Fire Behavior and Effects in Fuel Treatments and Protected Habitat on the Moonlight Fire

Prepared by

The Fire Behavior Assessment Team

Scott Dailey[A], JoAnn Fites[A], Alicia Reiner[A], Sylvia Mori[B]

[A]USDA Forest Service, Adaptive Management Service Enterprise Team
[B]USDA Forest Service, Pacific Southwest Research Station

June • 2008

This report presents findings and recommendations derived from evaluating the use and effectiveness of fuel treatments and fire behavior in treated and untreated areas on the Moonlight Fire. It is based on firsthand observation of fire behavior as well as follow-up post-fire surveys of fire behavior evidence and effects and the analysis of satellite-derived fire effects data.

CONTENTS

Cover Photos

Main photo*:* Moonlight Fire smoke column development at 4PM on September 4, 2007. Image was taken from nearby Keddie Ridge by Ron Lunder. (Source: Wildlandfire.com.) **Inset photo***:* Moonlight Fire crown fire behavior. Image taken by Randy Jennings, USDA Forest Service.

Figures

Tables

Acknowledgments

We would like to thank the following people who assisted with collecting, providing, and analyzing information for this report: Larry Craggs, Pete Duncan, Jon Lamb, Jack Sevelson, Phil Shafer, and Ryan Tompkins, *USDA Forest Service, Plumas National Forest*; Klaus Barber, Tanya Kohler, and Dave Weixelman, *USDA Forest Service, Pacific Southwest Region;* Jason Moghaddas, *Feather River Land Trust*; Steve Beckwitt, *ESRI*; Mike Campbell, Chris Clervi, and Todd Decker, *USDA Forest Service, Adaptive Management Services Enterprise Team.*

Special thanks go to the following people who provided review comments: Pete Duncan, Jon Lamb, Kyle Merriam, *USDA Forest Service, Plumas National Forest;* Eric Knapp, *USDA Forest Service, Pacific Southwest Research Station*; and Kris Boatner, *USDA Forest Service, Tahoe National Forest.*

A big thanks goes to technical writer-editor Paul Keller, *Wildland Fire Lessons Learned Center.* Paul provided review comments and formatted the document.

EXECUTIVE SUMMARY

Fire Behavior, Suppression, Fuel Treatments, and Protected Areas

Background

- The Moonlight Fire burned 64,997 acres, mainly on the Plumas National Forest.
- The fire started the afternoon of Sept. 3, 2007 and declared contained on September 15, 2007.
- The fire burned through areas protected for California spotted owl and goshawk habitat (Protected Activity Centers and home range core habitat), hazardous fuels treatment areas, silvicultural treatment areas, untreated areas, privately owned land, and up to the wildland urban interface around Indian Valley.
- Dry conditions, steep topography, large areas of heavy fuel loadings, and frontal winds contributed to intense, plume-dominated fire behavior with long-range spotting.

Key Findings

- The Moonlight Fire burned through 22 owl PACS, 25 owl core areas, and 7 goshawk core areas. Within owl PACS, 64 percent of the total acreage had 75 to 100 percent canopy cover change (reduction). Within owl core areas, 68 percent of the total acreage had 75 to 100 percent canopy cover change. Within goshawk core areas, 46 percent of the total acreage had 75 to 100 percent canopy cover change. It is possible that the degree of canopy cover change resulting from this event will have limiting affects on the utility of this area as viable owl and goshawk habitat.
- Fire behavior was more intense with higher canopy cover crown change (reduction) in untreated areas, including protected owl/goshawk habitat, compared to treated areas. Areas treated with a combination thinning/prescribed burning showed the greatest ability to reduce burning intensity.
- Although tree crown change (reduction) in untreated areas protected as owl/goshawk habitat was not statistically different from other untreated areas, the data illustrates a strong trend toward greater crown consumption in untreated areas protected as owl/goshawk habitat.
- Defensible fuel profile zones (DFPZs) were used for suppression efforts, but there was not a sufficient density to provide effective use on many parts of the fire. This is in contrast to the Antelope Complex Fire that occurred adjacent to the Moonlight Fire, where a high proportion of the fire's area had been treated for fuel hazard reduction. In at least one instance on the Antelope Fire, crews experienced intense fire behavior in a treated area and were able to utilize other nearby treated areas for effective fire suppression.
- Similar to the Antelope Complex Fire, on several occasions the fire exhibited intense fire behavior, including the observation of plume-dominated fire. Accelerated rates of spread were observed in association with the formation of a convective heat-induced smoke column. In addition to extremely dry conditions and unstable atmospheric conditions associated with the passing of a cold front, this fire behavior was possibly associated with large areas of untreated fuels.

Recommendations

- Consider the use of more fuel treatments which reduce surface fuels, including prescribed fire.
- Consider treating larger portions of landscape to effectively reduce the likelihood of fires gaining momentum and increasing in intensity to a point where fuel treatments and suppression efforts become ineffective.
- Consider watershed-scale prescribed burns to reduce fuels across more acreage, particularly in steeper ground and sensitive areas where other treatment options are limited.
- Consider placing a larger number of fuel treatments across the landscape to provide suppression forces with fuels conditions advantageous to fire control, including more options for contingency lines.
- Consider treating in or around protected areas to enable these sites to withstand fire with lesser effects. Treating these areas could also reduce the chance of these sites contributing to increased fire behavior in the adjacent landscape.

The goal of this report is to assess the effectiveness of fuel treatments burned by the Moonlight Fire. The report also compares fire behavior and effects in different land management areas, including several types of silvicultural harvests and California Spotted Owl and Goshawk habitat.

I INTRODUCTION

Today, a combination of climate change and past human activity is producing more wildfire activity in forested lands across the western United States. During the last several decades, climate changes causing an earlier onset of fire seasons have increased the frequency of larger wildfires in the western United States (Westerling et al. 2006). Additionally, fire suppression and extensive grazing in the early 1900s helped decrease fire activity—allowing fuels to accumulate over the past 50 to 100 years (Miller and Tausch 2001, van Wagtendonk and Fites-Kaufman 2007).

This report is based on:

- Interviews with firefighters by Dr. Jo Ann Fites and her Fire Behavior Assessment Team during and after the fire; and
- A quantitative post-fire assessment of fire behavior evidence and immediate post-fire effects to forests, habitat, and soils.

Background

The Moonlight Fire, ignited from timber harvest operations, burned 64,997 acres, mainly on the Plumas National Forest (Figure 1). The fire started the afternoon of September 3, 2007 southeast of Moonlight Peak. Its first afternoon, the fire grew more than 200 acres. On the second day of the fire, cumulus clouds built-up over the fireline that caused downdrafts—winds that pushed down and out in all directions upon reaching the land surface.

These winds pushed the fire down Lights Creek drainage about 4-5 miles per hour and threw embers downwind up to two miles in front of the fire, causing spot-fires. Changing wind direction and steep terrain—with limited road access—increased fire size and hindered suppression efforts.

The Moonlight fire was declared contained September 15, 2007. The fire burned through hazardous fuel reduction areas, silvicultural treatments, untreated areas, and areas protected for California spotted owl and goshawk habitat (Protected Activity Centers and home range core habitat), as well as non-Forest Service land, and privately owned land and up to the wildland urban interface around Indian Valley.

Fuel reduction treatments are being implemented to protect natural resources from catastrophic wildfires. Various government and non-government groups implement fuel treatments in the wildland-urban interface to minimize fire activity near homes and home loss due to wildland fires.

The U.S. Forest Service also strives to reduce fuels to protect wildlife habitat and forest resources from larger, more severe wildfires. Large-scale catastrophic fires can eliminate habitat, negatively impacting California Spotted owls (Bond et al. 2002).

Despite the widely understood importance and typically high cost of fuel treatments, their impacts and effectiveness are not entirely understood by land managers, researchers, or the general public.

The size, placement, and amount of vegetation alteration needed to reduce severe fire behavior are still debated (Agee et al. 1999).

An optimum method for determining the effectiveness of different amounts and types of fuel treatments is to measure and evaluate their effectiveness during a wildfire (Fites and Henson, 2004, Lentile et al. 2007, Freeman et. al. 2007).

Most reported evidence is based on modeling potential fire behavior. While this approach is practical, it is laden with many underlying assumptions. Additionally, there is a generally insufficient underlying science in fire behavior models to support these evaluations in a definitive way.

Very few studies have assessed fire behavior and fire severity regarding fuel treatments and owl habitat using wildfire case studies rather than fire behavior modeling (Thompson et al. 2007, Russel, G.T. 2003, Ager et al. 2007).

Objective of this Assessment and Report

Utilize direct observation and immediate post-fire assessment of fire behavior evidence from satellites and field plots to evaluate effectiveness of fuel treatments and fire behavior in protected habitat for the owl and goshawk.

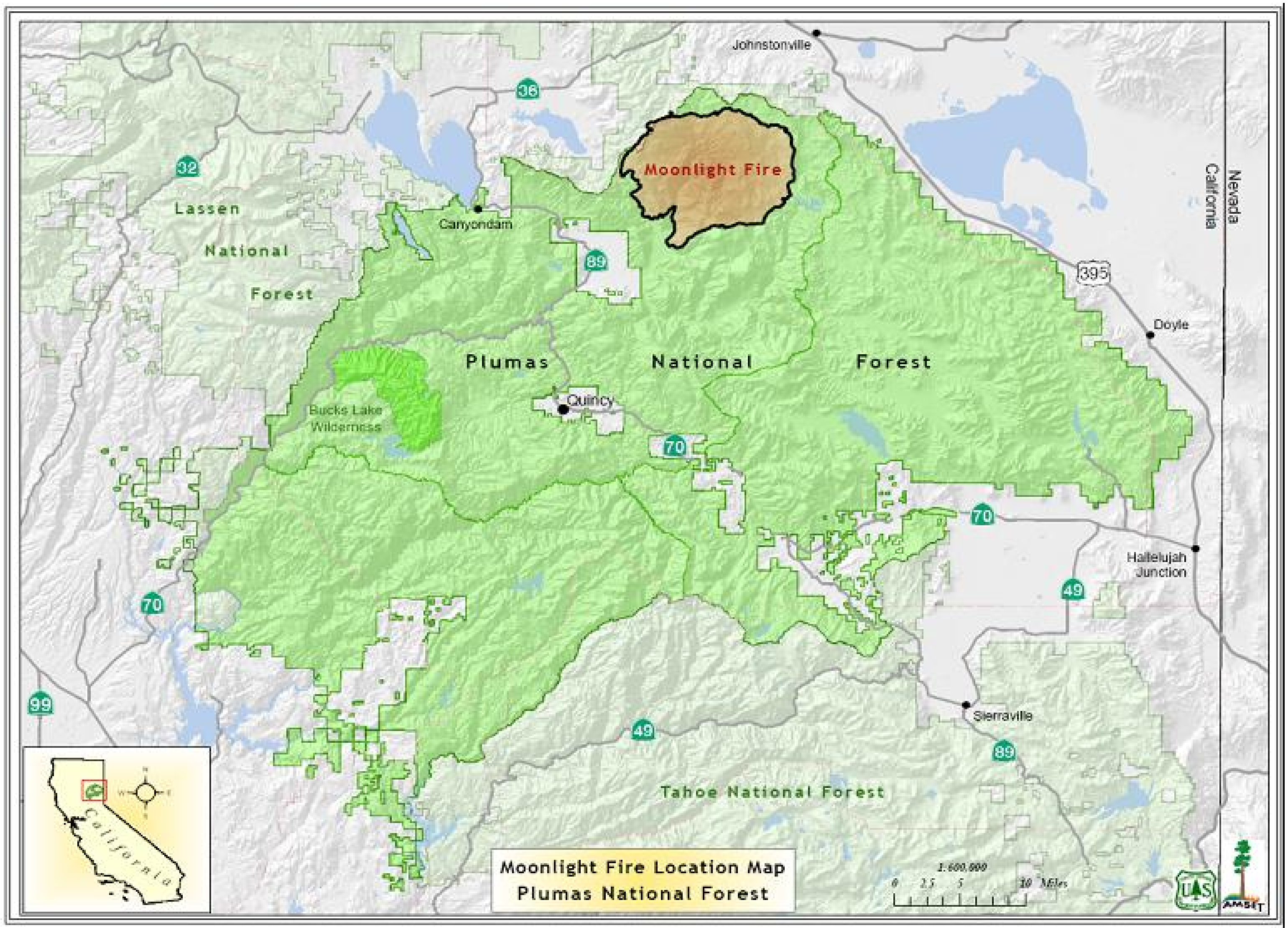


Figure 1 – Moonlight Fire Location Map.

The fire spread down Lights Creek drainage very rapidly, at 4-5 mph, with spot fires occurring two miles ahead of the fire. Firefighting was temporarily halted due to unsafe conditions.

II FIRE BEHAVIOR AND SUPPRESSION IN RELATION TO WEATHER AND FUEL TREATMENTS

Fire Chronology

Figure 2 – First day of the Moonlight Fire, September 3, 2007.

The Moonlight Fire was reported at 2:25 p.m. on September 3, 2007. The fire started about one mile southwest of Moonlight Peak on the Plumas National Forest.

When firefighters arrived on scene shortly afterwards, southerly winds were pushing the fire north-northeast in relatively flat to gently sloped terrain.

Short- and long-term conditions were dry, with low fuel moistures and low relative humidity (RH) values[1]. Key fire behavior indices[2] were well above average in the days leading up to the fire, and throughout the fire—with observations of maximum recorded values.

High wind speed and fuel loading contributed to a rapid rate of spread and numerous spot fires[3]. Between 1:00 p.m. and midnight that first day, weather conditions became worse, with relative humidity dropping from 30 to 9 percent, and peak winds ranging from 9 to 27 mph. These dangerous conditions limited the effectiveness of firefighting resources.

By 9 p.m., the fire had grown to 242 acres and was approaching the 29N46 Road.

Moonlight Fire: Second Day

In the morning hours of September 4, the fire continued extending northeast past

[1] 1hr and 10 hr fuels were 2 and 3 percent, 10 and 1000 hr fuels <6 percent, live fuel moistures 90-110 percent, and minimum RH was 7 percent on the first day of the fire.

[2] "Energy Release Component" (ERC) is a number related to the available energy available per unit area within the flaming front of the fire. It reflects potential fire intensity based on longer term live and dead fuel moisture conditions. Burn Index (BI) is related to the potential difficulty of fire control as a function of how fast and how hot a fire could burn. BI is a function of ERC values, but is more sensitive to short-term changes in the wind and relative humidity.

[3] Spot fires are small fires generated by embers lofted outside the perimeter of the main fire. When a fire is producing spot fires, it is said to be "spotting".

Figure 3 – Cold front passing during the Moonlight Fire.

Cairn Butte and into steep drainages adjacent to Lights Creek.

By noon, the fire was 1,810 acres. A cold front moved through the area that afternoon, causing erratic winds and cumulus cloud development. Unstable atmospheric conditions associated with this weather contributed to the intense and unpredictable fire behavior.

Despite prevailing southeasterly winds, down drafts from thunder cloud cells (and possibly some wind/topography interaction) pushed the fire south-southwest down Lights Creek drainage.

Firefighters report that the fire spread down Lights Creek drainage very rapidly, at 4-5 mph, with spot fires occurring up to two miles in front of the fire. Firefighting was temporarily halted due to unsafe conditions.

That night, there were reports of lighting strikes in the area of the fire. Once again, peak winds were high, ranging from 12 to 24 mph. The fire continued to spread rapidly down Lights Creek drainage through the night of September 4.

Moonlight Fire: Third Day
September 5 brought the similar weather and intense fire behavior with rapid rates of spread. Winds were now coming from the northeast.

Fire spread continued to the south-southwest toward the wildland-urban interface areas of Indian Valley. Suppression efforts were limited due to extreme fire behavior, spotting up to one mile, and limited road access in China Gulch and Superior Ravine.

By 4 p.m. the fire had grown to 22,041 acres.

Moonlight Fire: Fourth Day
On September 6, continued winds from the northeast pushed the fire south and southeast.

The fire reached 28,000 acres with little containment because of limited access, steep topography, and extreme fire behavior due to large areas of untreated fuels.
By this point, the fire stretched from Indicator Peak in the north, nearly to Rattlesnake Peak in the south (See Figure 9). On this day, the fire had attained about half of its size, but was still located mainly west of the East Branch of Lights Creek.

Figure 4 – Post-fire condition, untreated.

Figure 5 – Post-fire condition, commercial thin site.

Moonlight Fire: Fifth Day

On September 7, wind direction was highly variable, but began pushing more out of the south and southwest. With this change in the wind, the fire's southward progression slowed as it began pushing more to the east.

The fire was now moving into areas that had more recent silvicultural and hazardous fuel treatment work. Commercial thinning projects that had previously occurred southwest of Rattlesnake Peak were also effective in slowing fire progression to the southeast and east. These treatments aided firefighters in controlling fire growth in that section of the fire.

Moonlight Fire: Sixth Day

On September 8, fire growth accelerated to the east, spurred by changing wind directions and warmer drier conditions that developed with the passing of the cold front. Earlier in the day, as the fire moved to the east and southeast, it burned into a Defensible Fuel Profile Zone (DFPZ[4]) which had been treated with thinning and mastication as part of the Hungry Fuel Project.

The fire made an uphill run east of the East Branch of Lights Creek toward the mastication units east of the 27N09 Road. According to firefighters, the fire dropped from an intense fire, with group torching and short crown runs, to a surface fire.

This fire transition allowed direct attack using bulldozers. However, due to long range spotting, the fire hooked around these suppression forces. The treatment area became surrounded by fire, thus losing its utility for fire suppression.

During the afternoon hours of September 8, the fire pushed quickly to the east, driven by dry winds from the west and southwest. Peak wind speeds ranged from 6 to 13 mph. Firefighters prepared to hold the fire at the North Antelope Fuel Project, a thin and prescribed burn project which was completed in 1997.

[4] DFPZs are areas approximately ¼ to ½ mile wide where fuel loadings are reduced. They usually are constructed along roads to break-up fuel continuity across the landscape and provide a defensible zone for suppression forces. Many DFPZs had been implemented in the area under the Herger-Feinstein Quincy Library Group Forest Recovery Act of 2000.

Figure 6 – Post fire condition, thin and mastication unit.

Figure 7 – Post fire conditions of thin and burn unit site.

As the fire burned into the fuel treatment area, it dropped to the ground with noticeably reduced flame lengths and intensity.

With the exception of 10 years of pine needle accumulation, surface fuels were described as minimal.

The fire approaching the treated area from the west was described as a crown fire. Before this fire entered the treatment area, it slowed somewhat due to topography as it came downhill from a low ridge to the west.

As the fire burned into the fuel treatment area, it was observed that it dropped onto the ground with noticeably reduced flame lengths and intensity.

Once the fire crossed Indian Creek near sundown, numerous spot fires began to develop within the fuel treatment, then beyond the fuel treatment on Wildcat Ridge to the east. Firefighters were having difficulty keeping up with these many spot fires within and beyond the treatment area. Spot fires on Wildcat Ridge quickly grew to acres in size, trees began torching, and within a short period of time, active crown fire was observed. At that point, crews were forced to abandon their efforts.

Moonlight Fire: Seventh Day

During the morning hours September 9, firefighters built indirect fireline up Wildcat Ridge. A burnout operation was conducted which burned downhill throughout the night. This burnout operation was successful and the fire's eastward progression was stopped.

Figure 8 – On September 7 and 8, westerly winds pushed the Moonlight Fire primarily to the east.

On September 9, the fire reached what would be close to its final size. It spread south to Taylor Lake, east near Antelope Lake, and north to the Diamond Mountain Motorway.

