Reintroducing Fire Into the Blacks Mountain Research Natural Area: Effects on Fire Hazard[1]

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Abstract

Frequent, low-intensity, surface fires were an integral ecological process in the Blacks Mountain Experimental Forest (BMEF) prior to the 20th Century. With rare exception, fires have been successfully excluded from BMEF since the early 1900s. The Blacks Mountain Research Natural Area (BMRNA) covers approximately 521 acres of BMEF in 5 compartments of approximately 100 acres each. With the help of the Lassen National Forest, we have begun to reintroduce fire to BMRNA using prescribed fire. Two compartments have been burned – one in fall of 1997, the other in fall of 2000. Stand conditions and responses are being compared to two compartments where fire has continued to be excluded. The fifth compartment – mostly meadow – is not being studied at this time. Although fire hazard reduction was not a primary goal of this project, the usefulness of prescribed fire treatments for fire behavior modification is of interest to many. This paper compares the ability of the prescribed fire to alter wildfire behavior through computer simulation of expected wildfire behavior and effects for treated and untreated stands. Though the application of prescribed fire initially reduced expected fire behavior, expected fire behavior was again quite high within a few years (~ 4-6 yrs). This is due to ensuing accumulation of dead fuel from the many small trees killed in the initial burns and the inability of prescribed fire to sufficiently thin the stands for a more lasting effect. We estimate it may take up to three applications of prescribed fire to achieve a level of fire behavior modification that is similar to a single application of mechanical treatment followed by a single prescribed fire.

Key words: *Cascade Range, fire effects, ponderosa pine, prescribed fire, research natural areas, white fir*

Introduction

Frequent, low-intensity, surface fires were originally an integral ecological process in the development of relatively open ponderosa pine (*Pinus ponderosa* Laws.) and Jeffrey pine (*P. jeffreyi* Grev. & Balf.) dominated forests of northeastern California (nomenclature follows Hickman 1993). The frequency of fire occurrence varied with the spatial scale of interest. For sites < 100 acres, mean fire intervals varied from ~5 to 17 years (Taylor 2000; Norman 2002). In contrast, years of widespread fires (10,000+ acres) across broad landscapes occurred with a median fire interval of 20.5 years (range 7-49) (Norman 2002).

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The introduction of sheep grazing in the 1800s, followed by fire suppression and other forest management activities in the 20th Century (Taylor 2000; Norman 2002), led to great changes in the structure of ponderosa pine forests of northeastern California, similar to that described for other forests throughout the western USA (Agee 1993; Taylor 2000; Norman 2002; Youngblood and others 2004). Higher stocking densities and increased fuel accumulations have led to conditions that more readily support high-intensity fires than is likely to have been the case historically (Dolph and others 1995; Taylor 2000; Norman 2002; Youngblood and others 2004).

Reduced stand density and reduced surface fuel loads often are required to enhance forest sustainability and ecological function, and to lower the likelihood of large, high-intensity wildfires (Weatherspoon and Skinner 1996). Within wilderness areas, many parks, and other natural areas intended to be managed primarily for natural processes, the tools for achieving these objectives over large areas are largely limited to using prescribed fire – either human or lightning ignited. However, after nearly a century of increasing stand densities and surface fuel loads, reintroducing fire to large areas will not be easy nor will it likely mimic the historical fires that burned in more open stands with lighter fuel loads.

Published simulation exercises have suggested that prescribed fire should be effective at reducing fire hazard (potential for high-intensity wildfire) immediately following treatment (van Wagtendonk 1996; Stephens 1998). This reduction in fire hazard is primarily due to the reduced surface fuels – needles and small woody material. There have been few studies on the effectiveness of using prescribed fire alone to achieve more lasting fire hazard reduction (e.g., Fulé and others 2002; Fernandes and Botelho 2003). The length of years of effective fire hazard reduction will depend not only upon the longevity of reduction in surface fuels, but also on the degree to which stand density and canopy conditions have been modified. These studies indicate that the care with which prescribed fire must be applied following the many years without fire makes it difficult to both restore historical structure and reduce fire hazard in an initial application of prescribed fire.

