Fire Behavior and Effects Relating to Suppression, Fuel Treatments, and Protected Areas

on the

Antelope Complex Wheeler Fire

prepared by

The Fire Behavior Assessment Team

Jo Ann Fites, Mike Campbell, Alicia Reiner, Todd Decker

August • 2007

Photo: Fire Behavior Assessment Team

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

CONTENTS

Cover Photo

The Wheeler Fire burns through an untreated area at night. Image captured by fire behavior sensors and video camera installed by the Fire Behavior Assessment Team.

Figures

Tables

EXECUTIVE SUMMARY

Fire Behavior, Suppression, Fuel Treatments, and Protected Areas

Background

- The lightning-ignited Antelope Fire Complex burned more than a total of 23,420 acres starting July 5, 2007 on the Plumas National Forest.
- The fire burned through areas treated for fuel hazard reduction, untreated areas, and areas protected for California spotted owl and goshawk habitat (Protected Activity Centers and home range core habitat), as well as Riparian Habitat Conservation Areas.
- During the fire's first two days, with limited suppression resources, it encompassed more than half of its final total burned area. This included a large area that burned with extreme fire behavior as combustion from the fire interacted with the atmosphere—creating a column that climbed to more than 25,000 feet and collapsed.

Key Findings

- Treated areas had significantly reduced fire behavior and tree and soil impacts compared to untreated areas.
- Treated areas were utilized during suppression along several flanks of the fire for both direct attack with dozers and handcrews, as well as for indirect attack with burn operations.
- Treated areas that burned during the first two days—when suppression resources were limited and fire behavior more uniformly intense—had reduced fire effects compared to untreated areas. In some areas, these treated sites had moderate to high severity effects.
- A Defensible Fuel Profile Zone treated area provided a safe escape route for firefighters when the column collapsed and two other escape routes were cut off by the fire.
- Observations of fire behavior during the first two days suggest that large untreated areas allowed the fire to build momentum and contributed to increased fire behavior (rate of spread and intensity). Thus, the influence of these untreated areas made it more likely that suppression resources could be overwhelmed, treated areas could be threatened and their effectiveness in thwarting fire spread and intensity diminished.
- Satellite imagery reveals that protected areas (owl and goshawk nest stands) had significantly greater tree severity compared to untreated or treated areas. A majority of the larger blocks of untreated areas contained these concentrations of owl and goshawk habitat protected areas.

Recommendations

- Consider treating a larger portion of landscapes to effectively reduce the likelihood of fires gaining momentum and increasing in behavior to a point where suppression and nearby fuel treatments become less effective.
- Consider treating protected areas to enable these sites to withstand subsequent fire with lesser effects and prevent them from contributing to greater and increased fire behavior across the adjacent landscape.

The goal of this evaluation is to assess fire behavior and effects in fuel treatments and protected areas in the context of suppression and weather.

I INTRODUCTION

Substantial money and time are invested in designing and implementing fuel treatments while simultaneously managing for wildlife and other resource values.

This report contains an evaluation of the use and effectiveness of fuel treatments and the resultant fire behavior that occurred in both treated and untreated areas during the July 2007 Antelope Complex Fire on the Plumas National Forest, located in northern California between the Sierra Nevada and the Cascade Ranges.

.
The report is based on:

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

BACKGROUND

The Antelope Fire was ignited by lightening July 5, 2007 on the Plumas National Forest. It burned a total of 23,420 acres, including areas treated for fuel hazard reduction, untreated areas, and locations protected for California spotted owl and goshawk habitat (protected activity centers and home range core habitat), as well as riparian habitat conservation areas.

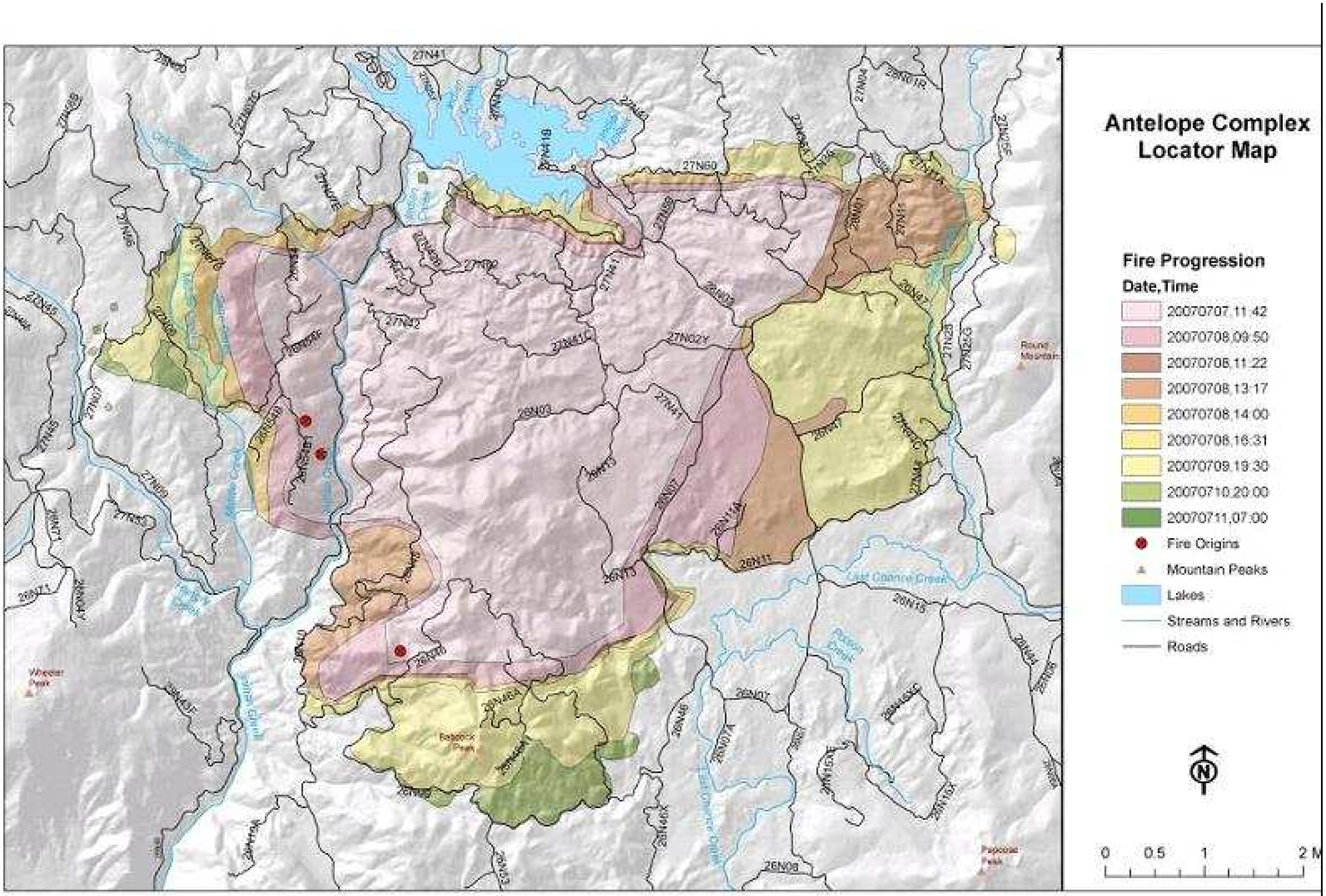
During the fire's first two days, with limited suppression resources, the fire encompassed more than half of its total burned area. This included a large area that burned with extreme fire behavior as combustion from the fire interacted with the atmosphere—creating a column that climbed to more than 25,000 feet and collapsed.

The Fire Behavior Assessment Team represents expertise in fire behavior, fuels, fire effects, and—importantly—highly experienced fire suppression personnel.

Operating under the U.S. Forest Service's Adaptive Management Services Enterprise Team, the Fire Behavior Assessment Team is a unique fire module that measures pre-fire fuels/vegetation, fire behavior (with sensors in the fire), and post-fire fuels/vegetation conditions during fires (wildfires, wildland fire use fires, and prescribed fires). Led by Dr. Jo Ann Fites, the team includes 6-12 fireline qualified personnel, at least one of whom is crew boss-qualified—or, more typically, division supervisor-qualified.

The goal of this report's evaluation is to assess fire behavior and effects in fuel treatments and protected areas in the context of suppression and weather.

The first section of this report provides a summary of information gained through direct observation of fire behavior and suppression; the second section outlines a more detailed post-fire survey of fire behavior evidence and effects.


Antelope Complex
Locator Map
Fire Progression
Date,Time
20070707,11:42
20070708,09:50
20070708,11:22
20070708,13:17
20070708,14:00
20070708,16:31
20070709,19:30
20070710,20:00
20070711,07:00
Fire Origins
Mountain Peaks
Lakes
Streams and Rivers
Roads
0
0.5
1
2 M
27N41
27N60
26N03
26N11
26N08

The fire burned primarily through dense, mixed conifer forest with intermixed shrubs that had not burned in almost 100 years—since 1910 when fire records were first recorded by the Plumas National Forest.

II Fire Behavior and Suppression in Relation to Weather and Fuel Treatments

Fire Chronology

On July 5, 2007, several fires were ignited by lightening, near Wheeler Peak and to the south near Hungry Creek in canyon terrain. The Wheeler Fire rapidly progressed downslope into Indian Creek drainage.

As the fire moved down into this drainage, it burned primarily through dense, mixed conifer forest with intermixed shrubs that had not burned in almost 100 years—since 1910 when fire records were first recorded by the Plumas National Forest.

Photo: Fire Behavior Assessment Team

Figure 1 – Column on the Antelope Complex Fire's second day, July 6, is visible from Sierra Valley, located approximately 20 miles to the south.

Even though the fire burned actively all night, firefighters were able to directly attack its heel. The following morning, as temperatures increased, humidities decreased, and up-canyon and upslope winds commenced, the fire progressed more rapidly up Indian Creek Canyon to the northeast—spreading with the prevailing wind direction.

Once again, the fire burned primarily through areas of dense forests and intermixed shrubs that had not burned since 1910 or 1920. (A portion of this area had burned in 1920.) During the heat of the day, when upslope and up-canyon winds occurred, the fire also made runs back upslope toward the west, burning primarily as a crown or high-intensity surface fire.

By late afternoon on the fire's second day, July 6, it had become established in a large area to the west of Dry Flat. A large, pyrocumulus column developed—verified by incident meteorologists—that reached an elevation of more than 35,000 feet (fig. 1).

From 6 to 6:30 pm, this column collapsed, resulting in very active crown fire that spread in all directions, including to the north toward Antelope Lake along the 28N03 Road, and to the south and east toward Dry Flat.

Areas that burned at this time show evidence of very intense fire with little to no needles remaining in the crowns, complete, or nearly complete, surface fuel consumption as well as soil discoloration in many places.

