Characterizing fire severity patterns in three wildland fire use incidents in the southern Sierra Nevada

Report prepared by Nicole Vaillant
USDA Forest Service
Adaptive Management Services Enterprise Team

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Summary

Wildland fire use (WFU) is a tool that has been utilized by managers in the Forest Service since the 1970s to reintroduce fire as a natural ecosystem process. Today it is also applied to meet additional resource objectives including restoration and maintenance of ecosystems and fire hazard reduction through lessening the extent and severity of future fires. Few studies have characterized the spatial pattern of fire severity in either wildland or WFU fires. The objectives of this report are to: 1) use remotely sensed data and geospatial analysis to understand the influence of weather, topography, and fuels on fire severity, and 2) characterize fire severity patch dynamics for the Albanita-Hooker, Crag, and Clover WFU Fires in the southern Sierra Nevada. A regression tree analysis was completed with elevation, slope, aspect, time since last fire, burn frequency, wind speed, temperature, relative humidity, energy release component, and vegetation type as explanatory values to describe change in canopy cover derived from remotely sensed data. Change in canopy cover was most described by relative humidity, slope, and vegetation type for the Albanita-Hooker Fire; elevation, temperature, and energy release component for the Crag Fire; and relative humidity, temperature, and energy release component for the Clover Fire. The majority of the Albanita-Hooker and Crag Fires resulted in unchanged to low fire severity (70 % and 89 %, respectively). Mean (area-weighted) patch size for unburned to low severity was approximately 10 and 50 times the size of moderate and high severity patches for the Albanita-Hooker Fire, and about 100 times the size of both moderate and high severity patches in the Crag Fire. In contrast, a bimodal distribution of fire severity was seen in the Clover Fire, with 28 % unchanged to low severity and 62 % high severity, with the largest mean (area-weighted) patches occurring in the high severity category (6,889 ac). It is intended that the findings from this report will help managers understand which factors have the most influence on fire severity, and use this information to determine if WFU incidents will adequately return landscapes to a more historical fire regime.

Key Findings

- The Albanita-Hooker and Crag Fires primarily resulted in unchanged to low fire severity; the majority of the Clover Fire resulted in high severity
- Based on regression tree analysis topographic features and weather variables were the most influential factors determining canopy cover change for all three fires
- The Clover Fire reburned seven fires, with the most recent fires appearing to limit fire growth
- Some vegetation types such as pine experiencing higher severity than what would have historically occurred

Background
It is accepted that over a century of fire exclusion and aggressive land management practices has altered the fire regime in the Sierra Nevada from one of frequent, low intensity fires to less frequent high intensity fires (McKelvey and Busse 1996). Recent work using remotely sensed data has shown the frequency, extent, and severity of wildfires to drastically increase in the Sierra Nevada from the 1970s until present (Miller et al. 2009a). Fire severity refers to the loss of organic matter above or below ground and describes the impact of fire on an ecosystem (Keeley 2009) and can be assessed remotely with the use of satellite imagery (Miller and Thode 2007). Managers can alter potential fire behavior and severity by manipulating surface and canopy fuels to reduce the overall fuel load and by breaking the vertical and horizontal continuity of fuels (Graham et al. 2004). Treatments are usually implemented with prescribed fire, manual or mechanical thinning of smaller diameter trees, or mechanical methods such as mastication (Graham et al. 2004). Unfortunately, these treatments are not always feasible or permitted in remote areas or in areas designated as wilderness. These areas present an opportunity for managers reintroducing fire to the ecosystem through the use of wildland fire (Miller 2003). Wildland fire use (WFU) is defined as “management of either wildfire or prescribed fire to meet resource objectives specified in Land/Resource Management Plans” (USDA/USDI 2009).

Although the terminology and the definition are new, the concept is not. Native Americans used fire to manipulate the landscape to enhance food production and materials for making baskets (Anderson 2006, van Wagtendonk 2007). With Euro-American settlement, the perception of fire in the western United States was one of fear and destruction and fire suppression became the policy (Pyne 1982). It was not until the late 1970s that the Forest Service changed their policy of complete suppression to fire management where suppression, WFU, and prescribed fire were all acceptable. Wildland fire use was initiated to restore fire as a natural ecosystem process, with much recognition of the benefits and needs associated with reintroducing fire, but with limited explicit objectives; today WFU is used to meet an increasing number of more definitive resource objectives associated with the maintenance of natural fire regimes, including healthy ecosystem function, and managing for natural extent and severity of future fires through fuel reduction (Zimmerman and Lasko 2006). Wildland fire use is viewed as a cost effective tool to reduce surface and canopy fuel accumulations and continuity at the landscape-level facilitating the creation of resilient forest (Black 2004). The goal of WFU is that, in time, fire will play a more natural role creating a mosaic pattern of stands at various stages of post-fire development over the landscape, gradually creating stand structures which were prevalent before fire suppression became the policy (Wells 2009).

Unfortunately there are limitations to applying WFU. Many of these limitations are political (Doane et al. 2006). In order to use WFU on any particular fire, both a Land and Resource Management Plan and Fire Management Plan authorizing the use of WFU must be in place, and then a recommendation to manage the fire as such must be made (USDA/USDI 2005). Other limitations include public perception and acceptance, fragmented landscapes with multiple ownership, smoke and air quality, and proximity and threat to valuable resources including property and natural resources. One of the primary concerns of land managers is whether or not implementing a WFU fire will result in the desired mosaic puzzle of forest stand structures (Miller 2007).

Objectives

To date few studies have characterized the spatial pattern of fire severity in either wildland fires or WFU fires (Odion et al. 2004, Collins and Stephens 2007, Collins et al. 2007, Collins et al. 2009). The objectives of this report are to: 1) use remotely sensed data and geospatial analysis to understand the influence of weather, topography, and fuels on fire severity, and 2) characterize fire severity patch dynamics for three WFU fires in the southern Sierra Nevada.

The Albanita-Hooker Fire (2003), Crag Fire (2005), and Clover Fire (2008) form a continuous area incorporating a diverse landscape consisting of coniferous forests, mountain chaparral, high elevation meadows, and desert brush. The fires occurred at different times during the fire season and lasted from a few days to over a month. Currently WFU and fire suppression both fall under the umbrella of appropriate management response (AMR) where multiple management tactics and objectives can be utilized on a single incident. It is intended that the findings from this report will help managers understand which factors have the most influence on fire severity, and use this information to determine if WFU incidents will adequately return landscapes to a more historical fire regime.

Methods

Study area

This study incorporates the area burned by the Albanita-Hooker, Crag, and Clover Fires (Table 1, Figure 1). The fires burned on both the Sequoia and Inyo National Forests. The Albanita-Hooker Fire started the afternoon of September 3, 2003 as two separate lightning caused fires: the Albanita and Hooker Fires. The fires were both managed as WFU fires. Around October 6, the two fires burned together and became the Albanita-Hooker Fire. The fire was contained at 4,707 ac on October 30. The Crag Fire started on July 24, 2005 at 15:34 from a lightning strike and was also managed as a WFU fire. The Crag Fire was contained at 1,510 ac on September 19. The Clover Fire started on May 28, 2008 from a lightning strike and was initially managed as a WFU fire. After a period of significant fire growth where the community of Kennedy Meadows was threatened, the fire was managed as a WFU fire in the western portion, and a suppression fire in the eastern portion under AMR. The Clover Fire was contained on June 30 at 15,046 ac.

