Vegetation and Soil Effects from Prescribed, Wild, and Combined Fire Events Along a Ponderosa Pine and Grassland Mosaic

Theresa Jain, Molly Juillerat,
Jonathan Sandquist, Mike Ford, Brad Sauer,
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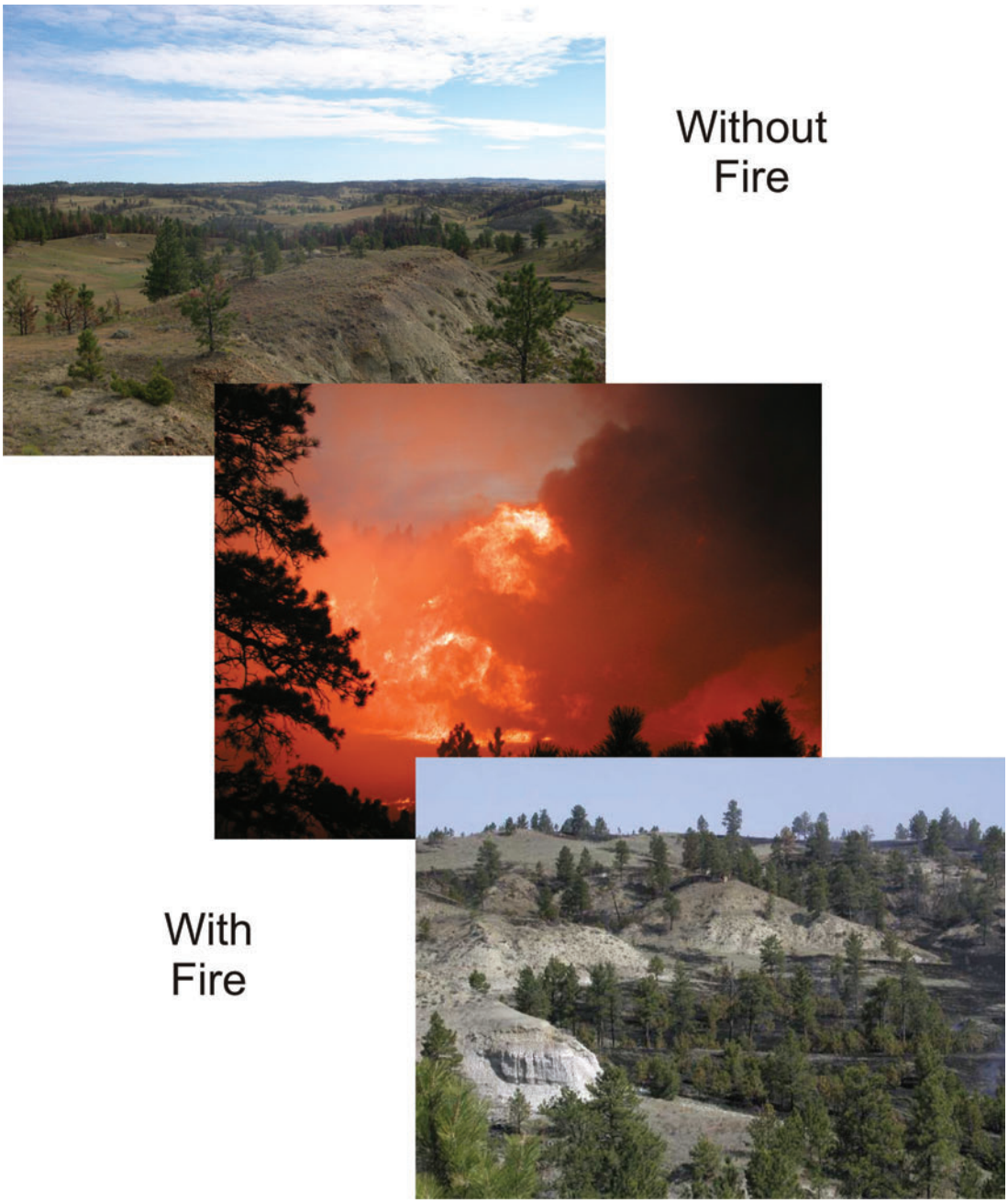

United States Department of Agriculture / Forest Service
Rocky Mountain Research Station

Research Paper RMRS-RP-67CD
September 2007

Jain, Theresa; Juillerat, Molly; Sandquist, Jonathan; Ford, Mike; Sauer, Brad; Mitchell, Robert; McAvoy, Scott; Hanley, Justin; David, Jon. 2007. **Vegetation and soil effects from prescribed, wild, and combined fire events along a ponderosa pine and grassland mosaic**. Research Paper RMRS-RP-67CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 39 p.

Abstract

We describe the efficacy of prescribed fires after two wildfires burned through and around these fires located in eastern Montana within the Missouri River Breaks. The objectives of the prescribed fires were to decrease tree density and favor increased herbaceous cover, thus decreasing the potential for crown fire. Our objective was to evaluate post-fire tree density, herbaceous cover, soil surface, and burn severity to determine if the prescribed fires fulfilled management objectives and if they affected post-wildfire outcomes. Because there is no information available on pre-fire conditions, we used a draft of the handbook *Forest Descriptions and Photographs of Forested Areas Along the Breaks of the Missouri River in Eastern Montana* (RMRS-GTR-186) of unburned sites as our frame of reference. We compared sites burned by prescribed fire alone, wildfire alone, and prescribed fire followed by wildfire to the unburned sites from the handbook. Statistical analysis showed no significance in tree density, herbaceous cover, and crown scorch, but we do report observed trends. Depending on the physiographic position, more trees survived in places burned by the combination of prescribed and wildfire than places burned only by the wildfire. The prescribed fires tended not to fulfill prescription objectives, particularly in tree density, until the second fire occurred. However, the wildfire tended to exceed prescription objectives because it killed too many trees. Compared to the unburned sites, all the fires tended to decrease litter and favor higher amounts of grass cover, thus fulfilling prescription objectives. Heterogeneity in vegetation characteristics such as canopy base height increased as a function of the combined fires. This CD describes detailed results and outcomes among the different fires and the unburned sites, and its accompanying photograph handbook provides examples of burned and unburned sites to use as a communication, calibration, and/or monitoring tool. Although the information is unique to a series of fires, the concepts and methods we used are applicable in other locales required to evaluate efficacy of fuel treatments.

Keywords: fuel treatment efficacy, wildland fire, fire effects, Rocky Mountains

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Introduction

Within the dry forests and grasslands of the western United States, a variety of factors such as excessive livestock grazing, fire exclusion, and excessive timber harvesting help to create favorable conditions for crown fires. These fires can hurt resource values such as livestock forage, recreational opportunities, wildlife habitat, and soil productivity (Agee 1993; Graham and others 2004; Van Wagner 1977). Today, the lands along the Missouri River Breaks in eastern Montana have forested and grassland conditions that favor high fire risk (USDI 2004). This rural area's infrastructure for decreasing forest fuels mechanically is limited, making the application of prescribed fires the most practical technique on many of the lands administered by the Bureau of Land Management (BLM). The BLM prescribes fire to decrease the abundance of saplings (ladder fuels), favor grass and forb production, and develop dispersed groups of ponderosa pine (*Pinus ponderosa*) with high canopy base heights (CBH), reflecting characteristics that were created by historical fire return intervals (USDI 2004). Because results from these prescribed fires have been highly variable, developing and using prescribed fire treatments have been an exercise in trial and error. Although these methods have provided anecdotal information, the process has yielded minimal information for use in validating fire prescriptions and determining their effectiveness in altering wildfire behavior and burn severity. An opportunity to study the effects of prescribed fire arose in 2003 when the Indian and Germaine wildfires burned in and around several prescribed fires along the Missouri River Breaks in eastern Montana (fig. 1). The combination of these fire events provided a unique opportunity to gather information on the effectiveness of prescribed fire in altering forest structure and subsequent burn severity (what remains after a fire).

Monitoring the effects from wildfires and prescribed fires is a necessary component in resource management (for example, Healthy Forests Restoration Act 2003). When monitoring effects from disturbances, the preferable technique is to characterize forest overstories (crown fuels) and surface conditions (surface fuels) prior to a disturbance, then return to the same location and characterize forest structure and burn severity after the disturbance. However, the location of a future forest disturbance, such as a wildfire, is usually unknown. It also may not be economical or feasible to conduct a complete forest inventory or to establish a grid of plots that is large enough to ensure sufficient pre-disturbance data. There

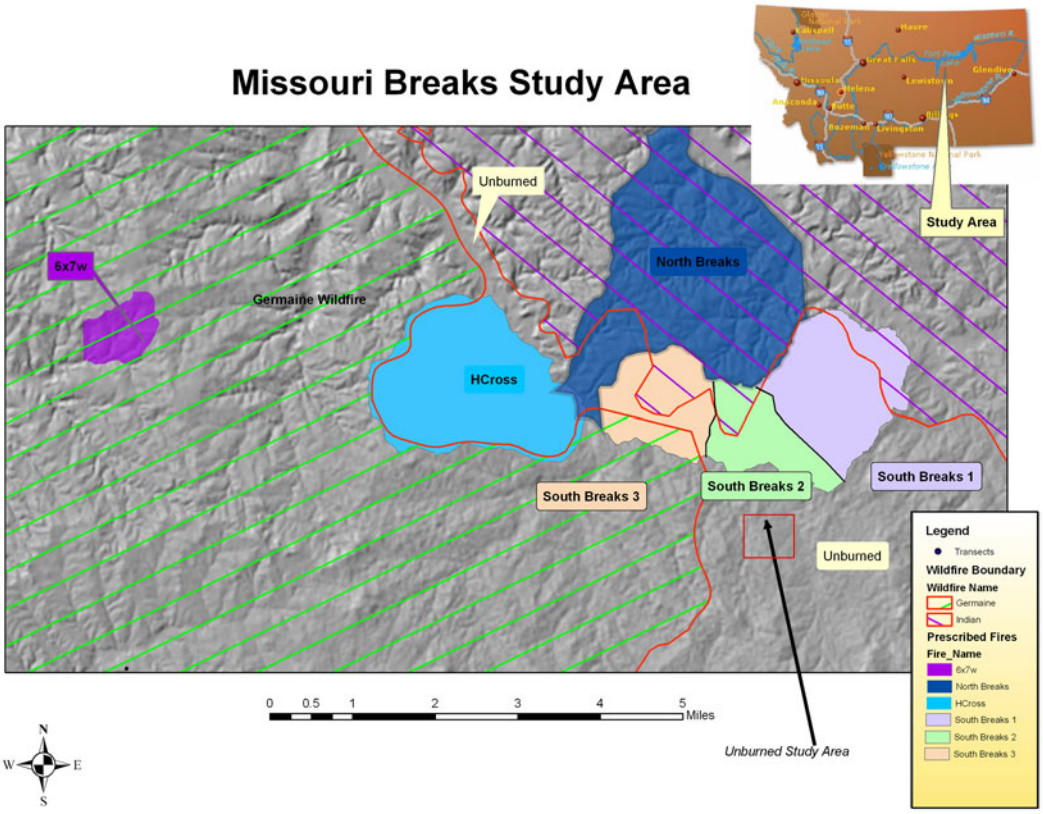

Figure 1—Study area is located within the Missouri River Breaks in eastern Montana. The study developed methods to compare post-fire outcomes of prescribed fires: 6X7W (burned in 1998), South Breaks 1, 2, and 3 (burned in 2001), HCross (burned spring of 2003), and North Breaks (burned spring of 2003). In August of 2003, a series of lightning storms ignited several fires along the Missouri River Breaks; two of these fires (Indian and Germaine) burned more than 100,000 acres through and around the prescribed fires. These provided an opportunity to evaluate fire effects of prescribed fire alone, wildfire alone, and prescribed fire followed by wildfire. We used sites that had not burned as a frame of reference to compare with burned sites.

is no specifically located pre-disturbance data from the Missouri River Breaks in either the prescribed fire or wildfire areas. Moreover, there was no data collection on specified locations after the prescribed fires. This study evaluates an alternative method for monitoring and evaluating environments created by a series of fires, where no pre-disturbance information is available.

We used a retrospective evaluation to examine the relation between current forested and grassland sites and burn severity in places (1) burned by prescribed fires alone, (2) where wildfires burned around prescribed fires, and (3) where wildfires burned through prescribed fires. In addition, we examined each prescribed fire to determine if it met the resource objectives outlined in the fire plans. This study will supply useful information about post-fire outcomes in places containing a mosaic of ponderosa pine and grassland areas. This document provides detailed summaries that accompany the photograph handbook RMRS-GTR-197 (Jain and others 2007b).

Study Area

The study area is located along the Missouri River in eastern Montana (fig. 1). Land ownership includes public lands administered by the BLM and the Montana State Department of Natural Resources and Conservation, with many large private ranches interspersed throughout the region. Today, the vegetation is composed of highly heterogeneous dispersed ponderosa pine and Rocky Mountain juniper (*Juniperus scopulorum*) forested areas interspersed by grass and shrublands (Arno 1979; Fischer and Clayton 1983; Mackie 1970) (fig. 2). Within these sites, ground level vegetation includes continuous or dispersed patches of grasses, ponderosa pine needle mats, shrubs, dense tree seedlings, and saplings. Canopy cover consists of scattered individual trees to patches of continuous cover (fig. 3). Grasses include little bluestem (*Schizachyrium scoparium*), prairie sandreed (*Calamovilfa longifolia*), blue grama (*Boutiloua gracilis*), western wheatgrass (*Pascopyrum smithii*), prairie junegrass (*Koeleria macrantha*), and green needlegrass (*Nassella viridula*). Intermixed shrubs include creeping juniper (*Juniperus horizontalis*), silver sagebrush (*Artemisia cana*), skunkbush (*Rhus trilobata*), and Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*).

Figure 2—The Missouri River Breaks landscape is highly heterogeneous, with forested places intermixed with areas that contain grassland characteristics. This is most likely the result of fire suppression during the last several decades.

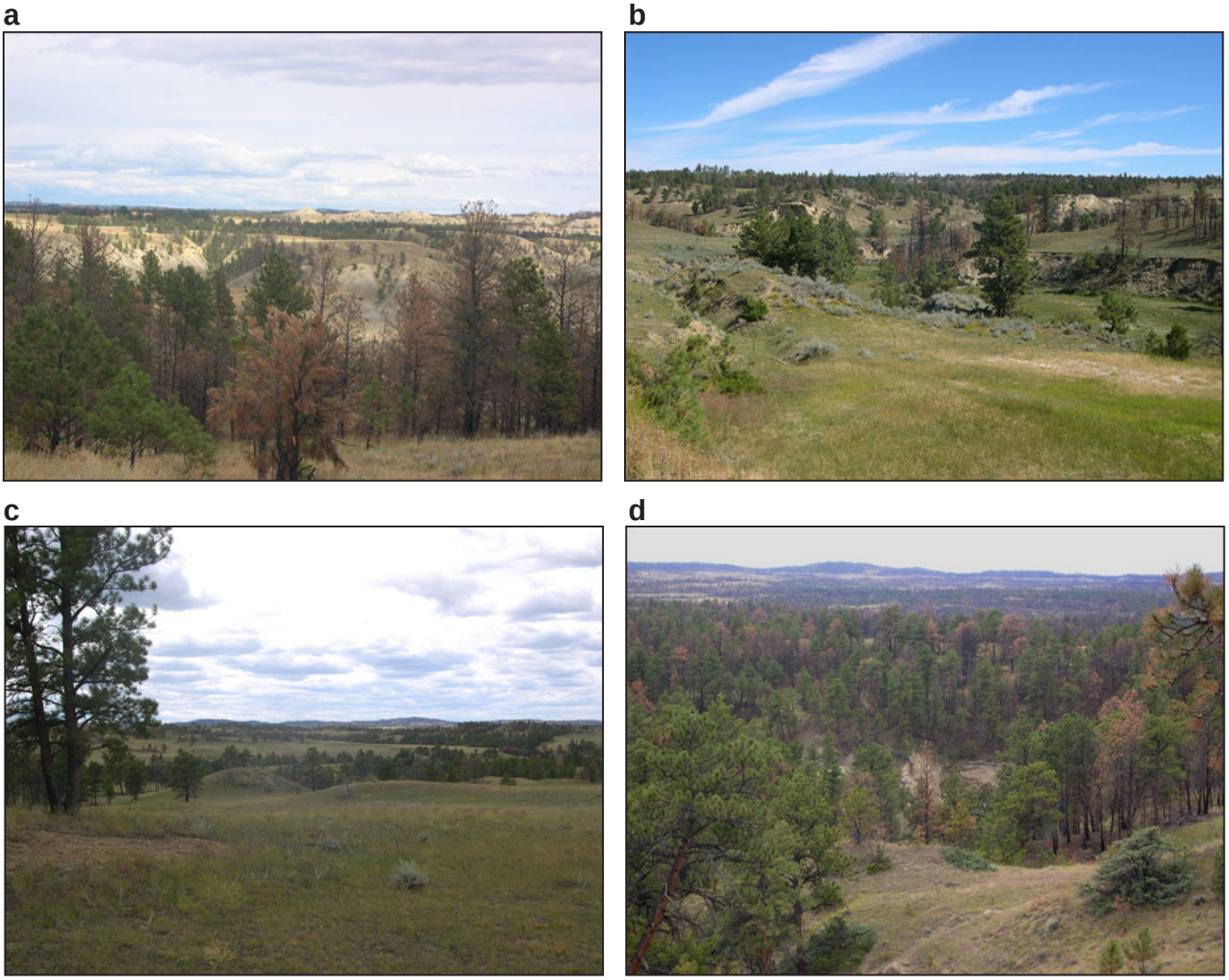

Figure 3—There was considerable variation in both forest structure and burn severity throughout the study area as illustrated by photographs taken on: (a) North Breaks prescribed fire and wildfire combined, (b) South Breaks 3, (c) HCross, and (d) North Breaks prescribed fires.