Suppression Efforts Aided

After July 6, extensive suppression resources arrived and the weather moderated. Fire behavior transitioned to mostly surface fire with torching of groups of trees or patches of forest with heavy ladder and surface fuels.

Throughout the course of the fire, firefighters utilized roads and prior fuel treatment areas—when they were available nearby—to conduct their burn operations (table 1). To slow or stop the main fire's progression during these operations, the ground crews burned from road edges back toward the main fire.

Initially during the Antelope Complex, based on firefighter observations and post-fire assessment, some stands in the "Hungry Fuel Project" that had been previously treated with prescribed fire and mastication[1] and, apparently resulted in reduced fire behavior. These areas, located on the fire's western flank along the 27N09 Road were also used in the suppression burn operations.

When the main fire moved into these treated areas, it transitioned from crown fire or high-intensity surface fire to moderate-intensity surface fire. This allowed firefighters to directly suppress the fire and safely apply burn operations.

This Hungry Fuel Project is part of a network of Plumas National Forest treatment areas known as "Defensible Fuel Profile Zones," designed and implemented primarily for hazardous fuel reduction—and to be used to aid potential suppression actions.[2]

When the main fire moved into these treated areas, it transitioned from crown fire or high-intensity surface fire to moderate-intensity surface fire. This allowed firefighters to directly suppress the fire and safely apply burn operations.

In the masticated units at night, according to some reports, flamelengths dropped to 2 feet, enabling direct attack with handline, dozers, and hose lays.

Where the masticated material was deeper, some embers were generated from trees that torched and embers that spotted to other areas. Overall, however, the

---

[1] Mastication, or mulching, is a mechanical fuel treatment that changes the structure and size of fuels in the stand. Trees and understory vegetation are chopped, ground, or chipped and the resulting material is left on the soil surface. Converting 20 tons per acre of understory biomass into small pieces would produce a uniform layer about 1 inch deep across the stand. From a fuels perspective, the total fuel loading is not immediately affected. However, the vertical height of the fuels is lowered and more fuel volume is shifted into 1 and 10-hour size classes. Ongoing studies will determine the effect of mastication on subsequent fire behavior and nutrient cycling.

[2] This "Defensible Fuel Profile Zone" network stretches across the Lassen, Plumas, and Sierraville ranger districts on the Tahoe National Forest as part of the Herger-Feinstein Quincy Library Group Act.

masticated units substantially aided suppression efforts.

Within this treatment area, where mastication was not possible on the steeper slopes, prescribed burns had been previously conducted. In 2006 when the Hungry Wildfire also burned into an area treated with prescribed fire the previous year, the fire diminished.

Photo: Fire Behavior Assessment Team

Figure 2 – During Wheeler Fire suppression efforts, a dozer (left) utilizes a portion of the Antelope Border Defensible Fuel Profile Zone that had been previously treated for fuel hazard reduction. The anemometer (also on left) is measuring wind. Special sensors on its base are noting fire spread rate and direction. This image was captured through a heat (or dozer) triggered video camera encased in a fireproof and heat resistant box.

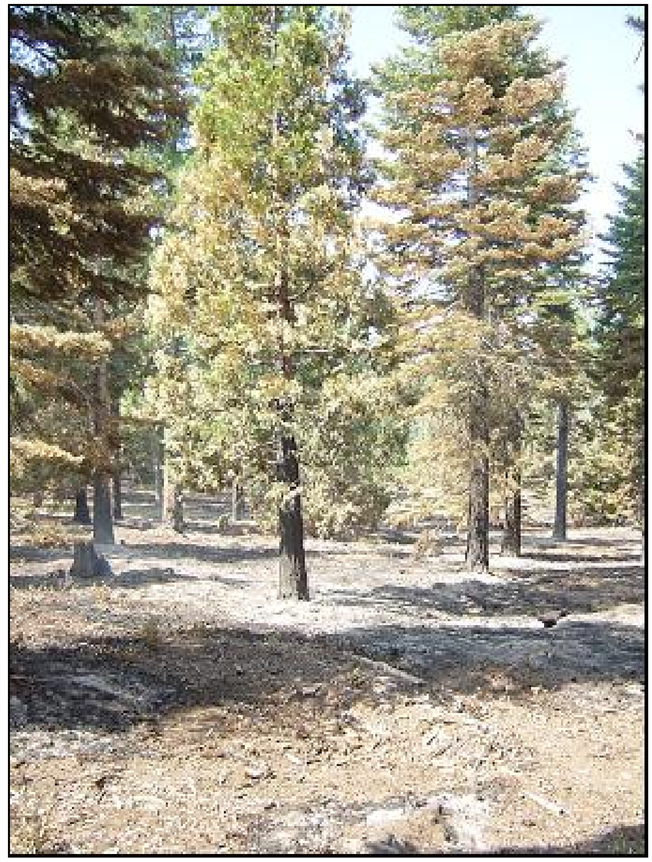
During the Wheeler Fire, both the prior Hungry Fire's burned areas and the Plumas National Forest's prescribed fire units slowed the fire's progression and aided suppression. Because only minimal firefighting resources were initially available, both the mastication and prescribed burn units were particularly significant in aiding suppression activities.

Treatments Stop Spot Fires

To stop the Wheeler Fire's progression, other treated areas along it's northern flank (beside the 27N59 and 27N36 roads) were also utilized for direct attack (figs 2, 3; table 1) and during burn operations.

This included the "Pinebelt Project" from the early 1990s and a portion of the Antelope Border Defensible Fuel Profile Zone. In both of these two project areas—located on the north and southeast flanks of the Wheeler Fire—observations and post-fire assessments confirmed that spot fires (that start from embers that cross fire control lines) were contained or went out on their own in these treated units. This also occurred on the Wheeler Fire's east flank in the previously treated Stony Defensible Fuel Profile Zone (fig. 6).

Direct evidence of this suppression phenomenon is detailed in this report's fire behavior assessment (available at <http://www.fs.fed.us/adaptivemanagement/projects/FBAT/FBAT.shtml). This data was retrieved by establishing fire behavior sensors in treated units where the cameras were tripped by the fire—or dozers. Dozers successfully stopped spot fires from reaching the fire behavior sensors.

Photos: Fire Behavior Assessment Team

Mastication Units

Figure 3 – When the Wheeler Fire burned through areas previously treated with mastication, it burned with high to very high severity (left) as well as low severity (right). The area on left received higher intensity fire that ran uphill from an adjoining slope. This ground also had a greater depth of masticated material. The site on the right was located on the lee side of this hill/slope, positioned on the other side of a road.

Similarly, treated areas (Pinebelt North, Dry Flat projects) on the south and east flanks of the fire (along the 28N03 and 26N46 roads) were used as "anchors" for burn operations.

To effectively conduct a burn operation that minimizes the likelihood of the fire control problems and "spotting" across firelines, firefighters prepare or "prep" the control line. This prep work includes removing ladder fuels, shrubs and small trees, as well as the lower limbs of trees near the margin of the road.

When a burn operation is conducted where a fuel treatment has previously occurred, the prep work is already completed or greatly reduced. With prep work conducted rapidly in an untreated unit, only the first 10 to 20 feet from the road is cleared of ladder fuels. Then when the road is fired off, the fire's intensity increases as it moves away from the road toward the main fire.

Often times, when the fire is moving fast, especially during initial attack, there is no time for prep work. The effect of fuel treatments along roads becomes even more critical.

Stands (or units) treated for fuel hazard reduction don't always stop a fire. Yet when they assist burn operation strategies, they can reduce the wildland fire's intensity and consequent fire severity effects.

Untreated Stands

Figure 4 – The Antelope Complex Fire burned through these untreated eastside pine stands exhibiting moderate (left) to very high (right) severity effects.

Suppression Action	Miles Overlap with Treated Area
Burn Operations	0.5
Prepared for Burn Operations, then Direct Attack Conducted	2.4
Minimum Direct Attack (minimal suppression effort)	3.0
Direct Attack	3.7

Table 1 – Linear amount of fuel treatments used for suppression.

In conjunction with the map (Figure 5 – on following page) of treated areas within and near the fire perimeter and locations of suppression operations, this table provides a quantitative measure for illustrating the effectiveness of fuel treatments in assisting fire suppression efforts. Fuel treatment areas comprised 26 percent of the total Antelope Complex Fire perimeter.

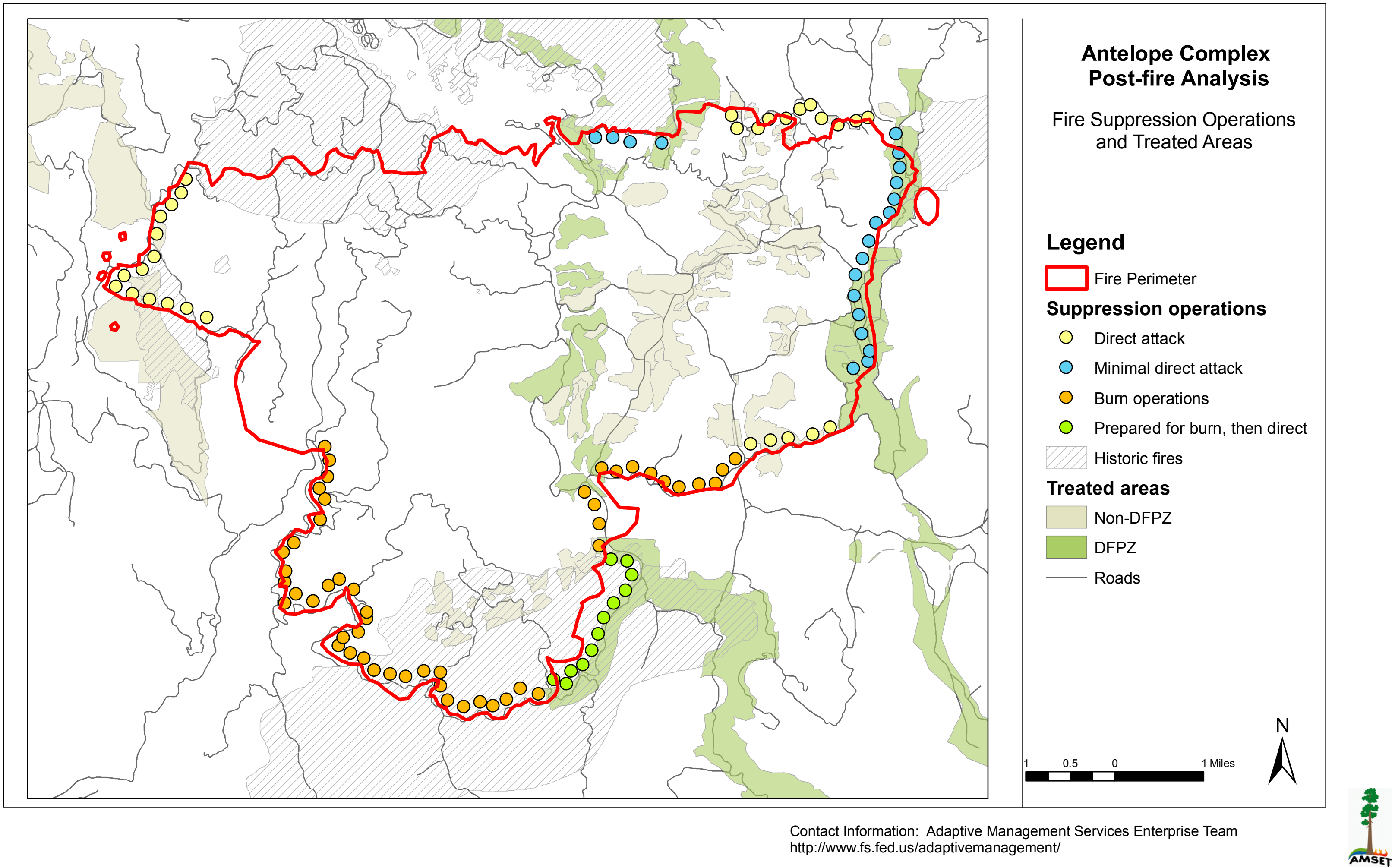


Figure 5 – Map of treated areas within and near the fire perimeter and locations of suppression operations.