Moonlight Fire: Days 8 through 13

On September 10 the fire reached 60,595 acres. Due to spotting, direct line was unable to hold the fire in check. On September 11, the fire was 63,140 acres with a considerable increase in fire containment. This was due to direct attack in favorable terrain and fuel treatment areas, as well as an increase in personnel.

Temperatures dropped and humidities rose during the next operational periods.

By September 13, the fire achieved its final size of 64,997 acres. Final containment was reached on September 15.

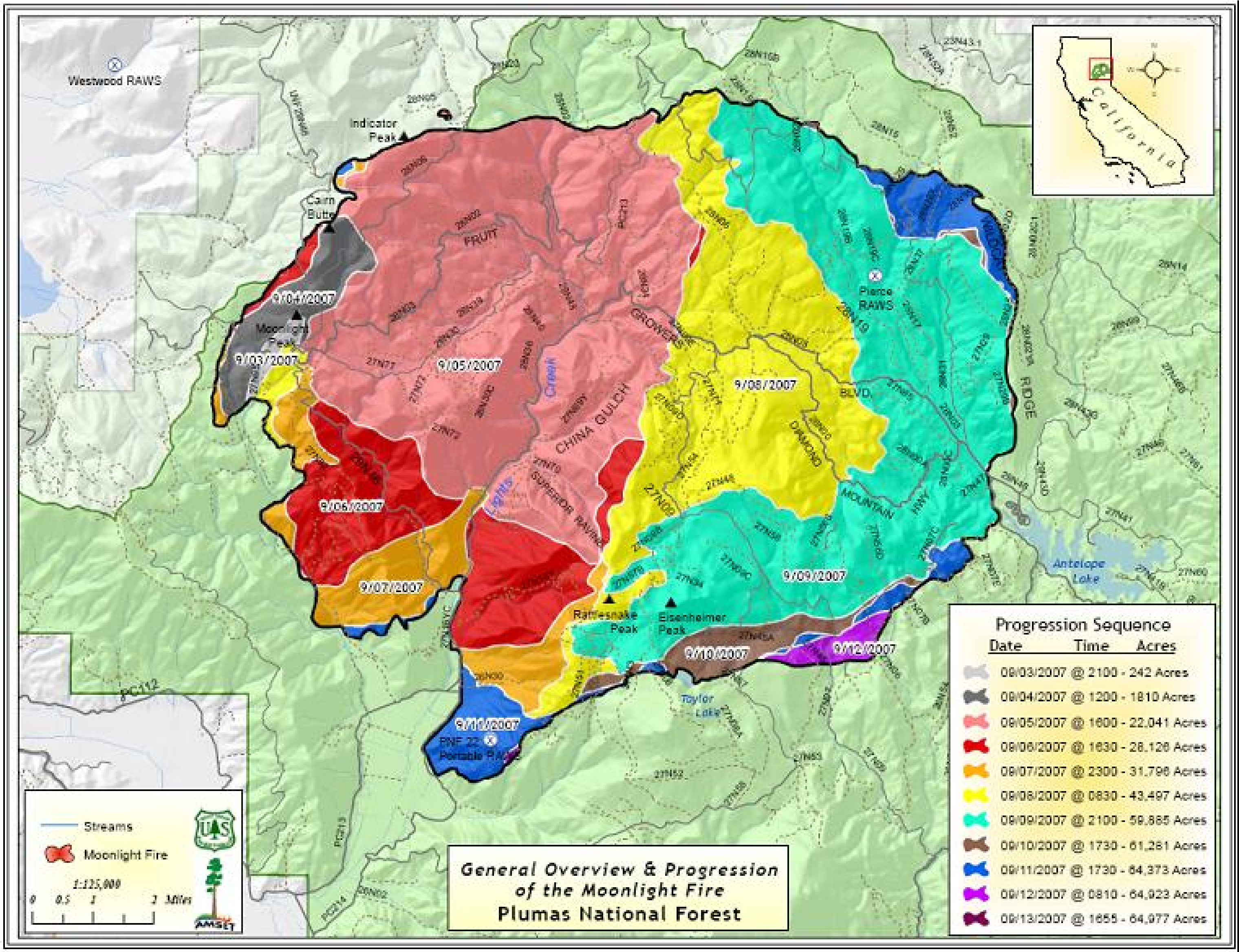


Figure 9 – Moonlight Fire Progression during its first 10 days, September 3 to 13, 2007.

III Post Fire Survey of Fire Behavior Evidence and Effects

Table 1 – Treatment Type Definitions

Treatment	Treatment Definition.
Salvage and Masticate	Salvage of trees which are dead or dying due to fire, insect infestation, or disease. Trees removed in salvage operations are generally larger (10" dbh and greater). Mastication treatments can vary by prescription and equipment used, but generally it involves reducing small trees (up to 10" dbh) and brush to small chunks (soda can-sized and smaller).
Old Harvest	Silvicultural treatments that occurred between 1983 and 1990 were assigned to the "old harvest" group. It was decided to separate these treatment types from more current treatments as the prescriptions prior to the early 90s were generally focused on removal of even-aged overstory trees larger than 10". In the early 90s the focus changed to removal of more intermediate sized trees. The market for biomass material which began in the early 90s allowed for the removal of sub-merchantable trees.
Thin and Burn	Understory thinning focused on removal of ladder fuels and reducing crown bulk density such that crown fire progression is unlikely under all but the most extreme weather conditions. Thinning is followed by a broadcast prescribed burn to consume surface fuels.
Commercial Thin	Generally, a mechanical thinning prescription for removal of larger trees (10" dbh and greater). This is different than pre-commercial thinning which is generally a hand-thinning prescription to remove material under 6 to 8" dbh.

The emphasis of the post-fire survey of the Moonlight Fire was on quantitative evidence of fire behavior and effects. Two complementary post-fire evidence data sets on fire behavior and effects were compiled from: 1) field plots, and 2) satellite imagery.

Data layers of treatment history, fire history, and Habitat Conservation Areas—sites protected[5] for the California spotted owl and goshawk—were compiled to allow a comparison of treated, untreated, and protected areas. Data analysis included both descriptive analysis with summary data in graphs, as well as formal statistical analysis using General Linear Models.

The emphasis of this assessment was on fire behavior and effects on National Forest lands. Therefore, private lands burned in the fire were not included.

For each data set, two different questions were addressed:

1. How did evidence of fire behavior and effects differ between broad categories of land status (including owl and goshawk habitat), recent wildfires, treated areas, and untreated areas?

2. How did evidence of fire behavior and effects differ between specific types of treatment, including: salvage and masticate, old harvest (1980-1990), thin and burn, and commercial thin. (See Table 1 above for treatment details.)

[5] The term "protected habitat" is used in this report for both Protected Activity Centers (nest stands that are not allowed any treatment activities in Herger-Feinstein Quincy Library Group national forests) and core habitat—where limited treatments are allowed.

Severity Code	Definition used for soil burn severity rating.
5	None to Very Low: Patchy, with some low severity.
4	Low: Litter partially blackened, duff unchanged.
3	Moderate: Litter charred or partially consumed, some duff affected, wood partially burned.
2	High: Litter mostly consumed, coarse light ash, duff charred, stumps consumed.
1	Very High: White ash, mineral soil altered, rotten logs consumed.

Table 2 – Soil severity rating levels applied to each plot. The rating system was based on a modified version of NPS protocol (USDI, 2003).

Data from Field Plots

Data were gathered in stratified randomly placed plots on the ground (field) for the first data set. (See Appendix A for details on sampling approach and protocols.) Information was also gathered on fire behavior evidence and effects, including:

- Tree crown consumption and scorch,
- Soil cover consumption and effects,
- Needle freeze and color,
- Understory vegetation consumption and effects, and
- Visible evidence of suppression.

Only crown consumption and soil effects were reported as values reflecting fire behavior and effects. Other measures were used as covariates in the analysis, or in support of subjective descriptions.

Where tree crowns are completely consumed by fire in small groups (groups of 4) or more, this provides strong evidence that crown fire occurred. Where needles remain, needle color and "freeze" provide an indication of the direction and intensity of fire spread. This needle "freeze" occurs when the fire is burning intensely; often moving in a specific direction with enough speed and intensity to "freeze" the needles in the direction the fire is burning.

Black needles indicate higher intensity fire; light-brown needles—with some green remaining—indicate lower intensity fire. The Fire Behavior Assessment Team (FBAT) included a person with extensive fire suppression experience to interpret and record evidence related to fire suppression. In addition, interviews of firefighters who were present for suppression activities were utilized.

The field plot data was summarized into three separate variables used in the analysis:

1. The average proportion of tree crown consumption (torch).
2. The average proportion of tree crown scorch.
3. The modal value for soil burn severity rating (Table 2).

Data from Satellite Imagery

Satellite-derived information on immediate post-fire severity to vegetation produced by the U.S. Forest Service's Pacific Southwest Region Fire and Aviation Management was used in this analysis.

These data are based on a nationally adopted process using LANDSAT satellite imagery. Several different interpretations of these data are available. The version based on canopy cover change (differences between pre-fire and post-fire canopy cover) was used for this analysis.

This was based on an index of fire severity—"delta normalized burn ratio" (dNBR). Extensive field-based calibration to interpret this imagery has been conducted in California, particularly within the Sierra Nevada area (Miller and Thode 2007).

Data Layers Compared

Data layers of treatment history, past wildfires, and California spotted owl and goshawk habitat were compiled to compare treated, untreated, and protected areas (Figures 10, 11).

Treatment history data were derived from varied sources of data on fuel treatments and other vegetation management activities, including timber harvest.

Random points were selected from these combined map layers with equal numbers selected for owl and goshawk nest stands, owl core habitat, treated areas and untreated areas.

Data analysis for both the plot and GIS data included descriptive analysis with summary of data in graphs, as well as formal statistical analysis using General Linear Modeling statistical techniques. (See Appendix B for more detail.)

The larger sample sizes for satellite data allow for determination of statistically significant differences. In some cases, these differences were not significant for plot data.

But, even though differences were not always statistically significant for the plot data, the trends paralleled the findings with satellite data and provide corroborative insight.

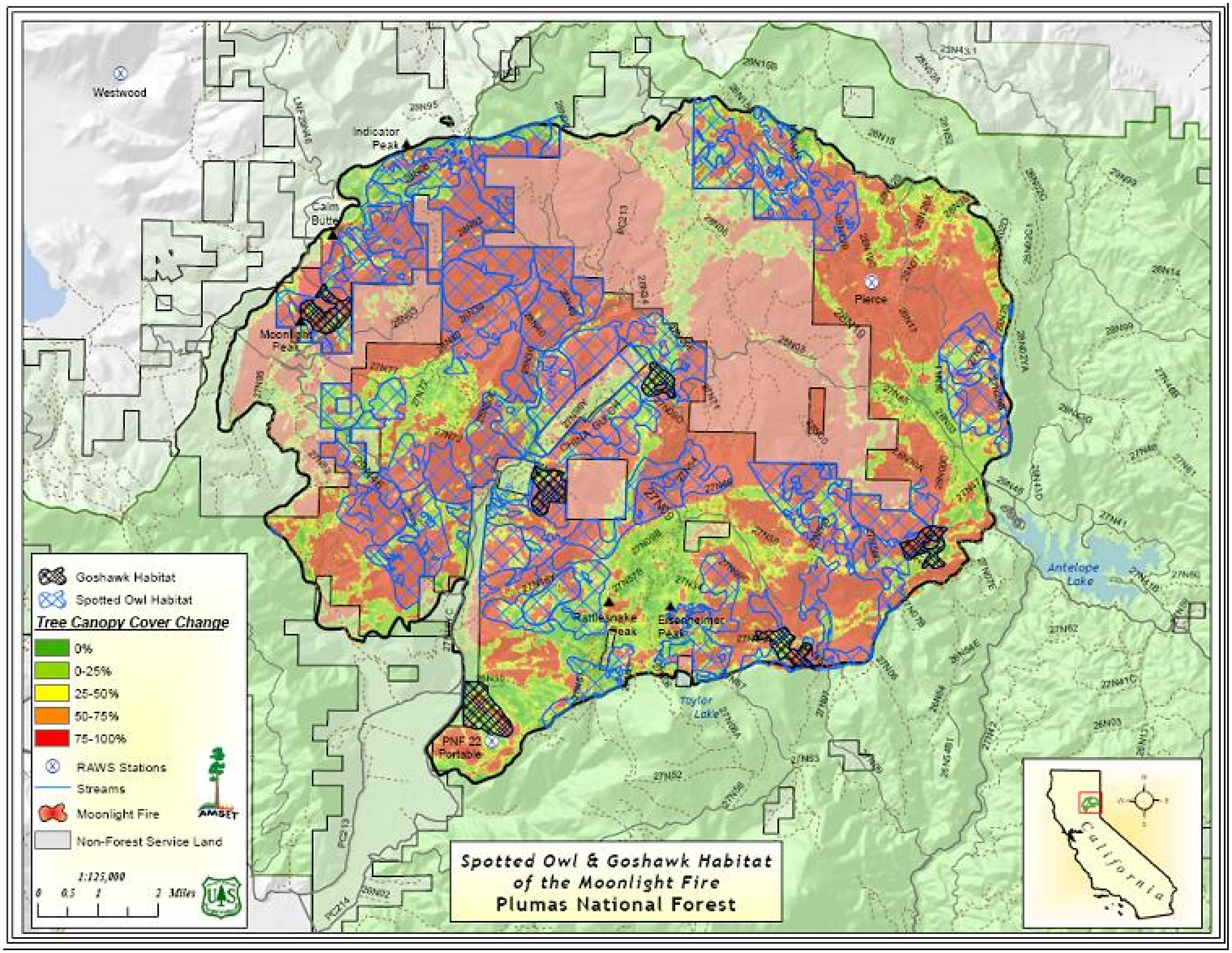


Figure 10 – Spotted owl and goshawk habitat. Canopy cover change derived from satellite data in the background.

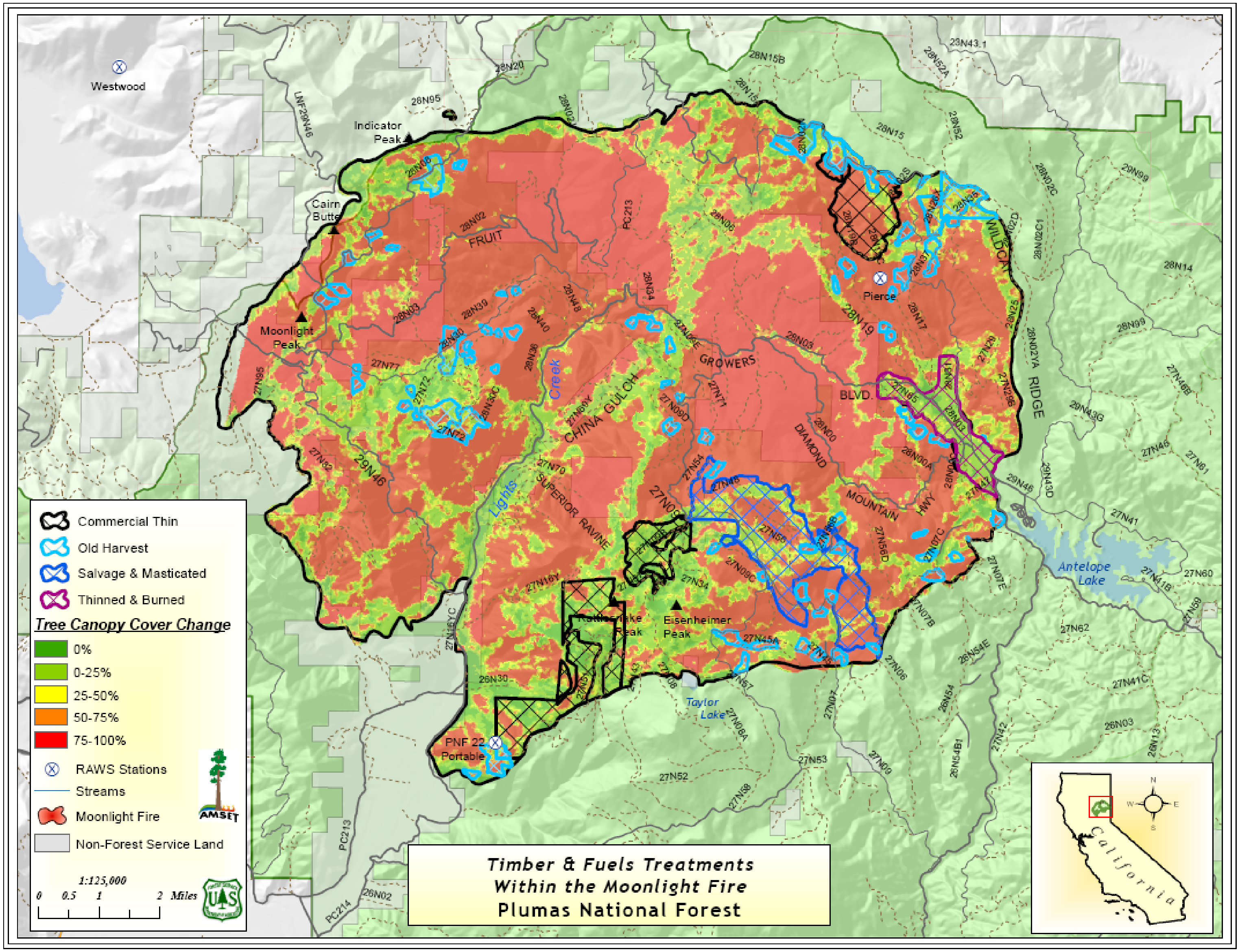


Figure 11 – Fuel treatment areas analyzed within the Moonlight Fire area. Canopy cover change derived from satellite data in the background.

Findings

Field Plot Data – Effects to Trees

Crown Consumption - Comparison Among Land Status Categories

Field plot data included the measurement of scorch[6] and torch[7] height. Statistical analysis showed that differences in scorch height among both land status categories and treatment types were not significant. Differences in torch height (crown consumption height) were found to be statistically significant. Therefore, crown consumption—as a percent of the total tree height—was used as a measure of effect to trees according to the field plot data collected.

Tree crown consumption is evidence of high fire intensity. High intensity surface fires can result in isolated crown consumption, including whole tree consumption of one to a few trees (tree torching). Tree crown consumption can also occur where the fire is carried through the tree crowns independent from the surface fire (crown fire).

Field plot data showed that treated areas had significantly lower levels of tree crown consumption—evidence of intense fire behavior, including crown fire—than untreated (Figure 12, Table B-3).

Because all land status categories exhibited a wide range in levels of crown consumption, multiple descriptive statistics are useful for comparing them. This analysis included the mean, median, and quartiles (25^{th} and 75^{th} percentiles).

Although differences were not statistically different between owl/goshawk habitat and other untreated or treated areas, median and mean values were greater. Mean crown consumption in owl/goshawk habitat were 35 percent, and 53 percent in untreated areas (Figure 13, Table B1), compared to a mean of 26 percent in treated areas.

Treated areas had significantly lower levels of tree crown consumption than untreated areas.

Treated areas had the lowest median value at 0 percent. This indicates that at least half of the treated plots that were measured had no crown consumption.

The wide range of crown consumption values within any given category could be due to any or all of the following factors which could affect fire severity: suppression activities, fuel loading, fuel moisture, weather conditions, and time of day burned.

[6] Scorch height on a tree is the highest mark of foliage discoloration due to heat or direct flame contact.
[7] Torch height on a tree is the highest mark of foliage consumption due to fire.