The Blacks Mountain Research Natural Area (BMRNA), within the Blacks Mountain Experimental Forest (BMEF) in the Cascade Range of northeastern California was set aside to study natural processes in interior ponderosa pine dominated forests (Cheng 2004). The team of scientists that designed the Blacks Mountain Interdisciplinary Ecological Research Project included four compartments of the BMRNA to study the reintroduction of fire to a forest that had experienced many decades of fire suppression and accompanying ecological changes (Oliver 2001). The goal of treatments in the BMRNA is to achieve a more open stand condition, dominated by larger trees, where most of the larger trees would survive fires burning under typical summer conditions. The team reasoned that the existing stand density and surface fuel loads would require that fire be reintroduced in stages – at least two, and likely three, applications of prescribed fire – before desired conditions were likely to be achieved. Attempting to achieve desired conditions more quickly would likely result in excessive damage to the surviving stands.

The intent of this paper is to describe the changes in stand density and simulate the effects on fire hazard resulting from the first application of prescribed fire in the BMRNA. Additionally, the logic for selection of appropriate fuel models to describe expected fire behavior under the different stand conditions is described.

Methods

Study Area

The Blacks Mountain Research Natural Area is made up of five disjunct compartments of approximately 100-125 acres (40-51 ha) each within the Blacks Mountain Experimental Forest and covers a total of 521 acres (211 ha). These compartments were set aside to receive no management manipulation shortly after the BMEF was established in 1934 and were later included in the U.S. Forest Service's Research Natural Area Program (Cheng 2004).

Elevation varies from 5600 to 6400 ft (~1700-1950 m). The topography is a gentle volcanic landscape with mostly shallow soils overlaying basalt. There are no perennial streams due to rapid percolation of runoff into the porous soils. Average annual precipitation is 22.55 inches (573 mm), most of which falls as snow in winter. Infrequent thunderstorms occur in summer. Temperatures range from – 15 to 85 ^{o}F (0.6-29.4 ^{o}C). The lower elevation compartments (A, C, and E) are mostly ponderosa and Jeffrey pine stands. Compartments B and D at higher elevation have stands dominated by ponderosa and Jeffrey pine in association with white fir (*Abies concolor* [Gordon & Glend.] Lindley) and incense-cedar (*Calocedrus decurrens* [Torrey] Florin) (Cheng 2004).

The four mostly forested compartments of the BMRNA were selected for this study – A, B, C, and D. Compartment E was not included as it is mostly meadow. Compartments B and C were randomly selected for reintroduction of fire through the periodic use of prescribed fire. Initial burns were conducted in 1997 (C) and 2000 (B). Compartments A and D will not be purposely burned and will serve as long-term control comparisons to the two burned compartments.

Data Collection

Canopy Fuels

Data to describe stand structural conditions were collected on nested, fixed-area plots centered on the established grid points. As part of the Blacks Mountain Ecological Research Project, the PSW Redding Lab has established a permanently monumented 328 x 328 ft (100 x 100 m) grid in each of the four forested compartments to facilitate interdisciplinary study of spatial relationships of a variety of environmental variables (Oliver 2000). Live trees and snags > 11.5 inches (29.2 cm) dbh were measured on .2-acre (.08 ha) plots. Trees 3.5 to 11.5 inches (8.9-29.2 cm) dbh were measured on .05 acre (.02 ha) plots while seedlings (>.5" [1.3 cm] base and <4.5' [1.37 m] high) and saplings (<3.5" [8.9 cm] dbh and >4.5' [1.37 cm] high) were tallied on .01 acre (.004 ha) plots (Oliver 2000).

Pre-treatment data were collected in all four compartments to describe existing stand conditions. Following application of prescribed fire in B and C, data were again collected at the same grid points at post-fire year 1 (both B and C) and post-fire year 5 (C only).

