United States Department of Agriculture

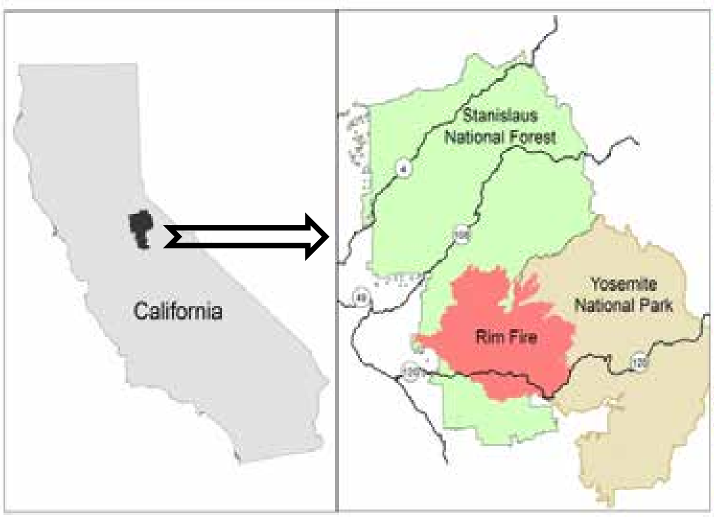
2013 Rim Fire

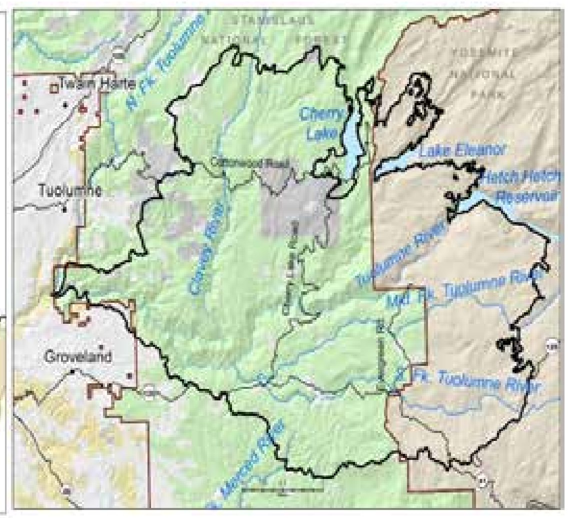
Fuel Treatment Effectiveness Summary

Forest Service | Pacific Southwest Region | R5-MR-060 | April 2015

2013 Rim Fire

Fuel Treatment Effectiveness Summary





Shelly Crook, Carol Ewell, Becky Estes, Frankie Romero, Lynn Goolsby and Neil Sugihara

USDA Forest Service

Dec. 1, 2014

Contents

List of Figures

List of Tables

Introduction

The Rim Fire started from an escaped campfire on Saturday, August 17, 2013 about 18 miles southeast of Sonora, California on the Stanislaus National Forest. Over the next several weeks it grew mostly to the north and east and burned across 257,314 acres of the Stanislaus National Forest (Stanislaus NF), Yosemite National Park (Yosemite NP), and private land making it the largest fire recorded in the Sierra Nevada Mountains over the last 100 years. An overview of the Rim Fire is presented to provide context (Table 1). To assess the initial effectiveness of the fuel treatments in the Rim Fire, we considered the objectives, design, age and location of the treatments as well as the weather, fuel conditions, intensity of the fire at the time it burned into the treatments, and severity of the fire near and within the treatment. The results are summarized for all treatments since 1995 within the Rim fire and case examples are presented to highlight fuel treatment effectiveness.

Table 1. Rim Fire Summary Information

Overview information for the Rim fire.

Information	Detail
Date of origin	August 17, 2013
Official containment date	October 24, 2013
Cause	Campfire
Location	Stanislaus NF (154,428 acres), Yosemite NP (78,753 acres), Private lands (22,973 acres), Bureau of Land Management (129 acres)
Total area burned	257,314 acres (104,131 hectares or 402 square miles)
Structures burned	11 residences, 3 commercial properties, 98 outbuildings

Conditions Leading to August 17

During the summer of 2013, the central Sierra Nevada Mountain Range was experiencing a second year of significant drought conditions (NOAA 2013; Palmer 1965). Precipitation for the previous two years was 50–70 percent of average, and less than 50 percent for that time of the year for the 8 months prior to the fire.

The Energy Release Component (ERC) is the primary fire index utilized by the Stanislaus NF for assessing fire season outlook and fire behavior potential. As live fuels cure and dead fuels dry, the ERC index increases, reflecting drying conditions and predicting potential fire behavior. The Mt. Elizabeth Remote Automated Weather

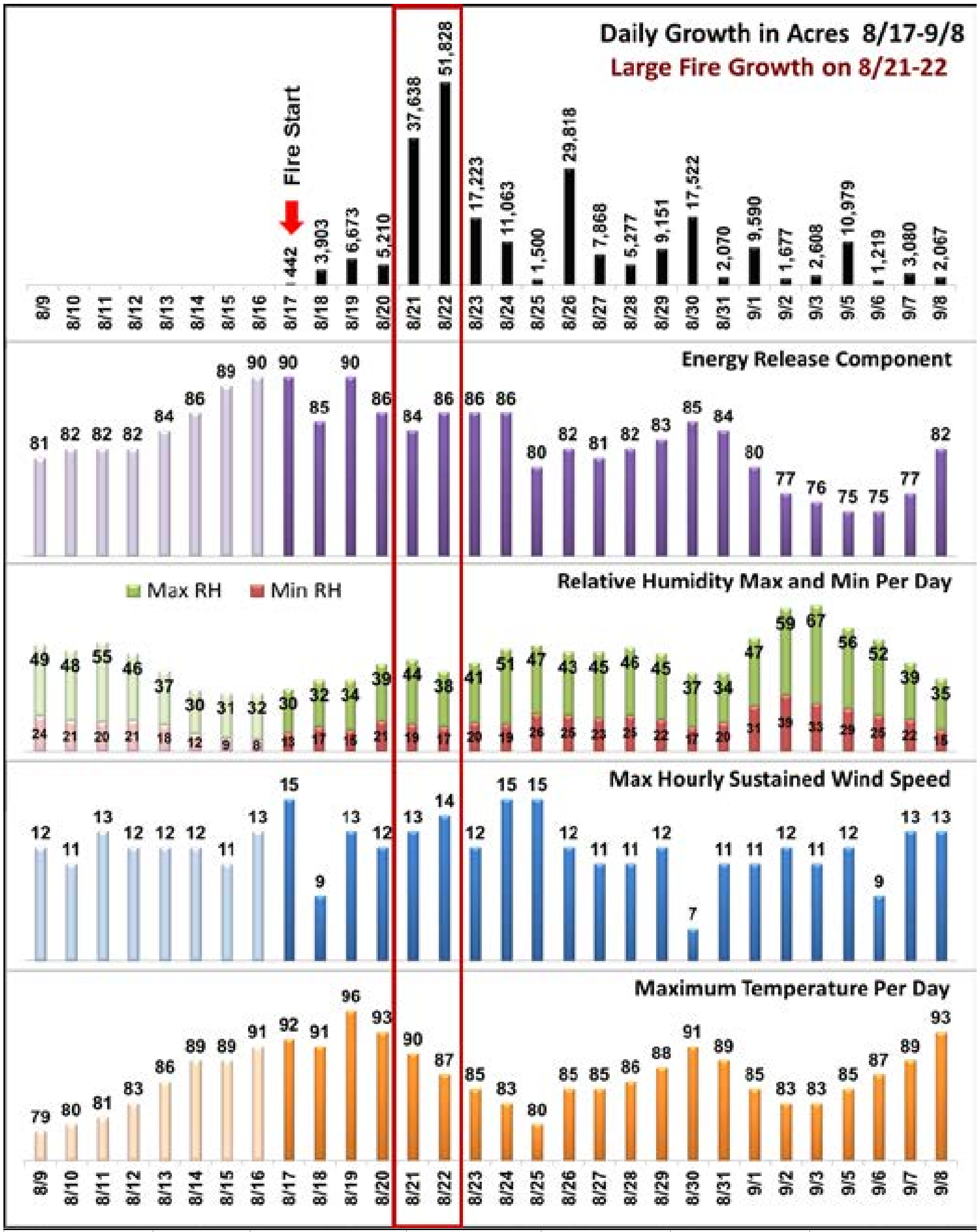
Station (RAWS) is used by the Stanislaus NF as the primary station for weather and fuel moisture calculations in determining seasonal conditions because of its central location and long weather history (1961 to present). As early as February 2013, the ERC from the Mt. Elizabeth RAWS was exceeding historic maximum for the 1997–2012 time period. This index remained above average for much of the fire season.

On August 17, 2013, the day the Rim Fire started, the ERC was calculated at 90. This was the highest level recorded for the 2013 fire season and just shy of the historic maximum of 91 for that date. Moreover, this placed the ERC index above the 97th percentile (the level at which less than 3 percent of the days in the historical period have calculated a higher ERC value), indicating a critical level and the potential for extreme fire behavior (Figure 1).

The Smith Peak RAWS is the closest RAWS to the start of the Rim Fire, located at 3870 foot elevation, four miles south of the fire’s origin. According to the Smith Peak RAWS the period preceding the start of the Rim Fire was above normal for summertime with warm, dry, and breezy conditions. The maximum daily temperature ranged from 79° to 92°F, the minimum relative humidity ranged from 8 to 24 percent and the peak sustained wind ranged from 11 to 15 mph (Figure 1).

Figure 1. Rim Fire Histogram.

Chart displays the daily growth in acres, Energy Release Component based on Mt. Elizabeth, and weather conditions for Aug. 9 to Sept. 8, 2013 from the Smith Peak RAWS. The week prior to the start of the Rim Fire is included to show conditions that set the stage on August 17th when the Rim Fire began. This chart's data is contained in an accessible data-table after the chart.



Date	Acres of fire growth	Energy Release Component	Relative Humidity Maximum	Relative Humidity Minimum	Maximum Hourly Sustained Wind	Maximum Temperature
August 9	0	81	49	24	12	79
August 10	0	82	48	21	11	80
August 11	0	82	55	20	13	81

Date	Acres of fire growth	Energy Release Component	Relative Humidity Maximum	Relative Humidity Minimum	Maximum Hourly Sustained Wind	Maximum Temperature
August 12	0	82	46	21	12	83
August 13	0	84	37	18	12	86
August 14	0	86	30	12	12	89
August 15	0	89	31	9	11	89
August 16	0	90	32	8	13	91
August 17	422	90	30	13	15	92
August 18	3,903	85	32	17	9	91
August 19	6,673	90	34	16	13	96
August 20	5,210	86	39	21	12	93
August 21	37,638	84	44	19	13	90
August 22	51,828	86	38	17	14	87
August 23	17,223	86	41	20	12	85
August 24	11,063	86	51	19	15	83
August 25	1,500	80	47	26	15	80
August 26	29,818	82	43	25	12	85
August 27	7,868	81	45	23	11	85
August 28	5,277	82	46	25	11	86
August 29	9,151	83	45	22	12	88
August 30	17,522	85	37	17	7	91
August 31	2,070	84	34	20	11	89
September 1	9,590	80	47	31	11	85
September 2	1,677	77	59	39	12	83
September 3	2,608	76	67	33	11	83
September 5	10,979	75	56	29	12	85
September 6	1,219	75	52	25	9	87
September 7	3,080	77	39	22	13	89
September 8	2,067	82	35	15	13	93

Chronology of the Rim Fire

August 17, 2013 was hot, dry and windy. At 3:00 in the afternoon, 25 minutes before the Rim Fire was discovered, the Smith Peak RAWS reported a temperature of 87 degrees, relative humidity of 17 percent, and sustained west winds of 15 mph with gusts up to 21 mph. The Rim Fire started in the canyon bottom, near the confluence of the Clavey and Tuolumne Rivers, growing rapidly upslope, burning up canyon into areas with difficult access for the first 2 days (August 17–18). Fire suppression efforts and personnel commitments continued to grow, but containment lines became more difficult to achieve.

