Evaluation of Wildland Fire Use Fires on the Sequoia and Stanislaus National Forests in 2003: Effects in Relation to Historic Regimes and Resource Benefits

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Preface

This paper is a combined report for three Wildland Fire Use (WFU) fires on the Stanislaus and Sequoia National Forest. We combined them because we felt there was greater applicability by combining the information. There were slightly two different scopes for the individual projects. The Sequoia was interested in a formal, peer-reviewed publication whereas the Stanislaus was interested primarily in an evaluation of the resource benefits of the WFU's and suggestions for development of resource management objectives. This report contains a draft of the paper for peer-review publication that we believe meets the needs of both projects. Our next step will be to obtain comments from both forests and several fire scientists.

Abstract

Wildland Fire Use (WFU) fires are wildland fires that occur as a result of a natural ignition source, such as lightning, and are managed for maximum resource benefit, with minimum fire suppression activities. The effects of WFU fires are controversial due to the nature of defining resource benefits in the context of the public and different factions within an agency such as the U.S. Forest Service. In an effort to quantify WFU fire effects, post one-year data were collected on three WFU fires on the Sequoia and Stanislaus National Forests. Data were collected at finer scales than data acquired through remote sensing (Miller and Thode 2007), which is commonly used to describe and map fire severity. Fine-scale data collected along transects allowed for an assessment of patchiness of fire severity, especially in vegetation types where mixed severities are common. A classification (Carleton and others 1996) was used to partition data into distinct groups based on both species composition of tree and shrub data and environmental variables such as elevation, slope, aspect, and slope position. Fire severity as a function of overstory tree mortality, scorch and torch heights, were described in the context of the six groups resulting from the classification. Results were compared to historical fire regimes. Results showed that:

- A high degree of variability in fire severity existed within each of the WFU fires.
- The observed fire behavior and fire severity are within the range of historic fire regime patterns. Some effects may be somewhat more severe than would have occurred across the bulk of the landscape in this forest type, but not out of the full range of likely historic fire patterns.
- The spatial complexity of the fires at all scales (from sub-patch, to patch, and landscape) was great. This is an aspect of historic fire patterns that is difficult to replicate with other vegetation management techniques.
- Multiple positive resource benefits occurred.
    - All areas appear to have experienced fire within their historic range, and a resulting improved condition class rating.

- Fuel loadings were reduced in many portions and broken up in continuity. This provides a reduction in fire hazard within and adjacent to the burn areas and a reduction in risk of subsequent high severity fire effects.
- A less obvious resource benefit of these WFU fires is their contribution to reduced landscape-level fuel hazard.

Understanding the effects of Wildland Fire Use Fires in the context of their historical range of variability is paramount to the policy decisions made concerning these fires.

INTRODUCTION

Wildland Fire Use (WFU) for resource benefits is a method that utilizes fire for resource management (Kilgore 1973) and as a strategy to reduce large fuel loads (Black 2004). WFU, which was historically called “prescribed natural fires” (Caprio and Graber 2000), began in 1968 when the National Park Service (NPS) allowed two lightning fires to burn in Kings Canyon National Park for restoration of fire in the National Parks in 1963 (Parsons and Botti 1996). Four years later, the Forest Service allowed their first lightning fire to burn in the Selway-Bitterroot Wilderness in Idaho (Agee 2000). The1995 Federal Wildland Fire Policy Report stated “…wildland fire, as a critical natural process, must be reintroduced into the ecosystem” and “prescribed natural fire” was renamed wildland fire use for resource benefits (WFU).

What began as an emphasis to restore fire as an ecosystem process, is now recognized as another means to reduce fire hazard. Today it is widely recognized that over a century of successful fire suppression and land management practices has resulted in accumulated fuel loads that have increased fire risk throughout most of the Western United States (Miller 2003, Caprio and Graber 2000). Although yet to be formally assessed, Miller (2003) states that “WFU has the potential to be an effective strategy for fuels management objectives”. The Federal Wildland and Prescribed Fire Management Policy (1998) seeks to achieve more of a balance between fire suppression and fire as a resource tool for fuels reduction and ecosystem health (Zimmerman and Bunnell 2000).

Along with defining WFU, the 1998 policy established a consistent protocol for managing WFU across all federal agencies. For a WFU to proceed, the main contingencies are that there be a Fire Management Plan (FMP) in place, there must be NEPA compliance, and the ignition must be of non-human origin. If these conditions are met, the Fire Use Manager (FUMA) establishes a Wildland Fire Implementation Plan (WFIP). At any point in this process suppression can be implemented if the wildland fire does not meet specific decision criteria.

There are three assessment and planning stages to the WFIP. Stage I is the initial fire assessment. Stage II is the short term implementation plan, which allows for verification of predictions and risk assessment. Finally, Stage III defines the long-term implementation actions such as maximum manageable area (MMA), resource objectives, and monitoring actions. It is important to note that until Stage III, there is no specific delineation of resource objectives. In wilderness areas or land allocations with similar management purposes, the resource benefits of WFU may be as simple as restoring fire as a process. In other areas, outside of wilderness, criteria for establishing resource objectives for WFU are less obvious.

Purpose and Objectives

The purpose of this study was to evaluate resource benefits for several wildland fire use fires in the Sierra Nevada. Our approach was several fold. First, we assumed that one key measure of the overall goal of beneficial restoration of fire as an ecosystem process is whether the WFU patterns were within the natural range of variability of historic fire regimes. Second, we assumed that quantifying fire effects would provide a means to evaluate resource benefits. Our specific objectives were to:

1. Quantify and compare patterns and effects of the WFU fires in relation to historic and natural range of variability of fires in these areas,
2. Evaluate the effects of the WFU fires on some key resource emphases for these areas including wildlife habitat and watershed function,
3. Evaluate the effects of the WFU fires on fuels, and effectiveness in reducing the likelihood of future, undesirable, uniformly high severity wildfires, and
4. Present potential guidelines for more specific resource objectives.

Three WFU fires in the Sierra Nevada were chosen that occurred in part, or primarily outside of wilderness areas: the Albanita-Hooker fire on the Sequoia National Forest; the Mudd fire on the Stanislaus National Forest; and the Kibbe fire on the Stanislaus National Forest and Yosemite National Park. Before describing the methods and results, we summarize the background on approaches for measuring fire effects and on historic fire regimes for this portion of the Sierra Nevada.

Fire Effects

Fire severity is defined as the degree of environmental change left after a fire (Lutes and others 2006) and refers to the effects of fire. The effects of fire can include those on soils, vegetation, air, wildlife, hydrological processes or other resources. Fire severity encompasses multiples spatial and temporal scales. The effects of fires can be evaluated across different time scales to incorporate immediate post one year fire effects and longer term fire effects that span numerous years (Lutes and others 2006). For our purposes, we are most interested in effects to vegetation, including: general plant community responses, changes in wildlife habitat, and indirect effects of fire on hydrologic processes through changes in soil cover and vegetation. The effects of fire on vegetation or plants includes direct outright mortality, top-kill or biomass consumption, sprouting, enhanced seed germination or seedling establishment, shifts in vegetation composition, and changes in vegetation structure (Miller 2000, Vaillant and others 2009).

Remote sensing is often used to describe fire severity on landscape scales (Key and Benson, citation), primarily in relation to soils and vegetation. The most widely used remote sensing approach is utilizing a “composite burn index” (CBI), comprised of an average of ratings for surface, understory vegetation, and overstory vegetation. Other approaches besides remote sensing include more detailed measurements of varied fire responses (e.g. mortality, biomass consumption, sprouting) with ground-based sampling. There is an ongoing effort to evaluate the utility and develop site-specific calibrations of remote sensing based fire severity evaluations for the Sierra Nevada (Miller and Thode 2007). For this study, we focused on detailed, on the ground measurements along transects bisecting the fires, to compliment and allow later comparison with the remote sensing based approach that is under development.

Condition Class

Fire regime condition class (FRCC) is a classification describing the departure of a current fire regime from historical natural conditions developed by federal land management agencies to establish consistent, nation-wide priorities for fire restoration and fuel hazard reduction (Hann and others 2003). Three classes are based on low (FRCC = 1), moderate (FRCC = 2), and high (FRCC = 3) departure from historical conditions. A departure from natural historical conditions, as quantified by higher FRCC ratings, results in changes to vegetation characteristics like species composition, structural stage, fuel composition, fire severity, and insect or disease caused mortality. Low departure is considered to be within the natural range of variability; while high departures are outside a natural range of variability (Hann and others 2003).

BACKGROUND: Historic Fire Regimes of the Sierra Nevada

Fire regimes are comprised of the patterns of fire frequency, intensity, severity, seasonality, predictability, and spatial patterns over time across landscapes (Agee 1993). In the Sierra Nevada, fire regimes varied historically across the landscape with elevation, precipitation, aspect, topographic position, soil conditions or site productivity, and vegetation (Chang 1996, Fites-Kaufman 1997, van Wagtendonk and Fites-Kaufman 2006). Fire patterns can vary by individual watershed or landscape, even if they have similar vegetation. For example, the role of fire can vary with how the landscape is oriented relative to prevailing wind patterns. Drainages that are aligned with prevailing wind patterns will have more frequent or larger or more intense fires than those that are sheltered from prevailing winds. However, rarely do we have fire history data for each landscape, and generalizations on fire regimes are often made based on similarities in the landscape topography, climate/weather and vegetation.

Sugihara and others (2006) developed an approach to characterizing fire regimes for California ecosystems that incorporates distributions (compared to averages) for multiple fire regime components (Table 1). The approach to describing fire regimes in terms of distributions, rather than averages, allows a more thorough understanding of the range of fire patterns that can occur for any one fire regime component, and over time and space for any particular area or ecosystem. For example, while historic fire regimes for the western, montane slopes of the Sierra Nevada are often uniformly characterized as frequent, low severity, there are important variations in fire return intervals, fire type, and fire severity amongst different parts of this portion of the landscape that can only be described by moving beyond “average descriptors” (van Wagtendonk and Fites-Kaufman 2006). Mixed conifer sites on drier south or west-facing slopes and ridges often have a more regular pattern of fire return intervals than more mesic north or east-facing slopes (Figure 1). The average fire return intervals are similar, but the regularity and distribution of the intervals differ, and there is a greater tendency for occasionally longer fire return intervals on the mesic sites that may facilitate establishment and historic presence of white fir and Douglas-fir, rather than ponderosa pine.

Table 1. Fire regime components from Sugihara and others (2006) used for characterizing fire regimes of California ecosystems.

Fire Regime Component	Component Metric
Magnitude	Intensity (fireline)
	Fire Type (e.g. surface-passive crown, active-independent crown)
	Severity
Spatial	Extent (size)
	Complexity (patchiness within a fire perimeter)
Temporal	Interval (years between fires)
	Season

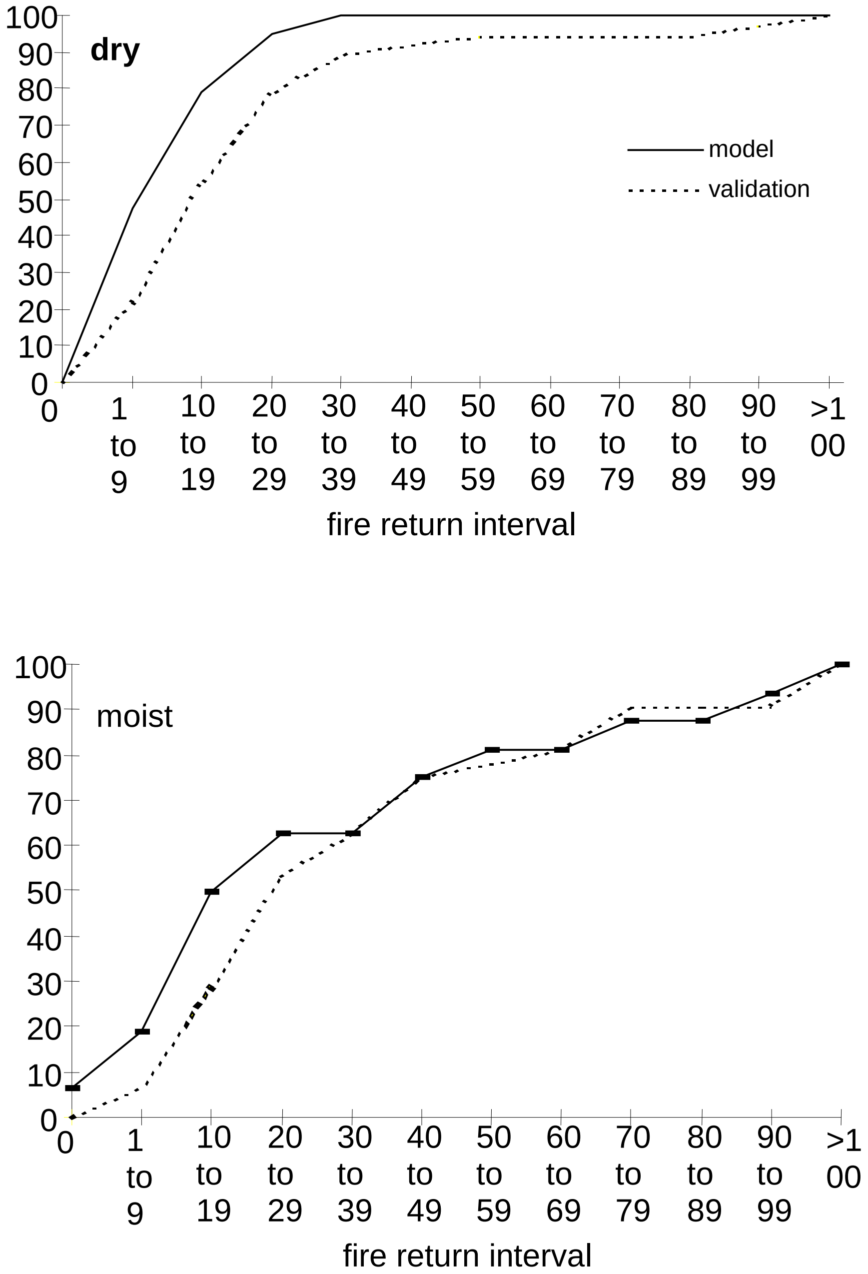


Figure 1. Distributions of fire return intervals from fire-scar based fire history study of contrasting mesic (moist) and dry sites in the montane, mixed-conifer zone of the Eldorado National Forest in the central Sierra Nevada (from Fites-Kaufman 1997).

Lower Montane Forest Zone

The lower montane forest zone includes both montane ponderosa pine and black oak forests, up through mixed or pure forests with white fir (van Wagtendonk and Fites-Kaufman 2006). The lower elevations of this zone are dominated by ponderosa pine, with varied amounts of live oak, sugar pine, incense cedar, and mountain dogwood. Large areas with black oak as a dominant or co-dominant occur in this zone, particularly on ridges or upper slopes or south or west aspects. In the northern portion of the Sierra Nevada, Douglas-fir is often present or even dominant on north or east-facing slopes. In this zone, as elevation increases, historic fires increasingly varied with aspect and/or topographic position. At higher elevations, white fire increases in amount and can form pure stands. Patches of shrubfields are common in the zone dominated by whiteleaf manzanita at lower elevations, or whitethorn and greenleaf manzanita at higher elevations.

Ponderosa pine/black oak type

Van Wagtendonk and Fites-Kaufman (2006) describe the historic fire regime for the ponderosa pine/black oak type as: primarily low intensity; with surface and passive crown fires as the most common fire type; and severity primarily ranging from low to moderate, with short, regular fire return intervals. At the lowest elevations or higher up on the drier south or west aspects and ridges, fires were generally frequent, ranging from fire return intervals of 5 to 15 years (<2 to <100 ha sample areas), with individual sites sometimes burning two years in succession (Caprio and Swetnam 1995, Fites-Kaufman 1997, Skinner and Chang 1996). With this type of fire frequency, the fire intensity and severity were most likely low because of lack of time to accumulate much fuel in between fires.

Fire history studies in black oak dominated areas are limited, but return intervals are likely similar to the drier mixed conifer sites. Fire severity patterns in oak-dominated sites would differ from the conifer-dominated areas. Black oak has thinner bark and is more susceptible to mortality from low or moderate intensity fires than many conifers, particularly at larger sizes. Consequently, a higher proportion of high severity effects often occur than in the conifer-dominated sites. The black oak sprouts back, primarily from crown sprouts, and often persists and dominates sites post-fire, because the sprouts grow faster than conifer seedlings. Numerous stands of pure and mixed black oak with multiple-stemmed trees are common in the Sierra Nevada, and indicate establishment from sprouting after fire.

In riparian areas low in the zone or north and east aspects higher in the zone, fire return intervals have been found to be greater, and more variable, than on the drier sites (Fites-Kaufman 1997). Fire return intervals generally were greater, most often more than 20 years, and with a high variability between intervals. Fire-scar tree intervals of 35 or 70 years were found on numerous such sites on the Eldorado National Forest. These more variable fire-scar intervals may be due to patchier fires that scarred fewer trees, or lack of fire. Fires were frequent enough to have low intensity and severity, but the gaps in intervals or patchier fires suggest that fuel accumulations occurred in some locations to create some higher intensity burning in small areas, resulting in severe fire effects. This pattern of some high severity fires has been suggested for both Douglas-fir (Fites-Kaufman 1997) and Giant Sequoia dominated mixed conifer (Stephenson and others 1991), based on age-structure and fire scar data.

White fir Type

White fir and Jeffrey pine dominate the upper portions of the lower montane zone. The vegetation varies considerably from mixed conifer to pure white fir forests, with the common element that white fir is generally a co-dominant or dominant. Sugar pine and incense cedar are commonly present. Extensive areas, particularly with rocky or shallow soils, may be dominated by or intermixed with evergreen shrubs. Huckleberry oak and greenleaf manzanita are the primary dominants. Whitethorn is also common.

The historic fire regime for the white fir type is described as: low to moderate intensity; surface-passive crown fire, to multiple (surface-passive crown to active crown) fire type regimes; low to moderate severity, and a short, variable fire return interval. There are no published fire history studies in this zone in the Sierra Nevada (van Wagtendonk and Fites-Kaufman 2006). Fire history studies that represent the most similar conditions are from the Caribou Wilderness of Lassen National Forest and Lassen National Park, in Jeffrey pine-white fir forests (Solem 1995). Fire return intervals there ranged from 23 to 32 years. However, precipitation at those sites is less than 100 centimeters (cm) a year, and in much of the northern Sierra, this zone receives greater than150 cm. The fire return intervals in upper montane forests that have more similar precipitation are most often greater than 40 years (Solem 1995, Taylor and Halpern 1991). Fire return intervals were probably somewhere in between, and tending to the higher end historically for this zone in the Sierra Nevada.

Research on historic fire intensity and severity is lacking for this zone, but white fir dominated types are thought to burn with mixed severity; like the similar upper montane red fir, but with a greater component of low severity fires. The pattern would be dominated by low intensity fires that are often patchy. At varied intervals associated with dry years, more intense fires would result in a patchwork of low, medium and high severity areas across the landscape.

Upper-Montane Zone

Red fir is the dominant species across most productive sites. The forests vary from pure red fir, to varied mixtures of red fir and white fir or lodgepole pine. Rocky areas are more prevalent than in other zones, and are typically dominated by Jeffrey pine and various amounts of evergreen shrubs or whitethorn. Greenleaf manzanita, huckleberry oak and pinemat manzanita are the prevalent shrub species.

Red Fir Type

The fire regime in red fir in the upper montane zone of the Sierra Nevada has been described as: moderate fire return intervals, with multiple intensity, severity, and fire types (van Wagtendonk and Fites-Kaufman 2006). The multiple fire regime class was developed based to a large degree to encompass the range of fire patterns in red fir. This is often labeled "mixed severity" for the severity component (Agee 1993). Multiple is a more detailed pattern that describes the typical pattern of varying intensity from either low to high, and severity from low to moderate to high, and fire type from surface-passive crown to passive-active crown. Because of the fuel conditions in red fir dominated forests, made of compact litter and duff but often patchy, high accumulations of downed wood, and dense forests, the fire behavior is widely varying in space and time.

Several fire history studies have been conducted in red fir, and red fir-white fir forests of the Sierra Nevada or southern Cascades. The most detailed work has been done by Taylor and others in the Lassen National Forest. He looked at both age-structure and fire scars, and estimated historic return intervals of 40 years or more in red fir, and mixed red fir-white fir forests (Taylor and Halpern 1991). In another study in the same area, he reported fire return intervals of 13 years in red fir-white fir forests, and 26 years in red fir forests (Taylor 1991). Overall, fires are thought to be less frequent than in the montane zones, or at least patchier.

Fire intensity and severity in red fir and upper montane zones are generally described as mixed (Agee 1993). Because of the compact nature of the surface fuels, due to small needles and heavy snowpacks, the forests tend to burn at low intensity and severity, often in a patchy pattern, or at high intensities when conditions are very dry. Severity when conditions are dry is often mixed with small to large patches of high severity, intermixed with patches of mixed or low severity. The rocky sites where Jeffrey pine is most prevalent, often burn with patchy intensity and severity at a fine-scale, due to discontinuities in the fuel bed. Patches of chaparral or forests mixed with chaparral tend to burn at high severity when they burn. These fires primarily are fueled by the shrubs rather than the surface fuels, and therefore primarily occur, or are the most widespread, when it is a dry year and foliar moisture levels are low.

In Yosemite National Park, wildland fire use has been applied to upper montane forests for several decades now. High severity patches as large as several hundred acres occur where forests are more continuous, but otherwise the mosaic of different severities is generally finer in scale.