Tree height and height to crown base data were not collected in the pre-treatment measurements in the BMRNA compartments. Therefore, these values were estimated by regressing height and height to crown base on diameter using data collected from compartments A and D that were not burned. Regressions were run for ponderosa/Jeffrey pine combined, incense-cedar, and white fir. Tree heights were constrained so that no individual live tree was estimated to be higher at pre-treatment than it was measured to be post-treatment.

Surface Fuels

The fuel inventory to describe the <3” diameter surface woody fuel conditions for fire behavior simulation has not yet been completed for the BMRNA compartments. For this paper, surface fuels were estimated by comparing fuel conditions in the compartments to available photo series (Maxwell and Ward 1980; Blonski and Schramel 1981) and then subjectively selecting an appropriate standard fire behavior fuel model (Anderson 1982; Rothermel 1983). Although there was variation in the fuel conditions within and between compartments, fire behavior fuel model 10 (Anderson 1982; Rothermel 1983) appeared to be the best fit in all four compartments for estimating pre-treatment fire behavior.

Biomass equations supplied by Powers (unpublished data at PSW Silviculture Lab, Redding, CA) were used to estimate the amount of fuel that has been added to the surface fuels from the trees killed by prescribed fire and had fallen by the 5^{th} year post-fire measurement in compartment C.

Data Analysis

Canopy fuel conditions were estimated using program FUELCALC (Reinhardt 2004). FUELCALC uses the tree data by plot for each stand and calculates several variables necessary for estimating crown fire potential and behavior. Output includes the following variables: canopy bulk density (CBD, lbs/ft^3), plot averaged canopy base height (CBH, ft), plot averaged stand height (SH, ft)[2], total canopy fuel weight (TFW, tons/acre), plot canopy cover (COV, percent), plot basal area of trees (BA, ft^2/acre), and trees per unit area (TPA, trees/acre). The 25th percentile of canopy base height was used for predicting passive crown-fire behavior (e.g., Fulé and others 2001).

Fire weather and fuel moisture conditions that existed during a recent wildfire at BMEF were used in the fire behavior simulation. Though it did not burn within the RNA compartments, the Cone Fire burned nearly 2000 acres of BMEF in September of 2002. Fire weather conditions during this fire were as follows, 1-hour fuel moisture (%) = 1, 10-hour fuel moisture (%) = 2, 100-hour fuel moisture (%) = 2, wind speed = 15 mph (range 9 – 20) (USDA Forest Service 2002). A wind reduction factor of 0.3 was used to reduce the 20 ft (6.1 m) measured wind speed to mid-flame wind speed to account for the influence of stand structure and canopy on wind. Canopy foliage moisture content was estimated to be 75% since the Cone Fire burned under dry, north wind conditions following the long, dry summer of the area.

Fire behavior was simulated using the spreadsheet program NEXUS (Scott 1999). NEXUS quantifies fire hazard by coupling existing models of surface and crown fire behavior to simulate overall fire spread and intensity as described by (Scott and Reinhardt 2001). For this study, the NEXUS estimates of Fire Type (surface fire, passive crown fire, active crown fire), Crown Percent Burned, Rate of Spread (ROS, chains/hour), Heat/Unit Area (btu/ft^2), Flame Length (ft), Scorch Height (ft), Torching Index (wind speed when torching begins), and Crowning Index (wind speed when active crown fire begins) were used for comparing pre- and post-treatment fire behavior. *Fig. 1* shows the general steps used in providing data to NEXUS to generate the estimated fire behavior parameters.

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[2] Stand height is the average height of the five tallest trees on each plot (Scott and Reinhardt 2005).