According to the initial Rim Fire Incident Meteorologist, the general weather pattern over the Rim Fire was hot and dry with a very unstable air mass. An area of low pressure was off the West Coast on August 18th as high pressure remained over the Southwest desert. This orientation allowed upper level moisture to stream in overhead from the south and southeast. The deepening low pressure helped to destabilize the atmosphere over the Rim Fire.

On the 3rd & 4th days (August 19–20) the fire expanded rapidly to over 16,000 acres. As a result of increasing upper level moisture and an unstable air mass the National Weather Service in Sacramento issued a Red Flag Warning for thunderstorms for August 19th through August 21st. During this time period thunderstorms did not seem to directly impact the Rim Fire as they remained east and north over the Sierra Crest.

On the 5th & 6th days (August 21 and 22) fire behavior and growth were *extreme*, with the burned area expanding to over 100,000 acres. The atmospheric instability allowed for plume dominated fire behavior on August 19 through August 22. Pyro-cumulonimbus were present each afternoon producing some precipitation, virga (precipitation that evaporates before reaching the ground), and lightning impacting the Rim Fire area on August 19 to 21. The air mass remained unstable on August 22nd facilitating for the fourth consecutive day of pyro-cumulonimbus effects. The Rim Fire burned a total of 89,466 acres or 35% of the total burned area in less than 48 hours. At 3:30 PM on August 21 the Incident Meteorologist reported the column from the fire had reached a vertical elevation of 43,000 feet. Figure 2 and 3, taken the afternoon of August 22nd; display the pyro-cumulonimbus cloud development along the east flank of the fire. Later that afternoon, the convection column collapsed creating downdrafts and strong surface winds, estimated to be greater than 100 mph in some areas, spreading the fire rapidly and in some areas and blowing down or breaking trees that had burned the day before. Figure 4 shows the effects of these winds on the standing, recently burned trees.

For the next seven to ten days fire spread was active, but the fire intensity was low to moderate allowing firefighters to make incremental progress. The containment of the fire perimeter proceeded slowly due to the large size and limited access. In the third week the fire activity decreased, with the fire burning primarily in the higher elevation wilderness areas on the northeast side of the fire. After September 8 fire growth was nominal until full containment on October 24th. Many different strategies were utilized during the Rim fire, and Sidebar 1 (Fight Fire with Fire) introduces one strategy.

Figure 2. Aerial view.

Aerial photo of the extensive smoke plume on the second big blow up day August 22, 2013.

Photo by Paul Clark, CAL FIRE.

Figure 3. Ground view.

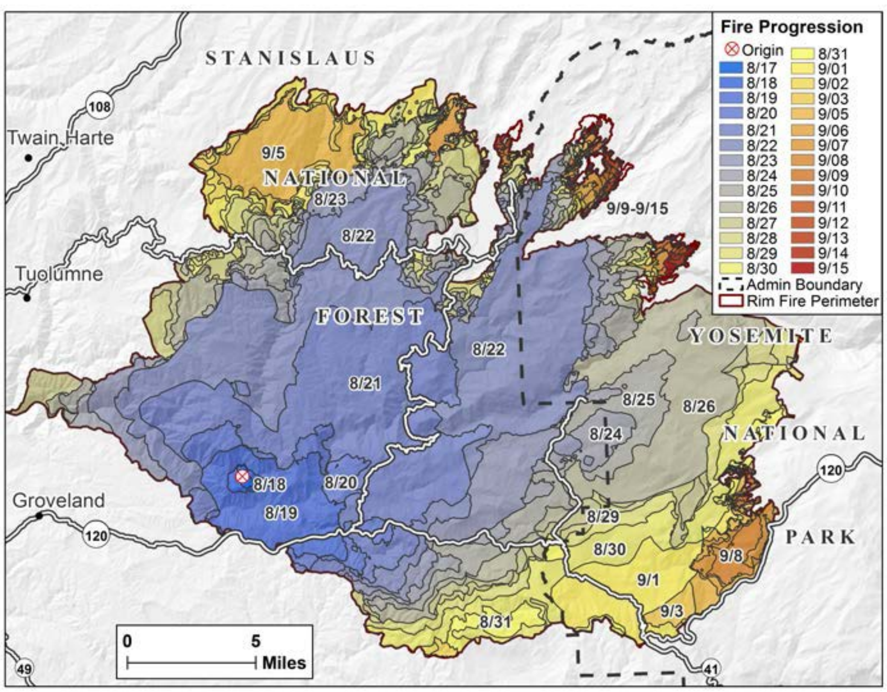
View from the Crane Flat Helibase webcam at the same time as Figure 2 on August 22, 2013.

Figure 4. Aftermath of the Fire.

Trees that burned on August 21 and were snapped off and blown over by the high down draft winds experienced on August 22.

Figure 5. Rim Fire progression from August 17 to September 15, 2013.

Map shows the fire's origin and its eastward progression toward Yosemite National Park daily between 8/17 through 9/15. The boundaries of the Rim Fire and the Admin boundary are shown.



Sidebar 1. Fight fire with fire

Burn-out tactics (strategic ignitions) are used to strengthen containment lines and decrease fire intensity, and were used on the northern and eastern flanks of the Rim Fire. Indirect containment lines are built away from the active fire's edge to take advantage of existing barriers (e.g., rocks, roads) and to provide for firefighter safety. If unburned fuel is left between the containment line and the main fire, it can burn intensely compromising the indirect line. This can result in spot fires across the indirect containment line. Burn-out operations consume unburned fuel between the main fire and the control lines, effectively widening the control line.

Firefighters have several methods of applying fire to the ground for burn-out operations. Aerial ignition by helicopters allows for large areas to be ignited more safely than hand ignitions, especially in steep, rugged terrain. Hand ignitions with drip torches work well when burning small areas or along the containment lines while supporting aerial ignitions.

"By lighting at the tops of the ridges, we can create a nice backing fire that removes surface fuels, while keeping the canopy intact."

Stanislaus Helicopter Superintendent, Dave Phillips

Figure 6. Left—Aerial ignition burn-out operation.

A helicopter view of an aerial ignition burn-out operation to slow the fire's movement coming out of Clavey Creek and moderate fire effects.

Figure 7. Right—Drip torch.

A firefighter utilizing a drip torch to ignite fuel between the main fire and the control line (AP Photo/U.S. Forest Service, Mike McMillan).

Ecological Setting Prior to the Rim Fire

Vegetation types within the Rim Fire area are adapted to the regular occurrence of fire, and are considered fire dependent ecosystems (Figures 8 and 9, Sugihara et al. 2006). Tables 2 and 3 summarize the general type and amount of vegetation within the Rim Fire perimeter and frequency of fire that is characteristic of these vegetation types. Shrublands and live oak woodlands cover most of the steep slopes in the canyon bottoms and lower slopes. Upper slopes and ridges above 4,000 foot elevation are often dominated by mixed conifer stands of ponderosa pine, red fir, and lodgepole pine forests. Open, rocky, glaciated landscapes are common in the upper elevations on the east side of the fire area.

Figure 8. Vegetation of the Rim fire and Surrounding Area.

Map showing the types of vegetation of the area including grass, shrub, oak woodland, and conifer. Grass, shrub, and oak woodland follow the river and stream valleys, while conifers are in higher elevations. Map also shows the Rim Fire's boundary and the administrative boundary. (CALVEG dataset 2005).

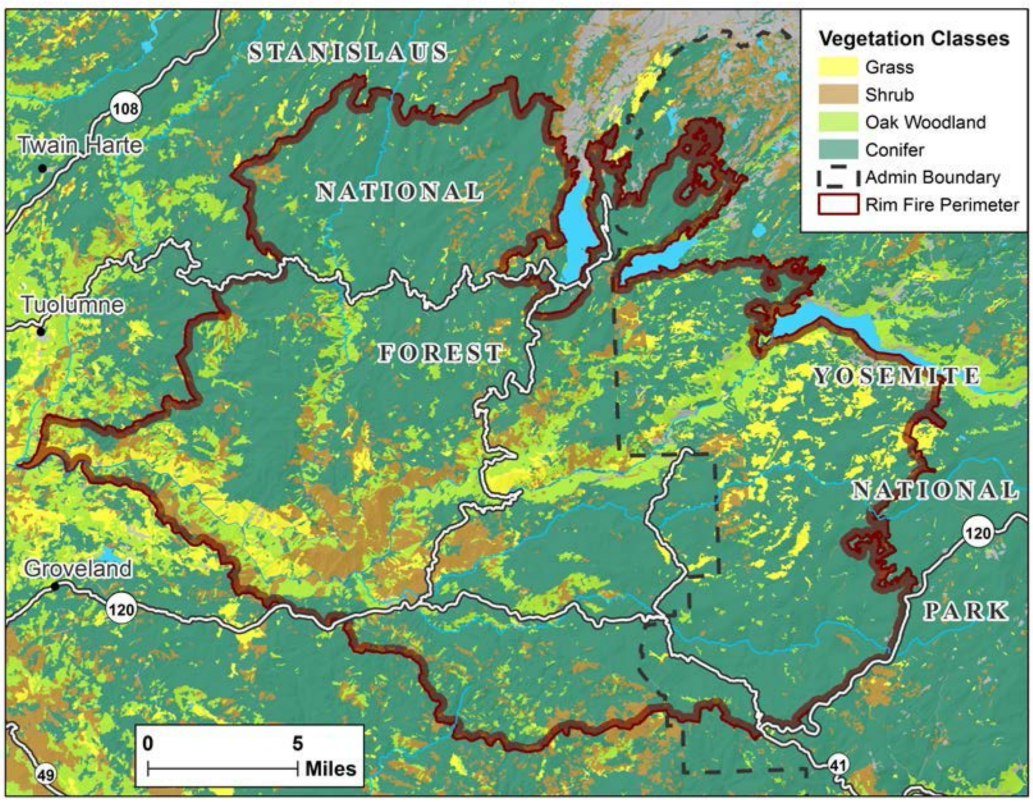


Table 2. Major vegetation types.

