Fire and Fire Surrogate Study in the Sierra Nevada: Evaluating Restoration Treatments at Blodgett Forest and Sequoia National Park[1]

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Management practices have altered both the structure and function of forests throughout the United States. Some of the most dramatic changes have resulted from fire exclusion, especially in forests that historically experienced relatively frequent, low- to moderate-intensity fire regimes. In the Sierra Nevada, fire exclusion is believed to have resulted in widespread vegetation changes, including greater density and cover of white fir (*Abies concolor)* and reduction in the area occupied by hardwoods and shrubs (Parsons and DeBenedetti 1979, Vankat and Major 1978). Fire exclusion has allowed both live and dead woody fuels to accumulate, increasing the probability of large, high-severity, stand-replacing fires (Stephens 1998, van Wagtendonk 1985).

Fire is an important ecological process in Sierra Nevada mixed conifer forests (Kilgore 1973). Many tree and shrub species depend on fire to expose mineral soil and create gaps for establishment. In the Sierra Nevada, the use of prescribed fire to restore these natural ecological processes began in the late 1960s in Sequoia and Kings Canyon National Parks. Today, Yosemite and Sequoia and Kings Canyon National Parks have active prescribed burning programs. Outside of the national parks, prescribed burning is conducted; however, its use is more variable and generally less widely implemented.

As human populations living in and adjacent to forested areas of the Sierra Nevada have increased, property losses due to wildfires have correspondingly increased, highlighting the need to address high-fire hazards in these forests. Concerns about potential escape risks of prescribed fires, perceived conflicts between meeting restoration goals with prescribed fire and growing trees for harvest, and concerns about smoke-dispersal impacts make it unlikely that prescribed fire will be the sole tool for reducing hazardous fuels and meeting ecosystem restoration goals. Mechanical thinning has been and will likely continue to be a widely applied alternative to fire. As resource managers and the scientific community grapple with the problem and try to devise strategies for managing fire and fuels in the Sierra Nevada, important gaps in the knowledge base remain. These include the following questions:

Can mechanical thinning be used as a surrogate for prescribed fire?

Historical structures and compositions of mixed conifer forests under a regime of relatively frequent, low- to moderate-intensity fire can be approximated using mechanical thinning. However, knowledge is limited about which of fire's ecological functions can be emulated by mechanical means and which cannot. The long-term ecosystem consequences of replacing one

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type of disturbance with another require investigation. For example, some understory shrubs and herbs require the direct effects of fire (heat and/or smoke) to stimulate germination. In addition, nutrient cycling following fire may be very different than nutrient cycling following mechanical thinning.

Can fuel reduction using prescribed fire be conducted without killing or injuring large numbers of overstory trees?

Exclusion of fire over the past century in Sierra Nevada mixed conifer forests has allowed fuels to accumulate to unnatural levels and become more spatially continuous, factors that might cause fire to have unnatural ecosystem impacts (Bonnickson and Stone 1982). There are concerns that prescribed fires could lead to high mortality of large trees because of cambium and fine-root damage during combustion. In addition, prescribed fires could be of uniformly high intensity, erasing the character of the original forest mosaic.

What are the ecological impacts of prescribed burning in alternate seasons when smoke dispersal impacts are not as severe?

The majority of prescribed burning in the Sierra Nevada is currently conducted during early fall, which coincides with or occurs after the period of maximum historical fire activity, as determined from tree fire scar records (Caprio and Swetnam 1995). Fall burning also coincides with the period of poorest air quality in adjacent populated areas of the Central Valley. Air quality concerns during this time of year often severely limit the number of days when prescribed burning can be conducted, particularly in the southern Sierra Nevada. Air quality is typically better during the spring or early summer, owing to greater atmospheric instability. However, early-season prescribed burning has the potential to affect trees, shrubs, and other forest species in different ways than late-season prescribed burning (Kauffman and Martin 1990). In addition, concern exists about the potential impact of early-season fire on animal species that may be more active during this time of year.

Fire and Fire Surrogate Study

The above questions are being addressed through a large national research effort, known as the Fire and Fire Surrogate (FFS) Study (http://ffs.fs.fed.us) (McIver and others 2001). The FFS study, funded by the Joint Fire Science Program, USDA Competitive Grants, and the National Fire Plan, consists of a network of 13 sites located in forested ecosystems across the United States, each characterized by a historical regime of frequent, low- to moderate-intensity fire. The objective of the national study is to evaluate the economics and ecological effects of alternative fuel-reduction methods. Each treatment is designed to produce a forest structure that would result in survival of 80 percent of the dominant and co-dominant trees if the treated area were to experience a wildfire at 80th percentile weather conditions.