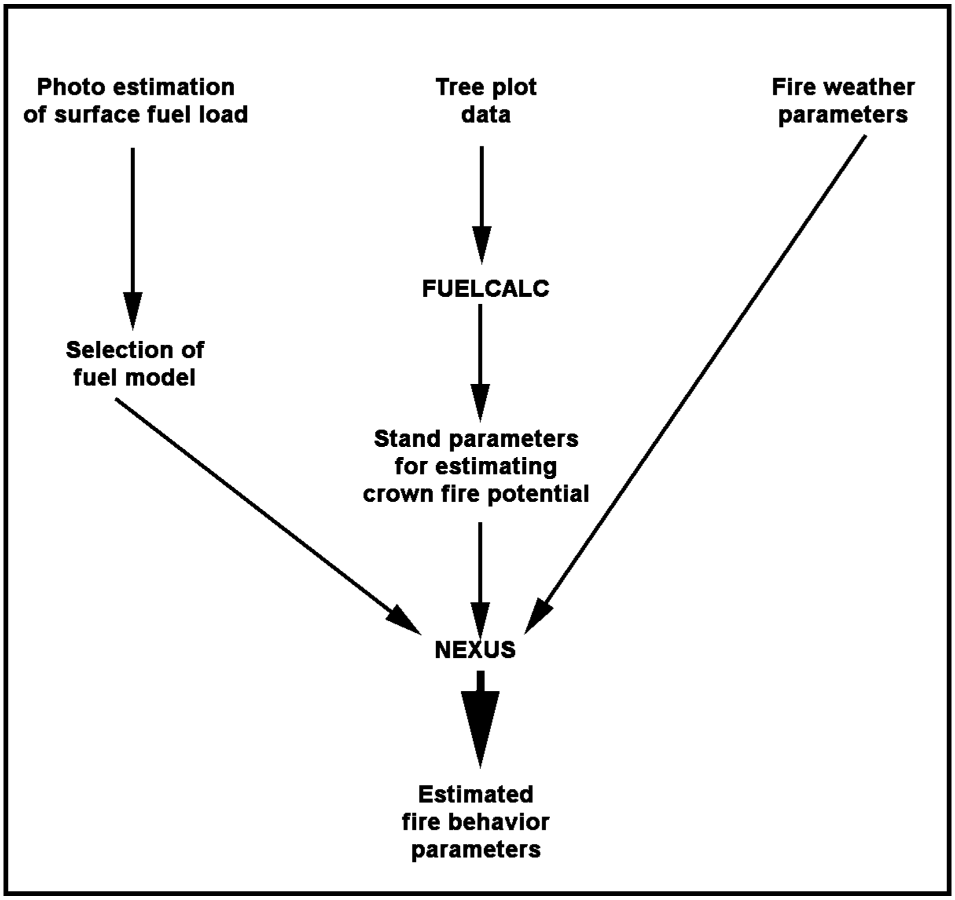

Figure 1— Steps used to provide data to NEXUS to estimate fire behavior.

Pre-treatment predictions of fire behavior were made for all four compartments. Post-treatment predictions of fire behavior were made for the first year following treatment for both of the treated compartments. Because the years of treatments were staggered, the Cone Fire occurred in the second year following treatment for compartment B and the fifth year following treatment for compartment C. Therefore, to estimate potential fire behavior had the Cone Fire been able to burn into the two treated compartments, fire behavior was predicted for the second year following treatment in compartment B and the fifth year following treatment in compartment C.

Results

Pre-treatment Stand Conditions

After many decades without fire, all four compartments had developed relatively dense stands with considerable accumulations of duff and litter (*table 1, fig. 2*). The median (25th - 75th percentile) density (trees/acre)[trees/hectare] of seedlings and saplings (<3.5” dbh [8.9 cm]) in each compartment were: A=1,050 (625-1,675) [2595 (1544-4139)], B=1,100 (600-1,800) [2718 (1483-4448)], C=750(450-1225) [1853 (1112-3027)], and D=1,150 (725-2,075) [2842 (1792-5127)].

