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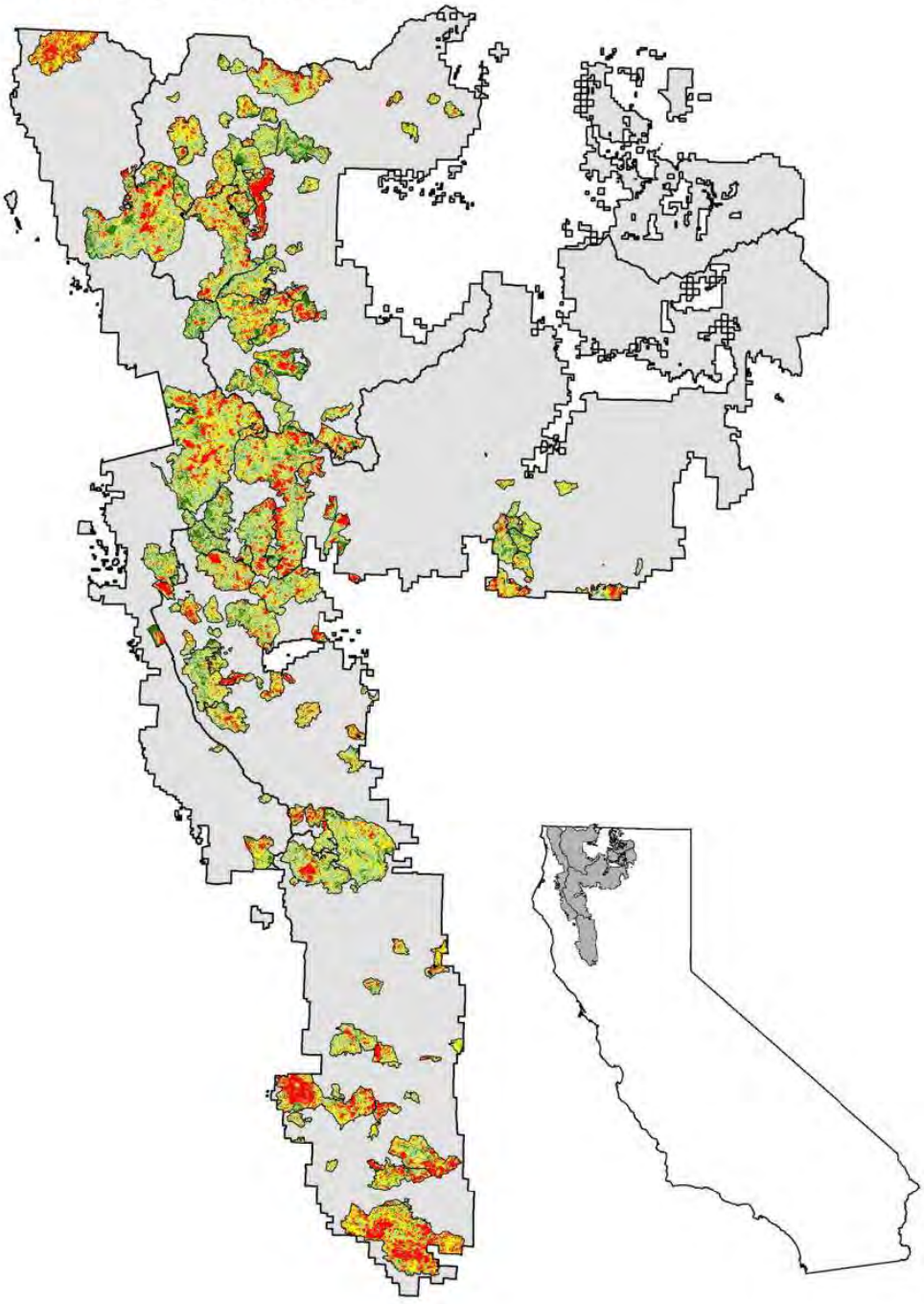

Northwestern California National Forests

Fire Severity Monitoring 1987 – 2008

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Executive Summary

Background

This report presents the findings of the Pacific Southwest Region Fire Severity Monitoring Program (FSMP) for the Klamath, Six Rivers, Shasta-Trinity and Mendocino National Forests of northwestern California covering the period 1910-2008. Portions of this report were first published in Miller et al. (2012). Data collected by the FSMP are important for addressing a number of pivotal resource management questions in the area, as well as providing input to land and fire management plans.

Objectives

The primary objectives of this project were to: 1) derive estimates of vegetation-based fire severity by directly mapping severity with satellite imagery for all large fires, 2) explore causal relationships, and 3) quantitatively evaluate current spatial and temporal trends in fire regimes within the study area.