Jeffrey Pine, Western White Pine, Mountain Juniper Type

Within the upper montane zone of the Sierra Nevada, small patches to large expanses of open, pine dominated forests and woodlands occur amongst red fir forests. The understory ranges from very sparse herbs or grasses or scattered shrubs, where soils are very shallow, to denser patches or continuous areas of shrubs. Sometimes these vegetation types intergrade with red fir in the same zone, or white fir forests from the adjacent lower elevation zone. Little research has been conducted on historic fire patterns in these vegetation types (Skinner and Chang 1996, van Wagtendonk and Fites-Kaufman 2006). Van Wagtendonk and Fites-Kaufman (2006) characterized the historic fire regime as: primarily surface-passive crown fire; low intensity and severity, with a moderate fire return interval. As with any chaparral or shrubland type, historic fire patterns are difficult to reconstruct because shrubs do not retain a record of fire scars like trees. For the eastside forest and montane woodland, van Wagtendonk and Fites-Kaufman (2006) described the chaparral fire regime as: high intensity, high severity, moderate return interval; and with a passive-active crown fire type. Fire return intervals in the upper montane, westside chaparral were likely longer than for those in montane areas on the eastern slopes of the Sierra Nevada.

Eastside Forest and Woodland

Eastside forests and woodlands of the Sierra Nevada vary in their composition and structure, but generally are characterized by Jeffrey pine or ponderosa pine, with varying amounts of white fir. Juniper may be present in varying amounts. In the southern Sierra Nevada, on the Kern Plateau, where the Albanita-Hooker fire occurred, the eastside forests are dominated by Jeffrey pine or co-dominated by white fir and Jeffrey pine. Pure stands of white fir are restricted to smaller patches on limited sites. Red fir may occur, but at higher elevations there is often a direct transition to subalpine forests comprised of lodgepole pine, limber pine, or foxtail pine. Aspen is found around meadows and sites with subsurface water. Lodgepole pine also occurs at lower elevations below the subalpine zone, but is more restricted to cold air drainages or meadow edges. Shrub patches of varying sizes occur intermixed with the forests and woodlands. The dominant shrubs include huckleberry oak (*Quercus* species), ceanothus, and manzanita.

Jeffrey pine, White fir and Mixed Conifer, Chaparral

There has been little fire history research conducted in the eastside forests and woodlands of the Sierra Nevada (Skinner and Chang 1996, van Wagtendonk and Fites-Kaufman 2006). Most of the more recent research has been conducted by Taylor and others in the Lake Tahoe Basin (Beaty and Taylor 2008). There, Taylor reported fire return intervals ranging from 5 to 47 years across several hectare size sites, with median fire return intervals from 12 to 22 years (Fites-Kaufman and others 2000). Van Wagtendonk and Fites-Kaufman (2006) characterized the historic fire regimes of Jeffrey pine forests and woodlands as: short fire return intervals, with low intensity and severity, and surface-passive crown fire type. They characterized the fire regime of white fir and mixed conifer forests and woodlands as: moderate fire return intervals, and with multiple intensity, severity, and fire types. The multiple fire regime class was described above for red fir in the upper montane zone, and includes a variety of intensities, severities (low, to moderate to high), and fire types (surface-passive crown to passive crown-active crown) in space and time. Agee's (1993) concept of mixed severity fire regime type applies. Intensity is often low, and fire behavior restricted to surface-passive crown fire types, but there are interspersed areas of higher fire intensity and active crown fire. More active fire behavior and severity can occur across larger areas during particularly windy and dry conditions.

Chaparral or patches of shrubs can have historic fire patterns the same as the forest types or woodlands they occur in, or slightly different for larger patches. Van Wagtendonk and Fites-Kaufman (2006) characterized the historic fire regime of east zone chaparral as: medium fire return interval; high intensity and severity; and passive-active crown fire type. Russell and others (1998) studied settlement patterns of fire in chaparral in the Lake Tahoe basin, and determined that fires were high severity and effects could last for over five years.

METHODS

Study Sites and General Fire Information

Albanita-Hooker Fire

The Albanita-Hooker WFU fire occurred on the east side of the Sequoia National Forest on the Kern Plateau (Figure 2). The Kern Plateau averages 15 inches of rain per year. Vegetation zones extend from the mid-montane to upper montane, composed primarily of Jeffrey pine (*Pinus Jeffreyi*), red fir (*Abies magnifica*), and lodgepole pine (*Pinus contorta*), with an understory shrub layer composed of huckleberry oak (*Quercus vaccinifolia*), manzanita (*Arctostaphylos sp*.) and ceanothus (*Ceanothus* sp.). The majority the area was classified as condition classes 2 or 3, with moderate or great departure from historic vegetation and fire regime conditions (Figure 3).

The fires began September 16, 2003. The Albanita and Hooker fires began as two separate lightning ignitions. Both fires were managed as wildland use fires and were eventually brought together to create the Albanita-Hooker WFU fire. Initially, both fires displayed low rates of spread and intensities, until an east wind event, coupled with single digit humidity and record high temperatures, resulted in increased fire activity and spread the fire to the south and southwest. Suppression activity increased, and the fire was eventually extinguished with a cold front that occurred approximately November 25, 2003. Final acreage of the fire was 4,483 acres.

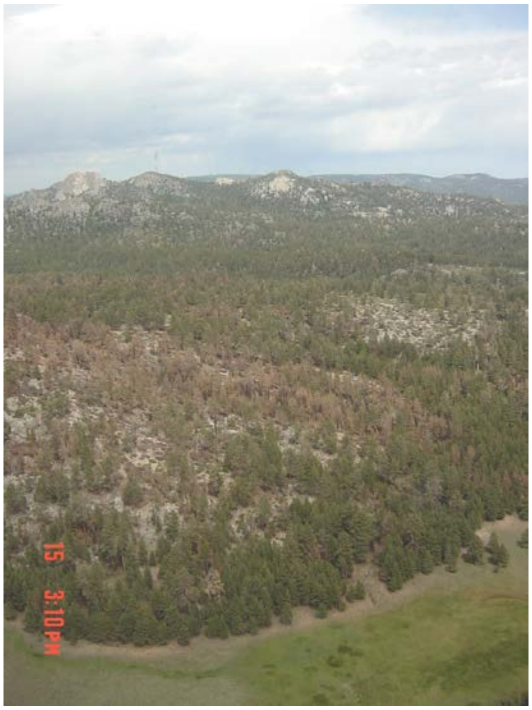
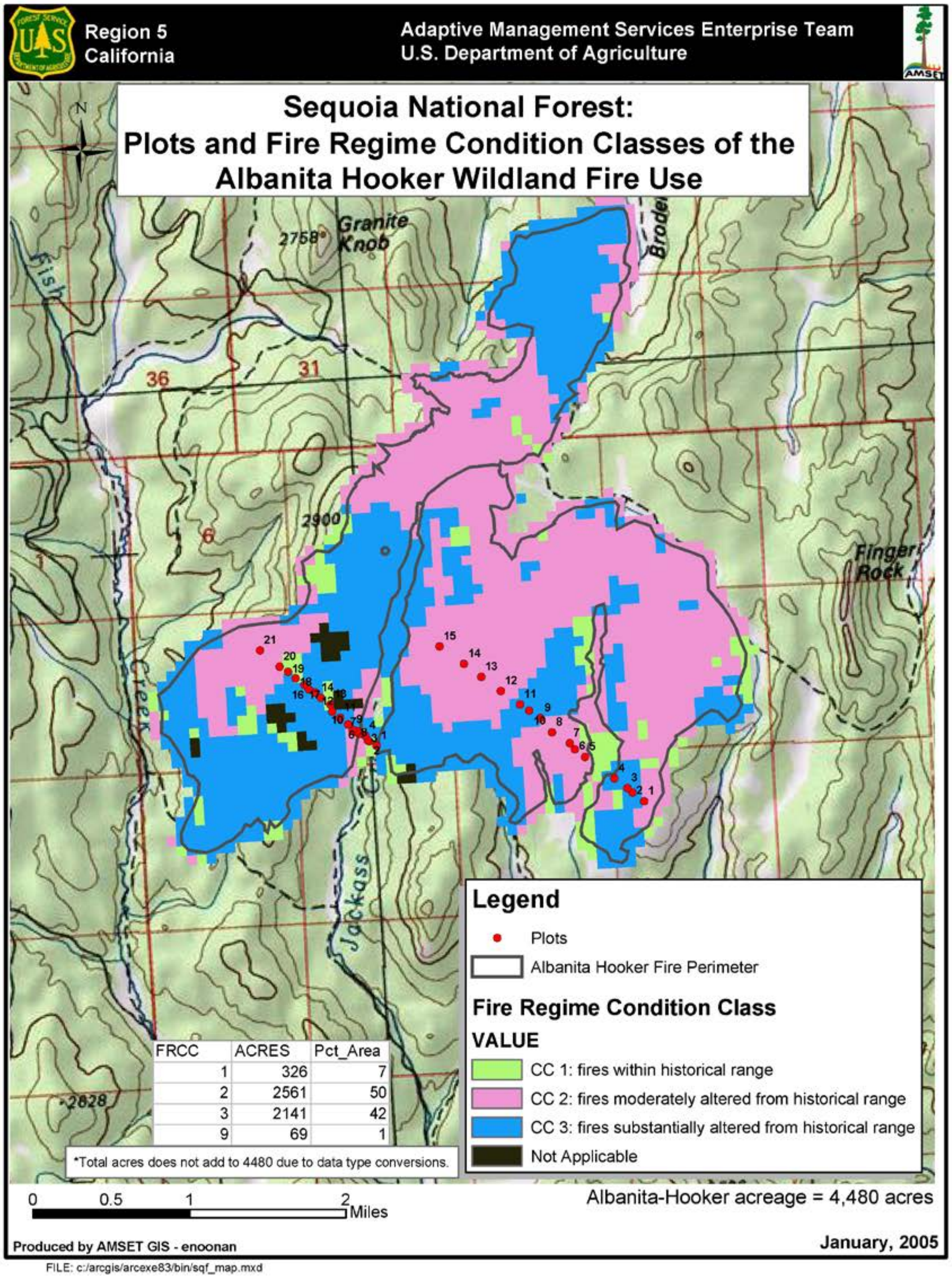


Figure 2. Albanita-Hooker Wildland Fire Use Fire on the Sequoia National Forest.



FRCC	ACRES	Pct_Area
1	326	7
2	2561	50
3	2141	42
9	69	1

*Total acres does not add to 4480 due to data type conversions.

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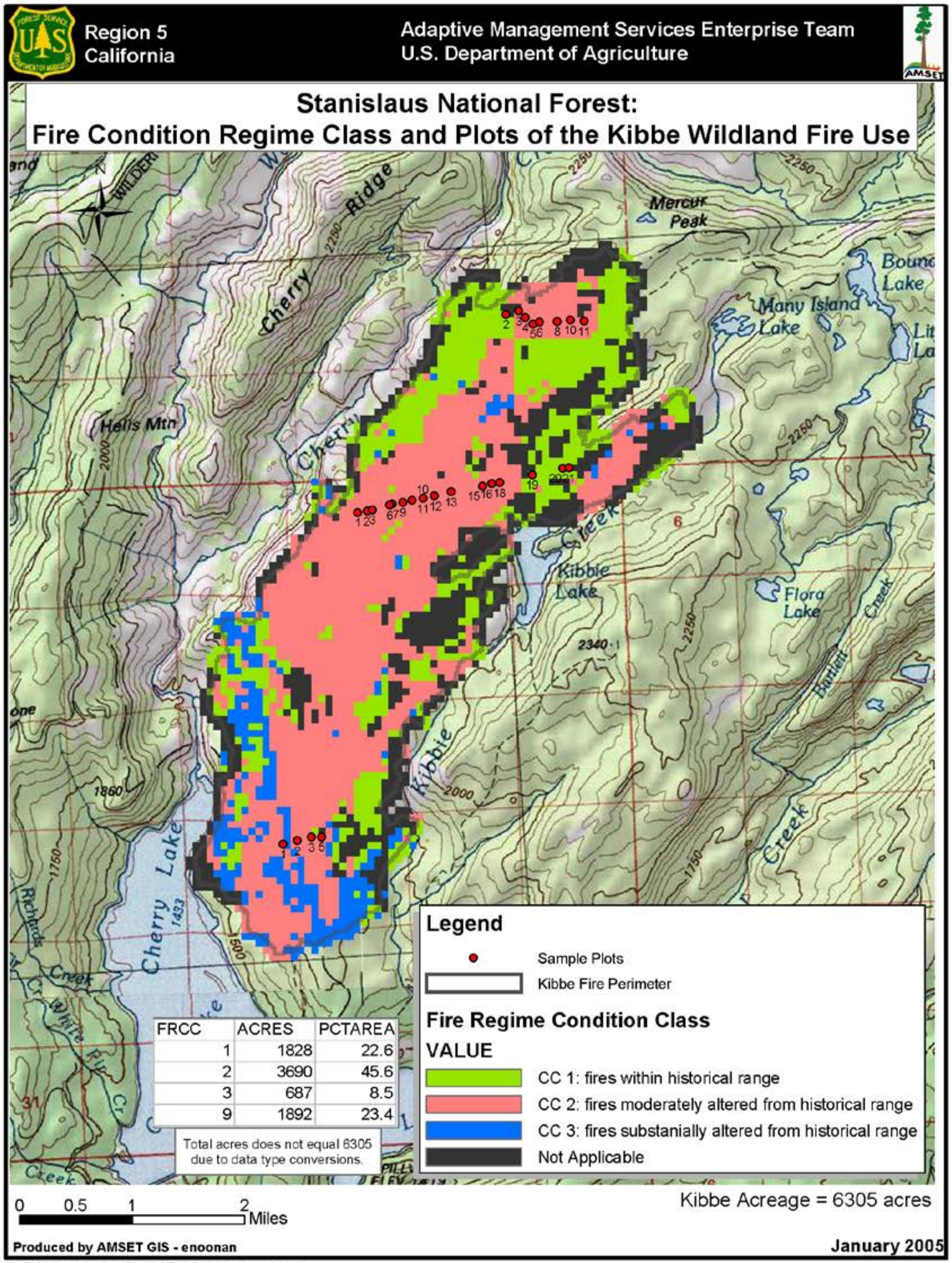
Figure 3. Albanita-Hooker fire regime condition classes, with plots and 2 transects shown.

Kibbe Fire

The Kibbe WFU fire occurred on the Stanislaus National Forest and Yosemite National Park (Figure 4). The Kibbe fire encompasses ecological zones that extend from the lower to upper montane. Lower montane zones are composed of black oak (*Quercus kelloggii*), ponderosa pine (*Pinus ponderosa*) and live oak (*Quercus wislizenii or Quercus chrysolepis*) forests, with interspersed chaparral shrub types. As elevations climb into the mid-montane zone, mixed conifer forests are dominated by Jeffrey pine and white fir, along with small amounts of sugar pine (*Pinus lambertiana*) and incense cedar (*Calocedrus decurrens*). The upper montane zone is dominated by red fir (*Abies magnifica*), with a sparser shrub understory of manzanita, huckleberry oak (*Quercus vaccinifolia*), and pinemat manzanita (*Arctostaphylos nevadensis*). The majority of the Kibbe fire is mapped as condition class 2, with a moderate level of departure from historic range (Figure 5).

The Kibbe WFU fire started August 31, 2003, and was located north of Yosemite National Park, adjacent to the park border. Within Yosemite NP, 2,952 acres burned. The Kibbe fire was extinguished approximately October 31, 2003 and totaled 6,305 acres. The Kibbe fire burned partly through an old fire area from 1998 that contained a large amount of fuels.

Figure 4. Kibbe Wildland Fire Use fire on the Stanislaus National Forest.



FRCC	ACRES	PCTAREA
1	1828	22.6
2	3690	45.6
3	687	8.5
9	1892	23.4

Total acres does not equal 6305 due to data type conversions.

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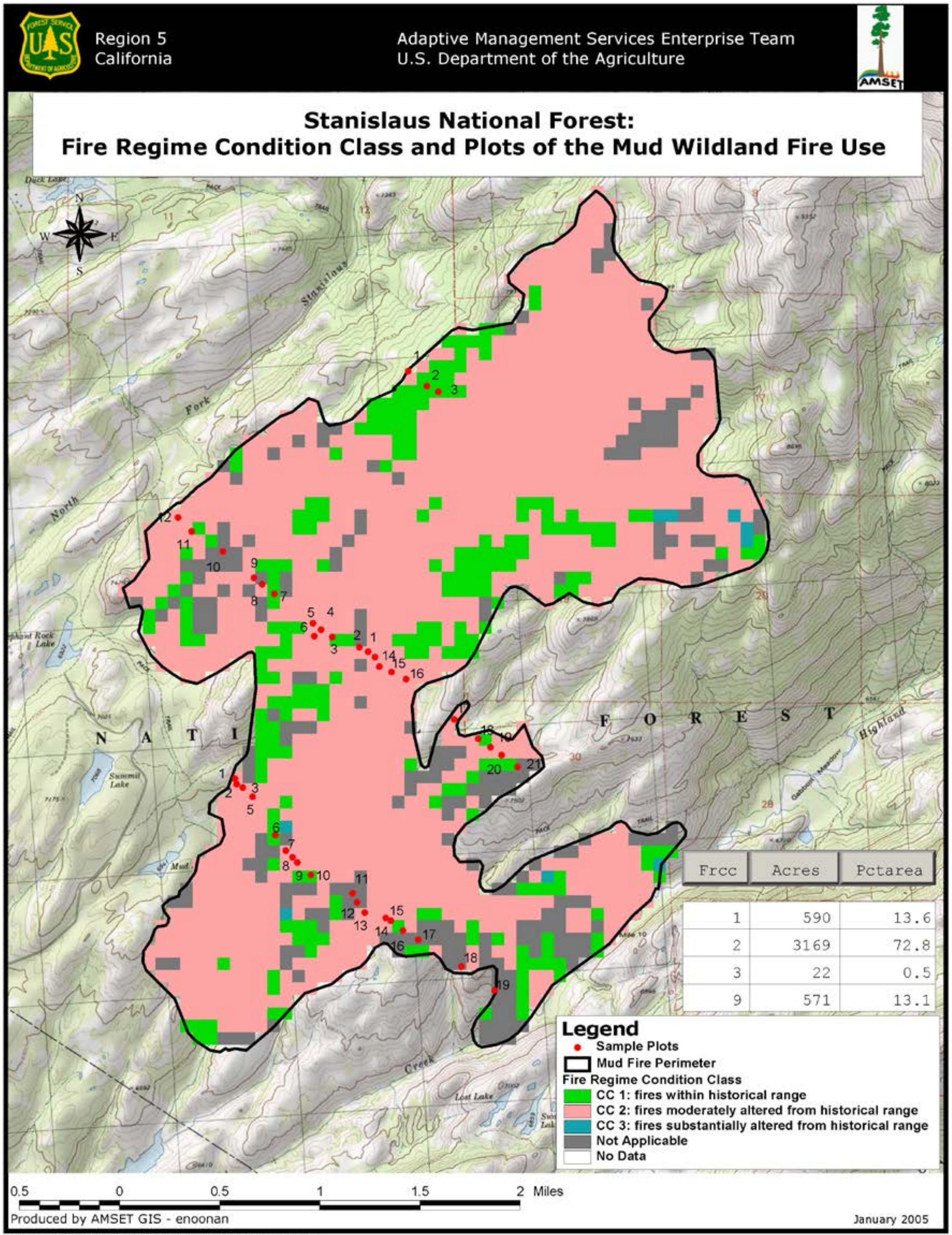
Figure 5. Kibbe WFU fire with fire regime condition classes, with plots and 3 transects shown.

Mud Fire

The Mud WFU fire encompasses the upper portions of the lower montane to upper montane ecological zones, which includes white fir and Jeffrey pine as dominant overstory types at lower elevations, and with red fir dominating in the higher elevations (Figure 6). Lodgepole pine occurs in varying amounts throughout. Large patches of montane chaparral occur, dominated by huckleberry oak, greenleaf manzanita, and some pinemat manzanita. The pre-fire forest included small pockets of insect induced mortality, which contributed to standing dead snags, and moderate to high levels of downed fuels. The majority of the area within the fire was classed as condition class 2, with a moderate level of departure (Figure 7). The Mud fire began on August 30, 2003 and was extinguished on October 30, 2003. It burned 4,049 acres.

Figure 6. Mud Wildland Fire Use fire on the Stanislaus National Forest. (Picture supplied by the Stanislaus National Forest.)



Frcc	Acres	Pctarea
1	590	13.6
2	3169	72.8
3	22	0.5
9	571	13.1

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Figure 7. Mud WFU fire with fire regime condition classes, with plots and 3 transects shown.

Field Measurements of Fire Effects and Severity

We utilized systematically placed transects to sample spatial patterns and randomly place plots to measure fire effects and severity. We gathered data on proportion of transect in different burn severity to vegetation, fire effects on tree, understory vegetation and soil surface layers. In addition, we sampled "effective cover" to evaluate a key component of effect to hydrologic function.

Sampling Approach and Transect Layout

Spatial patterns and different measures of fire severity were sampled along systematically placed transects in each fire. Transects were placed perpendicular to the primary fire progression pattern to represent variation by major ecological zone and within each zone to encompass variation in aspect, slope and position in the landscape (Table 3, Figures 3, 5, 7). The data were collected one year post-fire.

Table 3. Transects by fire, displaying transect distance in meters, and the range of elevation in feet. Transect length was used to quantify landscape proportions of different levels of both shrub and overstory tree severity.

Fire	Transect	Length (m)	Elevation Range (ft)	Ecological Zone	Dominant Vegetation
Albanita-Hooker	1	1,586	7,839-9,003	Eastside montane	Jeffrey pine, white fir, aspen, montane meadows, montane chaparral
Albanita-Hooker	2	2,721	8,331-8,784	Upper Montane /Subalpine	Lodgepole pine, aspen, montane meadows
Mud	1	2,581	6,790-7,141	Montane/Upper Montane	Jeffrey pine, white fir, montane chaparral
Mud	2	3,150	6,963-7,429	Montane/Upper Montane	Jeffrey pine, red fir, montane chaparral
Mud	3	390	7,455-7,629	Upper Montane	Red fir
Kibbe	1	740	5,799-6,409	Lower Montane	Ponderosa pine, black oak, mixed conifer
Kibbe	2	3,667	6,750-7,219	Montane	White fir, Jeffrey pine, lodgepole pine
Kibbe	3	1,430	7,800-7,947	Upper Montane	Red fir

Spatial Patterns of Fire Severity

Along each transect, homogenous patches of fire effects were identified and mapped. Patch boundaries were determined by a number of measures. First, a substantial change in the ocular estimation of fire severity, exemplified by a transition from slight crown scorch to total crown consumption; or complete consumption of shrubs versus decadent shrubs with 1 hour fuels still attached, would determine a change in patch type. Furthermore, a change in slope, dominant species composition, or vegetation structure would also determine a patch change.