Table 1: Dates, size, and designation for the Albanita-Hooker, Crag, and Clover Fires.

	Year	Start date & time[1]	Containment date	Fire size[2] (ac)	Fire designation
Albanita-Hooker Fire	2003	9/03 1500	10/30	4707	WFU
Crag Fire	2005	7/24 1534	9/19	1510	WFU
Clover Fire	2008	5/28 1400	6/30	15046	AMR

[1]Start dates and time from ICS-209 forms (Available at: http://fam.nwcg.gov)
[2]Fire size is based on the remotely sensed data not the official estimated fire size
WFU – wildland fire use; AMR - appropriate management response

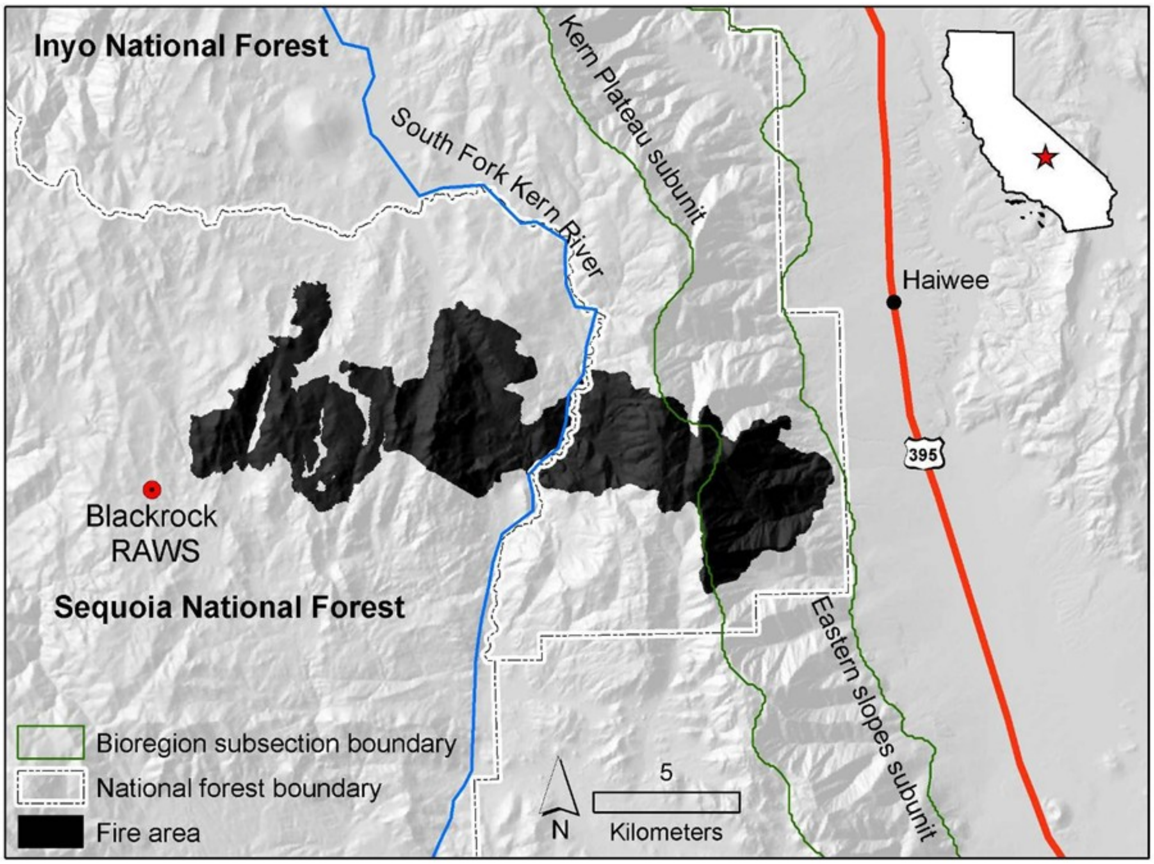

Figure 1: Study area including national forest boundaries, fire location, and Blackrock remote automated weather station.

The majority of the study area burned on the Kern Plateau subsection of the Sierra Nevada bioregion (Cleland et al. 2007). The Kern Plateau subsection is a high plateau west of the Sierra Nevada crest, with elevations ranging from about 3,000 to over 11,000 ft. It has a temperate to cold and semi-arid to subhumid climate and averages 10 to 30 in of precipitation per year with the majority falling as snow in the higher elevations. Vegetation zones include eastside and upper montane zones and are composed primarily of Jeffrey pine (*Pinus jeffreyii*), red fir (*Abies magnifica*), and lodgepole pine (*Pinus contorta*) with an understory shrub layer containing manzanita (*Arctostaphylos sp.*), mountain mahogany (*Cercocarpus sp.*), and ceanothus

(*Ceanoutus sp.*). There are also large wet meadows bordered by areas of sagebrush (*Aremesia sp.*) throughout the Kern Plateau.

A portion of the Clover Fire burned off of the Kern Plateau to the east into the Eastern Slopes subsection of the Sierra Nevada bioregion (Cleland et al. 2007). This subsection includes the very steep eastern slope of the Sierra Nevada. The Eastern Slopes subsection average 8 to 50 in of precipitation per year with the majority falling as snow in the higher elevations. Higher elevations singleleaf pinyon (*Pinus monophylla*), and juniper (*Juniperus sp.*) trees are common in addition to those found at higher elevations of the Kern Plateau. At mid to lower elevations the vegetation is dominated by shrubs, including: creosotebush (*Larrea sp.*), saltbush (*Atriplex sp.*), blackbush (*Coleogyne sp.*), bursages (*Ambrosia sp.*), and sagebrush.

<u>Spatial data</u>
Post-fire estimates of fire effects were based on the relative version of the delta Normalized Burn Ratio (RdNBR) obtained from the US Forest Service Remote Sensing Applications Center. Images were obtained one year before fire, and immediately post-fire (Clover Fire), and one year post-fire (Albanita-Hooker and Crag Fires). Immediate post fire data was used for the Clover Fire because this was the only available data at the time of analysis. Percent canopy cover change (0 to 100 %) and fire severity categories (unchanged to low <25 %, moderate 25-75 %, high >75 % change in canopy cover) derived from RdNBR were used for this study (Figure 2).