Historical fire return intervals in the study area occurred every one to seven years (USDI 2004). Today, unburned sites are typified by characteristics (high-density pockets of trees) that develop due to succession caused by lack of fire (Biswell 1972; USDI 1979a; USDI 2004). Lack of fire combined with some livestock grazing have changed the area from characteristics present under historical conditions (Mackie 1970; USDI 1979b; USDI 2004). The Indian (33,954 acres) and Germaine wildfires (66,496 acres) burned through the area in August of 2003 (fig. 1). These wildfires burned in and around prescribed fires (ranging from 200 to 3000 acres) that were applied in 1998 (6X7W), 2001 (South Breaks 1, 2, and 3), and spring of 2003 (North Breaks and HCross) (table 1). The sites burned by prescribed fires, wildfires, or a combination of the two were similar to the unburned areas prior to these disturbances.

Table 1—The number of observations for each fire event, prescribed fire name, and wildfire name. A combined fire event refers to sites that were initially burned by a prescribed fire followed by a wildfire. A wildfire event refers to sites burned only by a particular wildfire, either the Germaine or Indian wildfires. A prescribed fire event refers to sites that burned only by a prescribed fire; however, these sites were surrounded by a particular wildfire. For example, the Germaine wildfire surrounded the HCross prescribed fire. The South Breaks prescribed fire has three distinct sections, because the fires were implemented at different times with different weather conditions and the local managers wanted to keep them separate. The number of transect segments are the number of replicates we used to compare burned and unburned sites. Horizontal distance is the total transect length characterized for a particular fire event.

Fire event	Prescribed fire	Wildfire	Number of transect segments	Horizontal distance (ft)
Wildfire	6X7W	Germaine	20	3981
Prescribed fire	6X7W	Germaine	0	0
Combined	6X7W	Germaine	18	4804
Wildfire	HCross	Germaine	9	2500
Prescribed fire	HCross	Germaine	13	2997
Combined	HCross	Germaine	8	1188
Wildfire	North Breaks	Indian	0	0
Prescribed fire	North Breaks	Indian	4	1708
Combined	North Breaks	Indian	15	5075
Wildfire	South Breaks 1	Indian	6	4184
Prescribed fire	South Breaks 1	Indian	22	9882
Combined	South Breaks 1	Indian	15	4658
Wildfire	South Breaks 2	Indian	0	0
Prescribed fire	South Breaks 2	Indian	18	7945
Combined	South Breaks 2	Indian	7	2663
Wildfire	South Breaks 3	Germaine & Indian	7	4374
Prescribed fire	South Breaks 3	Germaine & Indian	12	2922
Combined	South Breaks 3	Germaine & Indian	19	6701

Methods

Summer rainstorms occur relatively often and create conditions where soils become slippery and sticky because of their high clay content (gumbo), creating conditions impossible for walking and or driving (Healy 2005). Therefore, our access to the area was limited to a three-week period in July and August of 2004, between rainstorms. The area is remote, the burned areas are quite large, and some places are inaccessible, which limited our ability to acquire plot data of sufficient density to identify statistically significant differences. However, to address the objectives of the study it was necessary to estimate post-fire conditions of crown, surface, and ground characteristics. To estimate forest structure, we developed a handbook titled Forest Descriptions and Photographs of Forested Areas Along the Breaks of the Missouri River in Eastern Montana, USA (Jain and others 2007a) containing photographs and related forest metrics of areas that reflected places that were departed from the historical fire intervals, referred to as fire condition class number 3 (Biswell 1972; Hann and Bunnel 2001; FRCC guidebook 2005; USDI 2004). Information from burned sites was compared to information from the handbook to determine change in tree density. We complemented this information with burn severity information on trees.

Photograph Handbook of Unburned Forest Characteristics

In unburned areas adjacent to the prescribed burn and wildfire areas (fig. 1), we used stratified random sampling, with physiographic position (strata 1) and tree density represented by canopy cover (strata 2) (table 2), to characterize and photograph sites used to develop the handbook. Within the study area, three two-person crews randomly located a starting point and direction and followed a linear transect. Upon crossing a physiographic position and area with low tree density (based on canopy cover), the crews established a random plot 50 feet from the transect, with direction dictated by the location of a second hand on a watch. After data was collected on the low-density site, the crew would continue along the transect until encountering an area with medium tree density, defined as twice the density as the low-density site. After this site was established, the crew would continue along the transect and identify a site with twice the density as the medium density site, defined as a high density site. This method continued until each crew identified a low, medium, and high tree density site within each physiographic position. This was repeated three to five times for each physiographic position and tree density (Jain and others 2007a).

At each located site, the crews took ocular estimates of soil surface characteristics on a 1/300th acre circular plot per replication. These characteristics included percent cover of litter, mineral soil, and rocks, as well as percent cover of grasses, forbs, low shrubs (≤ 0.2 inch basal stem diameter or ≤ 1 foot tall) and medium shrubs (> 0.2 inch basal stem diameter or > 1 foot tall) (Jain and others 2007a). Down wood was not abundant (determined by sub-sampling) and therefore was not reported.

The trees were described using a 1/24th acre circular plot and all trees greater than 12.0 inches diameter breast height (dbh) (4.5 feet above surface on uphill side of tree) were quantified with a variable radius plot (20 basal area factor prism), with

Table 2—For unburned sites, the minimum, median, maximum trees per acre, average basal area, and average percent cover for each tree density class within a physiographic position.

Physiographic position	Density (number of replicates)	Description: Trees per acre: Minimum	Median	Maximum	Average basal area (ft^2/acre)	Average canopy cover (%)
Riparian	Low (n = 3)	0	216	552	8	9
	Medium (n = 3)	669	864	956	43	32
	High (n = 3)	525	1306	1704	84	54
South aspect	Low (n = 6)	0	41	120	19	11
	Medium (n = 7)	72	163	464	43	29
	High (n= 6)	744	1128	2300	120	67
North aspect	Low (n = 8)	0	240	1104	10	11
	Medium (n = 6)	261	490	1200	56	39
	High (n = 6)	744	1116	1920	110	66
Ridge or bench	Low (n = 3)	0	24	38	7	4
	Medium (n = 3)	192	336	816	6	12
	High (n = 3)	336	712	840	89	57

sampling proportional to tree size. Diameters and heights were taken for each tree and CBH and uncompacted crown ratio were measured directly (fig. 4a, table 3). With a hard hat placed at plot center, the crews took two photographs from the down slope direction of the plot to represent a close-up view and a distant view (Jain and others 2007a).

After data collection, we summarized the data using the Forest Vegetation Simulator (FVS), eastern Montana variant (Crookston and Stage 1999; Dixon 2003; Wykoff 1986; Wykoff and others 1982) to obtain trees per acre, snags per acre, total cubic foot volume, merchantable cubic foot volume, basal area, and canopy cover. We categorized the tree data into four tree height classes: ≤ 6 feet, > 6 to ≤ 12 feet, > 12 feet to ≤ 23 feet, and > 23 feet. We developed tables for each site that included the percent ground cover, average height, and crown ratio within each tree height class, and plot attributes (for example, trees per acre and canopy cover) (fig. 4a, table 3). To calculate biomass we used numbers of stems within a basal stem diameter class (Brown 1976) (table 3).

The combination of photographs and data tables served as a tool to estimate the change in forest density (for example, trees per acre, canopy cover, and basal area). We organized this information into Forest Descriptions and Photographs of Forested Areas Along the Breaks of the Missouri River in Eastern Montana, USA (Jain and others 2007a) according to how we stratified the sites (phyisographic position and overstory density), identifying physiographic positions as waterways (ravines and gullies), south-facing aspects (≤ 25 and > 25 percent slope angle), north-facing aspects (≤ 25 and > 25 percent slope angle) and ridges or benches (referred to as ridges throughout document) (table 2).

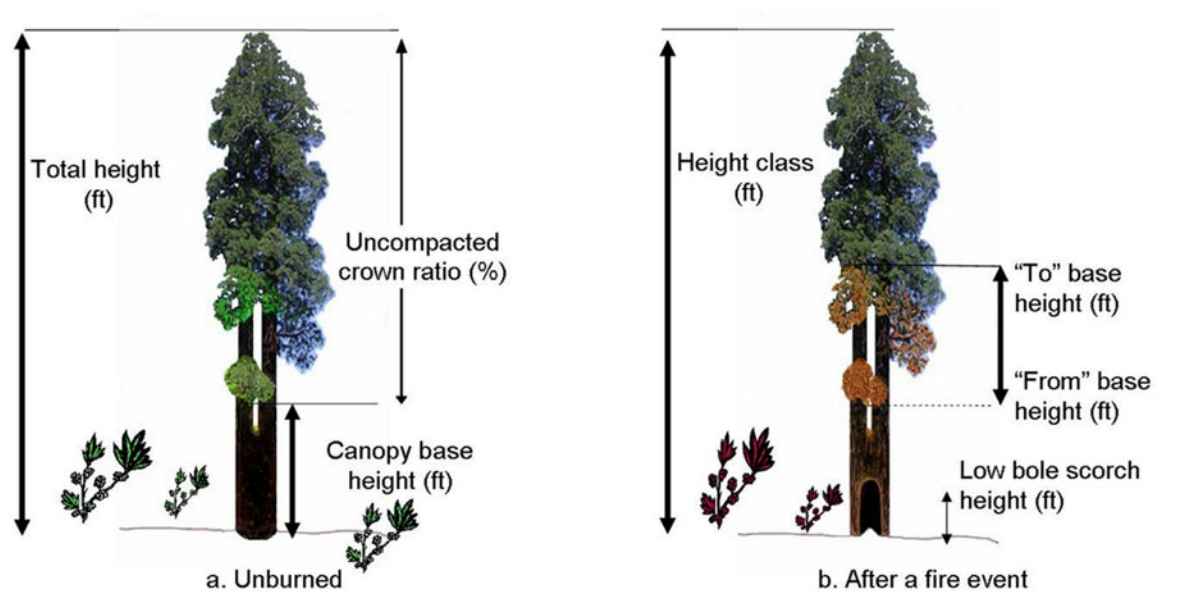

Figure 4—An illustration of how we quantified crown ratio, canopy base height, and total height in unburned areas (a). After the fire event, the rise in canopy base height between the pre-fire (from) and the post-fire (to) was measured directly based on live branch locations on burned sites (b).

Table 3—The following information describes forest characteristics, how they were measured, and the plot size used when obtaining the measurements for unburned sites. Also included are the calculation and/or reference used to summarize data.

Characteristics	Direct measurement (level of precision)	Plot size	Calculation used and/or literature reference
Forest floor and surface			
Litter, mineral soil exposure, grass, forbs, shrub (%)	Ocular estimate of proportion of cover (± 5%)	1/300th acre circular plot	Proportion of 1/300th acre plot presented as percent
Shrub biomass (tons/acre)	Number of basal stems in two diameter and height classes (low = ≤ 0.2 in or ≤ 1.0 ft tall; med = > 0.2 in or > 1.0 ft tall)	1/300th acre circular plot	Regression equation for estimating total above ground weight, based on number of basal stems for big sagebrush (*Artemisia tridentata*) and common Juniper (*Juniperus communis*) (Brown 1976)
Tree characteristics			
Trees & snags ≤ 12.0 inches diameter breast height (dbh) breast height = 4.5 feet	Tally by height (nearest foot), species, and diameter (± 0.1 in)	1/24th acre circular plot	Trees per acre = tree tally per plot multiplied by 24
Trees & snags > 12.0 inches diameter breast height (dbh) breast height = 4.5 feet	Tally by height (nearest foot), species, and diameter (± 0.1 in)	Sampling proportional to size using a 20 basal area factor prism	Stand table factor multiplied by tree count per plot in a diameter class (Dilworth 1970, page 267); Forest Vegetation Simulator (FVS), eastern Montana variant (Dixon 2003)
Total basal area (ft^2/acre)	Tally by height (nearest foot), species, and diameter (± 0.1 in)	1/24th acre circular plot, and through sampling proportional to size	Dilworth 1970, page 267; FVS, eastern Montana variant (Dixon 2003)
Total volume (ft^3 /acre)	Tally by height (nearest foot), species, and diameter (± 0.1 in)	1/24th acre circular plot, and through sampling proportional to size	FVS, eastern Montana variant (Dixon 2003; Wykoff 1986)
Merchantable volume (ft^3 /acre)	Tally by height (nearest foot), species, and diameter (± 0.1 in)	1/24th acre circular plot, and through sampling proportional to size	FVS, eastern Montana variant (Dixon 2003); merchantability standards: 1 foot stump height to a 2 inch top (Wykoff 1986)
Tree crown characteristics			
Canopy base height (ft)	Height from surface to lowest live branch (± 1.0 ft)	1/24th acre circular plot, and through sampling proportional to size	Average canopy base height for all trees within a height class per plot
Uncompacted crown ratio (%)	Percent of tree with crown from lowest live branch to top of tree (± 1%)	1/24th acre circular plot, and through sampling proportional to size	Average crown ratio for trees within a height class per plot
Total canopy cover (%)	Uncompacted crown ratio and tree species (± 5%)	1/24th acre circular plot, and through sampling proportional to size	Estimates of total canopy cover accounting for crown overlap, FVS, eastern Montana variant (Crookston and Stage 1999; Dixon 2003)

Quantifying Forest Structure and Severity of Burned Areas

Burn severity has many different definitions in the literature (Albini 1976; Chandler and others 1991; Davis 1959; Jain and others 2004; Jain and others 2006; Jain and Graham 2007; Rothermel 1983; Ryan and Noste 1985; Simard 1991; Wells and others 1979). Because of this inconsistency, and to ensure clarity, we define burn severity as the post-fire environment (what is left) of trees, ground-level vegetation, and soil.

The objective of this study was to determine if the prescribed fires, wildfires alone, or prescribed fires followed by a wildfire affected the post-fire environment (burn severity), tree density, and surface vegetation and mineral soil exposure differently. The fires burned very heterogeneously, due to local weather and variations in physical setting, overstory structure, ground-level vegetation, and soil surface (fig. 3). Recognizing this abundant variation, we wanted to pair our observations (such as wildfire only versus prescribed fire followed by wildfire) because physical

setting, vegetation, and weather would tend to be spatially similar if sites were closer to each other (Cressie 1993). This, combined with the short sampling period and remoteness of the study area, led us to use linear transects that crossed two fire events. In addition, these transects would cross many different physiographic positions within the burned areas.

As such, we were able to describe considerable variation in forest structure and burn severity. Transects were located randomly and to save time and increase sampling area, transect width was not designated; rather, areas were stratified into specific physiographic positions and tree densities that matched the photograph handbook (Jain and others 2007a) of unburned sites. By using the photograph handbook as a calibration tool, we could obtain estimates of trees per acre, volume per acre, and tree size without installing a plot. With this information, combined with actual burn severity measures and estimates of ground and surface characteristics, we were able to quantify the post-fire variation in structure and severity. This enabled us to characterize a minimum of 12 miles of burn severity and site characteristics in nine days quickly and efficiently (table 1).

For the transect locations, we used ArcGIS 8.3 (ESRI 1999-2002) to create random points that occurred at the boundaries between different fire events and randomly select 20 points per fire combination. After this, we numbered the locations in each fire, wrote them on a piece of paper, and pulled a minimum of 10 points from a hat with the goal to sample as many transects as possible given the time constraints. The location of the transects was based on these randomly selected points. Transect direction went perpendicular to the fire boundary radiating from the selected point.

