redistribution of large wood.
[c] Average per hectare costs = total of each (individual cost*unit hectares)/total hectares
[d] Average (hectare) production = total hectares/172 hours

RESULTS

Forest structures and species composition

Prior to treatment, the density of trees in Canyon Creek varied from several hundred to several thousand of trees per hectare (fig. 2). Western hemlock, western redcedar, Douglas-fir, and grand fir dominated the sites with a presence of western white pine, ponderosa pine, and western larch (fig. 2). Canopy cover ranged from 28 percent (fig. 2b), exemplified by small crowned western redcedar to large crowned (77 percent) western hemlock and western redcedar (figure 2a). Multiple canopy layers were the norm with the intermediate and suppressed crown classes dominated by western hemlock and western redcedar. However, small amounts (< 10 percent canopy cover) of western white pine (fig. 2d), ponderosa pine (fig. 2c), and western larch (not shown) were present in the dominant canopy class.

Our application of free selection created a variety of forest structures and compositions (fig. 5). The 1st quartile (the first 25 percent of the observations when ranked from low to high residual canopy cover) of the distribution of canopy cover occurred predominantly in areas where we removed numerous trees with thin crowns and abundance of disease (purposely located strips) (fig. 5a). These areas contained <1 percent canopy cover consisting of up to 12 through 25 trees/ha of western larch, or western redcedar, or Douglas-fir, or western white pine (not shown) with residual basal areas in the range of 2 m^2/ha. In the second quartile (26 through 50 percent) of observations, the canopy cover ranged from 10 through 12 percent and ranged from 30 through 57 trees/ha consisted of western larch and western white pine, creating a maximum basal area of 9 m^2/ha reminiscent of a shelterwood (Nyland 2002) (fig. 5b). The maximum canopy cover for the third quartile (51 through 75 percent) of observations was approximately 20 percent comprising 14 m^2/ha of western redcedar and western white pine and in some cases Douglas-fir (fig. 5c). Canopy cover in the fourth quartile (76 through 100 percent) of observations, tended to be >50 percent and basal area ranged from 21 through 37 m^2/ha of western hemlock and western redcedar (fig. 5d). Contrary to traditional seed-tree and shelterwood harvesting, regular spacing among trees was non-existent; rather, trees were grouped, clumped, and irregularly distributed across the sites (fig. 5). On all sites, average canopy base heights ranged from 11 through 20 m with the 25th quartile ranging from 5 through 19m.

Table 5. Slash treatment costs for mastication. Approximately 15 ha had activity fuels masticated. Costs are associated with administration (admin.), and actual work (masticate). Variation in cost was due to steepness of slope and leaving residual trees.

			Debris distribution							
	Area			After (% change)		Costs/ha (US dollars)				
Unit number	treated (ha)	Slope (%)	Before (Mg/ha)	>8cm	<8cm	Masticate	Admin.	Total	Residual trees/ha	Prod. (ha/hr)
8_4	1.6	7	76.7	-54	54	914	109	1,022	32	1.95
12b	0.4	7	83.2	-32	175	1,010	121	1,131	32	1.78
8_2	1.6	2	46.6	-32	124	1,030	123	1,153	32	1.73
14	0.6	2	105.8	-23	150	1,078	128	1,206	35	1.66
8_3	0.6	5	42.1	-64	27	1,097	131	1,228	32	1.63
12	0.7	10	87.7	-51	110	1,112	133	1,245	32	1.61
8_1	1.8	5	53.8	-41	92	1,112	133	1,245	32	1.61
10	0.9	5	78.2	-23	54	1,221	145	1,366	27	1.46
4b	0.7	12	61.9	-37	66	1,279	152	1,431	31	1.41
23b	0.5	49	114.1	-63	-4	1,363	162	1,525	24	1.31
9a	1.3	15	129.6	-65	90	1,426	169	1,595	45	1.26
23	0.7	10	114.1	-63	-4	1,474	176	1,651	30	1.21
7a	1.1	5	75.8	-32	224	1,479	176	1,656	35	1.21
4a	0.9	5	77.8	-53	-23	1,566	186	1,752	38	1.14
15	0.7	17	54.7	-54	99	1,571	186	1,757	25	1.14
9c	0.4	44	105.6	-47	136	1,619	193	1,813	45	1.11
14b	0.3	30	124.0	-54	24	1,634	196	1,830	40	1.09
7b1	0.2	10	96.6	-32	66	1,972	234	2,207	35	0.91
16a	0.1	49	84.1	-72	-14	3,374	401	3,775	50	0.52
Mean (ha)	**0.8**	**10**	**37.8**	**-47**	**99**	**1,297**	**156**	**1,453** [a]	**34**	**0.23** [b]

[a]Average per hectare costs = total of each (individual cost*unit hectares)/total hectares
[b]Average (ha) production = total hectares /65.34 hours

Slash treatments

One-hundred and eighty two hours were spent grapple piling 16.8 ha with an additional 520 hours spent hand slashing the material before it was piled (table 4, fig. 3c). The highest piling costs occurred in areas (unit 17) with abundant standing trees that required slashing. Often these costs were confounded with high administrative costs due to crew and machine operator supervision. When slope angles approached 45 percent, the machine operator needed more finesse, thus slowing the machine. In addition, with these steep slope angles, slashing crews tended to become more readily fatigued, slowing productivity and increasing costs. Nevertheless, the machines piled an average of 0.1 ha/hr with slashing, piling, and administrative costs together averaging $1771/ha (table 4). The following fall, crews spent 108 hours burning the piles, which cost an additional $106/ha, resulting in a total of $1877/ha for treating the slash by machine piling.