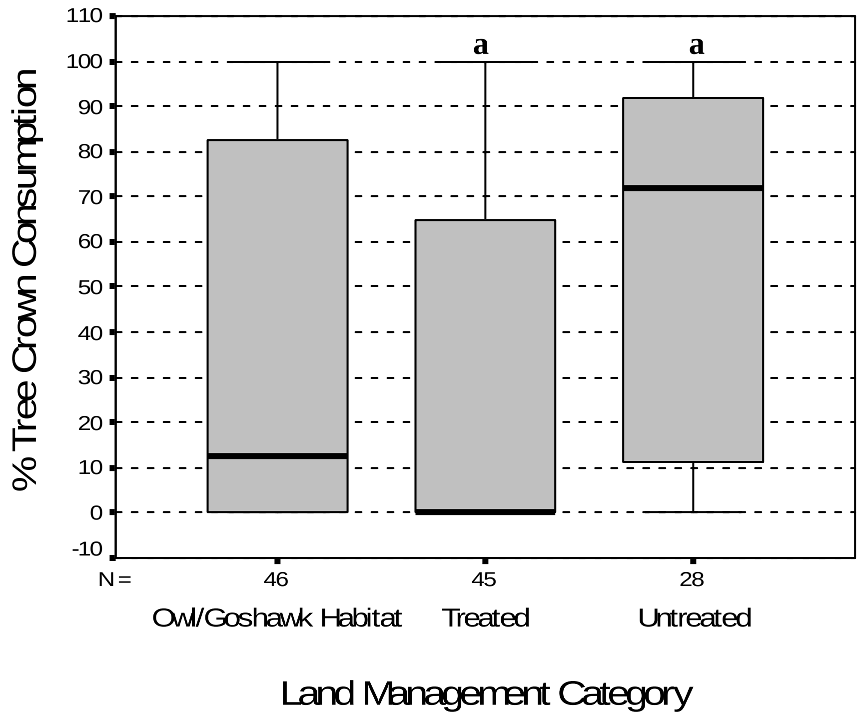


Figure 12 – Box plot of tree crown consumption by land management category: owl/goshawk habitat, treated areas, and untreated areas according to field plot data. The bold center line represents the median. Lower and upper box represents the 25th and 75th percentiles, respectively. Significant differences among categories are noted with letters above the bars. (a) p-value = 0.012, Bonferroni adjusted alpha = 0.017, significance at an experiment-wise error rate = 0.05.

Figure 13 – Variation of fire effects in owl/goshawk habitat.

Crown Consumption - Comparison Among Treatment Categories

Treatments included both silvicultural treatments as well as projects designed specifically for hazardous fuels reduction.

The silvicultural treatments included "old harvest" projects which occurred from 1983 through 1990 and commercial thin projects that occurred from 1991 to the present. These treatments were separated out for comparative purposes due to differences in silvicultural prescriptions that included a greater component of overstory removal for treatments occurring in the 1980s, and a greater market for biomass during the 1990s which allowed for increased removal of smaller understory trees.

Two areas within the Moonlight Fire boundary were treated specifically for hazardous fuel reduction in DFPZs. One was treated with a combination of thinning and prescribed fire[8], and the other was treated with both salvage and mastication[9].

Areas treated with thinning and prescribed burn had the lowest mean values of crown consumption at 11 percent (Table B4). However, the differences among the treatment types were not shown to be statistically significant (Figure 14, Table B6). This is possibly due to the lower sample sizes available from the field sampling. The difference between the thin/prescribed burn treatment and the other treatments was shown to be significant with the greater sampling that occurred for the satellite derived data (Figure 22, Table B15).

Thin/prescribed burn plots showed very little variation overall, having two outlier values, with the remaining 14 plots showing zero percent crown consumption. The lack of variation is possibly due to more uniform fuel conditions across the treatment area, but could also be related to consistency in suppression activity, topography, weather, or time of day when the burning occurred.

The reason for reduced fire behavior in the thinned/prescribed burn group is likely due to reductions in one or more of the key fuel components, including: ladder fuels, crown bulk density, and surface fuels. Surface fuel in the thinned/prescribed burn unit at the time of the fire was described as "very minimal, with 2 to 3 inches of litter".

Areas treated with mastication are useful during fire suppression because they reduce ladder fuels, thus reducing the chances for crown fire initiation. By reducing fuel bed depth, mastication can also reduce fire intensity, flame length, and rate of spread. The reduced flame lengths and rate of spread of fire following mastication is more likely to allow for direct attack in areas where it might not have otherwise been possible. However, high temperatures and longer residence time generated from increased surface fuel loading can kill trees by damaging cambium, roots, or crowns (Busse et al 2005, Knapp et al. 2006, Knapp et al. 2008).

Plots in areas treated with a combination of salvage and mastication and old harvest areas had greater mean values for canopy cover consumption at 37 percent and 35 percent reduction, respectively. All treated areas showed lower crown change than untreated sites, which had a mean value of 46 percent reduction. Salvage/masticate and old harvest treatments showed high levels of variation. However, both had median values of zero percent, indicating that at least half of plots sampled in those treated areas showed no crown change.

Untreated plots showed a wide range of crown consumption with values ranging from zero to 92 percent —for 25th and 75th percentile levels, respectively. The median value for crown consumption was also the highest for untreated plots, at 29 percent reduction.

[8] Most plots in the "thin and burn" group were located in the North Antelope treatment units.
[9] Most plots in the "salvage and masticate" group were in the Hungry treatment units.

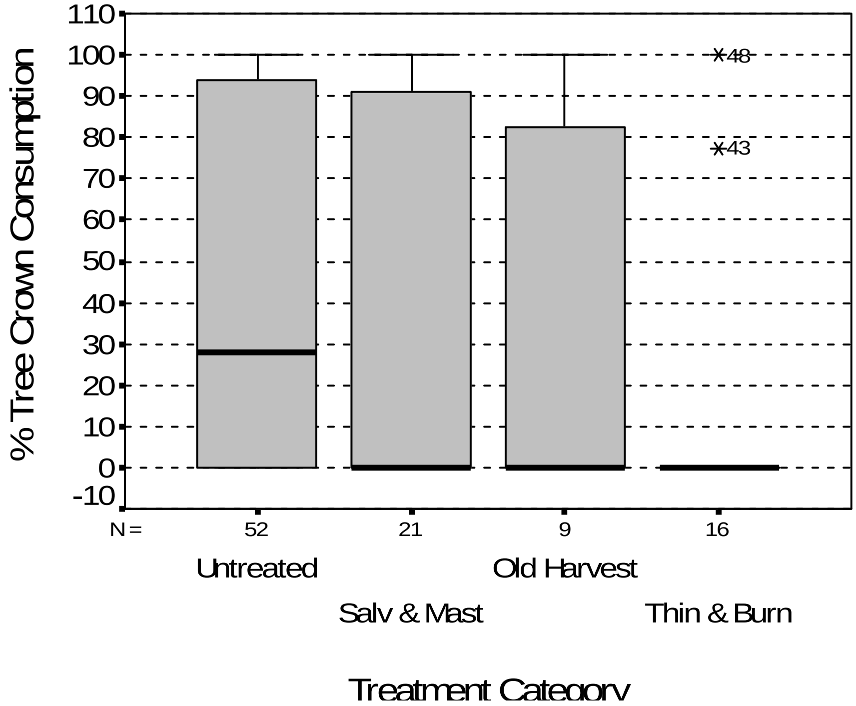


Figure 14 – Box plots of tree crown consumption by treatment category: untreated, salvage and masticate, old harvest, and thinned and prescribed burn areas according to field plot data. The bold center line represents the median. The lower and upper box represents the 25th and 75th percentiles, respectively. Differences between treatment categories were not shown to be statistically significant. Bonferroni adjusted alpha = 0.0083, significance at an experiment-wise error rate = 0.05.

Figure 15 – Variation of fire effects in untreated areas.

Figure 16 – Variation of fire effects in salvage and masticated units.

Figure 17 – Variation of fire effects in old harvest units.

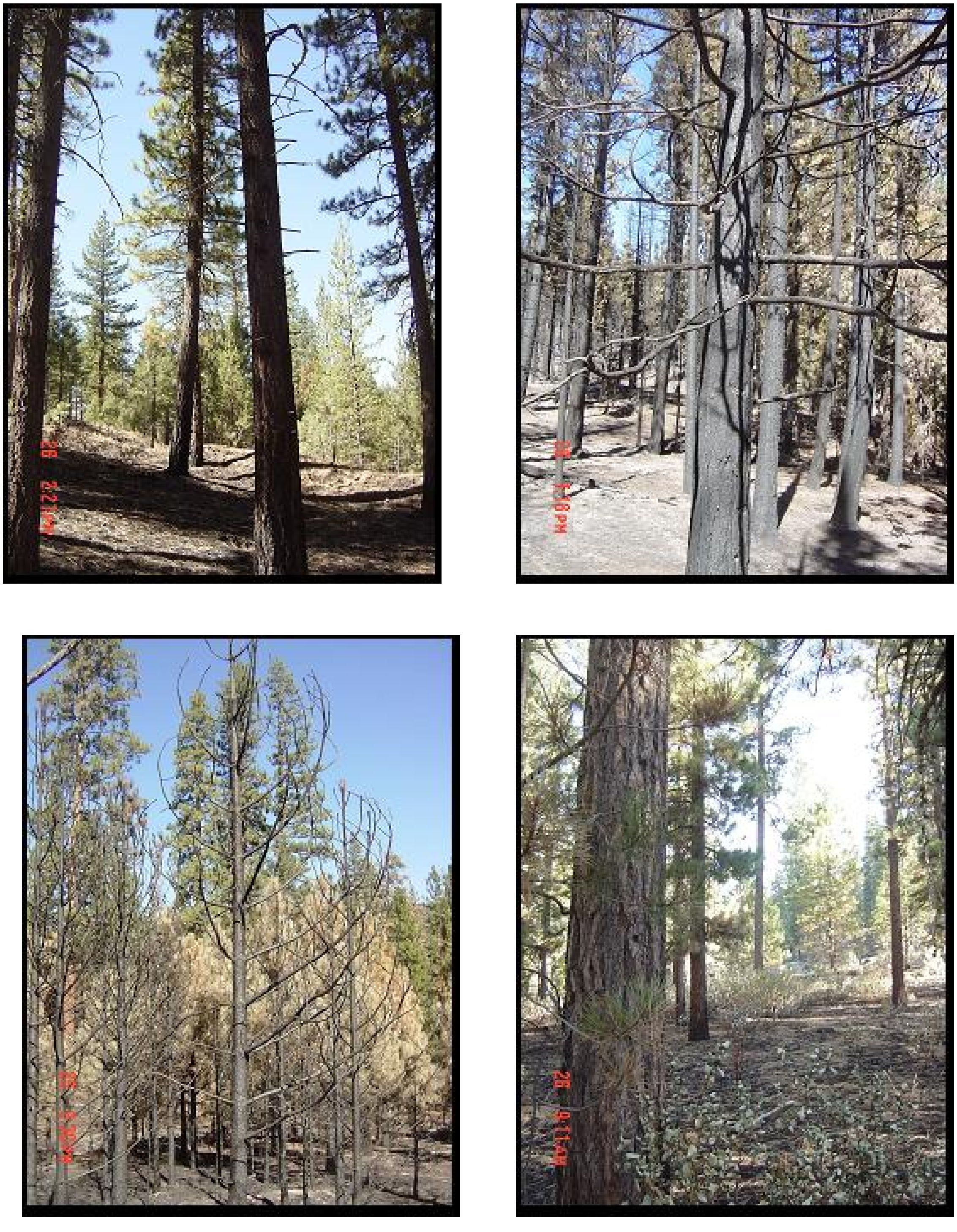


Figure 18 – Variation of fire effects in thinned and prescribed units.

Field Plot Data – Effects to Soils

Soil Severity - Comparison Among Land Status Categories

Field data on fire effects to soils was categorized into five levels of severity (Table 1). Differences among the land categories were statistically significant (Tables B8 and B9). Severity was greater in untreated areas and protected habitat and lower in treated areas and areas of recent wildfire (Stream Fire, 2001). Untreated and protected habitat areas had more than 75 percent of plots rated as high or very high soil severity (Figure19), while less than 50 percent of treated sites were rated as high or very high soil severity. Recently burned areas had the least number of sites with high or very high severity ratings—32 percent[10].

Soil effects from fire are dependent, in part, on surface fuel accumulations. Treated areas had various surface fuel accumulations, depending on treatment type and time since treatment. Some treatments increase surface fuels, such as mastication (Fites et al., 2007), increasing the potential for greater soil effects. The following section contains analyses of the differences in soil severity among different treatment types.

Soil Severity - Comparison Among Treatment Categories

Field data was collected on soil effects within treatment types. Thin and burn treatments revealed soil effects that were much less than all other treatment types (Figure 20). Combined salvage and mastication treatments had similarly high soils severity effects as untreated sites.

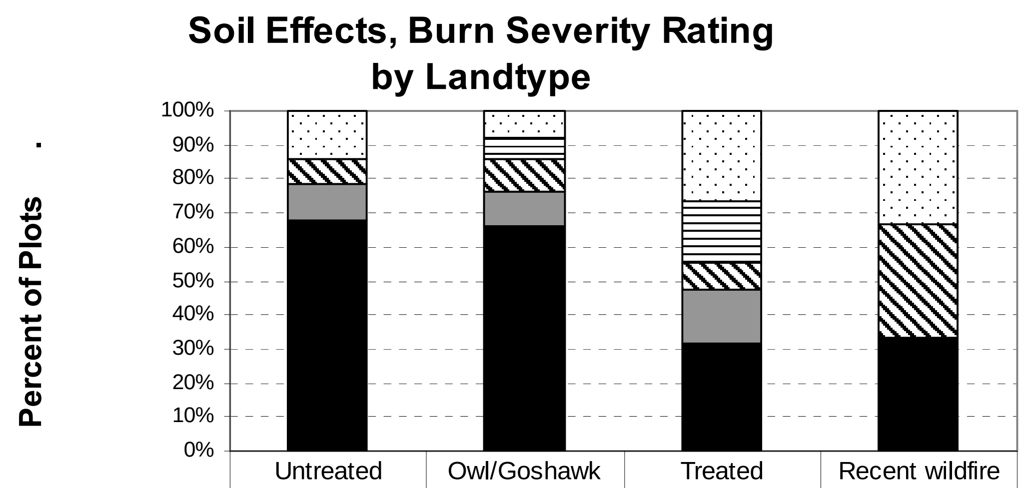
Combined "very high" and "high" ratings accounted for over 75 percent of both untreated and salvage/mastication plots. It should be noted that of the 21 plots analyzed for soil effects in salvage/mastication plots, 6 plots were located in untreated streamside management zones (SMZs) within the larger treated units. Of those 6 plots, 4 had very high effects, 1 was low, and 1 was very low.

Old harvest areas had combined "very high" and "high" severity in under 60 percent of the plots. Thin and prescribed burn treatments had a combined "very high" and "high" severity in less than 20 percent of the plots.

Soil effects in treatments are dependent on the type and volume of surface fuels that are present, as well as—because additional surface fuels will naturally accumulate following any treatment—the amount of time since the treatment occurred.

Depending on post-activity treatment of slash generated in timber harvest treatments, there can be large additions of surface fuels remaining in those areas. Hazardous fuel reduction treatments that include mastication will see increases in surface fuels. If these surface fuels do not have time to decompose prior to burning, they have the potential to increase the severity of fire effects on soils.

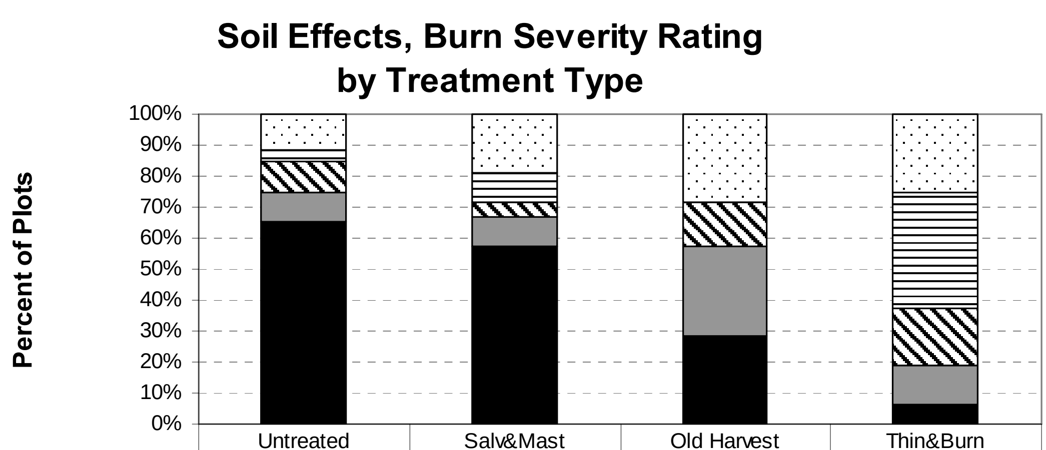
[10] Note that the sample size for the recent fire area is very small (n=3), making it difficult to say the results presented are representative.



	Untreated	Owl/Goshawk	Treated	Recent wildfire
Very Low Severity	4	4	10	1
Low		3	7	
Moderate	2	5	3	1
High	3	5	6	
Very High	19	33	12	1

Number of Plots per Land Category

Figure 19 – Burn severity rating for soil effects among land treatment categories.



	Untreated	Salv&Mast	Old Harvest	Thin&Burn
Very Low Severity	6	4	2	4
Low	2	2		6
Moderate	5	1	1	3
High	5	2	2	2
Very High	34	12	2	1

Number of Plots per Treatment Type

Figure 20 – Burn severity rating for soil effects among treatment categories.

Satellite Data – Effects to Trees

Changes in Tree Canopy Cover Among General Land Management Types

Random point data were attributed with treatment, habitat type, and topographic information (elevation, slope, aspect, slope position), as well as severity information from the satellite imagery. The severity data was a continuous rating from 0 to 100 percent—indicating low to high tree canopy cover change. A greater change in canopy cover signifies greater evidence of crown fire behavior.

Canopy cover change as reported for the satellite derived data is based on detected changes to vegetative foliage, including scorch as well as canopy consumption.

Canopy cover change was found to be significantly less in treated areas than both owl/goshawk protected activity centers (PACS) and owl/goshawk core areas[11]. Canopy cover change was also found to be significantly less in treated areas than in untreated areas (Figure 21, Table B15).

Differences among owl/goshawk PAC and core areas were not significantly different from each other, nor were recent fire areas compared to all other land management categories. However, mean and median values for recent fire areas show less canopy cover change than the owl/goshawk habitat areas and, also, less than untreated areas.

The mean value of canopy cover change for both owl/goshawk PACs and core areas was the same, 76 percent. Treated and recent fire areas had very similar mean values, 50 percent and 51 percent, respectively. Untreated areas had a mean canopy cover change of 65 percent.

The box plots for canopy cover change demonstrate the high level of variability in the data. The treated areas showed a great range of variability with 25th and 75th percentile values ranging from 8 percent to 100 percent.

In contrast, the owl/goshawk PAC and core areas showed far less variability than the other management types with 25th and 75th percentile values of 55 to 100 percent, and 60 to 100 percent, respectively.

Note that the median value for both the owl/goshawk habitat types were 100 percent—indicating that at least half of the plots had 100 percent canopy cover change.

[11] Owl and goshawk PACS were reported separately from core areas. This was done because core areas have higher standards for delineation. One might expect that these differences in vegetation structure could lead to differences in fire behavior and effects.