Each transect crossed two fire events (wildfire versus prescribed fire, or wildfire versus a prescribed fire followed by a wildfire) from the beginning to the end of each transect. A transect's horizontal distance ranged from approximately 3000 to 6000 feet with 1200 to 3000 feet occurring within a particular fire (figs. 5 and 6). We placed 31 transects within the combination of fires, with a minimum of four transects per fire. A UTM (universal transverse mercator) coordinate was obtained at the beginning and end of each transect and at the beginning and end of each individual physiographic position, which was defined as a transect segment (fig. 6).

After identifying a transect segment, crews matched the burned area with an unburned vegetation plot with a similar physiographic position (aspect, waterway, ridge) and vegetation (tree density based on canopy over and general surface characteristics such as grassland versus forested) from the handbook and recorded the unburned plot number. After this, crews estimated the amount of live trees remaining after the fire by recording the percent change in density based on the selected unburned table. For example, if no trees burned in the fire then there was 0 percent change in density, if half of the trees burned then the value was 50 percent change in density, and if the fire killed all the trees then the crew recorded 100 percent. The crew also directly recorded an estimate of percent cover of surface characteristics (litter, including litter fall from trees since the most recent fire, forbs, mineral soil, grass, and low and medium sized shrubs) after walking through the transect segment. We also noted soil burn severity based on the following degrees of char: unburned, light (litter present but blackened), moderate (no

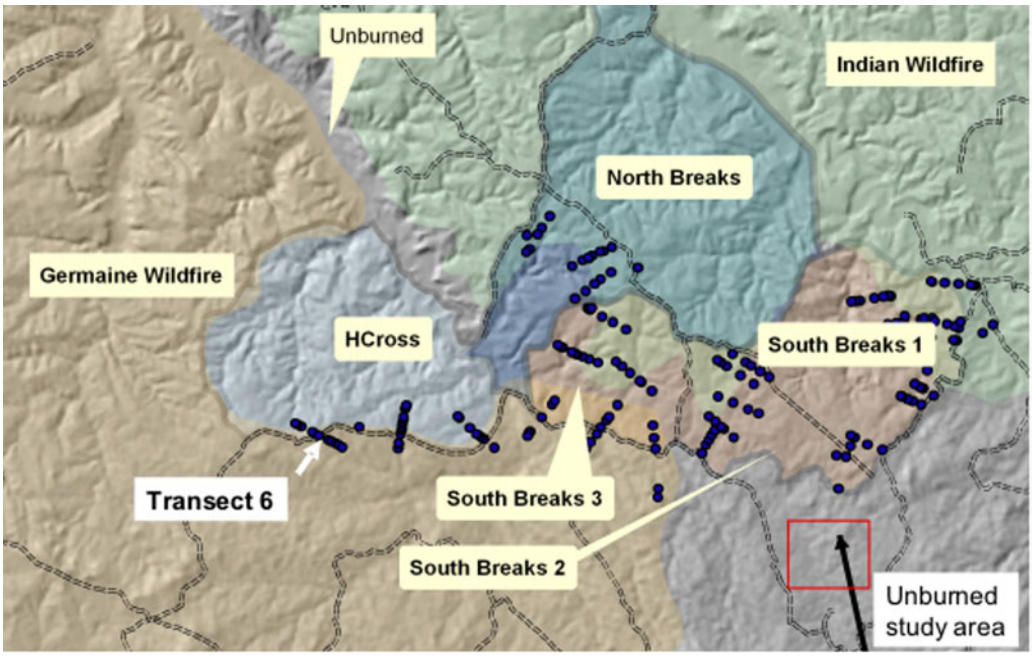

Figure 5—An illustration of transects used to quantify burn severity of soils, surface vegetation, and tree canopy and change in tree density. For example, transect 6 crosses the HCross and the Germaine fire event. This transect was approximately 6000 feet (horizontal distance) long. Observations were transect segments (between dots), indicating where forest structure and burn severity were characterized.

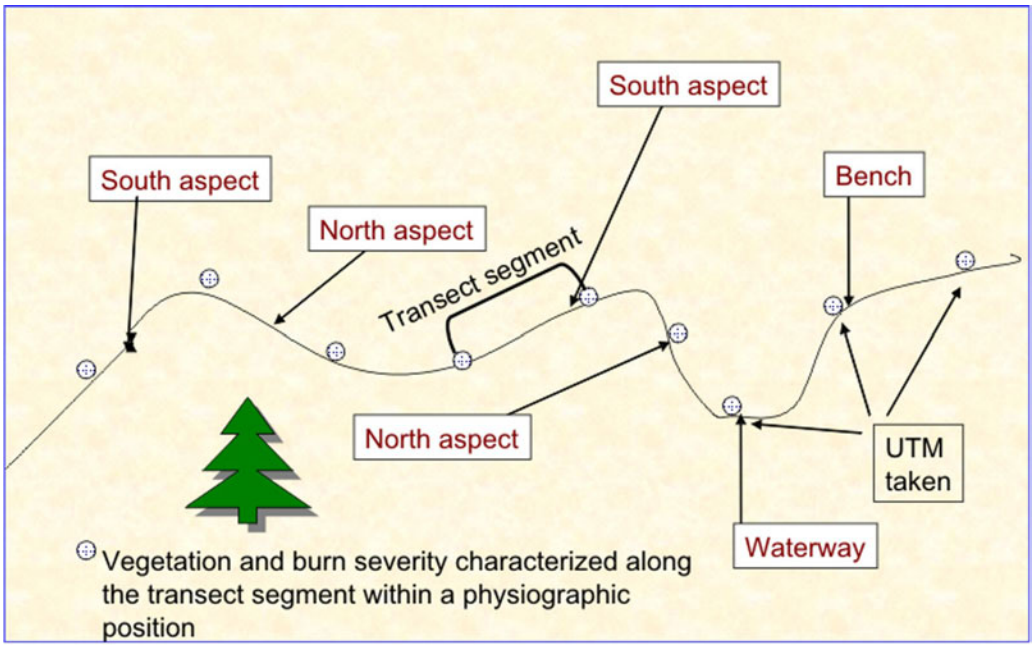

Figure 6—For each physiographic position (transect segment), forest structure (change in tree density) and the burn severity (what was left) were characterized. Universal transverse mercator (UTM) coordinates were recorded at the beginning and end of each physiographic position, the beginning and end of the entire transect, and at the border between two fire events.

litter present, black, or gray colored soil), and high (no litter present, orange coloration to soil) (Jain and others 2006; Ryan and Noste 1985; Wells and others 1979). Within each tree height class, the increase in CBH on live trees was recorded after estimating the height to live crown pre-fire (where live branches were before being killed by the fire) and the current height to live crown (where the live branches were after the fire, at the time of observation by the crew). The crew also recorded the extent of low bole scorch height on trees within each height class (fig. 4b).

In addition to these descriptions, crown scorch was also placed into the following burn severity classes: no sign of scorch all needles green; scorch with most needles green; scorch with most needles brown ; scorch with all needles brown; or scorch or needle consumption without any needles remaining (Jain and Graham 2007; Ryan and Noste 1985). To accompany the structure and severity quantifications, each crew took a photograph of the landscape, vegetation, and the soil surface. We then paired the photographs and data from the burned and unburned sites, enabling us to use the unburned site as a frame of reference for the burned site. We compared the post-fire outcomes to this frame of reference, which reflects current vegetation characteristics.

Statistical Analysis

Three different fire events were defined: prescribed fire alone (HCross, North Breaks, or South Breaks 1, 2, and 3), wildfire alone (Germaine or Indian), and a combination of the two (table 1). We used a linear mixed model (Schabenberger and others 2002) to determine if there were statistically significant differences among the fires in litter cover, mineral soil exposed, forb, grass, and shrub cover. We used transect sections as our replications for a given physiographic position (waterway, ridge, north-facing aspect, and south-facing aspect). Because the prescribed fires were designed to decrease tree density in specific height classes (USDI fire prescriptions, unpublished), we used the post-fire tree densities to evaluate differences among the fires and the paired unburned sites in the analysis. For example, for the HCross prescribed fire, we compared the trees per acre that differed on sites burned by the HCross prescribed fire alone (N=13) versus the Germaine wildfire (N=9) versus the HCross followed by the Germaine wildfire (N=8) versus unburned sites (table 1).

Results And Discussion

Evaluation of the Fire Prescriptions

Although we conducted an analysis to determine if we could detect statistically significant differences (p-value ≤ 0.10) among fires, we found no significant differences using any of the attributes. This lack of significance was not surprising, as the Missouri River Breaks landscape consists of a variety of physical settings and vegetation mosaics (figs. 2 and 3). Physical setting, fuels, and weather all influence fire behavior and effects and can vary immensely, depending on time of day and location where the fire burned. Places that contain a continuous distribution of live and dead plant material (fuels) burn very differently than places

that contain discontinuous fuels typified by mosaics of different vegetation (trees versus grasses, versus shrubs) (Finney 2001). Moreover, relative humidity, fuel moistures, and air temperatures can vary depending on physical setting (waterways versus ridges or south-facing aspects) and time of day.

We did not have fire progression maps and detailed weather information to account for these sources of variation, which more than likely contributed to the variation in fire behavior and burn severity, and subsequently influenced our statistical results. Although we did not detect statistically significant changes, we did discover several interesting trends.

We organized our results within the six prescribed fires and within different physiographic positions. The four physiographic positions are waterways, which include ravines and gullies, all south-facing aspects, all north-facing aspects, and ridges. We report surface characteristics (percent cover of mineral soil, litter, and vegetation) within the four physiographic positions. Litter and mineral soil exposed were a more consistent indicator of burn severity than char classes. For trees, we merge ridges within south-facing aspects. Each section contains the fuels, resource objectives, fire prescription (desired weather and prescribed fire objectives), weather summary obtained during the prescribed fire, and the resulting post-fire condition for the soil surface, ground level vegetation, tree density, and CBH. We also report the weather that occurred during the wildfires from three local weather stations (Chain Butte, Dry Blood Creek, and South Sawmill) and used FireFamily Plus to provide weather summaries (Bradshaw and McCormick 2000). Complementing this information is an evaluation to determine if the prescribed fire met the resource objectives. To illustrate trends in our results among the different fires we use quantile box plots to show the distribution of the data (fig. 7).

6X7W Prescribed Fire

The 6X7W prescribed fire burned 365 acres on April 29, 30, and May 1, 1998 (fig. 1). Prior to the fire, the area contained pockets (approximately three acres in size) of young ponderosa pine trees (1 to 20 years old and 6 to 8 feet tall) growing on north- and east-facing aspects (USDI 6X7W fire prescription, unpublished). Interspersed throughout the area were old (> 100 years old and 40 to 80 feet tall) single ponderosa pines. South- and west-facing aspects contained isolated pockets of old ponderosa pine with young pines in the understory. Depending on the aspect, tree density varied, with some sites having 60 percent canopy cover (fig. 8). Open savanna grasslands were also present throughout the area. In places where livestock were grazed (southwestern corner of area) fine fuels (grasses) were minimal. However, in other locales, fine fuels (grass, litter, and shrubs) were continuous and small pockets of Rocky Mountain juniper were present in drainages and north-facing aspects.

The 6X7W prescribed fire was intended to introduce fire into the area, although the fire managers recognized that one fire would probably not reduce fuels to a satisfactory amount and they recognized multiple fires may be required. Because the Germaine wildfire burned the entire area where the 6X7W occurred, we were unable to evaluate areas only burned by the 6X7W. However, the combination of prescribed fire (first fire) and wildfire (second fire) provided an opportunity to evaluate post-fire forest characteristics. In addition, there could be an opportunity to evaluate whether the prescribed fire tended to moderate the effects of the wildfire.

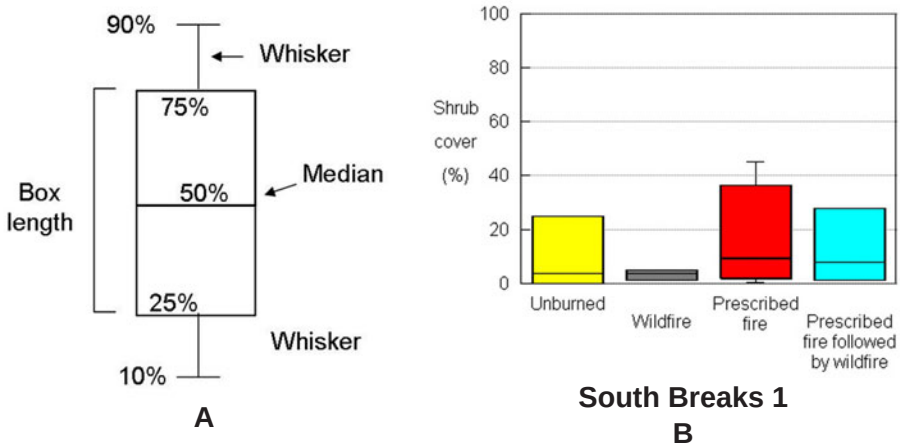

Figure 7—We used quantile box plots to show how observations are dispersed among the different fire events. Graph A shows a quantile box and whisker plot. These plots contain three elements: the box length, the median (black line in box), and two whiskers. A quantile box and whisker plot is created by first ranking observations, such as percent cover, from observations containing the lowest amount of cover to observations containing the highest amount of cover. Then the observations are divided into classes using the following thresholds: 10%, 25%, 50%, 75%, and 90%.

Graph B shows what the shrub cover is at each of these thresholds and the length of the whisker and length of the box shows the variation in shrub cover between each of the thresholds. This graph shows shrub cover in waterways within the South Breaks 1 prescribed fire (red box). Shrub cover ranged from 0 to 45% (from end of whisker to end of whisker), the median was 9% shrub cover (line in middle of box), and the observations above the median had more variation in shrub cover (9 to 45%) than the observations below the median (0 to 9%). In addition, 25 to 75% of the observations (observations represented within the box) ranged from 2 to 38% shrub cover. This would indicate that many of the observations had very little amounts of shrubs present, but patches did exist that contained high shrub cover in the prescribed fire. Boxes without whiskers indicate three values that reflect the percent cover of shrubs (not to be confused with observations). However, in some cases, such as in unburned riparian areas, there were only three observations (table 2). For communication purposes, we used a quantile box and whisker plot rather than the standard box and whisker plot (quartile box plots) sometimes displayed in other scientific publications.

Figure 8—An example of sites that contained greater than 60% canopy cover that may have occurred heterogeneously prior to the prescribed and wildfires.

Average air temperature (range not available) during the prescribed fire was within prescription of 70° F (table 4). Relative humidity averaged (range not available) 25 percent, and mid-flame wind speed (3 to 7 mph) occurred within the prescriptive range. Fuel moistures were also within prescription and ranged from 9 percent in the 1-hour fuels to greater than 12 percent in the 1000-hour fuels. Live fuel moistures ranged between 155 to 200 percent.

During the Germaine and Indian wildfires, air temperature, relative humidity, and wind speed were similar to those that occurred during the 6X7W, except fuel moistures, which were less. Depending on time of day, minimum fuel moistures were 1, 2, 4, and 8 percent for 1-hour, 10-hour, 100-hour, and 1000-hour fuels, respectively. In addition, air temperatures tended to exceed 74° F and the minimum relative humidity was 8 percent. Thus, fuel and weather conditions during the wildfires tended to be drier and warmer than weather conditions during the prescribed fire.

Table 4—The desired (prescribed) and observed weather parameters at the time of implementation. The prescribed fires include the 6X7W, HCross, North Breaks, and South Breaks (which required three different ignitions and burning periods) No. 1, No. 2, and No. 3. Also, included are the weather conditions during the Germaine and Indian wildfires. Observed fuel moistures, energy release component, and burning index for the North Breaks and wildfires were obtained from three (Chain Butte, Dry Blood Creek, and South Sawmill) weather stations. The pine-grass savanna fuel model and the weather from these stations were summarized using FireFamily Plus (Bradshaw and McCormick 2000). Observations of temperature, relative humidity, and wind speed and direction for the wildfires were also obtained from the same weather stations. Other observations were conducted on site. Pocket card (tool used in fire danger rating system) values were obtained from the Northern Rockies, Miles City Field Office for the Pine-grass Savanna fuel model (USDI 2006). Typically, pocket cards are used for national fire danger rating and fire fighter safety (Andrews and others 1998) and are usually not used during prescribed fires. However, the authors included these values to provide context.