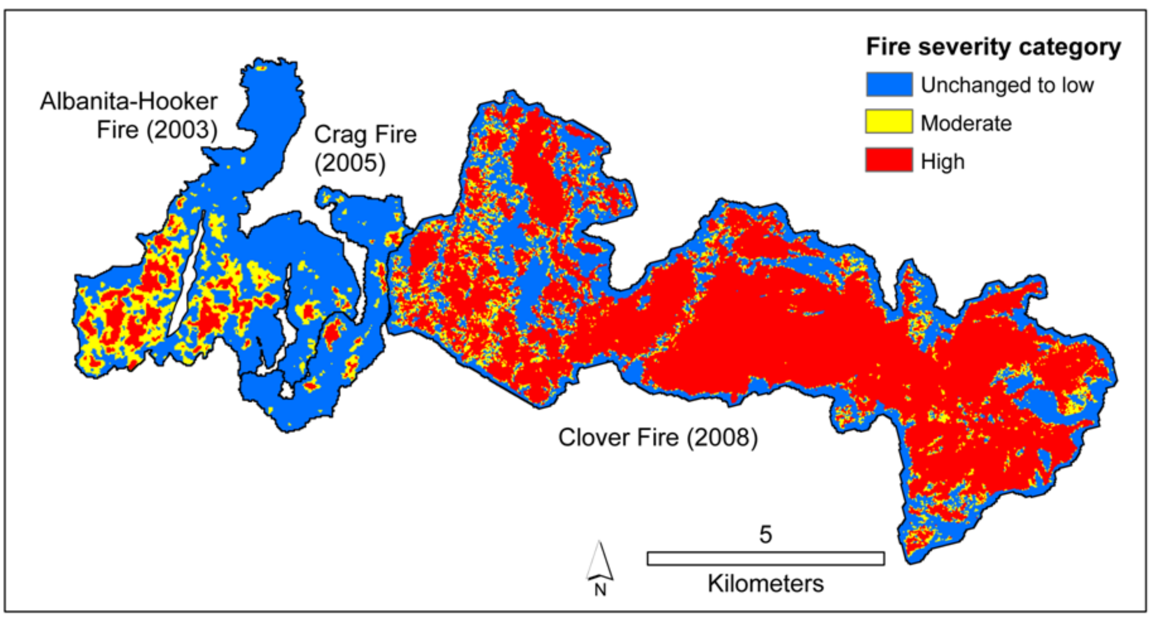

Figure 2: Fire severity categories (unchanged to low is < 25 %, moderate is 26 to 75%, and high is >75% change in canopy cover) for the Albanita-Hooker, Crag, and Clover Fires. Fire severity classes are from Miller et al. (2009) and are classified based on change to canopy cover.

Canopy cover change is a commonly accepted measure of fire severity. Furthermore, canopy closure is important for characterizing habitat conditions for species such as the California spotted owl (*Strix occidentalis*), northern goshawk (*Accipiter gentilis*), and fisher (*Martes pennanti*) which are potentially present in the study area. The RdNBR data and its derivatives are all 30 m pixel ArcGIS (vers. 9.2, ESRI, Redlands, CA) GRID data.

Landfire National products provide continuous 30 m pixel ArcGIS GRID data for fire behavior, fire regime, vegetation, and fire effects for the entire United States (data available at: www.landfire.gov). Elevation, slope, aspect, and existing vegetation data were downloaded and utilized for this project. Existing vegetation data was simplified into nine categories based on similar vegetation type or burning characteristics (Table 2).

Table 2: Area and percent of landscape burned in the Albanita-Hooker, Crag, and Clover Fires by dominant vegetation group.

	Albanita-Hooker Fire		Crag Fire		Clover Fire	
	Area (ac)	%	Area (ac)	%	Area (ac)	%
Pine	2455	52	712	47	4140	28
Fir	1067	23	187	12	783	5
Pinyon-juniper	3	<1	<1	<1	1042	7
Woodland	<1	<1	0	0	450	3
Riparian	181	4	77	5	179	1
Sage	29	1	23	2	2307	15
Shrub	790	17	354	23	4029	27
Grass	19	<1	7	<1	56	<1
Sparsely vegetated	141	3	145	10	1654	11
Non-burnable	21	<1	4	<1	406	3
Totals	4707		1510		15046	

For each fire, fire progression maps were obtained from either the fire's Incident Management Team or the Sequoia National Forest (Figure 3). Progression maps provide daily or multiple day fire perimeter growth which is used to relate weather characteristics to burn periods. The progression maps were converted into 30 m pixel ArcGIS GRIDS in order to assign weather metrics (see below for description) to each point in the burned area.

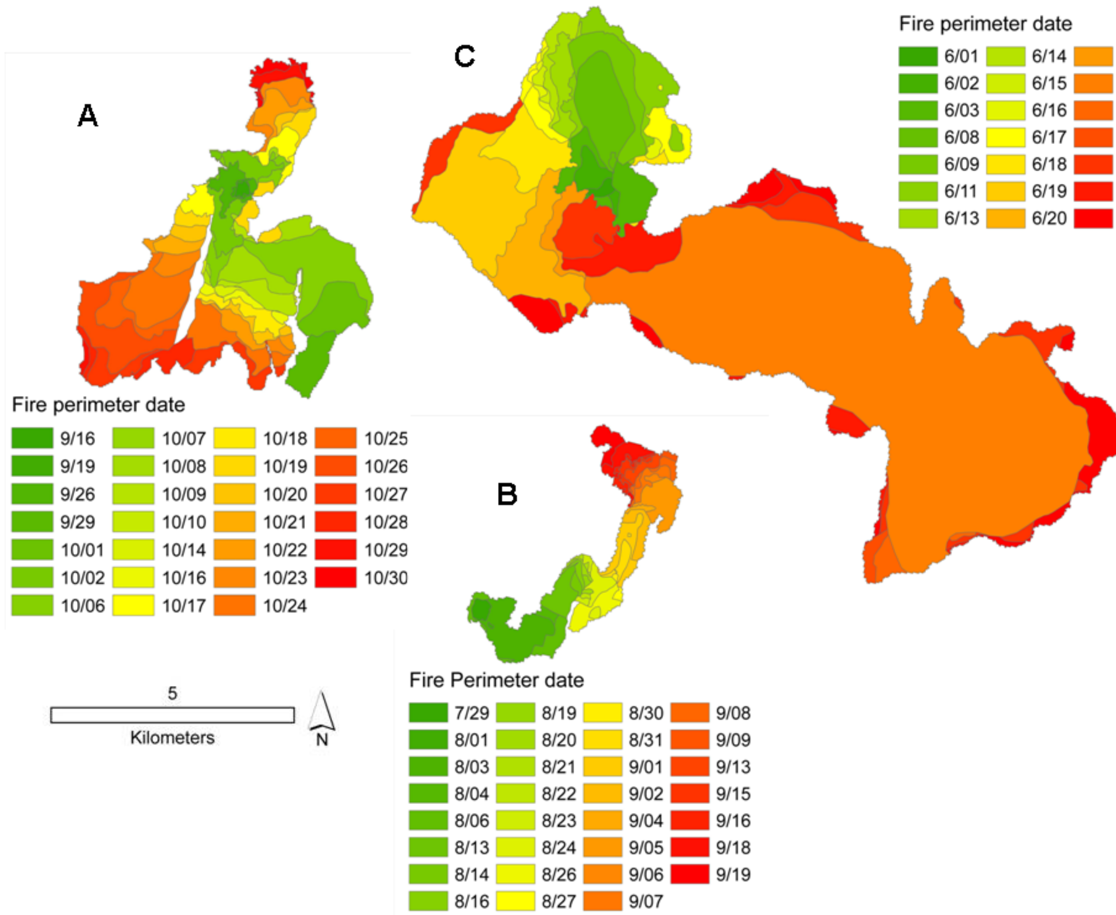

Figure 3: Fire progression maps for the Albanita-Hooker (**A**), Crag (**B**), and Clover (**C**) Fires.