A little over 65 hours was spent masticating 15 ha (table 5, fig. 3d). By masticating, the objective was not to remove the material but to change its consistency, size, and distribution and bring the material in contact with the forest floor to favor its decomposition (Graham et al. 2005). Material ≥7.6 cm in diameter consisting of logs, limbs, and unwanted standing trees was converted to small chunks and wood pieces <7.6 cm. For example, mastication reduced total fuel loadings (tons/hectare) of wood ≥7.6 cm in diameter by an average of 47 percent; however, there was a two-fold increase in the abundance of small material (table 5). There were a few sites, particularly in unit 4a, where the small material was also reduced by 23 percent.

The mastication machine treated an average 0.23 ha/hr, with an average cost of $1453/ha including administrative costs (table 5). Masticating slash on steep slopes (>50 percent slope angle) required additional care by the operator to maintain machine stability, which slowed production and escalated costs (i.e. unit 16a at $3775/ha) (table 5). Even though the machine was capable of working in areas with abundant standing trees, these residual trees prevented the operator from freely swinging the boom and required operator diligence not to damage them, also decreasing productivity and increasing costs. In general, the machine operator, after instruction, made all decisions on what live trees to cut and how the fuels were to be treated but an on-site administrator observed and directed the mastication when necessary. As such, the mastication treatment created a wide variety of standing tree compositions and structures as well as a multitude of forest floor conditions.

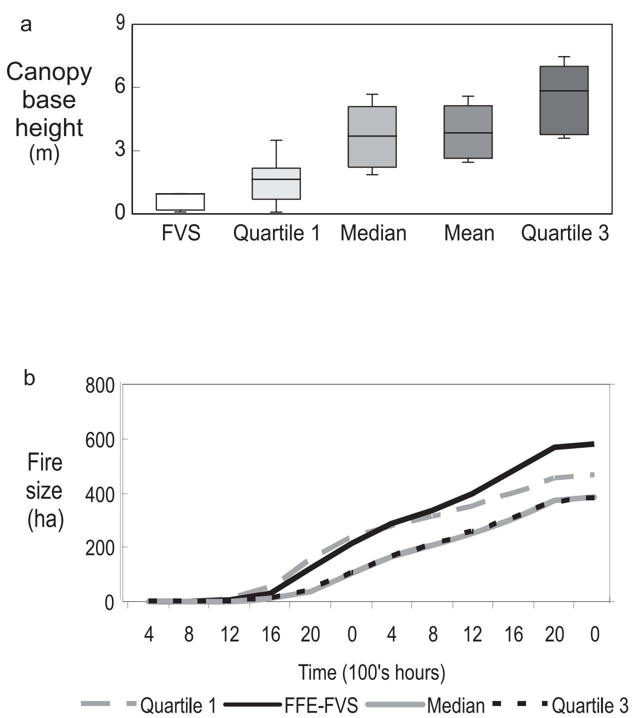


Figure 6— Influence of canopy base height (CBH) on fire size. We selected four canopy base height values from our observations to determine which canopy base height should be used in our model simulations. Fire and Fuels extension of the Forest Vegetation Simulator (FFE-FVS) value is the CBH when canopy bulk density exceeds 0.011 kg/m3 (Reinhardt and Crookston 2000) (a). We used a frequency distribution to identify the average, 25th, 50th, and 75th quartile. Average CBH and the 50th quartile had similar distributions; therefore, we used the 50th quartile in our evaluation. Although the 50th and 75th quartiles were different heights, fire size was similar for both values (b). The FVS calculated value burned the largest area followed by the CBH value reflected at the 25th quartile (b). For this analysis, we used the 25th quartile value to evaluate the efficacy of treatment juxtaposition in the FARSITE and FlamMap simulations because it appeared to reflect expected fire behavior.

In very similar physical and forest conditions, the masticator treated more area on the average in one hour (0.23 ha/hr) when compared to the grapple piling (0.10 ha/hr) (tables 4 and 5). Moreover, it was less expensive ($1453/ha) to masticate the slash than grapple pile it ($1877/ha), as the grapple piling required slashing, piling, and pile burning while mastication treated the slash in one step. However, mastication does not remove material but it instead changes its structure and distribution. Because mastication temporarily increased the amount of fine fuels, it also increased the fire hazard at least in the short-term (Graham and Jain 2007). However, the retention of woody material on sites will conserve nutrients and provide organic materials to the forest floor (Harvey et al. 1987). Slope steepness and abundance in the residual tree density tended to affect both mastication and machine piling equally, slowing productivity and increasing costs.