			Wind		Fuel moisture						
Fire	**Temperature**	**Relative humidity**	**Speed**	**Direction**	**1-hour**	**10-hour**	**100-hour**	**1000-hour**	**Herbaceous**	**Energy release component**	**Burning index**
	(^{0} F)	**(%)**	**(mph)**	**(cardinal)**	**----------(%)----------**						
Pocket Card	> 85	< 20	> 15					< 11		> 14	
6X7W Prescribed Fire was burned April 29, 30, and May 1, 1998											
Prescribed	50 to 90	15 to 40	3 to 15	All	6 to 14	8 to14	10	12 to 15	130 to 200		
Observed	70	25	3 to 7	S, E, NE	9	10	12	>12	155 to 200	17, 20	32, 42
HCross Prescribed Fire was burned April 22-23, 2003											
Prescribed	70	15 to 40	3 to 15	All	6 to 14	8 to14	10 to 30	Unknown	130 to 200		
Observed	66 to 76	26 to 31	6 to11	E, SE	5	10	12	16	150 to 200	15, 18	25, 52
North Breaks was burned April 25-26, May 26-28, 2003											
Prescribed	68 to 72	20 to 35	5 to 7								
Observed	50 to 79	20 to 40	2 to 10	S, SE	5 to 8	7 to 9	9 to 14	14 to 18	Unknown	12, 15	26, 39
South Breaks Prescribed Fire No. 1 was burned May 17-19, 2001, No. 2 was burned April 23-25, 2001, and No. 3 was burned May 2-4, 2001											
Prescribed	60 to 70	28 to 50	3 to 11	All	7 to 9	8 to 11	10 to 13	12 to 15	80 to 120		
Observed											
No. 1	61 to 65	20 to 30	6 to 16	SE, NW	9	9 to 11	10 to 12	> 12	90 to 110	19, 21, 22	41, 51, 80
No. 2	59 to 64	20 to 25	7 to 17	W, NW	9	9 to 11	10 to 12	> 12	90 to 110	17, 18, 21	44, 44, 65
No. 3	63	25 to 30	5 to 15	N, NW	9	9 to 11	10 to 12	> 12	90 to 110	16, 21, 22	41, 35, 59
Germaine & Indian wildfire burned July 17 through July 28, 2003											
Observed	74 to 91	8 to 33	4 to 9	All	1 to 6	2 to 6	4 to 6	8 to 9	64 to 75	15 to 20	21 to 39

Except on ridges, after both fires, the variability in litter cover (10 percent to 86 percent) was greater on unburned sites than on burned sites (0 to 20 percent) (fig. 9). On south-facing aspects the median litter cover was similar across all sites irrelevant of fire history (unburned versus burned). In contrast, on north-facing aspects and waterways the median litter cover of unburned sites was approximately 60 percent while on burned sites the median litter cover was approximately 20 percent. This result suggests that the two fires,

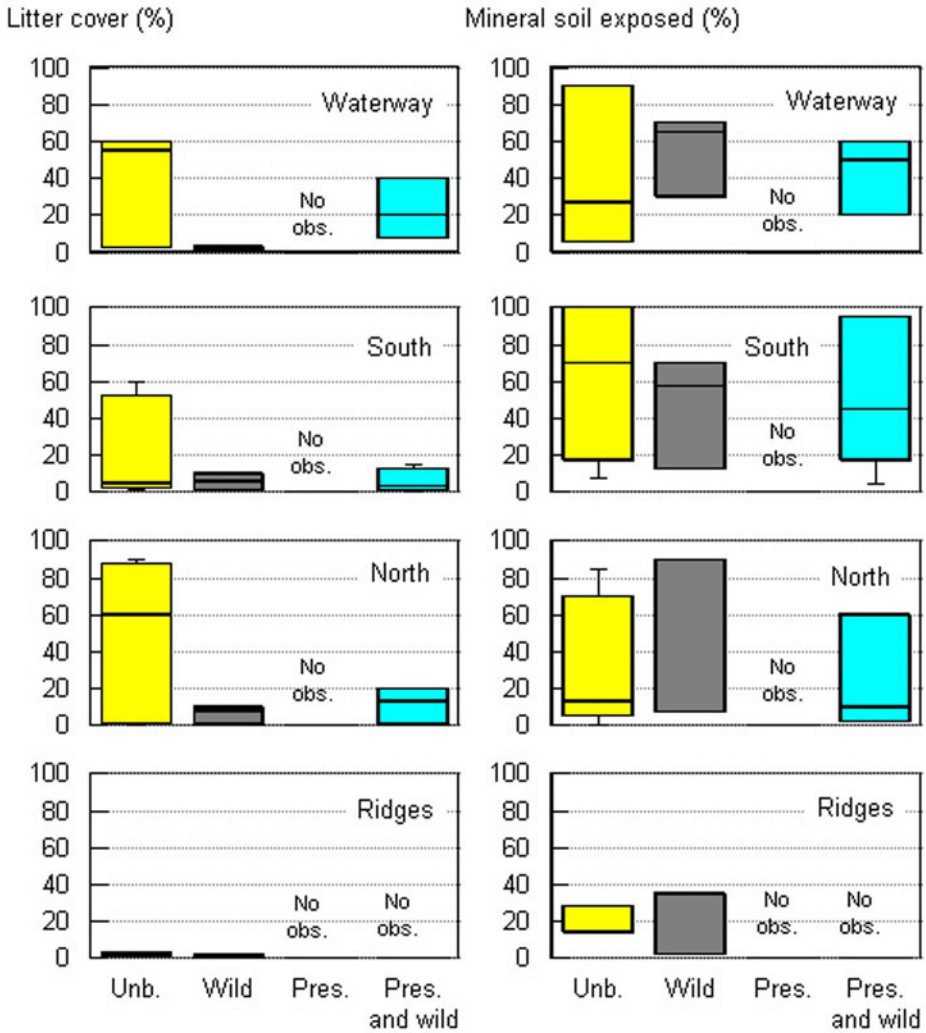

Figure 9—Percent litter cover and mineral soil exposed for sites that burned through and around the 6X7W prescribed fire and unburned sites. Since the Germaine wildfire burned through the entire area where the 6X7W prescribed fire occurred, there were no observations that evaluate only the prescribed fire. The site had very few distinct ridges; therefore, we did not obtain observations in these places. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

when combined, influenced the continuity of litter cover. The median and variation of exposed mineral soil tended to be similar for all sites, except for waterways, whether burned or unburned, suggesting that the fires did not necessarily expose more mineral soil.

One of the prescribed fire objectives was to stimulate native forb and grass production (table 5) (USDI 6X7W fire prescription, unpublished). There was a slight increase in forb cover on sites burned by the combined fire event.

Table 5—Resource objectives for the prescribed fires conducted within the Missouri River Breaks. In all prescribed fires the primary resource objective were to return fire to the area, remove hazardous fuel buildup, restore rangelands to native grasses, forbs, and shrubs, increase overall herbaceous productivity, and remove tree encroachment into meadows and grasslands. Each column identifies the percent target mortality of trees. The prescriptions did not provide target mortality values for Rocky Mountain juniper, except to decrease its abundance. Prescription objectives for all the prescribed fires designated a desire to increase native shrub, forb, and grass abundance.

	6X7W		HCross	North Breaks	South Breaks	
Vegetation	**Target mortality on north & east aspects**	**Target mortality on south & west aspects**	**Target mortality on all aspects**	**Target mortality on all aspects**	**Target mortality on all aspects**	**Target mortality on northwest aspects**
Ponderosa pine abundance						
Pine stands	—	80 to 90%	—	—	—	—
Young pine within stands (≤ 12 feet tall)	60 to 70%	50 to 60%	80%	60 to 80%	≤ 90%	—
Mid-aged pine within stands (> 12 to ≤ 23 feet tall)	—	—	80%	50 to 70%	≤ 90%	—
Old-aged within stands (> 23 feet tall)	—	—	< 20%	< 20%	≤ 60%	≤ 20%
Rocky Mountain juniper abundance	Decrease	Decrease	Decrease	Decrease	—	—

Although we did not identify individual species, the fires tended to increase grass cover (fig. 10). The combined fires had grass cover on south- and north-facing aspects ranging from 5 to 78 percent within the 25th and 75th percentile (fig. 10). On unburned sites grass cover on the same aspects varied from 5 to 55 percent within the same percentile range. Grass cover on sites burned only by the wildfire did not differ substantially from unburned areas. However, on burned sites in waterways there tended to be less grass cover compared to the cover observed on unburned waterways. The median shrub cover tended not to differ among the sites. However, there was more variation in shrub cover in burned areas on ridges after the wildfire compared to unburned areas (fig. 10).

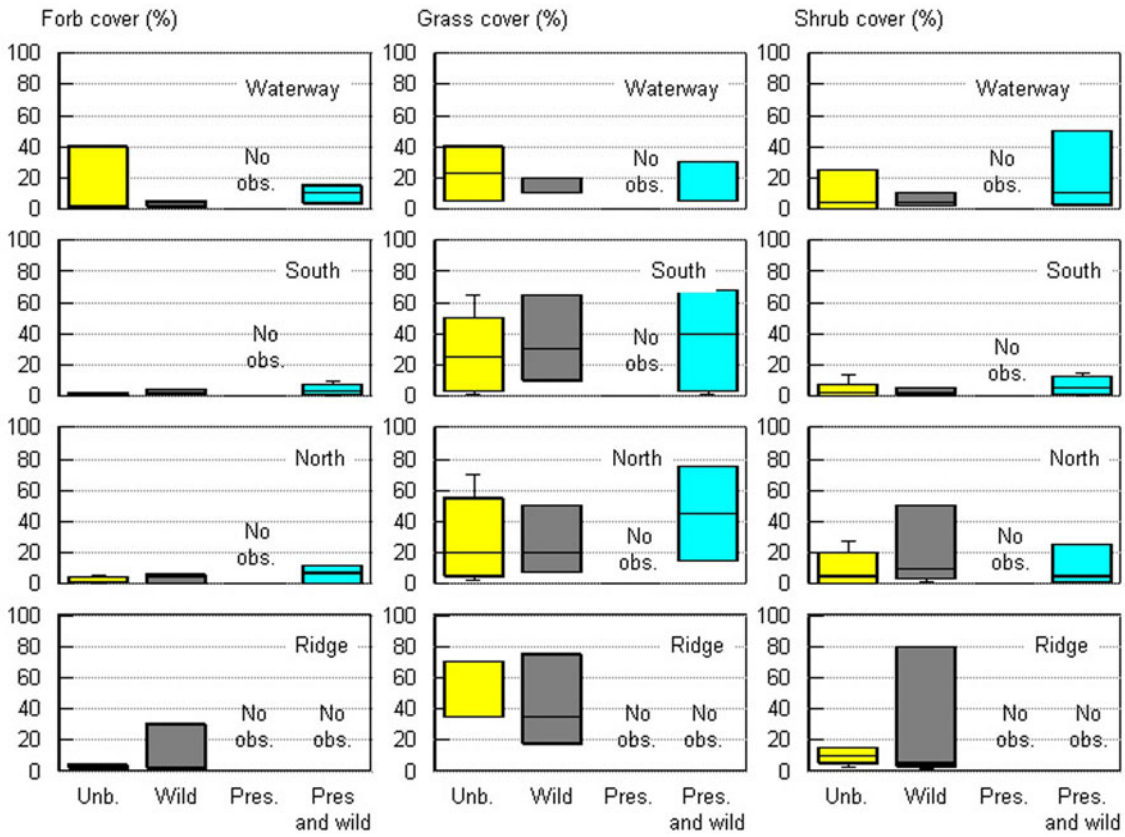

Figure 10—Percent forb, grass, and shrub cover for areas within and surrounding the 6X7W prescribed fire. Plots show the variation among the different fire events and unburned sites. Since the Germaine wildfire burned through the entire area where the 6X7W prescribed fire occurred, there were no observations that evaluate only the prescribed fire. The site had very few distinct ridges; therefore, we did not obtain observations on these places. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

The intention for the prescribed fires was to remove (kill) 60 to 70 percent of the young ponderosa pine on north and east aspects and kill 50 to 60 percent on south and west aspects (table 5) (USDI 6X7W fire prescription, unpublished). In addition, the objective was to decrease the abundance of Rocky Mountain juniper in all areas. In general, the wildfire exceeded these desired characteristics, as it killed most trees less than or equal to 12 feet, except for a very few within waterways (fig. 11a). The combined fire had 50 percent fewer small trees, fulfilling prescription objectives. With sites burned by both fires, the median CBH of small pines (≤ 12 feet tall) did not change, while the variation in CBH did increase on

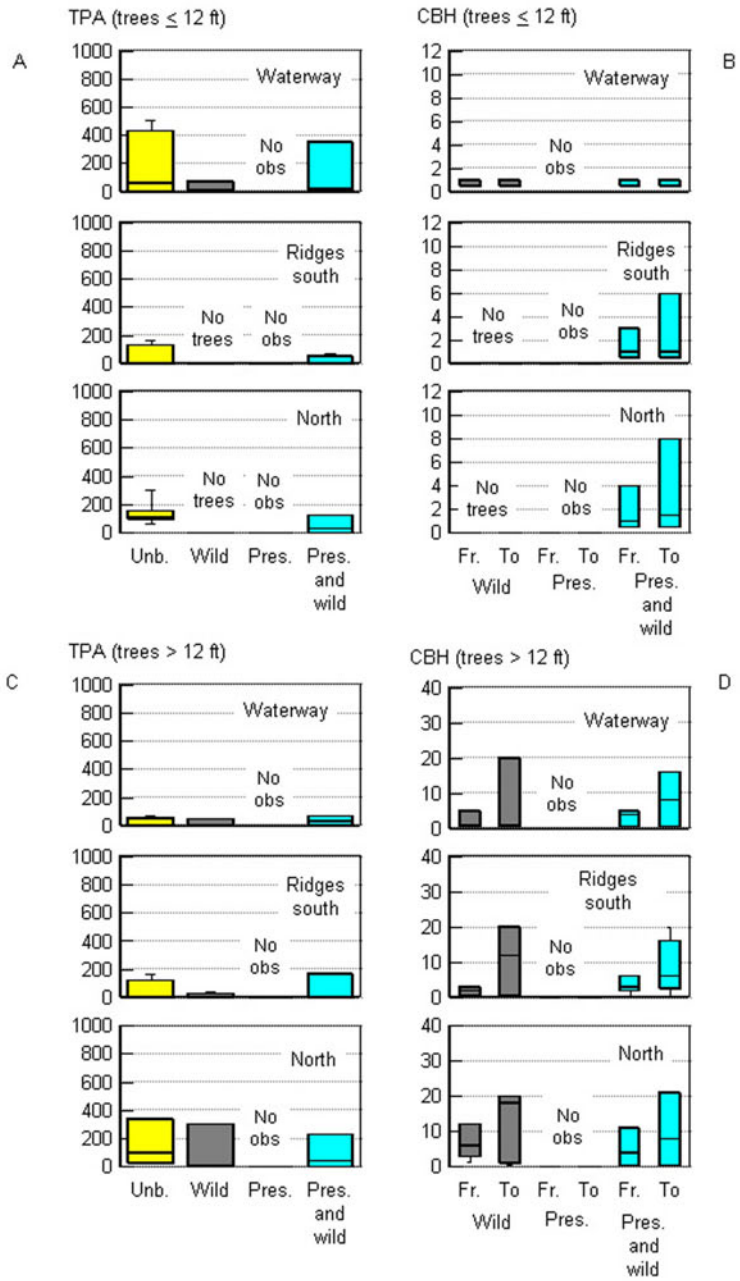

Figure 11—Trees per acre (TPA) (A and C) and canopy base height (CBH) (B and D) for small (≤ 12 feet tall) and large (> 12 feet tall) trees, located on areas surrounding and within the 6X7W prescribed fire. Figures are organized by three physiographic positions: waterways, which include gullies and ravines; ridges/south, which includes south-facing aspects and ridges; and north-facing aspects. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. wild = prescribed fire followed by wildfire, Fr = from pre-fire CBH, and To = to post fire CBH.

north and south aspects (fig. 11b). This lack of change in CBH median is probably due to some patches of trees burning and changing the CBH, while in other places the wildfire did not alter the CBH. The greatest abundance of Rocky Mountain juniper was in the waterways and north-facing aspects; however, on the sites we sampled after the fires, no juniper survived.

The design for the prescription fires was to remove 80 to 90 percent of the tall ponderosa pine trees on south- and west-facing aspects (table 5) (USDI 6X7W fire prescription, unpublished). On northerly aspects, there was little difference in tall (> 12 feet) ponderosa pine densities (trees per acre) between the unburned and wildfire sites and only a slight decrease in tree density on sites burned by both the prescribed and wildfire (fig. 11c). On ridges and southerly aspects, there tended to be fewer tall trees left on sites burned by the wildfire, with a decrease of 50 to 60 percent. Unburned sites and areas burned by both fires had similar tree densities. The wildfire appeared to achieve the 80 to 90 percent ponderosa pine mortality target set forth in the prescribed fire objectives on south-facing aspects (table 5), while the combined fire event did not (USDI 6X7W fire prescription, unpublished). However, these results may also suggest that on these same aspects, the prescribed fire created forest structures that minimized large tree mortality during the wildfire.

For tall trees that survived in areas burned only by the wildfire, the median CBH on ridges and south-facing aspects was 6 feet and on north-facing aspects, the median CBH was 8 feet (fig. 11d). In waterways, there was considerable variation in CBH; however, the median CBH did not differ when compared to all sites.