Approach

The basic approach was to develop a fire severity atlas for large fires (>1000 acres) that occurred 1987-2008 using satellite imagery and fire severity mapping methods based on existing US-Geological Survey, National Park Service and Forest Service protocols. The severity data are derived from satellite images acquired the year following the fire occurrence. In this report, estimates of vegetation-based severity are reported in four categories: unchanged, low, moderate, and high; where high is approximately equivalent to a 95% change in live cover. Because Forest Service vegetation mapping protocols define forests to have at least 10% tree cover, a 95% change represents a slightly conservative estimate of conversion from forest to non-forest. Trends in percent area burned at high-severity are analyzed in a variety of vegetation types and cover types, and in patch sizes of high-severity fire in conifer forests. All analyses were performed only on areas administered by the U.S. Forest Service. We also report temporal trends in fire size and annual burned area between 1910 and 2008 for all fires >100 acres in the analysis area using the fire history database for the state of California. Finally, we explore relationships of percent high-severity fire, fire ignition type (human vs. lightning), number of fires, fire size, and annual burned area to climate and a number of other independent variables.

Findings

1. For the period 1910-2008, mean and maximum fire size and total area burned per year of fires >100 acres all reached their highest levels after the year 2000, but the number of fires at the end of the period was still less than during the 1920s. Regression analysis for fires since 1970 shows that number of fires >100 acres, mean and maximum fire size, and total area burned per year all increased. Although the total number of lightning ignitions during 1970-2008 remained constant, the number of lightning ignitions resulting in fires larger >100 acres increased. Conversely, the

total number of human ignitions fell, while the number of human ignitions resulting in fires > 100 acres remained constant.

2. Approximately one third of the study area burned between 1910 and 2008. Excluding water and barren areas, 34% burned at least once, 7% at least twice, and 1% three or more times. Fire rotation, used as an estimate of fire return interval, was 267 years in forested areas in 1934; rotation period steadily increased to a peak value of 974 years in 1984. Rotation values fell to 256 years in 1987, the year with the second most area burned. In 2008, the year with the most area burned, the rotation period fell to 95 years, which is still 3-6 times higher than estimates of the pre-settlement mean fire return interval.

3. For fires >100 acres, individual fire size, duration, number of fires, and total area burned per year were all significantly higher for lightning-ignited fires than human-ignited fires. Percent high-severity was lower in lightning-caused fires than human-caused fires (11 vs. 28%), but there were no significant differences in mean or maximum high-severity patch size. or ignition dates. Lightning fires tended to occur under drier climatic conditions than did human caused fires, even though both tended to occur under drier than average conditions.

4. Between 1910 and 2008 average annual precipitation increased an average of 0.12 inches per year. Winter maximum and all seasonal minimum temperatures also increased, led by summer minima. Splitting the dataset into early (1910-1959) and later (1960-2008) periods, correlations of fire variables shifted from inverse correlations with PDSI in the early period, to inverse correlations with summer precipitation in the later period. Summer precipitation dipped below average from 1999-2008 coincidently with mean and maximum fire size, and total area burned at their highest levels. However, mean summer precipitation was lowest during the 1920s, yet number of fires was the only fire statistic that was larger during this period than during 1999-2008. Even though summer precipitation was low during the 1999-2008 period, mean annual precipitation during this period was more or less equal to the 99 year average.

5. Regardless of cover or vegetation type stratification, there were no clear trends in percent high-severity or mean maximum high-severity conifer patch size over the 1987 to 2008 period. Mean high-severity conifer patch size exhibited a decreasing trend over the period. However, all severity analyses were influenced by four years (1987, 1999, 2006 and 2008) with wide-spread large lightning ignited fires that were atypical of the longer 1910-2008 period.

6. Stratified by either forest or cover type, the percentage of area per fire burning at high-severity ranged from 9% to 18%. Percent high-severity was lowest for areas dominated by Douglas-fir (9%) and in conifer forests with trees of medium to large diameter (12%). In conifer cover types, percent high-severity increased with decreasing tree diameter size.

7. When comparing the percentage of high-severity per fire the first and second time an area burned there were differences between forest types (all densities and size classes combined.) Douglas-fir forests that had not experienced fire since at least 1910 but then burned after 1986 did so at an average of 9% high-severity. In areas where we had record of a previous fire in Douglas-fir before 1987, a second fire occurring between 1987 and 2008 tended to burn at similar levels of high-severity (10%) if the second fire occurred within 30 years after the first fire. Second burns occurring in Douglas-fir more than 30 years after the initial fire were significantly less severe however (5%). In contrast, percentage of high-severity the second time mixed conifer, fir/high elevation conifers types burned was generally less the than the first time burned regardless of interval between first and second time burned.