Two FFS study sites are located in the Sierra Nevada, one at Blodgett Forest in the northern/central Sierra Nevada and another in Sequoia National Park in the southern Sierra Nevada. At the Blodgett Forest site, the consequences of four management options are being assessed: (1) mechanical treatment alone, (2) prescribed fire alone (early season or late season), (3) mechanical treatment and prescribed fire, and (4) untreated control. Treatments at the Sequoia National Park site include early-season prescribed fire, late-season prescribed fire, and untreated control. No mechanical treatments are being used at the Sequoia National Park site because mechanical thinning is not currently a landscape-scale management option on most national park lands in the Sierra Nevada. Treatments at Blodgett Forest are similar to those being studied at 11 other sites nationwide. All sites in the network, including Blodgett Forest and Sequoia National Park, will be used to evaluate the same ecological and economic components, which include overstory and understory vegetation, fuel and fire behavior, soils and the forest floor, wildlife, entomology, pathology, treatment costs, and utilization economics.

A common research design will facilitate meta-analyses at the site and national levels and broaden the scope of data being collected at the two Sierra Nevada sites. Results from Blodgett Forest and Sequoia National Park thus will be directly comparable to treatments applied at other sites, including the southern Cascades in California, Hungry Bob in northeastern Oregon, Lubrecht Forest in western Montana, Southwest Plateau in Arizona, and Jemez Mountains in New Mexico. In addition, seasonal prescribed fire data collected at Sequoia National Park will be comparable to data collected at the Hungry Bob and the Lubrecht Forest sites, where prescribed burns have been applied in fall and spring, respectively.

Methods

Blodgett Forest

The University of California's Blodgett Forest Research Station is located approximately 20 kilometers east of Georgetown, California. Study plots are in mixed conifer forest stands at elevations ranging from 1,100 to 1,410 meters (m) above sea level. Forest stands in this area are composed of sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), white fir (*Abies concolor*), incense- cedar (*Calocedrus decurrens*), Douglas-fir (*Pseudotsuga menziesii*), and California black oak (*Quercus kelloggii*). The presettlement fire return interval for the study site ranged from 4 to 9 years on a 15-hectare (ha) scale; however, the last large fire in the Blodgett Forest area occurred nearly a century ago.

Twelve 15-ha study plots (three prescribed fire only, three mechanical treatment only, three mechanical treatment and prescribed fire, and three controls) were established in 2000. Mechanical treatments included a commercial thinning from below followed by mastication of 85 percent of the submerchantable trees and small snags (less than 15 centimeters diameter at breast height [dbh]). The small material was masticated using a track-mounted rotary masticator, and the resulting fuels were shredded into pieces less than 1 m in length. Desired forest conditions were estimated using computer models with parameters set to meet the 80:80 criteria described below in *table 1*. Prescribed burning was conducted during fall 2002 before the first significant rainfall. Most of the burning occurred at night when relative humidity, temperature, wind, and fuel moistures were within prescription.

Table 1. *Desired conditions within the Blodgett Forest fire and fire surrogate units.*

	Percent overstory cover	Percent overstory crowns touching	Percent of stand with two layers	Height to live crown base (m)	Snags/ha over 30 cm dbh	Large woody debris/ha > 30 cm	Surface fuel load (tonnes/ha)	Percent soil covered by duff
Maximum	60	20	15	n.a.	5	7.5	60	75
Minimum	35	0	0	1	0	0	25	50
Average	45	15	10	3	2.5	5	49	40

Sequoia National Park

The Sequoia National Park study site lies within the Marble Fork watershed of the Kaweah River. Study plots are located on 15- to 25-degree slopes and west- and northwest-facing aspects at elevations ranging from 1,900 to 2,150 m above sea level. Forests in this area are old-growth, and tree species composition, in order of abundance, is as follows: white fir (*Abies concolor),* sugar pine (*Pinus lambertiana),* incense-cedar (*Calocedrus decurrens*), red fir (*A. magnifica* ssp. *shastensis*), Jeffrey pine (*P. jeffreyi),* ponderosa pine (*P. ponderosa),* dogwood (*Cornus nuttallii*), and California black oak (*Quercus kelloggii*). Estimates of the presettlement fire return interval range from 20 to 40 years (communication) for forests and aspects of the type found at the study site. However, before the start of this project, study plots had not experienced fire for at least the past 110 years.