HCross Prescribed Fire

The HCross prescribed fire burned approximately 2,325 acres on April 22 and April 23, 2003 (fig. 1). Prior to the prescribed fire the forests were heterogeneous and contained multi-aged ponderosa pine trees (USDI HCross fire prescription, unpublished). The core of the site contained dense patches of young (1 to 20 years old) and mid-aged (20 to 40 years old) ponderosa pine. Forests in the west and northwest portions of the area were mainly old (> 100 years old) ponderosa pine with some dense patches of intermediate canopy layers containing young and mid-aged trees (fig. 1). The area was open with scattered ponderosa pine, with occasional pockets of dense young and mid-aged ponderosa pine in the northern portion. Young and mid-aged ponderosa pine were also present throughout the grasslands and grass and shrub abundance was low.

Weather conditions were not as warm and dry as for the wildfires (table 4). The observed air temperature for the HCross ranged from 66 to 76° and relative humidity ranged from 26 to 31 percent. For the wildfires air temperature ranged from 74 to 91° and relative humidity ranged from 8 to 33 percent. One-hour fuels for the wildfires and HCross were within the same range; however, the 10-hour, 100-hour, and 1000-hour fuels within the HCross area had higher moisture contents than the wildfires with 5, 10, 12, and 16, respectively.

Portions of the HCross prescribed fire were subsequently burned by the Germaine wildfire. Therefore, we were able to compare the effects of a prescribed fire alone with those of a wildfire, and those of a prescribed fire followed by a wildfire. Because of time and access issues, our sampling and subsequent summaries

reflect the southern portion of the HCross fires (fig. 5). The amount of litter cover after the different fires varied depending on physiographic position (fig. 12). On ridges and waterways, there was slightly more litter cover within places that had a prescribed fire or a combination of the two compared to places that were unburned. Accumulation of litter in waterways from erosion of uplands or litter fall from overstory trees may have increased the amount of litter. On north- and south-facing aspects, litter cover was less on sites burned by the prescribed fire and much less on sites burned by the wildfire, compared to the unburned sites. Mineral soil exposed tended to follow an inverse relationship with litter cover (fig. 12). For example, in places where more litter cover occurred less mineral soil tended to be exposed, such as on south-facing aspects.

For vegetation cover, grasses showed the greatest difference. Median grass cover was higher on all burned sites when compared to unburned sites, except

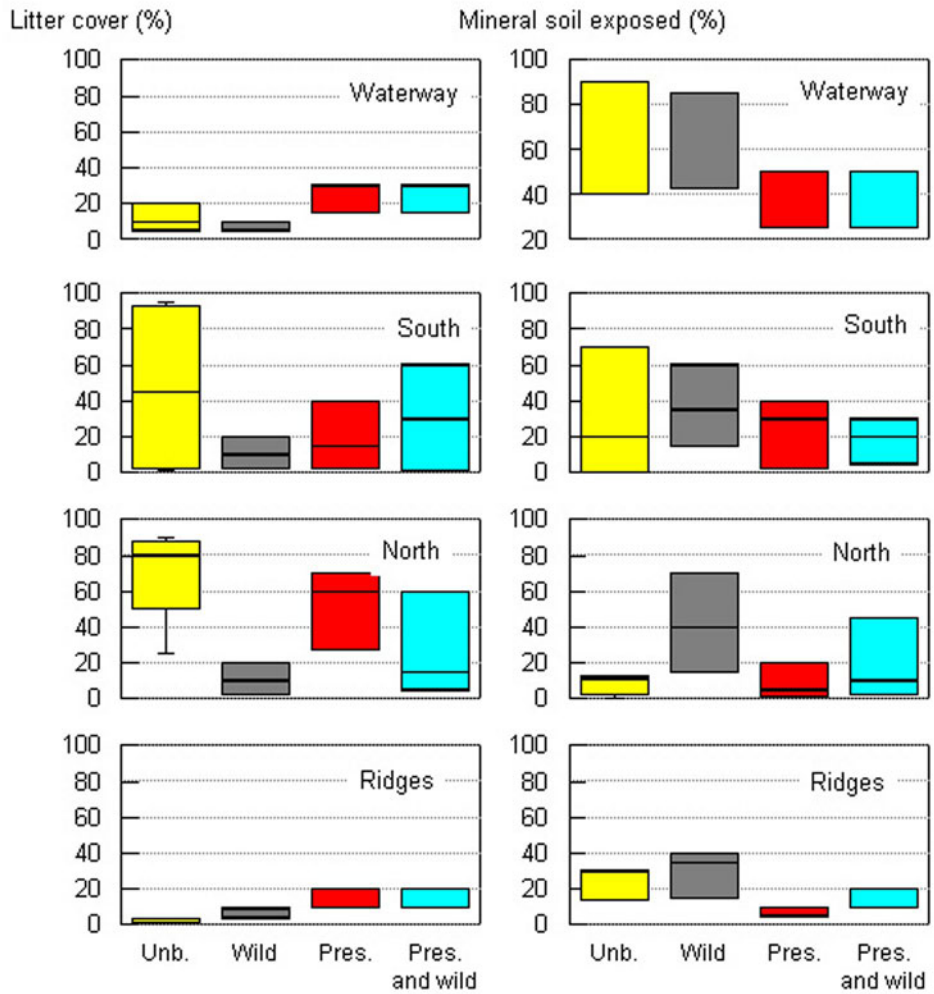

Figure 12—Percent litter cover and mineral soil exposed for sites that burned through and around the HCross prescribed fire, wildfire, and combined fire event. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

within waterways (fig. 13). Sites burned by both fires had the most grass cover, particularly on south-facing aspects with a median cover of 65 percent. Forb or shrub cover did not differ substantially among the areas burned by the three fire events and unburned sites.

The design of the prescribed fire was to restore the forest structure in a way similar to what occurred historically and reduce the amount of ladder fuels and tree density (USDI HCross fire prescription, unpublished). The goal of the fire was to remove 80 percent of the young ponderosa pine, kill 80 percent of the mid-aged ponderosa pine, and kill less than 20 percent of the old ponderosa pine (table 5). Either all the trees less than 12 feet tall were killed, as with most places burned by the wildfire, or there was no considerable difference in tree densities

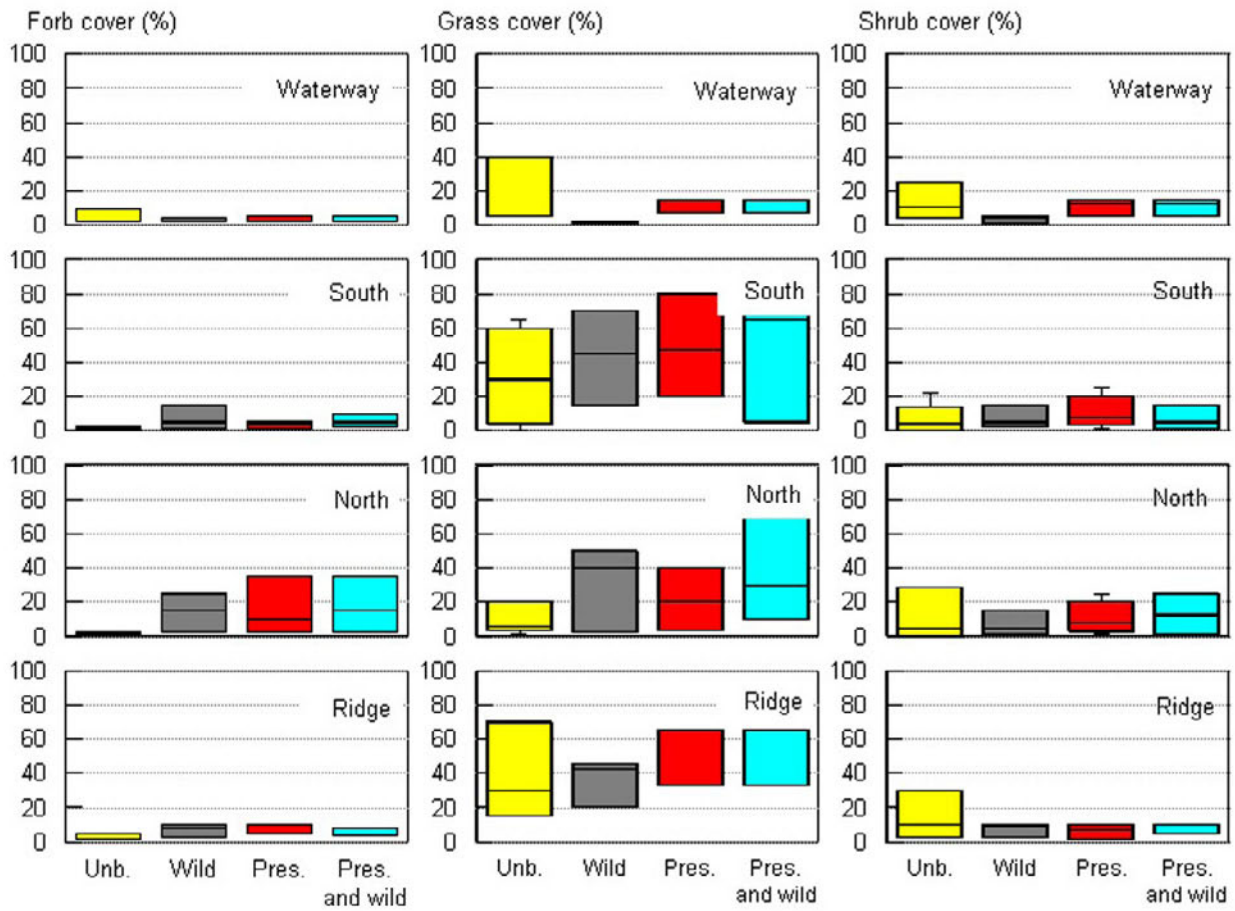

Figure 13—Percent forb, grass, and shrub cover for areas within and surrounding the HCross prescribed fire. Plots show the variation among the different fire events. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

between unburned and burned sites (fig. 14a). The wildfire and combined fires tended to have the least amount of trees surviving one year after the wildfire. The prescribed fire alone on south- and north-facing aspects had similar post-fire tree densities compared to the unburned sites. In waterways, where very few trees existed, there were no trees present after the wildfire, and very few trees present after the combined fire event. In summary, the HCross did not change tree density until it was complimented by the wildfire.

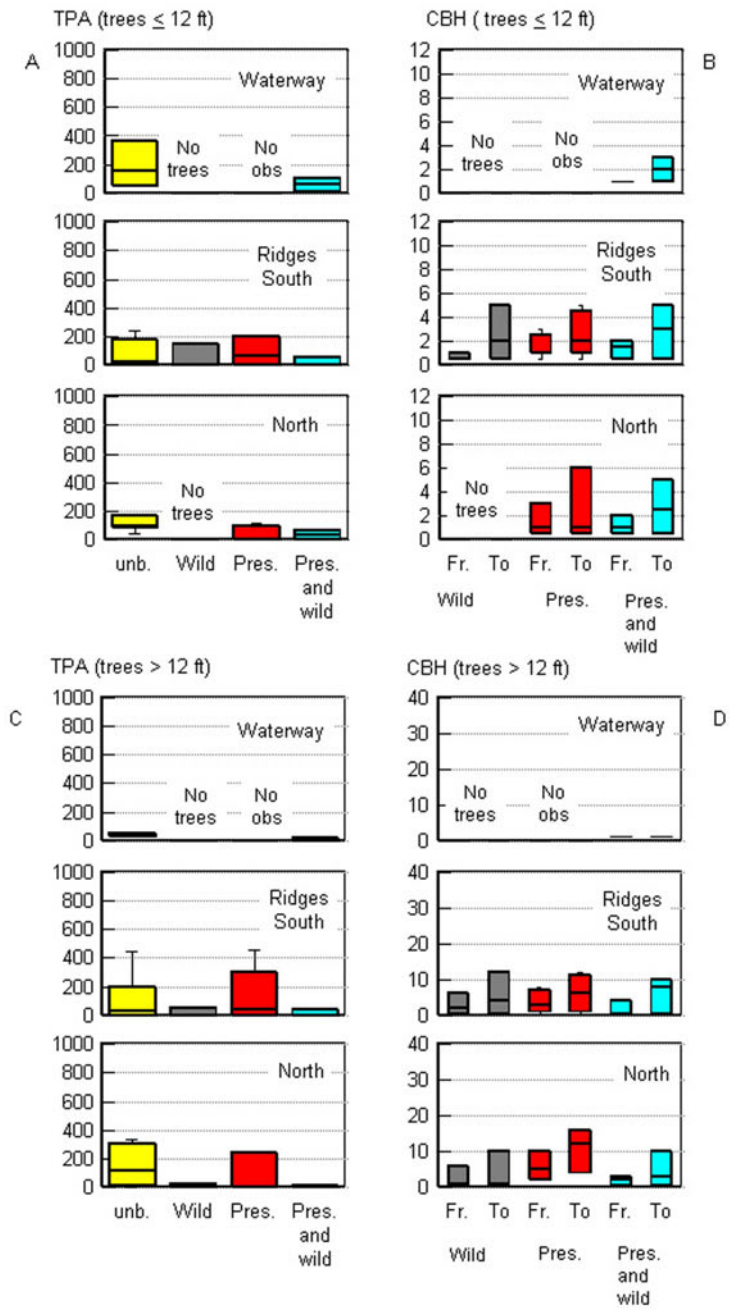

Figure 14—Trees per acre (TPA) (A and C) and canopy base height (CBH) (B and D) for small (≤ 12 feet tall) and large (> 12 feet tall) trees, located on areas surrounding and within the HCross prescribed fire. Figures are organized by three physiographic positions: waterways, which include gullies and ravines; ridges/south, which includes south-facing aspects and ridges; and north-facing aspects. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. wild = prescribed fire followed by wildfire, Fr. = from pre-fire CBH, and To = to post fire CBH.

Using the unburned sites as a frame of reference, in areas burned by the HCross less than 80 percent of the young trees were killed and more than 20 percent of the large trees were killed, thus underachieving target mortality for young trees and overachieving for older (> 23 feet) trees (USDI HCross fire prescription, unpublished) (table 5). In contrast, areas burned by the wildfire and areas burned by the combined fire events killed greater than 80 percent of the young trees, exceeding prescribed fire objectives (table 5, fig. 14a).

For surviving young trees, the median CBH increased and had high amounts of variation after the combined fires (14b). On north-facing aspects after the prescribed fire (fig. 14b, d), CBH on surviving tall trees increased from a median of 5 feet to a median of 13 feet (fig. 14d). In places burned by both fires, the range in variation of CBH increased, although the median did not differ substantially. Similar results occurred within sites where the wildfire had occurred.

North Breaks Prescribed Fire

The North Breaks prescribed fire burned approximately 3,769 acres on April 24-25, 2003, and May 26-28, 2003 (fig. 5). The fuels prior to treatment were forested lands containing multi-aged ponderosa pine (USDI North Breaks fire prescription, unpublished). Dense patches of young (< 20 years old) ponderosa pine were abundant with some pine encroachment into the grasslands. Many of the large trees (> 80 years old and 10 inches in diameter) were located in drainages and on north-facing aspects with a few isolated individuals distributed throughout the area. Vegetation included areas of grasslands with small shrubs interspersed throughout these sites. The area along the fire perimeter was easily accessible to livestock, which may explain why fine fuels (grasses) were minimal and heterogeneously distributed.

As with the other prescribed fires, the design for the North Breaks was to restore the forest to conditions comparable to those that occurred historically (USDI North Breaks fire prescription, unpublished). This included increasing native grass and forbs and increasing all herbaceous occurrences (USDI North Breaks fire prescription, unpublished) (table 5). In addition, the objective was to reduce crown fire potential in the ponderosa pine stands by removing dense understories of young and mid-aged trees, and stop pine encroachment within the grasslands and meadows. We sampled sites burned by the North Breaks prescribed fire and sites that burned by both the North Breaks and Indian wildfire. Because of accessibility limitations, we did not sample the area burned by the Indian wildfire alone that occurred adjacent to the North Breaks.

The North Breaks burned as the prescription detailed (table 4), with relative humidity ranging between 20 and 40 percent, wind speeds varying between 2 and 10 mph, and fuel moistures ranging from as low as 5 percent in 1-hour fuels to as high as 18 percent within the 1000-hour fuels. Most of the area burned by the North Breaks burned again during the Indian wildfire, which burned during a warmer and drier period. The exception was a small area on the southwest corner, where we concentrated our data collection to obtain observations from both fires.