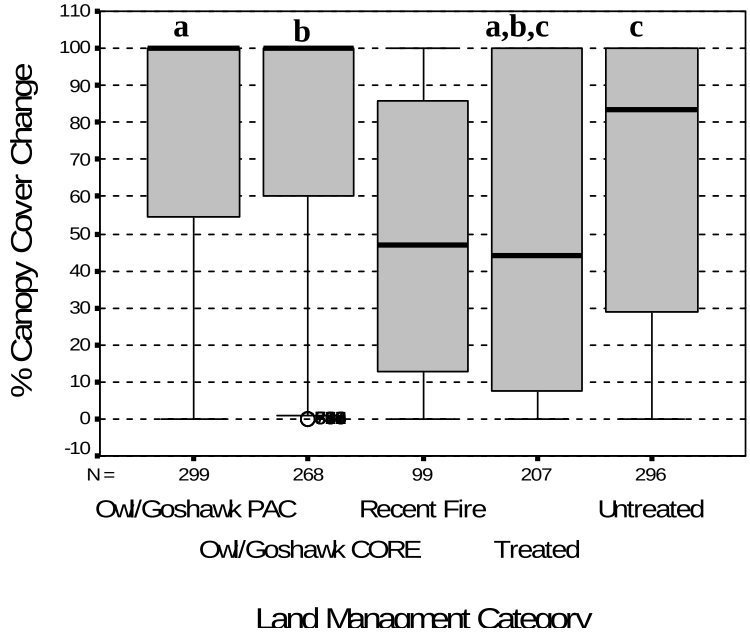


Figure 21 –Box plot of percent canopy cover change by land management category for randomly selected points from satellite derived data. Categories include: owl/goshawk habitat, recent fire areas, treated areas, and untreated. The bold center line represents the median. The lower and upper box represents the 25th and 75th percentiles, respectively. Significant differences among categories are noted with letters above the bars. (a, b, and c) p-values all < 0.0001. Bonferroni adjusted alpha = 0.005, significance at an experiment-wise error rate = 0.05.

Changes in Tree Canopy Cover Among Treatment Types

Overall, units that were treated with a combination of thinning and prescribed burn show significantly less canopy cover change than all other treatment types and untreated areas. It should be noted that the thin and burn type is the only treatment type compared which effectively reduces surface fuels. Units treated with a combination of salvage and mastication and old harvest units show canopy cover change similar to untreated areas. While commercial thin units were not significantly different than untreated, salvage/masticated, or old harvest, these areas did show wider variety in canopy cover change, including lesser change than those other areas.

Untreated and old harvest areas had the highest mean value for canopy cover change, both 71 percent (Table B16).

Salvage/masticated units were similar, with a mean value of 67 percent. Commercial thin units had a mean value of 46 percent.

Thin/prescribed burn units had the lowest mean canopy cover change of 12 percent.

Commercial thin areas showed the greatest variability with 25th and 75th percentile values of 1 to 98 percent. The median value was 40 percent. Untreated, salvage/masticated, and old harvest areas were similarly variable with 25th percentile values of 39, 32, and 38 percent, respectively—with 75th percentile values of 100 percent. Thin/burn values showed relatively little variability, with 25th and 75th percentile values of 2 and 11 percent, respectively.

The results of analysis for the thin/prescribed burn units were very similar to the field plot results, with mean values of 12 and 11 percent, respectively.

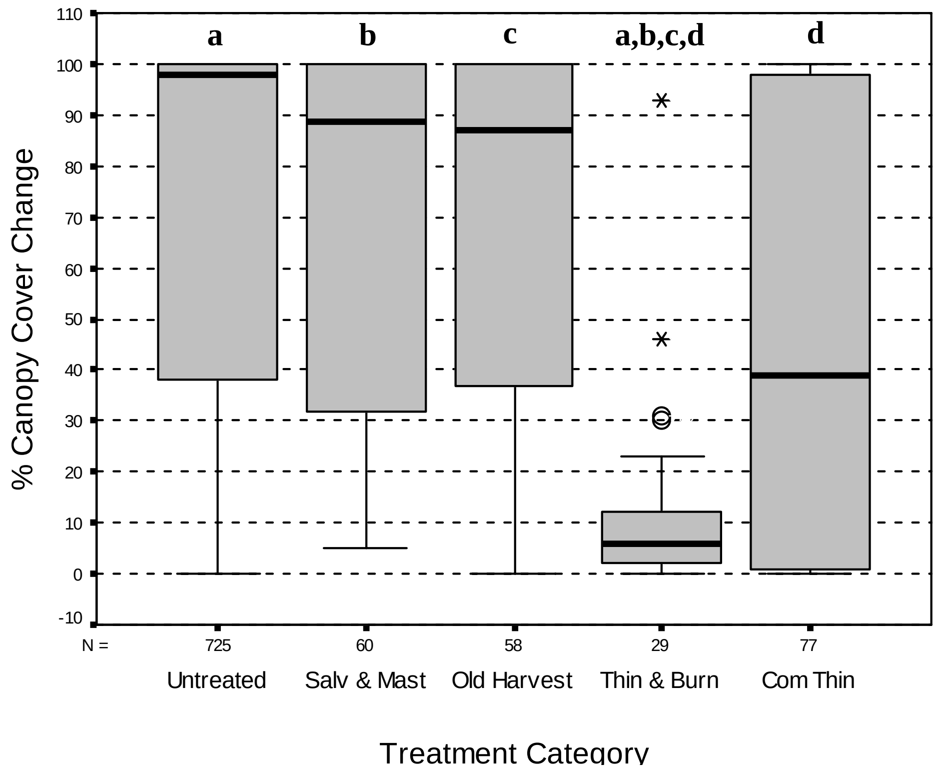


Figure 22 – Box plot of percent canopy cover change by treatment category for randomly selected points from satellite derived data. Categories include: untreated, salvage/mastication, old harvest, thin/burn, and commercial thin. The bold center line represents the median. The lower and upper box represents the 25th and 75th percentiles, respectively. Significant differences among categories are noted with letters above the bars. (a, b, c and d) p-values all < 0.0001. Bonferroni adjusted alpha = 0.005, significance at an experiment-wise error rate = 0.05.

Weather and Associated Fire Behavior Indices

Without question, weather is a key component influencing fire behavior and fire effects. Extreme fire weather conditions are most always present when intense and erratic fire behavior is exhibited—as occurred on the Moonlight Fire.

The weather values used in this report were gathered from three remote area weather stations (RAWS) located in the vicinity of the fire: Chester, Pierce, and Westwood (Tables C-1, C-2, and C-3). The values collected from these weather stations were averaged for analytical purposes.

On the first day of the fire, key weather components were in place for a fire to grow quickly. Maximum wind gusts were 22 mph, the minimum relative humidity (RH) was 7 percent, maximum temperature was 89 degrees (F), and 1-, 10-, and 100-hour fuel moistures were at 2, 3, and 6 percent. Herbaceous fuel moisture was 11.5 percent (Figures 23-30).

After the fire's first day, associating the key weather components with fire behavior (fire growth) becomes very complex. To highlight this point, the day with the greatest fire growth, September 5, was the day with the highest RH, 22 percent, and the lowest maximum temperature of 76 degrees (F). Winds were relatively strong, with maximum gusts at approximately 20 mph.

The remainder of the fire's days, fire growth defies correlation with weather and the moisture content of the smaller fuels. Statistical analysis showed no significance of weather fluctuations in relation to daily fire growth. There are some possible explanations for this finding.

One possible reason for lack of correlation between weather and fire growth is that the scale of fire growth, 24-hour increments, is too great for the finer-scale changes that occur in daily weather.

The next reason is that although there were a relatively high density of RAWS stations located in the fire vicinity, the greatest affect of variations in the weather on fire behavior were possibly seen on a more localized spatial scale.

Longer term dry conditions leading up to the fire cannot be ignored as being a very important factor in producing the high fire intensity and extreme fire behavior exhibited by the Moonlight Fire. The energy release component (ERC) index is based primarily on longer term fuel moisture levels. Because the ERC is based on a larger time scale (includes previous 7 days in calculations), it cannot be correlated well with daily fire behavior.

In the weeks leading up to the fire—as well as during the fire—ERC values were well above average, reaching 90th and 97th percentile conditions on several days before and during the fire. According to the Westwood RAWS station, there were five days that reached the maximum ERCs on record from 1998 to 2007 for the period of August 15th to September 15th (Figure 33).

Burning index (BI) values are based on some longer-term factors, including the ERC—as well as shorter term weather factors, including wind and relative humidity. BI was also well above average for most of the fire period, with two days showing maximum values for 1998 to 2007 (Figure 32). However, fluctuations in BI did not match fluctuations in fire growth (Figure 31).

Variation in wind speed (sustained winds and maximum wind gusts) was not shown to correlate with variation in fire growth. Maximum wind gusts, however, were relatively high throughout the fire, ranging from 14 to 24 mph.

Unstable air associated with the cold front contributed to cumulus buildup which caused erratic wind directions, with both updrafts and downdrafts. The unstable air also supported unusually large column development, which also generated its own strong and erratic winds. These winds are known to be very influential on fire behavior, but are present on relatively small time and spatial scales making them difficult to match to fire behavior at larger scales.

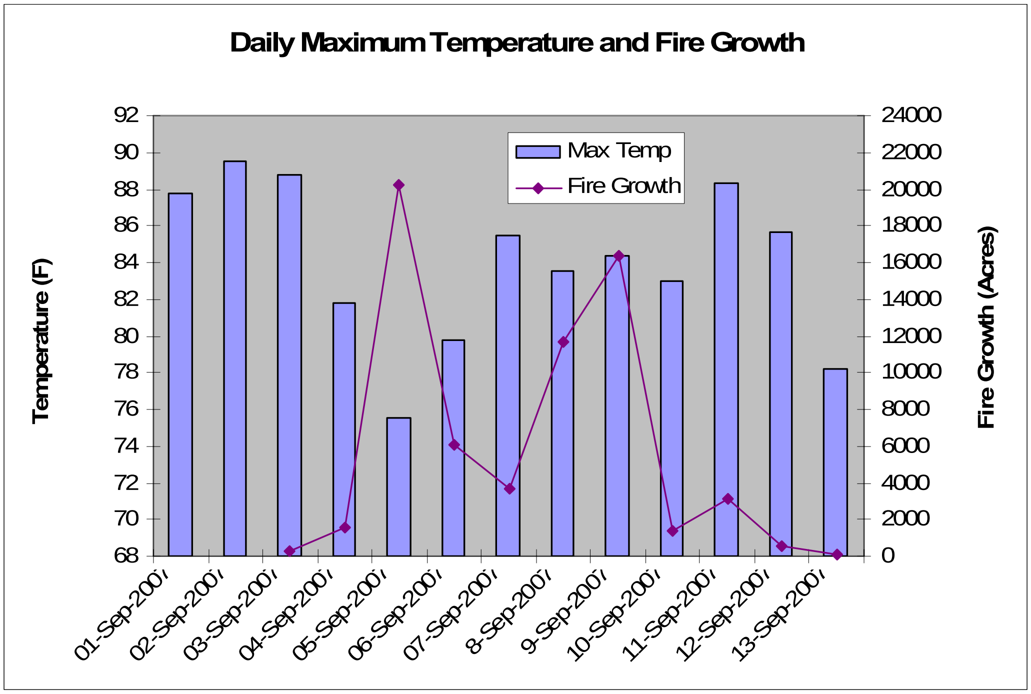


Figure 23 – Daily fire growth (acres) and daily maximum temperature (Fahrenheit). Temperature values are the mean value for the Chester, Pierce and Westwood RAWS stations.

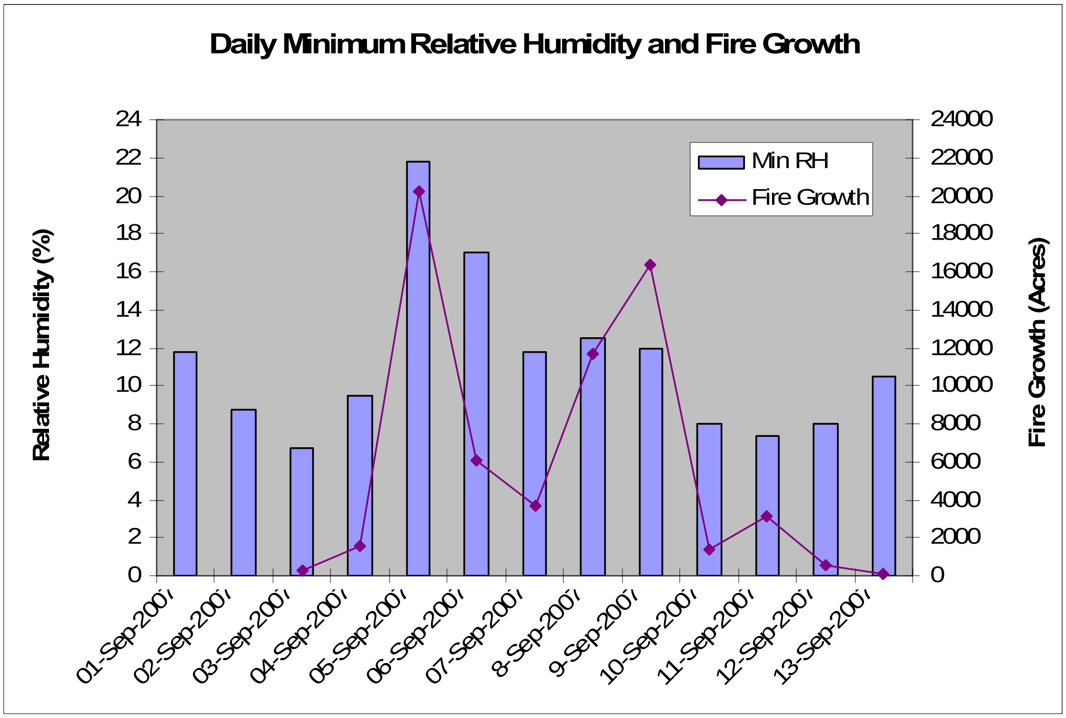


Figure 24 – Daily fire growth (acres) and daily minimum percent relative humidity. Relative humidity values are the mean value for the Chester, Pierce and Westwood RAWS stations.

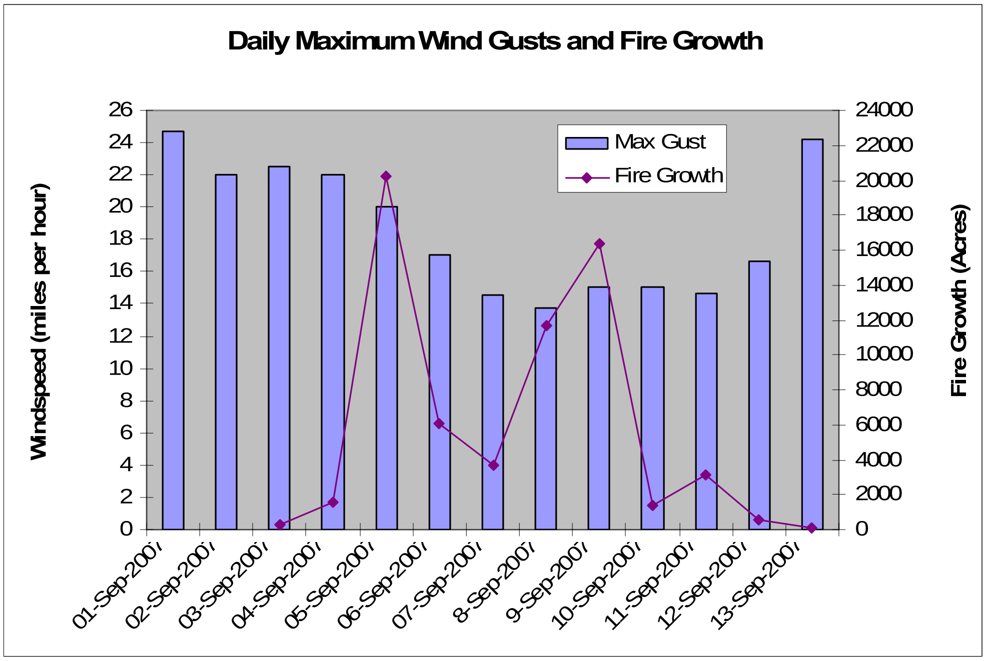


Figure 25 – Daily fire growth (acres) and daily maximum wind gust (mph). Maximum wind gust values are the mean value for the Chester, Pierce and Westwood RAWS stations.

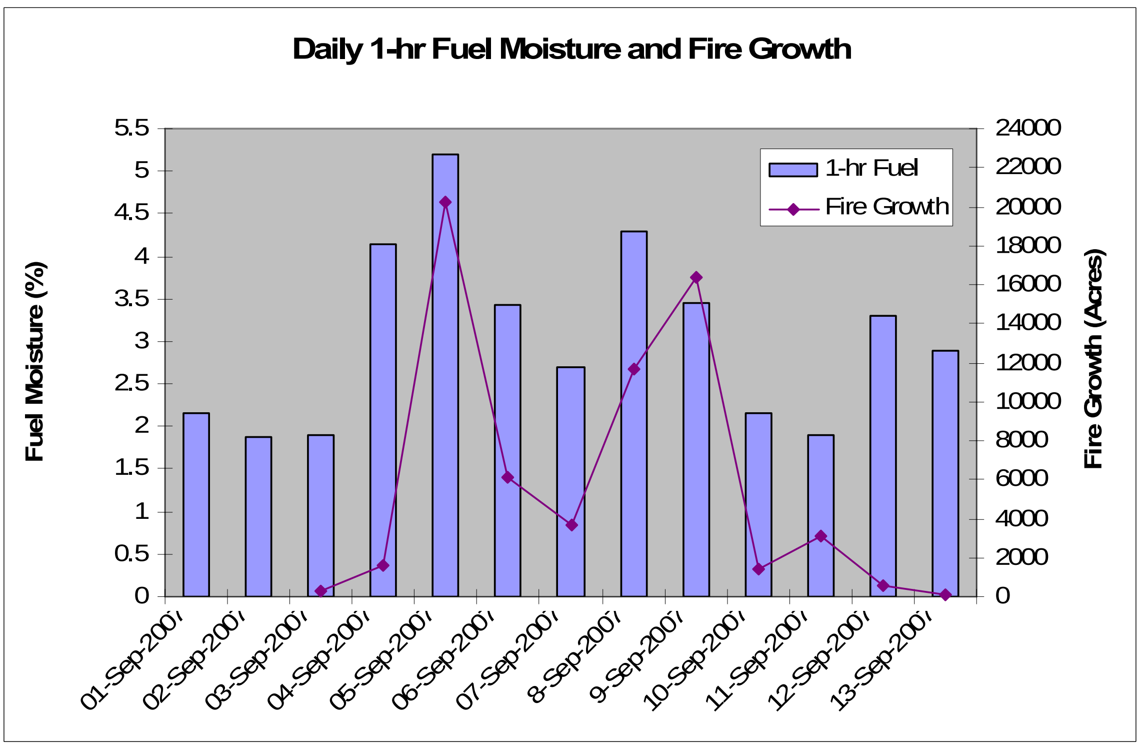


Figure 26 – Daily fire growth (acres) and daily 1-hour fuel moistures. Fuel moisture values are the mean value for the Chester, Pierce and Westwood RAWS stations.

