# Fire Performance in Traditional Silvicultural and Fire and Fire Surrogate Treatments in Sierran Mixed-Conifer Forests: A Brief Summary[1]

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### Abstract

Mixed conifer forests cover 7.9 million acres of California's total land base. Forest structure in these forests has been influenced by harvest practices and silvicultural systems implemented since the beginning of the California Gold Rush in 1849. Today, the role of fire in coniferous forests, both in shaping past stand structure and its ability to shape future structure, is a central force driving both the direction and political debate around forest management on public lands. The purpose of this paper is to demonstrate stand structures which contribute to effective fuel treatments and to provide data which will help managers design desired conditions for future fuel treatment projects. Dr. Jim Agee and Carl Skinner have outlined four principles of fuel treatments which should be integrated when implementing treatments with a goal of enhancing fire resiliency. Stand structures which performed the best with respect to potential fire behavior incorporated most or all of the four principles of fuel reduction. Modification of fire behavior and severity will likely continue to be a driving force in forest management. In most cases, this goal will have to be integrated with multiple forest values and uses, particularly on public lands.


## Introduction

Mixed conifer forests cover 7.9 million acres (7.8 %) of California's total land base (CDF 2003a). Forest structure in these forests has been influenced by harvest practices and silvicultural systems implemented since the beginning of the California Gold Rush in 1849. These management practices were partially a reflection of land use, economic trends, and societal values of forestlands during different periods of development of the Sierra Nevada Range (Beesley 1996). With the on-set of the California Gold Rush, harvesting of Sierran forests was associated with providing wood for mines and their associated towns and residences (Beesley 1996); it is noted that photographs and sketches from mining communities depicted "…barren environments around mining settlements" (Beesley 1996). Much of the area around Lake Tahoe was heavily logged in the late 1800's (Taylor 2004), and much of the wood removed from the Lake Tahoe Basin was used in the Comstock silver mining

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region of Nevada (Landauer 2004, Peterson 1996).

With the development of the transcontinental railroad, demand increased for wood to build the Central Pacific and other Sierran Railroads (Beesley 1996). It was estimated that over 300 million board feet alone was needed to construct the wooden snow sheds near the western summit of the railroad (Beesley 1996). Use of narrow gauge railroads for logging increased the efficiency of wood removal (Beesley 1996, Stephens, 2001, Young 2003) and favored the removal of both ponderosa pine (*Pinus ponderosa* Dough. Ex. Laws) and sugar pine (*Pinus lambertiana* Dougl.) over Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), white fir (*Abies concolor* Gord. & Glend.), and incense cedar (*Calocedrus decurrens* [Torr.] Floren.)(Polkinghorn 1984). The emphasis on the removal of pine was observed by John Leiberg (1902), who was surveying forest conditions of lands in present day El Dorado, Plumas, and Tahoe counties. Leiberg (1902) described his ideas of what future forest conditions might be under these types of harvest practices as follows: *"The Old Forest of the west slope of the Sierra will have been cut away, and the young growth will consist largely of red fir, white fir, and incense cedar."* After World War II ended, demand for lumber increased on Federal Lands (Beesley 1996). This demand led to an increasing emphasis on silvicultural prescriptions which maximized growth and yield (Hirt 1994).

Today, the role of fire in coniferous forests, both in shaping past "stand structure" (definition Helms 1998) and in its ability to shape future structure, is a central force driving both the direction and political debate around forest management on public lands (Stephens and Ruth 2005, USDA 2004). Management of public lands now has an emphasis placed on creating stand structures which have some improved level of fire resiliency. This paper compares and discusses results from two recently published papers (Stephens and Moghaddas 2005a, c). The purpose of this paper is to demonstrate stand structures which contribute to effective fuel treatments, and to provide stand structure data which will help managers design desired conditions for future fuel treatment projects.