A fire atlas (Figure 4) was used to determine the burn frequency, which is the number of times a pixel had burned prior to the fire event (0, 1, or 2), and the time since last fire. The fire atlas includes all fires greater than 100 ac and many smaller fires that have occurred in California from around 1900 through 2008 (data available at: www.fs.fed.us/r5/rsl/clearninghouse). The earliest fire on record for the study area occurred in 1944. For areas where no previous fire was recorded, a default value of 100 yrs was assigned. As with the fire progression maps, burn frequency and time since burn maps were converted into 30 m pixel ArcGIS GRIDS for consistency among the data.

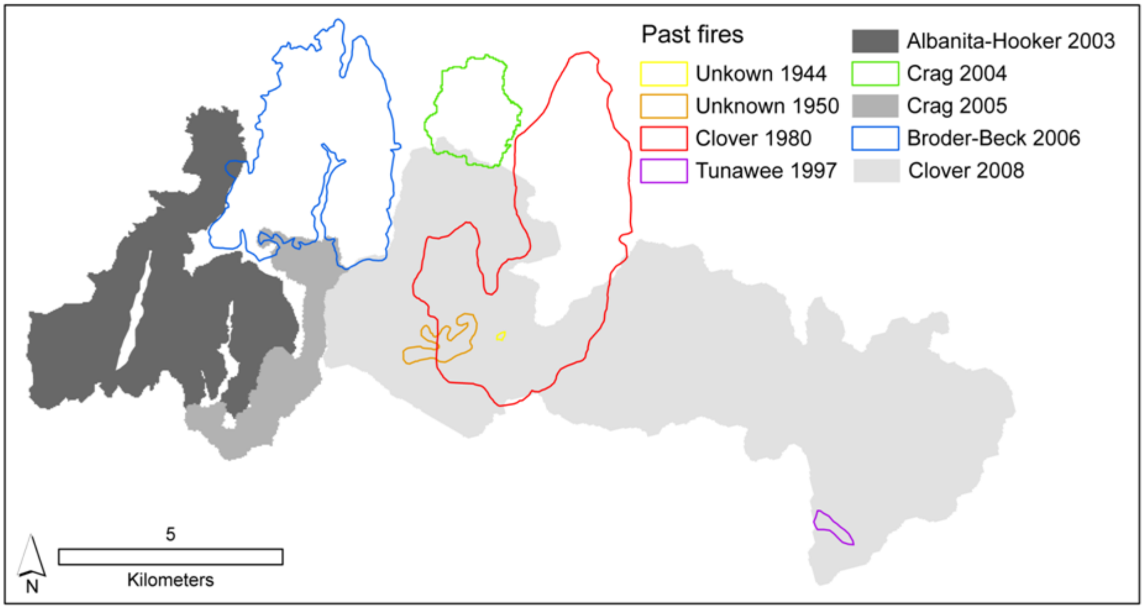

Figure 4: Fire atlas for the area surrounding the Albanita-Hooker, Crag, and Clover Fires. Fire perimeter data available at: http://www.fs.fed.us/r5/rsl/clearinghouse/

Weather data

Weather data was collected from the Blackrock remote automated weather station (RAWS) which is located at 36° 5' 37" latitude, -118° 15' 40" longitude (Figure 1). Daily maximum temperature, minimum relative humidity, windspeed, and energy release component were calculated in Fire Family Plus (RMRS/SEM 2002) for the individual fire dates associated with fire progression (Table 3, Figure 5). Calculated weather variables were then applied to the fire progression maps to assign daily (or averages of values if the progression was for multiple days) values for the statistical analysis.

Table 3: Summary statistics for weather and topographical features for the Albanita-Hooker, Crag, and Clover Fires.

	Albanita-Hooker Fire		Crag Fire		Clover Fire	
	Mean	Range	Mean	Range	Mean	Range
Maximum temperature (ºF)	80	60-83	75	61-83	78	61-80
Minimum relative humidity (%)	10	2-22	14	4-32	12	5-20
Wind gust speed (mph)	7.9	0-14.0	9.4	5.0-17.6	10.3	8.0-13.0
Energy release component (BTU/ft^2)	38	12-50	47	24-52	44	23-48
Slope (%)	13	0-41	10	0-48	22	0-55
Elevation (ft)	8527	7779-9406	8520	8015-9157	7717	4521-9469

Data analysis

To characterize the spatial patterns of fire severity FRAGSTATS (vers. 3, McGarigal et al. 2002) was used in conjunction with ArcGIS. FRAGSTATS is a spatial pattern analysis program and was used to calculate the number of patches, mean patch size, and area-weighted mean patch size for the three fire severity categories for each fire. An area-weighted mean puts more emphasis on the larger patches and less on the smaller patches. A high proportion of patches in the burned area were represented by a single to a very few pixels in size which is why an area-weighted mean was used in conjunction with the arithmetic mean.

A regression tree analysis was completed using R (ver. 2.8.1, R Core Development Team 2008) to explain the variation in fire severity. Regression tree analyses are a form of exploratory analysis where multiple explanatory or predictor variables are used to characterize a singe response variable (De'ath and Fabricus 2000). With regression tree analysis the response variable is continuous; however, the explanatory variables can be either continuous or categorical. Regression tree analyses are simplistic yet robust and are often used for ecological data analysis because they do not require the data to be normally distributed. For this analysis the response variable was change in canopy cover and the explanatory values were: elevation, slope, aspect, time since last fire, burn frequency, wind gust speed, maximum temperature, minimum relative humidity, energy release component, and vegetation type. The "sample" tool in ArcGIS was used to extract values for the response and explanatory variables for each pixel in all three fires for use in the regression tree analysis. Each tree was "pruned" with a complexity parameter of 0.01 (Finney et al. 2005). The complexity parameter insures a split must decrease the overall lack of fit by that amount.

Results

Spatial pattern of fire severity

Frequency distributions of percent change in canopy cover for both the Albanita-Hooker and Crag Fires were skewed to the left with the majority of the burned areas having unchanged to low fire severity; the Clover Fire had a bimodal distribution with the majority of the fire area resulting in high severity (Figure 5). The distribution is further exemplified by the fire severity maps (Figure 2) and the patch dynamic outputs (Table 4). Mean (area-weighted) patch size was largest for the unchanged to low severity class for the Albanita-Hooker and Crag Fires and high severity for the Clover Fire, 2,688 ac, 1,315 ac, and 6,889 ac, respectively (Table 4).