Wildfire Simulation

Influence of canopy base height

We used a mid-slope ignition point to evaluate four different CBHs; the FFE-FVS CBH calculation, the 1st quartile, median, and 3rd quartile CBHs (figs. 1b. and 6a). The FFE-FVS calculation produced the lowest canopy base heights, followed by the 1st quartile estimate of CBH, which was 2 m. Estimating CBH using the medians produced a CBH of approximately 4 m and the CBH for the 3rd quartile was estimated at 6 m. We used these different estimates of CBH to determine their influence on a wildfire's development, if it were to burn in Canyon Creek, without any of our treatments in place in the summer of 1967 (fig. 6b). Our simulations showed that if the median and 3rd quartile canopy base heights were used to estimate CBH, the overall size and rate of spread of a fire was less when compared to the rate of spread and size of a fire using the 1st quartile and FFE-FVS estimated CBHs. There was little or no difference in fire size and rate of spread between the median and 3rd quartile CBH. In contrast, there were some minor differences in fire size and rate of spread using CBHs estimated by FFE-FVS (more aggressive fire behavior) and with CBH estimated using the 1st quartile (fig. 6b). Based on these results, we selected the 1st quartile for the wildfire simulation.

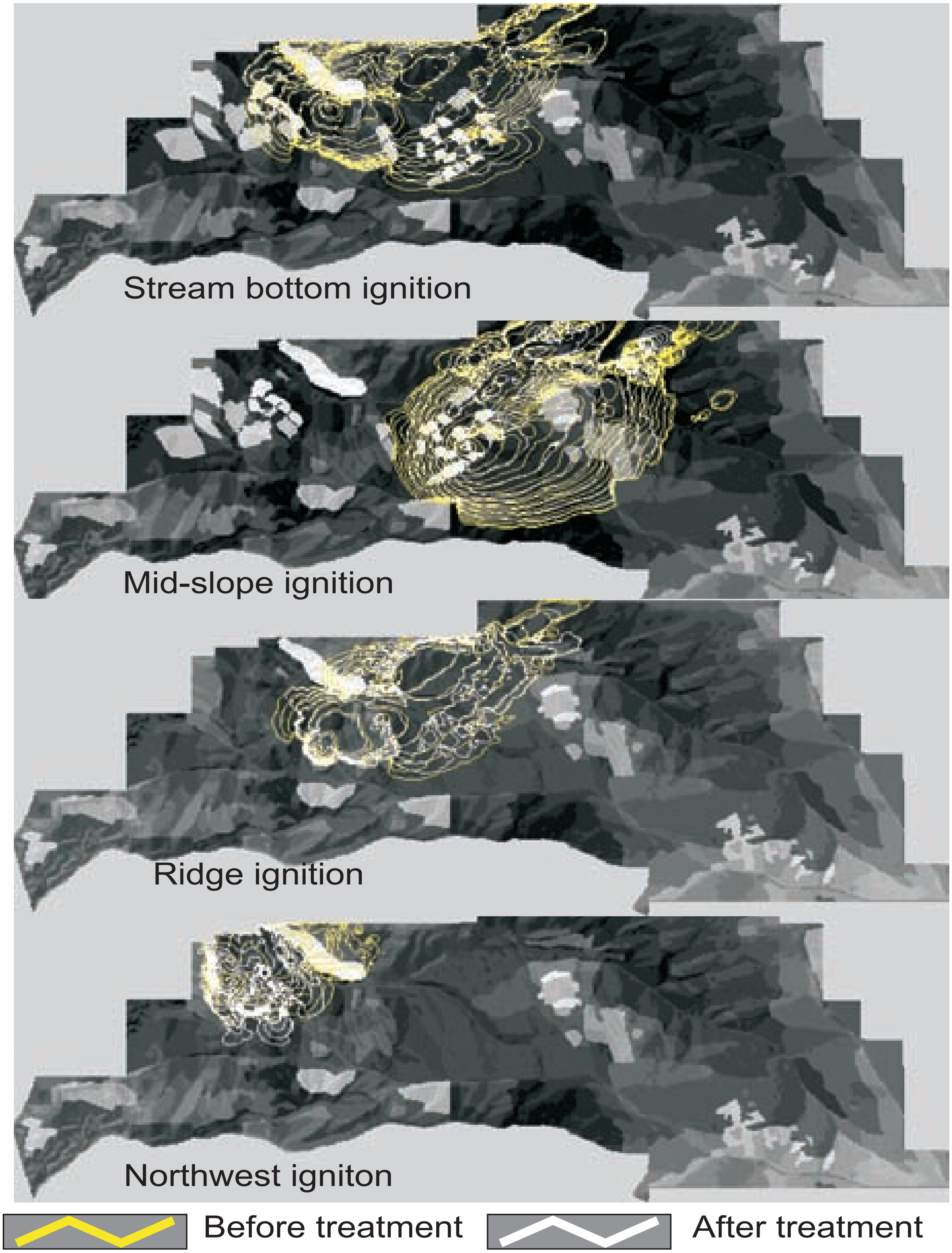


Figure 7— FARSITE comparison of fire progression before (yellow) and after (white) treatment. We evaluated fire progression using four ignition points (stream bottom, mid-slope, ridge, and in the northwestern part of the study area) (see fig. 1b). For illustration, the treated landscape is in the background. Although total fire size did not decrease substantially, fire progression changed when burning occurred through treated areas, by circling around units and changing fire shape.