Treated Areas Transition Fire from Crowns to Surface

When the Wheeler Fire was burning most actively—exhibiting high intensity and fast spread and the column developed—the fire burned through several treated areas.

During these periods, the fire was an intense (high heat output) crown fire. However, when it entered the previously treated areas, it transitioned to a surface fire. While tree crowns were scorched in most of the treated areas, they were totally consumed in the surrounding non-treated areas (figs 4, 6, 7, and 8).

Photo: Fire Behavior Assessment Team

Figure 6 – When the Wheeler Fire burned into the Stony Defensible Fuel Profile Zone—that had been previously treated for fuel hazard reduction—the fire spread stopped. When the fire moved into this area, the weather was moderate and it was burning as a surface fire.

Once the fire moved through the treated areas, it jumped back up into the crowns and regained its intensity. Therefore, if a larger expanse of treated area would have been available, this might have had a more moderating effect on fire behavior—exhibiting a more sustained transition from crown to surface fire.

It is also apparent that the fire gained momentum and increased in intensity and spread as it developed in large areas of dense fuels that had not been recently burned or been treated for fuel hazard reduction. In some cases, these areas coincided with drainages or steep slopes. One of these areas was a large block directly to the south of Antelope Lake, where the column developed and collapsed.

Firefighter safety is *always* a mainstay to fire suppression activities. During the collapse of the the Wheeler Fire column on the evening of July 6, firefighters were working at the southeast end of Antelope Lake (in the vicinity of the 28N03 and 27N41 road junction).

Column Collapse Requires Quick Retreat

As fire behavior increased, fire crews were attempting to suppress spots along the road to Long Point. Two members of the Fire Behavior Assessment Team were also scouting this area for fire behavior measurements. They had met with several senior fire suppression staff from the Plumas National Forest.

As the column collapsed, all of these people had to make a rapid exit from the area. Two of the roads were quickly blocked by the now rapidly growing, intense crown fire. The only safe exit was to the north along the 27N41 Road.

This exit was located within a portion of the Antelope Border Defensible Fuel Profile Zone. This previously treated area reduced the fire’s intensity and behavior, providing sufficient time for fire crews and Fire Behavior Assessment Team members to safely exit as the fire’s behavior suddenly changed and intensified.

Photos: Fire Behavior Assessment Team

Defensible Fuel Profile Zone

Figure 7 – The combination of fire behavior and vegetation inside previously treated areas in a Defensible Fuel Profile Zone demonstrated moderate (left) and light (right) surface fire behavior.

The Fire Behavior Assessment Team conducted both detailed fire behavior/fuels and post-fire effects measurements and a rapid assessment of fire behavior through different fuel types—in particular, those areas that had already undergone fuel treatments. The use of treated areas on suppression and fire behavior served as the emphasis of the assessment.

III Post Fire Survey of Fire Behavior Evidence and Effects

The emphasis of the post-fire survey of the Wheeler Fire was on quantitative evidence of fire behavior and effects. Two complementary post-fire evidence data sets on fire behavior and effects were compiled: one from field plots and the other from satellite imagery.

Data layers of treatment history, fire history, and Riparian Habitat Conservation Areas—sites protected[3] for the California spotted owl, goshawk and streams—were compiled to allow a comparison of treated, untreated, and protected areas. Data analysis included both descriptive analysis with summary of data in graphs, as well as formal statistical analysis using General Linear Models.

Data From Randomly Placed Plots

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

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

When tree crowns are consumed by fire—crown fire—needle color and freeze provide an indication of the direction and intensity of fire spread. Black needles indicate higher intensity fire; light-brown needles, with some green remaining, indicate lower intensity fire. Needle freeze occurs when the fire is burning intensely, often moving in a specific direction with enough speed to "freeze" the needles in the direction the fire is burning.

Evidence of suppression on the Wheeler Fire was based on observations of handline construction, dozer tracks, and other evidence of burn operations.

Each Fire Behavior Assessment Team crew contained a representative with extensive burn operation experience to record these observations. In addition, direct observation of suppression during the fire was utilized for the associated information on suppression. These data were summarized into four separate variables used in the analysis:

1. The average proportion of crown consumption computed from tree data.
2. The average proportion of crown scorch computed from tree data.
3. The modal soil severity rating (5 classes) was used (see table 2).
4. A composite rating of fire behavior based on crown consumption, scorch, and needle color was computed (see table 2).

[3] 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 for composite tree rating	Definition for soil rating (based on NPS system but with rating levels reversed to correspond with tree ratings)
0	Unburned	Unburned
1	Little or no crown effects.	Very low: Patchy, with some low severity.
2	Low scorch (brown needles).	Low: Litter partially blackened, duff unchanged.
3	Heavy needle scorch (dark brown/red needles, no freeze).	Moderate: Litter charred or partially consumed, some duff affected, wood partially burned.
4	Very heavy needle scorch (red/black needles) and freeze.	High: Litter mostly consumed, coarse light ash, duff charred, stumps consumed.
5	Heavy needle consumption.	Very high: White ash, mineral soil altered, rotten logs consumed.

Table 2 – Severity rating levels applied to each plot.

Satellite-derived information on immediate post-fire severity to vegetation produced by the Pacific Southwest Region Fire staff served as another important source of data evidence for the Fire Behavior Assessment Team.

These data are based on a nationally adopted process using LANDSAT satellite imagery—adjusted for differences in pre-fire canopy cover. Extensive field-based calibration to interpret this imagery has been conducted in California, in particular, within the Sierra Nevada area (Miller and Thode 2007, figs 9a and 9b).

Treated areas and recently burned areas had significantly lower evidence of fire behavior and severity levels than untreated areas.

Several different interpretations of these data are available. The version based on changes to pre-fire canopy cover was used for this analysis, with five categories:

1. 0% canopy cover mortality
2. Canopy cover mortality 1-24%
3. Canopy cover mortality 25-49%
4. Canopy cover mortality 50-74%
5. Canopy cover mortality ≤75%

Findings

Overall, as many of the figure photographs in this report confirm, there was a significant difference in fire behavior evidence and effects (severity) between treated and untreated areas. (See Appendix B for details on statistical analyses.)

Based on the plot data, a significantly greater proportion of high severity soil and tree levels occurred in untreated areas compared to treated areas (figs 10-12). Less than 20 percent of the treated areas received “high” or “very high” tree severity, compared to 45 percent of untreated areas (fig. 10).

While plots in protected areas had the greatest level of “very high” severity (fig. 11), this was not a statistically significant difference from other untreated areas. Similar results, however, were obtained from a statistical analysis of the satellite-based tree severity mapping (table 3).

Treated areas and recently burned areas had significantly lower severity levels than untreated areas. With this more comprehensive data set in which riparian areas were omitted due to overlapping data issues, there was a statistically significantly higher level of severity in protected areas (owl and goshawk core and nest stands) than in other untreated portions of the landscape.

Sufficient spatial information was not available on treatment of riparian areas within more recent and older treatments to separate out these effects spatially.

Photos: Fire Behavior Assessment Team

Prescribed Fire Stands

Figure 8 – The Antelope Complex Fire burned with both low intensity (left) as well as moderate to high intensity as surface fire (right) moved through areas that had already been treated with prescribed fire.