Within the area burned by the North Breaks, litter cover was substantially less than areas that were unburned (fig. 15). Depending on physiographic position, sites burned by both fires had litter cover ranging from 7 to 40 percent compared to the unburned areas, such as within waterways, in which litter cover varied from 5 to 95 percent. The median for mineral soil exposure on north-facing aspects after the prescribed fire was 80 percent and on sites burned by both the prescribed and wildfire, the median mineral soil exposure was approximately 55 percent (fig. 15).

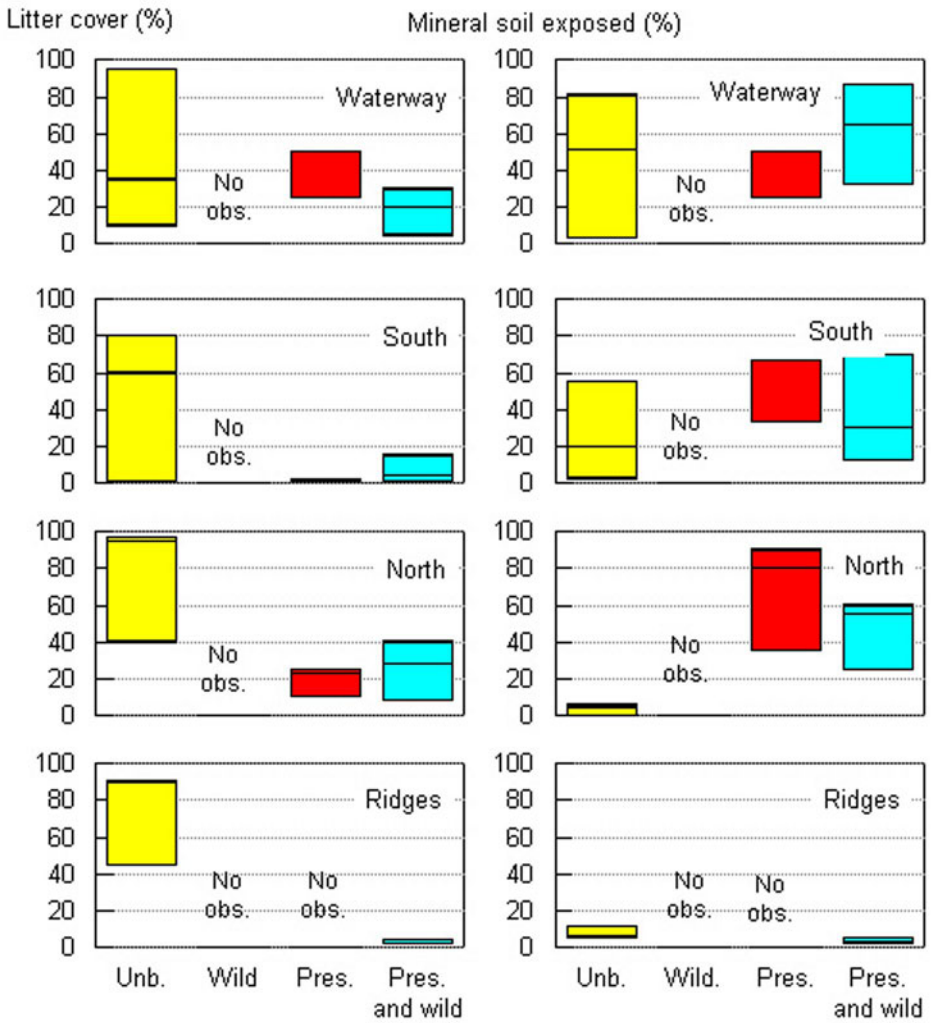

Figure 15—Percent litter cover and mineral soil exposed for sites that burned through the North Breaks prescribed fire. On ridges there were no observations obtained in places burned by the prescribed fire alone. No observations for the wildfire alone surrounding the North Breaks were obtained because the area was not accessible. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

On sites burned by both fires, grass, forb, and shrub cover did not differ from amounts occurring on unburned sites (fig. 16). The design for the North Breaks prescribed fire was to kill 60 to 80 percent of the young ponderosa pine trees (< 60 years old), 50 to 70 percent of the mid-aged ponderosa pine trees, and up to 80 percent of the ponderosa pine encroaching into open grasslands (USDI North Breaks fire prescription, unpublished). While accomplishing this, the objective would be to retain the mature tree structure (no more than 20 percent mortality) (table 5). On the North Breaks prescribed fire, most (83 to 95 percent) of the trees

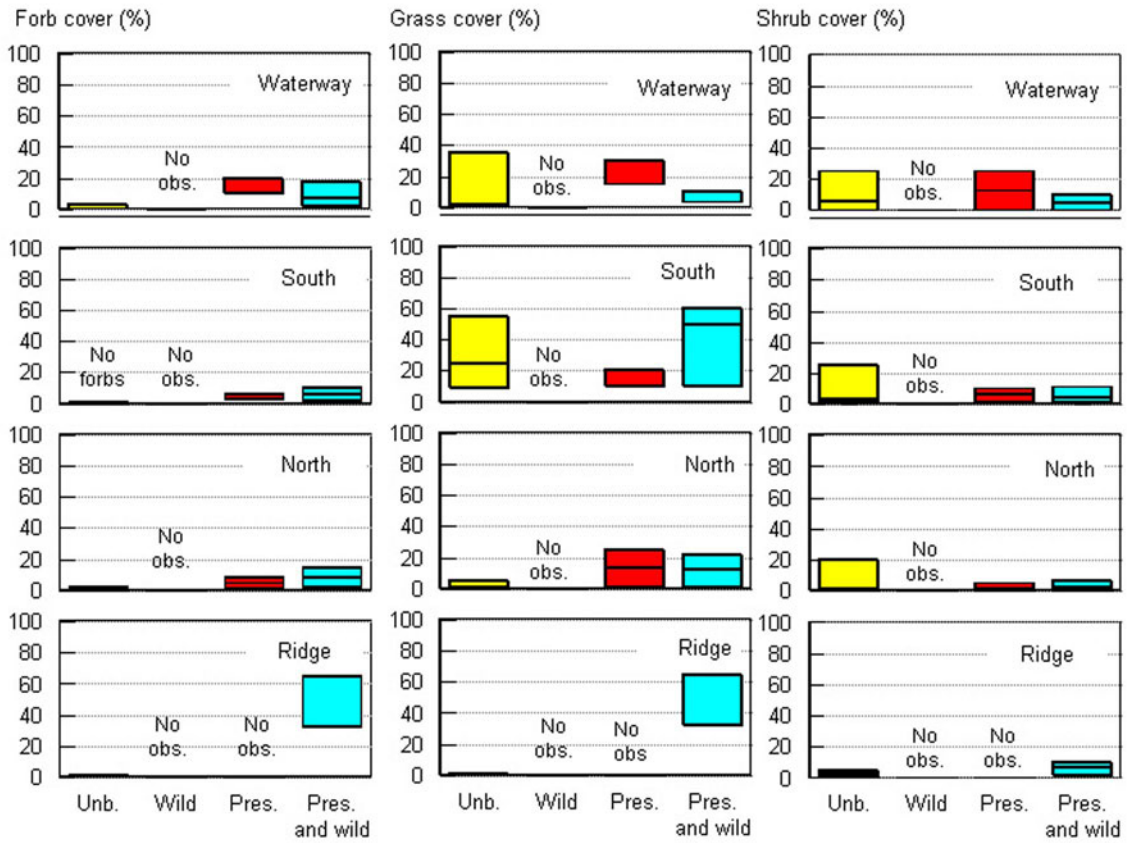

Figure 16—Percent forb, grass, and shrub cover for areas within and surrounding the North Breaks prescribed fire. Plots show the variation among the different fire events. On ridges there were no observations obtained in places burned by the prescribed fire. No observations for the wildfire surrounding the North Breaks were obtained because the area was not accessible. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

≤ 12 feet tall were killed except within waterways (fig. 17), which was above the target mortality outlined in the prescription. On most places median trees per acre for large trees (> 12 feet tall) after the fires did not differ substantially from the median trees per acre on the unburned sites; however, the range was far less than

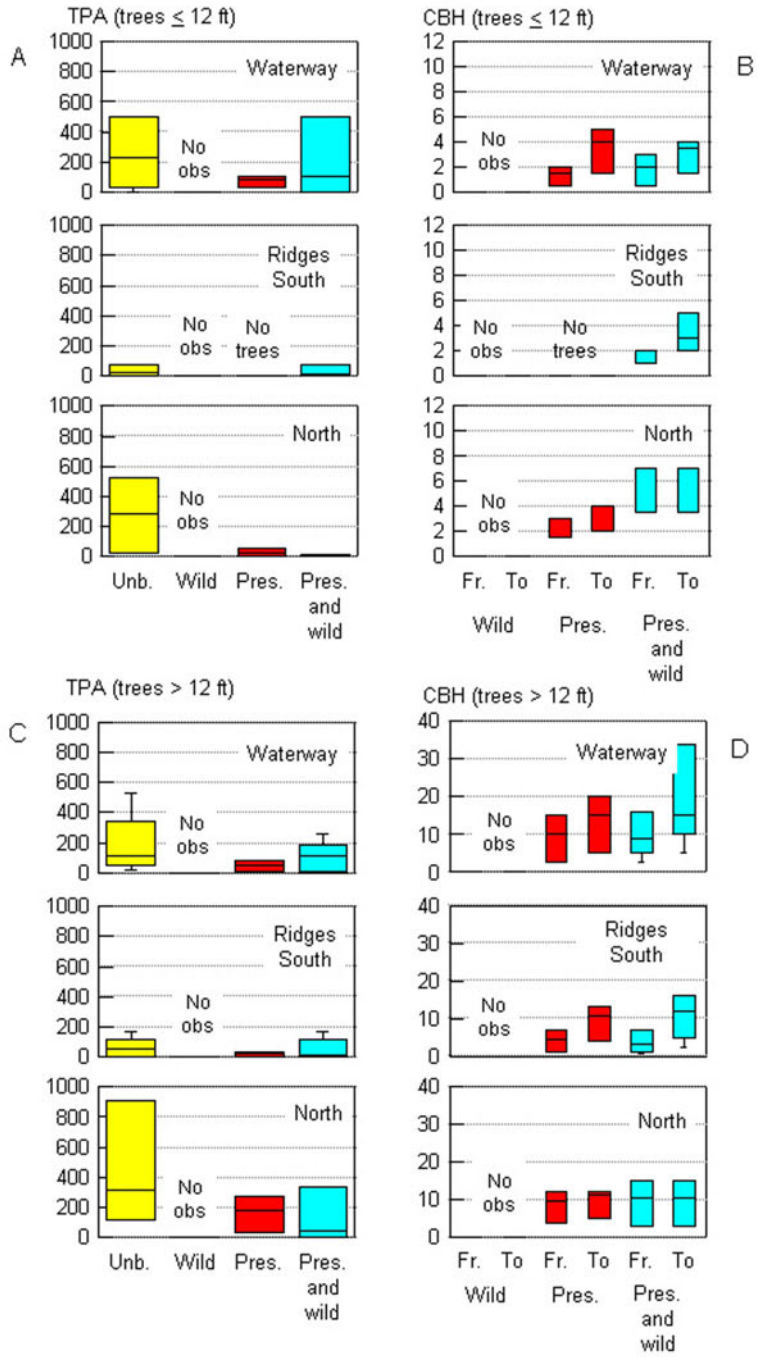

Figure 17—Trees per acre (TPA) (A and C) and canopy base height (CBH) (B and D) for small (≤ 12 feet tall) and large (> 12 feet tall) trees located on areas surrounding and within the North Breaks prescribed fire. Figures are organized by three physiographic positions: waterways, which include gullies and ravines; ridges/south, which includes south-facing aspects and ridges; and north-facing aspects. No observations for the wildfire surrounding the North Breaks were obtained because the area was not accessible. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. wild = prescribed fire followed by wildfire, Fr. = from pre-fire CBH, and To = to post fire CBH.

the range for the unburned sites. For example, on north-facing aspects, trees per acre on burned sites (both prescribed and combined fire events) ranged from 25 to 350 compared to 100 to 900 on unburned sites. When observing individual tree size, mortality decreased as tree height increased. Trees < 23 feet tall had similar mortalities of 50 percent, which fell within the prescription target. Mortality was lowest (40 percent) in trees larger than 23 feet tall, yet still exceeded the prescription target of 20 percent. Median CBH of the surviving small trees increased up to 5 feet (top of range) within the prescribed fires and up to 7 feet within the combined fire event. For large trees, depending on physiographic position, the prescribed fire increased the median CBH from 5 to 12 feet on south-facing aspects and from 10 to 15 feet in waterways (fig. 17). There were limited amounts of Rocky Mountain juniper and the fires killed what trees were present.

South Breaks Prescribed Fires

Full implementation of the South Breaks prescription required three separate burning periods and ignition techniques. Although the prescription and the objectives were the same for all three burns, differences in slope, physiographic positions, fuels, and ignition times may have influenced the fire effects. Therefore, we summarized the results as a comparison among the three prescribed fires. The South Breaks fire burned 3,075 acres during the spring of 2001 (fig. 1). South Breaks 1 covered approximately 1,452 acres and burned on April 17-19. South Breaks 2 burned approximately 715 acres on April 23-25 and South Breaks 3 burned approximately 908 acres on May 2-4. Prior to the fires a variety of grasses, sedges, and shrubs were dispersed through out the area, intermingled with groups and patches of trees (USDI South Breaks fire prescription, unpublished). Three age classes of ponderosa pine existed within the area: young (< 20 years old, ≈ 3 feet tall), mid-aged (40 to 60 years old, ≈ 20 feet tall), and old (> 100 years old, ≈ 40 feet tall). One-third to five acre patches (occasionally exceeding 1200 trees per acre) of young trees (< 3 feet tall) covered 30 percent of the site (50 percent canopy cover). Mid-aged trees (exceeding 800 trees per acre) occurred in three to five acre patches. Old trees occurred in patches of seven to 13 acres and covered approximately 40 percent of the area. The objective of the prescribed fire was to reduce the intensity and severity of future surface fires and decrease the potential for crown fire. This required increasing native grasses and forbs, minimizing the fire impact on shrub communities, and decreasing tree densities (USDI South Breaks fire prescription, unpublished) (table 5).

Although not as warm or dry as the wildfire, weather at the time of the fires varied, but not substantially (USDI South Breaks fire prescription, unpublished) (table 4). Relative humidity ranged between 20 to 30 percent for all three fires. Across all sites, air temperature during South Breaks 1 ranged from 61 to 65° F, 59 to 64° F during South Breaks 2, and averaged 63° F (range not available) during South Breaks 3. Wind speed ranged from 5 to 17 mph, with the South Breaks 2 having the widest range in wind speed (7 to 17 mph). Fuel moistures were similar across all three sites. The energy release component (ERC) did vary among the three fires, particularly on the first burning day (table 4). South Breaks 3 had an ERC of 16, followed by South Breaks 2 with 17, and South Breaks 1 with 19. All three burns had a maximum ERC of 21 or 22.

Areas burned by South Breaks 2 tended to have less litter cover after the combined fire event (prescribed fire followed by wildfire) within waterways and on north-facing aspects when compared to areas burned by South Breaks 3. Litter cover after South Breaks 3 tended to be similar to unburned sites, except on ridges, where litter cover was less than 30 percent. Within the area burned by South Breaks 1, the prescribed fire appeared to be less effective at decreasing litter cover (high variability) when compared to the combined prescribed and wildfire or the wildfire alone (low variability in litter cover) (fig. 18). In the burned sites there was either more mineral soil exposure (up to 80 percent) or a similar amount to the unburned areas (fig. 19).