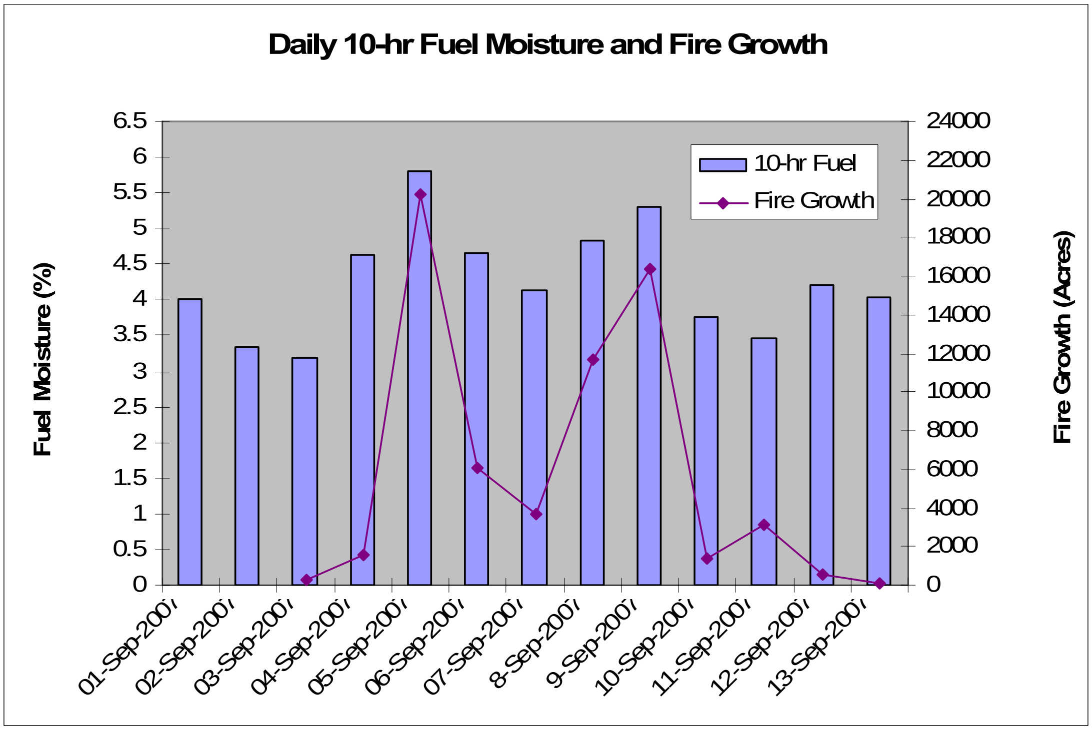


Figure 27 – Daily fire growth (acres) and daily 10-hour fuel moistures. Fuel moisture values are the mean value for the Chester, Pierce and Westwood RAWS stations.

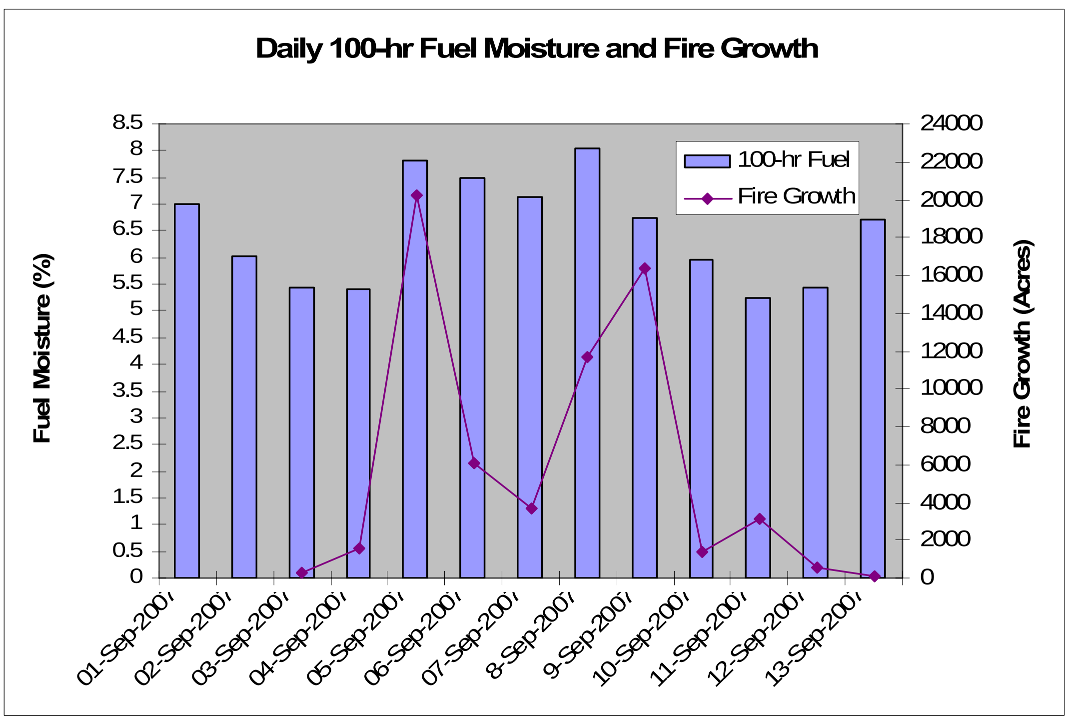


Figure 28 – Daily fire growth (acres) and daily 100-hour fuel moistures. Fuel moisture values are the mean value for the Chester, Pierce and Westwood RAWS stations.

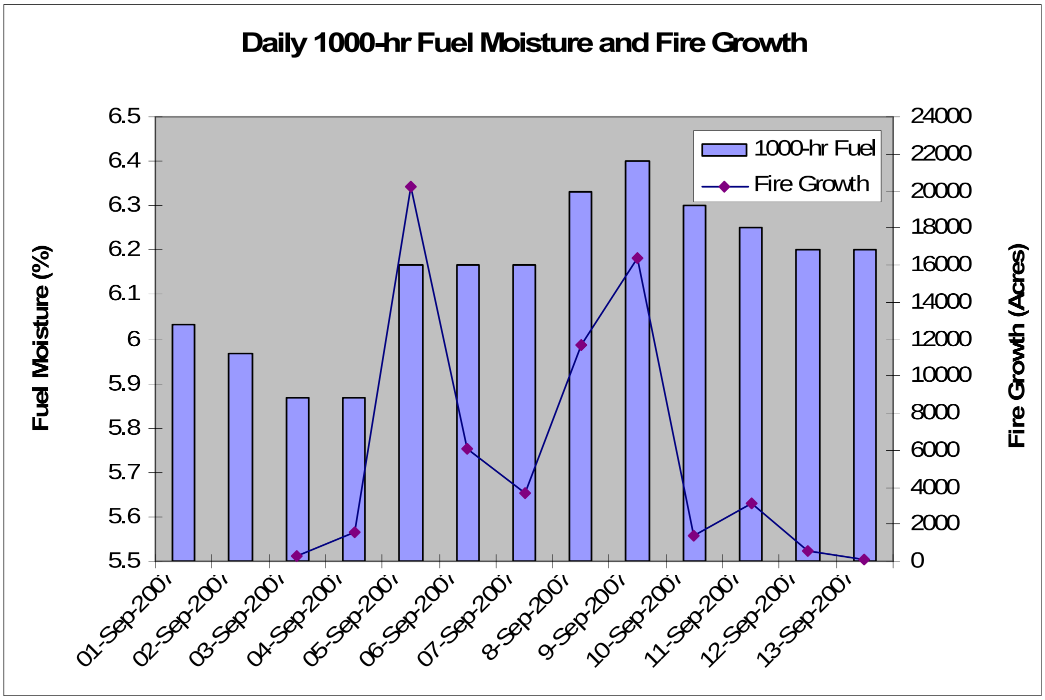


Figure 29 – Daily fire growth (acres) and daily 1000-hour fuel moistures. Fuel moisture values are the mean value for the Chester, Pierce and Westwood RAWS stations.

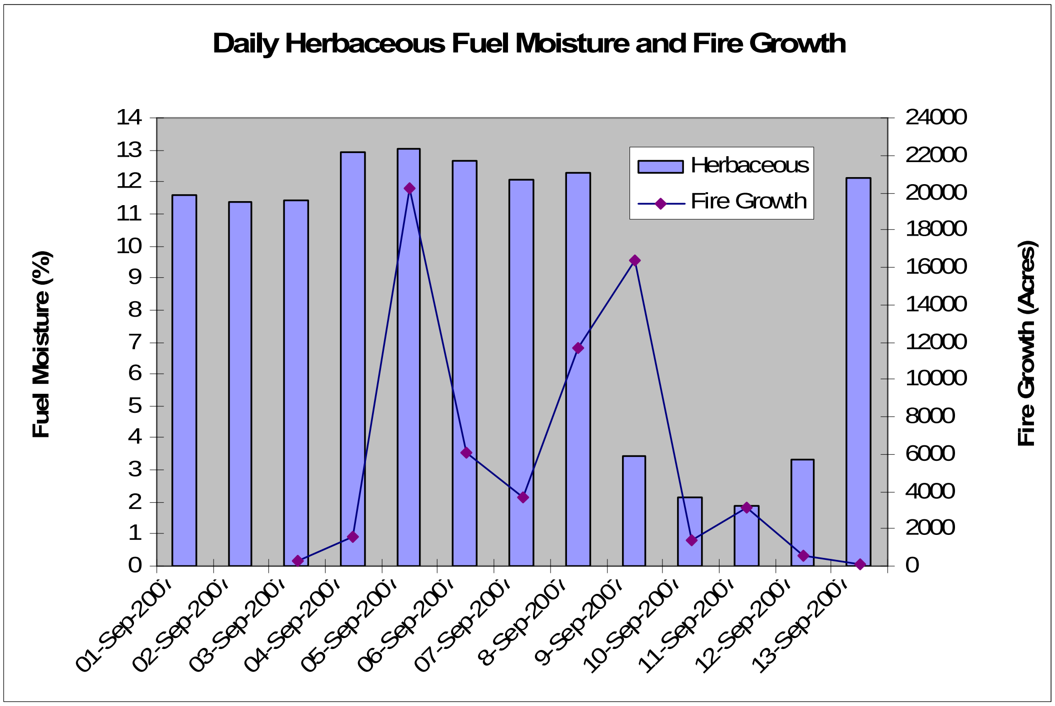


Figure 30 – Daily fire growth (acres) and daily herbaceous fuel moistures. Herbaceous fuel moisture values are the mean value for the Chester, Pierce and Westwood RAWS stations.

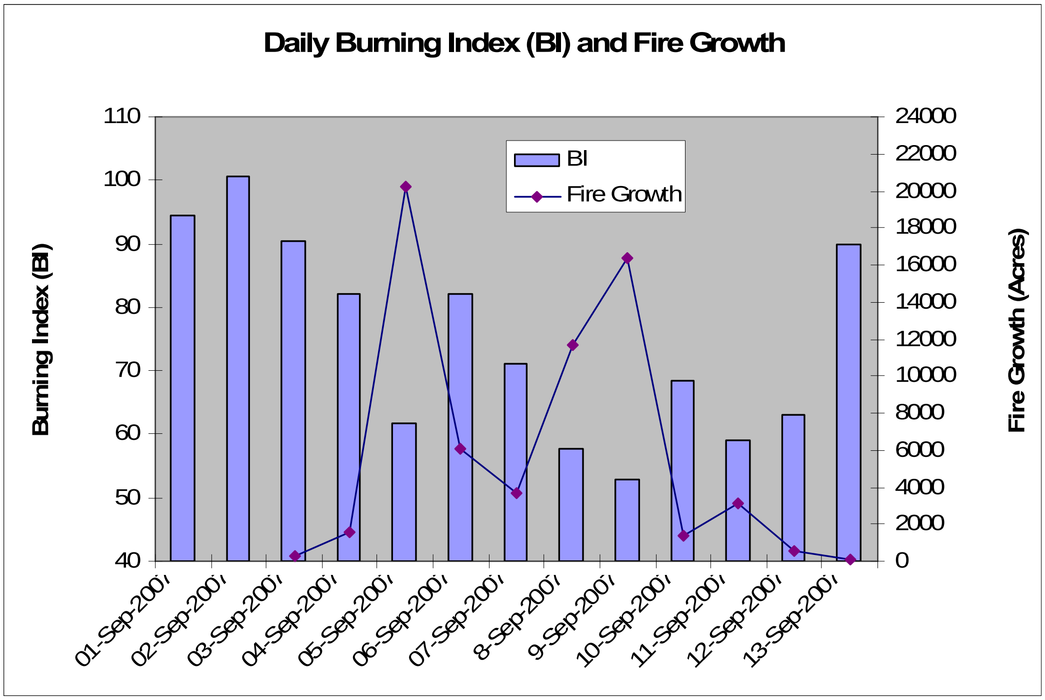


Figure 31 – Daily fire growth (acres) and Burning Index (BI). Burning index values are the mean value for the Chester, Pierce and Westwood RAWS stations

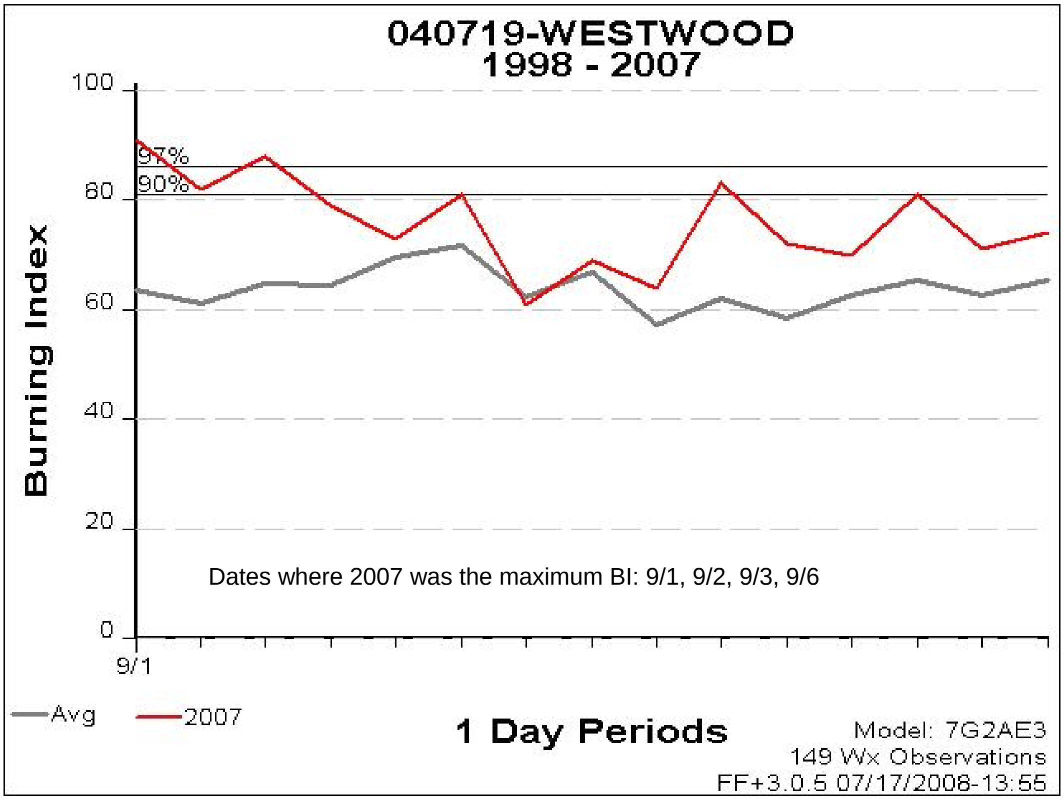


Figure 32 – Burning Index (BI) for the period from September 1, to September 15, 2007.

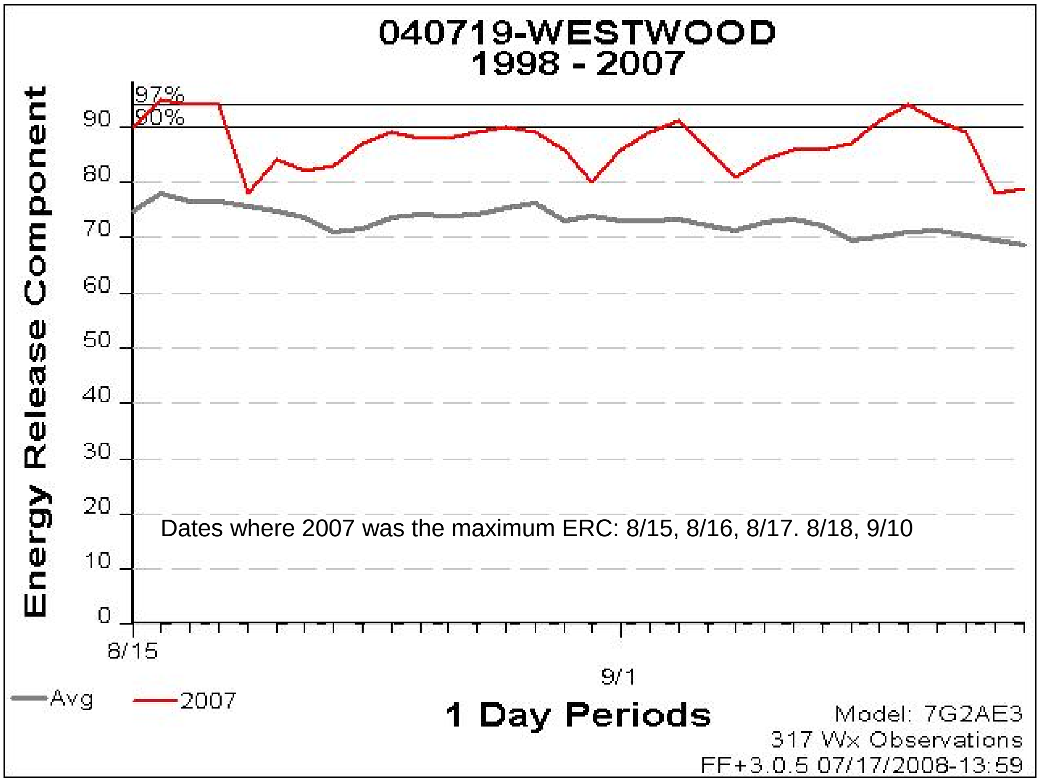


Figure 33 – Energy Release Component (ERC) for the period from August 15, to September 15, 2007.

IV CONCLUSION

This post-fire assessment of the Moonlight Fire provides the opportunity to quantify the effects of a high intensity, plume-dominated wildfire on treated areas, untreated areas, and those areas protected for Spotted Owl and Goshawk habitat.

Treated areas, including timber harvest prescriptions and hazardous fuel reduction treatments, are often utilized by fire suppression forces to assist in controlling wildfires. According to firefighters who were on the ground during the Moonlight Fire, areas treated for hazardous fuel reductions were effective in reducing fire behavior from crown to surface fires. This effect on fire behavior allowed the initiation of direct attack. However, under the extreme conditions that the moonlight fire burned, crews were not always able to effectively use treated areas to stop the fire.

The Antelope Complex Fire—with similar terrain, fuels, and weather conditions—occurred directly adjacent to the Moonlight Fire's area earlier the same year (2007). More extensive placement of treatment units within the Antelope Complex Fire area allowed for greater success in utilizing those treatments during fire suppression. Large untreated areas on the Antelope Complex Fire were observed to allow a buildup of momentum and an increase in the fire's rate of spread and intensity (Fites et al. 2007). Where a similar buildup of momentum occurred, suppression effectiveness in DFPZs was limited—just as it was on the Moonlight Fire. However, on the Antelope Complex, there were other DFPZs nearby that *were* able to be used effectively. On both fires, DFPZs were effective in reducing fire effects.

As part of the larger matrix of untreated fuels, protected habitat adds to the development of plume-dominated fires. This effect contributes to extreme fire behavior that can result in widespread areas of high severity effects.

A high number of owl nest stands and core habitat burned at high severity during the Moonlight Fire. These fire effects will likely pose negative effects to at least a portion of the owls who survived the fire. Fewer goshawk nest stands were located in the fire area. However, potential negative effects are still possible to this species.

It is therefore recommended that fuels be reduced inside these habitat areas to:

- ❖ Reduce the severity of fire effects to protected habitat,
- ❖ Increase the effectiveness of treatment units for suppression needs, and
- ❖ Help minimize widespread high severity effects across the adjoining landscape.