Once the patch was established, the beginning and end of the patch was recorded with a global positioning system (GPS), which recorded location within 1 to 15 meter accuracy, depending upon the GPS unit used. Most of the GPS measurements were corrected to within 1m accuracy, including all locations on the Albanita-Hooker fire.

Plots were randomly placed within each patch. At each plot we took photographs, recorded site information, and collected data on fire effects. From the end of the patch, a random distance and direction was chosen to establish a plot center within the extent of the patch. At plot center, aspect and slope were measured, and location was recorded using a GPS. Photos were taken facing both north and at a recorded azimuth that captured representative burn severity for the patch. Overall, general patterns of species composition, canopy cover, topography, and general patterns of burn characteristics were recorded for each patch.

Substrate and Understory Vegetation Effects

A burn severity coding matrix was used from the National Park Service fire monitoring handbook to rate burn severity of the substrate (soil surface, duff and litter layers), and understory live vegetation (USDI NPS 2001) (Appendix A). At plot center, two 3 meter by 3 meter subplots, extending both north and south, were used to rate levels of understory burn severity of the substrate, herb/grass, shrub, and seedling layers. Levels of burn severity are rated from 1 (heavily burned) to 5 (unburned). Percent cover of each substrate component (soil, small and large downed fuels, duff and litter) and rock were recorded to allow calculation of effective cover. Effective cover is a measure of soil cover that would reduce the impact of precipitation on soil erosion and is comprised of cover by litter, duff, downed wood, rocks or low lying vegetation. Herbaceous, grass, shrub, and seedling species and percent cover were also recorded.

Tree Mortality and Effects

Tree mortality, scorch and torch height, bark char, and sprouting were measured for trees. The point-centered quarter method (Cottom and Curtis 1956; Mueller-Dombois and Ellenberg 1974) was used to obtain an unbiased measure of tree mortality and effects with minimum sampling time. This technique also allows calculation of tree density, and along with other tree measures (size, height and species), canopy fuel conditions. The plot is divided into four quarters representing the four cardinal directions. The north quarter extends from 315º to 45º, the east quarter extends from 46º to 135º, etc. Within each quarter, the distance from plot center to the closest tree and pole was measured using a laser (Impulse Laser Technology Inc.) for a total of 4 overstory trees, and 4 pole sized trees per plot. Overstory trees were classified as those with diameters at breast height (dbh) greater than 15.2 cm, while pole trees as those with dbh equal to or less than 15.2 cm.

Trees were tagged, and data collected and recorded on: species, dbh (cm), total height (m), estimated pre-fire height to live crown base (m), percent basal char, scorch height (m), torch height (m), mortality, decay class, and qualitative descriptions of health. Scorch is measured from the base of a tree to the height of brown needles in the crown. Torch is measured from the base of a tree to the height of blackened needles in the crown. Mortality was noted for all trees and poles, and a tree or pole was determined alive if it had any green foliage still attached. Azimuth from plot center to the tree and pole stems was recorded for potential future re-sampling, and longer term mortality studies.

Fire behavior and weather

We obtained records of fire behavior and weather observations made during the fires, as well as conducted field interviews with the WFU fire managers on patterns of fire behavior in relation to weather and vegetation or topography. This information is described in detail in Appendices B and C.

Pre-Fire Condition Class

GIS data for condition classes were obtained from the California Department of Forestry and Fire Department, and used for this analysis (http://frap.cdf.ca.gov/data/frapgisdata/select.asp). Each condition class was summarized by percent area within the final fire boundary using ArcGIS.

Vegetation and Substrate Severity Analysis and Evaluation

Severity was summarized by patch, based on plot averages or estimates. Substrate and understory (primarily shrub) severity were calculated based on the average severity rating for the two subplots. Tree severity was based upon levels of overstory tree mortality and crown consumption (Table 4).

Table 4. Fire severity classes as a function of mortality of overstory trees (greater than 15.2 cm), crown scorch (height from base of tree to browned needles in the crown), and crown torch height (height from base of tree to consumed needles in the crown).

Tree Severity				
Class	Severity Rating	Mortality	Scorch Height	Torch Height
5	very low	<25%	0	0
4	low	>=25-50%	0	0
3	moderate	>50-75%	0	0
2	high	>75%	equal to tree height	less than tree height
1	very high	>75%	equal to tree height	equal to tree height

Fire severity data were summarized in three different complementary ways. First, data were summarized by transect within each fire, representing different ecological zones. Secondly, data were summarized by individual WFU fire. Finally, patch level data were aggregated by ecological vegetation types. The ecological vegetation types were developed using a multivariate statistical approach. Severity ratings and proportion of the area in different severity levels were evaluated primarily for overstory tree and shrub layers. We chose not to composite the ratings to enable evaluation if their patterns were concurrent or distinct.

Constrained Indicator Species Analysis (COINSPAN) (Carleton and others 1996) was used to classify the plot data collected in each patch into discrete ecological groups. COINSPAN is a divisive classification technique that allows for direct analysis of environmental gradients. COINSPAN uses canonical correspondence ordinations (CCA; ter Braak 1987) to align plots along a gradient that reflects plant species gradients together with environmental gradients. These gradients are then grouped into similar species/environment classes using TWINSPAN (Hill 1979) sample-classification divisions. Because COINSPAN classification is based on species groups together with environmental variables, it produces an ecological classification that reflects dominant gradients in the data. Data were classified according to species composition and environmental variables including slope, aspect, slope position, and elevation.

Comparisons of Fire Patterns with Historic Fire Regimes and Condition Class Changes

Comparisons of the fire behavior and severity patterns of the WFU fires and historic fire regime patterns were made qualitatively based upon observations of fire behavior in relation to weather and topography and measured patterns of fire severity. Changes in condition class were based upon landscape patterns of the fires, and a qualitative assessment of post-fire fuels conditions.

Evaluation of Resource Benefits

As with condition class, evaluation of resource benefits was primarily qualitative, but based upon the post-fire effects data. Key resource issues and areas of concern were determined based on interviews with the WFU fire managers. Some common issues and some unique issues were noted for each fire. For all of the fires, a key issue was whether patches of high tree mortality were outside of the range of historic variability for fire regimes in these areas. For the Albanita-Hooker WFU fire, key issues were effects to Pacific fisher habitat and effects to aspen stands and riparian areas. On the Kibbe fire, unique issues were potential impacts of the fire on water quality in the Cherry Lake Reservoir, a municipal water source, and effects to critical deer migration habitat.

RESULTS

Albanita-Hooker WFU Fire Effects and Severity

Effective Cover

Effective cover varied by both transect, and corresponding vegetation type and substrate severity rating (Figure 8). In general, effective cover ranged between 20 and 40%, reflecting the patchy nature of vegetation and litter cover in the dry, eastside forests of the Kern Plateau. Patches with moderate severity ratings for the substrate actually had higher cover than less severely burned sites on the lower elevation transect. This is a reflection of increased burning with greater fuel accumulations on the patches with denser vegetation.

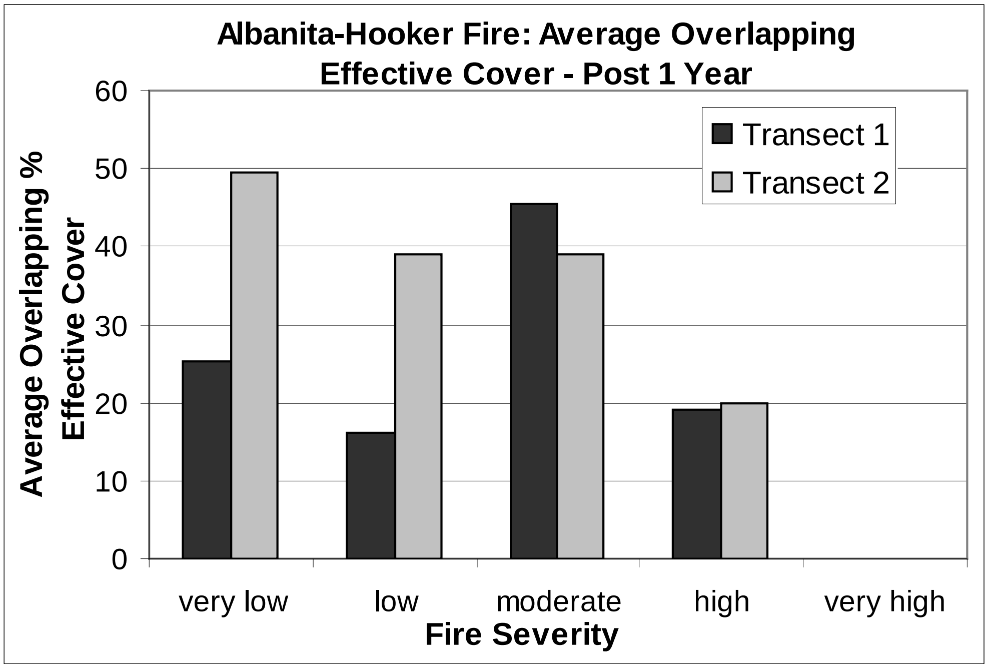

Figure 8. Average overlapping effective cover for the Albanita-Hooker WFU fire per transect. Average overlapping effective cover is the summation of post one year percent cover of 1 hour to 1000 hour fuels (downed woody fuels that range between 0.01” – 20” diameter), litter, and rock cover, which can exceed 100%. Transect 1 represents Jeffrey pine/white fir/aspen while transect 2 represents Jeffrey pine/lodgepole pine/white fir.

Shrub Severity and Effects

Shrub effects varied widely but with a little over half of patches sampled with shrubs exhibiting moderate to high severity (Figure 9). This is in part due to the importance of shrub patches in the understory and surface fuels in these dry, patchy forests. Fuels are patchy and centered around patches of shrubs and associated trees or patches of forest. Therefore, they are likely to burn with moderate or greater severity or remain unburned.

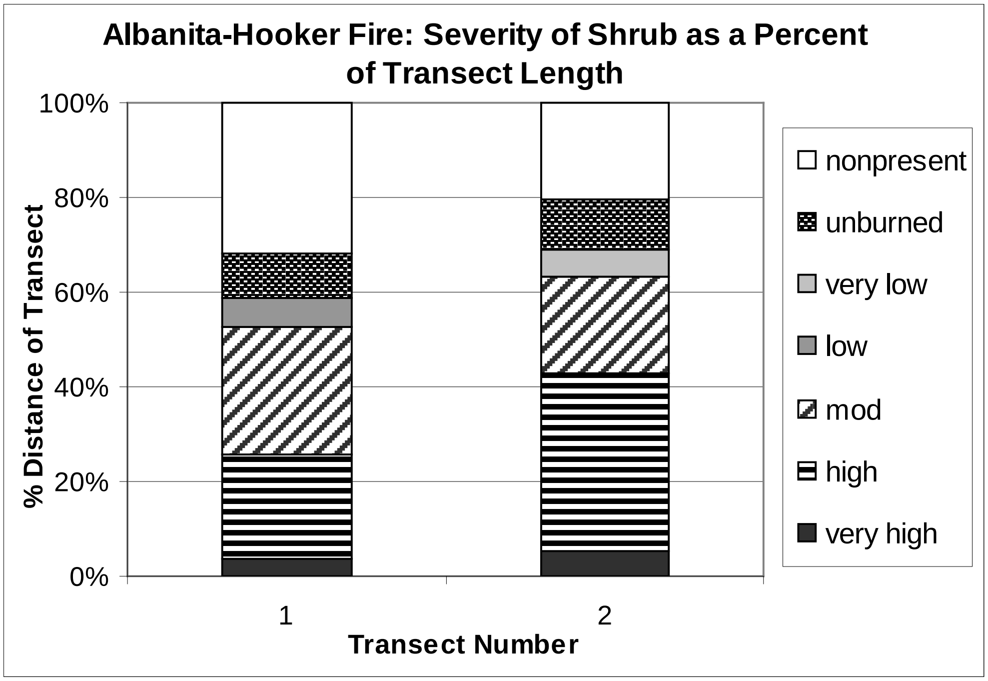

Figure 9. Shrub burn severity as a percent of transect length for the Albanita-Hooker WFU fire. Shrubs are rated according to the NPS burn severity coding matrix from 5 (unburned) to 1 (heavily burned or "very high" severity). Transect 1 represents Jeffrey pine/white fir/aspen while transect 2 represents Jeffrey pine/lodgepole pine/white fir.

Tree Severity and Mortality

The majority of the patches (>70% transect length) exhibited low to very low tree mortality and severity (Figure 10). The proportion of the transects with high or very high mortality and severity, was less than 10 to 15%. Tree stands tended to be denser or with greater surface fuel accumulations, and positioned in two locations. One type of stand was mid-slope; most influenced by periodic, dry desert influenced winds. The second type of stand was in the riparian areas; dominated by lodgepole pine, which has a tendency to develop large surface fuel accumulations naturally over time. However, there was a high variability in mortality and severity patterns even in dense stands (Figure 11).

The graph of tree mortality in relation to tree density showed that even with density as high as 300 trees per acre, there was still considerable ranges of mortality extending from 0 to 100 percent (Figure 11). At higher density, there appears a weaker correlation of increased mortality with density.

Considerable post-fire aspen sprouting was observed in the several patches intersected by the transects. The number and height of sprouts tended to be greater where substrate severity was higher. In contrast, unburned aspen patches showed little aspen regeneration, and considerable decadence in the overstory.

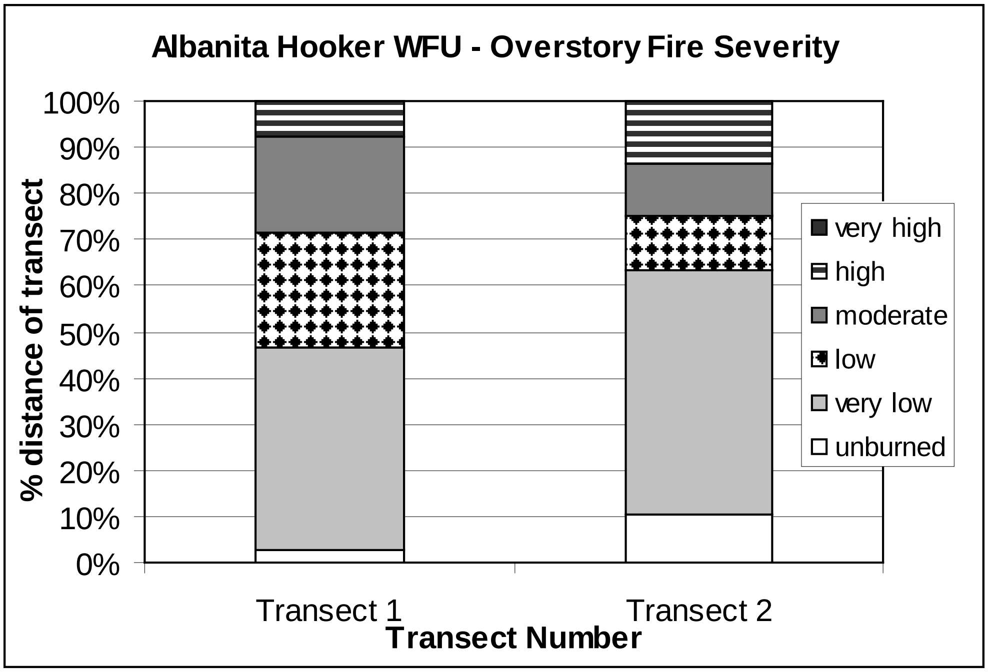

Figure 10. Overstory tree (>15.2 cm dbh) fire severity as a percent of total transect length for the Albanita-Hooker WFU fire. Overstory fire severity is a function of mortality, scorch height (measured from the bottom of a tree bole to the brown needles on the crown), and torch height (measured from the bottom of a tree bole to the blackened needles on the crown). Transect 1 represents Jeffrey pine/white fir/aspen while transect 2 represents Jeffrey pine/lodgepole pine/white fir.

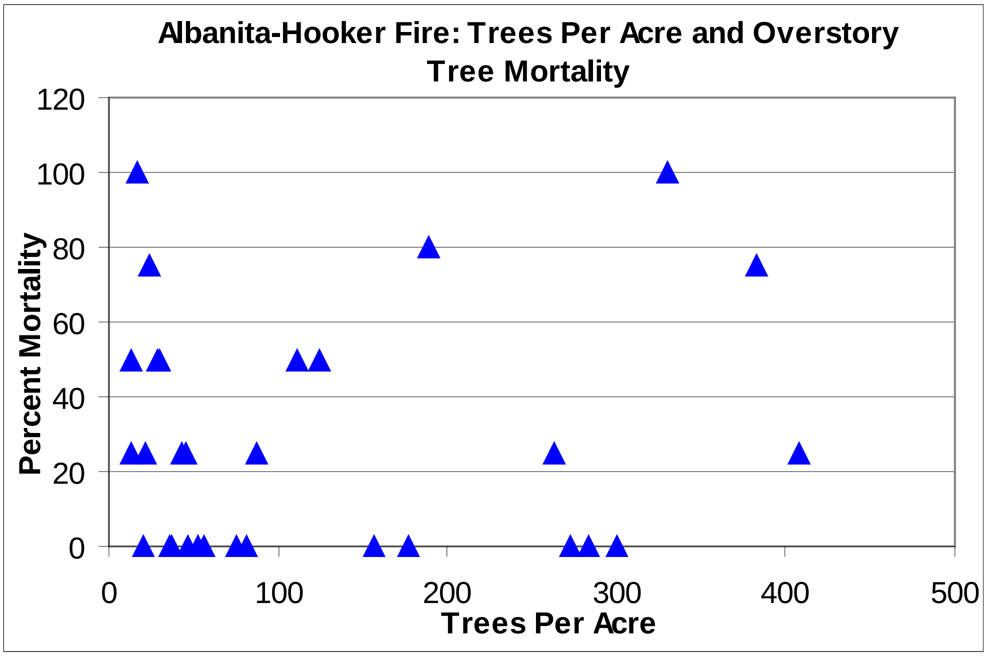

Figure 11. Tree mortality compared to trees per acre for overstory trees on the Albanita-Hooker WFU fire. Trees per acre and mortality were measured from 4 trees larger than 15.2 cm diameter. The point center quarter method was used to quantify density.

Mud Fire Effects and Severity

Effective Cover

Effective cover ranged between 20 and 80% cover (Figure 12). Lower effective covers corresponded with higher substrate severity ratings, but generally exceeded 40% on all but the most severely burned patches. These patches occupied a low proportion of the sampled transects.

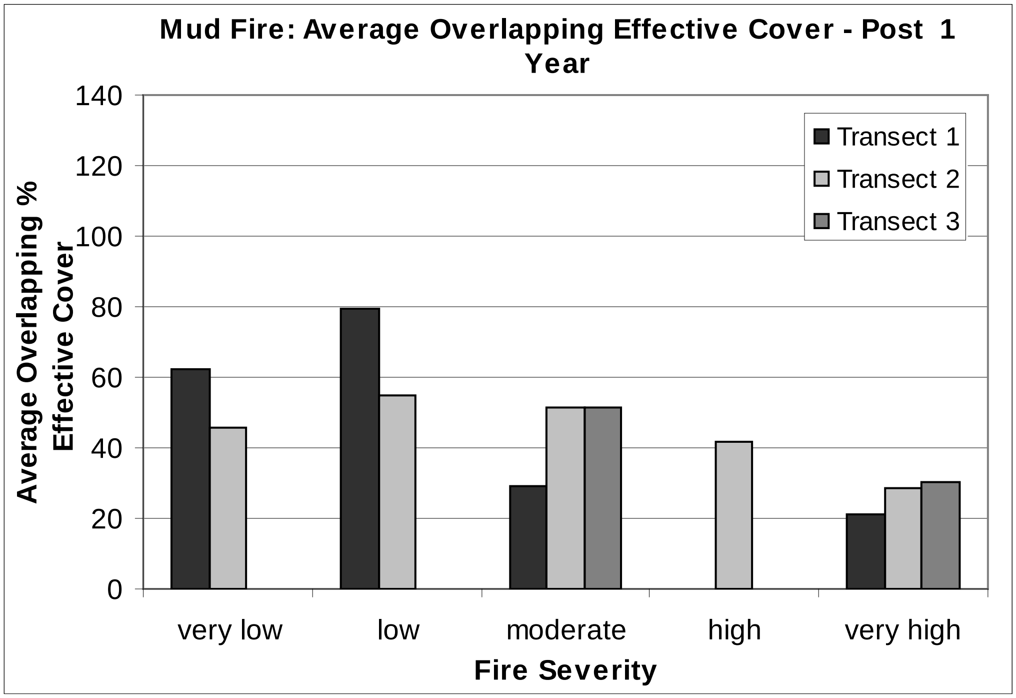

Figure 12. Average effective cover (overlapping, can exceed 100%) for the Mud WFU fire by transect. Average overlapping effective cover is the summation of post one year percent cover of 1 hour to 1000 hour fuels (downed woody fuels that range between 0.01" – 20" diameter), litter, and rock cover, which can exceed 100%. Transect 1 is low elevation white fir/Jeffrey and lodgepole pine; transect 2 is mid elevation lodgepole pine/red fir; transect 3 is high elevation red fir.