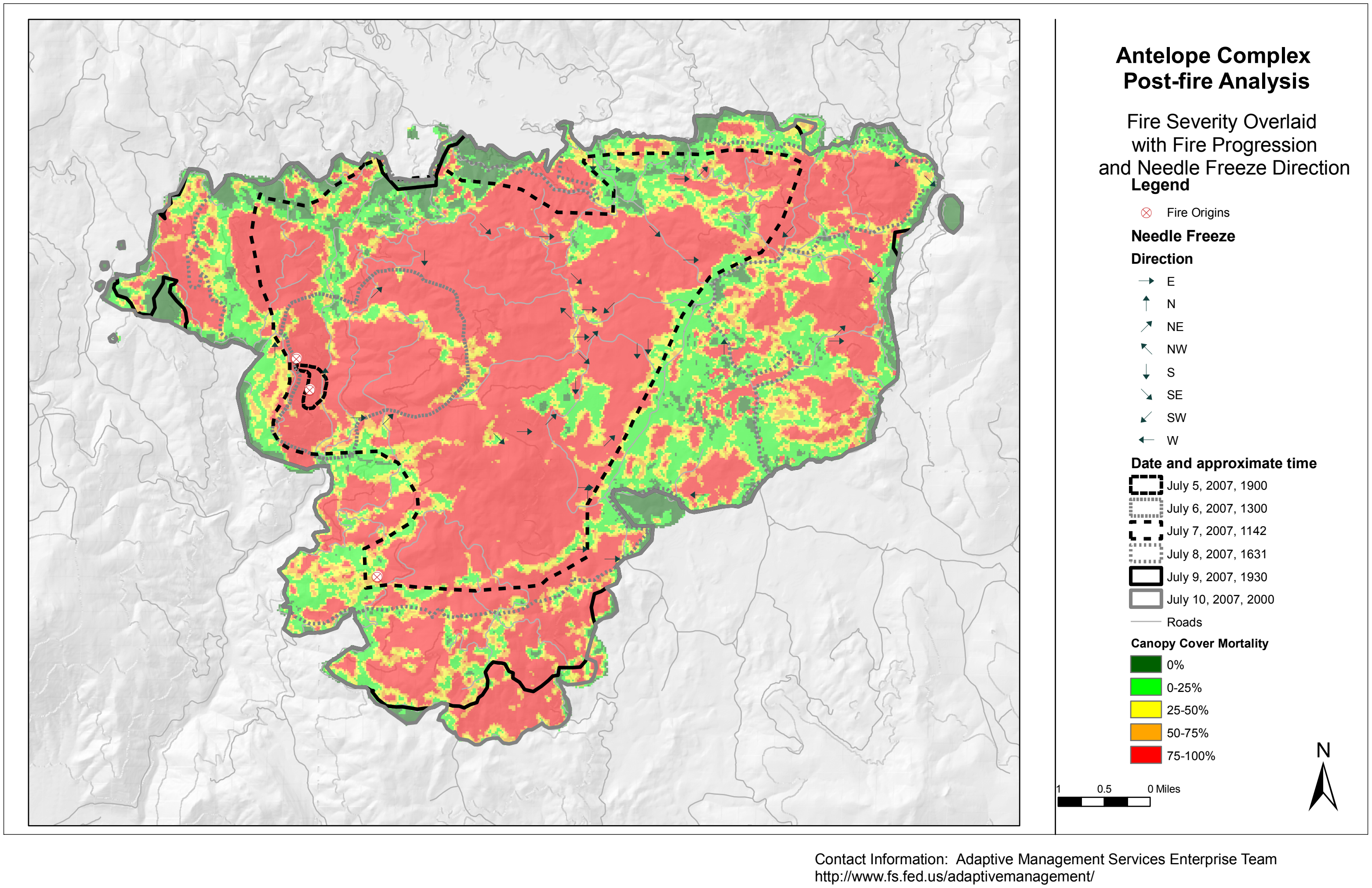


Figure 9a – Map of post-fire severity from LANDSAT imagery along with fire progression and needle freeze.

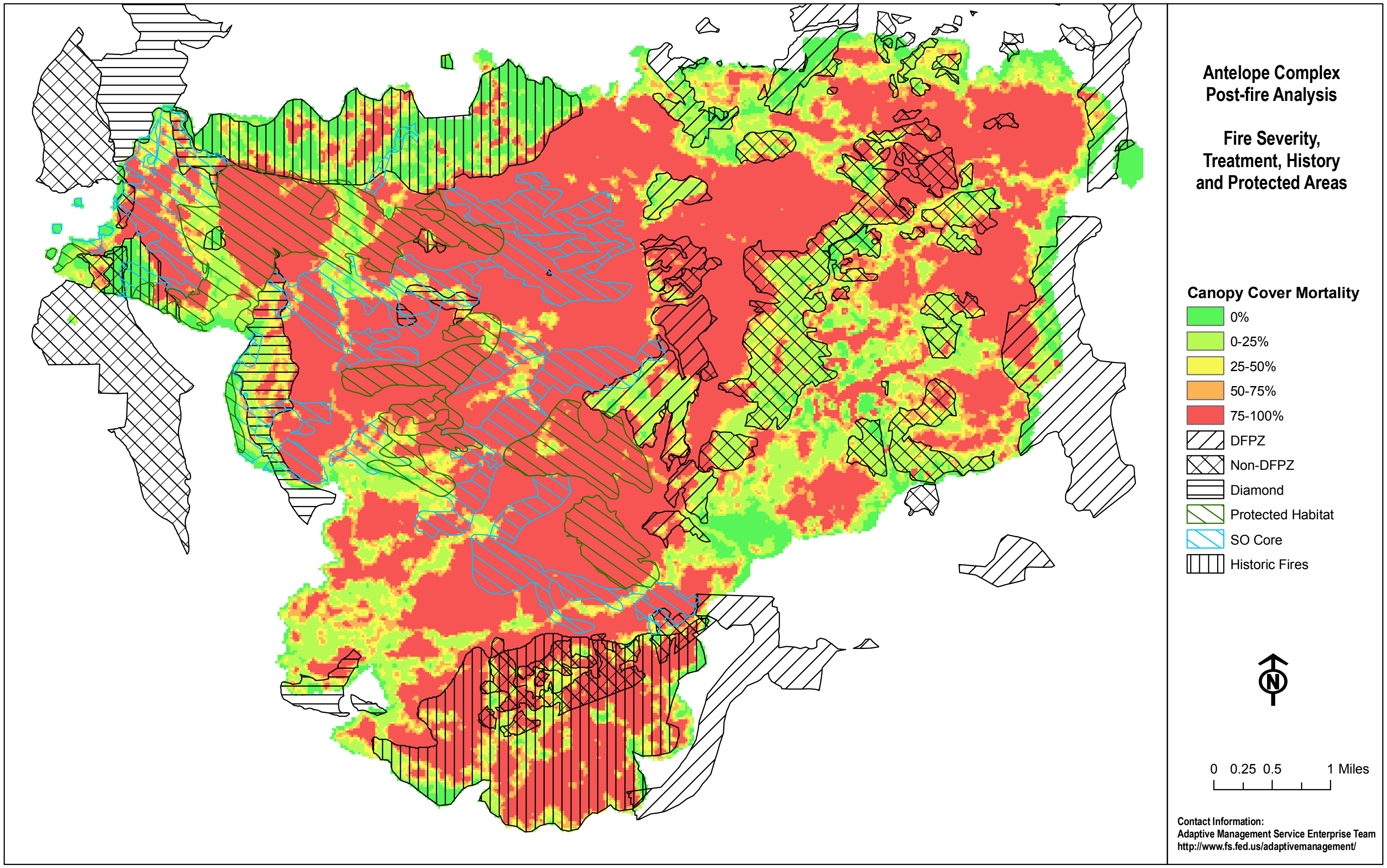
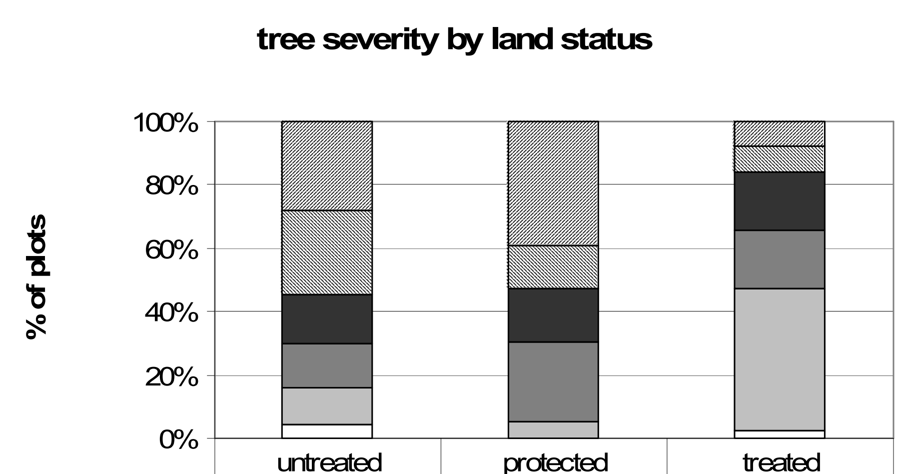


Figure 9b – Map of post-fire severity from LANDSAT imagery with treated and protected areas, and recent fires.

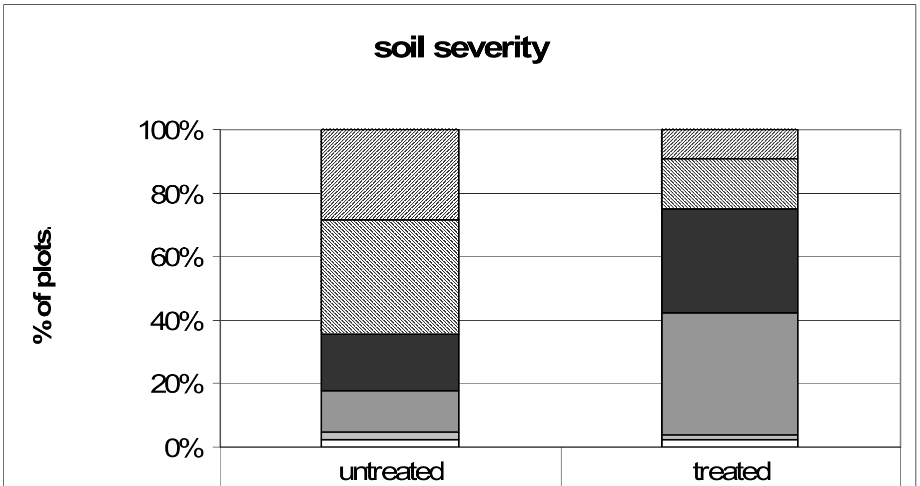
	untreated	treated
v. high	57	6
high	40	6
moderate	29	14
low	32	14
very low	17	34
unburned	5	2

Figure 10 – Proportion of plots sampled by fire behavior evidence rating for treated and untreated areas.



	untreated	protected	treated
v. high	34	23	6
high	32	8	6
moderate	19	10	14
low	17	15	14
v. low	14	3	34
unburned	5	0	2

Figure 11 – Proportion of plots sampled by fire behavior evidence rating in three different land status categories: untreated, protected, and treated. Protected areas include owl and goshawk-Protected Activity Centers and Riparian Habitat Conservation Areas.



	untreated	treated
v. high	51	7
high	65	12
moderate	32	25
low	23	29
v. low	5	1
unburned	4	2

Figure 12 – Proportion of plots sampled by soil severity rating for treated and untreated areas.

Land Status	**Mean**	**Standard. Error**	**95% Confidence Interval**	
			Lower Bound	**Upper Bound**
Untreated [a]	3.9	.08	3.8	4.1
Protected [b]	4.4	.08	4.3	4.6
Recent wildfire [c]	2.4	.08	2.2	2.6
Treated [c]	3.1	.08	2.9	3.3

Table 3 – Summary of mean post-fire severity levels from satellite mapping among treated, untreated, protected (owl and goshawk habitat), and recently burned areas. (Note that "protected" includes core habitat in addition to Protected Activity Centers.) Under the land status column, categories denoted with different letters in the superscript have significantly different means. See Appendix B for details on statistical test results.

Additional Analysis

Some additional preliminary analysis was conducted to compare the post-fire evidence of behavior and effects among the different treatment types (figs 13 and 14). Because a comprehensive data set was not available across the area, this analysis is preliminary.

This information was compiled rapidly from different sources of data from the two fire-affected ranger districts, the Beckworth and Mt. Hough districts. Interviews were also conducted with a variety of individuals, including: Division (district fire management officer), Suppression Battalion (assistant district fire management officer, suppression), Fuels Battalion (fuels officer), hotshot superintendent, hotshot foreman or captain, initial attack incident commander, and district fire ecologist. To make this analysis more definitive, further data verification by the districts would be necessary.

Despite the preliminary nature of this analysis, contrasting results have surfaced. Some of the sample sizes are low for individual treatments (such as selective harvest and mastication). Therefore, they may not be representative. Although Defensible Fuel Profile Zones (DFPZs) are lumped here, interviews with district personnel confirmed that most of these areas were treated with both thinning and burning.