8. Differences in the percentage of high-severity per fire were found between the major forest types when they were stratified by cover type (density and tree diameter size class). The first time forests composed of medium/large diameter trees burned after 1987, they burned with a significantly lower percentage of high-severity than did forests of small diameter trees, except for open Douglas-fir and fir/high elevation forests. Regardless of density or tree diameter size Douglas-fir showed no significant difference between first and second time burned within 1-30 years. However, closed medium/large mixed conifer, closed and open small mixed conifer, and closed medium/large fir/high elevation conifer forests all burned with a significantly lower percentage of high-severity the second time they burned within 1-30 years compared with the first time they burned. Patterns were less clear for other cover types.

9. In conifer vegetation types, percentage of high-severity and high-severity patch size within individual fires tended to be larger: a) with larger fire size, b) in fires that ignited later in the year, and c) in years when less total area burned across the study region. Percentage of high-severity in each fire was more strongly (negatively) related to total area burned per year than fire size. Percentage high-severity was also inversely related to spring precipitation and larger patches of high-severity tended to occur in forests closer to the Pacific coast. Generally, years with the largest fires and most total area burned were characterized by less winter and spring precipitation than years with smaller fires and less total area burned.

Discussion

During the 1987-2008 period in NW California, mean and maximum fire size and total annual area burned all increased to levels above any recorded since the US Forest Service began keeping records at the beginning of the 20th century. Despite this increase in fire size and area burned, the annual number of fires remains below the maximum in the 1920s. Annual number of fires, fire size and annual burned area now are more directly related to precipitation during the fire season than earlier in the 20th century even though regional precipitation has increased. During the earlier portion of the 20th century, number of

fires, fire size and annual area burned in NW California were all most strongly (negatively) associated with the summertime Palmer draught severity index (PDSI) (PDSI integrates temperature and precipitation anomalies over the summer months, but it has a lag built in so that it does not respond to short-term inputs of small amounts of precipitation).

There has also been a strong temporal increase in the importance of lightning fires in NW California. During the early half of the 20th century lightning accounted for about 42% of area burned in all recorded fires, but by the end of the century more than 87% of area burned was caused by lightning. We hypothesize that the increasing importance of summer precipitation later in the study period may be related to an increase in dominance of lightning-caused fires. What little precipitation occurs in this Mediterranean climate during the summer months is largely the result of occasional convective thunderstorms that also produce the lightning that is the source of most of the area burned. Annual precipitation in NW California has on average increased since the beginning of the 20th century, but almost entirely during the October to May rainy season (i.e., not during the summer fire season), however our analysis suggests that amount of precipitation at the time of ignition has become more important in recent decades than seasonal drought in driving fire activity and fire area. Ironically, dry years in which large areas burn due to lightning-ignited fires are often years of relatively little lightning activity. Because summer precipitation is almost entirely convective in nature, years with greater lightning activity are also those with greater summer precipitation, which results in less area burned. In NW California, the outcome of these relationships is that years that produce fewer lightning strikes account for most of the area burned by lightning-caused fires. This is similar to results found in the Pacific Northwest (Washington and Oregon), where the number of lightning strikes was not found to be directly proportional to the number of fire starts (Rorig and Ferguson 2002).

We propose that the increasing importance of rainfall during thunderstorms to fire activity late in the study period may be partly due to the ability of fire crews to access fires and suppress them during their initiating stage. The last half of the study period has seen dramatic improvements in the ability of fire crews to more quickly access much of this rugged region, on the ground and especially in the air. When a lightning ignition is accompanied by rain, fire spread and intensity are reduced and first response crews have more time to reach the ignition area before the fire becomes too large to control. Therefore, wetter conditions at the time of ignition lead to fewer fires that escape initial attack. However, lightning events that trigger many simultaneous ignitions can overwhelm the capacity of fire crews to promptly reach every ignition, increasing the response time. Longer suppression response times diminish the effectiveness of the window of reduced fire behavior that would have resulted from convective rainfall accompanying the lightning start. Similarly, in the early portion of the study period fire fighters had poor access to wildland ignitions, which would have reduced the effectiveness of any precipitation accompanying ignitions. Long suppression response times allow live and dead fuel moistures, and therefore PDSI, to play a greater role in subsequent fire behavior and fire suppression effectiveness during the early portion of the study period.