Table 4
Patch dynamics of the Albanita-Hooker, Crag, and Cover Fires.

	Fire severity class	Number of patches	Mean patch size (ac)	Area-weighted mean patch size (ac)
Albanita-Hooker Fire	Unchanged to low	30	111	2688
	Moderate	64	15	277
	High	47	10	52
Crag Fire	Unchanged to low	1	1315	1315
	Moderate	33	5	12
	High	16	5	15
Clover Fire	Unchanged to low	342	12	3111
	Moderate	1457	<1	7
	High	224	42	6889

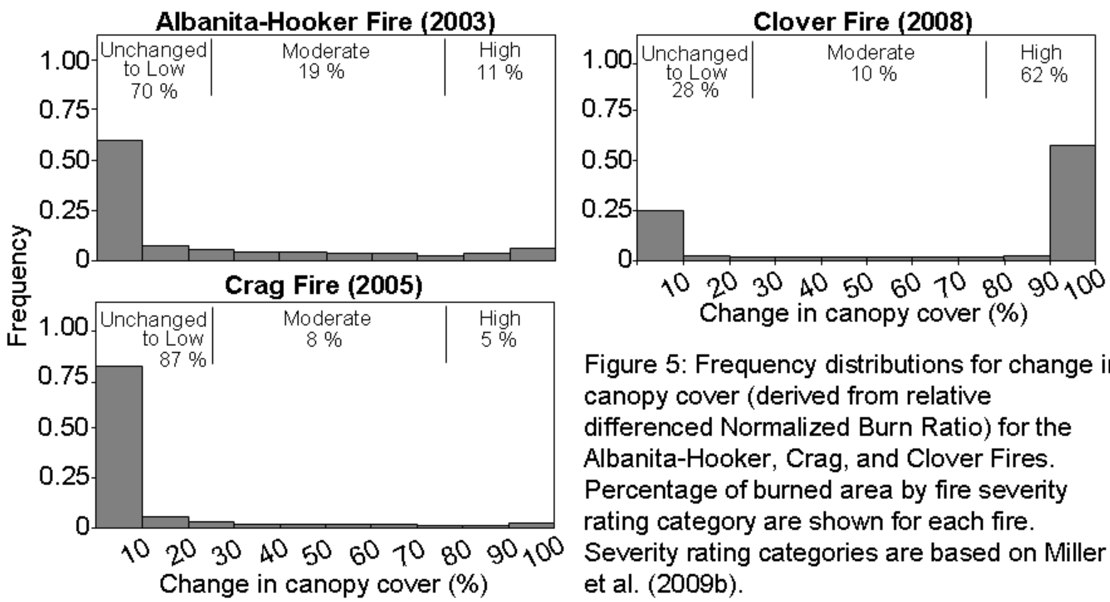

Figure 5: Frequency distributions for change in canopy cover (derived from relative differenced Normalized Burn Ratio) for the Albanita-Hooker, Crag, and Clover Fires. Percentage of burned area by fire severity rating category are shown for each fire. Severity rating categories are based on Miller et al. (2009b).

Regression tree analysis

The resulting pruned regression trees are shown in Figures 6, 7, and 8. The regression tree illustrates predictor variable influence decreasing from top to bottom (variables shown to have the greatest influence on canopy cover change are located at the top of the regression tree). The predictor variable and value (or categories) associated with each split are shown to the left and right of each node. For the terminal nodes the number of pixels and the mean change in canopy cover (%) are listed. The tree for the Clover Fire was the most simplistic (5 splits) and the tree for the Crag Fire was the most complex (15 splits). Although burn frequency and wind speed were also explanatory values used in the regression tree analysis, neither was used in tree construction because these values were not found to significantly describe canopy cover change.

The explanatory values used to describe canopy cover change for the Albanita-Hooker Fire were: minimum relative humidity, maximum temperature, energy release component, slope, elevation, aspect, and vegetation type (Figure 6). Minimum relative humidity was the most influential factor for determining canopy cover change for the Albanita-Hooker Fire. Lower relative humidity values (<3.5%) are associated with larger changes in canopy cover. After relative humidity, vegetation type and slope were used to explain the change in canopy cover due to fire. Pine, pinyon-juniper, shrubs, and woodland areas contributed to larger changes in canopy cover than fir, grass, riparian, sparsely vegetated, sage, and non-burnable types. Steeper slopes contributed to larger changes in canopy cover than shallower slopes. The third level of importance for explaining the change in canopy cover for this regression tree were vegetation type, aspect, and elevation. South, southeast, and southwest aspects, higher elevations, and pine, pinyon-juniper, shrubs, sparsely vegetated areas, and woodlands all contributed to larger changes in canopy cover. Additional splits are attributed to vegetation type, energy release component, temperature, and slope. The subsequent split for vegetation type is similar in effect to the prior split; however, sparsely vegetated areas are now associated with larger changes in canopy cover. Relative humidity (>3.5 %), shallow slopes (<14.5 %), and fir, grass, non-burnable, riparian, and sage vegetation types explain the lowest change in canopy cover (3 %). Low relative humidity (<3.5 %), pine, pinyon-juniper, shrubs, and woodlands above 2556 m in elevation are associated with the highest change in canopy cover (66 %).

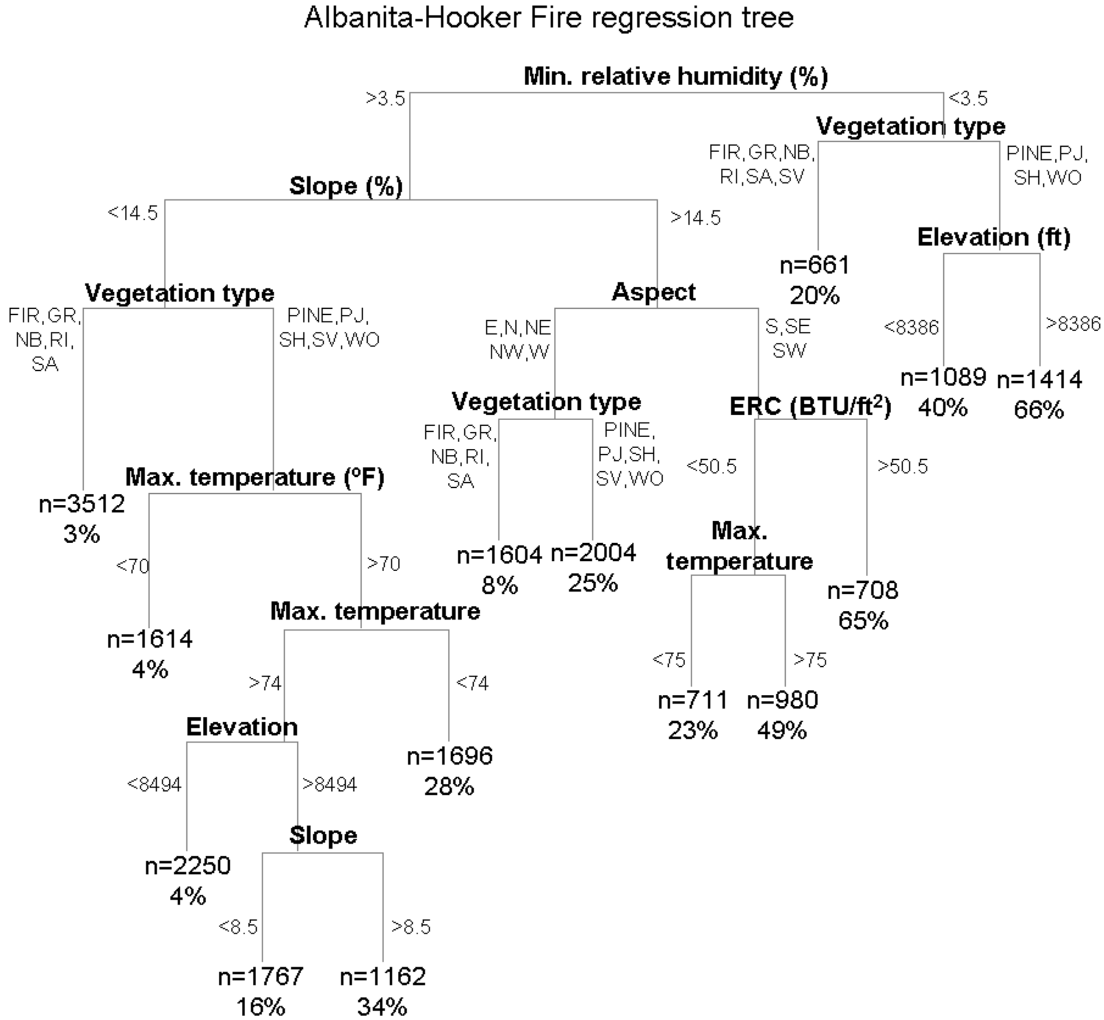

Figure 6: Regression tree for the Albanita-Hooker Fire. The number of pixels along with the mean value of percent canopy cover change are reported for each node. The total R^2 for the tree is 40%. ERC – energy release component

For the Crag Fire, elevation was the most significant factor explaining change in canopy cover where the smallest change in canopy cover values were associated with elevations less than 8,360 ft. After elevation, maximum temperature was the next most important factor. Here higher temperatures resulted in higher severity. The third level of explanation is from energy release component, where lower values were associated with higher severity. Aspect and time since last fire are the next most important factors in explaining fire severity. South and southeast aspects and greater than 51 years since the last fire are associated with higher severity. There is no set trend for splits lower in the tree, factors used to explain the variability are: elevation, relative humidity, slope, and energy release component. For specifics on additional splits, refer to Figure 7. High elevation (8,500 ft), low energy release component (<22.5 BTU/ft^2), and long fire free intervals (>51 years) all contributed to the highest fire severity (81 % canopy cover change) for the Crag Fire. The smallest change in canopy cover (0 %) was attributed to high energy release component (>22.5 BTU/ft^2), south and south east aspects, high relative humidity (>23 %), shallow slopes (<13 %), and higher elevation (8,071 ft).

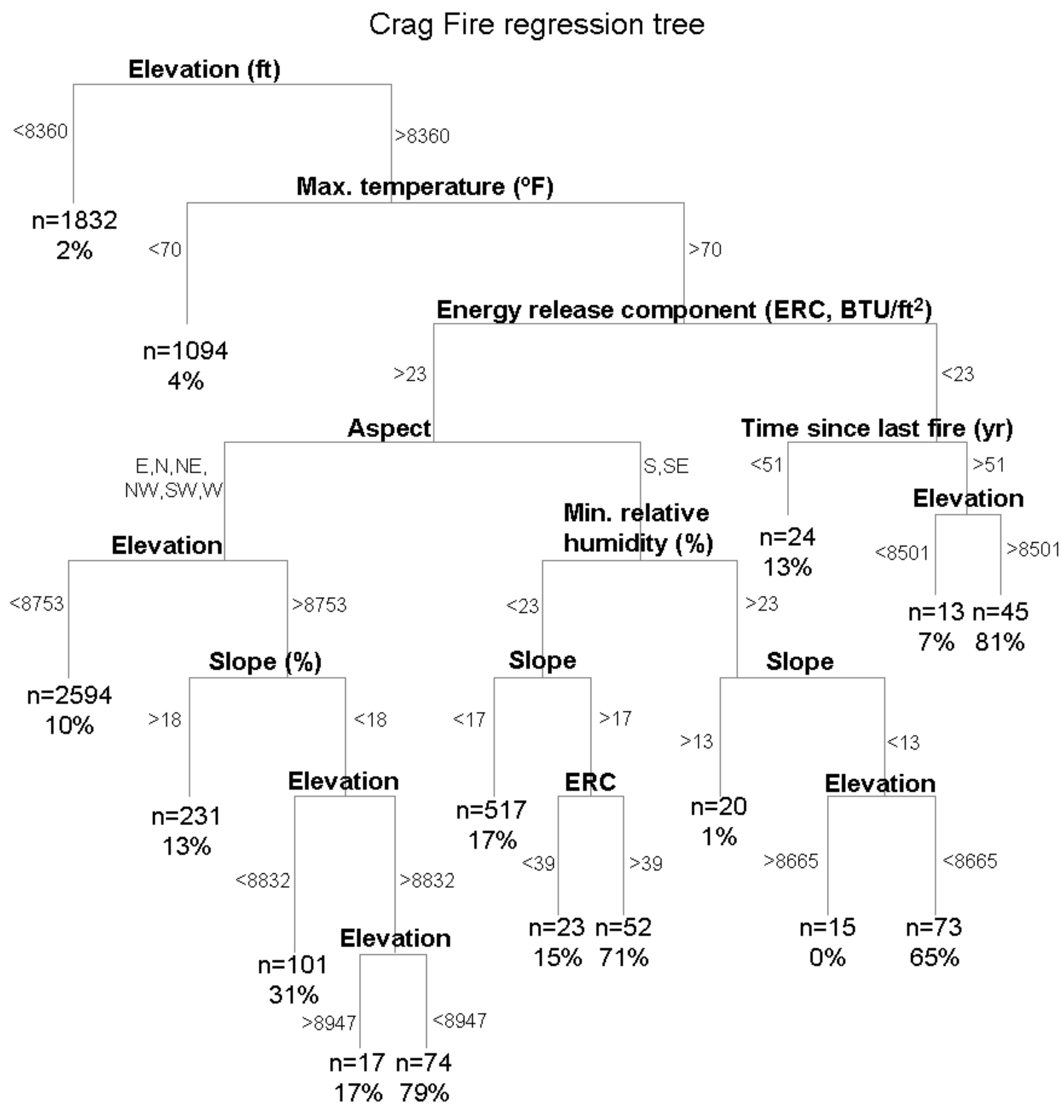

Figure 7: Regression tree for the Crag Fire. The number of pixels along with the mean value of percent canopy cover change are reported for each node. The total R^2 for the tree is 32%.