This recommendation does not necessarily mean that entire home ranges need to be treated, or treated intensely. The old growth trees and snags favored for nests are key habitat elements. It is clear that doing nothing is not effective in reducing the likelihood of high-severity fire that can reduce habitat suitability for a full century or more.

Key Findings

- The Moonlight Fire burned through 22 owl PACS, 25 owl core areas, and 7 goshawk core areas. Within owl PACS, 64 percent of the total acreage had 75 to 100 percent canopy cover change (reduction). Within owl core areas, 68 percent of the total acreage had 75 to 100 percent canopy cover change. Within goshawk core areas, 46 percent of the total acreage had 75 to 100 percent canopy cover change. It is possible that the degree of canopy cover change resulting from this event will have limiting affects on the utility of this area as viable owl and goshawk habitat.
- Fire behavior was more intense with higher canopy cover crown change (reduction) in untreated areas, including protected owl/goshawk habitat, compared to treated areas. Areas treated with a combination thinning/prescribed burning showed the greatest ability to reduce burning intensity.
- Although tree crown change (reduction) in untreated areas protected as owl/goshawk habitat was not statistically different from other treated areas, the data illustrates a strong trend toward greater crown consumption in untreated areas protected as owl/goshawk habitat.
- Defensible fuel profile zones (DFPZs) were used for suppression efforts, but there was not a sufficient density to provide effective use on many parts of the fire. This is in contrast to the Antelope Complex Fire that occurred adjacent to the Moonlight Fire, where a high proportion of the fire's area had been treated for fuel hazard reduction. In at least one instance on the Antelope Fire, crews experienced intense fire behavior in a treated area and were able to utilize other nearby treated areas for effective fire suppression.
- Similar to the Antelope Complex Fire, on several occasions the fire exhibited intense fire behavior, including the observation of plume-dominated fire. Accelerated rates of spread were observed in association with the formation of a convective heat-induced smoke column. In addition to extremely dry conditions and unstable atmospheric conditions associated with the passing of a cold front, this fire behavior was possibly associated with large areas of untreated fuels.

Recommendations

- Consider the use of more fuel treatments which reduce surface fuels, including prescribed fire.
- Consider treating larger portions of landscape to effectively reduce the likelihood of fires gaining momentum and increasing in intensity to a point where fuel treatments and suppression efforts become ineffective.
- Consider watershed-scale prescribed burns to reduce fuels across more acreage, particularly in steeper ground and sensitive areas where other treatment options are limited.
- Consider placing a larger number of fuel treatments across the landscape to provide suppression forces with fuels conditions advantageous to fire control, including more options for contingency lines.
- Consider treating in or around protected areas to enable these sites to withstand fire with lesser effects. Treating these areas could also reduce the chance of these sites contributing to increased fire behavior in the adjacent landscape.

V APPENDICES

Appendix A – Plot Sampling and Protocol

Data was collected after the Moonlight Fire between September and October 2007. Treatment areas, Owl/goshawk habitat, and fire history information was gathered to determine how and where sampling would occur. Plots were assigned using a stratified random approach. Plots were placed in all known and accessible treated areas and protected habitat areas. Because of salvage logging operations, several smaller areas of the fire were not accessible.

For both treated and untreated areas, the majority of sampling was conducted where there was road access for time-efficient sampling. The influence of roads on fire behavior evidence and effects was avoided where observed. Plots were placed at both even and randomly selected intervals along roads, depending on the length of the road and whether or not a treatment had occurred. Where treatments occurred, plots were placed at a distance of 0.5 mile along the road— beginning at the edge of the land status or treatment type where the road first crossed. In untreated areas, plots were placed at pre-determined distances, every 0.6-1.0 miles along the road. Plot center points were located by moving at right angles from the road at randomly determined distances at least 500-feet from the road. To obtain plots in spotted owl PACs, some plots were located well beyond 500 feet from roads, at randomly determined distances.

Information Gathered at Each Plot

The location of each plot was recorded with GPS that could be corrected to less than 1m accuracy. We took a photo facing north. For trees, we utilized a point-center-quarter sample (Mueller-Dombois and Ellenberg 1974) where the nearest tree in each cardinal direction quadrant is sampled. For each tree, we recorded:

- Species,
- An ocular estimate of the percent crown change,
- An ocular estimate of percent crown scorch, and
- Measured tree height and height to live crown[12] prior to the fire (using an impulse laser to the nearest 0.1m).

For understory vegetation and soil effects, we utilized the National Park Service severity rating system (NPS 2003) which consists of a five-category subjective rating. This rating was determined occularly within a 20-foot radius area.

[12] Height to live crown estimations were based on available evidence indicating where that would have existed prior to the fire. Evidence included recently killed branches, remnant foliage, and the presence of needle freeze.

Appendix B – Statistical Analysis

Two different analyses were conducted that used:

1. Plot data, and
2. Satellite-derived severity mapping data.

For each data set, two different questions were addressed:

1. How did evidence of fire behavior and effects (tree torch for both, and soils for plot data) differ between broad categories of land status, including: owl and goshawk habitat, recent wildfires, treated areas, and untreated areas?
2. How did evidence of fire behavior and effects (tree torch for both, and soils for plot data) differ between specific types of treatment, including: salvage and masticate, old harvest (1980-1990), thin and burn, and commercial thin.

Null Hypothesis:

1. There were no differences in fire effects between broad categories of land status.
2. There were no differences in fire effects between specific types of treatment.

In this analysis, depending on data type, both general linear model (GLM) procedures (McCullouch and Searle 2001) and cross-tabulation based Chi-Square tests were used. Continuous data including crown change or satellite indices were analyzed using the GLM procedures. Ordinal data (such as soil severity ratings) were analyzed using the Chi-Square tests. The percent crown consumption (torch) from the plot data and the crown cover percent (CC) for the satellite data were analyzed by fitting General Linear Models for normally distributed residuals (Neter and Wasserman, 1974). Exploratory analyses were conducted to determine explanatory variables using the AIC criterion (Burnham and Anderson, 1998). In addition, the distributions of the residuals of the explanatory variables were explored using Wood (2006). The statistical models are as follows:

Plot Data

For land status:

$$\text{Torch}_{il} = a + TLS_l + \sum_{k=1}^{K} b_k \text{S}_{ik} + error_{il} \quad (1)$$

For vegetation (silvicultural) treatment:

$$\text{Torch}_{iv} = a + TVT_v + \sum_{k=1}^{K} b_k \text{S}_{ik} + error_{iv} \quad (2)$$

Satellite Data

For land status:

$$\text{CC}_{iv} = a + CCLST_v + \sum_{k} bb_k \text{S}_{ik} + f(TPOS_i) + g(ELEV_i) + h(TMPMAX_i) + r_1 * PCO_i + error_{iv} \quad (3)$$

For vegetation (silvicultural) treatment:

$$CC_{iv} = a + CCVT_l + \sum_k bb_k S_{ik} + f(TPOS_i) + g(ELEV_i) + h(TMPMAX_i) + s(PCO_i) + error_{iv} \quad (4)$$

Notation Description

Responses:
$Torch_{il}$= tree crown consumption percent for land status *l*, *l*=1 (Owl/Goshawk Habitat), 2 (treated), and 3 (untreated) for tree *i*.
$Torch_{iv}$= tree crown consumption percent for vegetation treatment *v*, *v*=1 (untreated), 2 (salv and mast), 3 (old harvest), 4 (thin and burn) for tree *i*.

CC_{il}= crown cover percent for land status *l*, *l*=1 (PAC), 2 (CORE), 3 (old fire) , 4 (treated), 5 (untreated) for random point *i*.
CC_{iv}= crown cover percent for vegetation treatment *v*, *v*=1 (untreated), 2 (salv and mast), 3 (old harvest), 4 (thin and burn) for random point *i*.
Explanatory variables:

TLS_l =land status effect *l* for torch response.
TVT_v =vegetation treatment effect *v* for torch response.
SLS_l =land status effect *l* for scorch response.
SVT_v =vegetation treatment effect *v* for scorch response.
$CCLS_l$ =land status effect *l* for CC response.
$CCVT_v$ =vegetation treatment effect *v* for CC response.

S_{ik} = spatial term *k*, *k*=1,2,…,*K* (*K*=8 for plot data, and *K*=15 for satellite data), function of the GIS X-Y coordinates obtained by the spatial smoothing tensor product for tree *i* (or random point *i*) to account for the spatial autocorrelation. These spatial terms were calculated by R Generalized Additive Model (GAM) mgcv-routine (R 2008; Wood, 2006).
$f(TPOS)_i$ = third degree polynomial of topographic position for random point *i*.
$g(ELEV)_i$=second or third degree polynomial of elevation for random point *i*.
$h(TMPMAX)_i$ = third degree polynomial of maximum temperature for random point *i*.
PCO_i=pre-fire tree cover for random point *i*.
$s(PCO)_i$ = third degree polynomial of pre-fire tree cover for random point *i*.
$error_{il}$ or $error_{iv}$ = residual error assumed Standard Normally distributed.

The parameters *a*, TLS_l , TVT_v, SLS_l, SVT_v, $CCLS_l$, $CCVT_v$, b_k, bb_k and the third degree polynomials' coefficients (t_1, t_2, t_3, e_1, e_2, e_3, x_1, x_2, x_3, r_1, r_2, r_3) were estimated by the SAS GLM procedure (SAS v. 9.1.3) for each of the corresponding equations. The multiple means' comparisons of the land status levels, vegetation treatment levels and maximum wind levels were tested by the *t*-test using the Bonferroni's approach (Miller 1981), to achieve an experiment-wise error rate=0.05. The residuals' autocorrelation was assessed using Semi-variogram by the geoR package (Diggle and Ribeiro, 2007). The normality of the residuals was assessed by diagnostic checks such as QQ-plots and histograms (Wood, 2006).

For the field plot data, no significant differences existed between the indices (crown consumption, or crown change) for topographic position, elevation, aspect, maximum daily wind gusts, minimum daily relative humidity, maximum temperature, year since treatment, and pre-fire tree cover. The spatial component was found to be significant, and therefore the spatial component and the treatment effects were included in the General Linear model for testing the significance of the treatments.

The satellite data response BARC was analyzed with the same statistical models and estimating techniques as used for the plot data crown scorch response. However, for this response, the following second degree polynomial variables were included in the statistical model as well: land type, treatment type, spatial effects, and a topographic position. The Akaike AIC criterion (Burnham and Anderson, 2002) was used to select the explanatory variables for the final statistical model. Topographic position was derived from a continuous index of position in the landscape calculated with ARC-GIS and DEM data.

Data for the GLM was derived from random pixel selections, stratified by the land status categories. To generate the data for the GLM, random points for each land use category were selected using GRID programming in GIS. A target of 300 points for each category was made. The actual selections varied from 288 to 300 per category.

Chi-Square Procedures for Analysis of Soil Effects

Soil severity was analyzed with a GLM, where land type, treatment type, and a spatial component (to account for the spatial autocorrelation) were fixed effects. Land status type and treatment type were applied as a binary variable. Eight indices (topographic position, elevation, aspect, maximum daily wind gusts, minimum daily relative humidity, maximum temperature, year since treatment, and pre-fire tree cover) were analyzed using a Chi-Square test in a cross-tabulation procedure. A Generalized Additive Model (GAM) was applied to extract the spatial component (Wood, 2006). The spatial component was estimated using with R-mgcv spline smoother (R 6.2.1, 2008). The pair-wise comparisons were done with the SAS GLM procedure (SAS v.9.1.3, 2003). The Bonferroni approach was used for the post-hoc tests of the pair-wise differences between how individual land type and treatment type interacted with tree torch and soil severity.

Results – Field Plot Data

Crown Consumption - Comparison Among
Land Status Categories for Field Plot Data

Post-hoc comparisons among categories showed that only differences between treated and untreated areas were statistically significant. Untreated areas had significantly greater tree crown consumption compared to treated areas (Table B3).

The raw data estimated treatment means for plot data are in Table B1; the estimated coefficients for plot data are shown in Tables B2; the pair-wise comparison tests are shown in Table B3.

Table B1 – Crown Consumption. Raw data means with standard error for each Land Status in percent.

Land status	# Obs.	Mean	Standard Error
Owl/Goshawk Habitat	46	35.3	8.3
Treated	45	25.9	6.0
Untreated	28	52.5	7.9

Table B2 - Parameter estimates for model with Land Status for the Crown Consumption response.

Explanatory Variable	Parameter	Parameter Estimate	P-value
Intercept	a	18.96074	0.490
S_1	b_1	4.8	0.840
S_2	b_2	-22.3	0.518
S_3	b_3	41.4	0.187
S_4	b_4	70.2	0.166
S_5	b_5	12.8	0.576
S_6	b_6	7.2	0.919
S_8	b_7	-1.6	0.953
S_8	b_8	148.3	0.011
Owl/Goshawk Habitat	TLS_1	21.5	0.439
Treated	TLS_2	3.2	0.912
Untreated	TLS_3	30.0	0.306

Table B3 – Pair-wise comparisons of Land Status levels for the Crown Consumption response. Negative values in the Estimate column indicate that the value of the second type is greater than the first.

Comparison	Estimate	P-value	Bonferroni adjusted α	Significance at an experiment-wise error rate=0.05
Treated vs Untreated	**-26.8**	**0.012**	**0.017**	**Yes**
Treated vs Owl/Ghawk	-18.3	0.060	0.017	No
Untreated vs Owl/Ghawk	8.5	0.446	0.017	No

Crown Consumption - Comparison Among Treatment Categories for Field Plot Data

Individual comparisons amongst treatment types were not significant (Table B6).

The raw data estimated treatment means for plot data are in Table B4; the estimated coefficients for plot data are shown in Tables B5; and the pair-wise comparisons' tests are shown in Table B6.

Table B4– Crown Consumption. Raw data means with standard error for each Treatment Type in percent.

Land Status	# Obs.	Mean	Standard Error
Untreated	52	45.8	6.0
Salv&Mast	21	37.3	9.8
Old Harvest	9	34.6	14.6
Thin&Burn.	16	11.1	7.6

Table B5 - Parameter estimates for model with Treatment Type for the Crown Consumption response.

Explanatory Variable	Parameter	Parameter Estimate	P-value
Intercept	a	25.3	0.086
S_1	b_1	-10.6	0.767
S_2	b_2	-21.8	0.658
S_3	b_3	10.1	0.875
S_4	b_4	43.5	0.548
S_5	b_5	-1.0	0.974
S_6	b_6	61.7	0.546
S_7	b_7	-12.5	0.768
S_8	b_8	173.6	0.024
Untreated	SVT_1	23.4	0.132
Salv&Mast	SVT_2	-3.4	0.911
Old Harvest	SVT_3	3.4	0.881
Thin&Burn	SVT_4	0	

Table B6 – Pair-wise comparisons of Treatment Type for the Crown Consumption response. Negative values in the Estimate column indicate that the value of the second type is greater than the first.

Comparison	Estimate	P-value	Bonferroni adjusted α	Significance at an experiment-wise error rate=0.05
Untreated vs Salv&Mast	26.7	0.325	0.0083	No
Untreated t vs Old Harvest	19.9	0.237	0.0083	No
Untreated vs Thin&Burn	23.4	0.132	0.0083	No
Salv&Mast vs Old Harvest	-6.9	0.821	0.0083	No
Salv&Mast vs Thin&Burn	-3.4	0.911	0.0083	No
Old Harvest vs Thin&Burn	3.5	0.881	0.0083	No

Soil Severity - Comparison Among Land Status Categories

Chi-Square tests and Symmetric Measures were performed using SPSS (SPSS Inc. 1999) to test for differences in soil severity among land status categories. Chi-square analysis tests the hypothesis that the row variable (soil severity) and column variable (land status) are independent without indicating strength or direction of the relationship. Symmetric Measures of association are those in which interchanging the two variables in the calculation does not alter the value of the measure (SPSS Inc. 1999). This analysis confirmed that significant differences do exist among land status types (Table B-8, and B-9), as well as among treatment types.

The number of plots sampled per land status category is shown in Table B-7.

Table B7 - Number of soils severity plots per Land Status Type from field plot data.

General Land Management Category	Number of Observations
Untreated	28
Treated	38
Owl/Goshawk Habitat	50
Recent Wildfire	3
TOTAL	119

Table B8 - Chi Square Tests for significant differences in soil severity among Land Status Type.
a. 14 cells (70%) have expected count less than 5. The minimum expected count is .25.

	Value	DF	Asymp. Sig. (2-sided)
Pearson Chi-Square	21.823[a]	12	.040
Likelihood Ratio	23.328	12	.025
Linear-by-Linear Assoc.	1.596	1	.207
N of Valid Cases	119		

Table B9 - Symmetric Measures analysis for significant differences in soil severity among Land Status Types.

a Not assuming the null hypothesis.
b Using the asymptotic standard error assuming the null hypothesis.
c. Based on normal approximation.

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Interval by Interval	Pearson's R	.116	.085	1.266	.208[c]
Ordinal by Ordinal	Spearman Correlation	.085	.090	0.926	.357[c]
N of Valid Cases		120			

Soil Severity - Comparison Among Treatment Categories

Chi-Square tests and Symmetric Measures were performed to test for differences in soil severity among treatment types. This analysis confirmed that significant differences do exist among treatment types (Table B-11, and B-12).

The number of plots sampled per land status category is shown in Table B-10.

Table B10 – Number of soil severity plots per treatment type from field plot data.

Treatment Status	Number of Observations
Untreated	52
Salv&Mast	21
Old Harvest	7
Thin&Burn	16
TOTAL	96

Table B11 – Chi Square Tests for significant differences in soil severity among Treatment Types.
a. 19 cells (76.0 percent) have expected count less than 5. The minimum expected count is .59.

	Value	DF	Asymp. Sig. (2-sided)
Pearson Chi-Square	29.422	12	.003
Likelihood Ratio	29.413	12	.003
Linear-by-Linear Assoc.	10.678	1	.001
N of Valid Cases	96		

Table B12 – Symmetric Measures analysis for significant differences in soil severity among Treatment Types.
a Not assuming the null hypothesis.
b Using the asymptotic standard error assuming the null hypothesis.
c Based on normal approximation.

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Interval by Interval	Pearson's R	.335	.095	3.450	.001[c]
Ordinal by Ordinal	Spearman Correlation	.365	.092	3.806	.000[c]
N of Valid Cases		119			

Results – Satellite Data

Canopy Cover Change - Comparison Among Land Status Categories for Satellite Data

Post-hoc comparisons among land status types showed that differences between treated and owl/goshawk PACs, treated and owl/goshawk core areas, and treated and untreated, were statistically significant. Untreated areas, as well as owl/goshawk PACs and owl/goshawk core areas, had canopy cover change that was significantly greater than treated areas (Table B15).

Table B13 – Canopy Cover Change. Raw data means and their standard error for each Land Status Category in percent.

Land Status	Number of Observations	Mean	St. error
PAC	299	76.0	2.1
CORE	268	76.2	2.2
Treated	207	50.4	2.9
Untreated	296	65.0	2.2
Recent Fire	99	50.6	3.8

Table B14 - Parameter estimates for model with Land Status Category for the Canopy Cover response.