# Methods

## *Study Site*

Both studies were undertaken in Sierra Nevada mixed conifer forests in the north-central Sierra Nevada at the University of California Blodgett Forest Research Station (Blodgett), approximately 20 km east of Georgetown, California. Blodgett Forest is located at latitude 38° 54′ 45″ N, longitude 120° 39′ 27″ W, between 3,600 and 4,600 ft above sea level, and encompasses an area of 4,400 acres. Species composition, site productivity, and management history (Olson and Helms 1996) of Blodgett forests are representative of 420,000 acres of high site California mixed conifer forestland (Davis and Stoms 1996, Hickman 1993, Mayer and Laudenslayer 1988).

## *Silvicultural Treatments*

Seven fire and fire surrogate and traditional silvicultural treatments are discussed in this paper. Further details on treatment and statistical analysis of vegetation structure, coarse woody debris and fuel characteristics, and fire performance of these stands can be found in three recently published papers (Stephens and Moghaddas 2005a, b, c). The seven silvicultural treatments, which are the four fire and fire surrogate treatments (FFS), and the three traditional silvicultural methods (Traditional), are described below.

## No Treatment (FFS)

This treatment assesses the effectiveness of no treatment in managed, second growth mixed conifer forests. The no treatment units had been previously thinned from below (in harvests prior to initiation of the study) using a lop and scatter treatment of activity slash (CDF 2003b) with retention of sub-merchantable material (less than 10 inches dbh).

## Fire Only (FFS)

The fire only units had been previously thinned from below (in harvests prior to initiation of the study) using a lop and scatter treatment of activity slash (CDF 2003b) with retention of sub-merchantable material (less than 10 inches dbh). Fire only units were burned with no pre-treatment of fuels except felling of snags and removal of ladder fuels adjacent to fire lines for firefighter safety. Ignition was completed using strip head-fires (Martin and Dell 1978), one of the most common ignition patterns used to burn forests in the western US. All prescribed burning (fire only and mechanical plus fire treatments) was conducted during a short period (10/23/2002 to 11/6/2002) with the majority of burning being done at night (Knapp et al. 2004). Night burning was preferred because relative humidity, air temperature, wind speed, and fuel moistures were within pre-determined levels to produce the desired fire effects.

## Mechanical Only (FFS)

Mechanical only treatment units had a two-stage prescription. In 2001, stands were commercially thinned from below to maximize crown spacing while retaining 125 to 150 $ft^2$/ac of basal with the silvicultural goal to produce an even species mix of residual conifers. Slash treatment was a lop and scatter of limb wood and tree tops from the harvested trees to an average depth of less than 30 inches (CDF 2003b). Following the commercial harvest, approximately 90 percent of understory conifers and hardwoods between one and 10 inches diameter at breast height (dbh) were masticated in place using an excavator mounted rotary masticator.

## Mechanical Plus Fire (FFS)

Mechanical plus fire experimental units underwent the same treatment as mechanical only units, but in addition, they were prescribed burned using a backing fire (Martin and Dell 1978).

## Individual tree selection (Traditional)

Thinning of trees across all diameter classes favoring removal of damaged, diseased, and suppressed conifers. The silvicultural goal is to recruit new cohorts of conifers and hardwoods, and to develop and maintain an uneven sized forest structure with multiple canopy layers. Minimum size of trees harvested are typically at least 10 inches dbh. Sub-merchantable material (less than 10 inches dbh) is retained. Post harvest fuel treatment includes lop and scatter of limb wood and tree tops from the harvested trees to an average depth of less than 30 inches (CDF 2003b).

## Thin from below (Traditional)

Low thinning favored residual forest composed of largest diameter trees in stand. Minimum size of trees harvested are typically at least 10 inches dbh; sub-merchantable material (less than 10 inches dbh) is retained. Post harvest fuel treatment includes lop and scatter of limb wood and tree tops from the harvested trees to an average depth of less than 30 inches (CDF 2003b). The silvicultural goal is to produce an open understory structure with many large overstory trees.