Table 1— *Pre-treatment median (25th -75th percentile) values of plot-level characteristics for trees >3.5" DBH for the Blacks Mountain Experimental Forest RNA compartments.*

Compartment	A	B	C	D
Trees/Acre	269.9 (126.2-542.9)	439.9 (280.0-715.0)	312.4 (192.6-472.7)	497.4 (196.3-612.3)
Basal Area (ft^2) / Acre	140.3 (113.6-177.2)	160.0 (126.5-202.7)	138.6 (117.9-178.4)	158.5 (134.12-612.3)
Canopy Cover %	52.2 (33.0-60.5)	64.1 (57.5-77.4)	60.4 (48.7-72.8)	59.8 (44.4-67.0)
Stand Height (ft)	75.5 (49.2-85.3)	72.0[1] (45.0-87.0)	69.0[1] (58.5-54.0)	64.0 (46.8-86.1)
Canopy Bulk Density (lbs/ft^3)	.0021 (.0017-.0027)	.0034 (.0022-.0048)	.0018 (.0011-.0026)	.0036 (.0022-.0054)
Canopy Base Height (ft)	16.4 (13.1-32.8)	13.1[2] (13.1-16.4)	16.4[2] (13.1-16.4)	13.1 (7.0-15.6)
Canopy Fuel Load (tons/acre)	7.3 (5.7-9.6)	8.3 (5.1-9.6)	4.3 (3.7-5.3)	7.1 (6.0-10.8)

[1] Post-treatment heights were used since pre-treatment heights were not measured.

[2] Canopy base height was estimated by regressing canopy base height against dbh from trees in compartments A and D for each species.

After considering the stand conditions and fuel accumulations, fire behavior fuel model 10 (Anderson 1982; Rothermel 1983) appeared to be the best fit in all four compartments. Using the weather and fuel moisture conditions that prevailed during the first day of the Cone Fire, the NEXUS simulation predicted passive crown fire in all compartments (*table 2*).

Figure 2— A typical view of pre-treatment conditions in the Blacks Mountain RNA showing dense understory of small trees. (Photo by John Anstead, USDA Forest Service).

Table 2— *Estimates of fire behavior under Cone Fire weather conditions for the Blacks Mountain RNA compartments under pre-treatment stand conditions (Wind 15 mph).*

Compartment	A	B	C	D
Fuel Model	10	10	10	10
Fire Type	Passive Crown	Passive Crown	Passive Crown	Passive Crown
Crown % burned	14	36	11	32
ROS (ch/hr)	24	42	21	27
H/A (btu/ft^2)	2056	2048	1745	2485
Flame Length (ft)	11	18	10	15
Scorch Height (ft)	93	139	76	117
Torching Index (mph)	12	10	12	5
Crowning Index (mph)	32	22	37	31

Figure 3 – One year post-treatment. Typical scene showing retention of dead needles in standing trees that were killed by the prescribed fire. All trees in the fore- and middle-ground are dead. (Photo by Carl Skinner, USDA Forest Service)

Post-Treatment Stand Conditions

One year following prescribed-fire treatments, tree density had been reduced by 14.7% in B and 16% in C (*fig. 3, table 3*). There were corresponding decreases in basal area, canopy cover, and canopy bulk density. The relatively small proportions of change are due to mostly small trees being killed by the prescribed fire. Among small trees, seedlings and saplings were only partly reduced as can be seen by comparing the pre- and post-treatment median (25th percentile - 75th percentile) density (trees/acre)[trees/hectare] of seedlings and saplings: B was reduced by 55% one year post-treatment to 500 (300-1,300)[1236 (741-3212)] and C was reduced by 80% to 150 (75-425)[371 (185-1050)] five years post-treatment.

Canopy bulk density is reduced in the first year following prescribed fire. Yet, canopy fuel load increases in B the first year and in C by the fifth year. This is counterintuitive and may be an artifact of having to estimate the pre-treatment tree heights.