Area covered by major vegetation types within the Rim Fire perimeter

Cover Type	Acres
Barren	1,876
Conifer	183,089
Oak woodland	30,559
Grass	13,997
Shrub	27,146
Urban	99
Water	548
Total Acres	257,314

Figure 9. Fire regimes for the Rim Fire area.

Map showing the distribution of fire regimes for the Rim Fire area. Most of the area is represented by fire regime I, fire regime III occurs in the canyons in scattered patches and fire regime II and IV occur in scattered locations at higher elevations. (Safford and van de Water 2013, Landfire 2013, FRCC 2010 Guidebook).

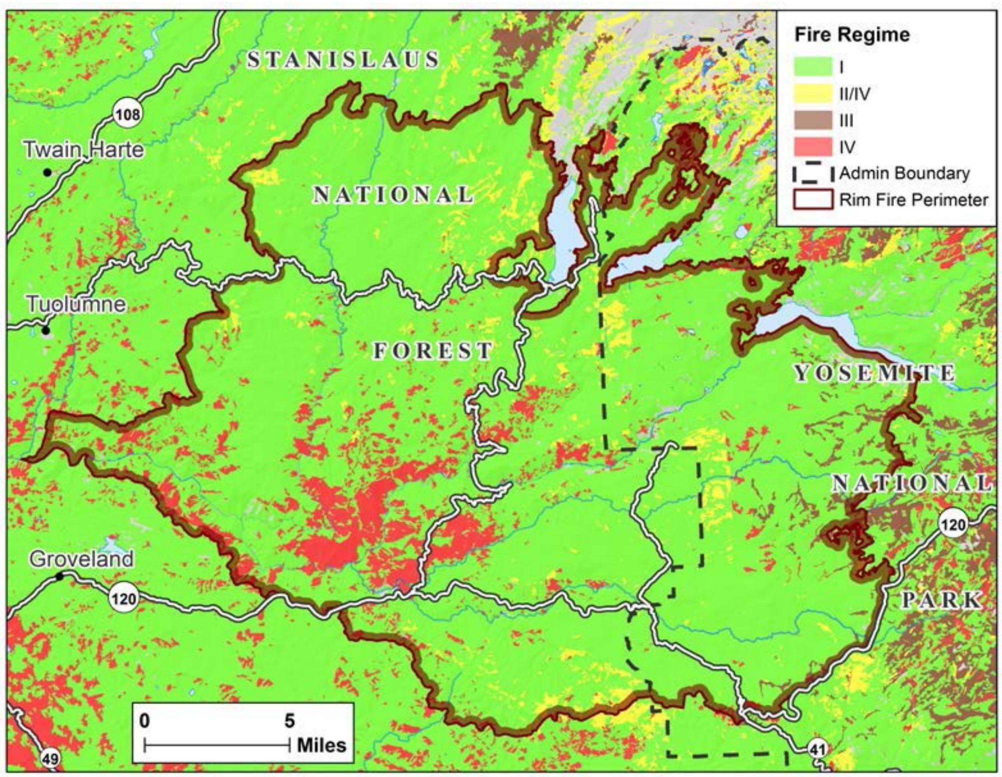


Table 3. Fire Regimes.

Pre-settlement fire regimes for the major vegetation groups in the Rim Fire area (Safford and van de Water 2013, Landfire 2013, FRCC 2010 Guidebook).

	Mixed Conifer and Ponderosa Pine	Grass	Live Oak woodland	Red Fir and Lodgepole Pine	Shrub
Fire Return Interval (years)	Frequent 0–35 years	Frequent 0–35 years	Infrequent 35–200 years	Infrequent 35–200 years	Infrequent 35–200 years
Fire Severity	Low/mixed	Replacement	Mixed/low	Mixed/low	Replacement
Fire Regime	I	II	III	III	IV

Fire History and Fire Return Interval Departure (FRID)

Fire return interval departure (FRID) is based upon fire history, the vegetation types and the pre-settlement fire regimes for those vegetation types, as outlined above. Figure 10 shows that prior to the Rim Fire, some of the area inside the Rim Fire footprint burned multiple times while other areas have not burned within the recorded fire history. Figure 11 illustrates the condition class departure category which represents the culmination of the departure between the historic fire regime (Figure 9 and Table 3) and actual fire history (Figure 10) for the area. A large portion of the landscape within the Rim Fire footprint was identified as moderate/high condition class. This means these areas have burned less frequently than was characteristic for this landscape, so these areas are more departed from historic conditions. Similarly, the areas identified as low departure had burned recently, and the fire regime and recent fire history were closer to historic patterns. If considering the time since last fire, we expect that most of the Rim Fire area is now in a low departure category (e.g., landscape fire processes are closer to historical patterns), though some areas in the shrublands have now burned too often based on recent fire history compared to their pre-settlement fire regime.

Figure 10. Fire history.

This map delineates the documented fire history in the area (1908–2011) with the most recent fire perimeter on top of previous fires. The 2013 Rim Fire boundary is delineated as a thick brown line.

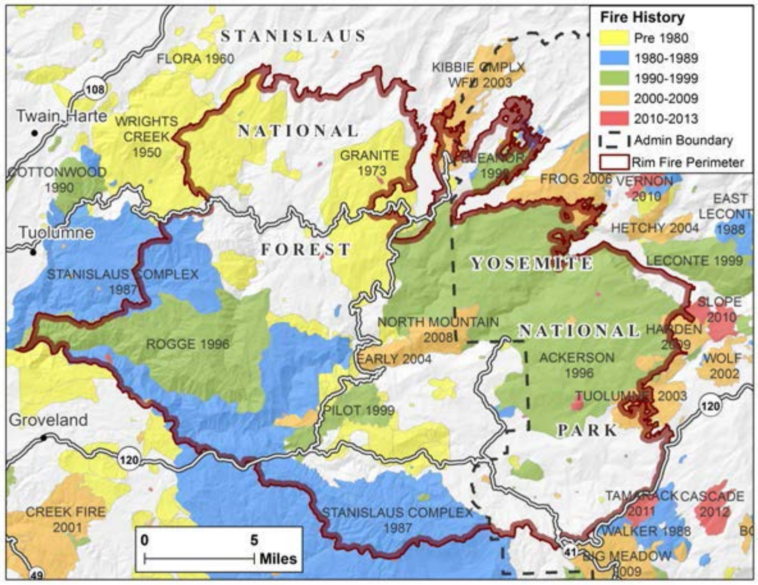
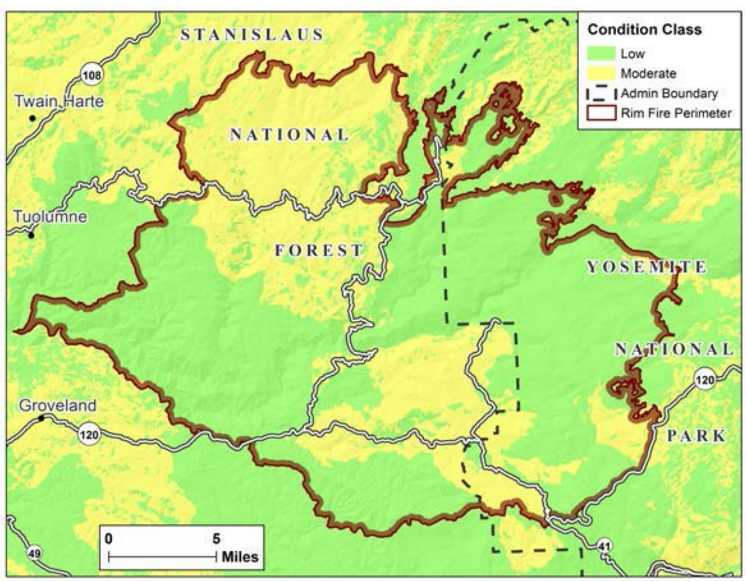


Figure 11. Fire return interval departure.

Prior to the Rim Fire most of the area is represented by low departure from characteristic fire return intervals. A wide band through the middle elevations is mostly moderate to highly departed and has a longer period of uncharacteristic fire exclusion.



Severity patterns within the Rim Fire

Fire severity is the effect of fire on ecosystem properties and is most often defined by the degree of soil heating or mortality of vegetation. Throughout this report fire severity is referencing the Rapid Assessment of Vegetation Condition after wildfire initial, immediate post-fire, composite burn index map (RAVG 2013).

Although vegetative severity mapping of the Rim Fire showed that 103,000 acres (40%) of the landscape had high burn severity (75 – 100% decrease in vegetative canopy cover), this severity was highly variable across the landscape. Differences were observed in fire severity patterns between August 21st and the 22nd (the two large growth days) and the remaining fire progression (Figure 12). Fire severity on August 21st and 22nd was highly influenced by prevailing weather conditions discussed previously in the fire chronology (Figures 13–15). Of the almost 90,000 acres burned during those two days, 60% of the area was initially categorized as high severity (Figure 14). Throughout the remaining days, fire severity was well distributed by severity type with only about a quarter of the area burning in high severity (Figure 15), an amount closely matching historic fire regime ratios (Safford and van de Water 2013, Landfire.gov). Preliminary observations indicate that patterns of fire severity during this time period were influenced by vegetation type, fuel conditions, and topography. Many areas within the Rim Fire perimeter had burned previously in recent fires (e.g., 1973 Granite Fire, 1987 Complex Fires, and 1996 Ackerson Fire). Within those past fire perimeters, certain areas have repeatedly burned at high severity primarily as a result of topographic location and vegetation type. These areas will most likely continue to burn at high severity in the future.

Figure 12. Vegetation severity.

Preliminary vegetation severity map displaying the 2 biggest fire progression days (Aug. 21st and 22nd) outlined in black.

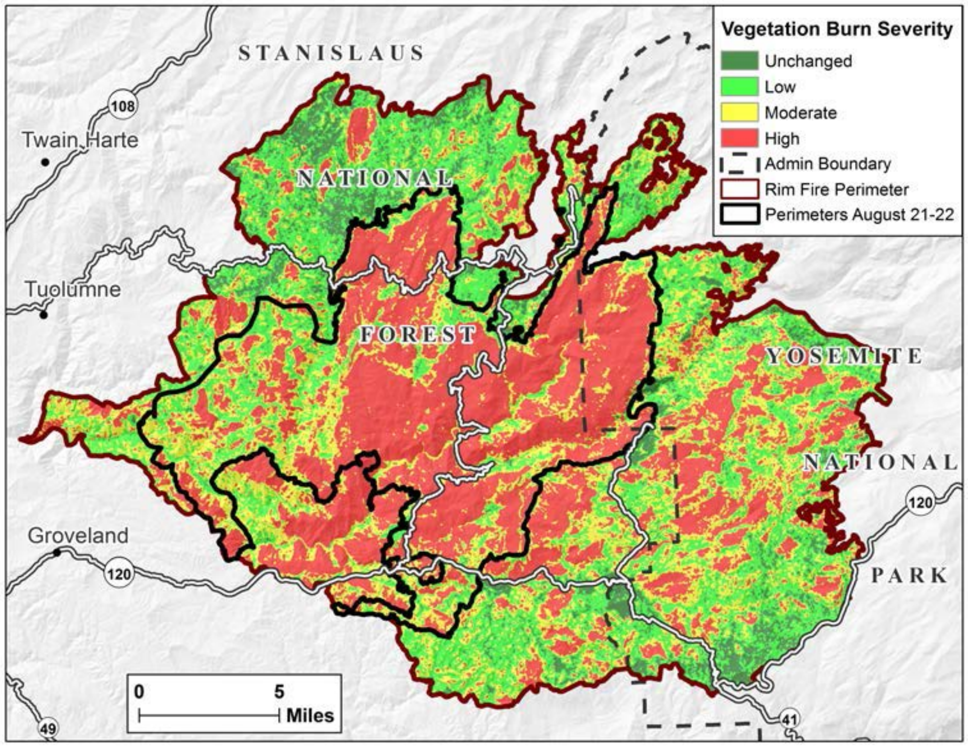


Figure 13. Left — Vegetation severity all burn days.