### Overstory Removal (Traditional)

This method called for the removal of all trees greater than 18 inches dbh while meeting minimum stocking standard (125 $ft^2$/acre) (CDF 2003b). Sub-merchantable material (less than 10 inches dbh) is retained. Post harvest fuel treatment includes lop and scatter of limb wood and tree tops from the harvested trees to an average depth of less than 30 inches (CDF 2003b). The silvicultural goal is to release intermediate and suppressed trees and maximize harvest volume.

## *Statistical Assessment of Vegetation Structure, Fuels Characteristics, and Fire Performance*

Vegetation was measured using 1/10th acre circular plots installed in each treatment unit on a systematic grid. Tree species, dbh, total height, height to live crown base, and crown position (dominant, co-dominant, intermediate, suppressed) were recorded for all trees greater than 4.5 inches dbh. Similar information was also recorded for all trees greater than 4.5 feet tall on a 1/100th acre nested subplot in each 1/10th acre plot. Surface and ground fuels were sampled with transects at each of the plots using the line-intercept method (van Wagner 1968, Brown 1974).

Fire behavior was modeled under the upper 90$^{th}$ percentile fire weather conditions. Percentile weather was computed using Fire Family Plus (Main et al. 1990). Forty-one years (1961 to 2002) of weather data from the Bald Mountain Remote Access Weather Station (NFAM, 2004), 2.5 miles west of Blodgett Forest, were analyzed with Fire Family Plus Software to determine percentile weather conditions. Fuels Management Analyst was used to model fire behavior, crowning index, torching index, scorch height, and tree mortality (Carlton, 2004). Torching and crowning indices are the 20-foot wind speed required to initiate torching (passive crown fire) or sustain a crown fire (active crown fire) within a stand (Scott and Reinhardt 2001).

Analysis is based on three replicates of each silvicultural system described. Analysis of variance (ANOVA) was used to determine if significant differences ($p < 0.05$) existed in vegetation structure (trees $ac^{-1}$, basal area $ac^{-1}$, height to live crown base, tree height, crown bulk density, and quadratic mean diameter), stand density index, 1-100 combined fuel load, crowning, and torching index for each silvicultural system. If significant differences were detected, a Tukey-Kramer HSD test was performed to determine which specific silvicultural system or reserve was different from another (Zar 1999). The Jump Statistical Software package (Sall et al. 2001) was used in all analyses.

# Results

Vegetation, fuel, and fire performance characteristics are summarized in *table 1*. Stand structure of traditional silvicultural and Fire Surrogate treatments were statistically similar in terms of stand density and tree height to crown base. The quadratic mean diameter of the Fire Surrogate mechanical plus fire was significantly higher than all other treatments. While tree height to crown base were statistically similar between treatments which did not incorporate fire, the relatively lower height to crown base and relatively higher surface fuel loads in traditional silvicultural systems affected the modeled potential for torching in these stands. Traditional silvicultural systems, which did not include removal of sub merchantable material and used only a lop and scatter of activity fuels, typically had a relatively higher likelihood of torching than fire surrogate treatments, which incorporated burning as a surface fuel treatment (*table 1*). The Fire Surrogate mechanical plus fire treatment had the lowest potential for crown fire when compared with the traditional thin from below treatment and the Fire Surrogate Study fire only treatment. Crown fire potential in the individual tree selection, overstory removal, and Fire Surrogate Study mechanical only treatments were similar.