Greatest Severity and Fire Behavior Ratings

Overall, the greatest severity and fire behavior ratings for soils and tree overstory were found in untreated areas and those treated with mastication and selective harvest.

Mastication reduces flame length, enabling firefighters to utilize more suppression options. But this treatment practice also generates great quantities of heat resulting in heavy tree scorch or crown consumption.

While selective harvest is a silvicultural treatment not necessarily designed to reduce fuel hazard, it *can* be designed to achieve both objectives (an intent of the Healthy Forests Restoration Act). The areas sampled under this analysis and study tended to be older individual tree selection harvests in which only medium or large trees were harvested—*not* additional smaller trees or understory fuels that affect fire behavior and effects.

More Variability in Fire Behavior and Severity

The DFPZ-treated areas show more variability in fire severity than other treatment types. This is due, in part, because, compared to the other treated areas, there was more variability in the fire weather and behavior experienced in the DFPZ's.

The day the column collapsed, some of the DFPZ's were hit by the intense fire. Other treatment areas were hit by fire on days when fire behavior was more variable, but less extreme. Likewise, most of the other treated areas were hit by fire on days when fire behavior was more variable but less extreme.

During the first part of the Wheeler Fire, wind gusts were greater, temperatures higher, and relative humidities lower (figs 15, 16, 17). The weather, initially, was somewhere in the range of the 93rd to 95th percentile for Energy Release Component (ERC). It should be noted that the DFPZ projects were designed to withstand fire weather during 90th percentile weather conditions and not more extreme conditions (J. Moghaddas, Mt. Hough District Fire Ecologist, pers. communication).

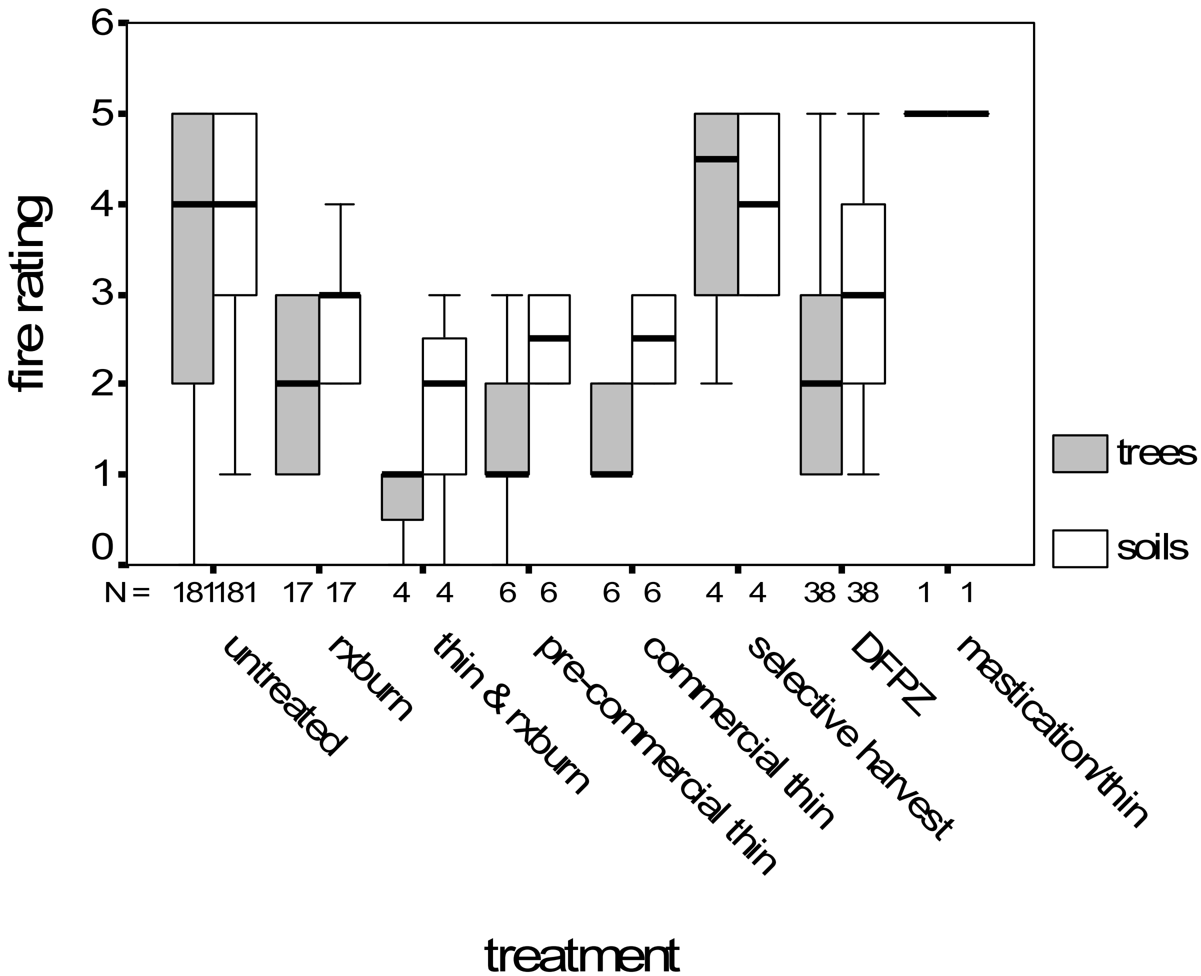


Figure 13 – Box plot of fire behavior rating for forests and soil severity rating from plots by treatment type—as well as untreated areas. DFPZ is Defensible Fuel Profile Zone. Rxburn is prescribed fire. The bar in the center is the median value. The lower end of the box is the 25th percentile; the upper end, the 75th percentile. N = the number of plots.

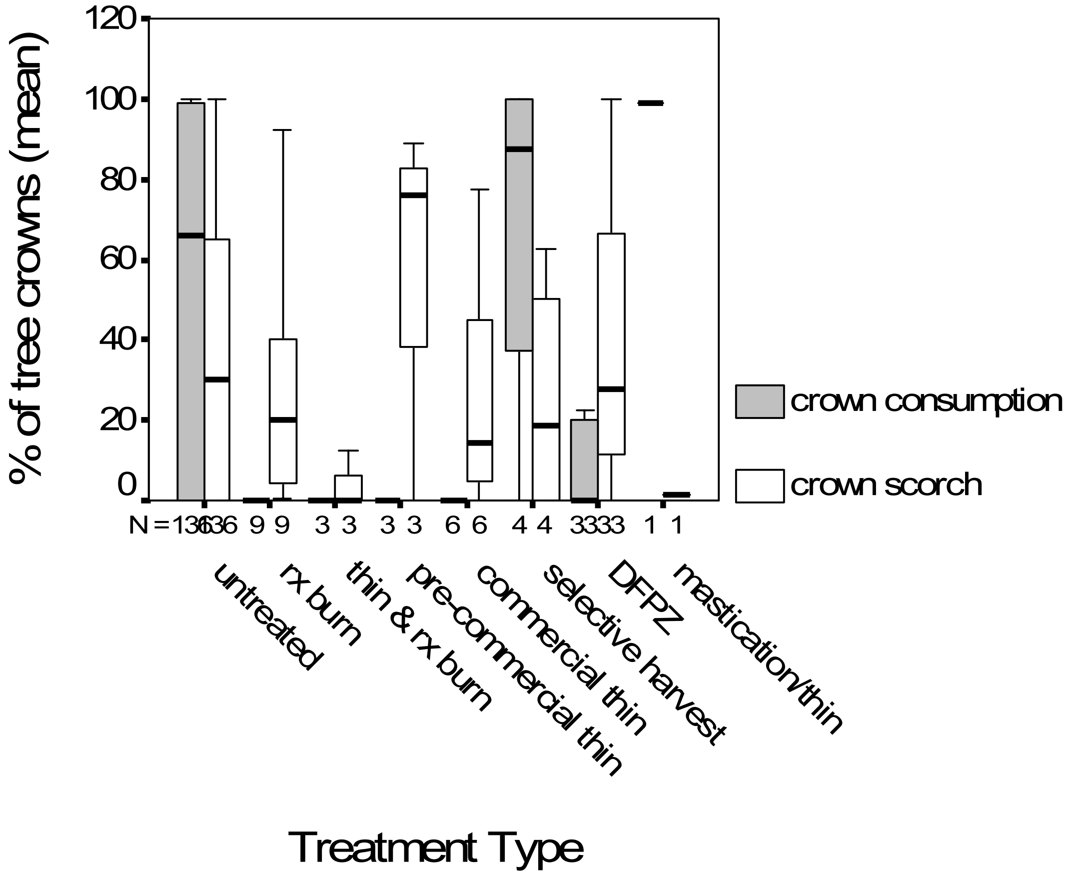


Figure 14 – Box plot of tree crown effects (consumption and scorch) from plots by treatment type as well as untreated areas. "DFPZ" is Defensible Fuel Profile Zone. "Rxburn" is prescribed fire. The bar in the center is the median value. The lower end of the box is the 25th percentile; the upper end, the 75th percentile. N = the number of plots.