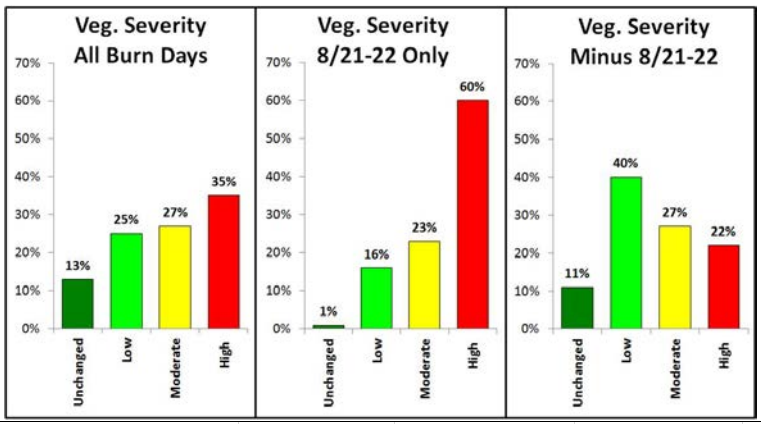
The proportion of the entire fire area within the vegetation severity classes is displayed for all burn days. All land ownerships are included.

Figure 14. Middle — Vegetation severity for August 21st and 22nd.

The proportion of the entire fire area within the vegetation severity classes is displayed for August 21st and 22nd only. All land ownerships are included.

Figure 15. Right — Vegetation severity excluding August 21st and 22nd.

The proportion of the area burned within the vegetation severity classes is displayed for all burn days excluding the two biggest progression days (Aug. 21st and 22nd). All land ownerships are included. These charts' data is contained in an accessible data-table after the charts.



days	unchanged	low	moderate	high
all	13	25	27	35
August 21 and 22 only	1	16	23	60
All excluding August 21 and 22	11	40	27	32

Fuel Treatments

Fuel Treatment Objectives

Land management agencies conduct several types of vegetation treatments, and one category is fuel treatments. Fuel treatments are management actions that are specifically designed to reduce fuel loading or modify fuel structure (e.g., chipping of shrubs). Fuel treatments are conducted throughout the Sierra Nevada to provide for human safety and protect communities, natural resources, and property by removal of vegetation or reduction of fuels in areas of special concern. Fuel treatments can also help meet ecosystem and natural resource management objectives, such as in remote areas and as secondary objectives after protection objectives. Fuel treatments can be divided into two categories, mechanical and fire treatments. Mechanical treatments modify fuel structure and/or remove fuels, and treatment types include tree thinning, mastication (chipping, shredding and grinding), and hand piling of fallen or cut branches for later burning. Fire treatments include burning of piled fuel, usually from a previous forest thinning project; managing naturally occurring wildfire to meet defined resource objectives; and burning an area within prescribed weather and fuel moisture conditions to reduce fuel loads.

Treatments are placed in the Wildland–Urban Interface (WUI) zone to provide for human safety and to protect structures and other human developments. Fuel treatments exhibit diminishing effectiveness over time as fuels accumulate, so they require maintenance or follow-up treatments to retain viability. This time frame normally coincides with the natural fire return interval of a particular vegetation type and could be estimated to be 10 –15 years within the Rim Fire. After this time frame the vegetation is regrown and effectiveness of the treatment declines.

Fuel Treatment Effectiveness Monitoring (FTEM)

The effectiveness of fuel treatments was tested when the Rim Fire burned through previously treated areas. Policy requires all federal land management agencies to report within 90 days on all fuel treatments treated in the past 10 years that have been tested by wildfires. This report includes those results as well as some fuel treatments dating back to 1995. This assessment provides information that can incrementally improve the types, locations, and effectiveness of future treatments by creating an adaptive management feedback loop. The scope of this report is limited to qualitative immediate post-fire trends that can inform decisions for longer term monitoring.

The objectives of the fuel treatments within the 2013 Rim Fire footprint included managing for forest resilience, protection of the WUI and recreation sites, and reducing hazardous fuels. Over half of the treatments implemented by the Stanislaus NF within the Rim Fire perimeter were impacted by the two-day period of rapid growth (34% of the total fire acreage). This area burned under what is classified as 97th percentile weather conditions (extreme); most fuel treatments are typically designed for less severe 90th percentile weather conditions (moderate). The purpose of the national fuel treatment effectiveness monitoring (FTEM) program is to help answer the following questions:

1. Did fuel treatments affect fire behavior by reducing the fire intensity and/or rate of spread?
2. Did fuel treatments contribute to the control/management of the wildfire?
3. What are the lessons learned that are important to help improve the federal hazardous fuels programs?

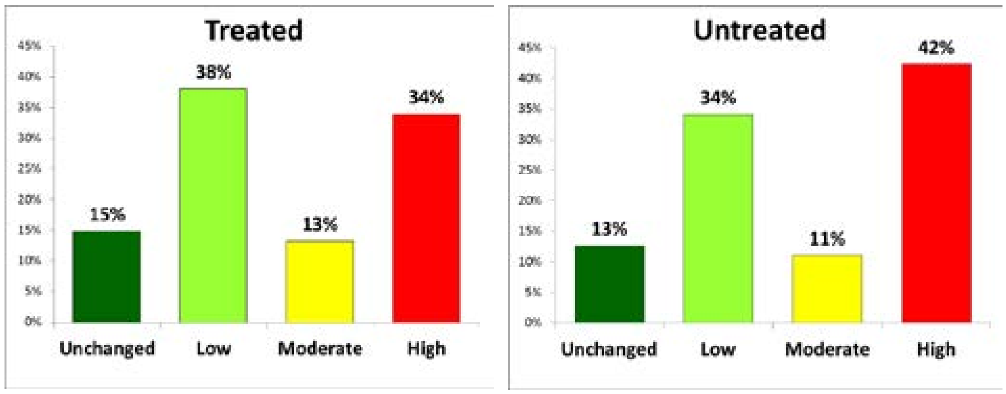
Field visits, eyewitness accounts and spatial analysis were combined to answer treatment effectiveness questions. Within the Rim Fire perimeter, over 500 treated units on the Stanislaus NF were first identified using a combination of GIS (Geographic Information System) and the FACTS (Forest Service Activity Tracking System) database. Then field assessments were completed on a subset of sites that had treatments in the last 10 years (2003–2013). When possible, incident staff were interviewed that witnessed fire behavior in or near the treatments. The remainder of this report focuses on fuel treatments managed by the Stanislaus NF.

FTEM Results

Within the final Rim Fire footprint about 30,600 acres of vegetation treatments by the Stanislaus NF had occurred between 1995 and 2013 including some areas with multiple overlapping activities (i.e., thinning 1 year and later burning an overlapping area). According to the initial post-fire vegetation severity assessment, 15% of the area was classified as unchanged (within immediate post-fire conditions indistinguishable from pre-fire conditions); 38% of the treatment areas was classified with low vegetation burn severity (surface fire with little change in cover and little mortality of the structurally dominant vegetation); 13% of the area was classified as having moderate vegetation burn severity (mixture of effects on the structurally dominant vegetation); and 34% of the fuel treatment area was classified as high vegetation burn severity (dominant vegetation has high to complete mortality) (Figure 16).

Figures 16 and 17. Treated and Untreated vegetation severity.

Left, the proportion of the area within fuel treatment areas (1995–2013) that was classified in vegetation severity classes within the Rim Fire footprint on the Stanislaus NF managed lands. Right, the proportion of the area outside of fuel treatment areas. These charts' data is contained in an accessible data-table after the charts.



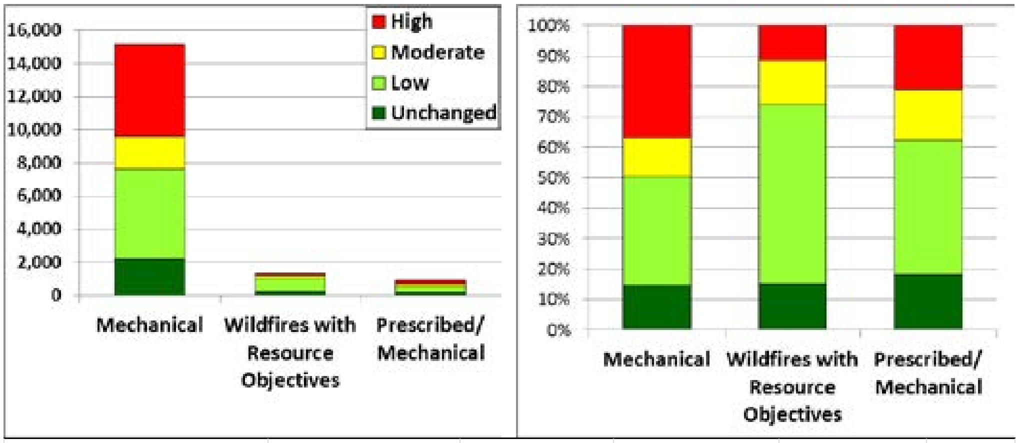
	Unchanged	Low	Moderate	High
Treated	15	38	13	34
Untreated	13	34	11	42

Fuel treatment areas within the Rim Fire perimeter have slightly less overall fire severity as compared to the adjacent un-treated areas as depicted in Figures 16–17. Most notable is the reduction of high severity from 42 percent in the untreated areas to 34 percent in the treated areas. Treatments that included prescribed fire either as a standalone application or following a mechanical entry had lower initial fire severity (Figures 18–19). Additionally, areas where previous wildfires were managed for resource benefit had lower initial fire severity (Figures 18–19).

While the overall effectiveness of fuel treatments looks fairly low, the story is much more complex than that. It is important to remember that the extreme burning conditions, including those on August 21–22 supported intense fire that resulted in much higher severity levels. The fire also burned in a wide variety of landscapes, vegetation types, and fuel treatment ages and types. The following case studies detail the effectiveness in selected situations.