Shrub Severity and Effects

Effects to the shrub layer varied widely amongst patches and between transects (Figure 13). The proportion of patches with high to very high severity ratings ranged from a little over 20% on transect 2 to over 60% on transect 3. Transect 2 contained a high proportion of rock outcrop that was sparsely vegetated and showed little to no shrub presence. It should be noted that transect three may not have been very representative, since the length was very short and it only encompassed a couple of patches (Figure 7). There was a high degree of variability in shrub severity amongst patches on the lowest elevation transect (transect 1).

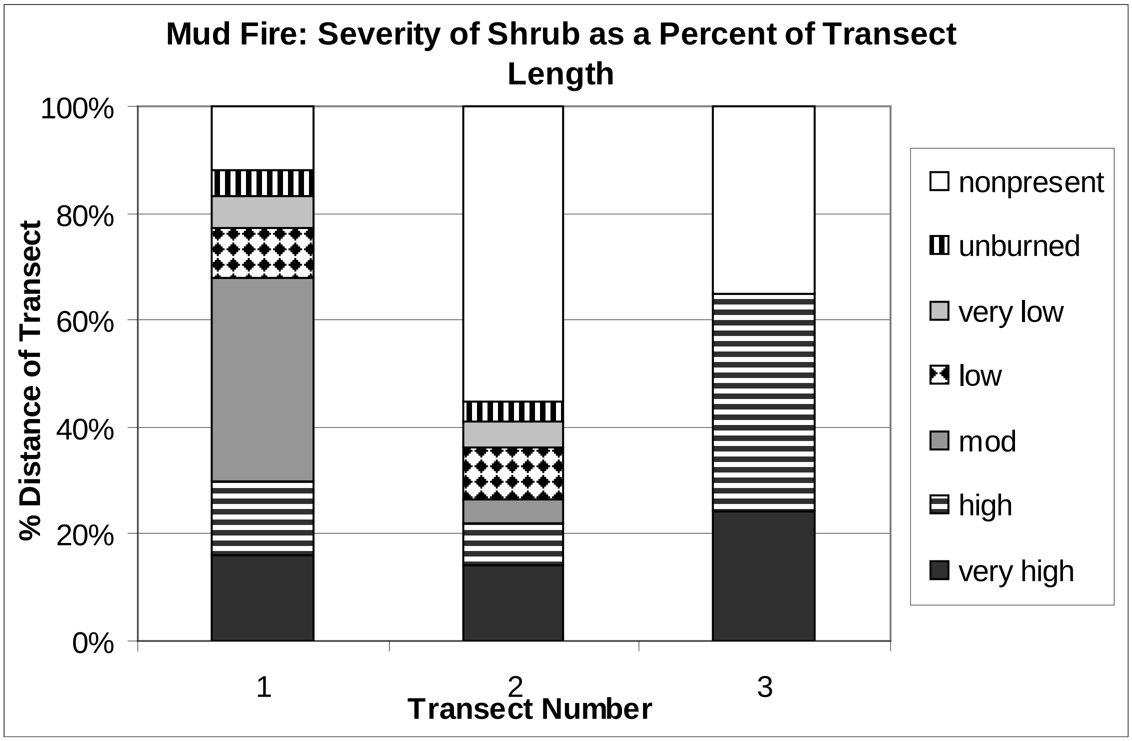

Figure 13. Shrub burn severity as a percent of transect length for the Mud WFU fire. Shrubs are rated according to the NPS burn severity coding matrix from 5 (unburned) to 1 (heavily burned or “very high” severity). Transect 1 is low elevation white fir/Jeffrey and lodgepole pine; transect 2 is mid elevation lodgepole pine/red fir; transect 3 is high elevation red fir.

Overstory Tree Mortality and Severity

Overstory tree mortality and severity varied amongst transects and within transects (Figure 14). The higher elevation transects in the upper montane, red fir zone had near even proportions of low, moderate, and high levels of mortality (transect 2). As stated in the shrub severity section, transect 3 included only a couple of patches that were located in areas burned at higher severity, and not representative of the pattern in that zone. Transect 1, at the lower elevations in the Jeffrey pine, white fir, and montane chaparral vegetation displayed higher levels of low severity (>50%), and lower levels of high severity (<30%).

As with the Albanita-Hooker fire, the densest stands had the greatest likelihood of high mortality (Figure 15). However, there was considerable variability in mortality level amongst stands of all densities. This reflects variability in levels and types of understory, live or surface fuels, and the time of day and weather conditions when the fire reached a particular stand.

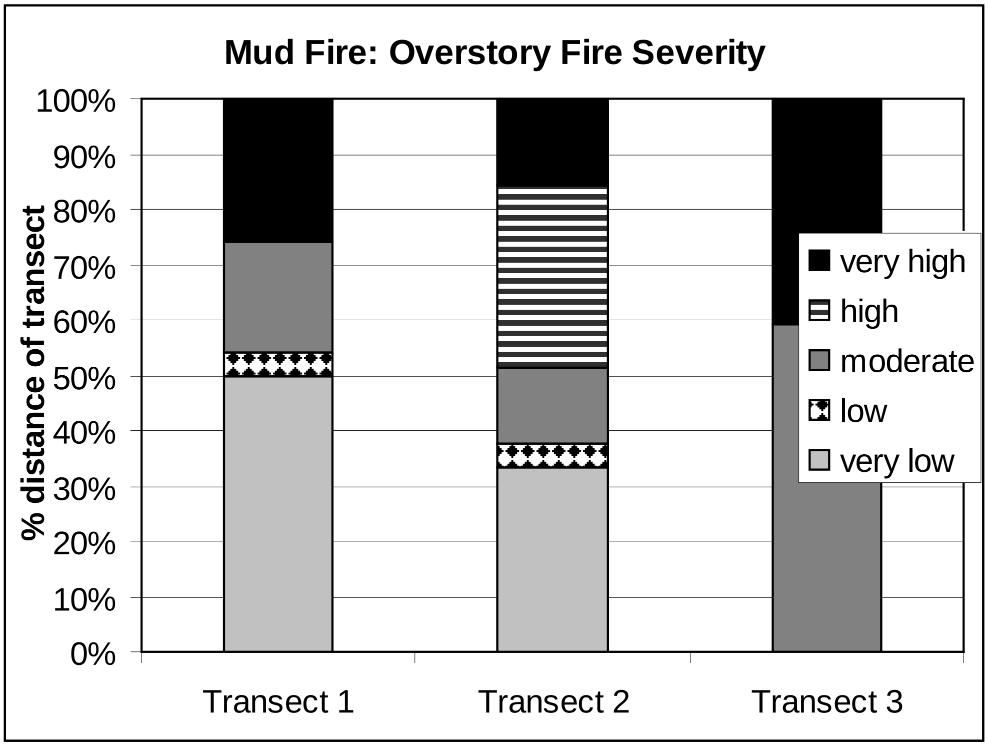

Figure 14. Overstory tree (>15.2 cm dbh) fire severity as a percent of total transect length for the Mud WFU fire. Overstory fire severity is a function of mortality, scorch height (measured from the bottom of a tree bole to the brown needles on the crown), and torch height (measured from the bottom of a tree bole to the blackened needles on the crown). Transect 1 is low elevation white fir/Jeffrey and lodgepole pine; transect 2 is mid elevation lodgepole pine/red fir; transect 3 is high elevation red fir.

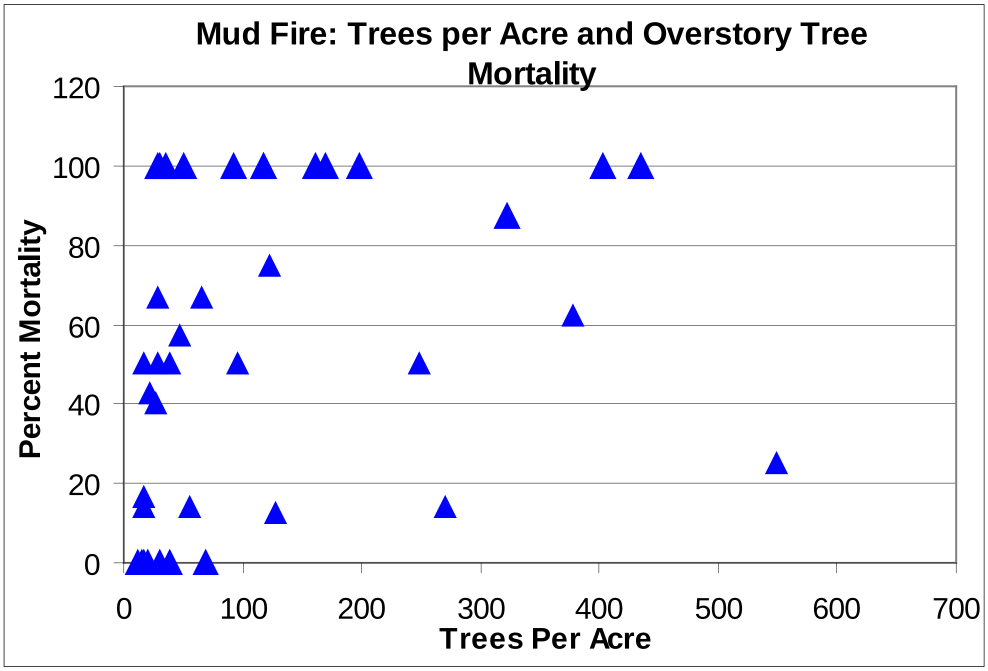

Figure 15. Tree mortality versus trees per acre for overstory trees (>15.2 cm dbh) on the Mud WFU fire. Trees per acre and mortality were measured from 4 trees larger than 15.2 cm diameter. The point center quarter method was used to quantify density.

Kibbe Fire Effects and Severity

Effective Cover

Effective cover was the greatest across all transects and substrate fire severities on the Kibbe fire, with levels ranging primarily between 80 and 100 percent (Figure 16). This may be due to the lower elevation and higher productivity sites compared to the other WFU areas. The lowest levels (20%) were measured in the highest elevation patches, with high substrate severity ratings. Although the lower montane zone was not sampled with great density, we observed that the patches which burned with high severity (according to substrate rating or tree mortality) tended to have a high post-fire effective cover because of post-fire scorched needle drop.

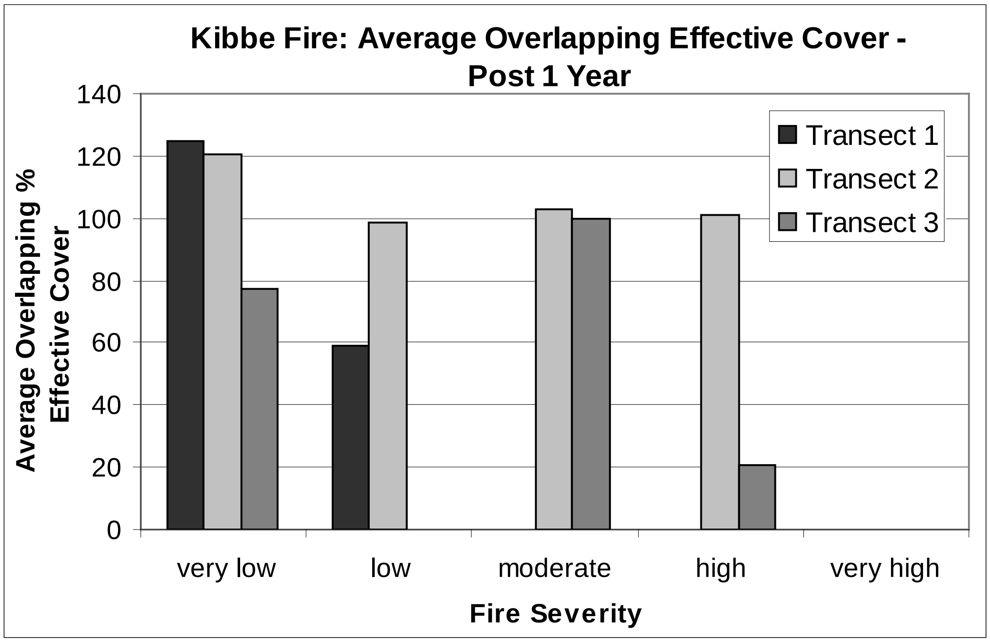

Figure 16. Average overlapping effective cover for the Mud WFU fire per transect. Average overlapping effective cover is the summation of post one-year percent cover of 1 hour to 1000 hour fuels (downed woody fuels that range between 0.01” – 20” diameter), litter, and rock cover, which can exceed 100%. Transect 1 represents low elevation Jeffrey pine/white fir with a manzanita shrub understory; transect 2 represents mid elevation white/red fir with huckleberry oak understory; transect 3 represents red fir with a pinemat manzanita shrub understory.

Shrub Severity and Effects

Shrubs were patchier on the Kibbe fire, and tended to burn at low to moderate severity, in contrast to the more mixed and high severity patterns on the Albanita-Hooker and Mudd fires (Figure 17). Patches with high severity ratings comprised less than 20% of the transects.

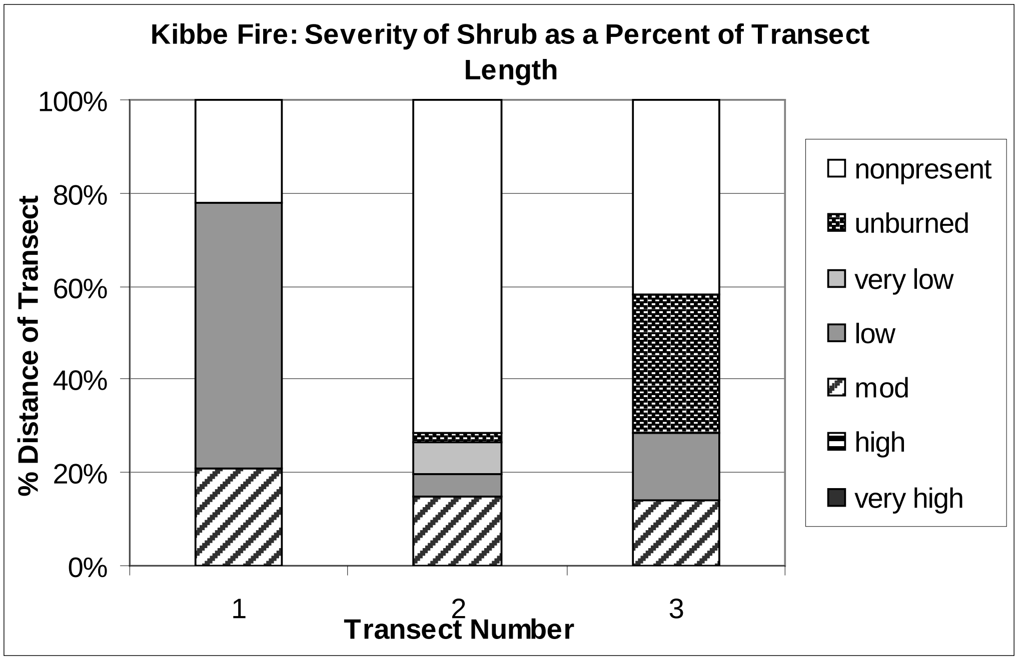

Figure 17. Shrub burn severity as a percent of transect length for the Kibbe WFU fire. Shrubs are rated according to the NPS burn severity coding matrix from 5 (unburned) to 1 (heavily burned or "very high" severity). Transect 1 represents low elevation Jeffrey pine/white fir with a manzanita shrub understory; transect 2 represents mid-elevation white/red fir with huckleberry oak understory; transect 3 represents red fir with a pinemat manzanita shrub understory.

Overstory Tree Mortality and Severity
Overall, along the sample transects, tree mortality was very low to low (Figure 18). However, high severity patches did occur, particularly in portions of the fire that are underrepresented by the transect. At higher elevations in the upper montane zone, the overall patterns of mortality also ranged to mixed proportions, including higher levels, as observed on the Mud fire. The second notable location was at the lowest elevation portions of the fire, in the lower montane zone in the ponderosa pine/black oak forests. Several patches of high severity were observed in this portion of fire, and although not reflected in the data presented in this section, they are included in the qualitative assessment of fire patterns compared to the historic fire regime.

Similar to the Mud fire, two trends are shown on the trees per acre versus mortality chart (Figure 19). First, a positive linear correlation exists for increases in mortality with increases of trees per acre, especially when trees per acre exceed 800. Second, mortality was highly variable in stands of lower tree density.

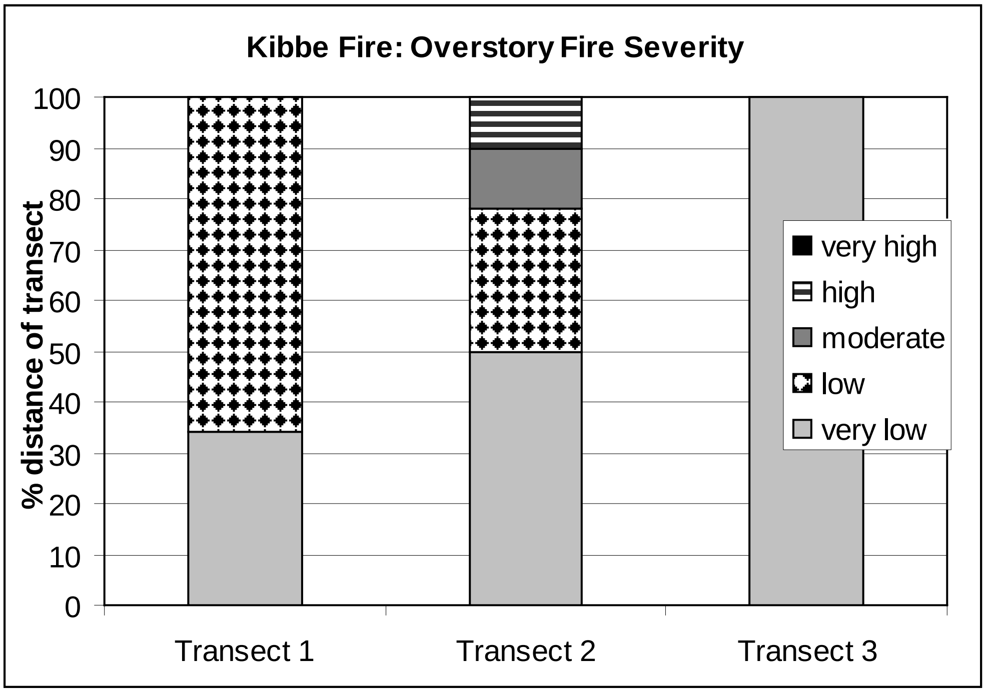

Figure 18. Overstory fire severity as a percent of total transect length for the Kibbe WFU fire. Overstory trees are greater than 15.2 cm diameter. Overstory fire severity is a function of mortality, scorch height (measured from the bottom of a tree bole to the brown needles on the crown), and torch height (measured from the bottom of a tree bole to the blackened needles on the crown). Transect 1 represents low elevation Jeffrey pine/white fir with a manzanita shrub understory; transect 2 represents mid elevation white/red fir with huckleberry oak understory; transect 3 represents red fir with a pinemat manzanita shrub understory.

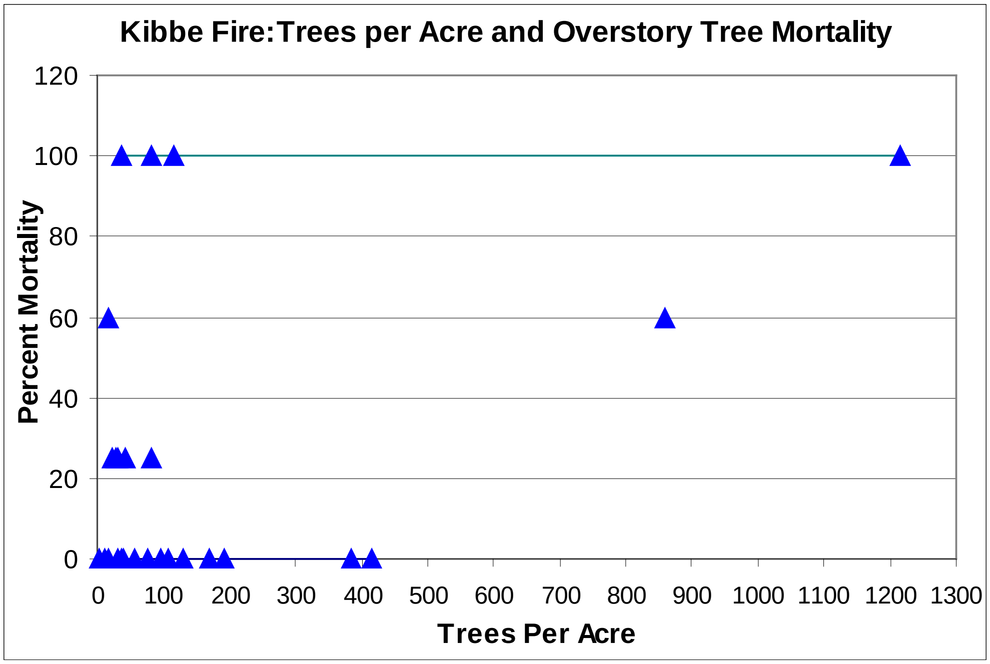

Figure 19. Tree mortality versus trees per acre for overstory trees on the Mud WFU fire. Trees per acre and mortality were measured from 4 trees larger than 15.2 cm diameter. The point center quarter method was used to quantify density.

Fire Behavior and Weather

The Wildland Fire Use (WFU) fires in 2003 on the Sequoia and Stanislaus National Forest were influenced by antecedent regional weather conditions. The southern Sierra Nevada region had three drier than average winters in a row, prior to the fires. Fire weather conditions in the summer of 2003 were not as severe as 2000 through 2002 period; although long-term drought persisted within the region. Beginning July 1, the region experienced mild fire weather conditions with extensive wet thunderstorm activity for about a 6 week period, ending approximately September 4. Live fuel moisture levels at low elevations below the fire areas were at very low levels. These conditions are not atypical for the Sierra Nevada, and long-term climatic patterns indicate that much more severe droughts have been common periodically throughout the range, over the past several thousand years (Stine 1996).