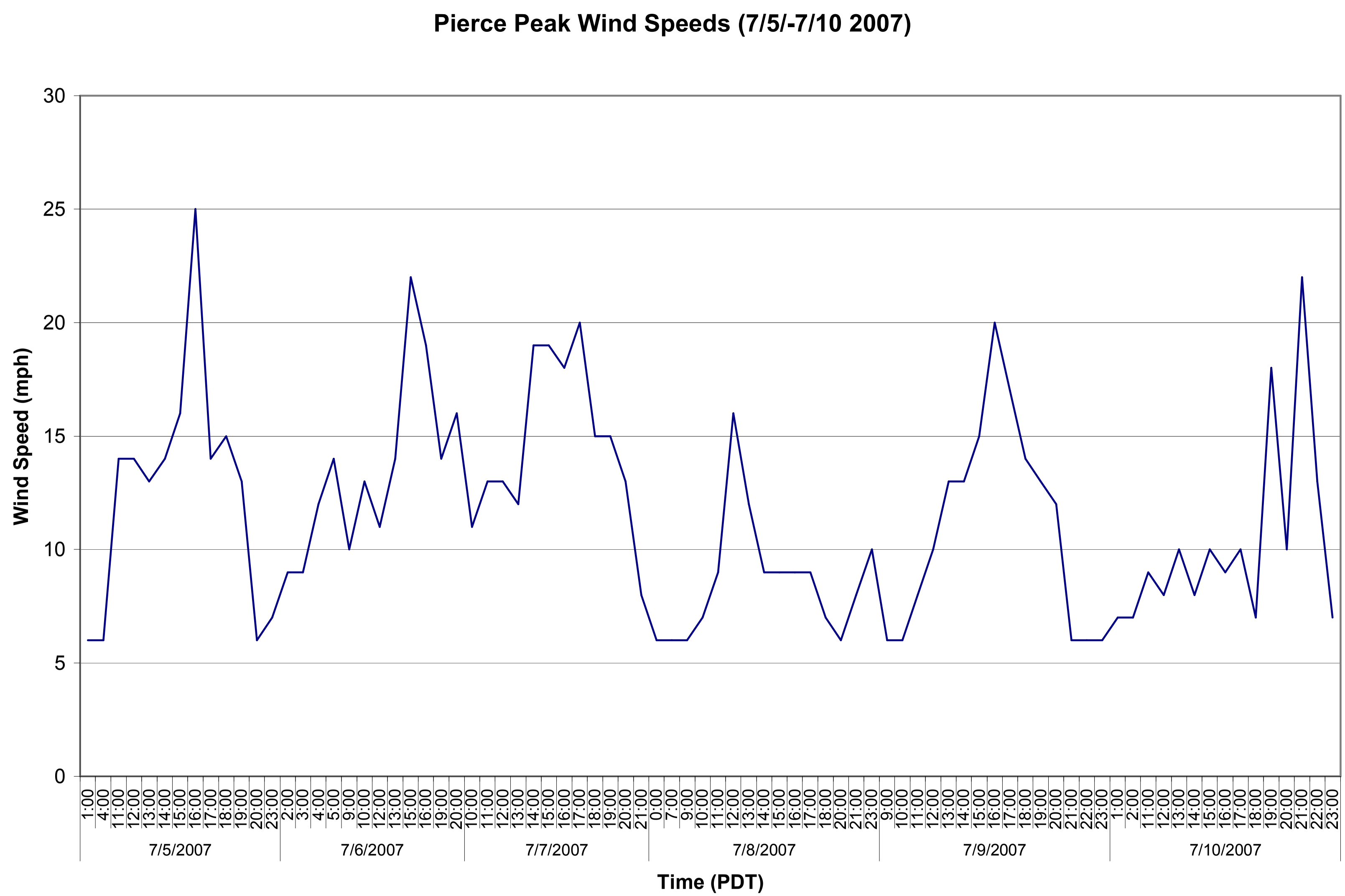


Figure 15 – Hourly maximum wind gusts recorded from the Pierce Weather Station during the duration of the Antelope Fire Complex.

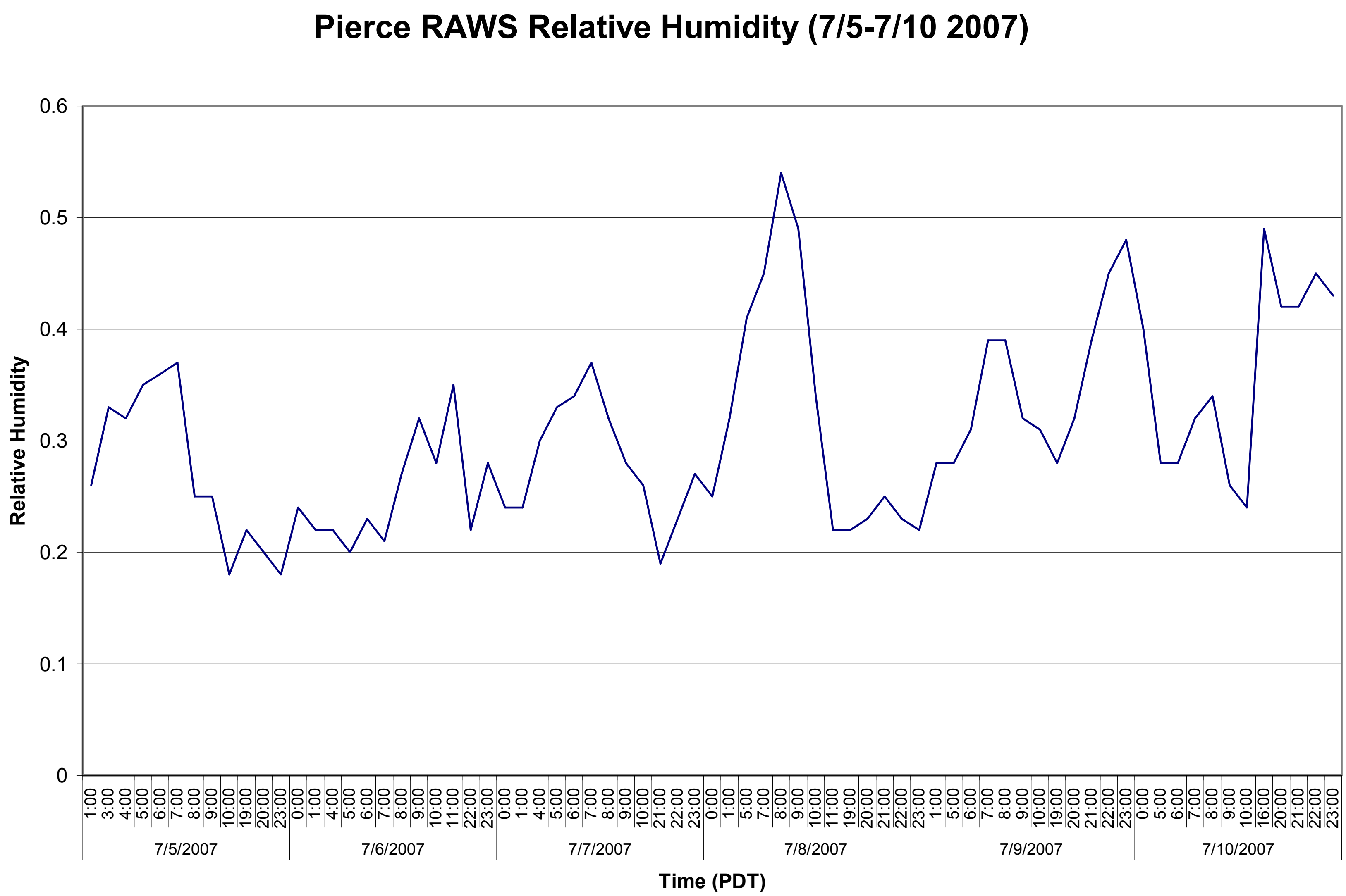


Figure 16 – Hourly average relative humidities from the Pierce Weather Station during Antelope Complex Fire.

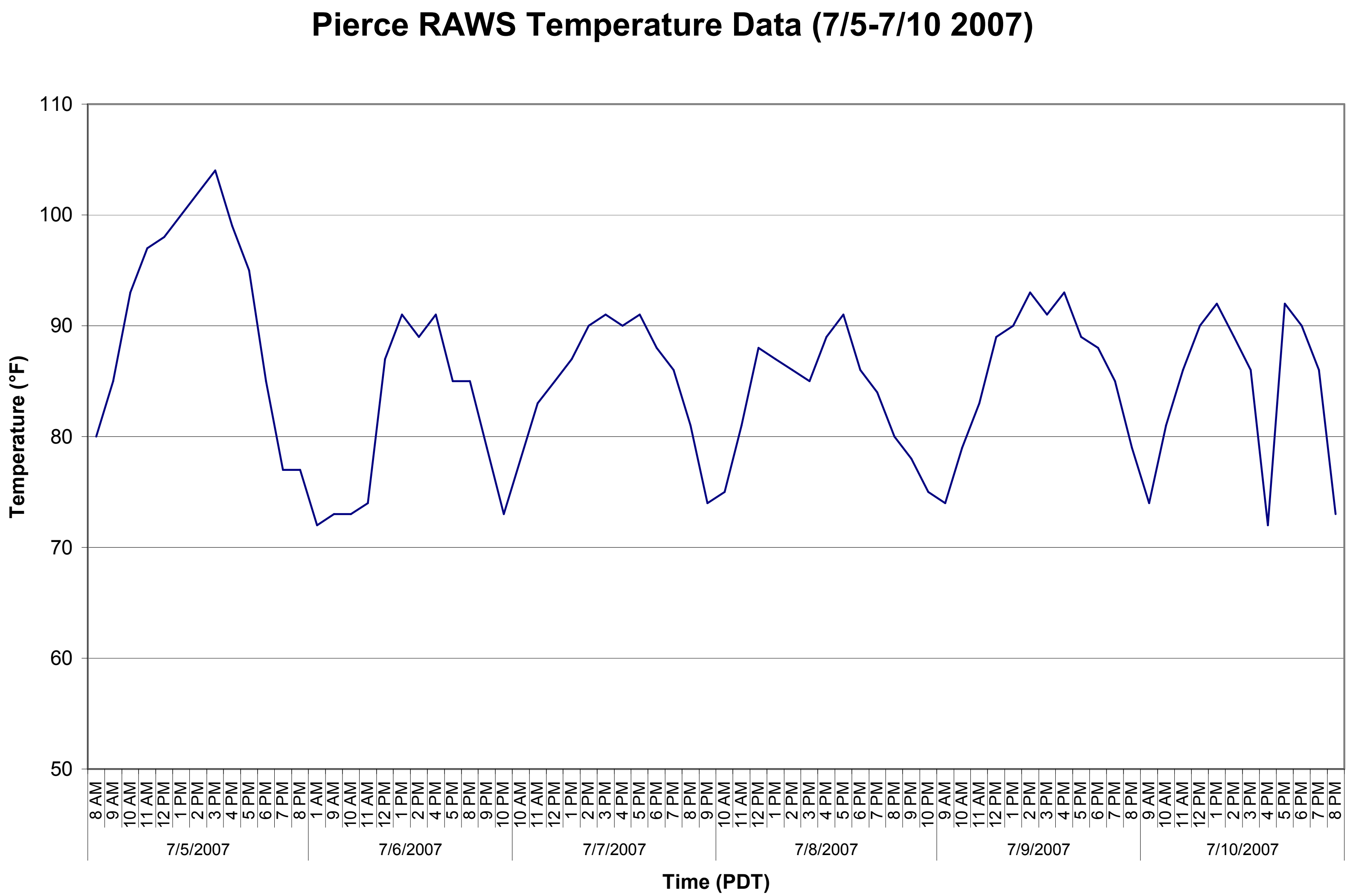


Figure 17 – Hourly average temperature from the Pierce Weather Station during the Antelope Complex Fire.

Consideration should be given to treating a larger portion of the landscape to reduce the likelihood of fires gaining momentum and increasing in behavior to a point where suppression and treatments become less effective.

IV CONCLUSION

The findings of this assessment are not unique among other fires that have occurred in the vicinity on the Plumas National Forest (such as the previous Stream and Boulder fires), or the northern Sierra Nevada area (the Cone Fire on the Lassen National Forest and Angora Fire on the Lake Tahoe Basin Management Unit).

While some of these fires (such as the Cone and Angora fires) have had more documentation on suppression use of treated areas or changes in effects and evidence of fire behavior, they *all* demonstrate that treated areas can reduce fire effects and as well as fire behavior.

Under the Fire Behavior Assessment Team's analysis and study of the 2007 Antelope Complex Fire, in addition to reduced fire effects and fire behavior, direct observation was reported on the use of treated areas during suppression. This occurred along several flanks of the active fire. This firsthand observation occurred for both direct attack with dozers and handcrews, as well as for indirect attack with burn operations.

One of the Plumas National Forest's Defensible Fuel Profile Zones treated area even provided a safe escape route for firefighters—and Fire Behavior Assessment team members—when the column collapsed and two other escape routes were cut off by the fire.

Fire Behavior Observations

Observations of fire behavior during its first two days suggest that large untreated areas (fig. 18) allowed the fire to build momentum and increase in fire behavior (rate of spread and intensity). This effect made it more likely to overwhelm suppression resources and lessen the effectiveness of treatments.

A large portion of this area was untreated due to protective measures imposed for California spotted owl and a smaller area for goshawk. Based on satellite imagery, these protected areas (owl and goshawk nest stands) had significantly greater tree severity compared to untreated or treated areas.

Although treated areas resulted in reduced fire behavior and effects, there were still severe effects when the fire gained momentum and burned through these areas, or when weather conditions were windier, hotter, or drier. The treatments were designed to work under high (90th percentile) and not the severe (greater than 90th weather percentile) weather conditions that ended up occurring on the Antelope Complex Fire.

Based on forecasts of increased temperatures and lengthier fire seasons, what is now 95th or 97th percentile weather conditions could become 90th percentile conditions in the near future.

It is therefore recommended that consideration be given to treating areas more intensively to enable them to withstand future 90th weather percentile conditions. Furthermore, consideration should also be given to treating a larger portion of the landscape to reduce the likelihood of fires gaining momentum and increasing in behavior to a point where suppression and treatments become less effective.

Finally, the Fire Behavior Assessment Team recommends that protected areas be treated to enable them to withstand subsequent fire with lesser effects, and to also prevent these areas from contributing to greater fire behavior across the adjoining landscape.

Photos: Fire Behavior Assessment Team

Stream Management Zones

Figure 18 – Stream management zones experienced very high (left) and moderate-to-high (right) fire intensity and effects on the Antelope Complex. Very high soil severity occurred in both of these sites.

Key Findings

- Treated areas had significantly reduced fire behavior and tree and soil impacts compared to untreated areas.
- Treated areas were utilized during suppression along several flanks of the fire for both direct attack with dozers and handcrews, as well as for indirect attack with burn operations.
- Treated areas that burned during the first two days—when suppression resources were limited and fire behavior more uniformly intense—had reduced effects compared to untreated areas. In some areas, these treated sites had moderate to high severity effects.
- A Defensible Fuel Profile Zone treated area provided a safe escape route for firefighters and Fire Behavior Assessment Team members when the column collapsed and two other escape routes were cut off by the fire.
- Observations of fire behavior during the first two days suggest that large untreated areas allowed the fire to build momentum and contributed to increased fire behavior (rate of spread and intensity). Thus, the influence of these untreated areas made it more likely that suppression resources could be overwhelmed and threatened treated areas and diminished their effectiveness in thwarting fire spread and intensity.
- Satellite imagery reveals that protected areas (owl and goshawk nest stands and core habitat) had significantly greater tree severity compared to untreated or treated areas.

Recommendations

- Consider treating larger portion of landscapes to effectively reduce the likelihood of fires gaining momentum and increasing in behavior to a point where suppression and treatments become less effective.
- Consider treating protected areas to enable these sites to withstand subsequent fire with lesser effects and prevent them from contributing to greater and increased fire behavior across the adjacent landscape.

V APPENDICES

Appendix A – Plot Sampling and Protocol

Data was collected during the Antelope Complex Fire (rapid plots from July 10-12, 2007) and approximately one month following the fire (detailed plots in early August). Plots were sampled using a stratified random approach. Because treated areas served as the emphasis of this study, all of them were sampled.

For both treated and untreated areas, the majority of sampling was conducted where there was road access to speed up the 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 distances of 0.1 to 0.3 tenths of a mile along the road. Where treatments did not occur, plots were placed at distances of 0.3 to 0.6 miles along the road.

At each place selected for sampling along a road, a random bearing was selected and the plot was placed at least 200-feet from the road—but, more often, this occurred at least 600 feet from the road. For one of the larger unroaded areas that contained two spotted owl nest stands, two transects were placed and samples were taken systematically along them. Both of these transects were oriented along an east-bearing to bisect the area and the variation in fire behavior and effects.

Information Gathered at Each Detailed Plot

At each detailed plot, the following information was gathered.

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 consumption,
- percent crown scorch, and
- measured tree height and best estimate of the height to live crown prior to the fire (using an impulse laser to the nearest 0.1m).

Where present, we also recorded needle color and freeze direction. For understory vegetation and soil effects, we utilized the National Park Service severity rating system (NPS 2003). The rating was based on an occular estimate within a 20' radius area.

In addition to the detailed plots described above, more than 50 rapid plots were placed during the fire. For the rapid plots, the same procedures were used to select the sample locations, but instead of detailed tree measurements, an ocular severity rating for trees was applied (table 2).

Appendix B – Statistical Analysis

A general linear model procedure (GLM) (McCullouch and Searle 2001) was used to analyze the data generated in this study.

This is a statistical method that is related to Analysis of Variance but is a more recent variant that is preferred by statisticians. A statistician from the US Forest Service Pacific Southwest Research Station was consulted on the appropriate model to apply.

A simple model was applied to the data where the land status (treated area, untreated area, recent wildfire, and "protected area") was a fixed effect. Post-hoc tests for differences between individual land use categories were conducted using a Multiple comparisons application of the Bonferroni statistic. All statistics were completed using SPSS (Norusis/SPSS Inc. 1999).

Two different analyses were conducted: 1) One that used plot data, and the other 2) that used satellite-derived severity mapping data.

1. Analysis with Plot Data

For the analysis with the plot data, three different analyses were conducted, the first two using tree data and evidence of fire behavior and the third using the soil severity rating.

For the first tree analysis and soil analysis, a combined data set of detailed plots and original rapid plots collected during the fire was created and used. For the rapid plots, a single fire behavior rating system was developed that combined information on crown consumption , scorch and needle color. (See table 2 in this report's section III *Post Fire Survey of Fire Behavior Evidence and Effects*.) The data on percent crown consumption and crown scorch were used to quantitatively apply the five level rating system to the detailed plots in addition to information on needle color (table B1).

Computed Fire Behavior Rating	Average crown scorch (%)	Average Crown Consumption (%)
1 (very low)	< 30	<=50
2 (low)	30-79	<=50
3 (moderate)	>=80	<=50
4 (high)		>=50 &<90
5 (very high)		>=90

Table B-1 – Composite fire behavior evidence for detailed plots, using crown scorch and consumption.

For the second tree-related analysis, only the detailed plot data was used. The variable of crown consumption was the dependent variable.

For all of these analyses, a simple approach was used with only one main fixed effect of land status. For land status, we utilized three categories: treated (Defensible Fuel Profile Zone or other), untreated “protected,” and untreated other. For this analysis, untreated “protected” included owl core habitat, owl and goshawk Protected Activity Centers and Riparian Habitat Conservation Areas.

Results of Analysis with Plot Data

A simple General Linear Model (GLM) model was applied to test for significant differences among different land use categories (fixed main effect). Three different analyses were run with three dependent variables of:

1. Fire Behavior rating,
2. Tree crown consumption, and
3. Soil severity rating.

Fire Behavior Data Including Rapid and Detailed Plots

There were a total of 256 detailed and rapid plots:

- 76 were in treated areas,
- 59 were in untreated protected areas, and
- 121 were located in other untreated areas.

Overall, a significant difference existed among these different land status categories (table B-2). Treated areas had significantly (p<.0001) lower fire behavior ratings than untreated areas (tables B-3 and 4). The mean fire behavior rating for treated areas was low (2), compared to moderate to high (3-4) for untreated areas (table B-3). There was no significant difference between untreated protected areas and other untreated areas.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Model	2418.154	3	806.051	396.101	.000
LANDSTAT	2418.154	3	806.051	396.101	.000
Error	514.846	253	2.035		
Total	2933.000	256			

a R Squared = .824 (Adjusted R Squared = .822)

Table B-2 – Results of General Linear Model analysis using plot data with the dependent variable of composite tree severity rating and the main effect of land use (LANDSTAT).

LANDSTAT	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Untreated Other	3.331	.130	3.075	3.586
Protected	3.559	.186	3.194	3.925
Treated	2.079	.164	1.757	2.401

Table B-3 – Mean values, standard error, and 95 percent confidence interval estimates for fire behavior ratings for each land use category.

(I) LANDSTAT	(J) LANDSTAT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Untreated	Protected	-.2287	.22651	.941	-.7746	.3172
	Treated	1.2516	.20879	.000	.7484	1.7548
Protected	Untreated	.2287	.22651	.941	-.3172	.7746
	Treated	1.4804	.24752	.000	.8838	2.0769
Treated	Untreated	-1.2516	.20879	.000	-1.7548	-.7484
	Protected	-1.4804	.24752	.000	-2.0769	-.8838

Based on observed means.
The mean difference is significant at the .05 level.

Table B-4 – Post-hoc multiple comparisons tests among different land use categories, using the Bonferroni statistic.

Tree Data Including Detailed Plot Data Only

A second analysis was conducted with the detailed plot data to test for differences in tree crown consumption. Tree crown consumption is one measure of transition to crown fire and type of crown fire—passive or active (Scott and Reinhardt 2001). Similar results to those described above for the fire behavior index were found for the amount of crown consumption (tables B-5 and B-6).

There was significantly less ($p<.0001$) crown consumption in treated areas than in untreated areas (table B-6) with an average of 19 percent crown consumption in treated areas compared to 51 percent in untreated areas. There were no statistically significant differences between untreated and protected areas (Riparian Habitat Conservation Areas, Owl and Goshawk Protected Activity Center's, and owl core habitat).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Model	395575.099	3	131858.366	76.388	.000
LANDSTAT	395575.099	3	131858.366	76.388	.000
Error	341780.724	198	1726.165		
Total	737355.824	201			

a R Squared = .536 (Adjusted R Squared = .529)

Table B-5 – Results of General Linear Model analysis using plot data with the dependent variable of tree crown consumption and the main effect of land use (LANDSTAT).

	Mean	Std. Error	95% Confidence Interval	
LANDSTAT			Lower Bound	Upper Bound
Untreated Other[a]	51.216	4.285	42.766	59.667
Protected[a]	51.597	5.997	39.771	63.423
Treated[b]	18.962	5.409	8.295	29.628

Table B-6 – Mean values, standard error, and 95 percent confidence interval estimates for tree crown consumption for each land use category. Note: "a" denotes categories not significantly different (p<.0001) from each other; "b" denotes categories significantly (p<.0001) different from those denoted with "a".