Table 6. The number of hectares burned by fires before and after treatment started from different ignition points (fig. 1) using weather from 1967 in FARSITE simulations.

Time	Ignition points				Fire type		
	Stream bottom	Mid-slope	Ridge	Northwest corner	Surface	Passive	Active
	----------Hectares burned---------				-----Percentage of area-----		
Before treatment	334	478	288	137	68	35	< 1
After treatment	382	446	280	122	71	32	0

Fire progression with and without treatments

Using FARSITE and FlamMap to simulate fires burning in Canyon Creek during very dry and hot conditions, the treatments, although small (many <2 ha), influenced the progression and behavior of the fires during the 1967 weather for four selected ignition points (fig. 7). The yellow contour lines reflect the fire's progression prior to the treatments and the white contour lines show the fire's progression after the treatments. The contour lines represent the distance the fire moved in a four-hour period. Because there were high winds in 1967 (32, 48, and 88 km/hr) from the west, the fires progressed to the northeast (fig. 7). Pronounced spotting (although we did not allow them to grow) occurred when there were no treatments compared to the simulations after treatments, particularly with the northwest ignition, mid-slope ignition, and stream bottom ignition. The ridge ignition showed a similar elliptical pattern in both the pre- and post-treatment simulations but the post-treatment simulation burned less area (280 ha) compared to pre-treatment (288 ha) (fig. 7, table 6).

Of the four ignition points tested, fire size decreased by 12 percent after the treatments using the northwest ignition (fig. 7, table 6). This ignition occurred within the middle of the treated area and treatment placement prevented the fire from burning outside the treated areas within the 43 hrs we simulated the fire. As a result, by treating the area we burned 122 ha compared to the 137 ha we burned if the area was untreated (table 6). Unlike with the other ignition points, with the stream bottom ignition point a larger area (382 ha) burned after the treatments compared to the pre-treatment fire size (334 ha). However, the backing fire slowed when the fire burned through the western block of treated units (fig. 7). The progression of both the before and after treatment fires using the mid-slope ignition point was similar. However, fire size after treatments was slightly less (446 ha) compared to the simulated fire before the treatments (478 ha) (table 6). Moreover, the treatments did not allow the fire to progress to the northeast to the same extent as the pre-treatment simulation. When we ignited the fire on the ridge, the fire was more susceptible to winds, but the treatments did slow fire growth, particularly on the northwest side of the treatments (fig. 7).

FlamMap simulates fire behavior characteristics for a given forest structure, topography, and weather scenario. There is no contagion among the pixels, the information provided reflects only one point in time, and there is no specific ignition point (Finney 2006). The point in time we selected in 1967 was September 1 at 2000 hours, the period with the highest wind gusts (fig. 4). Although we only had 3 percent of the Canyon Creek drainage treated, the treatments modified the fire behavior, changing the treated sites from a passive crown fire to a surface fire (fig. 8). The northwest corner of the area burned in the simulations included a small area where an active crown fire occurred (typically a very rare event) before the treatments. With the treatments in place, this active crown fire fragmented this area; thus, the treatments created a diversity of forest structures minimizing the amount of active crown fire. Flame lengths of fires simulated before the treatments were 1.5 to 3.0 m while fires simulated after the treatments had flame lengths 0.3 to 0.6 m in the areas treated (fig. 9).

DISCUSSION

Applying the free selection system to restore Inland Northwest moist forests

The objective was to apply treatments in Canyon Creek to enhance research opportunities at PREF and to create forest conditions resilient to both native and introduced disturbances. We wanted to create heterogeneous forest structures and compositions and reduce the amount of

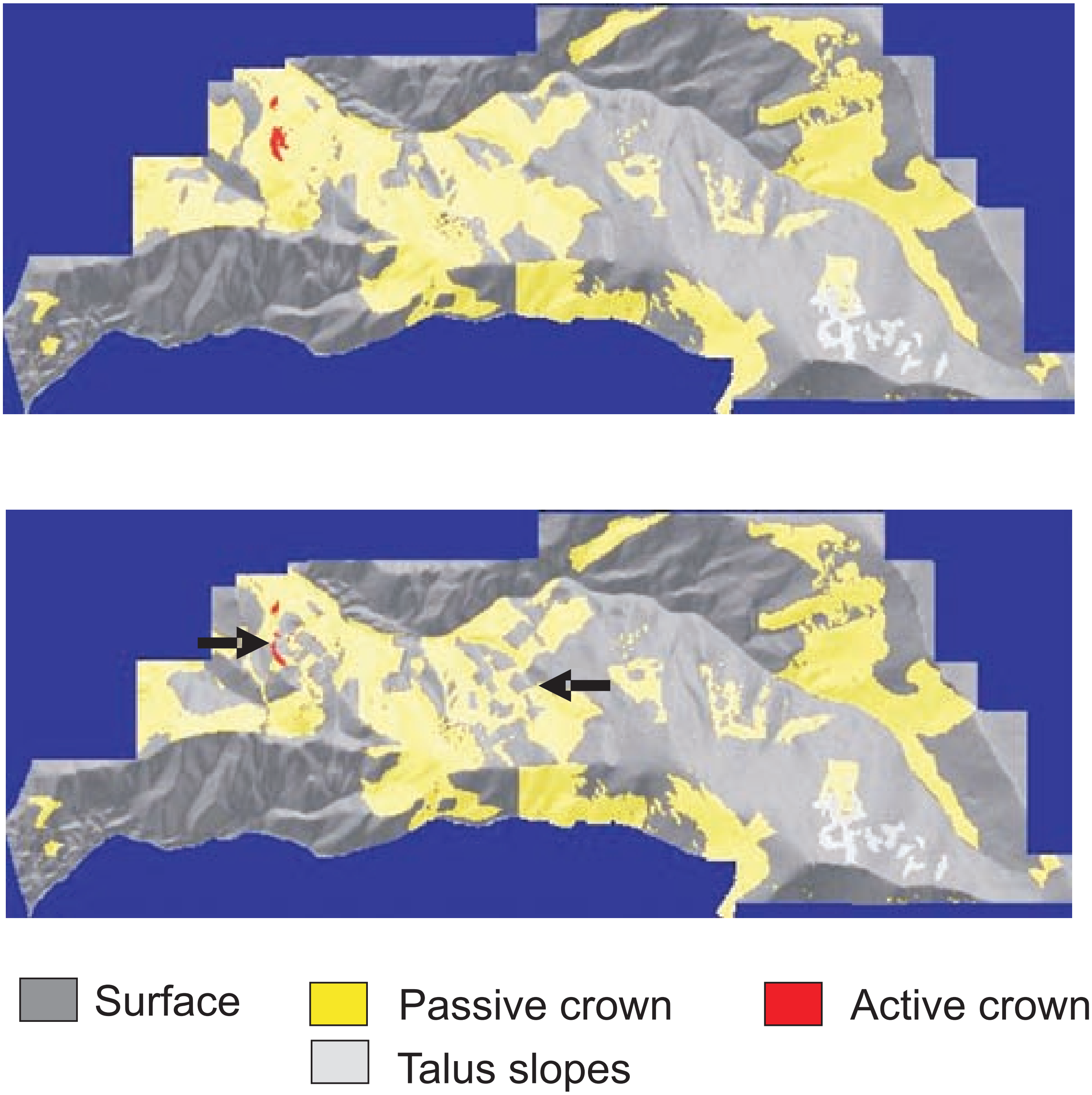


Figure 8— Fire activity before and after treatment from the FlamMap simulation. A FlamMap simulation evaluates individual characteristics within each pixel independently at a given point in time and determines its potential fire activity. The arrows show treatment locations. Crown fire was abundant across the landscape without treated areas (orange and yellow). Fire activity changed from a crown fire to a surface fire within treated sites (grey).

suppressed trees, mistletoe infected western larch, dead and dying western white pine, and ladder fuels. Moreover, we wanted to rejuvenate a stagnate forest and increase the presence of western white pine and other early-seral species. The key to our implementation was using our vision, future accessibility, current conditions, and desired future conditions to develop silvicultural prescriptions (Graham and Jain 2005). Through adaptive management, we will determine the timing, extent, and intensity of the next entry as we continue to monitor the development of the forests in Canyon Creek to determine if they fulfill the conditions we outlined in our objective. Most importantly, the conditions we created and those that develop will offer abundant research opportunities now and in the future.

Free selection was adaptable at incorporating new information such as adding findings from Jain et al. (2002, 2004) that describe canopy opening thresholds for establishment (40 percent), competitive advantage (55 percent) and free-to-grow (92 percent) (table 1). Incorporating these western white pine canopy opening thresholds not only facilitated regeneration opportunities but also will be useful for de-

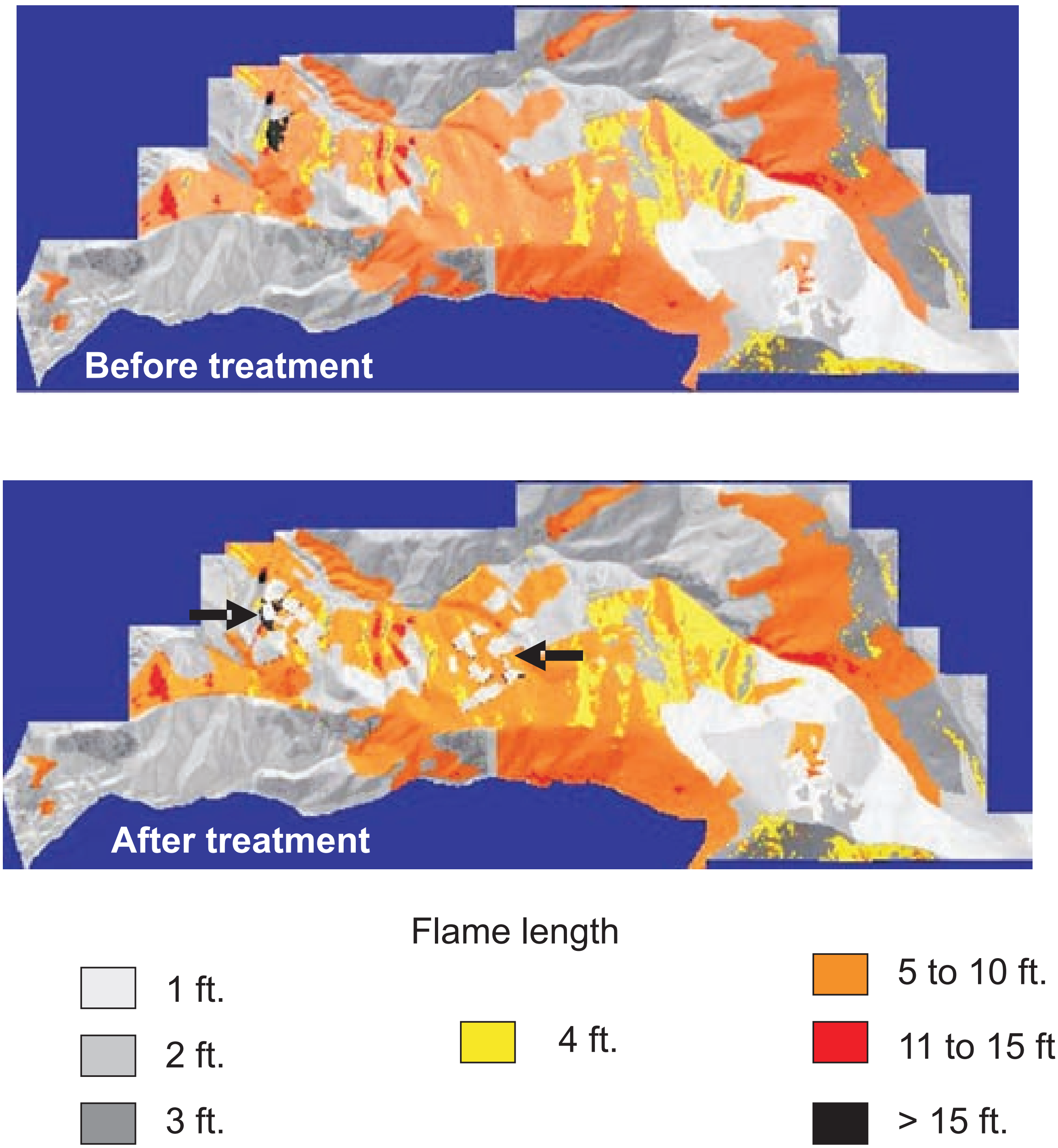


Figure 9— Flame length before and after treatment from the FlamMap simulation. A FlamMap simulation evaluates individual characteristics within a particular pixel independently and determines its potential flame length. The areas prior to treatment had potential flame lengths of 1.5 through 3 m and on the northwest corner had > 15 m lame lengths. After treatments, the flame lengths were 0.3 m (arrows).

termining residual canopy densities in future entries (e.g., overstory removal, cleanings, and weedings) to insure the vegetation of Canyon Creek develops as desired--as would be necessary in all selection systems (Marquis 1978, Meyer 1943). In addition, applying the thresholds created a diversity of forest conditions that reflect environments created by small-scale disturbances (e.g., weather, wind, fire).

The results from using free selection created a fine scale mosaic (0.05 ha) that contained a diversity in canopy cover (fig. 5), surface vegetation composition and structure, coarse woody debris amounts and structure, and a variety of forest floor conditions, ranging from undisturbed to masticated to burned with some mineral soil exposed. These conditions should produce abundant natural regeneration of groups and clumps of forbs, shrubs, and trees of all species in addition to the artificial regeneration of western white pine, ponderosa pine, western larch, and western redcedar planted in micro-sites to ensure their establishment and abundance. This mosaic would develop in response to the wide range of operational environments reflected in this first entry of a selection system.

Grapple piling versus mastication

Mastication costs appeared to be very high ($300/hr), leading to the conclusion that it is more expensive then typical slash treatments (prescribed fire or grapple piling). However, this is not always the case and mastication is a superb slash treatment alternative in areas where trees are not resistant to fire. In addition, a masticator can remove undesirable standing material, treat surface fuels, and prepare planting or seed germination sites in one operation. In contrast, grapple piling, or for that matter any kind of slash piling, requires slashing of unwanted standing and surface materials, piling the slash, and the subsequent burning of the piles, and often months to 10's of months can transpire between operations, delaying planting. In addition, by not removing both fine and coarse woody debris from the site, we conserve the organic and nutrient materials. However there are disadvantages to masticating slash and a major one is that slash is not removed but it is redistributed toward the fine fuel classes thus temporarily increasing the fire hazard (2 to 3 years) (Graham and Jain 2007).

Wildfire simulation

Although FARSITE and FlamMap are easy to use, calibration of the models requires people who are knowledgeable in fire behavior. Moreover, preparing the input data can be labor intensive, requiring GIS skills and appropriate data available that reflects the variability across a landscape, can be a major limitation. Although the models can simulate fires in forests with high amounts of variation, the data are rarely available with sufficient resolution to take advantage of these abilities. For example, although we conducted the simulations using 15 m cell size, the data we used could only be summarized to a "stand" with all of the cells within a stand having the same values. Therefore, rather than identifying variation in fire progression and behavior within a stand, we were simulating the variability in fire progression and behavior across stands. We did have LiDAR data (30 cm resolution) that could create a very complex landscape but did not have enough spatially explicit sample plots to take full advantage of the LiDAR data.

We determined that the FFE-FVS and 1st quartile CBH created similar results compared to the results from simulating the median or 3rd quartile CBH (fig. 6). Based on these results, we selected the 1st quartile crown base height to conduct our evaluation. These results indicate that determining CBH from associated attributes is an alternative to depending on only expert knowledge to determine CBH. To obtain a quartile from the original data, we used the tree list from FFE-FVS using the TREELIST keyword (Dixon 2002) and then a spreadsheet to calculate the different CBH quartiles. The default minimum height threshold for calculating CBH or canopy bulk density in FFE-FVS is 2 m which excludes all shorter trees. Because we had so many short trees <0.3 m, we used the CANCALC keyword and adjusted the minimum height to 0.3 m. Thus, CBH determined by FFE-FVS produced simulated fire results similar to the 1st quartile CBH. This finding emphasizes that when using a model, a basic understanding is required of how it works and that further evaluation of the minimum height CANCALC keyword and its impact on the FFE-FVS calculation of CBH is warranted.

Wildfire suppression opportunities due to treatment juxtaposition

In this study, we had two objectives concerning the placement of the treatments. One was to increase the heterogeneity of forest structure so that if a wildfire were to occur, the fire would create a heterogeneous burn severity (what a fire leaves behind). We also wanted to alter potential fire behavior to provide opportunities for fire suppression. Based on our simulations and information on the relation between forest structure and burn severity, we believe we achieved both objectives within the short-term (estimate of 30 years) (Jain and Graham 2007, Jain et al. 2006, Graham et al. 2004, Peterson et al. 2005, Scott and Reinhardt 2001, Stephens 1998, Stephens and Moghaddas 2005a, 2005b, Stratton 2004). Although our treatment units were small, the juxtaposition of the units (partially overlapped) contributed to our success in modifying fire behavior (Finney 2001). If the treatments were overlapped as the fire moved through, the rate of spread slowed and created delays while the fire flanked around the unit sides (fig. 7).

Under the 1967 weather, the presence of the treatments did not decrease the ultimate size of the fires substantially (table 6); however, the window of opportunity to connect the fuel breaks safely, became substantially larger. When a fire ignition occurred in the stream bottom, the juxtaposition of the treatments would provide an opportunity for fire crews to connect the fuel breaks and increase the likelihood of slowing or stopping the fire. Although the mid-slope ignition started where only a few treatment units affected fire growth, the treatments were effective at reducing the extent of the fire run. Moreover, the backing and flanking fires through the west side of the eastern treatments would allow suppression forces to have a greater opportunity to take safe action on the east flank and connect the treated fuel breaks. With the ridge top ignition, although more susceptible to the winds, both treatment blocks did slow fire growth. Moreover, when the simulated fires burned through these units using FlamMap, the flame lengths were 0.3 m, providing excellent suppression opportunities. This is because fires with flame lengths <1.2 m can generally be attacked at the back or flank of the fire directly by firefighters using hand tools and handlines thereby increasing the ability to actively manage the wildfire (National Interagency Fire Center, 2005).

We were pleased that the treatments were located within high fire risk areas (crown fire potential). We purposely located cuttings in locations to remove suppressed or diseased trees or both and the results from our FlamMap simulations show the same areas were also high risk for crown fire. Although our units were small and contained clumps of trees with interlocking crowns, they influenced burn severity. This impact is most likely related to the high (>5 m) canopy base heights and the slash treatments (surface fuel reductions). In addition, the high diversity of forest floor conditions we created (e.g., burned surfaces, masticated woody debris, exposed mineral soil, untreated areas) would result in a multitude of different soil burn severities (Jain et al. 2006). This diversity will provide many opportunities for seed germination (new and seed stored in the duff) and tree planting, creating a forest reflecting characteristics similar to historical conditions (Marshall 1928). If such fires were to occur, they would kill many western white pine, western hemlock, and western redcedar, but many would also survive, as would the large ponderosa pine and western larch. Although there is always, a risk of wildfire in Canyon Creek, the treatments through our simulation analysis would provide opportunities for suppression and the remaining forest structures would provide vectors for the forest to recover.