Explanatory Variable	Parameter	Parameter Estimate	P-value
Intercept	*a*	6575.23	0.200
S_1	bb_1	-14.6	0.227
S_2	bb_2	1.7	0.901
S_3	bb_3	13.0	0.714
S_4	bb_4	-47.6	0.003
S_5	bb_5	18.2	0.605
S_6	bb_6	29.1	0.377
S_8	bb_7	30.5	0.041
S_8	bb_8	32.1	0.099
S9	bb_9	26.5	0.460
S10	bb_{10}	13.2	0.506
S11	bb_{11}	7.0	0.653
S12	bb_{12}	257.4	0.002
S13	bb_{13}	-26.0	0.130
S14	bb_{14}	3.9	0.805
S15	bb_{15}	58.5	0.103
PAC	TLS_1	18.8	0.020
CORE	TLS_2	16.4	0.044
Treated	TLS_3	-4.4	0.570
Untreated	TLS_4	12.0	0.133
Recent Fire	TLS_5	0	
TPOS	t_1	0.8	0.008
$TPOS^2$	t_2	-0.01	0.084
$TPOS^3$	t_3	0.00006	0.139
ELEV	e_1	-1.3	0.025
$ELEV^2$	e_2	8.7	0.017

$ELEV^3$	e_3	-187.4	0.009
TMPMAX	x_1	-224.9	0.232
$TMPMAX^2$	x_1	2.9	0.213
$TMPMAX^3$	x_1	-0.01	0.197
PCO	r_1	0.1	0.107

Table B15 – Pair-wise comparisons of Land Status Category for the Canopy Cover response. Negative values in the Estimate column indicate that the value of the second type is greater than the first.

Comparison	Estimate	P-value	Bonferroni adjusted α	Significance at an experiment-wise error rate=0.05
PAC vs CORE	2.4	0.431	0.005	No
PAC vs Treated	**23.2**	**<0.0001**	**0.005**	**Yes**
PAC vs Untreated	6.7	0.048	0.005	No
PAC vs Recent Fire	18.8	0.019	0.005	No
CORE vs Treated	**20.8**	**<0.0001**	**0.005**	**Yes**
CORE vs Untreated	4.3	0.214	0.005	No
CORE vs Recent Fire	16.4	0.044	0.005	No
Treated vs Untreated	**-16.5**	**<0.0001**	**0.005**	**Yes**
Treated vs Recent Fire	-4.5	0.567	0.005	No
Untreated vs Recent Fire	12.0	0.133	0.005	No

Canopy Cover Change - Comparison Among Treatment Types for Satellite Data

Post-hoc comparisons among categories showed that differences between thinned with prescribed burn units and all other treatment types were statistically significant. Untreated areas, salvage and mastication units, old harvest units, and commercial thin units all had canopy cover change that was significantly greater than those units treated with a combination of thinning with prescribed burn (Table B18).

Table B16 – Canopy Cover Change. Raw data means with standard error for each Treatment Type in percent.

Land Status	Number of Observations	Mean	Standard Error
Untreated	725	71.0	1.4
Salv&Mast	60	67.4	4.6
Old Harvest	58	70.8	4.8
Thin&Burn	29	12.2	3.5
Com Thin	77	45.5	4.9

Table B17 - Parameter estimates for model with Treatment Types for the Canopy Cover response.

Explanatory variable	Parameter	Parameter Estimate	P-value
Intercept	*a*	6049.9	0.270
S_1	bb_1	-25.4	0.091
S_2	bb_2	23.9	0.072
S_3	bb_3	-93.6	0.022
S_4	bb_4	-64.9	0.0001
S_5	bb_5	6.6	0.879
S_6	bb_6	13.2	0.682
S_7	bb_7	71.6	<0.0001
S_8	bb_8	51.8	0.034
S_9	bb_9	6.5	0.819
S_{10}	bb_{10}	12.7	0.592
S_{11}	bb_{11}	3.0=	0.851
S_{12}	bb_{12}	267.4	0.007
S_{13}	bb_{13}	-25.3	0.099
S_{14}	bb_{14}	23.2	0.205
S_{15}	bb_{15}	-30.0	0.453
Untreated	SVT_1	4.6	0.378
Salv&Mast	SVT_2	0.9	0.917
Old Harvest	SVT_3	6.5	0.344
Thin&Burn	SVT_4	-45.1	<0.0001
Com Thin	CVT_5	0	
TPOS	t_1	0.54	0.101
$TPOS^2$	t_2	-0.01	0.4035
$TPOS^3$	t_3	<0.001	0.440
ELEV	e_1	-0.6	0.388
$ELEV^2$	e_2	3.6	0.348
$ELEV^3$	e_3	-84.0	0.274
TMPMAX	x_1	-225.9	0.260
$TMPMAX^2$	x_2	2.9	0.227
$TMPMAX^3$	x_3	-0.01	0.199
PCO	r_1	-1.1	0.011
PCO^2	r_2	0.03	0.004
PCO^3	r_3	-0.0002	0.006

Table B18 – Pair-wise comparisons of Treatment Types for the Canopy Cover response.

Comparison	Estimate	P-value	Bonferroni adjusted α	Significance at an experiment-wise error rate=0.05
Untreated vs Salv&Mast	3.7	0.621	0.005	No
Untreated t vs Old Harvest	-1.9	0.731	0.005	No
Untreated vs Thin&Burn	**49.8**	**<0.0001**	**0.005**	**Yes**
Untreated vs Com Thin	4.6	0.378	0.005	No
Salv&Mast vs Old Harvest	-5.6	0.473	0.005	No
Salv&Mast vs Thin&Burn	**46.0**	**<0.0001**	**0.005**	**Yes**
Salv&Mast vs Com Thin	0.867	0.917	0.005	No
Old Harvest vs Thin&Burn	**51.6**	**<0.0001**	**0.005**	**Yes**
Old Harvest vs Com Thin	6.5	0.344	0.005	No

Appendix C - Weather Data

Weather data was obtained from the Chester, Pierce, and Westwood Remote Automated Weather Stations (RAWS) that are located in or near the Moonlight Fire area (Figure 9). RAWS weather data collected during the Moonlight Fire are displayed in Tables C-1, C-2, and C-3.

Table C-1 – Weather data during the Moonlight Fire from the Chester RAWS.

Date/Time	Temp (°F)	Relative Humidity (%)	Wind Speed (mph)	Peak Wind (mph)	Wind Direction°	Peak Wind Direction °	Solar Radiation (W/m*m)
9/3/2007 0:02	91	8	2	24	239	159	777
9/3/2007 5:02	59	22	0	5	286	336	0
9/3/2007 10:02	45	29	0	4	305	293	0
9/3/2007 15:02	55	26	0	0		17	4
9/3/2007 20:02	86	12	4	8	126	84	873
9/4/2007 0:02	85	6	10	26	170	156	771
9/4/2007 5:02	55	22	0	3	303	181	0
9/4/2007 10:02	46	40	0	0		308	0
9/4/2007 15:02	55	41	0	0		210	4
9/4/2007 20:02	76	20	5	13	293	126	876
9/5/2007 0:02	76	20	3	12	250	248	752
9/5/2007 5:02	52	48	1	s	303	305	0
9/5/2007 10:02	40	72	0	3	295	294	0
9/5/2007 15:02	50	57	0	4	283	260	4
9/5/2007 20:02	75	24	7	14	35	122	848
9/6/2007 0:02	81	20	7	15	95	9	730
9/6/2007 5:02	63	31	0	7	165	16	0
9/6/2007 10:02	48	50	0	4	308	302	0
9/6/2007 15:02	53	48	0	0		267	5
9/6/2007 20:02	79	21	5	13	154	127	707
9/7/2007 0:02	81	17	5	11	149	135	571
9/7/2007 5:02	57	39	0	4	294	15	0
9/7/2007 10:02	49	48	0	0		286	0
9/7/2007 15:02	51	50	0	0		292	4
9/7/2007 20:02	82	20	4	6	53	50	776
9/8/2007 0:02	84	23	2	14	266	166	644
9/8/2007 5:02	57	47	0	4	271	16	0
9/8/2007 10:02	50	58	0	0		302	0
9/8/2007 15:02	48	65	0	0		294	2
9/8/2007 20:02	83	18	4	5	128	162	698
9/9/2007 0:02	87	15	2	9	295	132	601
9/9/2007 5:02	58	30	0	3	285	344	0
9/9/2007 10:02	50	43	0	0		21	0
9/9/2007 15:02	48	49	0	0		268	2
9/9/2007 20:02	79	17	2	6	135	168	536
9/10/2007 0:02	87	14	4	9	142	159	606
9/10/2007 5:02	56	33	0	5	283	345	0
9/10/2007 10:02	48	35	0	4	296	287	0
9/10/2007 15:02	49	32	0	4	298	258	2

Date/Time	Temp (°F)	Relative Humidity (%)	Wind Speed (mph)	Peak Wind (mph)	Wind Direction°	Peak Wind Direction °	Solar Radiation (W/m*m)
9/10/2007 20:02	82	11	4	8	145	154	728
9/11/2007 0:02	84	10	5	12	146	159	681
9/11/2007 5:02	59	18	1	4	307	287	0
9/11/2007 10:02	44	28	0	0		278	0
9/11/2007 15:02	43	33	0	0		283	3
9/11/2007 20:02	82	12	2	6	100	143	783
9/12/2007 0:02	88	15	3	16	244	164	610
9/12/2007 5:02	57	43	0	0		310	0
9/12/2007 10:02	53	40	0	4	295	291	0
9/12/2007 15:02	55	38	0	0		288	3
9/12/2007 20:02	82	22	5	8	98	114	790
9/13/2007 0:02	80	13	6	21	180	172	707
9/13/2007 5:02	52	30	0	3	326	308	0
9/13/2007 10:02	47	38	0	5	289	303	0
9/13/2007 15:02	47	45	0	0		264	2
9/13/2007 20:02	71	16	6	16	197	157	819
9/14/2007 0:02	66	19	11	24	165	164	706
9/14/2007 5:02	43	66	0	0		268	0
9/14/2007 10:02	41	74	0	0		324	0
9/14/2007 15:02	44	66	0	3	313	258	2
9/14/2007 20:02	65	30	5	11	142	194	752

Table C-2 – Weather data during the Moonlight Fire from the Pierce RAWS.

Date/Time	Temp (°F)	Relative Humidity (%)	Wind Speed (mph)	Peak Wind (mph)	Wind Direction °	Peak Wind Direction °	Solar Radiation (W/m*m)
9/3/2007 0:15	87	6	5	16	235	180	627
9/3/2007 5:15	63	20	2	6	324	332	0
9/3/2007 10:15	60	25	2	5	326	18	0
9/3/2007 15:15	69	20	2	5	76	12	110
9/3/2007 20:15	88	9	6	17	149	211	927
9/4/2007 0:15	82	11	6	23	76	203	608
9/4/2007 5:15	59	23	2	10	294	300	0
9/4/2007 10:15	56	34	3	9	304	300	0
9/4/2007 15:15	60	35	2	5	266	236	123
9/4/2007 20:15	75	19	5	23	285	279	1024
9/5/2007 0:15	71	22	4	23	37	212	613
9/5/2007 5:15	52	45	4	16	353	330	0
9/5/2007 10:15	46	58	3	12	352	50	0
9/5/2007 15:15	53	55	2	7	355	218	137
9/5/2007 20:15	72	28	7	17	119	31	937
9/6/2007 0:15	76	22	2	15	296	338	550
9/6/2007 5:15	58	36	3	13	27	17	0
9/6/2007 10:15	52	46	2	5	353	103	0
9/6/2007 15:15	61	39	3	10	59	51	131
9/6/2007 20:15	77	14	6	18	123	144	944
9/7/2007 0:15	72	21	2	15	179	79	134

Date/Time	Temp (°F)	Relative Humidity (%)	Wind Speed (mph)	Peak Wind (mph)	Wind Direction °	Peak Wind Direction °	Solar Radiation (W/m*m)
9/7/2007 5:15	60	27	2	4	358	11	0
9/7/2007 10:15	54	39	1	6	7	73	0
9/7/2007 15:15	57	40	1	3	182	358	99
9/7/2007 20:15	78	14	5	13	344	19	518
9/8/2007 0:15	71	11	4	10	105	118	18
9/8/2007 5:15	62	27	1	6	30	5	0
9/8/2007 10:15	55	41	2	7	323	49	0
9/8/2007 15:15	60	35	2	3	77	330	108
9/8/2007 20:15	73	16	2	13	358	104	239
9/9/2007 0:15	78	13	6		271		0
9/9/2007 5:15	61	31	2	6	342	330	0
9/9/2007 10:15	54	39	1	5	327	30	0
9/9/2007 15:15	57	39	6	13	119	107	40
9/9/2007 20:15	68	18	7	20	254	271	874
9/10/2007 0:15	64	16	6	22	342	248	490
9/10/2007 5:15	47	55	5	10	313	273	0
9/10/2007 10:15	40	72	1	3	331	9	0
9/10/2007 15:15	46	58	2	3	98	277	31
9/10/2007 20:15	60	29	8	16	262	323	865
9/13/2007 0:15	78	13	6		271		0
9/13/2007 5:15	61	31	2	6	342	330	0
9/13/2007 10:15	54	39	1	5	327	30	0
9/13/2007 15:15	57	39	6	13	119	107	40
9/13/2007 20:15	68	18	7	20	254	271	874

Table C-3 – Weather data during the Moonlight Fire from the Westwood RAWS.

Date/Time	Temp (°F)	Relative Humidity (%)	Wind Speed (mph)	Peak Wind (mph)	Wind Direction °	Peak Wind Direction °	Solar Radiation (W/m*m)
9-3-2007 23:47 GMT	77	11	12	27	162	203	565
9-3-2007 22:47 GMT	81	10	9	23	183	160	741
9-3-2007 21:47 GMT	82	9	9	22	176	220	875
9-3-2007 20:47 GMT	82	10	9	21	180	150	951
9-3-2007 19:47 GMT	79	13	10	20	162	151	972
9-3-2007 18:47 GMT	76	15	9	19	176	157	933
9-3-2007 17:47 GMT	74	16	10	18	159	152	51
9-3-2007 16:47 GMT	70	18	9	13	164	174	659
9-3-2007 15:47 GMT	68	22	6	10	159	159	453
9-3-2007 14:47 GMT	65	26	5	9	153	151	245
9-3-2007 13:47 GMT	60	29	5	11	150	165	6
9-3-2007 12:47 GMT	60	29	5	8	150	141	0
9-3-2007 11:47 GMT	60	30	4	8	153	152	0
9-3-2007 10:47 GMT	59	30	3	5	157	190	0
9-3-2007 9:47 GMT	58	28	1	6	172	195	0
9-3-2007 8:47 GMT	61	24	1	4	141	115	0
9-3-2007 7:47 GMT	61	22	0	3	136	318	0

Date/Time	Temp (°F)	Relative Humidity (%)	Wind Speed (mph)	Peak Wind (mph)	Wind Direction °	Peak Wind Direction °	Solar Radiation (W/m*m)
9-3-2007 6:47 GMT	65	19	2	4	311	318	0
9-3-2007 5:47 GMT	65	18	1	7	336	295	0
9-3-2007 4:47 GMT	66	15	4	8	307	284	0
9-3-2007 3:47 GMT	65	19	4	8	293	258	0
9-3-2007 2:47 GMT	68	18	5	8	281	252	0
9-3-2007 1:47 GMT	76	15	3	17	179	251	87
9-3-2007 0:47 GMT	81	9	8	18	247	246	376
9-4-2007 23:47 GMT	67	29	12	24	247	252	581
9-4-2007 22:47 GMT	68	28	11	24	251	227	744
9-4-2007 21:47 GMT	68	29	12	23	244	257	237
9-4-2007 20:47 GMT	67	29	10	21	229	219	971
9-4-2007 19:47 GMT	67	26	7	21	208	255	957
9-4-2007 18:47 GMT	64	29	9	21	228	196	946
9-4-2007 17:47 GMT	63	38	6	13	201	247	44
9-4-2007 16:47 GMT	59	44	4	11	195	172	639
9-4-2007 15:47 GMT	58	44	6	11	168	181	310
9-4-2007 14:47 GMT	55	49	4	12	227	256	258
9-4-2007 13:47 GMT	52	47	5	14	238	224	3
9-4-2007 12:47 GMT	52	45	3	12	168	160	0
9-4-2007 11:47 GMT	54	42	5	12	125	135	0
9-4-2007 10:47 GMT	56	40	6	12	143	172	0
9-4-2007 9:47 GMT	55	42	5	11	134	157	0
9-4-2007 8:47 GMT	56	41	5	10	134	116	0
9-4-2007 7:47 GMT	58	37	5	13	135	129	0
9-4-2007 6:47 GMT	60	30	7	13	163	173	0
9-4-2007 5:47 GMT	60	27	4	12	172	183	0
9-4-2007 4:47 GMT	61	23	4	9	158	128	0
9-4-2007 3:47 GMT	63	20	4	10	172	243	0
9-4-2007 2:47 GMT	65	19	5	15	255	230	0
9-4-2007 1:47 GMT	72	13	9	18	238	239	50
9-4-2007 0:47 GMT	76	9	9	24	170	167	247
9-5-2007 23:47 GMT	70	29	7	17	68	73	530
9-5-2007 22:47 GMT	69	29	9	19	73	65	720
9-5-2007 21:47 GMT	70	30	6	18	103	59	888
9-5-2007 20:47 GMT	68	33	9	19	79	38	939
9-5-2007 19:47 GMT	65	38	8	21	55	79	961
9-5-2007 18:47 GMT	61	41	10	19	64	67	908
9-5-2007 17:47 GMT	58	50	9	18	75	38	40
9-5-2007 16:47 GMT	54	56	8	18	62	71	639
9-5-2007 15:47 GMT	53	61	8	16	68	68	57
9-5-2007 14:47 GMT	51	67	2	11	65	52	220
9-5-2007 13:47 GMT	45	78	8	11	43	50	4
9-5-2007 12:47 GMT	44	81	3	7	39	57	0
9-5-2007 11:47 GMT	45	78	5	9	31	45	0
9-5-2007 10:47 GMT	46	76	6	11	33	32	0
9-5-2007 9:47 GMT	47	72	7	11	42	25	0
9-5-2007 8:47 GMT	46	74	5	9	42	27	0
9-5-2007 7:47 GMT	46	75	4	10	27	345	0
9-5-2007 6:47 GMT	46	72	5	16	23	356	0
9-5-2007 5:47 GMT	48	63	4	13	50	355	0
9-5-2007 4:47 GMT	49	58	5	13	46	324	0
9-5-2007 3:47 GMT	46	74	1	12	74	286	0