Figures 18 and 19. Vegetation severity by fuel treatment type.

Rim post-fire vegetation severity by fuel treatment type, expressed in acres (left side) and as a percent of the treatment areas (right side) on Stanislaus NF managed lands. The charts' data is contained in accessible data-table below.



Treatment	Unchanged	Low	Moderate	High	Total
Mechanical	2213 (14%)	5433 (37%)	1959 (13%)	5573 (36%	15177
Managed Wildfire	207 (15%)	801 (58%)	200 (15%)	156 (12%)	1364
Prescribed/Mechanical	164 (18%)	399 (44%)	150 (17%)	190 (21%)	904

In Yosemite National Park, days with extreme fire behavior (strong plume activity) during the Rim Fire resulted in moderate to high severity fire effects regardless of forest conditions, fire history or topography. Calmer weather conditions, recently burned areas and higher elevations produced lower severities (Lydersen et al. 2014).

Fuel Treatment Effectiveness Case Studies

Several fuel treatments were selected as case studies to further explore the settings, project objectives, methods and effectiveness during the Rim Fire (Figure 20). A summary of the case studies is included in Table 4. Several case studies involve mechanical treatments with prescribed fire as a second entry to enhance forest resilience and protect the WUI zone. Another case study looked at a wildfire managed with resource benefit objectives as a method to treat fuels and enhance landscape resilience and ecosystem benefits.

Figure 20. Fuel treatment map.

Map of the fuel treatments conducted on the Stanislaus NF (1995–2013) within to the Rim Fire area with focus case study treatments located.

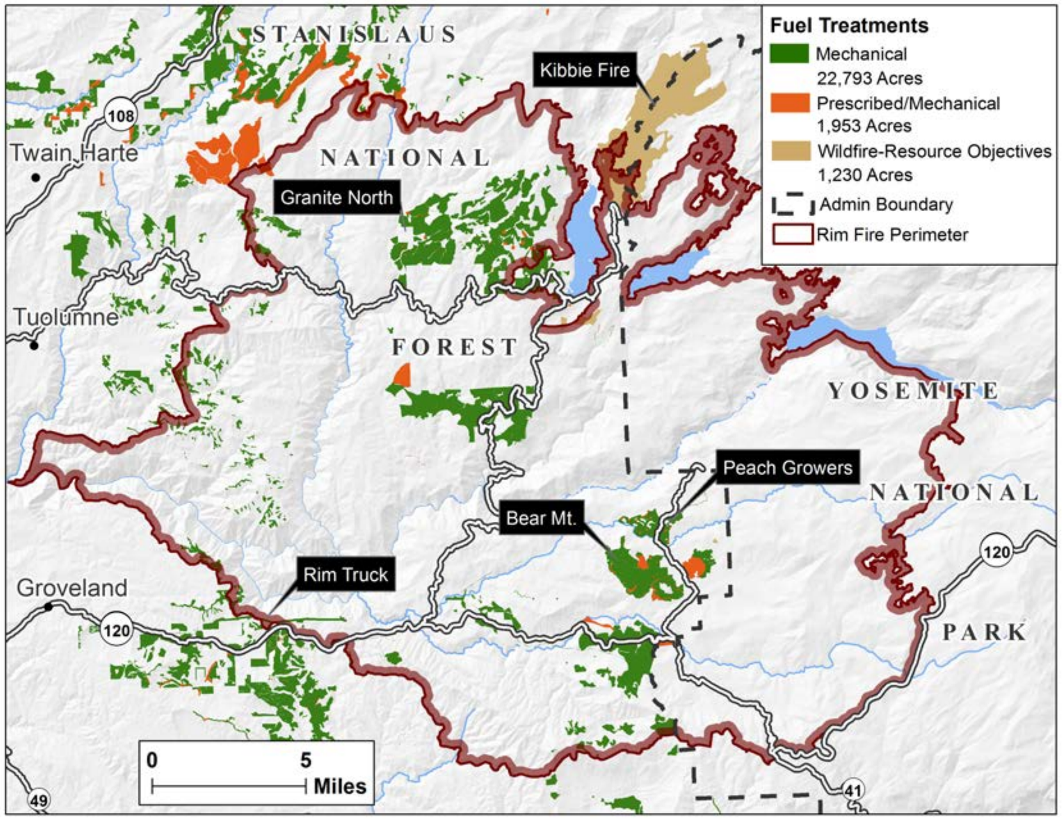


Table 4. Case Study Areas.

Summary of Rim Fire fuel treatment effectiveness in case study areas.

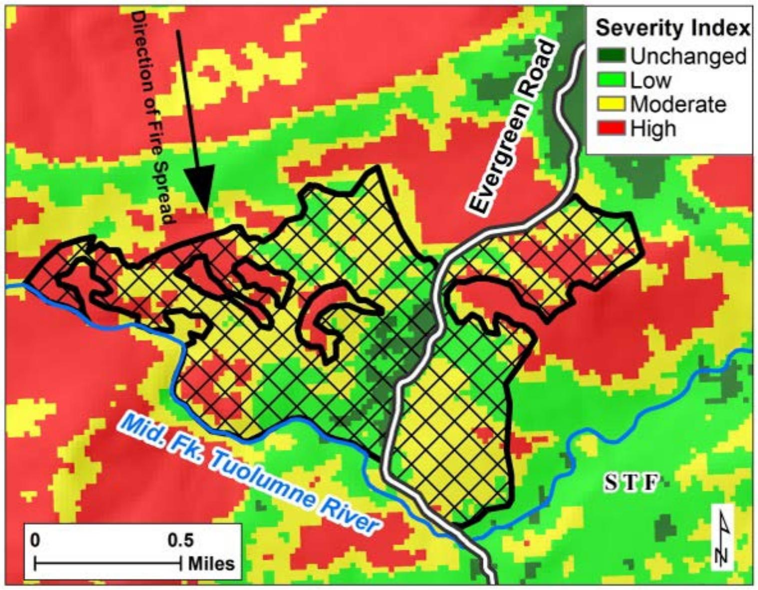
Treatment Area	Treatment Objective	Change Fire Behavior (% Yes/No)
Bear Mountain	Forest Resilience	81/19
Peach Growers	Wildland Urban Interface Protection, Forest Resilience	96/4
Rim Truck Fuel Break	Wildland Urban Interface Protection	100/0
North Granite Stewardship Project	Forest Resilience	75/25
2003 Kibbie Fire	Wildfire with resource benefits	73/27

Combined Mechanical and Prescribed Fire Treatment

PEACH GROWERS – WILDLAND URBAN INTERFACE

Figure 21. Peach growers.

Overview map of the initial fire severity within the Peach Growers Fuel treatment area. Arrow indicates approximate fire spread path.



Setting: Stanislaus NF land surrounding a summer home tract with several leased cabins and a developed campground. Homes are within the stand. The Peach Growers treatment area is approximately 780 acres divided into 47 treatment units.

Project objective: Protect structures and improve forest resilience by reducing intensity and mitigating the consequences of a potentially damaging wildfire.

Methods: Mechanical and hand thinning of trees, hand and tractor piling, pile burning, and broadcast burning. In addition to the treatment of surrounding vegetation, the area around the Forest Service lease summer home tract was treated. After consultation with the permit holders, small diameter and insect attacked trees were removed around the cabins creating open stand conditions.

Effectiveness during Rim Fire: As the Rim Fire approached from the west, firefighters were able to protect the summer home group using a dozer line around the structures and burning out around them (Figure 22). The fuel treatments provided a safer place for fire fighters to work and a relatively good chance of having a successful operation. The surrounding forest also saw significant change in fire behavior as the fire transitioned from very high intensity in untreated stands to low or moderate intensity as it entered stands where fuels reduction work had occurred (Figure 23).

Figure 22. Structure protection.

Firefighters were able to easily construct fireline and burn out fuels (foreground) to protect the Peach Growers recreation cabins and protect the area's scenic and recreational values.

Figure 23. Stand protection.

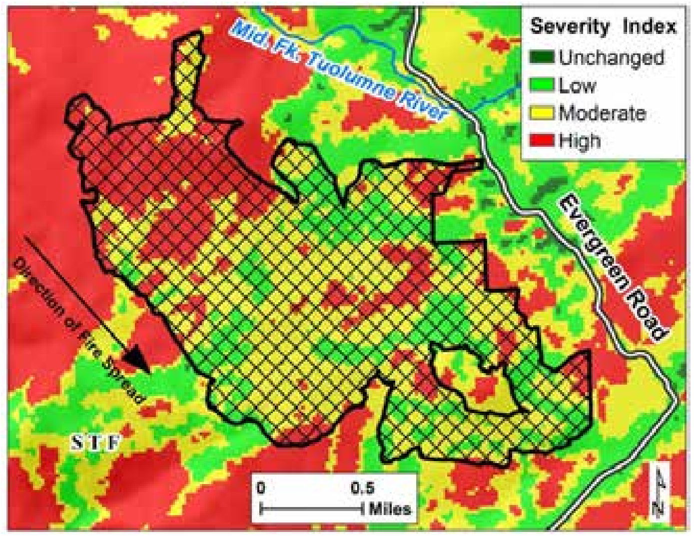
High intensity fire approached the Peach Growers fuel reduction area from untreated areas downhill from the road on the left, into a recently thinned area on the right. Fire intensity and severity were reduced as evidenced by needles still present in the crown.

Combined Mechanical and Prescribed Fire Treatment

BEAR MOUNTAIN – FOREST RESILIENCE

Figure 24. Bear Mountain.

Overview map of Bear Mountain fuel treatment area with initial fire severity. Arrow indicates approximate fire spread path.



Setting: Stanislaus NF west of Evergreen Road. The treated area is estimated at 1,648 acres divided into 110 treatment units.

Project objective: Improve forest resilience by reducing future fire intensity and mitigate the damage from a potential wildfire.

Methods: Mechanical thinning using a variety of techniques including lop and scatter, thin from below, and selective tree removal. Prescribed fire was used as a follow-up treatment on some units following mechanical thinning.

Effectiveness during Rim Fire: The Rim Fire moved swiftly to the south and east through these treated units. During extreme burning conditions, and limited property concerns, fire firefighter safety was the priority and the Bear Mountain area saw little firefighting action. Treatment effectiveness was variable based on slope, treatment type, and proximity to untreated vegetation. Treated units had reduced fire severity compared to surrounding untreated vegetation (Figure 24). Prescribed burning that followed mechanical treatment reduced fire intensity, and survival of these stands is likely (Figures 25 and 26).

Figure 25. Reduced fire intensity.

Mechanical thinning and prescribed burning treatments reduced intensity as fire passed through. Fire consumed the surface fuel with low flame heights leaving the tree canopy nearly unaffected.

Figure 26. Reduced fire severity.