Albanita-Hooker WFU Fire

Fire behavior during the Albanita-Hooker WFU fire was variable, exhibiting mostly surface and passive crown fire types. Fireline intensities were mostly low to moderate, with flame lengths mostly ranging from less than a foot to 8 feet. Occasional small higher intensity runs occurred in patches with higher fuel concentrations, or particularly in denser forest patches when the fire burned during times of lower humidity and higher windspeeds.

Temperature and wind speed, were at or above average. Relative humidity and fuel moisture were at or below average during the time the fire was making its biggest runs. In general, the fire had a south/southwesterly spread, which was the effect of the east winds, which occur 18 to 30% of the time, with an average speed of 10 miles per hour for this time of month (Appendix B). These conditions are not unusual for this landscape, because of the proximity to the desert to the east. The greatest windspeeds are often observed in mid-slope positions with east exposures.

Mud and Kibbe WFU Fires

Fire behavior was variable on the Mudd and Kibbe fires, but mostly varied between surface and passive crown fire types, similar to the Albanita-Hooker fire. Fire behavior and weather for the Mud and Kibbe WFU fires were influenced by a combination of above average temperature and wind speed, and below average relative humidity and fuel moisture. The conditions were conducive to the times when the WFU fires made their biggest runs. Beginning approximately September 8th, temperatures were climbing above average, and relative humidity and 1-hour fuel moisture were in the decline.

An interview with the forest fuels specialist and wildland fire use managers indicated that offshore flow weather patterns had a definite effect on fire behavior. Offshore flow, leads to higher than average temperatures and lower than average relative humidity, with little night time recovery. This scenario can be expected 10 to 15% of the time from the middle of August to the end of fire season. During the evening, winds would be the down slope and canyon with the fire backing down. In the morning, temperatures would climb and general up slope up canyon flow would set in, fires would then race up slope into drainages expanding the fire perimeter (Appendix C).

Pre-Fire Fire Regime Condition Class

Fire Regime Condition Classes (FRCC) presented above (Figures 3, 5, 7) were mapped before these fires and represent pre-fire conditions. A majority of the area burned in the fires occurred in areas rated as moderate departures from natural, historical fire regimes (FRCC 2). However, the Albanita-Hooker WFU had 42% of the area burned in FRCC class of 3, which was a high departure. Areas with a FRCC of 9 consist of barren areas, rock, or water (Table 5).

	FRCC (% area burned)			
Fire	1	2	3	9
	low departure	moderate departure	high departure	barren/not applicable
Albanita-Hooker	7	50	42	1
Kibbe	23	46	9	23
Mud	14	73	1	13

Table 5. Fire Regime Condition Classes from the Albanita-Hooker, Kibbe, and Mud WFU fires and percent area per FRCC class.

DISCUSSION

There was a high degree of variability in fire severity within each of the WFU fires. This was evident in the proportion of the transects with different severity levels for both substrate, shrub, and overstory tree layers. Further, there was a non-linear relationship between shrub and overstory tree severity ratings—areas with high shrub fire severity often did not correspond with areas of high tree severity. Patches with highest tree severity tended to have higher tree densities, particularly in mid-sized trees. This forest structure corresponds with highest levels of canopy bulk density. However, not all patches of high tree density burned with high intensity and resulting high severity effects. The higher severity patches tended to burn under conditions of higher winds and lower humidity, which are not uncommon for these landscapes during the summer and early fall.

The observed fire behavior and fire severity are within the range of historic fire regime patterns. In general, the highest elevation locations, in the upper montane forests dominated by red fir, burned with a pattern of mixed or multiple intensity and severity. The upper portions of the lower montane zone, dominated by white fir and Jeffrey pine forests, also burned with mixed or multiple intensity and severity. The eastside montane forests burned primarily with low to moderate intensity and severity. The lowest elevations in the Kibbe fire, in the ponderosa pine/black oak forests, burned at the high end of severity for the historic fire regime patterns. This is not unexpected given the preceding dry years and dry, windy weather during part of the fire. The effects may be somewhat more severe than would have occurred across the bulk of the landscape in this forest type, but not out of the full range of likely historic fire patterns.

The spatial complexity of the fires at all scales, from sub-patch, to patch and landscape was great. In fact, complexity was so great that it made sampling difficult and more time consuming than originally planned. This is an aspect of historic fire patterns that is difficult to replicate with other vegetation management techniques.

There appear to be multiple positive resource benefits. All areas appear to have experienced fire within their historic range, and a resulting improved condition class rating. Based on our assessment, we observed that condition class was reduced (improved) by at least one level for the burn areas.

Fuel loadings were reduced in many portions and broken up in continuity. This provides multiple resource benefits, including reduction in fire hazard within the burn areas, reduction in fire hazard to adjacent areas, reduction in risk of high severity fire effects to adjacent reservoirs and reduction in risk of modification to wildlife habitat from high severity fires. In addition, for wildlife habitat, there were also many responses of shrubs that would improve their vigor and forage value, both through sprouting, enhanced germination, and increased light through opening of the overstory canopies. For old growth forests, the reduced fire hazard provides an increased likelihood of maintenance of existing old growth trees, and survival of medium sized trees that form the recruitment pool.

In the Albanita-Hooker WFU fire there was a pronounced invigoration of previously decadent aspen stands from the fire. Sprouting was increased in the areas burned at moderate to high intensity. Conifer competition was reduced. High mortality patches in the lodgepole pine and aspen stands adjacent to the creek will provide increased coarse woody debris, and the potential for raising the level of the streambed that appeared deeply incised.

A less obvious resource benefit of these WFU fires is their contribution to reduced landscape level fuel hazard. While fuels management priorities tend to be currently focused on lower elevation sites, with climate change, fire season length at higher elevations will likely increase, perhaps including an increase in fire size and severity. Furthermore, particularly on the Stanislaus, there is a likely landscape level benefit from wildfires associated with east-wind events that start in the higher elevations, and sweep toward lower elevations, where wildland urban interface areas are located.

ACKNOWLEGEMENTS

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APPENDIX A: Weather Discussion for the Albanita-Hooker WFU fire, on the Sequoia National Forest from 09/03/03 – 10/30/03

Introduction

The southern Sierra Nevada region had three drier than average winters in a row, prior to the Albanita-Hooker Wildland fire use fires (WFU). The fire area experienced average precipitation the winter before, driven by a mild El Nino particularly during the spring of 2003. Due to the warmer than average winter and spring, the snow pack in the Kern River basin was about 70% of average. Fire weather conditions in the summer of 2003 were not as severe as 2000 through 2002 period, although long-term drought persisted within the region. Beginning around July 1, the region experienced mild fire weather conditions, with extensive wet thunderstorm activity for about a six week period, ending approximately September 4.

The Albanita-Hooker Wildland Fire Use Fire (WFU) was composed of two lighting caused fires that started on September 3, 2003. The Cannel Meadow Ranger District experienced a series of thunderstorms for five consecutive days, which resulted in ¾ of an inch of rain within the fire area.

Data source

Data were gathered from a variety of sources for this analysis. Archived climate information for the region was collected from WFAS (Wildland Fire Assessment System) site. Archived weather maps were collected to identify and illustrate the climate at the time of the WFU fire. WIMS (Weather Information Management System)\KCFAST (Kansas City Fire Access Software) was used to gather archived weather data from three Remote Automatic Weather Station (RAWS).

After consulting with the fuels specialist from the Cannell Meadow Ranger District, the Bear Peak RAWS (station 044730) was chosen to represent the weather at the WFU site. This station was closest to the project area. Furthermore, it had approximately 12 years of recorded weather data usable for FireFamilyPlus, a program used for the weather analysis. The data from this station were from 1991 to present. The Bear Peak station is most representative of the elevation and fuel typing of the Albanita-Hooker fire area, and it reflects the desert influence, which influenced fire behavior later in the burning period.

Weather Discussion

A high pressure was settling in after the Albanita-Hooker WFU fire was detected. At this time, temperatures were above normal for this time of year, and relative humidity was below average, due to an offshore flow that developed.

A conversation with Fuels Specialist and Wildland Fire Use Manager, Jim Yearwood, indicated that the desert influence affected the fire behavior. This event leads to east winds, with higher than average temperatures, and lower than average relative humidity; thus escalating fire behavior. Fire size would not have increased significantly without the influence of dry weather and windy conditions. Without a strong influence of wind and the resultant spotting, sparse fuels would not have successfully propagated the fire growth that occurred for this complex (Yearwood, personal communication). Furthermore, fires at higher elevations, such as the Albanita-Hooker complex, generally don’t burn unless the weather is above the 90th percentile. The off shore/desert influence is most common when a high pressure is sitting over the region. The intensity of the east wind for this area is dependent upon the strength of the high pressure front (Yearwood, personal communication).

The picture below shows the progression map for the Albanita-Hooker, with an increase of activity around 10/10 to 10/26, coincident with peak weather conditions.

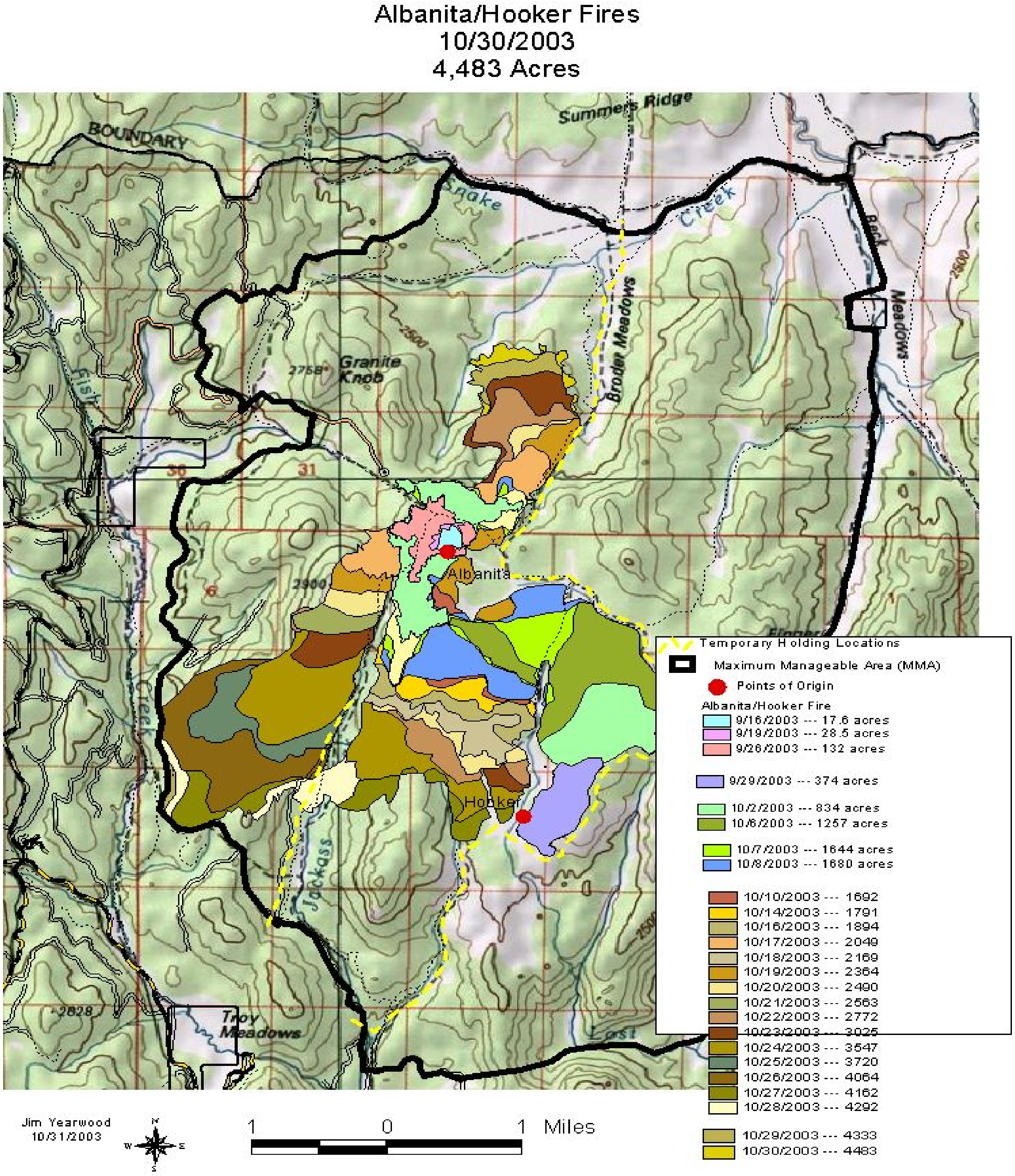


Figure 1. Albanita-Hooker WFU progression map (Jim Yearwood, 2003).

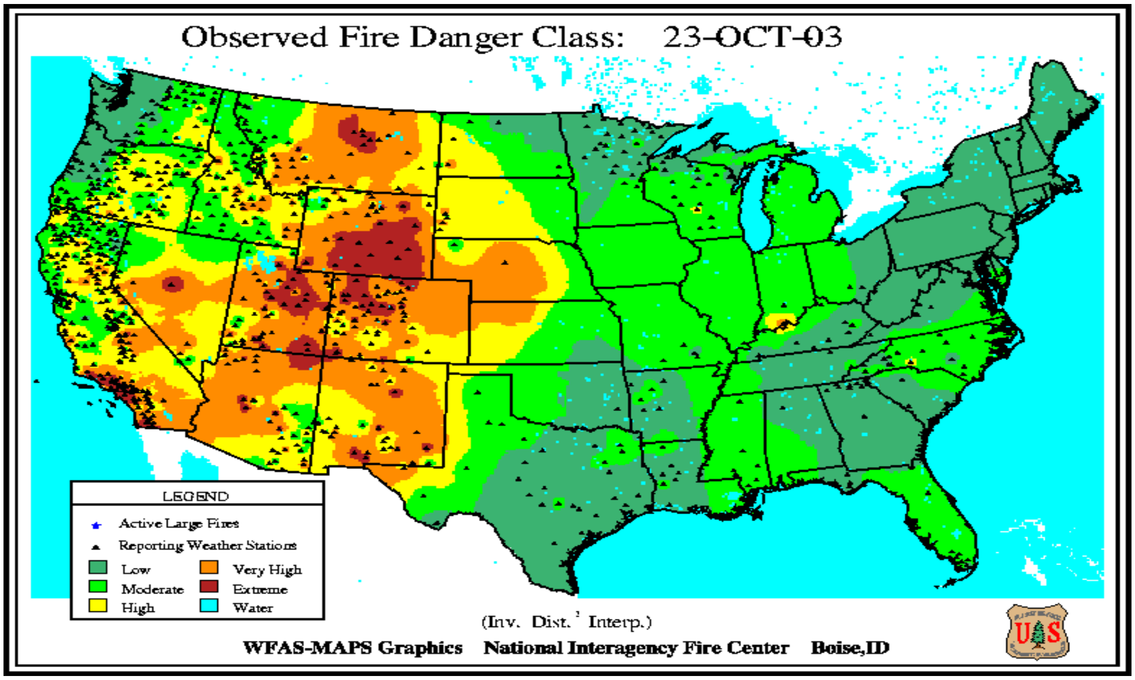


Figure 2. Observed Fire Danger Class for October 23, 2003.

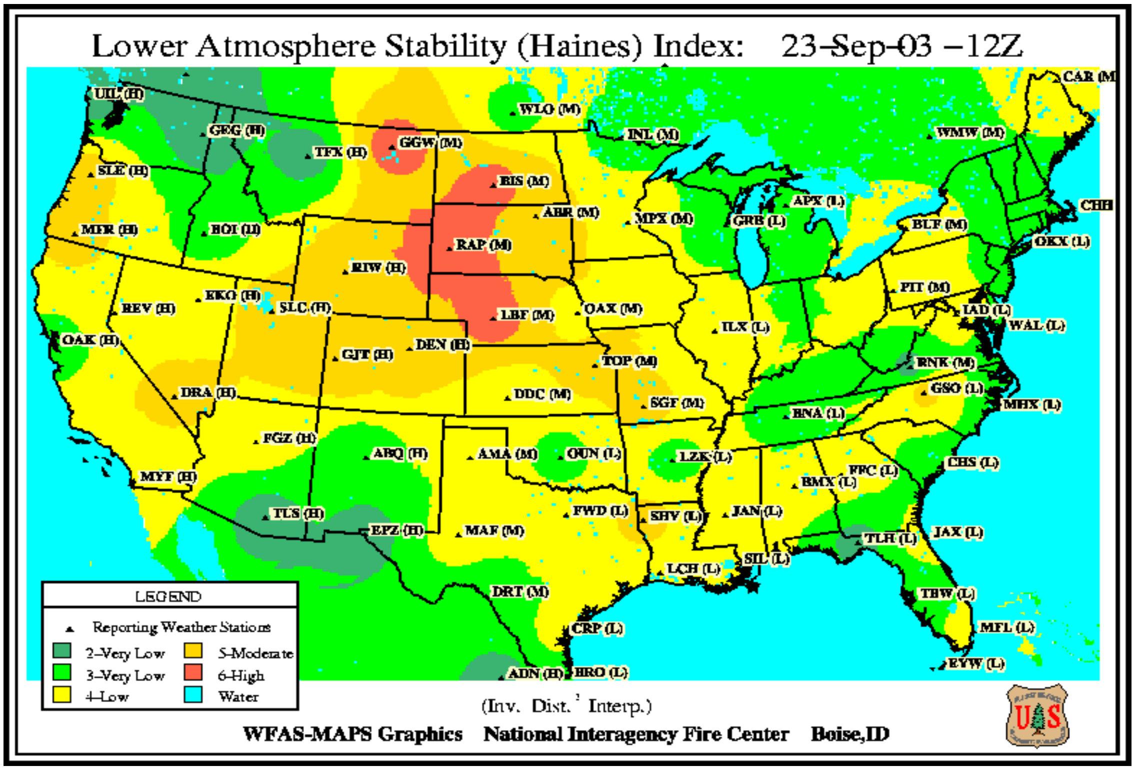


Figure 3. Lower Atmosphere Stability Index for September 23, 2003.

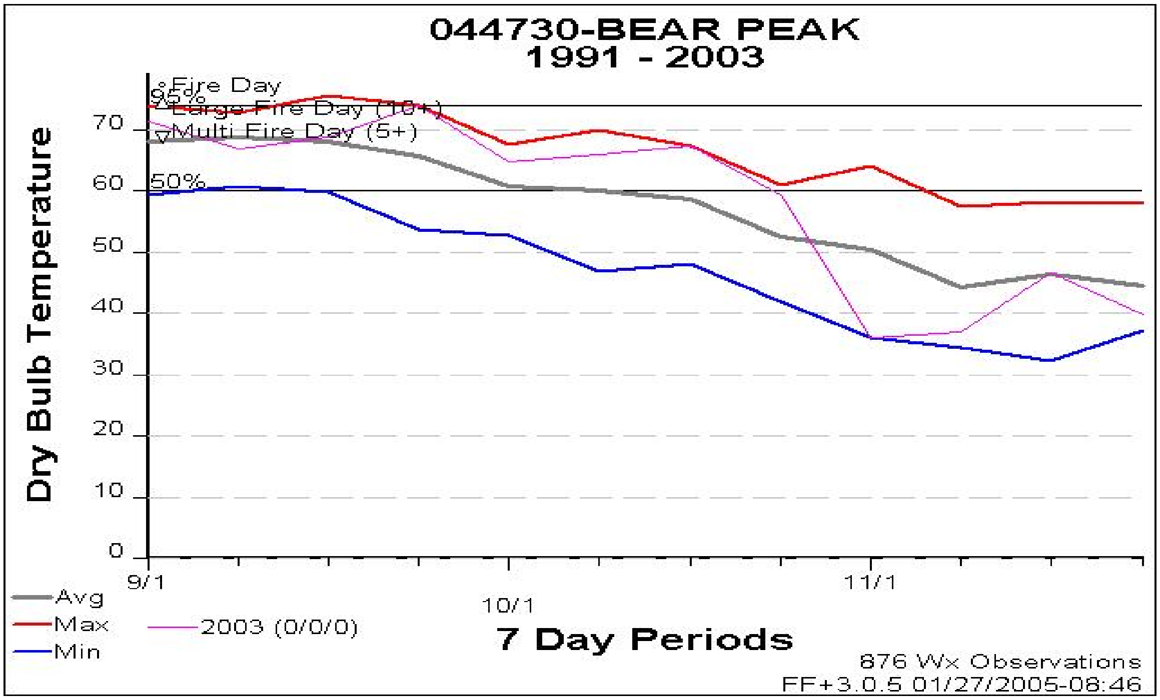


Figure 4. Dry Bulb Temperatures for a 7 day period from the Bear Peak RAWS station.

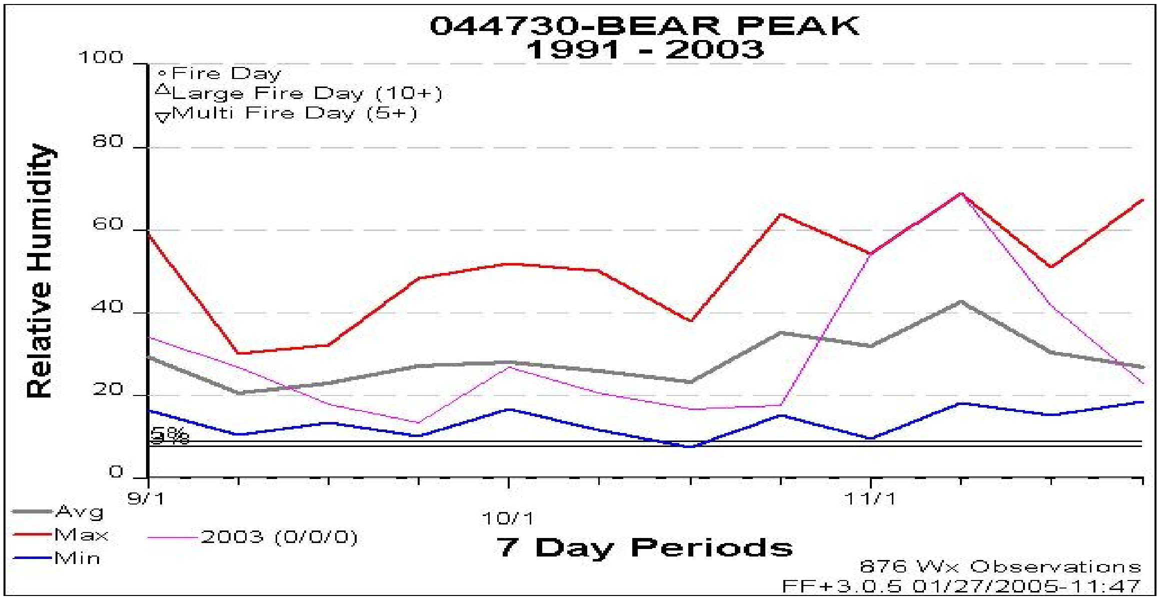


Figure 5. Relative humidity for a 7 days period from the Bear Peak RAWS station.