Nine 15-ha study plots (three early-season prescribed fire, three late-season prescribed fire, and three control) were established at the Sequoia National Park study site in 2000. Late-season prescribed burns were conducted in fall 2001, and early-season prescribed burns were conducted during late spring and early summer of 2002. Moisture content of fuels at the time of ignition was determined by weighing collected samples before and after oven drying.

Both Study Sites

Vegetation variables were measured in subplots within each experimental unit (10 0.1-ha subplots in Sequoia National Park experimental units and 25 0.04-ha subplots in Blodgett Forest units) before treatment application. Each tree was labeled; its dbh measured; and species, status (alive or dead), and health noted. Similar data were collected for saplings, defined as individuals with a height greater than 1.37 m and dbh less than 10 cm. Fuels were evaluated using methods described by Brown (1974). Litter; duff; and 1-, 10-, 100-, and 1,000-hour fuel loads were calculated using equations described by van Wagtendonk and Sydoriak (1998) and van Wagtendonk and others (1996). Area burned at Sequoia National Park study plots was estimated by mapping burned and unburned segments along fuel transects.

Early Results and Discussion

Research at the Blodgett Forest and Sequoia National Park FFS sites is still in the early stages, and most post-treatment data will not be collected until 2003 and 2004. Post-treatment results from Blodgett Forest are available only for the period after thinning and before burning. Post-treatment data from both sites should be considered preliminary.

Mechanical thinning and mastication reduced total fuel loads from 150.0 tonnes/ha to 101.9 tonnes/ha *(table 2)*. Much of this reduction can be attributed to a loss of litter, duff, and 1,000-hour (greater than 7.62 cm) fuels. Litter and duff (combined) and 1,000-hour (sound plus rotten) fuels decreased by 37.3 and 12.8 tonnes/ha, respectively. Losses in litter and duff may be explained by the ubiquitous disturbance resulting from harvest and mastication treatments. Litter and duff were completely removed from many of the main skid trails throughout treatment units. Loss of 1,000-hour material was observed to be primarily in large rotten fuels. These fuels may have been redistributed or otherwise broken up during harvest and mastication treatments.

Thinning and mastication increased the fuel load in small-diameter woody fuel classes and also increased the fuel depth *(table 2)*. These increases in activity fuels may in turn affect rate of spread and flame length of surface fires. Whether these effects are significant is still pending further data collection and analysis. Although total fuel load was somewhat reduced by thinning and mastication alone, the desired condition *(table 1)* was not met. [Since the Sierra Science Symposium was held, prescribed burns have been completed within these units. The prescribed burns removed much of the remaining ground fuels. Final fuel reduction estimates will be available at a later date.]

Fuel loading was very high before the prescribed burns, averaging 192.8 tonnes/ha across all plots. More than half this fuel was found in the litter and duff layers *(table 2)*. The early- and late-season burns consumed 66 and 79 percent of the fuels, respectively. This difference was statistically significant ($P = 0.015$). Lower fuel consumption during the early season was likely due to higher fuel moisture levels. Moisture in 1,000-hour and duff fuels averaged 24 and 38 percent, respectively, at the time of the early-season burns; moisture in these fuels averaged 10 and 12 percent, respectively, at the time of the late-season burns.

Table 2— *Preliminary results from fuel transects measured in the three mechanical plus fire treatment units at Blodgett Forest and in all treatment units at Sequoia National Park. Post- burn data are not yet available at Blodgett Forest. For fuel size classes, 1 hour is 0–0.64 cm, 10 hour is 0.64–2.54 cm, 100 hour is 2.54–7.62 cm, and 1,000 hour is greater than 7.62 cm.*

Site	Treatment phase	Litter & duff	Small woody (1, 10, 100 hr)	Large woody (1000 hr)	Total fuel load	Fuel depth
		---------------------------- tonnes/ha			---------------------	cm
Blodgett	Pretreatment[1]	103.5	12.7	33.8	150.0	9.9
Blodgett	Post-harvest[2]	65.5	12.9	29.0	107.4	13.1
Blodgett	Post-mastication[3]	66.2	14.6	21.0	101.9	16.1
Blodgett	Post-burn	-	-		-	-
Sequoia	Pretreatment (All plots)[1]	105.6	8.4	78.7	192.8	10.6
Sequoia	Post treatment (Early burn)[4]	26.1	2.6	33.9	62.7	4.0
Sequoia	Post treatment (Late burn)[4]	16.4	2.1	19.9	38.4	4.1

[1]Pre-treatment data were taken in summer 2001.
[2]Post-harvest data were taken after harvest was complete (spring/summer 2002) and before mastication.
[3]Post-mastication data were taken after mastication of understory nonmerchantable material was completed (summer/fall 2002).
[4]Post-burn data taken during summer 2002.