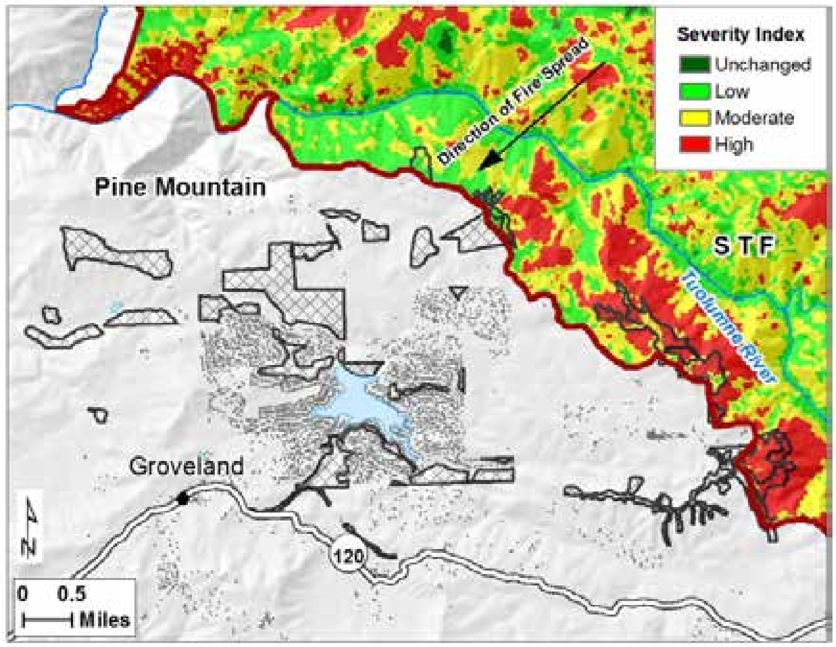
On Bear Mountain, prescribed fire following mechanical thinning protected this stand from high intensity wildfire. Brown needles and trunk char are from prescribed fire during the spring of 2013. The Rim Fire burn pattern was discontinuous here as evidenced by intact ground cover and brown needles still on the trees, rather than consumed. The severity was high in surrounding untreated stands.

Wildland Urban Interface Protection

Ferretti Road Community Defense Projects

Figure 27. Feretti Road/Pine Mountain Lake.

Overview map of the Ferretti Road/Pine Mountain Lake community defense areas with initial fire severity. Arrow indicates approximate fire spread path.



Setting: The Ferretti Road area is a community on the east side of Groveland and the Pine Mountain Lake communities. This community area is under the management of CAL FIRE (Tuolumne–Calaveras Unit) and Stanislaus NF direct protection areas. Multiple treatment areas are located here including the Rim Truck Trail, private landowner treatments, and Stanislaus NF's Long Shanahan treatment units, which cumulatively focus on the vegetation and fuels bordering the private land on the west/southwest edge of the Forest near the Rim Fire's southwestern edge.

Project objective: Create a strategic advantage for fire control by establishing a fuel break to facilitate fire line construction affording the communities of Pine Mountain Lake, Groveland, and Big Oak Flat protection from wildfire coming out of the Tuolumne River drainage to the north.

Methods: The Rim Truck Trail is a 15 mile long shaded fuel break with total treatment area of about 420 acres that borders Rim Truck Trail Road. This treatment was coordinated by the Southwest Interface Team (SWIFT), a local collaborative between federal, state, and local entities, that functions similar to a fire safe council (Sidebar 2). A shaded fuel break was constructed using mechanical and hand thinning and followed by pile burning (Figure 28). Responsibility for accomplishing the treatment was divided between Cal Fire/Tuolumne County (11 miles) and Stanislaus NF (4 miles). The project was largely completed in 2012 and was in a maintenance regime with recurring treatments required to keep it effective.

The Stanislaus NF Long Shanahan units consist of several hazardous fuel reduction projects including mechanical treatments and piling and burning of fuels over the last 10 years. Treatments near Ferretti Road were utilized for Rim fire containment tactics and included dozer lines and aerial retardant.

Sidebar 2. Rim Truck Trail

Figure 28. Shaded fuel break (left).

Rim Truck shaded fuel break under growth was cleared to create a strategic advantage for fire control.

Figure 29. Dozer line (right).

Rim Truck fuel break dozer line was easily completed to support burn-out operations on the 2013 Rim Fire.

"The fuel breaks played a critical role in reducing the intensity of the fire in the Pine Mountain Lake community, their purpose was to reduce fuel loads and the work done the past five to seven years made the difference."

SWIFT coordinator Allen Johnson

From a September 3, 2013 article by Tracey Petersen, MML News Reporter (http://www.mymotherlode.com/news/local/159735/swift-saves-lives-homes.html): Recounts of firefighting efforts along the Rim Truck fuel break describe a difficult engagement where the fire did spot over the fireline a number of times. The open fuel condition aided firefighters containing those spot fires in the fuel break. The fuel break served as a feature from which safe and effective firefighting actions could be initiated and had a significant role in the successful defense of communities on the southwestern edge of the Rim Fire (Figure 29).

The Tuolumne Trails private camp is also located off of Ferretti Road between federal and SWIFT treatment units. The camp had completed some fuel reduction efforts that, in addition to the dozer lines and aerial retardant used during the Rim Fire, amounted to a success story for this important special needs children's camp used by the community and visitors from afar (Sidebar 3).

Sidebar 3. Tuolumne Trails

Camp Tuolumne Trails (www.tuolumnetrails.org) was right on the edge of the fire near the Groveland communities (Figures 30–31).

"Thanks to dedicated fire fighters and a miraculous DC-10 with a timely fire retardant drop, the camp was saved! We lost a little vegetation and we have a significant clean-up job ahead. On the other hand, camp remains beautiful, and there are opportunities to see some newly opened areas created by back burning and firebreaks."

The Tuolumne County Aviation News article (http://www.tuolumnecountyaviation.us) by Richmond (2013)

Figures 30 and 31. Tuolumne Trails.

Photos from the Tuolumne Trails camp staff: Left side— looking south when the Rim Fire was threatening the area. Right side — Rocketship Education (www.rsed.org) program visitors during fall season 2013 in areas impacted by the fire.

Effectiveness during Rim Fire: Early in the Rim Fire, firefighters were able to establish a dozer line within the existing fuel break and surrounding treatments, strategically use aerial retardant to slow fire spread, and were successful in holding the fire along these treatments, effectively keeping fire out of all communities it was designed to protect.

Combined Mechanical and Prescribed Fire Treatment

North Granite Stewardship Project – Forest Resilience

Figure 32. North Granite Stewardship Project.

North Granite Stewardship Project vegetation severity distribution. Arrow indicates approximate fire spread path. Flesh out this caption to describe the graphic.

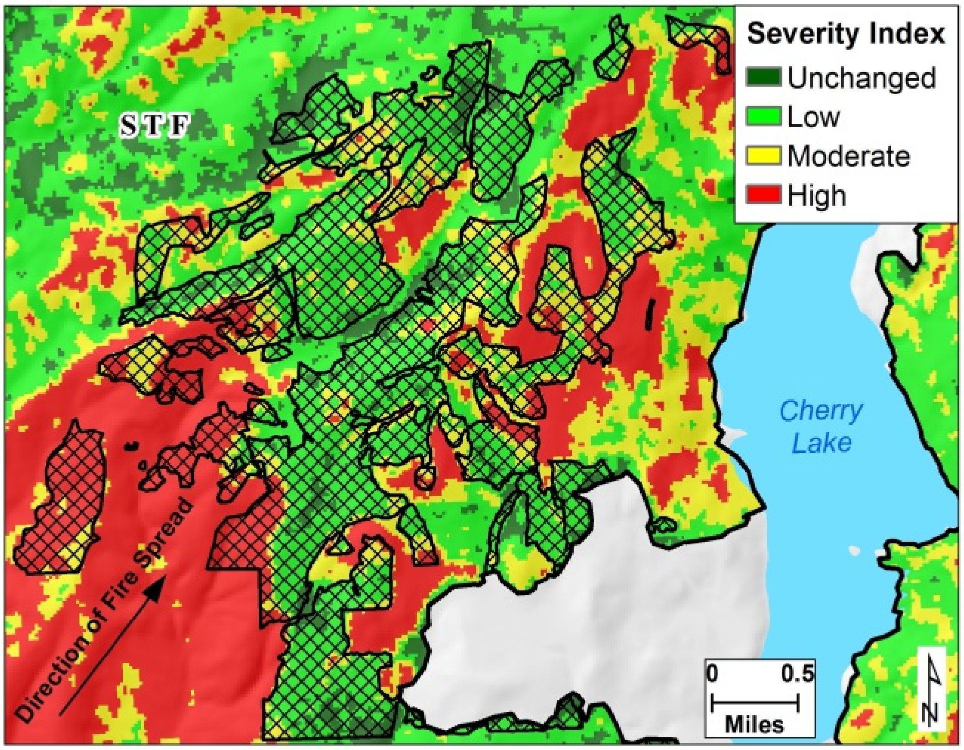


Figure 33. Mechanical thinning.

Thinned treatment unit in the North Granite Stewardship Project showing increased tree spacing and reduced surface and ladder fuels.

Setting: Located on the Stanislaus NF near the west side of Cherry Lake. In 1973 the Granite Fire burned 16,290 acres and resulted in high fire severity and high tree mortality on 50% to 70% (LANDSAT imagery) of those acres. Much of the area was replanted after the Granite Fire and was a well-established pine plantation at the time of the Rim Fire.

Treated area: Between 2003 and 2010, fuels reduction and plantation maintenance treatments were conducted in the North Granite Stewardship Project, a large area incorporating 66 separate treatment units covering over 3,330 acres (Kobziar et al. 2009, Figure 33).

Project objective: The primary objectives of the treatments were forest and plantation resilience, to reduce wildland fire risks, and reduce competition between trees.

Methods: The primary and initial treatments were pre-commercial thinning (916 acres) and commercial thinning (1,224 acres) to reduce tree spacing and open up crown closure. The thinning was followed up with slash removal; larger material was hauled off site, with the smaller material piled and burned in place. Mastication was conducted on 1,160 acres to shred small trees and brush.

Effectiveness during Rim Fire: About 500 acres were impacted by the plume dominated and associated extreme fire behavior on August 22nd, and about 90% of the 500 acres was initially categorized as high vegetation severity. The remainder of the treated area burned over the course of the next 10 days (August 23–September 1). The vegetation severity of the treatment units that burned on these days was predominately low (Figure 33). Onsite post-fire data collection indicated that 45 of the 66 treated units were successful at reducing fire behavior. Based upon these observations and the vegetation severity mapping, the North Granite Stewardship Project was successful at meeting the objectives of reducing wildfire risks and creating a more resilient plantation on over 70% of the treatment area.

Wildfire Managed for Resource Benefit Objectives

2003 Kibbie Fire

Figure 34. Kibbie Fire.

Overview map of Kibbie Fire with initial fire severity.