With the shift in the association of fire statistics from PDSI to summer precipitation, the annual number of fires escaping initial attack within our study area has increased during the last portion of the 20th century, but overall numbers still remain below historical levels. In concert with the increase in number of fires, total area burned is moving closer to pre-settlement levels. Fire rotation in forested areas decreased from around 267 years early in the 20th century to about 95 years in 2008, primarily due to the increase in total area burned during 1987-2008. Importantly, even this reduction to a 95-yr fire rotation is still 3 to 6 times longer than estimates of past fire rotation reported from the literature (Taylor and Skinner 1998, 2003, Stephens et al. 2007, Van de Water and Safford 2011). Although there has been a shift in fire management policy in recent years to manage some fires for ecological benefit (e.g. not fully suppressing fires that are burning under more benign weather and fuel conditions), primarily in wilderness areas, the practice of suppressing most ignitions remains. It is therefore evident that the increase in area burned is at least partially due to more ignitions escaping initial attack and fires growing large, even under full suppression efforts.

We found no clear temporal trend in the percentage of forest area burning at high-severity for the period 1987-2008. But 1987, 1999, 2006 and 2008, all of which are included in our fire severity dataset, experienced the most area burned during the whole 1910-2008 period. Moreover, the two years with the most area burned bracket the period of the 1987-2008 severity dataset used in this report. In each of these years, fires were primarily caused by widespread lightning events that severely strained fire suppression resources. Overall fire severities were relatively low due to burning for weeks to months through variable, often moderate meteorological conditions and the fact that many of the fires burned well into the fall. It is probable that the coincidental timing of our severity dataset with the two years with the most area burned in a century precluded us from detecting any underlying trend in percentage of high-severity.

Our findings in NW California differ from results for the Sierra Nevada and adjacent southern Cascades, where an increasing trend in percentage of high-severity fire for some forest types has been reported (Miller et al. 2009b). Differences between regions may be explained by differences in topography of NW California when compared with the Sierra Nevada or the Southern Cascades. While topography in both NW California and the Sierra Nevada is extremely rugged, canyons in the Sierra Nevada and the relatively broad ridgetops tend to align with westerly winds, whereas the topography in NW California is much more dissected, leading to air entrapment and formation of temperature inversions. In addition, road access tends to be more limited in NW California, making fire suppression efforts difficult. Consequently, years with multiple contemporaneous ignition events (e.g., 1987, 1999, 2006, and 2008) can produce swarms of large fires that burn for months, many into late fall when weather conditions aid in the final containment of the fires. In NW California, fire intensity historically was lowest on lower slopes and north- and east-facing aspects, and greater on mid- and upper-slope positions, especially on south and west facing aspects, where higher temperatures and afternoon winds promote drier conditions (Weatherspoon and Skinner 1995, Taylor and Skinner 1998, Alexander et al. 2006). Long-term

temperature inversions under stable air masses that are common within the region during the summer can trap smoke in valleys leading to cooler temperature and higher humidity resulting in less severe fire effects at lower-slope positions (Robock 1988, 1991). Reduced fire intensity, less crowning, and more surface fire are more common under temperature inversions. When temperature inversions erode, large areas of high-severity fire can occur due to higher temperatures and increased winds (e.g., Megram fire 1999, Motion and Panther fires 2008). Very strong inversion effects characterized much of the 1987 and 2008 fire years, resulting in lower than average fire severity even though 100,000s of hectares of forest burned.

Like other studies in NW California, we found that percentage of high-severity within fires was lower in stands dominated by medium and large trees than in stands dominated by small trees (Weatherspoon and Skinner 1995, Jimerson and Jones 2003, Alexander et al. 2006). We also found whether an area had burned or not in the recent past also influenced severity. We found that closed canopy medium/large (CCM) forests which burned a second time after 1910 burned with a lower percentage of high-severity per fire than when they burned the first time. When stratifying by vegetation type, we found differences in the percentage of high-severity between forests burned the first or the second time. For Douglas-fir, percentage of high-severity per fire was not significantly different the first time burned vs. the second time burned within the first 30yrs. But when the interval between first and second fire was >30 years, high-severity was significantly less than first time burned (5 vs. 9%). In contrast, percentage of high-severity in mixed conifer and fir/high elevation conifers was less when burned a second time compared with first time burned.