## Discussion

An understanding of stand conditions which meet fire performance goals is critical to effective fuel treatment planning. There is consensus that reducing surface, ladder, and some degree of canopy fuels, in conjunction with each other, can mitigate fire behavior at a stand level (Peterson et al, 2005). There is also general consensus that "no treatment", particularly in second growth stands that have been subjected to past harvest and fire suppression, will not improve fire performance in a given stand (Agee 2002, Stephens and Moghaddas 2005a, c). Data from the studies discussed support these fuel reduction concepts. Agee and Skinner (2005) have outlined four principles of fuel treatments which should be integrated when implementing treatments with a goal of enhancing fire resiliency (these principles were discussed by Dr. Agee in his presentation at this conference). Implementation of these treatments should emphasize them in order from (1) to (4) at the stand level: (1) reducing surface fuels, (2) increasing height to live crown base, (3) decreasing crown density, and (4) retaining the largest trees in the stand through thinning. Implementation of these treatments should emphasize these treatments in order (1-4) at the stand level. The importance of treating surface fuels as part of a larger fuel treatment strategy has been identified in previous research (Stephens 1998).

In this comparison, stands which performed the best with respect to potential fire behavior incorporated most or all of the four principles of fuel reduction (Agee and Skinner 2005, Peterson et al. 2005). Fire Surrogate treatments (fire only and mechanical plus fire), which implemented surface fuel, ladder fuel, and crown fuel reduction while retaining the largest trees in the stand, performed best. Performance of the Fire Surrogate mechanical treatments was followed next by the traditional thinning from below. Within traditional silvicultural treatments, individual tree selection and overstory removal performed most poorly with respect to torching, though they did have a higher crowning index than the FFS fire only treatment and the traditional thinning from below. The FFS no treatment performed most poorly in all stands, indicating that previously managed second growth stands with residual activity fuels may need additional treatment to improve stand level fire performance. On the other hand, use of a whole tree harvest system, which include removal of sub-merchantable materials (<10-inch dbh) and/or prescribed burning of surface fuels, may limit deposition of harvest related activity fuels (Agee and Skinner 2005) and somewhat improve performance of traditional silvicultural systems.

When implementing fuel treatments, it is important to consider the short- and long-term tradeoffs that come with modifications of stand structure. Traditional silvicultural systems typically maintain higher stocking levels than Fire Surrogate

**Table 1.** *Average vegetation, fuel, and fire performance (torching and crowning index) characteristics and standard errors of seven silvicultural treatments that were the four fire and fire surrogate treatments (FFS) and three traditional silvicultural methods (Traditional). Mean values in a column followed by the same letter are not significantly different (P > 0.05).*