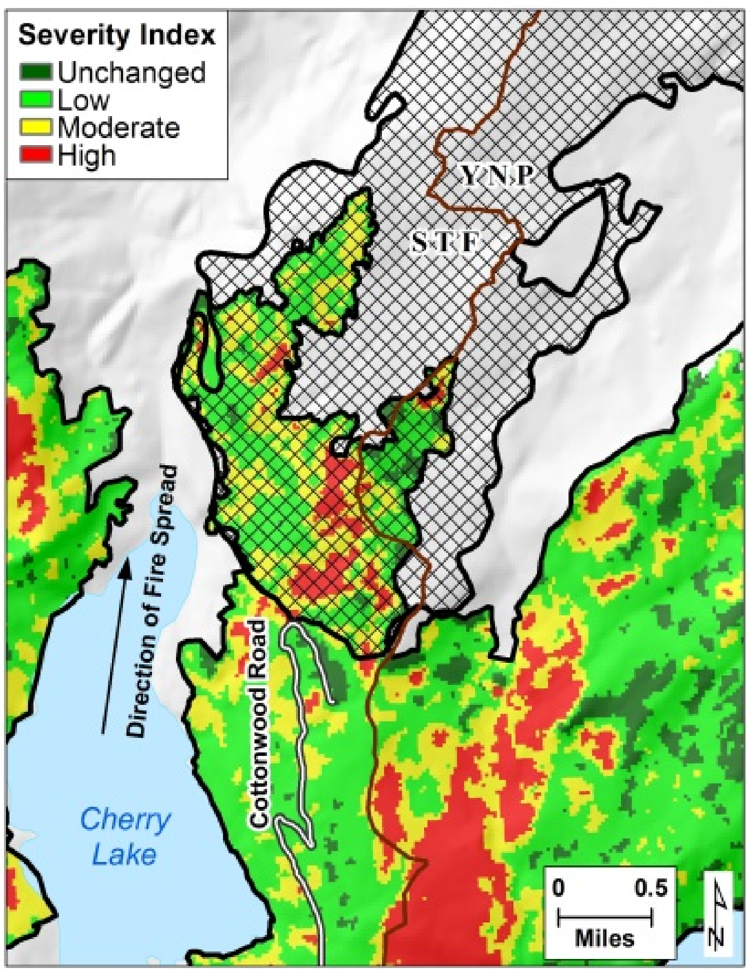


Figure 35. Kibbie fire re-burn.

View of the Rim Fire re-burning in the Kibbie Fire footprint as seen from the west shore of Cherry Lake. Most of the area burned with low to moderate fire severity.

Setting: The Kibbie Fire started on August 31, 2003 on the Stanislaus NF on the northeastern side of Cherry Lake and adjacent to the Yosemite NP border (Figures 34–35). The Kibbie Fire was managed by the Stanislaus NF and Yosemite NP to meet natural resource objectives until October 31, 2003 and totaled 6,305 acres. The Kibbie Fire encompasses several ecological zones, extending from 5,000 to 7,200 feet elevation. Prior to the Kibbie Fire, the majority of the area was categorized as low to moderate departure from its historic fire regime. The Rim Fire burned into a portion of the Kibbie Fire footprint starting on August 24th and continued for many days, eventually re-burning about 1,400 acres.

Project objective: The Kibbie Fire was a lightning-ignited wildfire managed within a predetermined land area and weather scenarios. The Kibbie Fire was managed to accomplish specific objectives to achieve positive effects on natural resources defined in the Land and Resource Management Plan (USDA Forest Service 2010). Goals included the restoration of fire as a natural process on the landscape, the reduction of fuel, and the maintenance of heterogeneous vegetation structures (Sidebar 4).

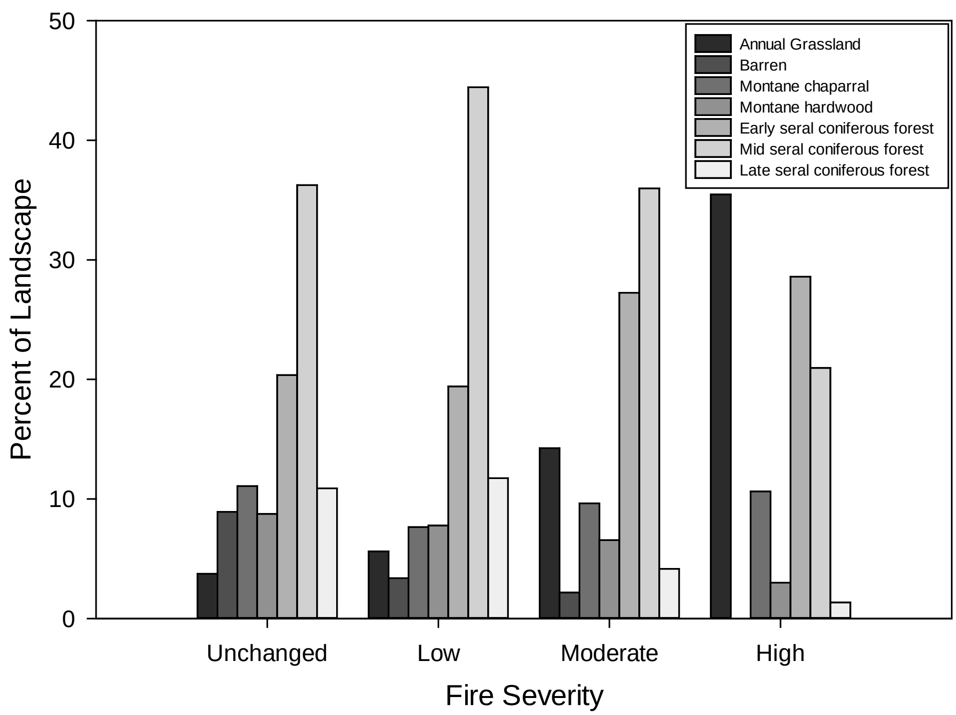
Methods: Understanding the effects of the Rim Fire re-burning the Kibbie Fire area will improve the agency's knowledge of the benefits of managing wildfires under certain conditions on the landscape. Post-fire conditions were assessed from satellite-derived severity data using the preliminary RAVG data. More rigorous scientific efforts have been initiated to expand on these initial observations.

Effectiveness during Rim Fire: Most of Kibbie Fire area that re-burned in the Rim Fire resulted in initial low to moderate fire severity (approximately 73%). Only 27%

of the area that re-burned resulted in high fire severity (Figure 34). Within these higher severity areas, patches were small and spread across the landscape. Of the areas that did result in high fire severity, most were associated with ridge tops and southwest facing slopes (Figure 36). In addition, high severity fire effects were also influenced by fuel conditions that were a direct result of the previous Kibbie Fire. Those areas that remained in early seral coniferous conditions, grassland or shrubland tended to re-burn at high severity. In addition, the mid-seral coniferous forest was nearly equally affected by different fire severities (Figure 36).

Figure 36. Kibbie Fire re-burn vegetation severity.

Bar graph displaying the initial vegetation severity by vegetation type following the Rim Fire in the area previously burned in the 2003 Kibbie Fire. The graph's data is contained in accessible data-table below.



Vegetation type	Unchanged	Low	Moderate	High
Annual Grassland	4	6	14	35
Barren	9	4	3	0
Montane Chaparral	11	8	10	11
Montane Hardwood	9	8	7	3
Early Seral Coniferous Forest	21	19	27	28
Mid Seral Coniferous Forest	35	44	35	21
Late Seral Coniferous Forest	11	11	4	2

Sidebar 4. Managing Wildfires for Natural Resource Benefits

Figure 37. Spotted owl.

This spotted owl was observed after the 2003 Kibbie Fire within the Kibbie Fire footprint.

Wildland fire is a general term describing any non-structure fire that occurs in the wildland. Wildland fires are categorized as either wildfires (unplanned ignitions, human or lightning caused) or prescribed fires (planned ignitions). Science has altered the way in which the federal land management agencies approach wildland fire and its management. The 1995 National Wildland Fire Policy acknowledged this intent to consider the use of wildfire to achieve resource benefits. The 2009 Guidance for Implementation of Federal Wildland Fire Management Policy includes the following excerpts:

- The intent of the framework is to solidify that the full range of strategic and tactical options are available and considered in the response to every wildland fire.
- A wildland fire may be concurrently managed for one or more objectives, and objectives can change as the fire spreads across the landscape. Fire managers view some ignitions as opportunities to move landscape conditions closer to desired conditions, as defined in their Land and Resource Management Plan. Managing wildfire for natural resource benefits allows for all or portions of the fire to spread naturally so that fire may play its natural ecological role, meeting multiple objectives such as decreasing fuel accumulations, improving structural heterogeneity, and maintaining vegetation in multiple seral stages.
- Nine guiding principles are foundational for Federal Wildland Fire Management Policy. The first and foremost is firefighter and public safety, this being the first priority in every fire management activity. Communities and resources critical to people continue to be protected, but now the role of natural fire in promoting the health of an ecosystem is also considered. This idea continues to be refined through research and technology so that fire can be understood and managed better.

Rim Fire Fuel Treatment Effectiveness Summary

This report summarizes our observations of the immediate post-fire effectiveness of the fuel treatments on the Stanislaus NF that had been implemented prior to the Rim Fire. Important insight can be gained by this preliminary evaluation of fuel treatment performance because it was initiated quickly following the fire and is able to document major trends in fuel treatment effectiveness while it is fresh in the minds of firefighters, observers and other interested people. It is important to note that these are preliminary observations based primarily on the FTEM protocols which are subjective evaluations of fuel treatment performance during and immediately following the Rim Fire. More focused, quantitative studies of fuel treatment effectiveness are ongoing both on the Rim Fire and other significant fires in the Sierra Nevada.

Sidebar 5. Fire Behavior Assessment Team (FBAT)

The USFS Fire Behavior Assessment Team visited nine case study areas during the Rim Fire to measure immediate pre- and post-fire fuel and vegetation conditions, as well as setup sensors to record active fire behavior. Five of the sites were in or adjacent to fuel treatment areas. Some noticeable differences were identified based upon the time of day the sites burned (and associated weather) in addition to the fuel treatments themselves. Figures 38 and 39 were taken within days before and after the Rim Fire burned a treatment where tree thinning then jackpot burning occurred in sequence between 2001 and 2005. Initial surveys showed excellent tree survivorship. This treatment unit also provided a safer area for fire control operations; the NW corner of the Rim fire was contained in this area. For detailed report see http://www.fs.fed.us/adaptivemanagement/projects/FBAT/FBAT.shtml

Figures 38–39. Before and after photos.

Pre-fire and immediate post-Rim Fire photos along a fuels and vegetation transect within the Wrights Creek area that was thinned and burned between 2001 and 2005 on the Stanislaus NF.

Were the Rim Fire Fuel treatments effective?

Fuel treatments were important in moderating the impacts of the Rim Fire on communities, human safety and natural resources. The fuel treatments that were in place were effective, exclusive of August 21st and 22nd when fire intensity and burning conditions were extreme.

Fuel treatment effectiveness was enhanced and limited by three major factors:

- Fire intensity/burning conditions
- Fuel treatment design/objective
- Fuel treatment age/maintenance

1. Rim fire intensity and burning conditions are important

On August 21st and 22nd both the rate of fire spread and fire intensity were extreme. Vegetation severity on these two days contrasts with the more moderate rate of fire spread and fire behavior during the rest of the fire.