Table 3–*Comparing pre-treatment and post-treament median (25th -75th percentile) values of plot-level characteristics for trees >3.5" DBH for the Blacks Mountain Experimental Forest RNA compartments B and C.*

Compartment	B	B	C	C	C
Time	Pre-burn	Burn+1yr	Pre-burn	Burn+1yr	Burn+5yrs
Trees/Acre	439.9 (280-715)	375.1 (230-510)	312.4 (192.6-472.7)	262.4 (162-330)	285.1 (140-325)
Basal Area (ft^2) / Acre	160.0 (127-203)	149.8 (110-204)	138.6 (117.9-178.4)	125.1 (103-164)	120.4 (106-168)
Canopy Cover %	64.1 (57.5-77.4)	58.8 (52.2-71.2)	60.4 (48.7-72.8)	45.3 (35.4-50.3)	45.1 (37.0-49.8)
Stand Height (ft)	72.0[1] (45.0-87.0)	68.9 (49.2-85.3)	69.0[1] (58.5-54.0)	69.0[1] (58.5-54.0)	68.9 (50.9-86.1)
Canopy Bulk Density (lbs/ft^3)	.0034 (.0022-.0048)	.0032 (.0027-.0043)	.0018 (.0011-.0026)	.0012 (.0008-.0016)	.0017 (.0014-.0023)
Canopy Base Height (ft)	13.1[2] (13.1-16.4)	13.1 (13.1-16.4)	16.4[2] (13.1-16.4)	19.7 (19.7-25.4)	19.7 (19.7-23.8)
Canopy Fuel Load (tons/acre)	5.3 (3.8-5.8)	8.3 (5.2-9.7)	4.3 (3.7-5.3)	2.8 (2.4-3.8)	6.3 (5.7-8.7)

[1] Post-treatment heights were used since pre-treatment heights were not measured. Differences are due to trees that existed in first measurements that were down by the last measurement.

[2] Canopy base height estimated by regressing dbh from trees in compartments A and D for each species.

Fuel model 8 (Anderson 1982; Rothermel 1983) was used to predict fire behavior in the first year following treatment for both compartments because initial changes in available fuels were primarily due to reduced amounts of needles and small fuels on the surface that easily ignite and carry fire. Fuel model 8 may over-predict fire behavior immediately post-treatment. However, of all of the available standard fuel models, model 8 predicts the lowest fire behavior. Additionally, fuel model 8 was considered appropriate because post-treatment data indicated that approximately 60% of the surface was still covered by fairly compact litter and duff, even though nearly all of the young, loose, highly flammable needles had been consumed. The changes in fuel conditions due to the prescribed-fire treatments initially reduced the predicted fire behavior in both treated stands considerably (*table 4*). Predicted behavior in both B and C was reduced from a high-intensity, passive crown fire to a low-intensity surface fire. Predicted spread rate, energy released, flame length, scorch height, and potential for passive crown fire (torching index) were all reduced in both compartments. However, it is important to note that the potential for the stands to carry a crown fire once it is initiated (crowning index) was generally not affected. This is because canopy bulk density was not appreciably affected by the treatments (*table 3*).

Table 4–*Comparing estimates of fire behavior under Cone Fire weather conditions pre- and post-treatment for Blacks Mountain RNA compartments B and C (Wind 15 mph).*

Compartment	B	B	B	C	C	C
Time	Pre-burn	Burn+1 yr	Burn+2 yrs	Pre-burn	Burn+1 yr	Burn+5 yrs
Fuel Model	10	8	9	10	8	11[1]
Fire Type	Passive	Surface	Surface	Passive	Surface	Surface
Crown % burned	36	0	0	11	0	0
ROS (ch/hr)	42	3	13	21	3	10
H/A (btu/ft^2)	2048	263	536	1745	263	1128
Flame Length (ft)	18	2	4	10	2	5
Scorch Height (ft)	139	2	20	76	2	30
Torching Index (mph)	10	119	24	12	192	35
Crowning Index (mph)	22	33	33	37	90	53

[1] Had fuel model 10 been used here instead of 11, the post-treatment predicted fire behavior would have been equal to that of pre-treatment by the fifth year.

Since the initial reduction in predicted fire behavior was mostly due to the reduction of needles and small twigs and not due to significant reduction of stand density or raising the canopy base height, fire hazard began to return quickly. Five-year re-measurement data were not yet available for compartment B. In order to account for changes over time in expected fire behavior due to accumulating needles and small twigs, fire behavior model 9 (Anderson 1982; Rothermel 1983) was used to predict expected fire behavior for two years post-treatment. Two years post-treatment was chosen since few of the small trees that were killed by the prescribed fire had fallen to become part of the surface fuels and was the condition of compartment B in the year of the Cone Fire. The dead, small trees began falling in large numbers in year four. Thus, this gives a prediction of the fire behavior that would have been expected had the fire been able to burn into compartment B.