We believe the severity pattern of higher severity when unburned for more than 30 years associated with CCM Douglas-fir in our study area is likely characteristic of areas with increased fuels due to fire suppression. The temperature inversions that occur in our study area lower fire intensity, especially at lower elevations where Douglas-fir forests dominate. High fire intensity is therefore controlled more by topography and fuel accumulation, rather than severe weather conditions. Additionally, a relatively short interval between two burns after many decades without fire is different than a short interval following centuries of frequent fires. We hypothesize that small diameter trees and understory shrubs that are killed but not consumed in the first low-severity fire become dried, and if a second fire enters the same area before the dead fuels decompose, these fuels could contribute to higher intensities than would otherwise occur. Severity in the second burn is influenced by the time since the stand last burned and the rate that dead fuels from the first fire decompose; leading to reduction of fuel load and an increase in fuel bed bulk density as fuels decompose and compact over time. Thus, there is a corresponding decrease in proportion of high-severity when the interval between fires increases. Due to the limited area in our dataset that burned three times we could not explore how the proportion of high-severity would change upon a third entry by fire.

The percentage of fire area that experienced high-severity was greater for human ignited fires than for lightning ignited fires in fires analyzed in this report. There are multiple indications that this relationship may be due to more aggressive suppression of human ignited fires. First, although it is possible that human ignited fires that escaped initial attack and became large enough to be counted in this data set are those that occurred under weather conditions more likely to lead to high-severity effects (and after weather conditions moderate the fires are contained), there was no evidence that human ignited fires occurred under seasonal climate conditions that would lead to more intense fires on average than lightning fires. There was no difference between average ignition date, and more human caused fires actually tended to occur in fire seasons that were less dry. Second, most of the large lightning fires occurred during years when there were many simultaneous ignitions across a broad area and total burned area was higher. Under these conditions (widespread, simultaneous ignitions of multiple lightning fires) fewer fire-fighting resources are available to suppress each fire than in the average human-ignition scenario, in which fires tend to occur in (relative) temporal isolation. Third, percentage of high-severity fire was also inversely related to total area burned per year. Fourth, fires that occur in close proximity to access corridors and urban areas tend to be of high concern and therefore aggressively suppressed, and centroids of human ignited fires were significantly closer to the WUI or Forest boundary on average (lightning = 2.2 miles vs. human = 1.2 miles). Finally, although lightning-ignited fires were generally larger than human ignited fires there was no difference in either mean or maximum conifer high-severity patch size between human and lightning ignited fires.

The question remains as to how much climate change, changes in forest structure due to past management, and changes in fire suppression practices have influenced trends in fire severity and fire occurrence. While no trend in fire severity could be detected, the data presented in this report suggest that fire frequency, fire size, and total burned area have strongly increased over the last 20+ years, and that climate is associated with a growing proportion of the variance in these variables. We believe that this pattern is the product of a changing climate plus increasing and more fire-prone fuels in some forest types, the latter driven by a combination of human- (fire suppression, land management practices, etc.) and climate-related (warming temperature, drier fire seasons, etc.) factors. Regardless, forested systems in NW California will burn under favorable weather conditions, and it is logical to expect more and larger fires under future climate change scenarios (Lenihan et al. 2008, State of California 2009, Gedalof 2011). A major question is whether we can reduce the intensity at which future forest fires will burn, and thereby minimize the negative ecosystem effects of fire while maximizing the positive effects. Overall, the evidence suggests that under the right meteorological, ecological, and political circumstances, wildland fires might be more extensively used in NW California to achieve management objectives such as reducing landscape-scale fire hazard, and restoring the ecological role of fire by increasing forest heterogeneity and sustaining biodiversity in fire-adapted forests.

Introduction

Background

Nationally publicized fires over the last couple of decades, beginning with the 1987 California and 1988 Yellowstone fires and continuing through the 2003 Southern California fires, have led to the prevailing opinion that fires are becoming larger and more severe on average (Skinner and Chang 1996, Arno and Fiedler 2005). As a result, changes were made in fire policy, as outlined in the National Fire Plan (USDA-USDI 2000) and funding increased for frontline fire fighting resources, fuels treatments, post-fire restoration, and community assistance. Most evidence used to support these policy changes has come from analysis of fire occurrence data. Recently, Westerling et al. (2006) used climate and fire occurrence data from the Western US to conclude that recent changes in climate have promoted increased large fire activity, higher large-fire frequency, longer fire durations, and longer fire seasons since the mid-1980s. Although there is substantial evidence for recent increases in fire size and frequency, a remaining and perhaps more significant question is whether or not there is a trend toward more acres experiencing higher severity fire and increased high-severity patch size.

Previous studies of severity patterns for NW California have been limited to a small sample of fires from one or two years (e.g., