The Effects of Prescribed Fire Season and Fire Surrogates on Crown-Fire Adapted Knobcone Pine Forests

<u>Final Report to the Joint Fire Sciences Program</u>

Project number: 03-3-3-57

Bureau of Land Management-South Cow Mountain Recreation Area and University of California Hopland Research and Extension Center, Mendocino & Lake County, California

Principal Investigators:

James Dawson
Area Fire Management Officer-Bureau of Land Management

Scott Stephens
Associate Professor of Fire Science-University of California, Berkeley

Joe McBride
Professor of Forest Ecology-University of California, Berkeley

Max Moritz
Adjunct Assistant Professor of Wildland Fire-University of California, Berkeley

Prepared by:

Danny Fry
Staff Research Associate-University of California, Berkeley

December 2007

Executive Summary

Ecosystems dominated by the serotinous (closed cone) knobcone pine (*Pinus attentuata*) are characterized by infrequent high intensity, high severity fires. Periodic fires that kill aboveground biomass induce the opening of cones and subsequent seed dispersal for the next generation. This dependency on stand replacing disturbances presents a challenge for natural resource managers exploring ways to effectively treat fire dependent ecosystems. Prescribed crown fires release high amounts of emissions and air quality regulators are becoming less supportive of such fires, especially if alternatives treatments are available. An experiment was conducted to assess the feasibility of different stand-replacing treatments on knobcone pine forest regeneration at the Bureau of Land Management South Cow Mountain Recreation Area and the University of California Hopland Research and Extension Center in the northern California Coast Range. Using a randomized design with replication, the seasonal effect (fall and spring) of prescribed fire treatments, mechanical (felling of trees and lop and scatter of fuels) followed by prescribed fire treatments, and mechanical treatments alone on knobcone pine seedling density was examined. This information can be incorporated into vegetation management plans for areas that have knobcone pine forests.

The project deliverables include: 1) the successful establishment of collaborative relationships with all partners, including Bureau of Land Management, University of California, Berkeley, University of California Hopland Research and Extension Center, and CALFIRE, 2) establishment of 21 permanent knobcone pine forest research plots, 3) baseline and post-treatment data collection including preliminary effects on recruitment and forest structure, 4) implementation of four experimental treatments, 5) documentation of treatment costs, and 6) establishment of a world-wide website. Multiple publications will be submitted to peer-reviewed scientific journals.

Findings described in detail in this report include:

- The prescribed fire treatments were not implemented due to conditions prohibiting the fire to burn into the units.
- For the completed treatments, there was no difference in knobcone pine seedling density following two post-treatment growing seasons.
- Prescribed fire in either season was effective at reducing fuel loads, especially in mechanically treated units where fuel loading increased approximately 300%.
- The mechanical followed by prescribed fire treatment was the most expensive to implement at \$4155 ha^{-1}, compared to \$762 ha^{-1} for the fire only treatments.

Weather conditions delayed the implementation of the prescribed fire treatment in some of the experimental units. Because of these delays only the preliminary results are reported here. Additional post-treatment monitoring will be required to fully assess the impacts of treatments on knobcone pine regeneration. The permanent plots installed in the 21 units provide the baseline data for continued monitoring as alternative treatments (girdling of live trees followed by prescribed fire) are implemented.

1. Introduction

Knobcone pine (*Pinus attenuata*) forests are challenging to manage because high intensity crown fires are thought to be necessary for successful regeneration. A closed cone species, knobcone pine trees retain seeds in sealed cones for their entire life span, releasing seeds for the next generation only after being exposed to heat from a fire. In a laboratory setting, sealed cones require exposure to 200˚F for approximately five minutes to open (Vogl 1973, Barbour et al. 1993).

Fire suppression policies initiated early in the 20th century have had significant effects on many forest ecosystems, including knobcone pine forests. Knobcone pines are relatively short lived compared to other pine species; tree vigor commonly declines after 50 years of age. Stands in the Santa Ana Mountains in southern California showed abundant signs of deterioration although most trees were less than 75 years old (Vogl 1973, Barbour et al. 1988). Long fire-free periods that exceed the life span of serotinous species deplete the available seed bank and pose the risk of local extirpation (Zedler 1995).

Managing this fire-dependent ecosystem through the use of prescribed crown fires is extremely problematic because of the potential for escape fire, the impacts on regional air quality, and the ability to successfully implementing such burning within very constrained operational periods. There is currently no information on this ecosystem type that enables managers to propose alternative treatments for restoration. One extensive study has investigated the ecology of knobcone pine in southern California (Vogl 1973). Information on seed release, tree morphology, and age structure were described. Another more recent study (Keeley et al. 1999) in central California determined that if knobcone pine forests are burned too frequently this may result in poor tree regeneration because of insufficient time for trees to produce viable seed.

Although the use of fire surrogates has been tested in other pine-dominated forest ecosystems (Fulé et al. 2002, Stephens and Moghaddas 2005), almost no information exists on the effectiveness of fire surrogates in crown fire adapted ecosystems. Advantages of fire surrogates include reduced less risk in implementation and air quality impacts. Information on viable treatments that could be used effectively in urban-wildland intermix areas and in recreational use areas would add important management options. This project was designed to provide managers with information that can be used to develop fire and forest management plans for knobcone pine. The objectives of this research are to determine if there are significant differences ($p < 0.05$) in knobcone pine seedling density after prescribed fire, mechanical followed by prescribed fire, and mechanical only treatments. In achieving the primary objective several secondary objectives will be addressed including the effect of the season of fire and fire surrogates on (1) fire hazard reduction, (2) recovery of competing vegetation, (3) resurgence of fuels, (4) costs of the different treatments, and (5) the identification of the most effective treatment for regeneration of knobcone pine that is least intrusive to air quality.

2. Methods

2.1 Study Area

This study was conducted at the Bureau of Land Management (BLM) South Cow Mountain Recreation Area and the University of California Hopland Research and Extension Center (39˚5´N, 123˚4´W) located in the interior Coast Ranges of northern California. The majority of this research was conducted on South Cow Mountain while only a small portion of the study (one experimental unit) was located on the adjacent Hopland Research and Extension Center. These two sites (hereafter COW) are in the Mayacmas Mountains, a range that straddles the southeastern Mendocino and western Lake County boundary. Elevation of COW ranges from 244 to 1220 m (800-4000 ft). BLM acquired the land in 1958 and since the 1970's the area has been managed for recreational purposes. The terrain is rugged in the 24,300 hectare (60,000 acres) unit, consisting mostly of steep chaparral covered slopes dominated by chamise (*Adenostoma fasciculatum*), manzanita (*Arctostaphylos* spp.) and oak (*Quercus* spp.). Scattered stands of Douglas-fir (*Pseudotsuga menzesii*) and mixed hardwood forests are found in drainages and on mesic slopes. Knobcone pines are found in relatively pure stands interspersed in chaparral, primarily on ridge tops and north-facing slopes. Vegetation management plans for the last 20 years have included prescribed burning, primarily in chaparral. Many of the knobcone pine stands on COW are 50+ years old, senescent, and are considered a high fire hazard.

Climate at COW is Mediterranean with cool, wet winters and hot, dry summers. Average winter and summer maximum temperatures in Ukiah (188 m above sea level (615 ft)) are 16˚C (61˚F) and 32.5˚C (90.5˚F), respectively. Average precipitation is 93 cm (36.6 in) falling mostly as rain. However, periods of snowfall occur at the upper elevations.

2.2 Experimental Treatments

Stands of knobcone pine that had a relatively continuous overstory canopy and were at least 25 years old were selected for treatment. Accessibility and operational limitations (e.g., site preparations, topographic conditions complicating burning operations) restricted the number of stands that could be used in this study. A total of 18 experimental units and three control units (CTL; no treatment applied) were randomly selected in a two-stage process. First, units that were deemed feasible for prescribed fire operations were selected from the pool of available stands. In this subset replicates of the prescribed fire treatment were assigned randomly. The remaining treatment types were randomly assigned to the pool of available stands. Experimental units ranged from one to two hectares (Figure 1).

The effects of two types of stand replacing treatments alone and in combination were examined in two seasons, fall and spring. Treatments were intended to mimic the high severity, stand killing effect of a wildfire that knobcone pine forests historically experienced. One treatment type, identified here as mechanical (MECH), was replicated on six experimental units (3 spring MECH and 3 fall MECH) in 2005. The MECH treatment involved felling trees and brush using a 6-8 man chainsaw crew; all activity fuels were lopped and scattered to a maximum height of 75 cm (48 in) above the ground surface. The second treatment type, prescribed fire (FIRE), was replicated on six experimental units (3 spring FIRE and 3 fall FIRE) in 2005. Headfire ignitions using a heli-torch were applied to each experimental prescribed fire unit. Similar ignition patterns were applied to all prescribed fire units in order to produce uniform flame lengths and rates of spread. It is not possible to duplicate the exact fire behavior in all units because of differences in topography, fuels, and weather conditions but significant attempts were made to make fire treatments as uniform as possible. Finally, the combination treatment, mechanical followed by prescribed fire (MECH+FIRE), was applied to six units (3 in spring and 3 in fall).

The experimental design described above was not fully implemented due to unfavorable weather conditions during the treatment phase. Initially, the fuels in the mechanically treated MECH+FIRE units were going to dry for approximately six months before the prescribed fire treatment was applied. The spring fire treatment was not attempted in 2005 and 2006 due to higher than normal precipitation. This delay resulted in different drying times for fuels, one year for fall MECH+FIRE units and two years for spring MECH+FIRE units. Additionally, because of the observed high intensity fire behavior during the burning of the first spring MECH+FIRE unit, only two of the three replicates were burned. For these units, only the initial post-treatment measurements were collected during the summer 2007, compared to two-year post-treatment measurements for both the MECH and fall MECH+FIRE units (Table 1).

Attempts to treat the fall FIRE units were unsuccessful due to weather conditions prohibiting the fire to carry into the tree crowns. It was determined that this treatment type may not be a feasible management strategy and alternatives were explored to treat these units. In the summer 2006, all live trees were girdled with an axe or chainsaw to induce mortality, which would presumably allow the fire to more easily ignite the tree crowns inducing the cones to open. As of the summer 2007 many of the trees have not died yet; therefore, these treatment types (spring and fall FIRE) are incomplete (Table 1).

2.3 Forest, Fuel and Vegetation Characteristics

Characteristics of forest structure were estimated by collecting measurements in 10 m radius circular plots. Five plots on a 40 m spacing were installed in each experimental unit prior to treatment; the starting point was chosen randomly. The plot center was marked by rebar. Slope, aspect and canopy cover was measured at the plot center. Percent canopy cover by species was estimated using a site tube at 25 points overlain the plot center on a 5 x 5 grid (5 m spacing). At each point on the grid, the sight tube indicated if a tree crown was directly overhead; the species of the tree was recorded if the grid point was under canopy. Percent canopy cover was estimated by the total number of points under canopy divided by the total number of grid points sampled (25). For each stem (>10 cm (4 in) diameter at breast height (DBH)) within the plot, the following were recorded: DBH, maximum height, height to live crown base, species and age (live knobcone pines). Plots were established and pretreatment forest, fuel and vegetation data was collected from 2004 to 2005.

To determine the age of knobcone pines in control (CTL) and FIRE units, trees were hand bored using an increment corer approximately 25 cm (10 in) above the ground surface. Tree age from the MECH+FIRE and MECH units was obtained from stump wedges collected after tree falling. Wedges were cut from accessible stumps using a chainsaw. Samples were sanded to a smooth finish so that annual rings could be counted under a microscope.

Surface and ground fuels were sampled at each plot on three 10-meter transects with random azimuths. Fuels were measured using the line intercept method (Brown 1974). One (0-0.64 cm) and 10-hour (0.64-2.54 cm) fuels were sampled from 0 to 3 m, 100-hour (2.54-7.62 cm) fuels from 0-5 m, and 1000-hour and larger fuels from 0 to 10 m on each transect. Duff, litter and fuel depth were measured at 0.4, 0.7, and 10 m on each transect. Ground and surface fuel loads were calculated by using appropriate equations developed to predict duff and litter fuel loads in conifer forests of California (van Wagtendonk et al. 1996; 1998). Coefficients required to calculate all surface and ground fuel loads were arithmetically weighted by the basal area fraction (percent of total basal area by species of the forest inventory plots) to produce accurate estimates of fuel loads (Stephens 2001).

On each day of the prescribed burning treatments woody fuel samples were collected in metal cans to determine live and dead moisture contents on a dry weight basis. Each fuel type (live 1 hour and dead 1, 10, and 100 hours knobcone pine) was collected in 3 replicates and oven dried at 85˚C for 24 hours. Duff, litter, and soil at 2 different depths (0-3 cm and 3-6 cm) were also sampled. Weather and fire behavior characteristics were recorded during the burns to aid in describing burning conditions and related fire effects. Observed flame lengths were used to estimate fire line intensity in kW/m (Byram 1959) for each prescribed fire treatment.

Identification, visual cover (Daubenmire percent cover classes, Barbour et al. 1999) and height (0.5 m intervals) of all shrub, forb and grass species was recorded in each plot. Additionally, the line intercept method was used to determine abundance by identifying the plant species intercepted at every 25 cm along every transect. Each species that intersected the vertical point in two strata (ground level to 0.5 m and 0.5m to 2 m) was recorded along the line transect. Abundance was calculated by the number of intersections in each strata divided by the number of points (400 per plot). Post-treatment fuel and vegetation data was collected in each experimental unit within five months of completion of the treatment, and during the spring and summer thereafter for two years. Because the prescribed fire treatment for the spring MECH+FIRE was conducted in April 2007, understory sampling was recently completed and results are summarized in Appendix 3.

2.4 Regeneration

Seedling (stems less than 1.4 m in height) density was measured in two 3 m^2 plots placed randomly outside the perimeter of each forest inventory plot. After tree felling in the MECH units, 300 mature cones were collected haphazardly from downed trees. Cones were processed at the nursery in Davis, California, where seeds were extracted and stored. Following the completion of the treatments, 125 seeds were sown into one of the 3 m^2 plots in each experimental unit. Post-treatment seedling data was collected in each 3 m^2 plot within five months of completion of the treatment, and during the spring and summer thereafter for two years.

2.5 Data Analysis

The total costs to implement the treatments were calculated on a per hectare (per acre) basis and compared between treatment types. Pretreatment forest, fuel and understory vegetation characteristics were tested for differences using analysis of variance (ANOVA). Because all experimental units were not re-measured after each of the treatments, as well as the incomplete experimental design, a standard two-factor repeated measures analysis could not be employed without violating test assumptions. Instead, a one-factor analysis of covariance (ANCOVA) was used, where the pretreatment measurements served as the covariate (Milliken and Johnson 2002, Stephens and Moghaddas 2005) in comparing treatment types for the most recent survey.

3. Results

3.1 Experimental Treatments and Forest Characteristics

The fall prescribed fire application was unsuccessful in inducing a crown fire in the fall FIRE units. While the brush down slope of the units was consumed, the fire was extinguished soon after entering the stand (Figure 2). Weather conditions during the burns were as follows: cloudy with an approaching storm, 17-20˚C, 40-53% relative humidity and wind 1.7-3.6 kph. Fuel and soil moisture contents collected on the day of the burn are shown in Table 2 under fall FIRE. The spring prescribed fire treatments were not attempted in 2005 and 2006 due to higher than normal precipitation. Rainfall totals for April and May combined in 2005 was 16.5 cm (6.5 in) and in 2006 was 16.8 cm (6.6 in), which was nearly double the average of 8.6 cm (3.4 in).

The mechanical treatment was applied to 12 experimental units for a total of 14.12 ha (35.3 ac). The cost of this treatment was \$4155.96 ha^{-1} (\$1662.24 ac^{-1}). Although the prescribed fire treatment was unsuccessful, the costs associated with the effort to burn the three experimental units (3.2 ha [8 ac]) using a heli-torch was \$762.20 ha^{-1} (\$304.88 ac^{-1}). The spring MECH+FIRE treatments, which were ignited using handheld drip torches, were implemented at a cost of \$4450.08 ha^{-1} (\$1779.89 ac^{-1}), only 7.7% more than the cost of the mechanical treatment alone. It should be noted that much of the burning operation costs were absorbed through the CALFIRE (formally known as California Department of Forestry and Fire Protection) budget for vegetation management.

Pretreatment forest characteristics did not differ between treatment types (Table 3). Average treatment unit tree age ranged from 35 to 67 years, but the range for individual trees was much larger (16-96 years). Most of the youngest trees were in PYR1, a spring FIRE treatment unit, which contributed to the smallest average DBH and highest average basal area, tree density and canopy cover for this treatment type (Table 2). This was due to a low intensity prescribed fire in 1988 that resulted in a cohort of pole-sized knobcone pines in the understory, which are now suppressed and dying.

3.2 Fuel characteristics

Pretreatment fuel characteristics did not differ between treatment types (Table 4). Following the mechanical treatment in the MECH+FIRE units, average total fuel load increased 130.5 to 137.5%, primarily in the larger size classes. There were no significant differences in the post-mechanical fuel characteristics between the spring and fall MECH+FIRE (Table 5). Comparing the 2007 data, many of the spring and fall MECH fuel components were not significantly different from each other, but were significantly larger than the CTLs (Table 6). Most of these differences were in the larger fuel size classes.

Fuels were reduced following the prescribed fire treatments (Table 6). Total fuel load was reduced by 60.6% and 71% for spring and fall MECH+FIRE, respectively. Despite the difference in time allowed for fuels to dry, two years for spring MECH+FIRE and one year for fall MECH+FIRE, none of their fuel components were significantly different. It should be noted that only two of the three replicates of the spring MECH+FIRE were treated. Compared to the MECH treatment types, the total fuel load for spring and fall MECH+FIRE was 53.8% and 63.5% lower, respectively, and these differences were statistically significant.

3.3 Regeneration

Pretreatment, seedlings were very rare across the study area. Although there were no seedlings in the initial 2005 post-treatment survey for the spring MECH plots, a few emerging individuals were found in the treated area. In the 2006 survey, seedling density varied strongly among the completed units (spring MECH, fall MECH and fall MECH+FIRE; Table 7). Seedling density did not differ between treatment types for either time period ($p>0.05$). Sown seeds in the post-treated area did appear to increase seedling density, but only in some of the plots and this was not statistically significant. There was evidence of seed caching in most of the treated areas (Figure 3).

4. Discussion

The need for effective treatments in regenerating knobcone pine forests on COW is evidenced by the age of trees. Many of the stands were greater than 50 years old, exhibiting signs of decreased vigor. Research that uses prescribed fire as a treatment type, especially high intensity crown fires, are difficult to implement due to operational, weather, air quality and resource limitations. In this study, prescribed fire treatments were either unsuccessful or not permitted on four occasions (spring and fall 2005-2006). Despite no measurable rainfall for the five months prior to the fall 2005 prescribed burn treatment, less than ideal weather and fuel moisture conditions were enough to prohibit even an understory surface fire. Fine scale mechanisms that control the spread of fire involve complex interactions of topography, weather and vegetation (Turner and Romme 1994), which are not well understood in knobcone pine forests. Improvements in modeling of crown fire behavior and effects will help in fire management planning and prescribed fire programs in this forest type.

For the untreated spring and fall FIRE units, an alternative treatment was proposed which involved girdling live trees to decrease moisture content of the crowns, then burning the units after the needles turn brown. By decreasing moisture content, the tree crowns will ignite more easily thereby inducing the cones to open. Trees were girdled during the summer 2006 and after one year, the crowns have recently begun to turn brown. These units remain incomplete and prescribed fire treatments are scheduled for spring 2008.

4.1 Regeneration

Seedling density from the second year post-treatment survey ranged from zero to over 45000 individuals ha^{-1}, which is two orders of magnitude higher than the pretreatment adult tree densities. During this survey both dead and new seedlings were found suggesting regeneration is still in early stages. These plots require long-term monitoring since regeneration dynamics of knobcone pine are unknown. This species may exhibit a survivorship curve similar to *Pinus halepensis*, its European counterpart. Seedling establishment in *P. halepensis* has been shown to stabilize 10-15 years post-disturbance and mortality is caused by both density-dependent and density independent effects (discussed in Keeley et al. 1999). Competition for resources will likely be an important factor in the seeded plots where extremely high seedling densities were recorded. Continued seed predation by small mammals and birds may also decrease knobcone pine regeneration potential. Evidence of seed caching was observed in plots, especially the mechanical units where cones were close to the ground and easily accessible. After the spring treatments cones open, releasing seeds but these seeds will remain dormant until the following spring since this coincides with the beginning of the summer drought. This provides seed predator's extensive opportunities to capture the seed bank. The fall treatments, which coincide with the beginning of the wet season, may fare better due to the opportunity for seeds to germinate and establish themselves prior to the onset of the dry season when seed predators are more active.

The excessive fuels remaining on the site in the MECH units create a fire hazard for the new cohort of knobcone pine trees. A fire-free interval that is too short to allow the cohort to accumulate a seed bank poses a risk to the lifecycle of a fire dependent species, known as the 'immaturity risk' (Zedler 1995). The combination treatment was effective at eliminating the excessive fuels; however the drying period (1-2 years) between treatment phases may decrease the available seed bank of the parent cohort. Numerous cones were already open and several one- to two-year old seedlings were observed in the treated areas prior to burning. The higher fire intensities certainly consumed or killed many seeds and seedlings.

4.2 Management Implications

Pre-historically knobcone pine forests probably burned in the late summer or fall because during these seasons ignitions were most common and fuel moisture and weather conditions were conducive to burning. Using prescribed fire as a management tool in these forests is challenging because high intensity fires are needed to open the cones. In the fall, the probability of an escaped fire is high and management agencies may not have the suppression resources available because of the wildfire season. While there may be opportunities to burn knobcone pine forest using prescribed crown fires, relying on this method as the only treatment option is impractical.

BLM has successfully suppressed fires in these forests but there is a constant concern of unauthorized ignitions since the area is open for public recreation. The combined fire hazard risk and cost of the mechanical treatment makes this method infeasible as a management option. Furthermore, this treatment may lead to problems for seedlings establishing roots in the high fuel loads.

The fire hazard is reduced when the mechanical treatment is followed with prescribed fire. The potential issue with this combination is a delay in conducting the burns after the forest has been mechanically treated, which would allow the cones time to dry and open releasing seeds. It is recommended that units be burned within six months after the mechanical treatment to reduce this impact. Over the next few years, with regeneration more established, the impact of the delays in burning can be more accurately assessed.

References

Barbour, M., B. Pavlik, and S. Lindstrom. 1993. California's Changing Landscapes: Diversity and Conservation of California Vegetation. California Native Plant Society, Sacramento, CA.

Barbour, M. and J. Major. 1988. Terrestrial Vegetation of California. California Native Plant Society, Sacramento, CA.

Barbour, M., J.H. Burk, W.D. Pitts, F.S. Gilliam, and M.W. Schwartz. 1999. Terrestrial Plant Ecology, 3rd Edition. Benjamin/Cummings, Menlo Park, CA.

Brown, J.K. 1974. Handbook for inventorying downed wood material. GTR INT-16. Ogden, UT: USDA Forest Service.

Byram, G.M., 1959. Combustion of forest fuels. In: K. P. Davis (Editor), Forest Fire: Control and Use. McGraw-Hill, New York, pp. 61-89.

Fulé, P.Z., W.W. Covington, H.B. Smith, J.D. Springer, T.A. Heinlein, K.D. Huisinga, and M.M. Moore. **2002**. Testing ecological restoration alternatives: Grand Canyon, Arizona. Forest Ecology and Management 170:19-41.

Keeley, J.E., G. Neíeman, and C.J. Fotheringham, 1999. Immatury risk in a fire-dependent pine. Journal of Mediteranian Ecology 1:41-48.

Miliken, G.A. and D.E. Johnson. 2002. Analysis of Messy Data, Vol. III: Analysis of Covariance. Chapman and Hall/CRC. 605 p.

Stephens, S.L. 2001. Fire history of adjacent Jeffrey pine and upper montane forests in the Eastern Sierra Nevada. International Journal of Wildland Fire 10: 161-176.

Stephens, S.L. and J.J. Moghaddas. 2005. Experimental fuel treatment impacts on forest structure, potential fire behavior, and predicted tree mortality in a mixed conifer forest. Forest Ecology and Management 215:21-36.

Turner, M.G. and W.H. Romme. 1994. Landscape dynamics in crown fire ecosystems. Landscape Ecology 9:59-77.

van Wagtendonk J.W., J.M. Benddict, and W.M. Sydoriak. 1996. Physical properties of woody fuel particles of Sierra Nevada conifers. International Journal of Wildland Fire 6: 117-123.

van Wagtendonk, J.W., J. M. Benedict, and W. S. Sydoriak. 1998. Fuel bed characteristics of Sierra Nevada conifers. Western Journal of Applied Forestry 13(3): 73-84.

Vogl, R. 1973. Ecology of knobcone pine in the Santa Ana Mountains, California. Ecological Monographs. 43:125-143.

Zedler, P.H. 1995. Fire frequency in southern California shrublands: biological effects and management options. In, Keeley, J.E. and T. Scott (eds) Brushfires in California Wildlands: Ecology and Resource Management. International Association of Wildland Fire, Fairfield, WA. pp. 101-112.

Figure 1. Map of knobcone pine forest study site on BLM South Cow Mountain Recreation Area, northern California Coast Range. Experimental unit locations are identified by name (see Table 1) and colored coded according to treatment type (Black, CTL; Red, fall FIRE; Green, spring FIRE; Violet, fall MECH; Yellow, spring MECH; Blue, fall MECH+FIRE; Orange, spring MECH+FIRE).

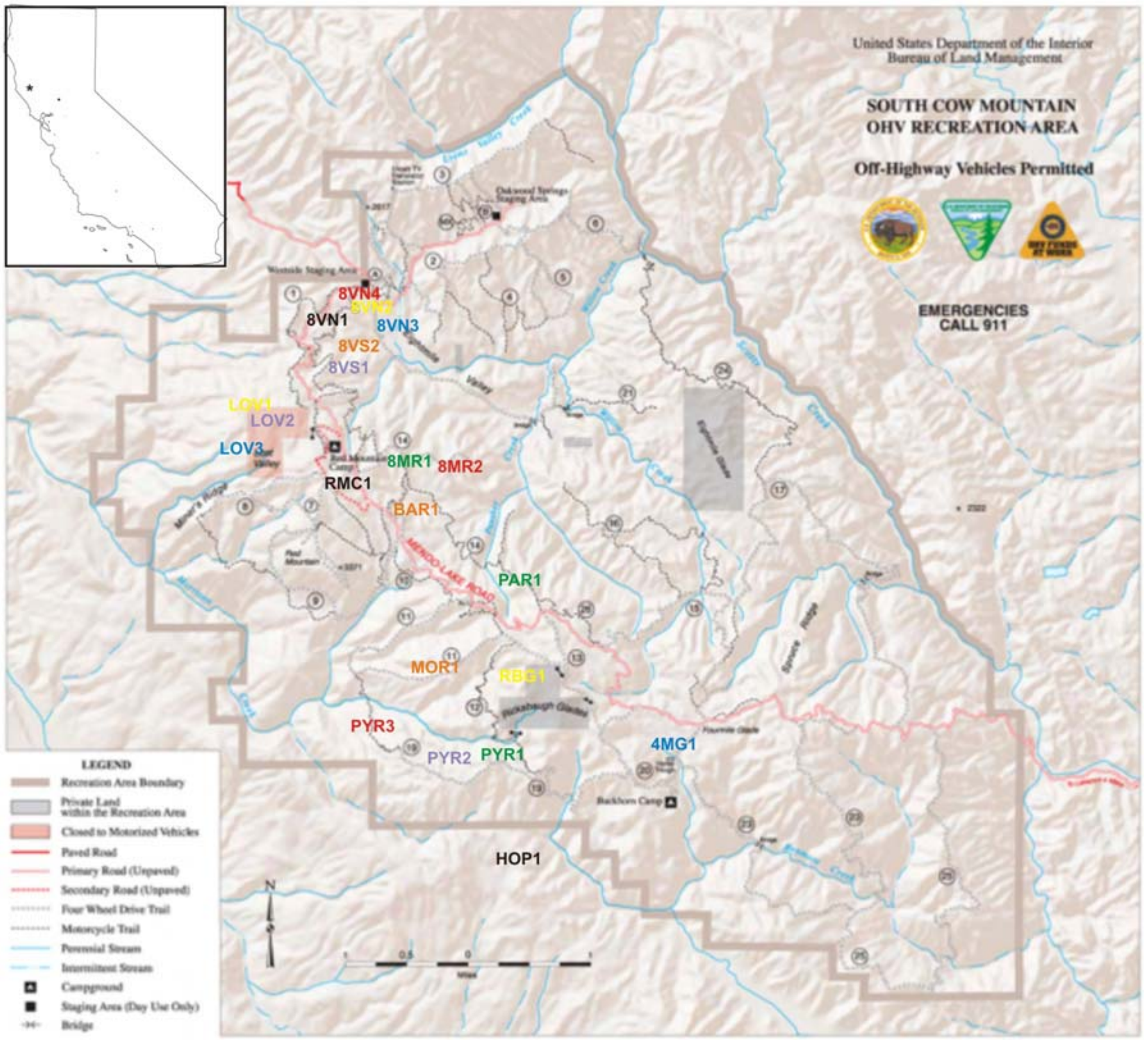

Figure 2. Fall prescribed fire treatment in mature knobcone pine forest on BLM South Cow Mountain Recreation Area, northern California Coast Range. The perimeter of the unit was ignited using a heli-torch. Note the consumed brush and scorched crowns on the southern edge of the unit (left side of photo) but the fire did not continue into the interior of the unit.

Figure 3. Evidence of seed caching in mechanically treated knobcone pine forest on BLM South Cow Mountain Recreation Area, northern California Coast Range. Up to 60 clustered stems were counted in several caches.

Table 1. Description of experimental treatments applied to knobcone pine forests on BLM South Cow Mountain Recreation Area, northern California Coast Range.

UNIT	ORIGINAL PRESCRIPTION	2007 STATUS	DESCRIPTION OF UNITS
8VN2	MECH spring 2005	Surveyed for 2nd year post-treatment	Mechanical in spring 2005
RBG1	MECH spring 2005	Surveyed for 2nd year post-treatment	Mechanical in spring 2005
LOV1	MECH spring 2005	Surveyed for 2nd year post-treatment	Mechanical in spring 2005
PYR1	FIRE spring 2005	Incomplete	Girdled Summer 2006, to be burned in spring 2008
8MR1	FIRE spring 2005	Incomplete	Girdled Summer 2006, to be burned in spring 2008
PAR1	FIRE spring 2005	Incomplete	Girdled Summer 2006, to be burned in spring 2008
8VS1	MECH fall 2005	Surveyed for 2nd year post-treatment	Mechanical in fall 2005
LOV2	MECH fall 2005	Surveyed for 2nd year post-treatment	Mechanical in fall 2005
PYR2	MECH fall 2005	Surveyed for 2nd year post-treatment	Mechanical in fall 2005
8VN4	FIRE fall 2005	Incomplete	Girdled Summer 2006, to be burned in spring 2008
8MR2	FIRE fall 2005	Incomplete	Girdled Summer 2006, to be burned in spring 2008
PYR3	FIRE fall 2005	Incomplete	Girdled Summer 2006, to be burned in spring 2008
8VS2	MECH+FIRE spring 2005	Surveyed for initial post-treatment	Mechanical in spring 2005, fire in spring 2007
MOR1	MECH+FIRE spring 2005	Incomplete	Mechanical in spring 2005, unburned
BAR1	MECH+FIRE spring 2005	Surveyed for initial post-treatment	Mechanical in spring 2005, fire in spring 2007
8VN3	MECH+FIRE fall 2005	Surveyed for 2nd year post-treatment	Mechanical in fall 2004, fire in fall 2005
LOV3	MECH+FIRE fall 2005	Surveyed for 2nd year post-treatment	Mechanical in fall 2004, fire in fall 2005
4MG1	MECH+FIRE fall 2005	Surveyed for 2nd year post-treatment	Mechanical in fall 2004, fire in fall 2005
RMC1	CTL	Untreated (control)	Surveyed
8VN1	CTL	Untreated (control)	Surveyed
HOP1	CTL	Untreated (control)	Surveyed

Table 2. Average (one standard error) fuel moisture contents (% by dry weight basis) sampled on the day of prescribed burning treatments in knobcone pine forests on BLM South Cow Mountain Recreation Area, northern California Coast Range. h-hour.

	Fall MECH+FIRE	Spring MECH+FIRE	Fall FIRE
0-3 cm Soil	19.6 (1.2)	28.9 (0.8)	15.4 (1.4)
3-6 cm Soil	19.3 (0.9)	27.4 (1.6)	14.9 (0.7)
Duff	76.3 (8.3)	73.2 (16.6)	135.6 (11.5)
Litter	63.4 (13.3)	9.9 (1.2)	43.2 (7.4)
1 h live	-	-	137.0 (2.5)
1 h dead	10.3 (0.7)	8.7 (0.5)	11.8 (1.2)
10 h dead	15.5 (3.7)	10.1 (2.9)	18.2 (3.4)
100 h dead	16.0 (3.3)	10.3 (0.5)	31.7 (8.3)

Table 3. Average (one standard error) pretreatment stand characteristics in mature knobcone pine forests on BLM South Cow Mountain Recreation Area, northern California Coast Range. Each treatment type was replicated in three 1-2 ha stands. No significant differences (p>0.05) were found between treatment types for any of the pretreatment forest characteristics. BA-basal area.

Treatment type	% Slope	% Canopy Cover	DBH (cm)	Height (m)	Height to live crown base (m)	Age (yrs)	BA (m^2 ha^{-1})	Trees (ha^{-1})
CTL	40.0 (3.7)	59.7 (6.7)	19.9 (1.0)	13.5 (1.3)	7.7 (1.9)	53.3 (6.5)	28.4 (2.0)	754.7 (71.5)
Spring MECH	32.1 (7.7)	56.0 (3.2)	20.6 (2.3)	-	-	59.7 (3.4)	26.4 (3.7)	674.8 (61.8)
Fall MECH	33.3 (5.0)	58.7 (5.4)	20.8 (1.4)	-	-	58.5 (4.1)	27.5 (4.0)	668.4 (42.4)
Spring MECH+FIRE	46.9 (5.1)	62.7 (3.1)	21.1 (1.7)	-	-	59.8 (2.2)	28.2 (1.1)	689.7 (79.2)
Fall MECH+FIRE	34.3 (5.3)	53.1 (9.4)	21.3 (1.3)	-	-	60.4 (3.2)	28.3 (0.8)	679.0 (97.5)
Spring FIRE	43.1 (3.2)	72.3 (2.8)	17.2 (3.9)	14.3 (2.3)	8.6 (1.6)	41.0 (3.4)	32.5 (3.0)	1540.6 (736.3)
Fall FIRE	30.6 (4.9)	55.7 (3.9)	21.7 (2.3)	16.4 (0.4)	9.3 (0.5)	54.8 (0.5)	29.1 (2.4)	708.8 (103.1)

Table 4. Average (one standard error) pretreatment fuel load (metric tons ha^{-1}; depth in cm) characteristics in mature knobcone pine forests on BLM South Cow Mountain Recreation Area, northern California Coast Range. No significant differences ($p>0.05$) were found between treatment types for any of the pretreatment fuel characteristics. h-hour

Treatment type	Duff	Litter	Fuel Depth	1 h	10 h	100 h	1000 h	Total
CTL	79.2 (9.7)	13.8 (1.8)	32.8 (1.6)	1.2 (0.2)	2.5 (0.4)	4.0 (2.0)	15.9 (6.8)	133.2 (20.6)
Spring MECH	63.8 (7.2)	12.2 (3.6)	14.7 (5.3)	0.9 (0.1)	1.9 (0.6)	1.7 (0.7)	8.9 (4.6)	108.8 (23.6)
Fall MECH	67.38 (4.3)	11.1 (0.8)	46.6 (16.8)	1.5 (0.4)	3.6 (0.8)	2.9 (1.1)	25.0 (12.9)	127.3 (13.5)
Spring MECH+FIRE	67.6 (8.7)	11.0 (0.9)	23.5 (8.8)	1.1 (0.1)	2.4 (0.2)	1.7 (0.1)	11.0 (4.5)	109.8 (12.7)
Fall MECH+FIRE	70.5 (6.1)	15.1 (13.5)	27.2 (4.6)	1.3 (0.1)	2.6 (0.1)	3.4 (0.7)	16.6 (5.7)	129.1 (14.8)
Spring FIRE	61.5 (10.2)	16.1 (3.4)	30.9 (4.7)	1.1 (0.2)	2.8 (0.5)	2.0 (0.5)	8.8 (4.3)	122.9 (14.7)
Fall FIRE	56.0 (2.4)	8.3 (0.7)	37.0 (9.4)	1.4 (0.2)	3.0 (0.7)	1.5 (0.7)	11.0 (5.8)	91.3 (6.3)

Table 5. Average (one standard error) post-MECH fuel load (metric tons ha^{-1}; depth in cm) characteristics in knobcone pine forests on BLM South Cow Mountain Recreation Area, northern California Coast Range. Measurements were collected prior to the prescribed fire treatment. h-hour

	Fall MECH+FIRE	Spring MECH+FIRE
Duff	72.6 (4.8)	79.0 (0.0)
Litter	28.7 (5.9)	14.3 (0.8)
Fuel Depth	49.7 (5.9)	72.1 (17.0)
1 h	2.6 (0.1)	4.9 (1.2)
10 h	10.5 (1.4)	20.6 (6.1)
100 h	7.2 (1.9)	13.6 (5.0)
1000 h	113.5 (29.7)	106.9 (9.6)
Total	297.6 (53.5)	260.8 (11.5)

Table 6. Average (one standard error) post-treatment fuel load (metric tons ha^{-1}; depth in cm) characteristics in knobcone pine forests on BLM South Cow Mountain Recreation Area, northern California Coast Range. Average values in a column followed by the same letter are not significantly different ($p<0.05$). h-hour.

Treatment	Duff	Litter	Fuel Depth	1 h	10 h	100 h	1000 h	Total
Control	79.2 (9.7)[a]	13.8 (1.8)[a]	32.8 (1.6)[a]	1.2 (0.2)[a]	2.5 (0.4)[b]	4.0 (2.0)[bc]	15.9 (6.8)[b]	133.2 (20.6)[b]
Spring MECH	69.0 (7.9)[a]	9.2 (0.5)[a]	41.6 (2.1)[b]	3.0 (0.1)[b]	7.8 (2.1)[a]	7.1 (1.3)[a]	116.4 (29.4)[a]	222.01 (38.1)[a]
Fall MECH	89.9 (10.1)[a]	11.9 (0.9)[a]	58.9 (10.2)[b]	3.3 (0.3)[b]	7.4 (0.8)[ab]	6.3 (0.7)[ab]	104.8 (9.1)[ab]	236.1 (8.1)[a]
Spring MECH+FIRE	19.2 (8.5)[b]	1.6 (0.6)[b]	6.5 (0.4)[c]	0.4 (0.0)[a]	0.6 (0.1)[b]	1.4 (0.3)[bc]	79.6 (31.9)[ab]	102.7 (27.1)[b]
Fall MECH+FIRE	10.3 (3.6)[b]	2.1 (0.5)[b]	7.5 (1.2)[c]	0.6 (0.2)[a]	1.2 (0.3)[b]	1.3 (0.3)[c]	67.0 (3.8)[ab]	86.2 (2.4)[b]
Spring FIRE	-	-	-	-	-	-	-	-
Fall FIRE	-	-	-	-	-	-	-	-

Table 7. Average (one standard error) post-treatment knobcone pine seedling density (ha^{-1}) in seeded (+Seed) and unseeded (–Seed) 3 m^2 plots on BLM South Cow Mountain Recreation Area, northern California Coast Range. In the seeded plots, 125 seeds were sown after the treatment was completed. *Treatments for these units were not completed until after the summer 2005 survey. [#]A seedling survey of the forest inventory plot was added in summer 2007. No significant differences ($p>0.05$) were found between plots for any of the post-treatment surveys. NA-not applicable.

	2005		2006		2007		
Treatment type	+Seed	–Seed	+Seed	–Seed	+Seed	–Seed	Plot[#]
CTL	NA	0 (-)	NA	0 (-)	NA	0 (-)	0 (-)
Spring MECH	0 (-)	0 (-)	2222.2 (444.4)	444.4 (444.4)	1555.6 (587.9)	666.7 (384.9)	522.0 (235.8)
Fall MECH	*	*	3333.3 (3006.2)	0.0 (-)	2666.7 (1387.8)	222.2 (222.2)	498.7 (291.9)
Spring MECH+FIRE	NA	NA	NA	NA	0.0 (-)	0.0 (-)	0.0 (-)
Fall MECH+FIRE	*	*	58666.6 (44015.1)	0.0 (-)	47111.1 (38193.1)	0.0 (-)	112.5 (22.2)
Spring FIRE	-	-	-	-	-	-	-
Fall FIRE	-	-	-	-	-	-	-

Appendix 1. Crosswalk between proposed and delivered FFS outreach activities, as indicated in the original proposal, dated January 6, 2003.

Proposed	Delivered	Status
Website	http://www.cnr.berkeley.edu/stephens-lab/kp_labweb.htm	In progress
Publications	See Appendix 2	In progress
Poster	Chapman, Jennifer. 2006. Fire Ecology on California's Public Lands and Preserves. In, California Interagency Prevention/Mitigation/Education Conference. Hilton Sacramento Arden West, Sacramento, CA. March 20-23, 2006	Done
	Fry, Danny and others. 2008. Stand-replacing treatments regenerating knobcone pine forests: effects of mechanical cutting and prescribed fire. In, Fire in the Southwest: Integrating Fire into Management of Changing Ecosystems. Conference hosted by The Association for Fire Ecology and Humboldt State University, California. Tuscon, Arizona. January 28-31, 2008.	In progress
Workshops/Presentations	Interagency Resource Advisory Council Meeting. BLM Ukiah Field Office, Mendocino County, CA. November 4, 2004	Done
	Interagency Resource Advisory Council Meeting. BLM Ukiah Field Office, Mendocino County, CA. Update meeting proposed for spring 2008.	In progress
Tours/Site Visits	Field tours at BLM South Cow Mountain Recreation Area for Regional Fire Safe Council and other interested groups. Proposed for spring 2008.	In progress

Appendix 2. Tentative title and journal source of proposed manuscripts for publication.

1. Forest structure, disturbance history and management of knobcone pine forests in the Mayacmas Mountains, northern California Coast Ranges.
Forest Ecology and Management.

2. Stand replacing treatments in knobcone pine forests: effects on regeneration, fuels and vegetation.
Journal of Vegetation Science.

3. Treatment costs and emissions in regeneration of crown fire adapted knobcone pine forests.
Fire Ecology.

Appendix 3. Understory Vegetation Sampling Results

Table 1E. Understory vegetation species cover and ground cover pre- and post-treatment in knobcone pine forests on BLM South Cow Mountain Recreation Area, northern California Coast Range.

		Pretreatment		Post-treatment	
Treatment type	Species/Cover Type	% cover	Height	% cover	Height
CTL	Bare Ground	3.0 (7.0)		3.0 (7.0)	
	Rock	2.3 (1.0)		2.3 (1.0)	
	Arctostaphylos glandulosa	5.4 (.8)	2.9 (0.6)	5.4 (.8)	2.9 (0.6)
	Quercus berberidifolia	17.0 (10.3)	1.9 (0.5)	17.0 (10.3)	1.9 (0.5)
	Quercus wislzeni var. frutescens	23.0 (8.8)	3.3 (0.5)	23.0 (8.8)	3.3 (0.5)
Spring MECH	Bare Ground	3.8 (0)		2.3 (0.2)	
	Rock	3.1 (1.8)		0 (-)	
	Arctostaphylos glandulosa	6.5 (1.8)	3.2 (0.8)	3.3 (0.8)	0.6 (0.1)
	Quercus berberidifolia	6.9 (2.0)	2.4 (0.4)		
	Quercus wislzeni var. frutescens	22.6 (8.8)	3.6 (0.5)	29.3 (5.4)	1.6 (0.2)
Fall MECH	Bare Ground	3.6 (0.6)		2.5 (0)	
	Rock	2.8 (1.0)		0.3 (0.3)	
	Arctostaphylos glandulosa	5.5 (1.1)	3.1 (0.6)	2.5 (0)	0.5 (0.1)
	Quercus chrysolepis	6.9 (3.9)	2.9 (0.6)	2.5 (0)	1.0 (0)
	Quercus wislzeni var. frutescens	31.8 (12.4)	3.7 (0.6)	33.3 (7.1)	1.2 (0.1)
	Ceanothus integerrimus	1.8 (0.4)	1.4 (0.4)	2.5 (0.2)	0.5 (0.1)
Spring MECH+FIRE	Bare Ground	3.6 (0.6)		38 (10.0)	
	Rock	2.8 (1.0)		3.1 (1.0)	
	Arctostaphylos glandulosa	9.7 (4.3)	3.1 (0.4)	2.5 (0.4)	0.5 (0.1)
	Quercus berberidifolia	5.1 (3.3)	1.3 (0.3)		
	Quercus wislzeni var. frutescens	28.1 (11.1)	3.9 (0.5)	17.0 (10.0)	0.7 (0.1)
Fall MECH+FIRE	Bare Ground	3.7 (0.5)		25.4 (12.5)	
	Rock	2.9 (0.8)		0.4 (0.2)	
	Arctostaphylos	9.6 (2.3)	2.8 (0.6)	3.1 (0.6)	0.6 (0.1)

	glandulosa				
	Quercus berberidifolia	12.1 (4.7)	2.5 (0.5)	2.5 (0)	0.8 (0.3)
	Quercus wislzeni var. frutescens	19.7 (5.8)	3.4 (0.4)	20.3 (5.1)	1.0 (0.2)
	Ceanothus integerrimus			4.5 (2.1)	0.5 (0)
Spring FIRE	Bare Ground	3.4 (0.7)			
	Rock	2.7 (1.0)			
	Arctostaphylos glandulosa	7.8 (3.9)	2.6 (0.5)		
	Quercus berberidifolia	20.7 (9.5)	2.9 (0.6)		
	Quercus wislzeni var. frutescens	18.3 (6.3)	3.9 (0.4)		
Fall FIRE	Bare Ground	3.5 (0.9)			
	Rock	2.5 (1.4)			
	Arctostaphylos glandulosa	8.4 (2.4)	3.3 (0.8)		
	Quercus wislzeni var. frutescens	29.9 (14.7)	3.8 (0.7)		