The second year prediction of fire behavior for compartment B suggests that the initial dramatic reduction in fire behavior will likely not last long. The Torching Index, which is most sensitive to the surface fuel load, was reduced from 119 mph (192 km/hr) immediately following treatment to 24 mph (39 km/hr). The second year figure is close to the maximum wind speeds measured during the Cone Fire and suggests that a danger of passive crown fire is likely to return as more fuel is added to the surface when the small, dead trees fall. The stand density was not reduced sufficiently to affect the Crowning Index which is most sensitive to canopy bulk density once the crowning phase of the fire has begun.

Fuel model 11 (light logging slash) was selected for simulating fire behavior for the fifth year post-treatment in compartment C for several reasons:

- Model 8 (slow spreading fires in compact litter beds) no longer applied due to the accumulation of needle cast and the fallen, small, dead trees.
- Model 10 (timber stands with large, down, dead fuels and understory ladder fuels) did not apply due to the effects of the prescribed fire – a) the prescribed fire consumed much of the heavy dead, down woody fuel, b) broke up continuity of surface fuels, and c) reduced the live, woody ladder fuels.
- Model 9 (long needle litter with limited down dead and no live understory ladder fuels) was not appropriate because a) fuel continuity was reduced by the prescribed burn and b) the accumulation of woody fuel resulting from the fallen small, dead trees killed by the prescribed burn exceeded that appropriate for the model 9.
- Model 11 (light logging slash) represents a) the accumulation of woody fuel over the 5 years since the prescribed burn and b) the limited number of years of accumulation of litter and needle cast since the prescribed burn. Model 11 predicts slower rate of spread but higher intensity than model 9.

Figure 4 – Four years post-treatment. Typical scene showing that many of the smaller trees killed by the prescribed fire have fallen and added to the surface fuel bed. (Photo by Carl Skinner, USDA Forest Service)

Fire behavior predictions based on using fuel model 11 to represent the fifth year post-treatment conditions for compartment C indicate that the initial dramatic reduction in fire hazard has largely been lost by the fifth year after the first application of prescribed fire. Several factors contributed to the rapid rebound of fire hazard. First, the needles, twigs, and small branches killed (scorched) in the burn have mostly dropped to the forest floor by the fifth year. Second, the many live trees remaining in the stand continue to annually contribute needles and small twigs to the forest floor. Thus, the ability for the fuel bed to ignite and carry fire is quickly regained. Third, many of the smaller trees killed outright by the prescribed fire had fallen and become part of the surface fuel load by the fifth year (*fig. 4*). Thus, an average of 8 (range 0-33) tons/acre [18 (0-82) Mg/ha] were estimated to have been added to the fuel bed. Fourth, stand density was not affected sufficiently to have a lasting effect on the potential for crown fire once surface fuels began to rebuild.

Conclusion

This simulation exercise indicates that fire hazard (the potential for high-intensity wildfire) was immediately reduced following an initial treatment with prescribed fire compared to pre-treatment conditions in the Black Mountain Research Natural Area. However, the reduction in fire hazard from a single burn appears to be short-lived for the following reasons: a) the prescribed fire did not appreciably affect canopy bulk density because only a portion of the smaller trees in the understory were killed while most intermediate and larger trees survived, b) though surface fuels were initially reduced, the scorched material in dead and living trees and annual shedding of needles and small twigs by surviving trees rebuilt the surface fuel bed within a few years, and c) the small trees that were killed subsequently fell and added to the surface fuel bed within five years of treatment. As field data become available for a more accurate portrayal of surface fuel condition, the results are likely to change somewhat. However, the relative differences over time are likely to remain.

Additional prescribed fires will be necessary to achieve reduction of fire hazard lasting more than a few years.

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