| | Tree height (feet) | | Height to live crown base (feet) | | Trees per acre | | Basal area (ft$^2$ per acre) | | Quadratic mean diameter (inches) | | Stand density index (Reineke, 1933) | | Crown bulk density (pounds per ft$^3$) | | Total 1, 10, 100 hour fuels (tons per acre) | | Torching index (miles per hour) | | Crowning index (miles per hour) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ave | *SE* | Ave | *SE* | Ave | *SE* | Ave | *SE* | Ave | *SE* | Ave | *SE* | Ave | *SE* | Ave | *SE* | Ave | *SE* | Ave | *SE* |
| No Treatment (FFS) | $51.1^{d}$ | *2.5* | 24.6 | *1.8* | $49.2^{a}$ | *34.1* | $246.2^{a}$ | *13.0* | $10.1^{bc}$ | *0.1* | $452^{a}$ | *26* | $0.005^{ab}$ | *0.0004* | 6.4 | *0.6* | $18^{c}$ | *0* | $21^{d}$ | *1* |
| Fire Only (FFS) | $58.5^{cd}$ | *1.5* | 24.2 | *1.0* | $178.7^{c}$ | *13.0* | $208.3^{a}$ | *10.6* | $14.7^{b}$ | *0.2* | $329^{ab}$ | *18* | $0.0045^{abcd}$ | *0.0002* | 2.0 | *0.5* | $308^{b}$ | *24* | $22^{c}$ | *1* |
| Mechanical plus Fire (FFS) | $74.6^{ab}$ | *3.1* | 31.2 | *2.5* | $96.7^{c}$ | *8.5* | $171.3^{ab}$ | *11.0* | $18.2^{a}$ | *1.4* | $248^{b}$ | *10* | $0.0026^{d}$ | *0.0001* | 2.1 | *0.2* | $415^{a}$ | *10* | $33^{a}$ | *1* |
| Mechanical Only (FFS) | $67.0^{bc}$ | *1.9* | 31.1 | *1.8* | $173.6^{c}$ | *56.5* | $178.5^{ab}$ | *3.4* | $14.8^{b}$ | *2.2* | $285^{ab}$ | *22* | $0.0028^{c}$ | *0.0001* | 7.6 | *0.3* | $46^{c}$ | *4* | $31^{abc}$ | *1* |
| Thin From Below (Traditional) | $52.8^{de}$ | *1.5* | 33.1 | *1.2* | $229.6^{ac}$ | *18.9* | $209.7^{a}$ | *27.7* | $12.9^{bc}$ | *0.3* | $346^{ab}$ | *42* | $0.0047^{abcd}$ | *0.0005* | 7.5 | *2.4* | $46^{c}$ | *4* | $23^{c}$ | *2* |
| Individual Tree Selection (Traditional) | $51.6^{de}$ | *2.2* | 20.6 | *3.8* | $232.4^{ac}$ | *53.5* | $172.2^{ab}$ | *18.2* | $11.9^{bc}$ | *0.7* | $296^{ab}$ | *38* | $0.0038^{abcd}$ | *0.0003* | 11.4 | *3.3* | $34^{c}$ | *9* | $27^{abcd}$ | *1* |
| Overstory Removal (Traditional) | $44.5^{e}$ | *5.3* | 21.4 | *6.2* | $258.8^{ac}$ | *85.0* | $110.3^{b}$ | *35.9* | $9.0^{c}$ | *0.8* | $211^{b}$ | *65* | $0.0041^{abcd}$ | *0.0007* | 10.0 | *3.4* | $36^{c}$ | *10* | $26^{abcd}$ | *4* |

treatments. Excessive reduction of canopy fuels can reduce annual volume growth, thereby possibly hindering long-term volume growth strategies. Maintaining higher stand densities may leave stands prone to other risks, including insect attack (Powell 1999). It is also important to understand the role of regeneration in any silvicultural system in order to sustain desired species and age class composition over the long term. The range of light conditions created by different stand structures may favor the germination and growth shade of intolerant species, depending on light availability at the forest floor (Ansley and Battles 1998). Finally, where feasible, treatments should be placed on the landscape to optimize their effectiveness in conjunction with past treatments or fires, topography, local weather patterns, adjacent vegetation types, and protection of resources at risk (Stratton 2004, Finney 2001).

## Conclusion

Current stand structure across much of the coniferous forests of the Sierra Nevada has been heavily influenced by past management practices. Many past silvicultural systems did not emphasize fire performance as a silvicultural objective. Primary fuel surface treatments consisted of lop and scatter treatments, which tended to increase surface fire intensity until slash had adequately broken down. In dry forest systems, slash in the 100- and 1,000-hour size classes can remain in Sierra Nevada forests for 20-30 years (Stephens and Moghaddas 2005c). It is important for managers to understand the history of the stand prior to writing prescriptions. Even-aged, relatively young (less than 150 year old) stands that have been exposed to decades of past management practices will need to be treated differently than older stands that have had little impact of past harvest but have been exposed to intensive fire suppression. Integrating surface and ladder fuel treatments into silvicultural prescriptions early in the planning process is crucial. Selecting harvest systems (whole tree vs. traditional lop and scatter) can affect the amount of fuels left on site (Agee and Skinner 2005).

Modification of fire behavior and severity will likely continue to be a driving force in forest management, particularly on public lands. In most cases, this goal will have to be integrated with other forest values and constraints including protection of water resources, scenic values, air quality, wildlife habitat, recreational use, and limited budgets. Integration with these other values may decrease the effectiveness of fuel treatments if they require retention of ladder fuels or limit post-treatment prescribed burn activities.

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