Challenges toward implementing the free selection silvicultural system

Study implementation offered several challenges to Forest Service District personnel, beginning with the Environmental Assessment (EA). The objective of any harvesting activity on an experimental forest is to provide conditions for research. Therefore, there were only two alternatives to evaluate in the EA; either conduct the study using the study plan (harvest) or do not conduct the study (do not harvest). The silvicultural prescriptions did not describe specific stand metrics such as opening size, residual canopy cover, and species compositions, making it difficult for the wildlife biologist, hydrologist, botanist, and other specialists to make informed judgments as to the impacts the treatments would have on other resources. To alleviate this challenge, we spent considerable time in the field with the EA Team Leader and specialists discussing the silvicultural prescription, and used many examples showing what Canyon Creek would look like after the treatments. Even though there were challenges in developing the EA and implementing the study, through our collaborative efforts we found solutions to the issues as they arose. Through these collaborative efforts, other interested groups did not appeal the decision, and implementation is progressing.

During completion, the arrangement of the units and the tree-marking plan was also challenging. This required many hours of reconnaissance to find all the locations to fulfill these objectives. When implementing the marking guides for the free selection, we found that persons with a forestry background (many years of experience or a degree in forestry) and with considerable tree-marking experience were able to grasp the concepts quickly. On the other hand, people who had tree-marking experience but non-forestry backgrounds who were accustomed to marking guides such as traditional seed-tree, shelterwood, or thinning prescriptions often described by basal area, stand density index, tree spacing, or other metrics had difficulty understanding the concepts used in free selection.

The objective was to create a diversity of forest floor conditions (planting and seed germination sites), requiring a variety of slash treatments, often within one treatment unit. For example, unit 7 (≈ 5 ha) had grapple piling, mastication, and prescribed fire distributed throughout the unit. To coordinate our efforts, we used a pamphlet containing photographs of each treatment area within a harvest unit and identified the research objectives, slash treatments, and planting needs associated with the treatment area. This enabled personnel from Research and National Forest Systems to work from a common understanding. The guide provided a way to document changes and points of discussion as the study progressed.

Planting

Two of the goals when planting were to have variation in density and species. We achieved variation in planting density by having non-plantable sites, incorporating normal expected mortality, and using differences in overstory canopy cover to guide the planting concentration. We achieved the variation in species as a function of overstory canopy cover and composition. With the cooperation of the contractor and crew leader, who understood which species favor a particular environment (e.g. western larch under low canopy cover versus western redcedar under high canopy cover) we were able to plant the desired species in the appropriate locations.

To accomplish the reforestation objectives, the District used a tree spacing (3 x 3 m) requirement, with either site preparation, full planting, or no site preparation interplanting for most of the units, with per hectare cost being the same for each site preparation type. For the units that required a little more finesse or thought as to where to plant trees (i.e. units 1, 2, and 24) at varying densities, it was more appropriate to pay by the hour. These units required tree planters to look up and assess the canopy opening coverage and size (minimum 50 percent canopy opening and 0.1 ha in size) to ensure competitive advantage was attainable. Although the cost per tree was higher (50 percent) when paying by the hour, the cost per hectare planted, was lower (35 percent). Although it is not always easy to make comparisons, due to size and number of openings and unit size, a crew has to walk through, based on our experience during implementation, the type of planting used in this study area can be a viable option for future applications. Moreover, the planting was successful due to a clear understanding of the objectives and good communication and trust between the District's Contracting Officer's Representative and the Contractor's crew leader.

CONCLUSION

Baker (1934) suggested that silvicultural systems are often confused with rigidity, but they are flexible based on management objectives and the forest conditions. Gifford (1902) and Schlich (1904) developed silvicultural strategies intended for harvesting and managing forests containing irregular structures and complex compositions. Therefore, the free selection concept we have developed and applied for restoring the moist forests is not new, but rather an extension of the many ideas expressed by other silviculturists. Ultimately, what we implement, test, accomplish, and display at PREF may or may not be appropriate in other places, different times, or to meet other objectives. However, the concepts, ideas, results, and thought processes we used and discovered when implementing the study are very applicable to other forest management and silvicultural decisions in other places with other objectives. The practice of silviculture has a proud heritage of being responsive to the needs of society. However, inherent in all of us is the resistance to change. Therefore, the challenge regarding the practice of silviculture is to develop methods to meet today's (wildlife, fire hazard) and tomorrow's (carbon sequestration, climate change) societal objectives. In meeting these challenges, some of our tried and true methods, systems, and procedures may need to be changed, which can be difficult. However, we have a long history and knowledge base from which we can draw on and this study added to this knowledge. The mutual learning by all involved with the study and their open mindedness of trying something different contributed to the implementation of this study's success.

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