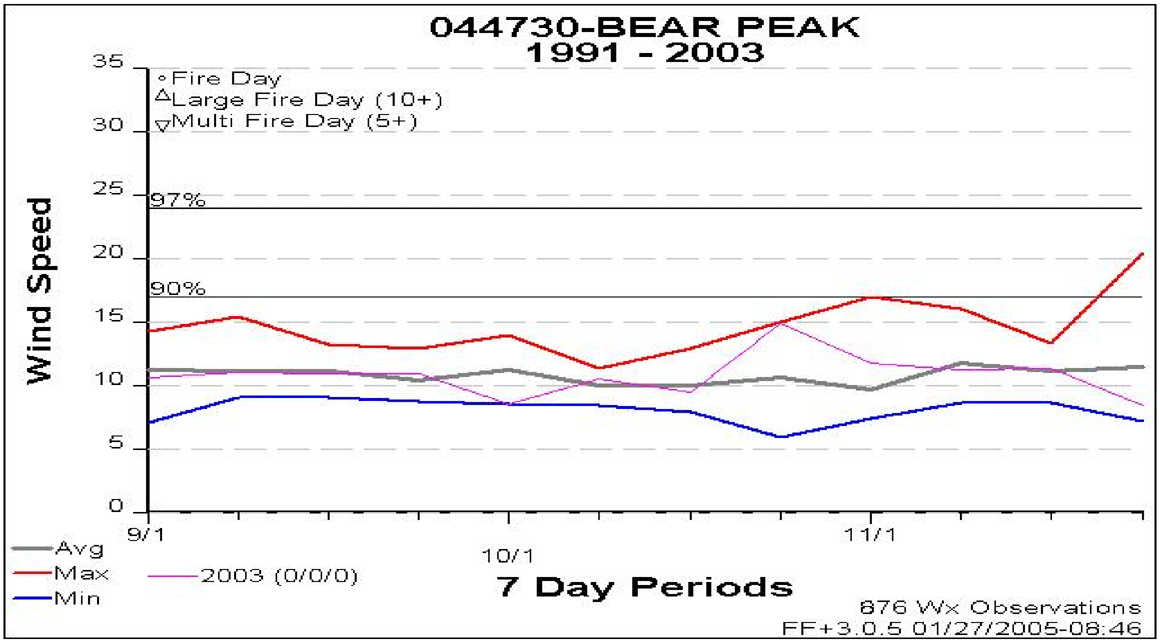


Figure 6. Wind speed for a 7 day period from the Bear Peak RAWS.

The pink line on the graphed charts, show the weather during the Albanita-Hooker WFU fire (figures 4-6). Fire weather conditions were high (figure 1 and 2), while temperature and wind speed, were at or above average (figures 3 and 5). Relative humidity and fuel moisture were at or below average during the time the WFU fire was making its biggest runs (figure 4)

The progression map showed that the WFU fire had a south/southwesterly spread, which was the effect of the east winds (figure 1). Fire Family Plus analyses from 12 years of RAWS data showed that winds coming from the east occurred 18 to 30% of the time with an average speed of 10 miles per hour for this time of month. It was late October when WFU manager decided to stop the forward spread of the WFU fire as it approached the MMA.

APPENDIX B: Weather Discussion for the Kibbie and Mud WFU fires on the Stanislaus National Forest

Introduction

The Wildland Fire Use (WFU) fires in 2003 on the Stanislaus National Forest were influenced by antecedent regional weather conditions. The southern Sierra Nevada region had three drier than average winters in a row, prior to the three WFU fires (Whit, Kibbie and Mud). Fire weather conditions in the summer of 2003 were not as severe as 2000 through 2002 period, although long-term drought persisted within the region. Beginning July 1, the region experienced mild fire weather conditions with extensive wet thunderstorm activity for about a 6 week period, ending approximately September 4.

Data source

Data were gathered from a variety of sources for this analysis. Archived climate information for the region was collected from WFAS, Wildland Fire Assessment System site. Archived weather maps were collected to identify and illustrate the climate at the time of the WFU fire. The Kansas City Fire Assessment Software (KCFAST) is a historical database for weather info. Weather Information Management System (WIMS) is current weather information spanning 3 months. Both were used to gather archived weather data from Mt. Elizabeth RAWS.

Weather Discussion

The Mt. Elizabeth RAWS was used for this weather discussion, because it is the NFDRS (National Fire Danger Rating System) station for the Stanislaus Forest, and it had the most data available for longer term weather analyses. There were micro RAWS set up for WFU fires, but they did not have 43 years of weather data recorded by the Mt. Elizabeth RAWS. Mt. Elizabeth RAWS represents lower elevations. Consequently, the data shown below may not accurately reflect the weather at the higher elevations where many of the WFU fires were burning. Further, this station does not reflect the off shore/east wind events as they occurred. Data were analyzed for specific days when the WFU fires had significant spread rates and increases in fire size. These dates include: September 15, 16, 17, 20, and October 2, 2003. The Keetch–Byram Drought Index and Lower Atmospheric Stability Index, more commonly known as the Haines index, were used to quantify the stability and dryness of the lower levels of the atmosphere, and to correlate these measures with the days of large growth (figures 1 to 10). Fire Family Plus was used to display how the weather during the WFU fires compared to historical weather of the same time frame (figures 11-15).

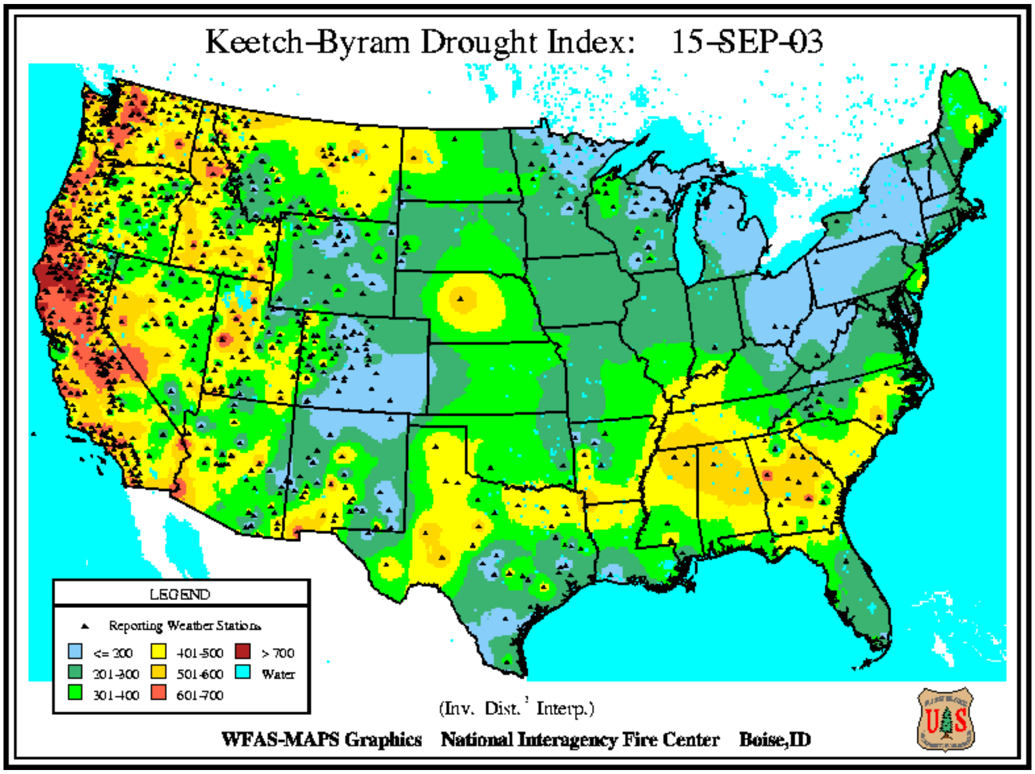


Figure 1. Keetch-Byram Drought Index for September 15, 2003.

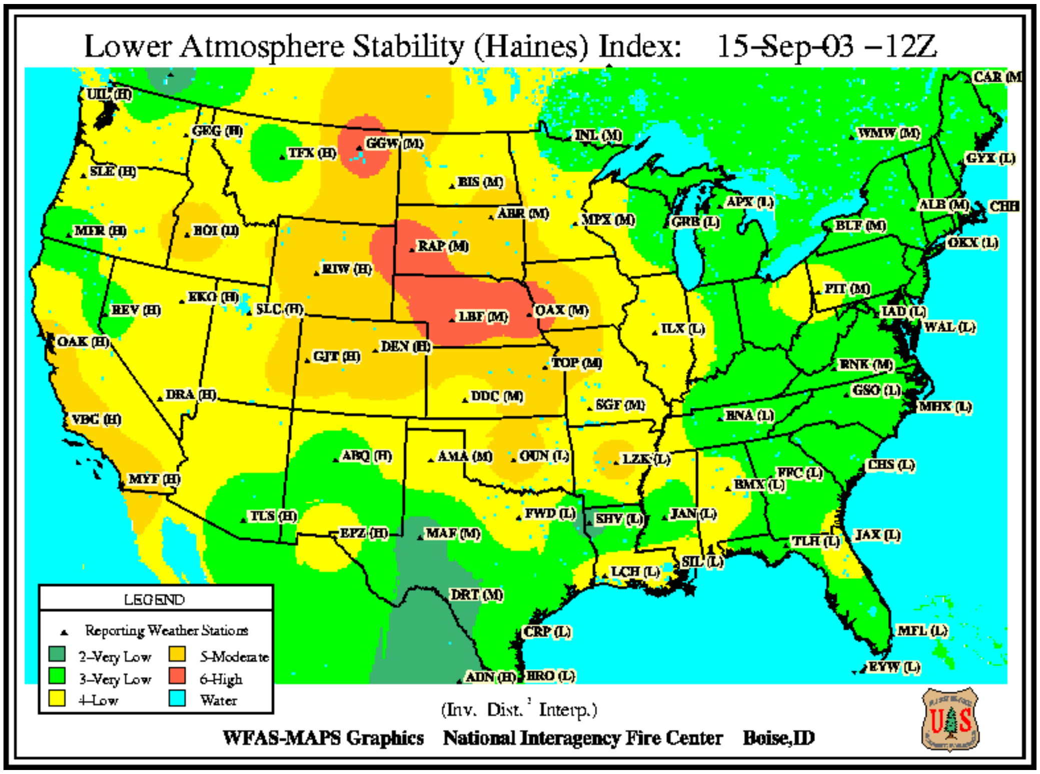


Figure 2. The Lower Atmosphere Stability Index for September 15, 2003.

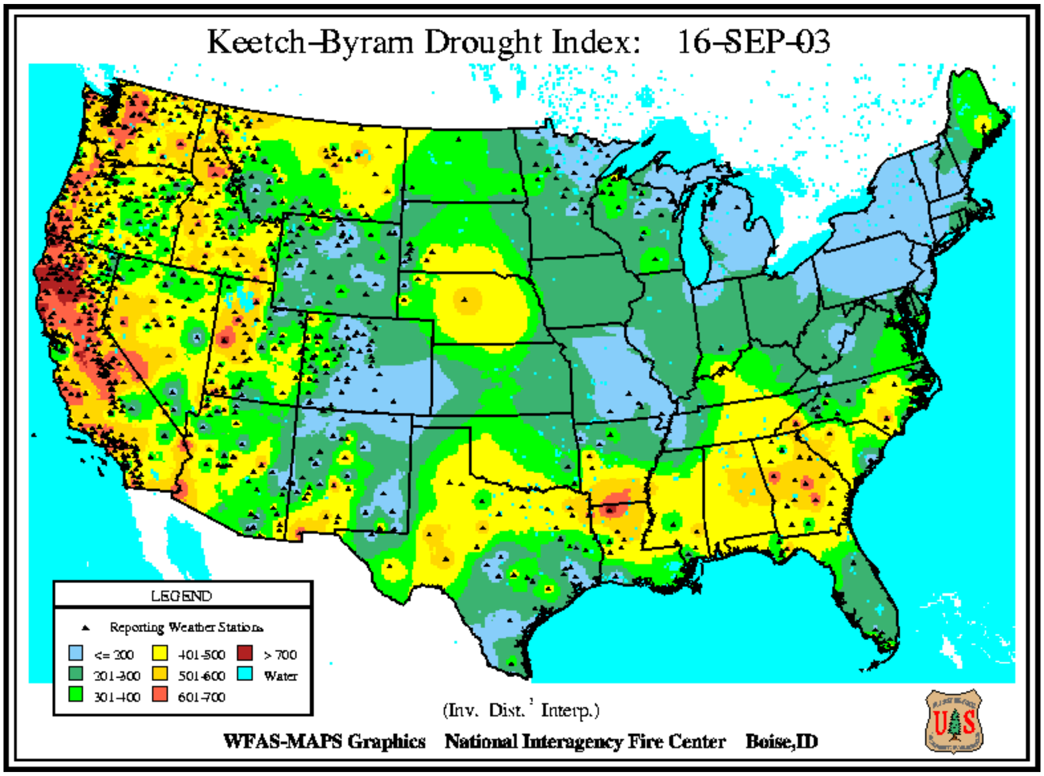


Figure 3. Keetch-Byram Drought Index for September 16, 2003.

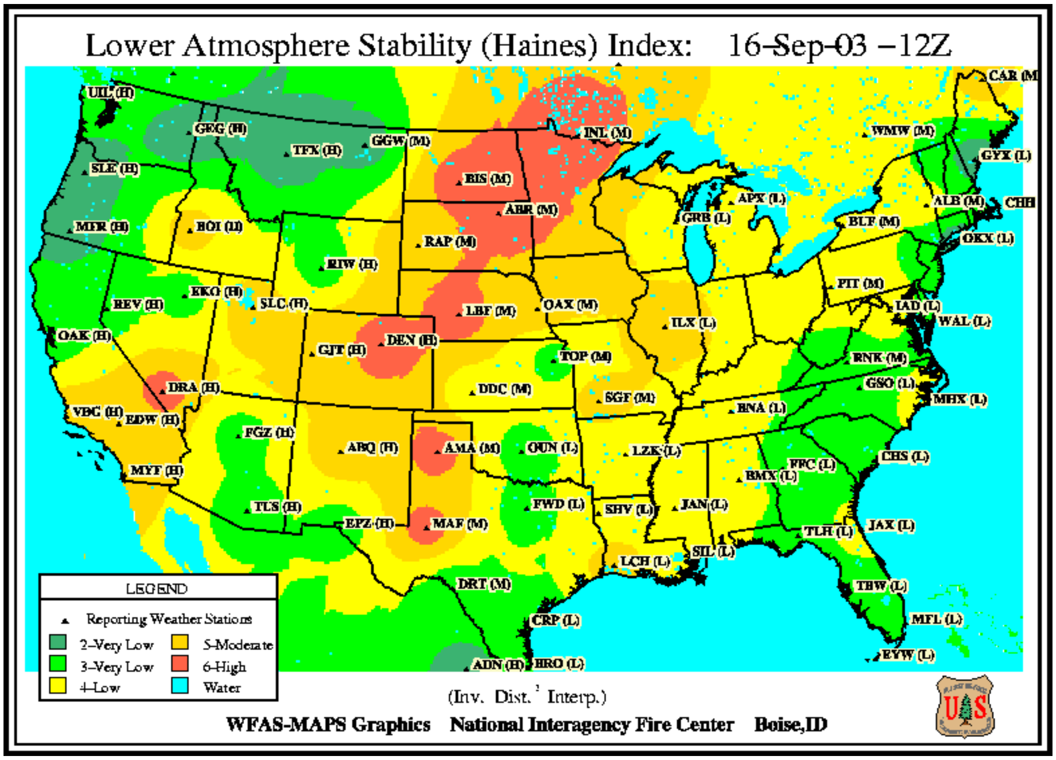


Figure 4. The Lower Atmosphere Stability Index for September 16, 2003.

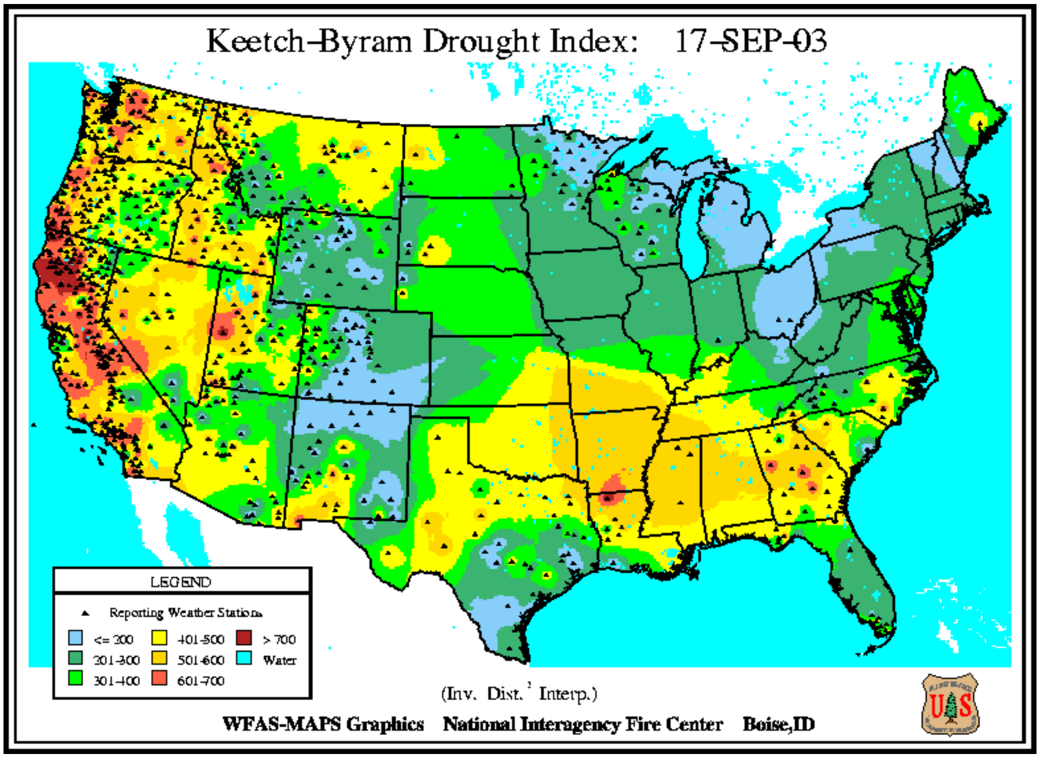


Figure 5. Keetch-Byram Drought Index for September 17, 2003.

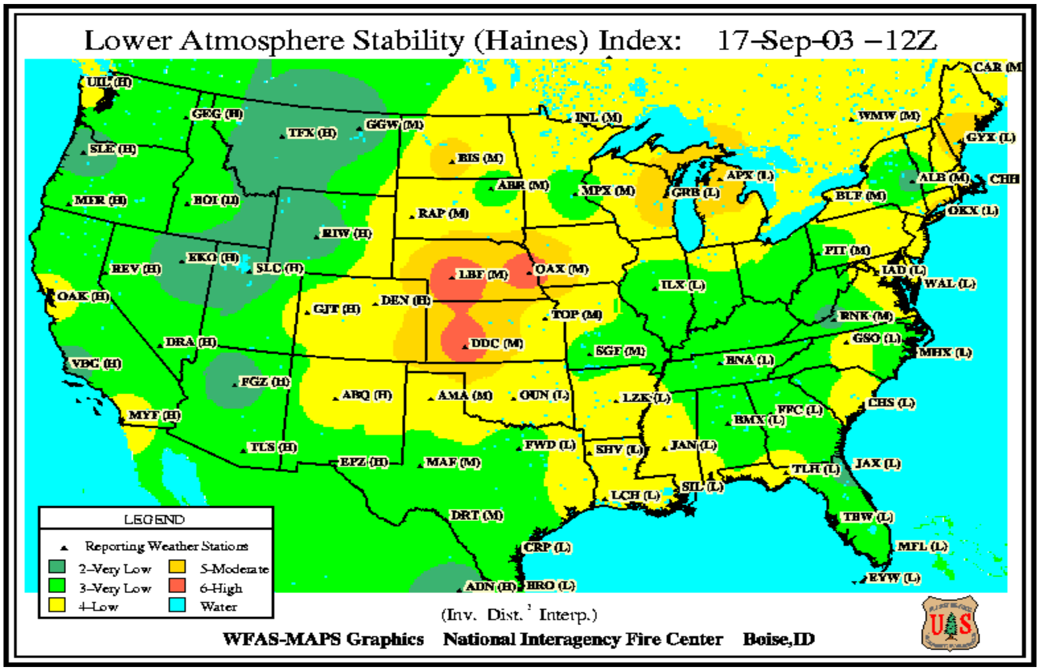


Figure 6. The Lower Atmosphere Stability Index for September 17, 2003.

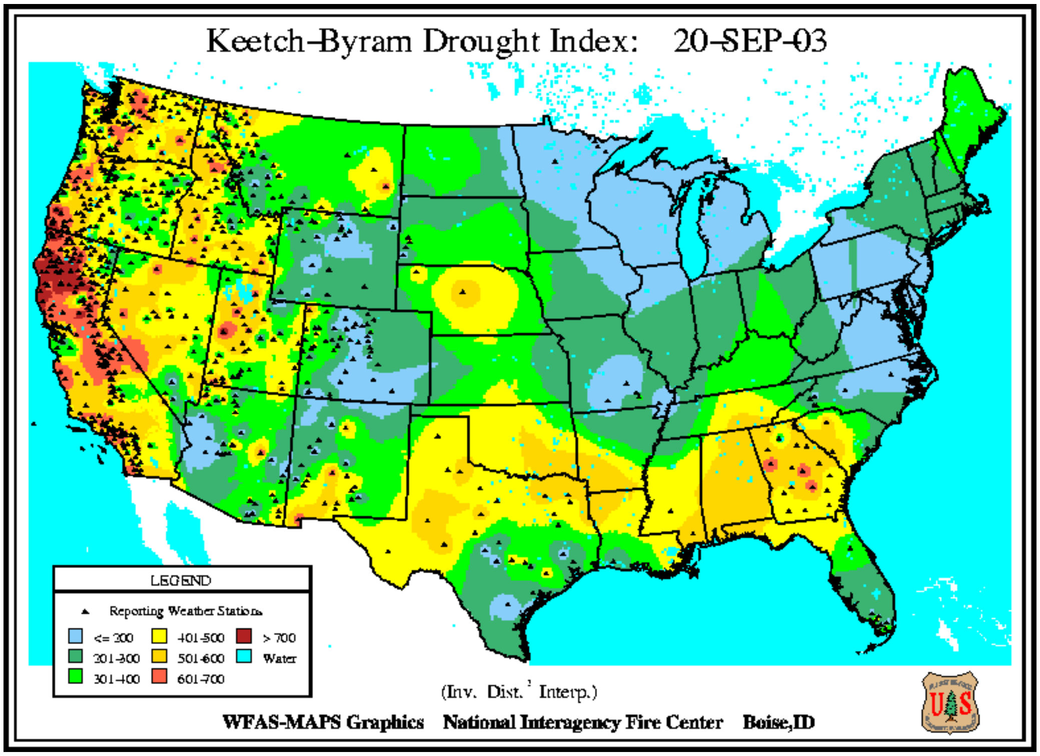


Figure 7. Keetch-Byram Drought Index for September 20, 2003.

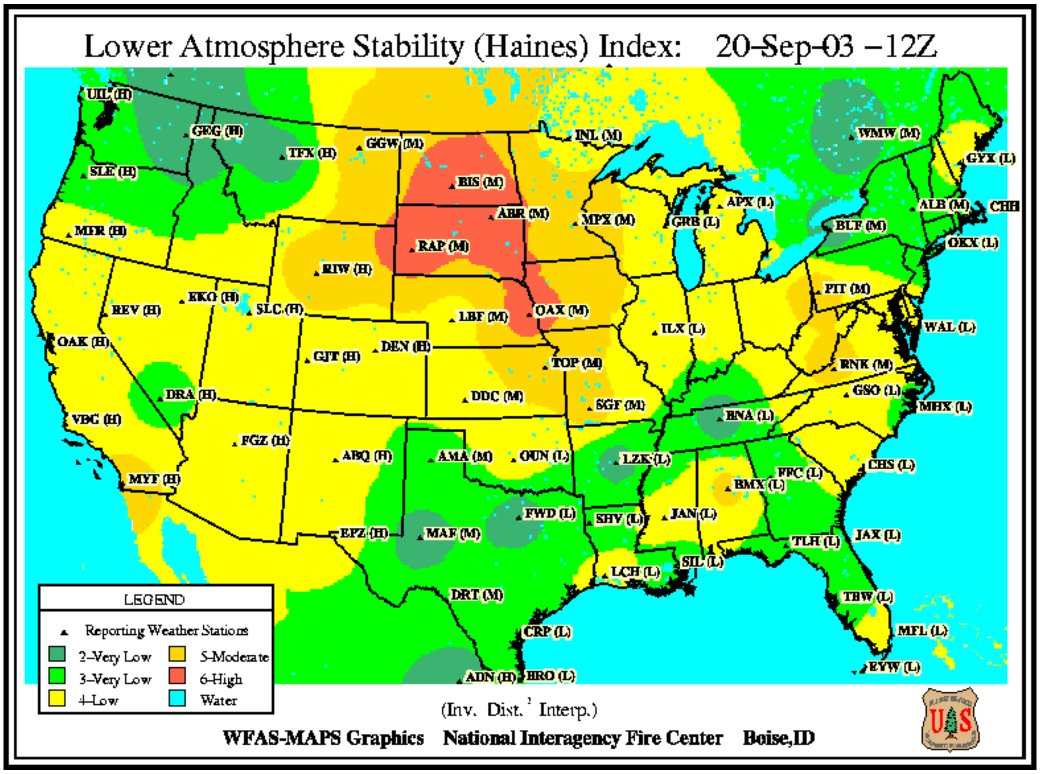


Figure 8. The Lower Atmosphere Stability Index for September 20, 2003.

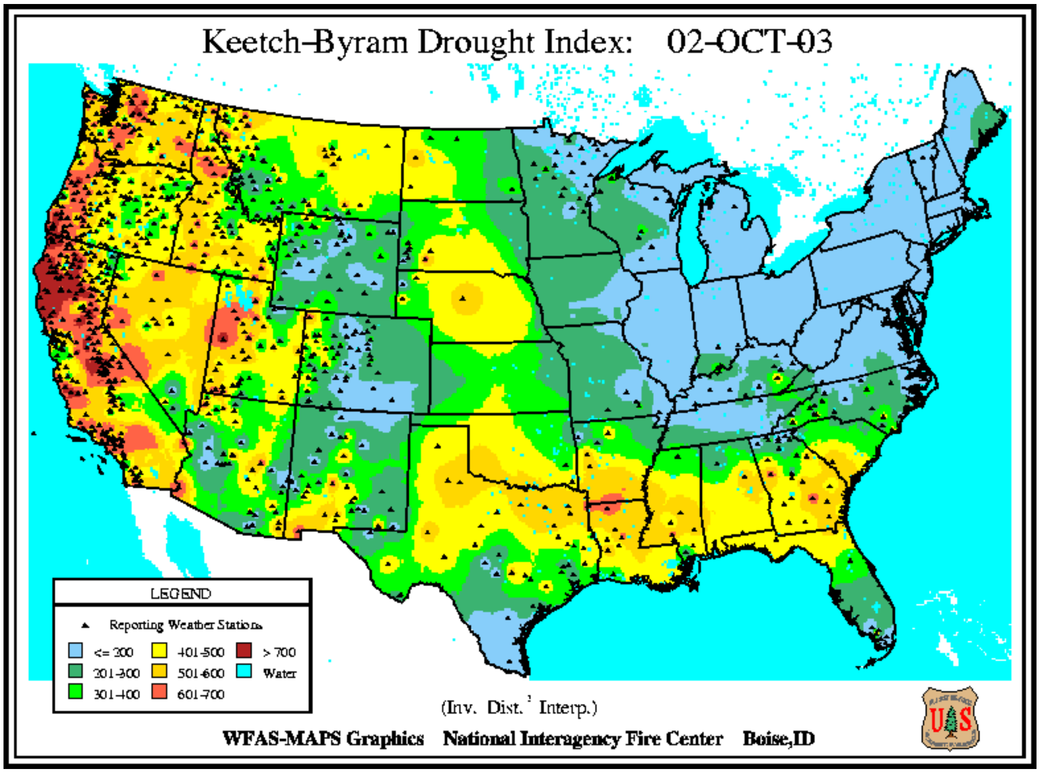


Figure 9. Keetch-Byram Drought Index for October, 3 2003.

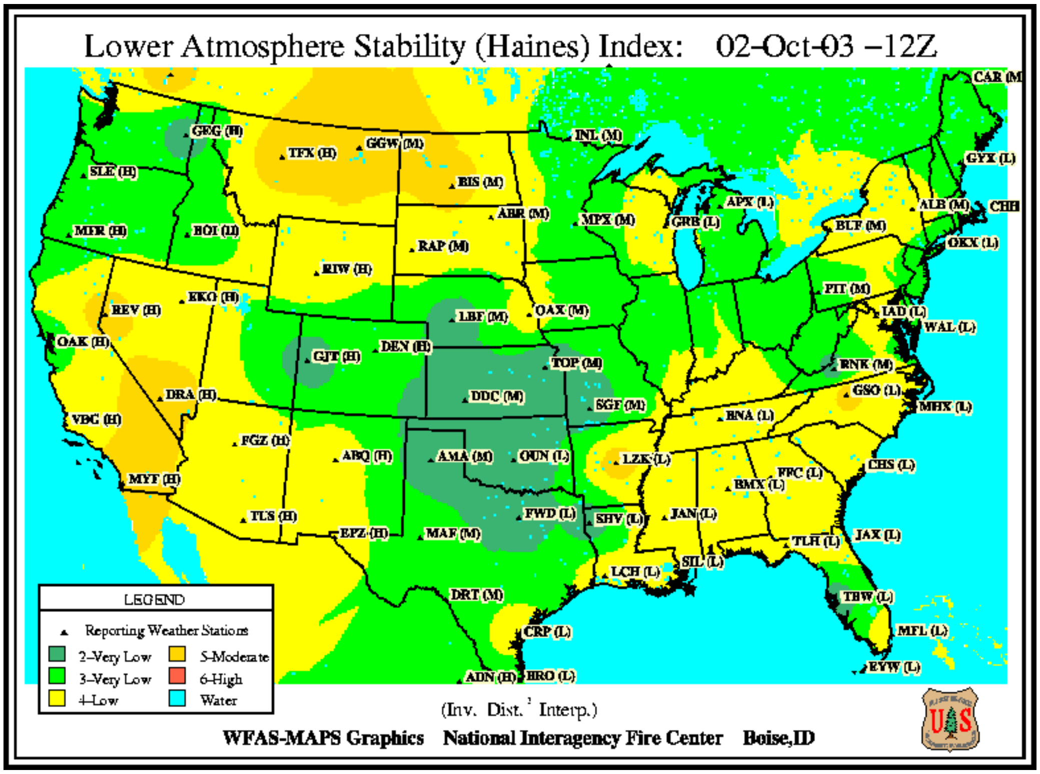


Figure 10. The Lower Atmosphere Stability Index for October 2, 2003.

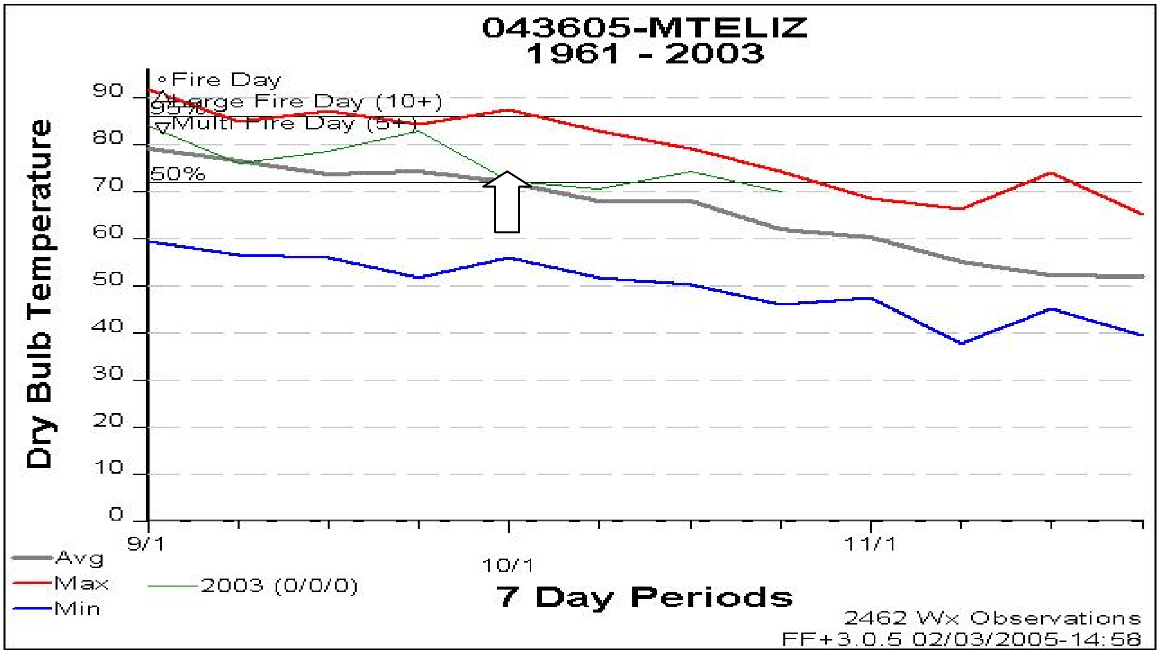


Figure 11. Dry Bulb Temperature from the Mt. Elizabeth RAWS, with the arrow showing the onset of increased fire behavior.

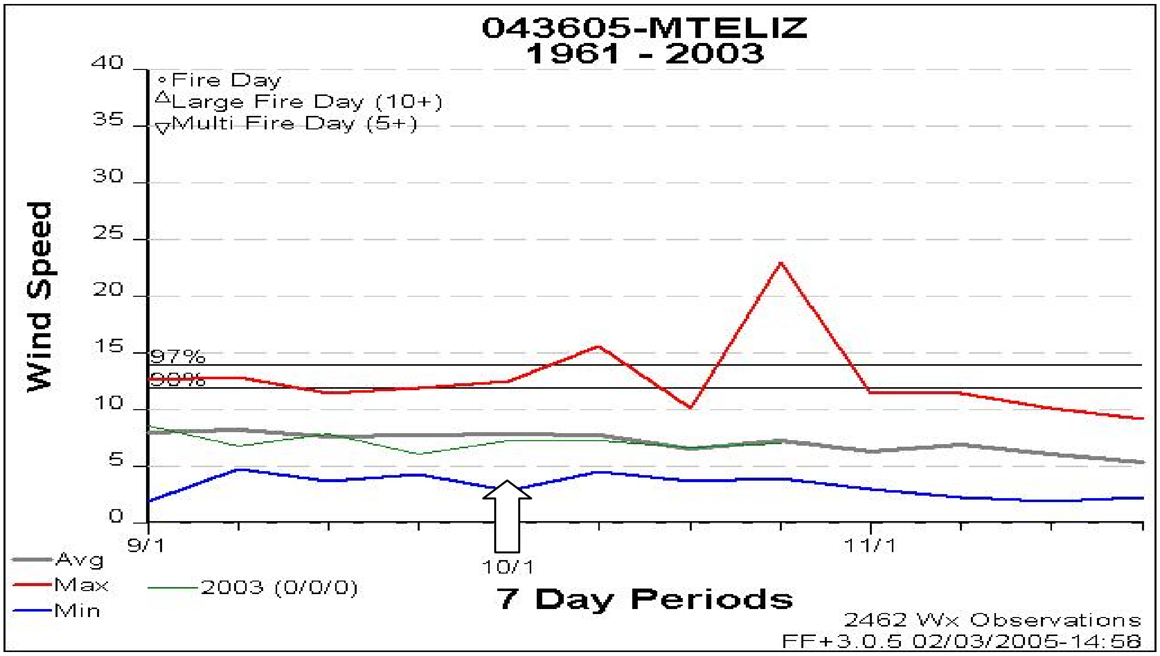


Figure 12. Wind speed from the Mt. Elizabeth RAWS, with the arrow showing the onset of increased fire behavior.

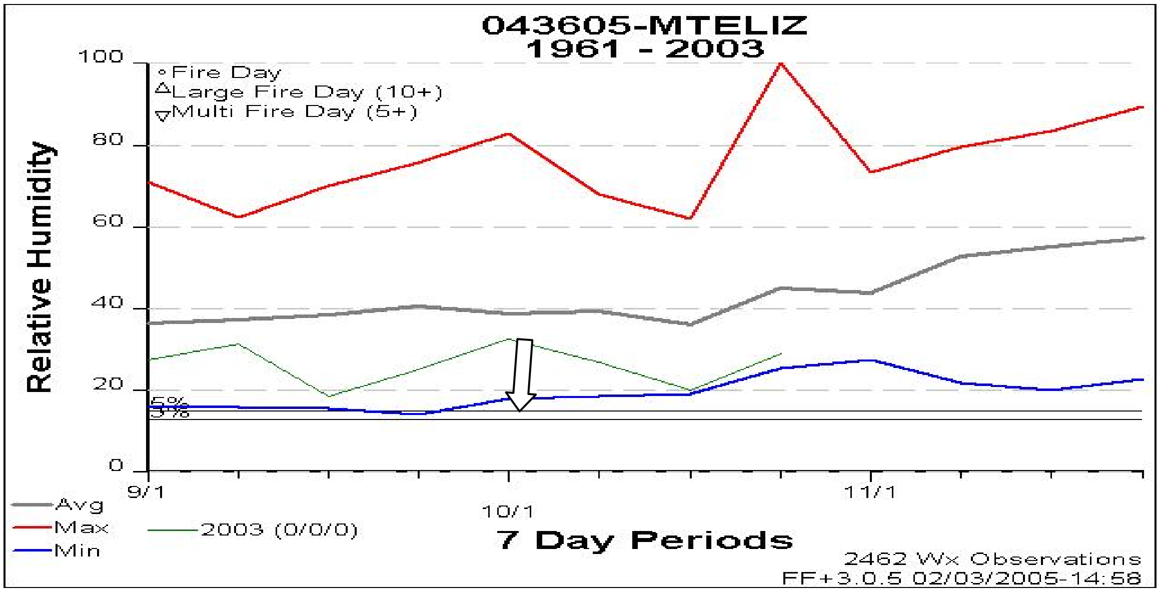


Figure 13. Relative humidity from the Mt. Elizabeth RAWS, with the arrow showing the onset of increased fire behavior.

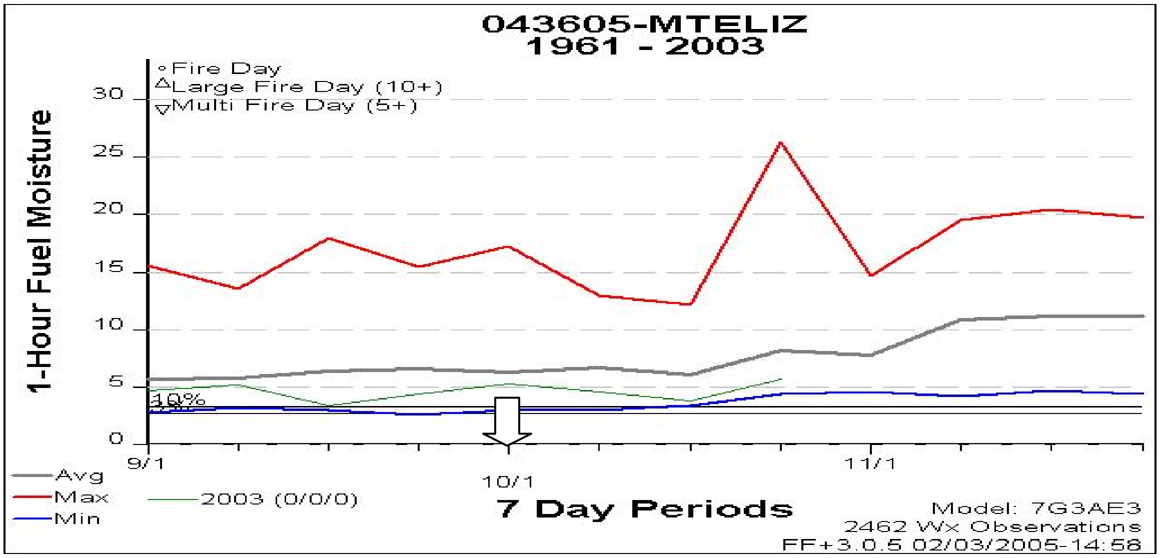


Figure 14. 1 hour fuel moisture from the Mt. Elizabeth RAWS, with the arrow showing the onset of increased fire behavior.

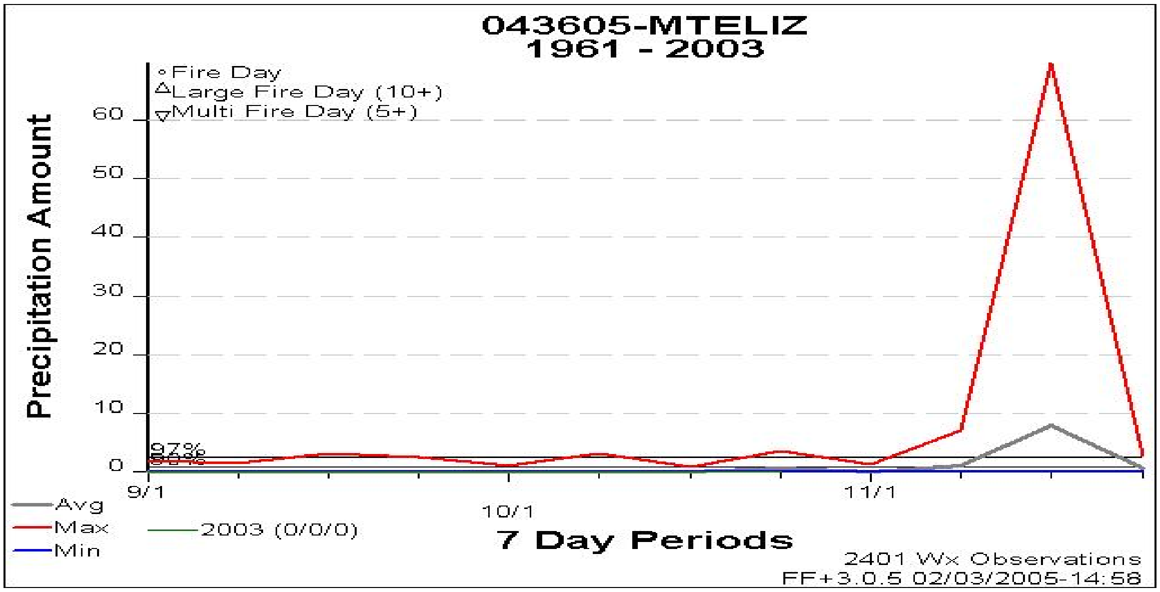


Figure 15. 1 hour fuel moisture from the Mt. Elizabeth RAWS, with the arrow showing the onset of increased fire behavior.