Soils Data

Results for soil severity were similar to those described above for the fire behavior rating, with significant differences (p<.0001) between treated and untreated areas (table B-7). There were significantly (p<.0001) lower soil severity ratings for treated areas (moderate) than for untreated or protected areas (high) (tables B-8, B-9).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Model	3057.338	3	1019.113	733.191	.000
LANDSTAT	3057.338	3	1019.113	733.191	.000
Error	351.662	253	1.390		
Total	3409.000	256			

a R Squared = .897 (Adjusted R Squared = .896)

Table B-7 – Results of General Linear Model analysis using plot data with the dependent variable of soil tree severity rating and the main effect of land use (LANDSTAT).

LANDSTAT	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Untreated	3.587	.107	3.376	3.798
Protected	3.864	.153	3.562	4.167
Treated	2.855	.135	2.589	3.122

Table B-8 – Mean values, standard error, and 95 percent confidence interval estimates for soil fire severity ratings for each land use category.

(I) LANDSTAT	(J) LANDSTAT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Untreated	Protected	-.2776	.18721	.418	-.7288	.1735
	Treated	.7315	.17256	.000	.3156	1.1474
Protected	Untreated	.2776	.18721	.418	-.1735	.7288
	Treated	1.0091	.20457	.000	.5161	1.5022
Treated	Untreated	-.7315	.17256	.000	-1.1474	-.3156
	Protected	-1.0091	.20457	.000	-1.5022	-.5161

Based on observed means.

** The mean difference is significant at the .05 level.*

Table B-9 – Post-hoc multiple comparisons tests among different land use for soil severity rating categories using the Bonferroni statistic.

Analysis with Severity Mapping Data

For the analysis of the severity mapping, the dependent variable was the severity level (continuous data on tree canopy change). For the primary version of the model, a simple approach was used with only one main fixed effect of land status (table B-10).

It was hypothesized that fire may have been more intense and created more severe effects in the more productive, mixed conifer forests. Because vegetation mapping of forest types is not considered sufficiently accurate to warrant a more detailed analysis, this simple proxy was used.

To generate the data for the GLM, random points for each land use category were selected using GRID programming in GIS (table B-10). A target of 300 points for each category was made. The actual selections varied from 288 to 300 per category (table B-10).

Land Status	Code	Number of Random Points
recent wildfire	1	288
treated (dfpz or other)	2	296
untreated owl core habitat	3	300
untreated owl or goshawk protected activity center	4	293
untreated other	5	296

Table B-10 – Number of random selections from the severity mapping data per land use category for statistical analysis.

Where areas overlapped between categories the order listed in the table was used to establish the primary category for analysis. For the most part, little overlap occurred. Where a recent fire overlapped a treated area or core habitat, however, it was coded as recent wildfire—considered to be the overriding influence on fire behavior and effects.

Results of the Analysis with Fire Severity Mapping Data

Simple Model

Overall for the simple model, a statistically significant (p<.0001) difference occurred in fire severity levels among different land status categories (table B-11).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	674486.496	4	168621.624	133.037	.000
Intercept	5255295.638	1	5255295.638	4146.263	.000
LANDCODE	674486.496	4	168621.624	133.037	.000
Error	1860657.082	1468	1267.478		
Total	7829427.000	1473			
Corrected Total	2535143.578	1472			

a R Squared = .266 (Adjusted R Squared = .264)

Table B-11 – Results of General Linear Model analysis using random points with the dependent variable of fire severity map rating and the main effect of land use (LANDCOD).

Average fire severity levels, based on canopy cover change, were high (>69% change) for all untreated categories, moderate (49% change) for treated, and low (23% change) for recent wildfire areas (table B-12).

LANDCODE	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Recent Wildfires	22.781	2.098	18.666	26.896
Treated	48.956	2.069	44.897	53.015
Untreated core habitat	79.503	2.055	75.471	83.535
Untreated PAC	78.744	2.080	74.664	82.824
Untreated Other	68.696	2.069	64.637	72.755

Table B-12 – Mean values, standard error, and 95 percent confidence interval estimates for fire severity ratings for each land status category.

There were statistically significant differences (p<.0001) between treated and all types of untreated categories, as well as between treated and recent wildfires (table B-13). In addition, treated areas had significantly lower severity levels than untreated areas and significantly higher severity levels than recent wildfire areas.

Severity levels were not significantly different among the two types of habitat (Protected Activity Centers, PACs, or core habitat). Owl core habitat had significantly (p=.002) higher severity than other untreated areas. Similarly, owl protected activity centers had significantly (p=.006) higher severity than other untreated areas.

(I) LANDCODE	(J) LANDCODE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Recent Wildfire	treated	-26.17	2.947	.000	-34.46	-17.89
	Untreated core habitat	-56.72	2.937	.000	-64.98	-48.47
	Untreated PAC	-55.96	2.954	.000	-64.27	-47.66
	Untreated other	-45.91	2.947	.000	-54.20	-37.63
Treated	Recent Wildfire	26.17	2.947	.000	17.89	34.46
	Untreated core habitat	-30.55	2.917	.000	-38.75	-22.35
	Untreated PAC	-29.79	2.934	.000	-38.04	-21.54
	Untreated other	-19.74	2.926	.000	-27.97	-11.51
Untreated core habitat	Recent Wildfire	56.72	2.937	.000	48.47	64.98
	Treated	30.55	2.917	.000	22.35	38.75
	Untreated PAC	.76	2.924	1.000	-7.46	8.98
	Untreated other	10.81	2.917	.002	2.61	19.01
Untreated PAC	Recent Wildfire	55.96	2.954	.000	47.66	64.27
	Treated	29.79	2.934	.000	21.54	38.04
	Untreated core habitat	-.76	2.924	1.000	-8.98	7.46
	Untreated other	10.05	2.934	.006	1.80	18.30
Untreated other	Recent Wildfire	45.91	2.947	.000	37.63	54.20
	Treated	19.74	2.926	.000	11.51	27.97
	Untreated core habitat	-10.81	2.917	.002	-19.01	-2.61
	Untreated PAC	-10.05	2.934	.006	-18.30	-1.80

Based on observed means.   ** The mean difference is significant at the .05 level.*

Table B-13 – Post-hoc multiple comparisons tests among different land use categories, using the Bonferroni statistic.

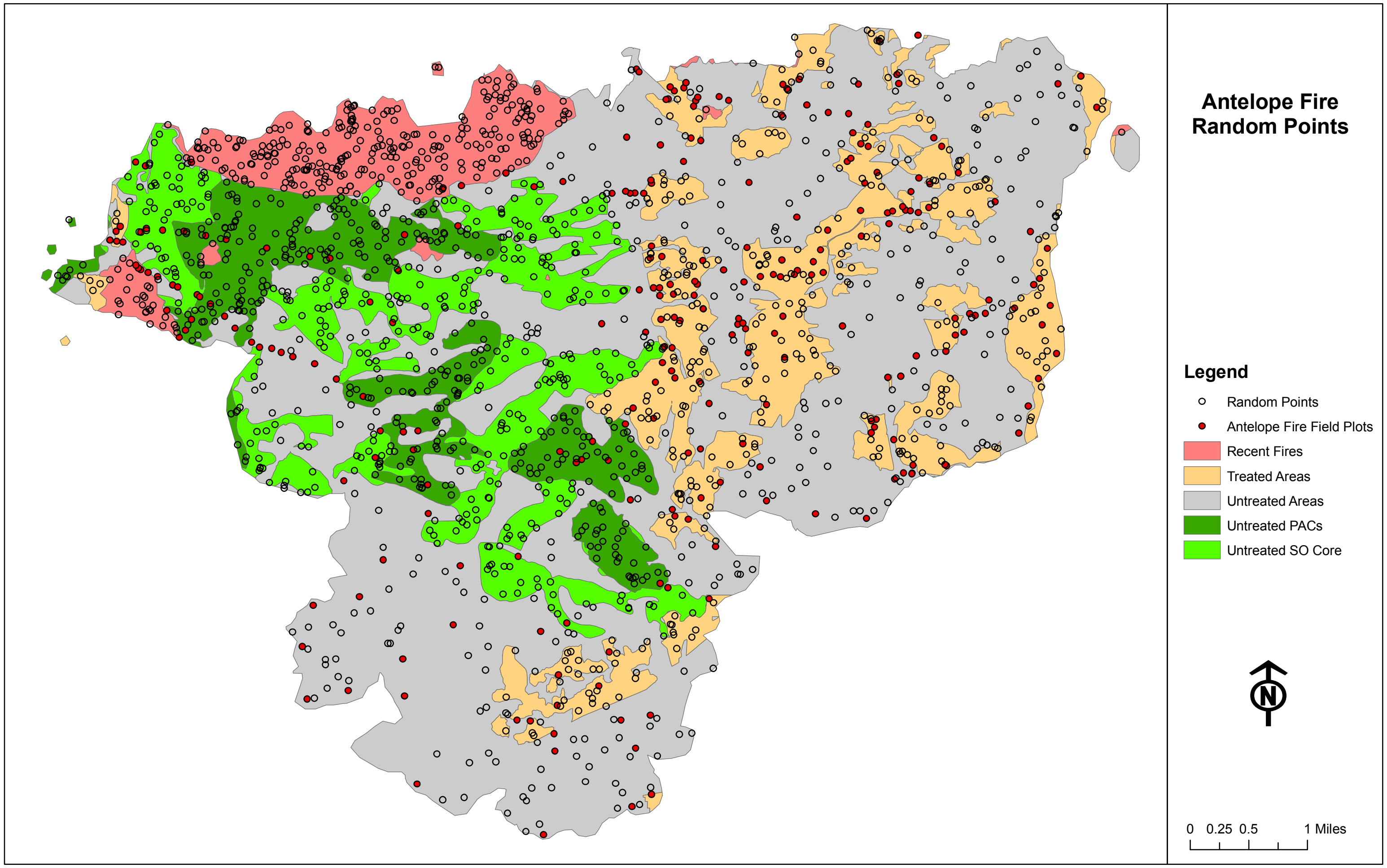


Figure A-1 – Map of mapped strata (recent fires, treated areas, untreated protected owl or goshawk activity centers [PACs], untreated owl core habitat [SO Core], and other untreated areas) with random plots and field plots overlain.

VI LITERATURE CITED

McCulloch, C.E. and S.R. Searle. 2001. General, Linear, and Mixed Model. Wiley Interscience, New York. 325 pages.

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

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.

Norusis/SPSS Inc. 1999. Advanced Statistics 7.5. SPSS inc., Chicago IL.

Scott, J.H. and E.D. Reinhardt. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. US Forest Service, Rocky Mountain Research Station, Research Paper RMRS-RP-29.