A. **Extreme fire intensity** can overwhelm any fuel treatment and cause high severity. Fuel treatments of all ages were subject to high severity effects when the fire behavior approaching the treatments was very high intensity and/or fast moving. The southern Granite Fire area treatments that burned on August 21st and 22nd sustained high vegetation severity while treatments burning in the following days in the northern Granite area received low to moderate severity ratings.

B. **Fire severity** was much more uniformly high on August 21st and 22nd than the rest of the fire. Large areas of uniform high severity occurred on those two days. The area burned in the rest of the fire was characterized by a mosaic of mostly low to moderate severity with occasional smaller sized patches of high severity.

2. Fuel treatment design and objective

A. **A wide range of project types** were called fuel treatments. Each project was designed to accomplish a set of management goals. Some goals were focused on other resource considerations, but all had design elements to manage wildland fuels.

B. **Vegetation manipulations** will influence potential fire behavior under a range of conditions. That range varies with the design of the project and subsequent fire weather or fire behavior of a future wildfire.

C. **The WUI treatments** affected by the Rim Fire differ by development type:

a. **Treatments in dispersed rural developments** in the forests had tree thinning and/or surface fuel reduction activities to modify fire behavior within the developments. These treatments were effective in reducing fire intensity and in giving suppression resources opportunities to protect structures.

b. **Treatments in larger higher density community areas**, Pine Mountain Lake and Groveland, were protected by the Ferretti Road community defense projects, which is one area in a series of fuel treatments designed for community protection and emergency access by keeping fire from reaching the communities. The fuel treatments were important in reducing fire intensity and in giving suppression resources opportunities to protect structures.

D. A comparison of the effectiveness of different types of fuel treatments indicates the following trends:

a. **Treatments that modify** all of the fuel layers are more effective in reducing fire intensity and severity than those designed to modify only a single layer. Examples are multiple or dual treatments, higher severity prescribed fire, or wildfire with resource benefit objectives that treat more than 1 fuel layer (understory/surface fuels and overstory).

b. **Fuel treatments** that were designed specifically to modify fire behavior were more effective. Treatments in which a primary objective was to modify potential fire behavior were more effective than those which had other resource objectives that were of greater emphasis than fire behavior modification. Silvicultural treatments intended to manage plantations did reduce the overall fuel load, but were more effective where they were also specifically designed to modify fire behavior.

c. **Wildfires managed for resource objectives** accomplished fuel reductions and restored fire as an ecological process. Managing wildfire under defined conditions has the potential to treat large areas, and is sometimes the only feasible large fuel reduction option in many remote areas.

d. **Treatment size and maintenance** influenced severity. Larger landscape level fuel treatments which were well maintained appear to have been the most effective at reducing the severity during the Rim Fire.

3. Fuel treatment age is important

The focus of this report is mostly on the FTEM protocol which includes fuel treatments that have been installed or maintained during the past 10 years. The numerous older treatments are outside the scope of this report, though a few were included. The following trends and observations were noted:

- **A. The effectiveness of any fuel treatment will change over time.** Most treatments are designed to be effective for a finite length of time, such as 10 years. Follow-up treatments are needed for a treatment to maintain effectiveness. Many treated areas within the Rim fire footprint were due for follow up treatments.
- **B. The last 10 years of fuel treatments** inside the Rim Fire were generally effective. Though large patches of high severity resulted from the Rim Fire on August 21st and 22nd, treatments implemented within the previous 10 years were largely effective when burning under low to moderate fire intensity.
- **C. Very recent treatments** were the most effective. During low to moderate fire intensity, recent treatments were especially effective at reducing fire effects and continuity.
- **D. The 2003 Kibbie Fire** was ten years prior to the Rim Fire and effectively reduced fire severity and intensity. The Kibbie Fire area was particularly effective as a fuel treatment and greatly moderated the Rim Fire's behavior, effects, and severity.
- **E. Maintenance of treatments is key** to treatment effectiveness and longevity. Periodic maintenance of in-place treatments is needed to mitigate the accumulation of fuels and prevent the re-establishment of vertical and horizontal fuel continuity.

> **"The Rim Fire also serves as essentially one large fuel reduction treatment area. Taking advantage of this landscape-scale fuel reduction is the challenge to both natural resource and fire managers now and in the decades to come."**
>
> The Authors

Information needs

Assessments of large complex events such as the Rim Fire are excellent opportunities to learn and to identify some of our main knowledge gaps. The following are focal areas of study that are important to address in the near future:

- **Treatment effectiveness and longevity** – Further investigation of treatment longevity is important to develop maintenance schedules. Consider which treatments, if any, have effectiveness past the 10-year time frame established for the national FTEM guidelines.
- **Assess the effectiveness of fire-only treatments**, including prescribed fire and wildfires managed for resource objectives. Were past wildfires and prescribed fires without mechanical treatments effective?
- **Assess the importance of scale in fuel treatments.** Are large landscape-scale treatments and maintenance more effective as suggested in the Rim Fire? Are they fiscally and operationally possible to implement?
- **Consider extensive use of wildfires managed for resource objectives under a predefined, prescribed range of conditions.** This is potentially a way to rapidly increase the area treated and address the concern that the pace of our treatments and maintenance of fuel treatments is too slow to keep pace with the rate of recurring wildfires. Continued treatment of the wildland urban interface and increasing the scale of low and moderate severity fire would have substantial ecological and economic benefits if implemented soon. We suggest National Forests identify large contiguous areas to concentrate their fuels reduction efforts, and then transition treated firesheds as available to prescribed and unplanned wildfires as future fuel maintenance tools (North et al. 2012).

Lessons Learned/areas for improvement

Fuel treatment effectiveness can be improved by incorporating these concepts:

- We usually can’t stop wildfires from entering treated areas, but fuel treatments can reduce wildfire spread and effects.
- Design fuel treatments specifically to reduce the potential for large high severity patches and fireline intensity in the treatment area during future wildfires.

- Maintain the fuel treatments at intervals designed specifically for the site and objectives.
- Utilize wildfires to treat fuels when burning under conditions where low to moderate fire severity and intensity can be expected.
- Large landscape designs and treatments are likely to be more successful than smaller, fragmented treatments.
- Manage more wildfires that occur in low to moderate burning conditions with multiple objectives to improve forest resilience. Expect and allow a mosaic of severity types.
- Extreme burning conditions can result in large areas of high intensity fire with high severity effects. These are determined by climate and weather, vegetation and fuel, topography, and ignitions. While some effects may be mitigated by fuel treatments, the benefits of the treatments can be overwhelmed by the intensity of the fire.

"When one tugs at a single thing in nature, he finds it attached to the rest of the world."

John Muir

Acknowledgements

Thank you to our local Fire Safe Councils, Cal Fire, Morris Johnson, Brenda Wilmore, Cathy Aldrich, Allen Johnson and SWIFT, Chris Schow, Kelly Martin, Susan Skalski, the current and former District Fuel Specialists, the Rim Fire Incident Management Teams, Miranda Stuart, and the Tuolumne Trails camp staff.

References

Camp Tuolumne Trails staff. 2013 photos by Jerry Baker. URL: http://www.tuolumnetrails.org/index.htm

Caprio, A.C., C. Conover, M. Keifer, P. Lineback, 1997. Fire management and GIS: a framework for identifying and prioritizing fire planning needs. In: Proceedings: 1997ESRI GIS Conference, San Diego, CA.

Fire regime condition class – Interagency fire regime condition class (FRCC) guidebook version 3.0. September2010. URL: http://fire.org/niftt/released/FRCC_Guidebook_2010_final.pdf

Fites-Kaufman, J.A., E. Noonan, and D. Ramirez. 2005, revised in 2013 for website distribution. Evaluation of wildland fire use fires on the Sequoia and Stanislaus National Forests in 2003: Effects in relation to historic regimes and resource benefits. USDA Forest Service, Adaptive Management Services Enterprise Team (AMSET). URL: http://www.fs.fed.us/adaptivemanagement/pub_reports/reports/SQF_STF_WFU_report_final_updateJan2013.pdf

Kobziar, L.N., J.R. McBride, and S.L. Stephens. 2009. The efficacy of fire and fuels reductions treatments in a Sierra Nevada pine plantation. International Journal of Wildland Fire 18 791–801.

LANDFIRE. 2013. Homepage of the LANDFIRE Project, U.S. Department of Agriculture, Forest Service; U.S. Department of Interior, [Online]. Available: http://www.landfire.gov/index.php [Dec. 2014].

Lydersen, J.M., M.P. North, and B.M. Collins. 2014. Severity of an uncharacteristically large wildfire, the Rim Fire, in forests with relatively restored frequent fire regimes. Forest Ecology and Management 328 326–334.

National Oceanic and Atmospheric Administration (NOAA). 2013. National Climate Data Center, Palmer Hydrological Drought Index, October United States Release. NOAA, Denver, CO. http://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers.php (Accessed Nov. 2013).

North, M., B. M. Collins, S. Stephens. 2012. Using Fire to Increase the Scale, Benefits, and Future Maintenance of Fuels Treatments. Journal of Forestry 110 (7) 392–401. http://www.fs.fed.us/psw/publications/north/psw_2013_north004.pdf

Palmer, W.C. 1965. Meteorological drought. *Research Paper No. 45.* U.S. Weather Bureau. NOAA Library and Information Services Division, Washington, D.C. 20852.

Rapid Assessment of Vegetation Condition after Wildfire (RVAG). 2013. Initial Rim Fire severity assessment data. Forest Service Remote Sensing Applications Center (RSAC). http://www.fs.fed.us/postfirevegcondition/index.shtml

Richmond, Virginia. 2013. Saving Camp Tuolumne Trails, in Tuolumne County Aviation News, winter 2013 edition, Sierra-Publishing.com. URL: http://www.tuolumnecountyaviation.us

Safford, H.D., and K. van de Water. 2013. Using Fire Return Interval Departure (FRID) analysis to map spatial and temporal changes in fire frequency on National Forest lands in California. Research Paper PSW-RP-266. USDA Forest Service, Pacific Southwest Research Station, Albany, California, USA.

Sugihara, N.G., J. van Wagtendonk, K. E. Shaffer, J. Fites-Kaufman, A. Thode (Editors), J. K. Agee (Foreword). 2006. Fire in California's Ecosystems. UC Press, Berkeley, CA. 596 p.

USDA Forest Service, Pacific Southwest Region. 2005. CALVEG dataset. URL: http://www.fs.usda.gov/main/r5/landmanagement/gis

USDA Forest Service, Pacific Southwest Region and The Nature Conservancy-California.2010 Departure (FRID) map, 2010 version. URL: http://www.fs.fed.us/r5/rsl/clearinghouse/r5gis/frid/

USDA Forest Service, Stanislaus National Forest — Forest Plan Direction. 2010. Pacific Southwest Region, USFS, Stanislaus National Forest. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5154788.pdf