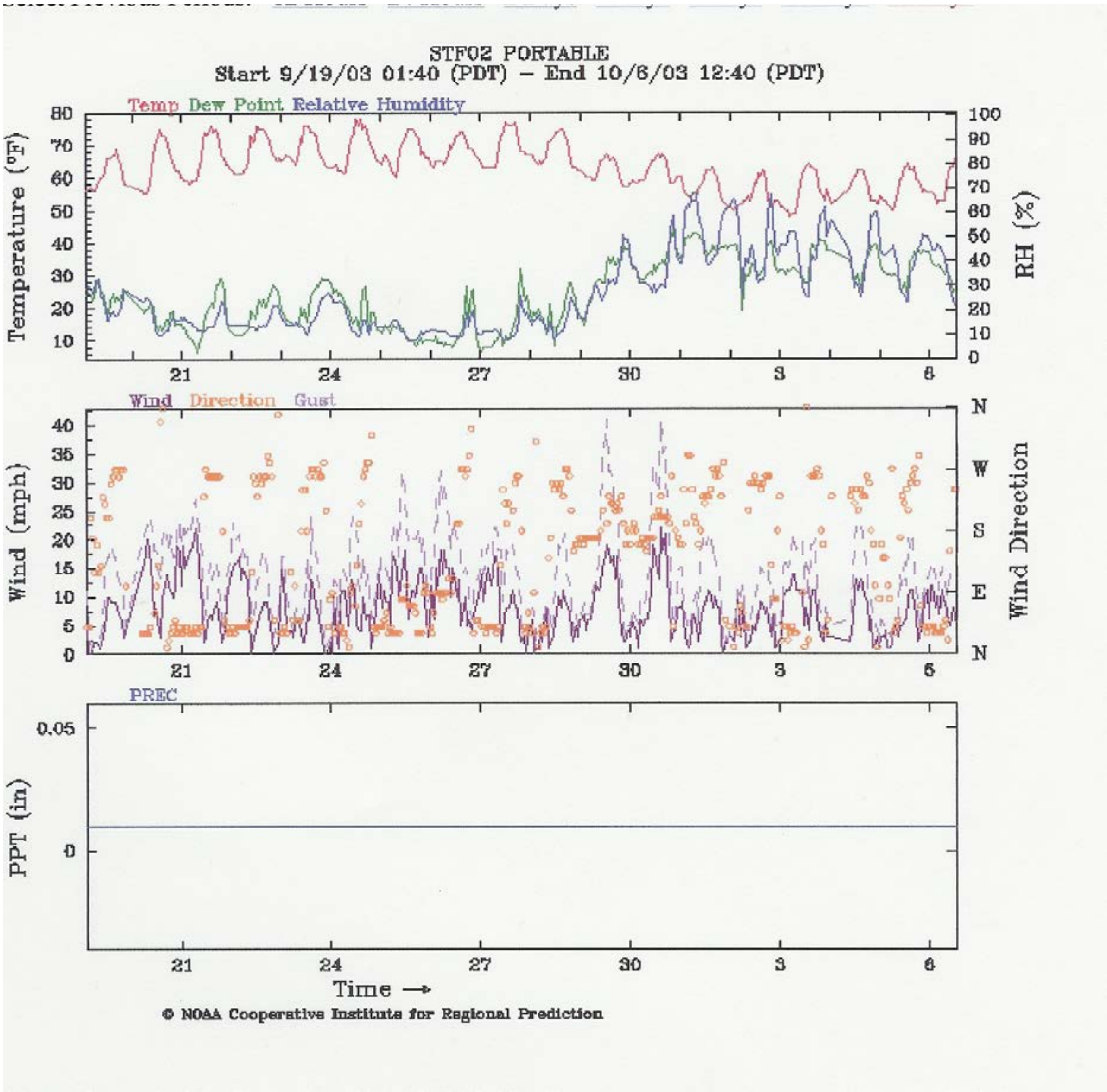


Figure 16. Three graphs obtained from the micro-RAWS on the Mud WFU fire from 9/19/03 to 10/6/03. The first graph shows the relationship between relative humidity and temperature. The second graph shows the wind and direction. Small orange circles show wind direction; purple solid line shows average wind speed; and the dotted line show gusts. The last graph shows the precipitation in inches, which was zero.

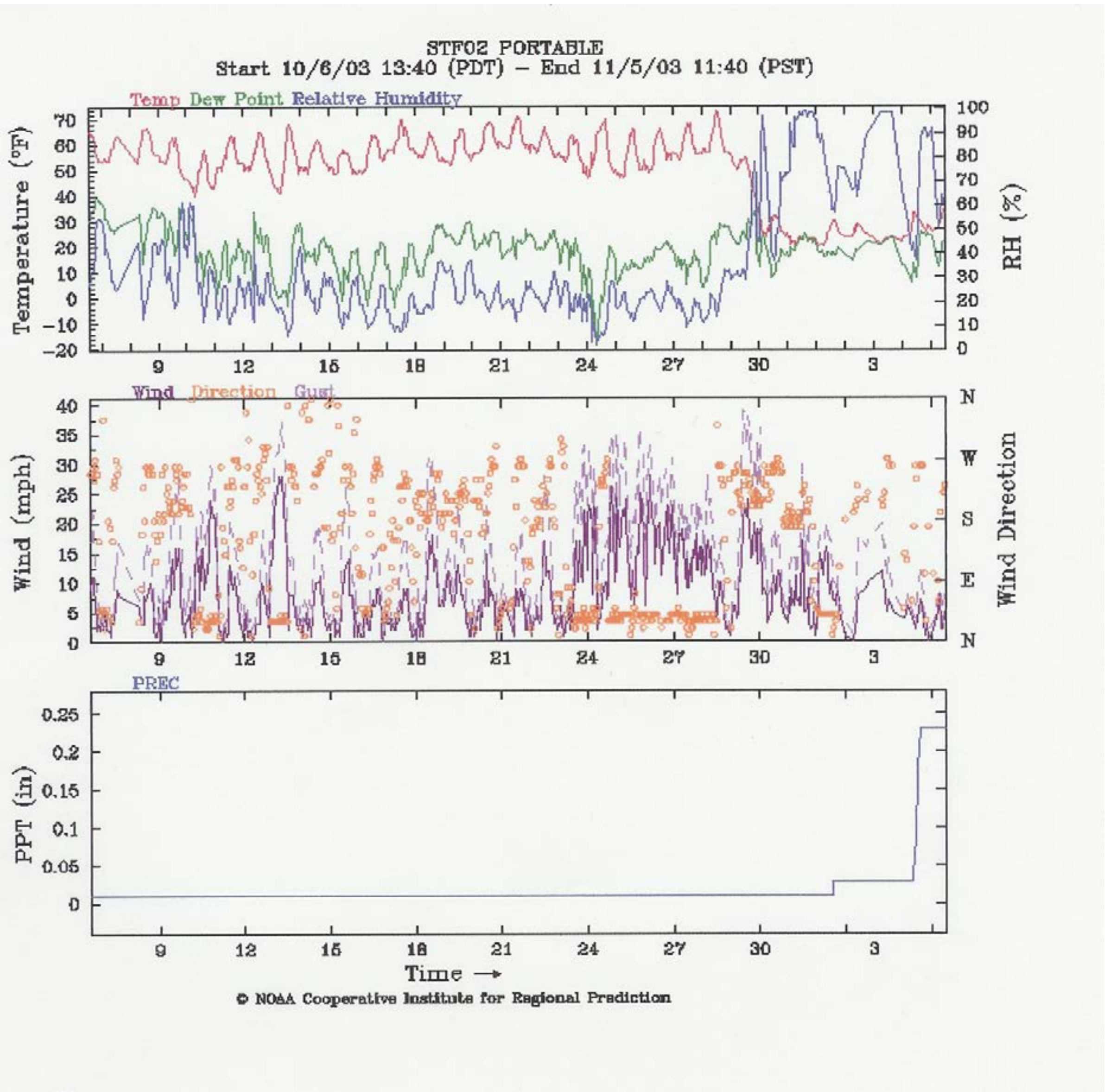


Figure 17. Three graphs obtained from the micro-RAWS on the Mud WFU fire from the next time period, 10/6/03 to 11/5/03. The first graph shows the relationship between relative humidity and temperature. The second graph shows the wind and direction. Small orange circles show wind direction; purple solid line shows average wind speed; and the dotted line show gusts. The last graph shows the precipitation in inches, which was zero.

Historical weather for the Mud and Kibbie WFU fires was derived from NFDRS station #043605, Mt. Elizabeth. These data represents 43 years of collection. The green line represents weather during the time all three of the WFU fires were burning (Figures 11-15). Fire weather conditions were high, as shown by above average temperature and wind speed; and below average relative humidity and fuel moisture. The conditions were conducive to the times when the WFU fires made their biggest runs. Beginning approximately September 8th, temperatures were climbing above average, and relative humidity and 1-hour fuel moisture were in the decline.

A conversation with the forest fuels specialist and wildland fire use managers indicated that the offshore flow had a definite effect on fire behavior.   Offshore flow leads to higher than average temperatures and lower than average relative humidity, with little night time recovery. This scenario can be expected 10 to 15% of the time from the middle of August to the end of fire season. During the evening, winds would be down slope and canyon, with the fire backing down. In the morning, temperatures would climb, and in general up slope or up canyon flow would set in. Fires would then race up slope into drainages, expanding the fire perimeter.

APPENDIX C: Air Quality Assessment of the Stanislaus and Sequoia WFU Fires

Wildland Fire Use (WFU) Air Quality

Thousands of acres are burned by wildfires in California each year. Wildfires caused by lightning burn at higher elevation where lighting storms tend to concentrate. These fires historically started burning in the spring/early summer, and continue to burn until changes in weather or lack of available fuels caused them to go out (Taylor 1998). Literature has documented Native Americans setting fires along travel corridors, favorite hunting areas, and near areas of habitation (Kimmerer and Lake 2001). Early Euro-Americans settlers also intentionally burned. Rangers, sheepherders, miners and loggers set fires to kill young trees and chaparral, stimulate forage plants, and consume forest fuels. Surprisingly little was written about the amount of smoke produced from these actions. Significant levels of smoke were likely present historically with the large amount of burning that occurred.

A half a century ago, attitudes about fire and smoke changed, resulting in the policies such as the "10 A.M" policy. This policy states: "If a fire starts, it should be extinguished by 10 the next morning". In 1955 the Federal Air Pollution Control Act was established and was the basis for the Federal Clean Air Act (CAA), which is a series of amendments and regulations that all fire managers follow today.

Our attitudes toward natural disturbance such as fire, insects, pathogen outbreaks, and windstorms are evolving to recognize these as being common and important processes (White 1979; Pickett 1980; White and Pickett 1985; Denslow 1987). Fire is recognized as the key landscape process that shaped natural forest patterns at the stand and landscape scale in montane conifer forest in the southern Cascades and Sierra Nevada Mountains in California (Kilgore 1973; Weatherspoon and others1992; Skinner and Chang 1996; Chang 1996). We recognize that without fire, a once open park-like forest has been transformed into a dense, fire intolerant forest. We also recognize that with fire, there is smoke. Returning natural fire back into the wilderness areas has been part of the Stanislaus and Sequoia Natural Forest missions for several years.

Stanislaus

In July of 2003 the Stanislaus N.F managed three Wildland Fire Use (WFU) fires: the Kibbie, Whit and Mud. Like most fires burning at high elevation at this time of year, the fires grew very slowly for the first couple of weeks. As for all WFU fires on the Stanislaus N.F wilderness areas, a Maximum Management Area (MMA) was designated. A Smoke Management Plan was initiated to meet Air Quality regulation. By late September very low relative humidity caused by a high pressure with an on shore flow, and near seasonally low fuel moistures, resulted in increased fire activity and smoke emissions (Table 2).

Sequoia

The Albanita-Hooker fire was composed of two Wildland Fire Use Fires that burned together. The Albanita and the Hooker fires were caused by lighting from thunderstorms that occurred on September 3, 2003. Both fires were a 10th of an acre in size when discovered, and were burning within mixed conifer stands. Fuel models 8, 9, 10 and 11 were used by the district fuels specialist to represent the fuel conditions. The Hooker fire was creeping through duff under moderate to high canopy cover. It was located on a southwest aspect at 15% slope, with an elevation of 8,200 feet. This fire was southeast of Hooker Meadow. The WFU fire was predicted to have a slow uphill spread to the north and the east through continuous fuels. The Albanita fire was also a surface fire that was burning through duff, with moderate canopy cover. The fire was located on an east aspect and a rocky 5% slope at an elevation of 8,700 feet. The fire was south of Jackass Peak and was predicted to have a slow rate of spread for a couple of weeks due to the area receiving ¾ inches of rain. Very low relative humidity caused by high pressure with an on shore flow, and near seasonally low fuel moistures, caused fire activity and smoke emissions to increase as shown on table 3.

Table 1 shows the Air Quality index that the US EPA developed to provide easy understandable information on local air quality. Table 2 shows the average 1 hour $PM_{2.5}$ accumulated during the time the smoke monitoring equipment was setup for the Stanislaus WFU. Table 3 shows the predicted emissions based on estimations using FOFEM.

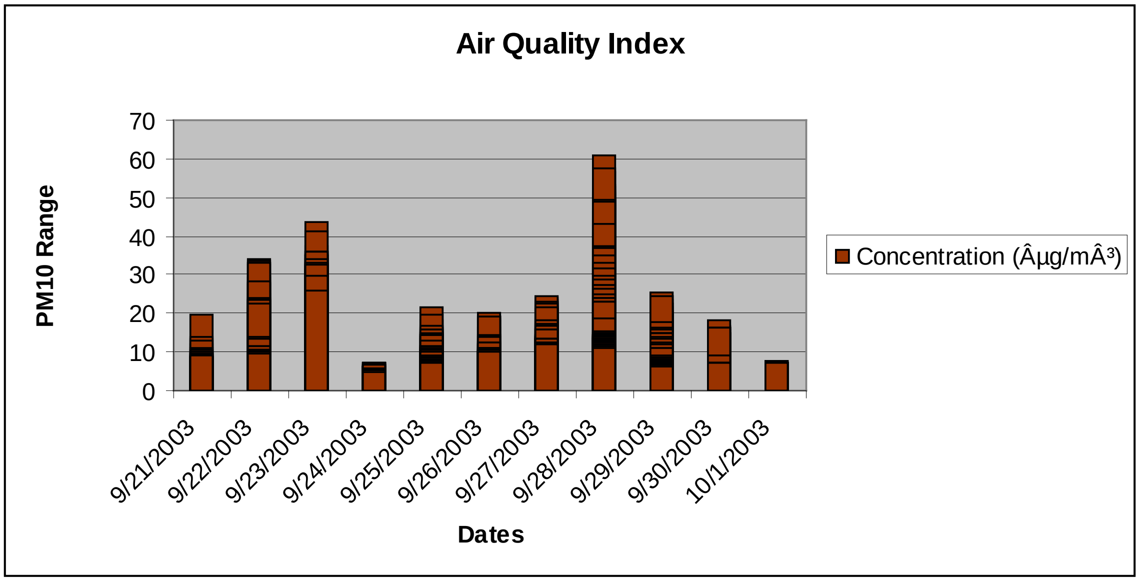
Table 1. Air quality index used by the EPA.

The US EPA has developed an Air Quality Index (AQI) (see chart below) to provide easy to understand information on local air quality and whether air pollution levels pose a health concern.

Air Quality Index health rankings are based on 1-hour and 24-hour concentration averages. EPA developed the health indices based on 24-hour averages. Idaho State's Department of Environmental Quality developed health indices based on 1-hour averages.

PM2.5 24-hr Avg. Concentration (ug/m3)	**PM2.5 1-hr Avg. Concentration (ug/m3)**	**Index Values**	**Visibility (Miles)**	**Level of Health Concern**	**Cautionary Statements**
0.0 – 15.4	**0.0 – 40.0**	**0-50**	**> 10**	**Good**	**None**
15.5 – 40.4	**40.1 – 80.0**	**51 – 100****	**5.1 – 10.0**	**Moderate**	**None**
40.5 – 65.4	**80.1 – 175.0**	**101 - 150**	**3.1 – 5.0**	**Unhealthy for Sensitive Groups**	**People with respiratory or heart disease, the elderly, and children should limit prolonged exertion.**
65.5 – 150.4	**175.1 – 300.0**	**151 – 200**	**1.6 – 3.0**	**Unhealthy**	**People with respiratory or heart disease, the elderly and children should avoid prolonged exertion, everyone else should limit prolonged exertion.**
150.5 – 250.4	**300.1 – 500**	**201 – 300**	**1.0 – 1.5**	**Very Unhealthy**	**People with respiratory or heart disease, the elderly and children should avoid any outdoor activity, everyone else should avoid prolonged exertion.**
250.5 +	**500.0 +**	**301 - 500**	**< 1.0**	**Hazardous**	**Everyone should avoid any outdoor exertion; people with respiratory or heart disease, the elderly and children should remain indoors.**

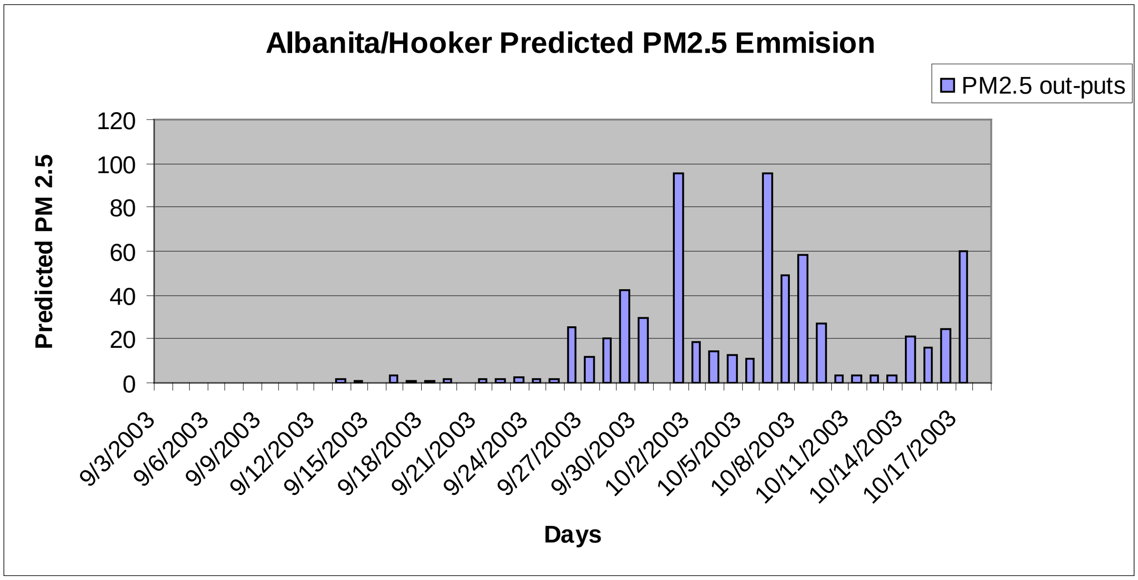
Table 2. Air quality index displaying levels of PM_{10} on the Stanislaus NF wildland use fires from September 21, 2003 to October 1, 2003.



Characterization of the true extent of effects of prescribed and wildland fires on ambient air quality may be incomplete due to the deficiency of air quality monitoring sites in rural areas, and the smoke monitoring equipment. Data from smoke emission monitors (Rams BLM 16 and 17 and USFS 36) were not setup until the WFU fires had been burning for weeks, making it difficult to accurately assess true smoke emission impacts for the extent of the fire. Also, particulate standards are based on 24-hour and annual averages, but smoke plumes may significantly degrade air quality in a community for just a few hours before moving or dispersing (Sandberg and others 2002).

PM 2.5 output reached the unhealthy level for sensitive groups on 9/28/03 (Table 2). Sensitive groups included people with respiratory or heart disease, the elderly, and children. It is suggested these groups limit their levels of exertion during periods of high PM 2.5 concentration. During the time the WFU fires were burning, the forest received numerous complaints, with as many as 47 complaints in one day. Smoky conditions were due to a high pressure system with an off shore flow that persisted for 7 days, and caused fire activity and smoke emissions to increase and shift the smoke flow to the nearby communities. Complaints were both visual and health related. At this time, the Stanislaus NF set up smoke monitoring equipment and held a public meeting, where they heard complaints, and also updated the public on the fires' condition. Dispersal of information amongst the nearby residents and communities subsided complaints.

Table 3. PM $_{2.5}$ Emissions from the Albanita-Hooker WFU fire.



As shown on the table above, the predicted PM $_{2.5}$ emissions would have reached the unhealthy level on 10/2 and 10/8; and unhealthy for sensitive groups on 10/9, 10/17 (people with respiratory or heart disease, the elderly, and children should limit prolonged exertion). Emission equipment was not set up until later, and for a short time, so this data cannot be validated. During the time the WFU fires were burning, several complaints were received but were not medical complaints.

Summary

It is clear there is still much that we don't know regarding the role of fire in wilderness ecosystems. WFU fire is one way to further our knowledge of fire in these systems. There is still room for improvement on how we manage wildland fire use fires; for example, assessing the capability of an air shed in handling multiple WFU fires simultaneously. Coordination between WFU managers and air districts is necessary to establish the number of WFU fires the air district can handle within a given time, and within a healthy range. Furthermore, establishing emission monitoring equipment as early as possible once the fire begins is important in establishing trends of both healthy and unhealthy emission days.

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