Weather factors and fire history were the only explanatory values used in constructing the tree for the Clover Fire (Figure 8). Relative humidity was the most influential factor for determining canopy cover change for the Clover Fire. Temperature and energy release component were the next most influential explanatory values. Higher temperatures and energy release component result in higher canopy cover change. The final level is defined by energy release component and time since last fire which further differentiated change in canopy cover after temperature. Lower values of energy release component and longer fire free intervals are associated with higher fire severity. The highest and lowest values of fire severity were associated with relative humidity >12.5 %, and an initial split to an energy release component >28 BTU/ft^2. The subsequent split to greater than or less than 45.5 BTU/ft^2 defined the greatest (low energy release component) and smallest (high energy release component) change to canopy cover.

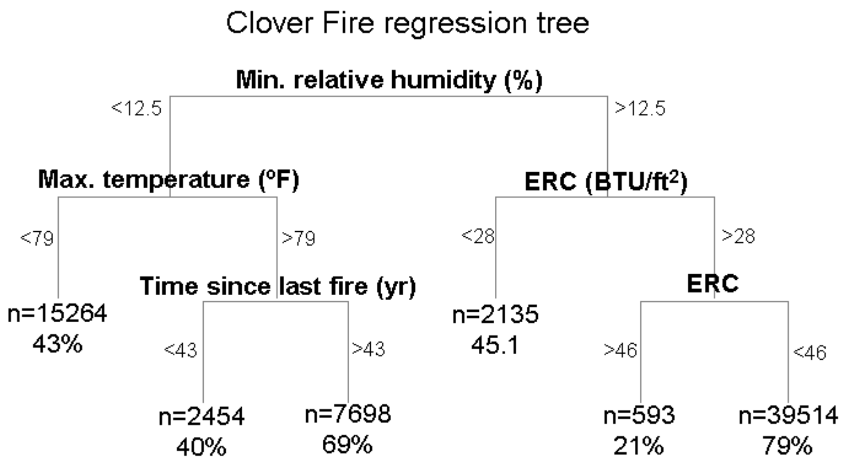

Figure 8: Regression tree for the Clover Fire. The number of pixels along with the mean value of percent canopy cover change are reported for each node. The total R^2 for the tree is 15%.
ERC – energy release component

Discussion

One of the primary goals of WFU is to create a patchwork of fire resilient stands returning forests to a historical fire regime (Wells 2009). A fire regime is comprised of five factors: seasonality, frequency, size, intensity, and severity. The historical fire regime in the Sierra Nevada is dependant on the ecological zone and the dominant vegetation present. The fires studied in this report exist primarily in eastside forest and woodland and upper montane forest (van Wagtendonk and Fites-Kaufman 2006). All three ecological zones are characterized by summer and fall fires. The eastside forest and woodland ecological zone can be divided into three major vegetation types: Jeffrey pine, white fir/mixed conifer, and chaparral. Jeffrey pine forests are characterized by frequent small to medium sized low severity fires, white fir/mixed conifer forests and chaparral experience moderately frequent medium sized fires with mixed severity for the forests and high for chaparral (van Wagtendonk and Fites-Kaufman 2006). Upper montane forests are divided into red fir and Jeffrey pine, western white pine, and mountain juniper vegetation groups. Red fir typically burns with medium frequency and fire size with mixed severity, and the Jeffrey pine composite has moderate frequency, small extent and low severity (van Wagtendonk and Fites-Kaufman 2006). Although the frequency of fires vary in the different ecological zones, the extent is typically small to medium and the severity is low to mixed in forested systems and high in shrublands.

The Albanita-Hooker, Crag, and Clover Fires burned under different fire conditions. The later season Albanita-Hooker and Crag Fires were smaller in extent and primarily burned with unchanged to low severity with small patches of moderate to high severity. The moderate spatial extent and the mixed severity witnessed in these fires are similar to the historical fire regime. Similar findings were observed for WFU fires burning in the Illilouette basin of Yosemite National Park (Collins and Stephens 2007, Collins et al. 2007, Collins et al. 2009). These fires did not differ in extent, frequency or severity from the historical fire regime (Collins et al. 2009). The difference in fire regime for the Albanita-Hooker and Crag Fires as compared to the fires in the Illilouette basin is the frequency in which fires historically occurred. The burned area for these two fires has been fire free for at least the past 100 years based on the fire atlas. The early season Clover Fire resulted in a bimodal distribution with the majority of the fire burning large patches under high severity. The rather large extent and large patches of high severity are likely outside of the historical range. Although dominant vegetation type was not used to describe fire severity in the regression analysis, the Clover Fire had the highest proportion of shrub dominated vegetation of the three fires (42 % shrub and sage categories combined) which could contribute to the large high severity patches. In addition, the Clover Fire experienced burning periods of much larger growth than the Albanita-Hooker and Crag Fires. In particular the June 23rd burning period resulted in 3,678 ha (9,089 ac) of growth (Figure 3) where fire behavior was plume dominated (personal observation) likely contributing to higher fire severity over a large area than was recorded for either the Albanita-Hooker or Crag Fires. Finally, the immediate post-fire imagery was used for the Clover Fire (because this is the only available data at this point), whereas, one year post-fire imagery was used for both the Albanita-Hooker and Crag Fires. The immediate post-fire imagery has the potential to overestimate fire severity; when the data becomes available it would be advantageous to compare the data sets and rerun the analysis for consistency among the three fires.

Regression tree analyses were used to describe the influences of weather, topography, fuels and fire history on fire severity which was characterized by percent change in canopy cover. Weather and topographic features were the dominant explanatory variables describing fire severity. The Albanita-Hooker Fire was the only fire where fuels (vegetation type) were a factor in predicting fire severity. Pine, pinyon-juniper, shrublands, and woodlands predicted higher fire severity than fir, grass, riparian and sage brush. These findings are slightly different than found by Collins et al. (2007) where white fir, lodgepole pine, and shrublands resulted in higher severity and red fir, juniper, Jeffrey pine and meadows resulted in lower fire severity. However, it must be noted that our vegetation grouping combine lodgepole pine and Jeffrey pine into one pine group and red fir and white fir into one fire group. The fact that pine predicted higher fire severity was interesting because Jeffrey pine historically burned frequently with low intensity surface fires (van Wagtendonk and Fites-Kaufman 2006). The long fire free interval (>100 yrs) found in the Albanita-Hooker fire might explain this deviation from the expected. However, it might be advantageous to re-run the statistics dividing out by pine species as was completed by Collins et al. (2007).
Relative humidity, temperature, and energy release component were the most common explanatory values for change in canopy cover for the three fires.