Forb cover on burned sites did not differ substantially when compared to the unburned sites and there were little to no differences among the different burns, except on north-facing aspects within the area burned by South Breaks 3, which had some

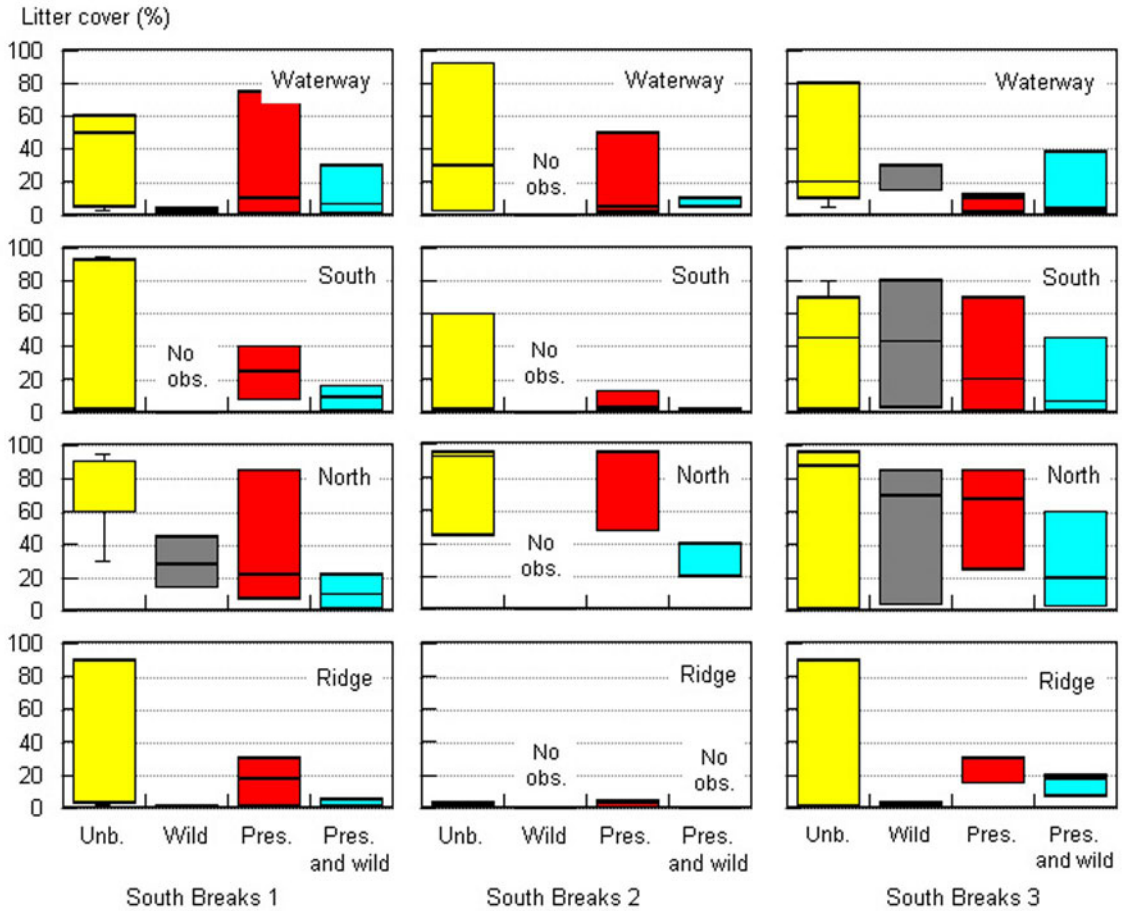

Figure 18—Percent litter cover for sites that burned through and around the South Breaks 1, 2, and 3 prescribed fires. Since the Germaine wildfire did not burn around the South Breaks 2 prescribed fire, there are no observations for wildfire. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

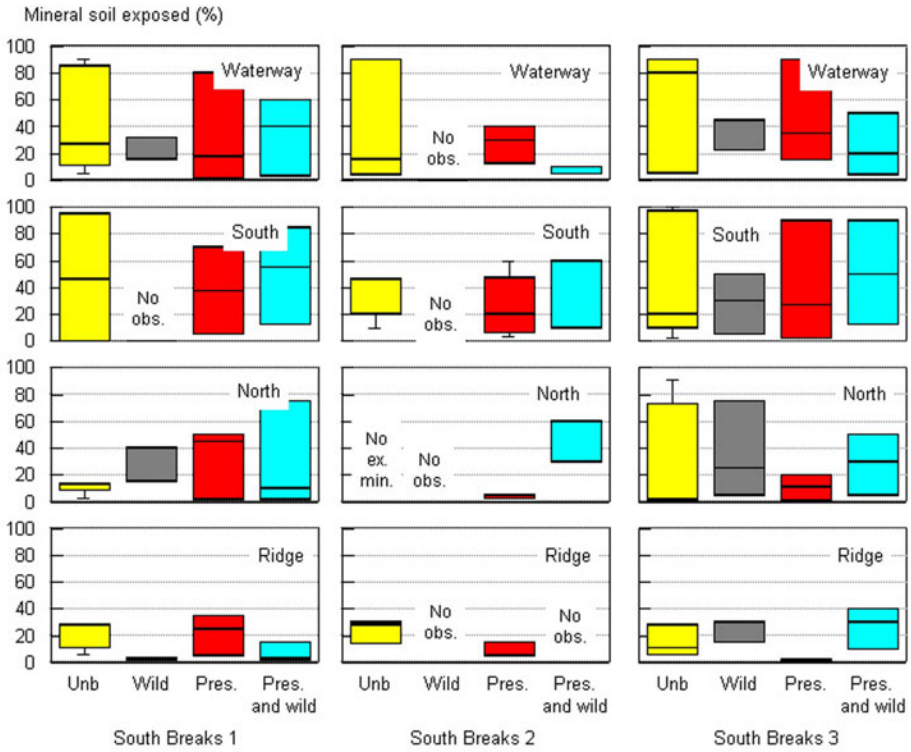

Figure 19—Percent mineral soil exposed for sites that burned through and around the South Breaks prescribed fires. Since the Germaine wildfire did not burn around the South Breaks 2 prescribed fire, there are no observations for wildfire. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

sites with forb cover as high as 40 percent (fig. 20). Grass cover was highly variable depending on the physiographic position and the fire (fig. 21). For example, on north-facing aspects burned by South Breaks 2 there was little to no grass cover while other physiographic positions contained areas that had high amounts of grass cover (> 60 percent). The most obvious differences in grass cover were in places where the wildfire burned near the South Breaks 1 and 3, where the range (box length) was more defined, than in other burned areas on similar physiographic positions. The areas burned by South Breaks 3 had the most diversity in grass cover, ranging from 0 on north-facing aspects after the wildfire to as high as 95 percent (at the 75th percentile) on ridges after the prescribed fire. Areas burned by prescribed fires tended to have more variability in shrub cover when compared to the other fires, especially within waterways (up to 50 percent), and in some cases on south-facing aspects (50 percent shrub cover) such as those burned by South Breaks 3 (fig. 22). However, in areas burned by the same fire there were no substantial differences in median shrub cover when compared to the unburned and burned sites.

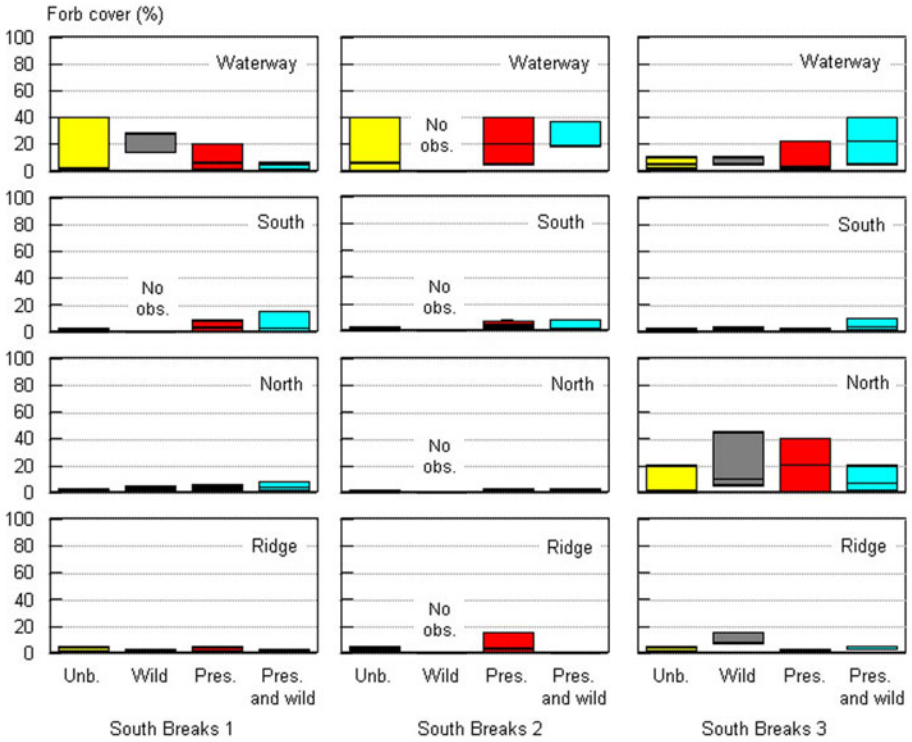

Figure 20—Percent forb cover for sites that burned through and around the South Breaks prescribed fires. Since the Germaine wildfire did not burn around the South Breaks 2 prescribed fire, there are no observations for wildfire. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

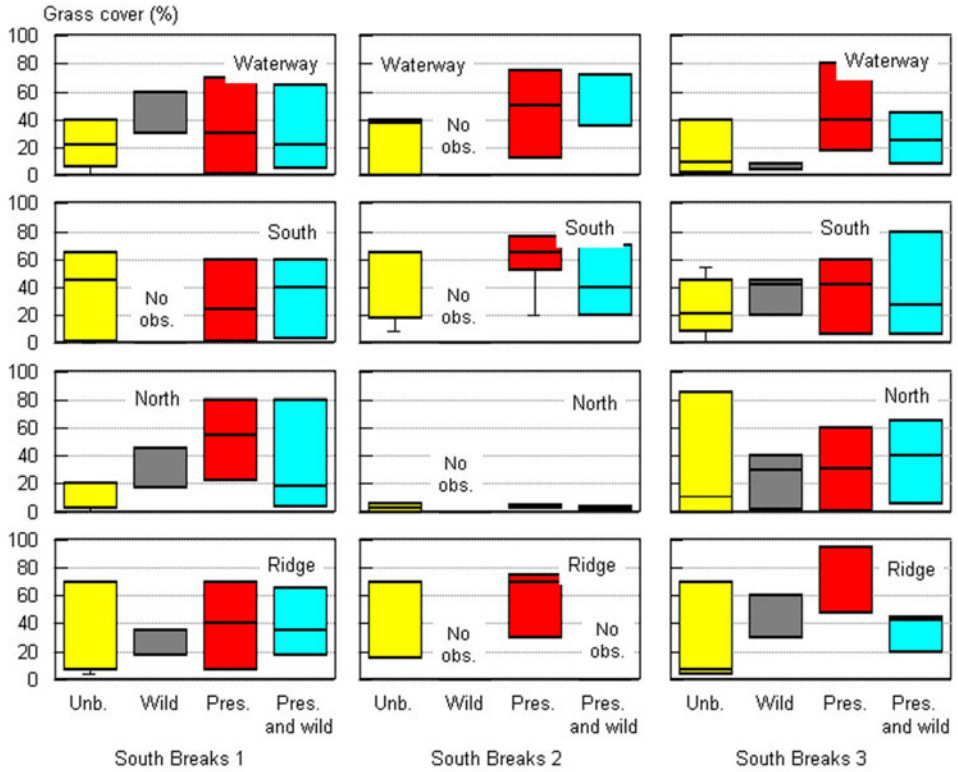

Figure 21—Percent grass cover for sites that burned through and around the South Breaks prescribed fires. Since the Germaine wildfire did not burn around the South Breaks 2 prescribed fire, there are no observations for wildfire. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

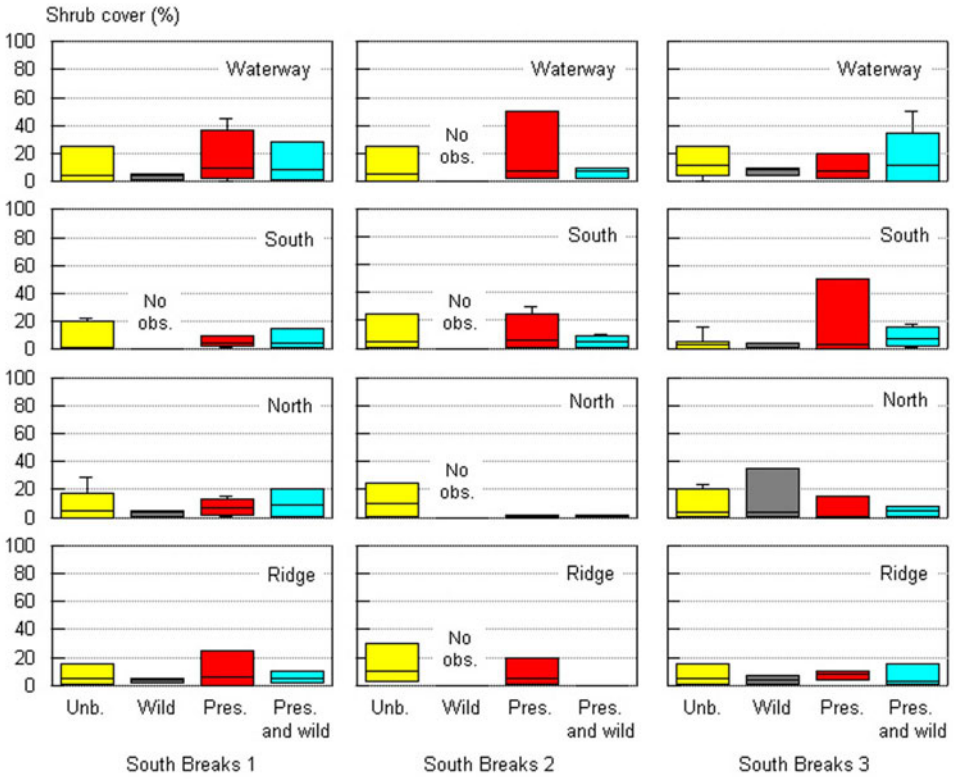

Figure 22—Percent shrub cover for sites that burned through and around the South Breaks prescribed fires. Since the Germaine wildfire did not burn around the South Breaks 2 prescribed fire, there are no observations for wildfire. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

The objective of the three South Breaks prescribed fires was to allow up to 90 percent mortality of young and mid-aged ponderosa pine and allow up to 60 percent mortality of old ponderosa pine (USDI South Breaks fire prescription) (table 5). Mortality of old ponderosa pine in the northwest area of the project was limited to 20 percent. Within South Breaks 1 and 3, there were very few small trees left after the fires (< 100 trees per acre) (fig. 23). There were fewer tall trees in South Breaks 3 after the fires when compared to the unburned sites, particularly within waterways (80 percent fewer trees) and north-facing aspects (50 percent fewer trees) (fig. 24). For the small trees that survived the fires, CBH increased in some cases to 8 feet, leaving very small amounts of green crown, which may influence future survival of these trees (fig. 25). South Breaks 2 on north-facing aspects after the prescribed fire appears to have had the greatest increase in CBH in surviving large trees, from a median of 5 feet to a median of 20 feet (fig. 26). In many cases, the variation in CBH of both the small and large trees increased after the fires (figs 25 and 26).

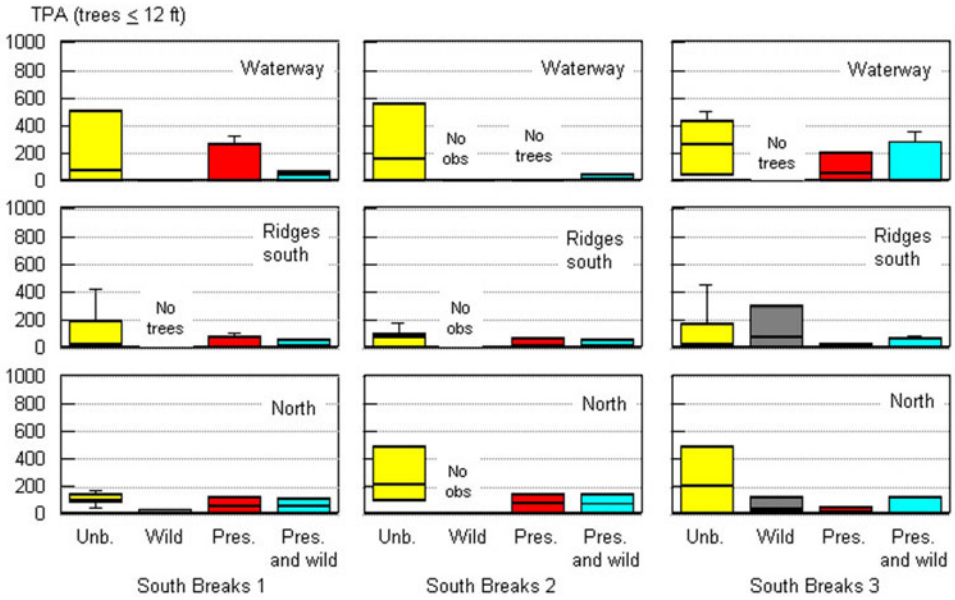

Figure 23—Trees per acre (TPA) of small trees (≤ 12 feet tall) on sites where the wildfire burned through and around the South Breaks 1, 2, and 3 prescribed fires. The graph is organized by physiographic position: waterways include ravines and gullies; ridges/south, which includes south-facing aspects and ridges, and north-facing aspects. Since the Germaine wildfire did not burn around the South Breaks 2 prescribed fire, there are no observations for wildfire. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

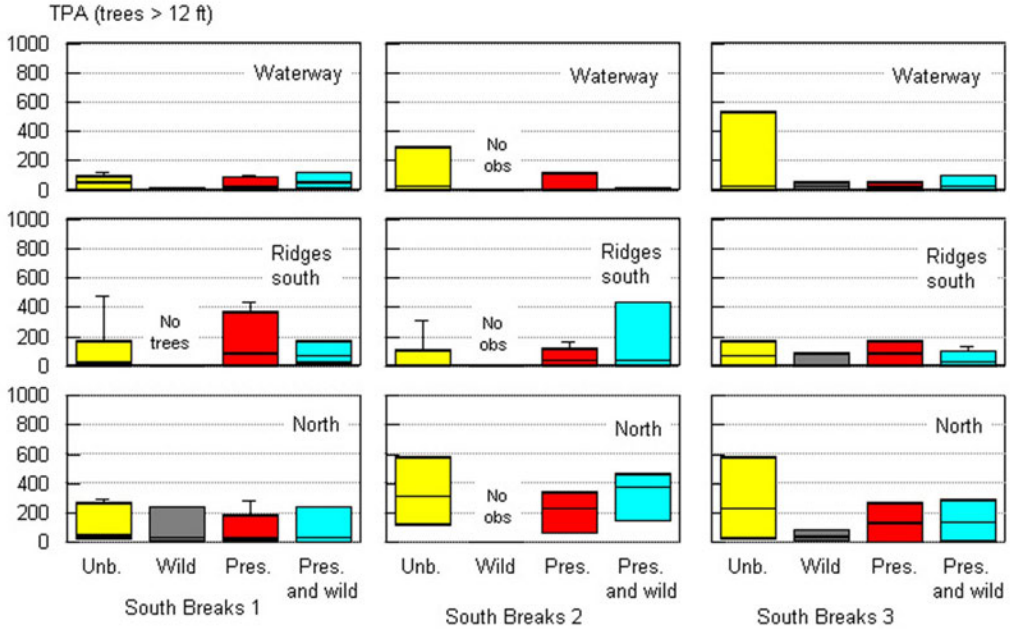

Figure 24—Trees per acre (TPA) for large trees (> 12 feet tall) on sites that burned through and around the South Breaks 1, 2, and 3 prescribed fires. The graph is organized by physiographic position: waterways include ravines and gullies, ridges/south, which includes south-facing aspects and ridges; and north-facing aspects. Since the Germaine wildfire did not burn around the South Breaks 2 prescribed fire, there are no observations for wildfire. Unburned sites are used as a frame of reference. Unb. = unburned, Pres. = prescribed fire, Pres. and wild = prescribed fire followed by wildfire.