Initial (first post-fire season) mortality of trees smaller than 50 cm dbh was significantly less within early-season burn units compared with late-season burn units *(fig. 1).* Mortality of trees larger than 50 cm dbh did not differ between units burned in different seasons. Overall mortality among these larger trees was very low, averaging 4.8 percent across all burning treatments. Initial mortality of trees was primarily due to crown scorch. Additional mortality is expected due to secondary causes (bole damage, bark beetles, and so forth). Before the burns, density of trees and saplings averaged 717/ha across all plots. Density remaining in the first season after the burns was 510/ha in the early-season burn units and 305/ha in the late-season burn units. The latter value falls within Sequoia and Kings Canyon National Parks' post-fire structural target of 60 to 325 trees/ha. If substantial secondary tree mortality does not occur in the early-season treatment units, at least one additional burn will be required to reach this structural goal in these units.

Mortality patterns were extremely heterogeneous within and among both the early-season and late-season burn units. Some areas burned intensely, leading to relatively high tree mortality, whereas other areas burned at low intensity, inflicting minimal visible damage to trees. The hypothesis that heavy fuel loads and greater continuity of fuels would lead to a uniformly intense fire was not supported within this mixed conifer vegetation type. Despite the long period of fire exclusion preceding the prescribed fire treatments, sufficient heterogeneity in fuels, vegetation type, and local weather conditions existed at the time of burning to create a highly variable post-burn landscape. Multiple regression analyses indicate that variation in percentage of basal area composed of pine trees and variation in total tree density explain at least some of the heterogeneity in burn pattern for the late-seaso

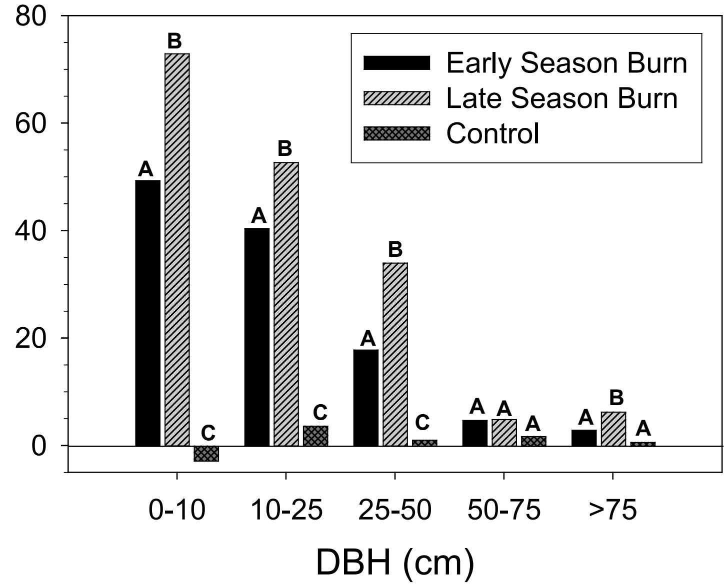

Figure 1— Initial tree mortality (from 2001 to 2002) in different size classes following early- and late-season prescribed burns at the Sequoia FFS site. Bars within DBH categories topped by different letters denote treatments that were significantly different by the chi square statistic, run on the tree number data.

treatment. Flame lengths were lower, and probability of burning was less in areas dominated by fir trees. This was likely due to the more compact nature of the short-needle ground fuels (Agee and others 1977, Stephens 2001). Differences in firing pattern may have also played a role.

The early-season burns were significantly patchier than late-season burns. Within the early-season units, 71 percent of the plot area was estimated to have burned, whereas late-season units had an estimated 85 percent of the plot area burned (P = 0.023). Islands of unburned habitat may be important for post-fire recolonization by some plant and animal species. Lower fuel consumption and reduced initial mortality of trees in the early-season burns demonstrate the potential value of this treatment, especially employed as an initial restoration burn where high fuel loading requires special care to avoid ecosystem damage. However, burning-season effects on herbaceous understory, small mammals, and birds have not yet been determined. Data collected in the coming years will help managers evaluate burning season as another tool for achieving desired ecological and fuels-reduction goals.

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