Date/Time	Temp (°F)	Relative Humidity (%)	Wind Speed (mph)	Peak Wind (mph)	Wind Direction °	Peak Wind Direction °	Solar Radiation (W/m*m)
9-5-2007 2:47 GMT	49	65	5	18	25	27	0
9-5-2007 1:47 GMT	53	55	7	20	21	326	24
9-5-2007 0:47 GMT	65	28	10	24	258	243	325
9-6-2007 23:47 GMT	71	22	5	11	63	71	319
9-6-2007 22:47 GMT	70	23	4	10	61	66	329
9-6-2007 21:47 GMT	70	24	6	15	59	59	290
9-6-2007 20:47 GMT	70	24	10	18	60	78	725
9-6-2007 19:47 GMT	70	25	7	19	85	52	754
9-6-2007 18:47 GMT	67	30	9	20	64	74	703
9-6-2007 17:47 GMT	65	34	9	17	66	42	190
9-6-2007 16:47 GMT	63	37	8	16	71	53	599
9-6-2007 15:47 GMT	61	39	9	17	67	60	61
9-6-2007 14:47 GMT	58	42	10	17	55	68	216
9-6-2007 13:47 GMT	54	46	5	10	55	34	7
9-6-2007 12:47 GMT	57	41	5	9	76	96	0
9-6-2007 11:47 GMT	55	45	3	11	70	93	0
9-6-2007 10:47 GMT	54	43	2	10	35	66	0
9-6-2007 9:47 GMT	57	42	6	12	51	40	0
9-6-2007 8:47 GMT	57	43	8	13	46	22	0
9-6-2007 7:47 GMT	56	43	6	13	61	52	0
9-6-2007 6:47 GMT	57	42	6	17	48	65	0
9-6-2007 5:47 GMT	59	41	7	16	43	39	0
9-6-2007 4:47 GMT	60	41	10	19	43	30	0
9-6-2007 3:47 GMT	61	39	7	11	39	33	0
9-6-2007 2:47 GMT	62	35	4	12	34	56	0
9-6-2007 1:47 GMT	66	30	5	17	50	47	22
9-6-2007 0:47 GMT	70	27	6	17	68	77	165
9-7-2007 23:47 GMT	77	19	7	16	228	249	491
9-7-2007 22:47 GMT	79	15	6	15	247	259	648
9-7-2007 21:47 GMT	78	18	4	18	196	263	810
9-7-2007 20:47 GMT	76	15	4	14	218	143	877
9-7-2007 19:47 GMT	78	14	8	19	155	144	940
9-7-2007 18:47 GMT	73	16	8	15	179	164	927
9-7-2007 17:47 GMT	72	21	6	10	162	164	251
9-7-2007 16:47 GMT	67	33	0	4	182	141	432
9-7-2007 15:47 GMT	68	29	1	2	99	180	148
9-7-2007 14:47 GMT	65	37	0	4	148	358	188
9-7-2007 13:47 GMT	58	41	2	4	359	347	6
9-7-2007 12:47 GMT	58	44	0	1	14	55	0
9-7-2007 11:47 GMT	59	40	0	3	115	58	0
9-7-2007 10:47 GMT	60	40	2	3	51	95	0
9-7-2007 9:47 GMT	59	40	1	3	132	68	0
9-7-2007 8:47 GMT	62	36	2	3	79	97	0
9-7-2007 7:47 GMT	62	33	1	2	115	108	0
9-7-2007 6:47 GMT	61	37	0	0		180	0
9-7-2007 5:47 GMT	63	31	0	0		155	0
9-7-2007 4:47 GMT	63	28	0	3	167	127	0
9-7-2007 3:47 GMT	64	27	0	0		237	0
9-7-2007 2:47 GMT	65	26	0	0		186	0
9-7-2007 1:47 GMT	68	24	0	6	178	40	52
9-7-2007 0:47 GMT	71	20	4	9	40	64	188
9-8-2007 23:47 GMT	79	15	7	14	231	265	486

Date/Time	Temp (°F)	Relative Humidity (%)	Wind Speed (mph)	Peak Wind (mph)	Wind Direction °	Peak Wind Direction °	Solar Radiation (W/m*m)
9-8-2007 22:47 GMT	80	15	4	12	209	248	649
9-8-2007 21:47 GMT	79	13	4	14	230	263	804
9-8-2007 20:47 GMT	77	14	6	13	209	245	851
9-8-2007 19:47 GMT	74	16	3	7	167	164	766
9-8-2007 18:47 GMT	72	26	3	7	127	118	746
9-8-2007 17:47 GMT	67	38	2	13	133	229	270
9-8-2007 16:47 GMT	65	32	2	5	319	334	434
9-8-2007 15:47 GMT	61	35	1	6	134	66	163
9-8-2007 14:47 GMT	58	37	3	10	61	66	96
9-8-2007 13:47 GMT	57	45	2	6	60	53	2
9-8-2007 12:47 GMT	57	46	2	8	59	59	0
9-8-2007 11:47 GMT	58	46	2	10	42	50	0
9-8-2007 10:47 GMT	58	48	3	7	10	309	0
9-8-2007 9:47 GMT	57	49	0	0		295	0
9-8-2007 8:47 GMT	58	45	0	0		136	0
9-8-2007 7:47 GMT	59	40	0	0		265	0
9-8-2007 6:47 GMT	59	47	0	2	278	254	0
9-8-2007 5:47 GMT	60	47	2	5	285	296	0
9-8-2007 4:47 GMT	59	39	4	10	281	276	0
9-8-2007 3:47 GMT	62	40	7	10	285	279	0
9-8-2007 2:47 GMT	63	32	0	7	132	119	0
9-8-2007 1:47 GMT	69	26	5	13	163	178	34
9-8-2007 0:47 GMT	74	20	7	15	165	232	265
9-9-2007 23:47 GMT	79	14	3	9	294	349	528
9-9-2007 22:47 GMT	79	14	2	14	74	76	538
9-9-2007 21:47 GMT	76	15	9	18	65	69	768
9-9-2007 20:47 GMT	75	16	5	10	62	64	782
9-9-2007 19:47 GMT	71	22	2	4	156	184	326
9-9-2007 18:47 GMT	71	22	2	7	187	109	483
9-9-2007 17:47 GMT	67	23	5	7	103	121	291
9-9-2007 16:47 GMT	62	25	0	4	128	93	227
9-9-2007 15:47 GMT	59	27	0	7	261	30	69
9-9-2007 14:47 GMT	59	25	4	11	30	47	21
9-9-2007 13:47 GMT	60	24	6	12	26	57	0
9-9-2007 12:47 GMT	61	23	7	10	33	44	0
9-9-2007 11:47 GMT	61	26	2	4	0	62	0
9-9-2007 10:47 GMT	61	26	1	3	62	47	0
9-9-2007 9:47 GMT	62	28	0	4	325	36	0
9-9-2007 8:47 GMT	63	29	5	10	42	50	0
9-9-2007 7:47 GMT	64	28	5	8	20	35	0
9-9-2007 6:47 GMT	63	32	3	6	342	356	0
9-9-2007 5:47 GMT	63	34	3	7	4	352	0
9-9-2007 4:47 GMT	63	34	3	4	324	305	0
9-9-2007 3:47 GMT	64	29	2	9	296	280	0
9-9-2007 2:47 GMT	67	24	6	11	288	298	0
9-9-2007 1:47 GMT	73	18	6	12	272	220	29
9-9-2007 0:47 GMT	78	13	9	16	246	225	285
9-10-2007 23:47 GMT	72	10	7	13	44	38	302
9-10-2007 22:47 GMT	74	10	7	16	52	43	435
9-10-2007 21:47 GMT	76	10	6	19	54	45	767
9-10-2007 20:47 GMT	74	10	8	18	49	43	827
9-10-2007 19:47 GMT	72	10	9	15	54	66	880

Date/Time	Temp (°F)	Relative Humidity (%)	Wind Speed (mph)	Peak Wind (mph)	Wind Direction °	Peak Wind Direction °	Solar Radiation (W/m*m)
9-10-2007 18:47 GMT	70	12	8	16	63	58	829
9-10-2007 17:47 GMT	67	13	6	12	99	130	183
9-10-2007 16:47 GMT	64	16	6	9	113	71	567
9-10-2007 15:47 GMT	63	14	4	8	116	66	83
9-10-2007 14:47 GMT	58	16	0	4	44	24	152
9-10-2007 13:47 GMT	54	18	3	5	13	74	2
9-10-2007 12:47 GMT	55	17	2	3	343	277	0
9-10-2007 11:47 GMT	56	16	1	11	294	90	0
9-10-2007 10:47 GMT	60	14	7	15	73	66	0
9-10-2007 9:47 GMT	61	14	6	10	76	76	0
9-10-2007 8:47 GMT	58	16	1	14	284	60	0
9-10-2007 7:47 GMT	61	16	4	16	46	15	0
9-10-2007 6:47 GMT	63	15	9	23	42	44	0
9-10-2007 5:47 GMT	62	20	2	11	294	5	0
9-10-2007 4:47 GMT	65	19	2	9	0	97	0
9-10-2007 3:47 GMT	66	18	4	11	33	17	0
9-10-2007 2:47 GMT	68	18	5	10	29	22	0
9-10-2007 1:47 GMT	73	17	1	8	0	66	39
9-10-2007 0:47 GMT	76	15	5	8	58	59	243
9-11-2007 23:47 GMT	81	8	5	11	227	231	477
9-11-2007 22:47 GMT	82	9	8	22	244	261	662
9-11-2007 21:47 GMT	81	8	5	14	213	235	789
9-11-2007 20:47 GMT	81	7	5	12	217	235	903
9-11-2007 19:47 GMT	79	6	4	8	192	222	877
9-11-2007 18:47 GMT	75	13	3	6	207	165	833
9-11-2007 17:47 GMT	72	15	0	5	183	210	208
9-11-2007 16:47 GMT	68	17	1	4	140	357	500
9-11-2007 15:47 GMT	66	13	0	0		308	148
9-11-2007 14:47 GMT	61	14	0	0		245	117
9-11-2007 13:47 GMT	59	14	0	0		291	3
9-11-2007 12:47 GMT	59	14	0	1	251	249	0
9-11-2007 11:47 GMT	62	13	1	4	339	348	0
9-11-2007 10:47 GMT	61	13	2	3	54	57	0
9-11-2007 9:47 GMT	61	13	0	3	69	100	0
9-11-2007 8:47 GMT	61	12	1	2	86	91	0
9-11-2007 7:47 GMT	62	13	1	7	50	126	0
9-11-2007 6:47 GMT	63	13	1	8	83	71	0
9-11-2007 5:47 GMT	63	13	1	5	144	137	0
9-11-2007 4:47 GMT	64	13	1	11	338	53	0
9-11-2007 3:47 GMT	63	13	1	12	79	57	0
9-11-2007 2:47 GMT	67	11	6	14	43	50	0
9-11-2007 1:47 GMT	68	11	6	14	48	44	37
9-11-2007 0:47 GMT	70	11	8	15	48	43	177
9-12-2007 23:47 GMT	76	10	6	18	208	204	508
9-12-2007 22:47 GMT	78	5	8	19	165	163	699
9-12-2007 21:47 GMT	79	10	7	16	174	162	852
9-12-2007 20:47 GMT	76	16	6	13	207	222	944
9-12-2007 19:47 GMT	75	22	4	14	228	154	944
9-12-2007 18:47 GMT	72	24	5	15	209	227	852
9-12-2007 17:47 GMT	70	35	5	12	187	173	95
9-12-2007 16:47 GMT	67	38	6	13	165	168	575
9-12-2007 15:47 GMT	66	37	6	11	132	122	76

Date/Time	Temp (°F)	Relative Humidity (%)	Wind Speed (mph)	Peak Wind (mph)	Wind Direction °	Peak Wind Direction °	Solar Radiation (W/m*m)
9-12-2007 14:47 GMT	63	37	0	4	109	150	156
9-12-2007 13:47 GMT	57	42	2	4	133	84	0
9-12-2007 12:47 GMT	57	48	2	3	123	130	0
9-12-2007 11:47 GMT	59	46	0	2	102	262	0
9-12-2007 10:47 GMT	60	44	0	5	313	237	0
9-12-2007 9:47 GMT	61	38	2	5	318	340	0
9-12-2007 8:47 GMT	61	44	4	5	341	341	0
9-12-2007 7:47 GMT	61	42	0	2	323	129	0
9-12-2007 6:47 GMT	62	41	0	3	108	64	0
9-12-2007 5:47 GMT	64	37	0	5	253	299	0
9-12-2007 4:47 GMT	63	39	4	7	279	276	0
9-12-2007 3:47 GMT	65	37	6	9	273	281	0
9-12-2007 2:47 GMT	68	32	7	10	284	246	0
9-12-2007 1:47 GMT	73	24	6	15	266	248	35
9-12-2007 0:47 GMT	79	11	6	13	232	261	226
9-13-2007 23:47 GMT	61	16	9	23	172	150	510
9-13-2007 22:47 GMT	63	15	12	25	159	127	700
9-13-2007 21:47 GMT	64	16	11	24	164	167	834
9-13-2007 20:47 GMT	66	16	9	22	176	163	916
9-13-2007 19:47 GMT	65	22	9	21	166	240	941
9-13-2007 18:47 GMT	63	26	9	21	193	148	905
9-13-2007 17:47 GMT	60	37	8	20	189	171	72
9-13-2007 16:47 GMT	57	53	8	15	180	172	618
9-13-2007 15:47 GMT	53	67	7	14	179	169	59
9-13-2007 14:47 GMT	52	65	7	15	157	154	125
9-13-2007 13:47 GMT	49	67	6	13	158	165	5
9-13-2007 12:47 GMT	50	63	5	11	152	152	0
9-13-2007 11:47 GMT	52	55	6	14	161	164	0
9-13-2007 10:47 GMT	53	50	4	8	173	175	0
9-13-2007 9:47 GMT	50	55	1	4	194	164	0
9-13-2007 8:47 GMT	52	51	0	4	139	146	0
9-13-2007 7:47 GMT	54	47	3	6	168	228	0
9-13-2007 6:47 GMT	54	41	1	8	225	180	0
9-13-2007 5:47 GMT	56	40	3	7	239	235	0
9-13-2007 4:47 GMT	56	40	3	9	247	270	0
9-13-2007 3:47 GMT	58	34	4	14	286	282	0
9-13-2007 2:47 GMT	61	28	5	16	278	250	0
9-13-2007 1:47 GMT	68	19	7	14	268	204	47
9-13-2007 0:47 GMT	74	10	4	14	194	163	287

Appendix D – The Adaptive Management Service Enterprise Team

The Adaptive Management Service Enterprise Team (AMSET) supports ecosystem and fire management with current science and informed solutions to resource managers. These capabilities and services range from simple tasks to complex, controversial, and seemingly intractable problems. AMSET also provides administrative and business support as well as information and technology solutions for interim, long-term or unanticipated needs.

The Fire Behavior Assessment Team (FBAT) is a unique AMSET module that specializes in measuring fire behavior on active fires, including wildland fire use, prescribed fire and wildfire. FBAT:

- Utilizes fire behavior sensors and special video camera set-ups to measure direction and variation in rate of spread, fire type (surface, passive, or active crown fire behavior) in relation to fuel loading and configuration, topography, fuel moisture, weather, and operations.
- Measures changes in fuels from the fire, and can compare the effectiveness of past fuel treatments or fires on fire behavior and effects.
- Can process and report data while on an incident, making the information immediately applicable for verifying LTAN or FBAN fire behavior prediction assumptions. In addition, FBAT's video and data are useful for conveying specific information to the public, line officers, and others.
- Collects and analyzes data to meet longer term management needs, such as verifying or testing fire behavior modeling assumptions for fire management plans, unit resource management plans, or project plans.
- Can address specific unit objectives such as effects to archeological, botanical, or wildlife habitat resources in relation to fire behavior and fuels.

How to Order FBAT

The FBAT team can be ordered from ROSS, where it is indicated as **"TEAM- FIRE BEHAVIOR ASSESSMENT – FITES".**

The team can be requested by the following steps: 1) Overhead, 2) Group, 3) Squad, and 4) in Special Needs box, Requesting–Fire Behavior Assessment Team- Fites' Team out of CA-ONCC 530-226-2800.

You can also contact the FBAT team directly by phone to notify that you are placing an order—to hasten the process. You can reach Nicole Vaillant at 530-277-1258, or 707-291-5146. Or, you can reach Mike Campbell at 530-288-3231 or cell (only works while on travel status) 559-967-7806.

VI LITERATURE CITED

Agee, J.K,. B. Bahro, M.A. Finney, P.N. Omi, D.B. Sapsis, C.N. Skinner, J.W. VanWagtendonk, C.P. Weatherspoon. 2000. The use of shaded fuel breaks in landscape fire management. Forest Ecology and Management 127:55-66.

Ager, A.A., M.A. Finney, B.K. Kerns, H. Maffei. 2007. Modeling wildfire risk to northern spotted owl (*Strix occidentalis* caurina) habitat in central Oregon, USA. Forest Ecology and Management 246:45-56/.

Bond, M.L., R.J. Gutierrez, A.B. Franklin, W.S. LaHaye, C.A. May, M.E. Seamans. 2002. Short-term effects of wildfire on spotted owl survival, site fidelity, mate fidelity and reproductive success. Wildlife Society Bulletin 30(4):1022-1028.

Burnham, K. P. and D. R.Anderson. 1998. Model Selection and Inferences. A Practical Information-theoretic Approach. Spring-Verlag, New York, Inc., 353 p.

Busse M.D., Ken R. Hubbert, Gary O. Fiddler, Carol J. Shestak, and Robert F. Powers (2005). Lethal soil temperatures during burning of masticated forest residues. International Journal of Wildland Fire. 14:267-276.

Fites-Kaufman J.A., D. Weixelman, 2001. Forest Health Pilot Monitoring Report: Vegetation, Fuels, Wildlife Habitat. USFS, Adaptive Management Services Enterprise Team.

Fites, Jo Ann, and Henson, Carol. 2004. Real-time evaluation of effects of fuel treatments and other previous land management activities on fire behavior during wildfires. Final Report of the Joint Fire Sciences Rapid Response Project. September 20, 2004; 13 p.

Fites-Kaufman, J.A., A. Reiner, S. Dailey, C. Ewell, S. Beckman, E. Noonan, T. Decker. 2007. Fuel Treatment Effectiveness and Effects Monitoring in the Pacific Southwest Region 1999-2006, Manager's Summary. Prepared for Pacific Southwest Region Fire and Aviation Management.

Freeman, J., Stohlgren, T., Hunter, M., Omi, P., Martinson, E., Chong, G. et al. (2007). Rapid assessment of post-fire plant invasions in coniferous forests of the Western U.S. Ecol. Appl., 17, 1656-1665.

Knapp, E., M.Busse, J. Morgan Varner III, C. Skinner, and R. Powers. 2006. Behavior and short-term effects of fire in masticated fuel beds. Proceedings of the Third International Fire Ecology and Management Congress, Nov. 13-17, San Diego, CA.

Knapp, E., J. Keeley, E. Ballenger, T. Brennan. 2008. Fuel reduction and coarse woody debris dynamics with early season and late season prescribed fire in a Sierra Nevada mixed conifer forest**.** Forest Ecology and Management, Vol. 208, Issue 1 - 3, Pages 383-397.

Lentile L., P. Morgan, C. Hardy, A. Hudak, R. Means, P. Robichaud, E. Sutherland, F. Way, S. Lewis, and P. Robichaud. 2007. Lessons learned from rapid response research on wildland fires. Fire Management Today 67(1): 24-31.

McCulloch, C.E., S. R. Searle. 2001. Generalized Linear and Mixed Models. John Wiley and Sons New York, NY.

Miller, R.F. and R.J. Tausch. The role of fire in juniper and pinyon woodlands: a descriptive analysis. Proceedings: The First National Congress on Fire, Ecology.

Mueller-Dombois D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons. 547 pages.

National Park Service. 2003. Fire Monitoring Handbook. Fire Management Program Center, National Interagency Program Center, Boise ID. 274 pages.

Prevention and Management. San Diego, CA Nov 27-Dec2000. Tall Timbers Research Station, Tallahassee, FL.

Parsons, J.P., S.H. DeBenedetti. 1979. Impact of fire suppression on a mixed-conifer forest. Forest Ecology and Management 2:21-33.

R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Russel, G.T. ed. 2003. Hayman Fire Case Study. General Technical Report RMRS-GTR-114. 404 pp.

SAS Institute, Inc. 2005. SAS procedures guide, version 9.1. Cary, North Carolina, USA.

S-PLUS. S-PLUS 3.4 Release 1 (1996) Insightful Corp., Seattle, WA, http://www.insightful.com/.

SPSS Inc., 1999. SPSS Inc., 1999. SPSS for Windows, Release 10. Chicago, IL.

Thompson, R.J., T.A. Spies, L.M. Ganio. Re-burn severity in managed and unmanaged vegetation in a large wildfire. 2007. Proceeding of the National Academy of Science 104(25):10743-10748.

van Wagtendonk, J.W., and D. R. Cayan. 2007. Temporal and spatial distribution of lightning strikes in California in relationship to large-scale weather patterns. Fire Ecology.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, T.W. Swetnam. 2006. Warming and earlier spring increase Western U.S. forest wildfire activity. Science 313:940-943.

Wood, S.N. 2006. Generalized Additive Models. An Introduction with R. Chapman & Hall/CRC, New York, 392 p.