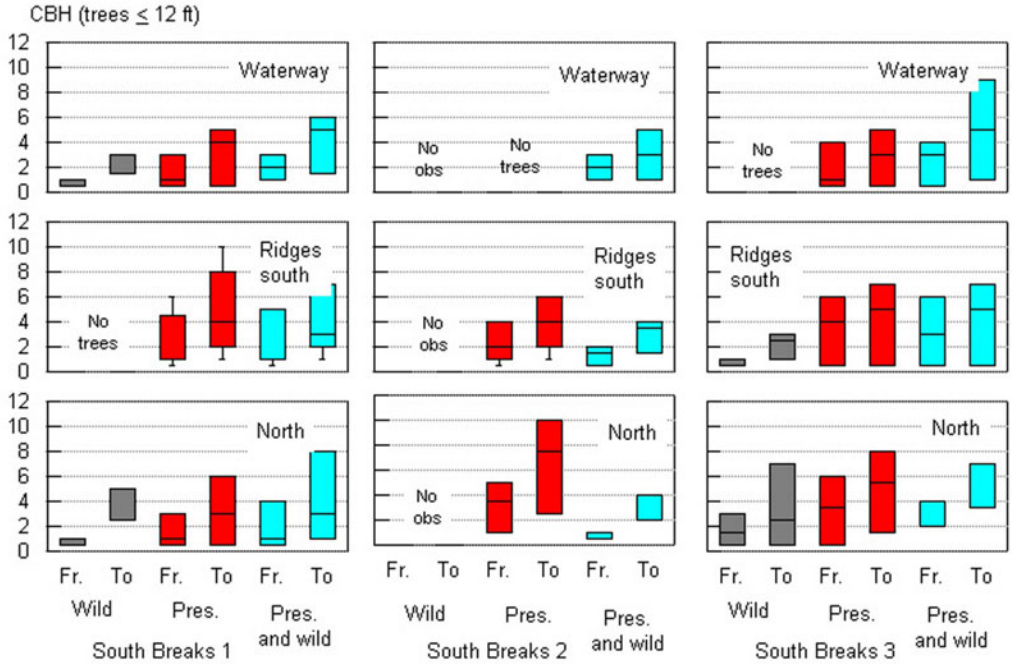

Figure 25—Canopy base height of small trees (≤ 12 feet tall) on sites that burned through and around the South Breaks 1, 2, and 3 prescribed fires. The graph is organized by physiographic position: waterways, which include ravines and gullies, ridges/south, which includes south-facing aspects and ridges; and north-facing aspects. Since the Germaine wildfire did not burn around the South Breaks 2 prescribed fire, there are no observations for wildfire. Unburned sites are used as a frame of reference. Pres. = prescribed fire, Pres. wild = prescribed fire followed by wildfire, Fr. = from pre-fire CBH, and To = to post fire CBH.

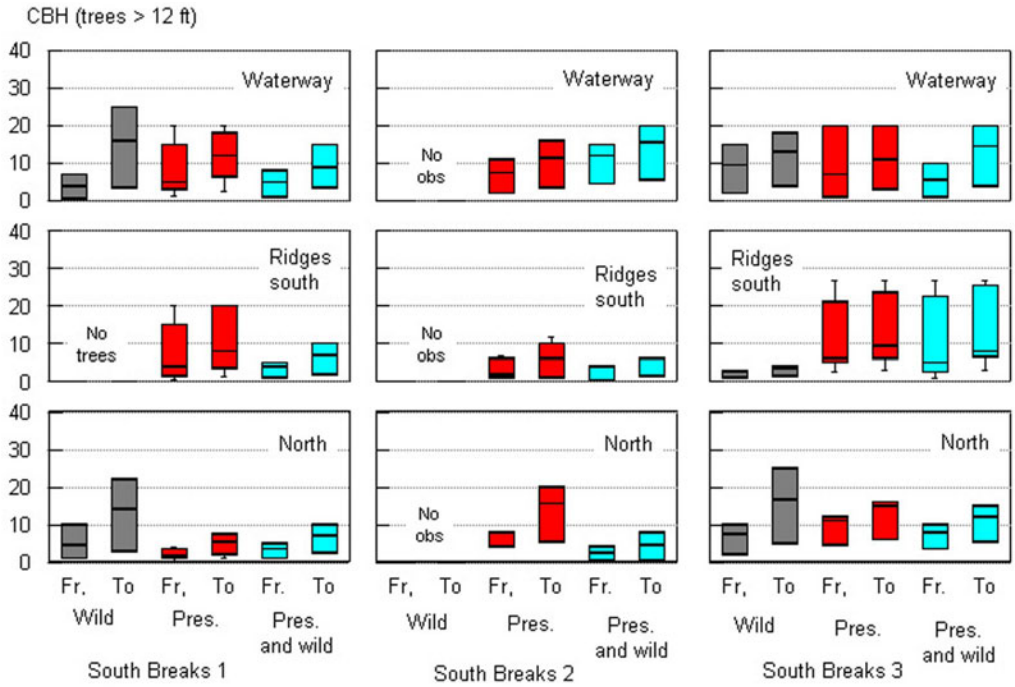

Figure 26—Canopy base height of medium to large trees (> 12 feet tall) for sites that burned through and around the South Breaks 1, 2, and 3 prescribed fires. The graph is organized by physiographic position: waterways include ravines and gullies; south facing aspects include ridges; and north facing aspects. Since the Germaine wildfire did not burn around the South Breaks 2 prescribed fire, there are no observations for wildfire. Unburned sites are used as a frame of reference. Pres. = prescribed fire, Pres. wild = prescribed fire followed by wildfire, Fr. = from pre-fire CBH, and To = to post fire CBH.

Tree Burn Severity Among the Fires

We just described how different forested and grassland characteristics on lands along the Missouri River in eastern Montana differed from unburned sites and the fires within the context of individual prescribed fires. However, a key objective was also to determine if the prescribed fires made a difference when the wildfires burned through them. To evaluate this component, we used the percent of observations for tree burn severity for trees > 12 feet tall within the wildfire and the combined fire event. We assumed that if a prescribed fire had influenced the distribution of tree burn severity, then the prescribed fire could have influenced the outcome. For example, the 6X7W combined fire event had a higher proportion of mixed green tree burn severity and fewer observations that contained brown crowns compared to the wildfire alone. In addition, there were no observations that contained trees with black crowns (no needles left), suggesting that a crown fire did not occur in our sampling area (Ryan and Noste 1985, Van Wagner 1973). Therefore, we could infer that the area that was burned by the prescribed fire favored a surface fire with minimal to no torching versus the wildfire which had some torching of crowns. Moreover, during the wildfire the surface fire had sufficient intensity to scorch the entire crown leaving only brown crowned trees. The area burned by both the 6X7W and the wildfire had some scorching of crowns; however, the heat produced was insufficient to scorch the entire crown.

Implementation of the HCross and North Breaks occurred during spring 2003 just prior to the wildfires, yet the Indian wildfire burned through the North Breaks while the Germaine wildfire did not burn completely through the HCross. Visual evidence suggests the wildfire stopped after it entered into the site burned by the HCross (fig. 1). However, in places within the HCross where the wildfire burned, no trees survived, while in places where only the wildfire occurred trees still contained green crowns (fig. 27). The lack of tree survival in the burned area within the HCross boundary is likely the result of greater burn severity. However, the fire did not progress through the entire prescribed fire but rather tended to burn around just within the edge of the HCross prescribed fire.

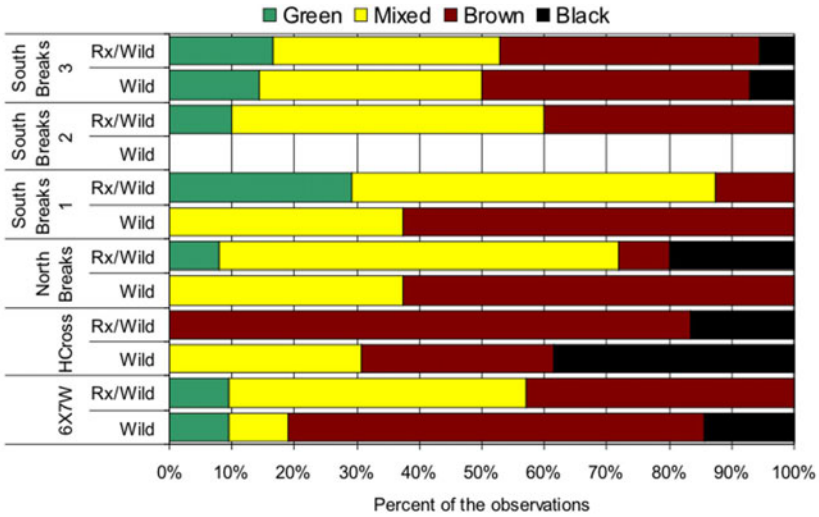

Figure 27—The different shaded colors indicate the percent of each crown severity for trees > 12 feet tall that occurred within a fire combination (Y-axis) (prescribed fire, wildfire, and prescribed fire followed by wildfire). Crown severity includes sites that contained green crowns (unburned), mixed (both green and brown needles present), brown (only brown needles present), and black (all needles consumed, only black stems and branches remain).

Several possibilities, although speculative, could have provided this diverse outcome between the HCross and North Breaks. Weather information during the different fires shows that the HCross energy release component ranged from 15 to 18 while the North Breaks was 12 to 15 (table 4). The higher values may indicate increased fire intensities during the HCross prescribed fire and possibly the removal of more surface fuels, preventing the wildfire from burning through the entire area. Another possibility is that the Indian wildfire may have burned more intensely than the Germaine and therefore, the higher intensity combined with remaining fuels in the North Breaks sustained the wildfire. In contrast, if the Germaine's fire intensity was much less, the change in fuels from the HCross prescribed fire may have been sufficient to stop wildfire progression.

We did not obtain observations on the wildfire that burned around the North Breaks; instead, we used the proportion of the area that the wildfire burned around South Breaks 1. In this situation, the North Breaks had a variety of tree burn severities, indicating that the combined fire event burned more heterogeneously than the sites burned only by the wildfire. Sites previously burned by the North Breaks prescribed fire contained areas with green trees and a larger portion of the observations contained mixed green tree burn severity. In addition, there were areas that had some crown torching, indicated by the presence of sites containing trees with black crowns (complete crown consumption). In contrast, the wildfire did not contain any observations that had green trees and many of the observations only had trees with brown crowns.

Sites previously burned by South Breaks 1 had up to 30 percent of the observations containing trees with green crowns and 55 percent of the observations contained mixed green tree burn severity. Only a very small percentage of the observations had brown crowns. These results could indicate the South Breaks 1 did alter the tree burn severity by decreasing tree mortality and favoring large tree survival. The other South Breaks prescribed fires and the North Breaks prescribed fire surrounded South Breaks 2; therefore, the Indian wildfire did not continue to burn south of these prescribed fires. This may indicate that the presence of previously burned areas allowed the fire to be controlled or it stopped because of the lack of fuel or change in weather. South Breaks 3 did not substantially alter tree burn severity; a very similar distribution of the observations occurred in both the wildfire and the South Breaks 3 prescribed fire.

Applying This Technique for Monitoring Fire Effects

We did not have pre-established plots or exact descriptions of sites prior to the fires; consequently, we were limited in our ability to quantify exactly the relation between pre-fire forest structure and post-fire results. In addition, physical setting and a particular year's weather can influence grass abundance (primary surface fuels). These factors, combined with grazing of both livestock and wildlife, can lead to high variation in biomass substantially from year to year and from place to place (Biswell 1972; USDI 1979b). Therefore, an accurate description of the primary surface fuels would have required detailed information just prior to each fire, including the wildfire, which was not available. Given these limitations, there was still a need to quantify changes and subsequent environments created by the different fires. Therefore, we used a combination of tools (frame of reference,

photograph handbook, and walk through exams) to provide a visual and descriptive characterization of post-fire environments and unburned sites. The photograph handbook (Jain and others 2007a) created from detailed plot data of the reference sites provided a way to estimate changes in tree density. The walk-through exams provided a quick and efficient way to characterize post-fire environments (burn severity) after the fires.

A shortcoming of this technique is the lack of detailed plots in the burned areas. However, in exchange for this lack of information, we maximized the amount of area sampled and the number of samples, given our limited time period and funding. More time and money would have provided more opportunity to conduct a detailed post-fire inventory, but in this case, it was not an option. Therefore, given our circumstances, our goal was to maintain some scientific rigor (incorporate randomness, repeatability, established sampling techniques) and do our best to minimize bias and partiality in our characterization.

The frame of reference does not reflect vegetation characteristics created from historical fire regimes, it is not a "reference condition," and it does not reflect a "historical range of variability" that is often used to provide management direction or quantify change (Hann and Bunnel 2001; Hann and others 1997; Morgan and others 1994; USDI 2004). Rather, our frame of reference was to provide baseline information of today's forested and grassland characteristics that occur in places within the Missouri River Breaks (Kaufmann and others 1994). Although this approach is not ideal and may not be a preferred method to use in other circumstances, it provides a quantifiable and repeatable technique for identifying variation in post-fire environments caused by different fires. Because it was in the authors' interest to characterize events surrounding specific prescribed fires, we reported a substantial amount of information, which at times can become cumbersome. However, the data is complete and may be applicable for a variety of uses, as identified in the accompanying photograph handbook (Jain and others, 2007b).

Conclusion

Based on our tree burn severity evaluation, it appears that some of the prescribed fires did influence the post-fire environment and fire behavior. We also noted that subtle differences in weather during prescribed fire implementation and wildfire intensity might have influenced wildfire progression through the HCross and the North Breaks. Although our results were not statistically different given the substantial variation, our results show trends where soil surface, ground-level vegetation, tree survival, and change in CBH did vary as a function of the fires. Because this was accomplished using an experimental design that minimized bias and partiality, this information provides an independent perspective on the influence of prescribed fire on wildfire effects.

Acknowledgments

This publication is a result of a cooperative effort between the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, and the U.S. Department of Interior, Bureau of Land Management in Montana and Oregon. We

would like to thank Gail Fullerton, Dan Frigard, Don Shipton, Jerome Funchess, Jim Hedgecock, and Christy Smith who all worked very hard collecting the data, taking photographs, and preparing tables. Joint Fire Sciences Program, Rocky Mountain Research Station, and the Bureau of Land Management, Montana, provided the funding.

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