One of the goals of WFU is creating a mosaic of burned and re-growing patches eventually allowing fires to burn more naturally. This mosaic is being recreated in areas where UFW has been utilized for many decades, such as Yosemite National Park. Collins et al. (2009) presents an explanation of two potential outcomes from WFU fires reburning previous fires in Yosemite National Park, extent constrained or low to moderate severity, and non-extent constrained moderate to high severity. It is proposed the dominant factors controlling these outcomes to be time since last fire and weather. If a fire burned less than 9 years prior it resulted in an extent-constrained fire, and the probability of reburn is more likely under more extreme fire behavior as calculated using the burning index (Collins et al. 2009). Although not explicitly explored in the analysis both outcomes are evident in the Clover Fire (Figures 2 and 4). The Clover Fire reburned the entire extent of two unnamed fires which occurred in 1944 and 1950, and the 1997 Tunawee Fire (all greater than 9 years prior). In addition, the Clover Fire appears to have been extent constrained by the more recent Broder-Beck (2006) and Crag Fires (2004 and 2005). The one anomaly is the 1980 Clover Fire where a large portion of that fire was reburned; however, there does appear to be some extent constraints occurring. Without further analysis is it difficult to determine the exact rational for this. Other factors which can limit the spread of a fire are natural barriers, such as wet meadows and rock escarpments which are both present in the study are and suppression actions. Even though these fires were managed as UFW, that does not mean fire was permitted to freely burn at all times, suppression tactics are often utilized to “heard” UFW fire to maintain desired fire behavior. In time, if fires are allowed to burn as WFU fires, it might be possible for the Kern Plateau to return to a more historic fire regime with a mosaic of fire resilient stands.

Wildland fire use can be used as a tool to reintroduce fire to the ecosystem, reduce unnatural fuel accumulations, and promote resilient forest structures under appropriate conditions. Weather and topographic features explained the majority of the variation in burn severity. Coupling the knowledge of driving factors for fire severity and the historical fire regime, future fires can be managed in such a way to promote desired fire behavior and effects. For example, if high temperatures with low relative humidity are expected and low severity is desired suppression tactics can be used to keep the fire in check until more favorable burning conditions return.

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References

Anderson, MK 2006. The use of fire by Native Americans in California. Pages 417-430 *in:* NG Sugihara, JW van Wagtendonk, J Fites-Kaufman, KE Shaffer, and AE Thode, editors. Fire in California's ecosystems. University of California Press, Berkeley, California, USA.

Black, A. 2004. The West is Burning. What's the Problem? Joint Fire Science Program, Missoula, MT

Cleland, DT, JA Freeouf, JE Keys, GJ Nowacki, C Carpenter, and WH McNab 2007. Ecological subregions: sections and subsections of the conterminous United States [1:3,500,000] [CD-ROM]. Sloan AM, cartog. USDA Forest Service General Technical Report WO-76

Collins, BM, and SL Stephens 2007. Managing Natural Fires in Sierra Nevada Wilderness Areas. Frontiers in Ecology and the Environment 5(10): 523-52

Collins, BM, M Kelly, JW van Wagtendonk, and SL Stephens 2007. Spatial patterns of large natural fires in Sierra Nevada wilderness areas. Landscape Ecology 22: 545-557

Collins, BM, JD Miller, AE Thode, M Kelly, JW van Wagtendonk, and SL Stephens 2009. Interactions among wildland fires in a long-established Sierra Nevada natural fire area. Ecosystems 12(1): 114-128

De'ath, G, and KE Fabricus 2000. Classification and regression trees: a powerful yet simple technique for ecological data analysis. Ecology 81(11): 3178-3192

Doane, DL. J O'Laughlin, P Morgan, and C Miller 2006. Barriers to wildland fire use: A preliminary problem analysis. International Journal of Wilderness. 12(1): 36-38

Finney, MA, CW McHugh, and IC Grenfell 2005. Stand and landscape effects of prescribed burning on two Arizona wildfires. Canadian Journal of Forest Resources 35: 1714-1722

Graham, RT, S McCaffrey, and TB Jain 2004. Science basis for changing forest structure to modify wildfire behavior and severity. USDA Forest Service, Rocky Mountain Research Station, General Technical Report, RMRS-GTR-120

Keeley, JE 2009. Fire intensity, fire severity and burn severity: a brief review and suggested usage. International Journal of Wildland Fire 18: 116-126

McGarigal, K, SA Cushman, MC Neel, and E Ene. 2002. FRAGSTATS: Spatial pattern analysis program for categorical maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Program available for download at:: www.umass.edu/landeco/research/fragstats/fragstats

McKelvey, KS, and KL Busse 1996. Twentieth century fire patterns on Forest Service lands. *In:* Sierra Nevada Ecosystem Project: Final Report to Congress Volume II, Chapter 41. University of California Davis, Wildland Resource Center, Rep. 37

Miller, C 2003. Natural fire regimes in wilderness. International Journal of Wilderness 9(2): 33, 48.

Miller, C 2007. Simulation of the consequences of different fire regimes to support wildland fire use decisions. Fire Ecology 3(2): 83-102

Miller, JD, and A Thode 2007. Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). Remote Sensing of Environment 109(1):66-80

Miller, JD, HD Safford, M Crimmins, and A Thode 2009a. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade mountains, California and Nevada, USA. Ecosystems 12(1): 16-32

Miller, JD, EE Knapp, CH Key, CN Skinner, CJ Isbell, RM Creasy, JW Sherlock 2009b. Calibration and validation of the relative differenced Normalized Burn Ratio (RdNBR) to three measures of fire severity in the Sierra Nevada and Klamath Mountains, California, USA. Remote Sensing of Environment 113(3): 645-656

Odion, DC, EJ Frost, JR Strittholt, H Jiang, DA Delasala, and MA Moritz 2004. Patterns of Fire Severity and Forest Conditions in the Western Klamath Mountains, California. Conservation Biology 18(4): 927-936

Pyne, SJ 1982. Fire in America: a cultural history of wildland and rural fire. Princeton University Press, Princeton, New Jersey, USA

R Development Core Team 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Program available for download at: http://www.R-project.org

RMRS [Rocky Mountain Research Station]/SEM [System for Environmental Management] 2002. Fire Family Plus User's Guide. Program available for download at: www.fire.org

USDA [US Department of Agriculture Forest Service]/USDI [US Department of Interior Park Service] 2005. Wildland Fire Use Implementation Procedures Reference Guide. Washington, DC

USDA [US Department of Agriculture Forest Service]/USDI [US Department of Interior Park Service] 2009. Guidance for Implementation of Federal Wildland Fire Management Policy. Version: February 13, 2009 Available at: http://www.nifc.gov/policies.htm

van Wagtendonk, JW 2007. The History and Evolution of Wildland Fire Use. Fire Ecology 3(2): 3-17

van Wagtendonk, JW, and J Fites-Kaufman 2006. Sierra Nevada bioregion. Pages 264-294 *in:* NG Sugihara, JW van Wagtendonk, J Fites-Kaufman, KE Shaffer, and AE Thode, editors. Fire in California's ecosystems. University of California Press, Berkeley, California, USA.

Wells, G 2009. Wildland fire use: managing for a fire-smart landscape. Fire Science Digest, a product of the Joint Fire Science Program. Issue 4, 11p.

Zimmerman, GT, and R Lasko 2006. The changing face of wildland fire use. Fire Management Today 66(4): 7-12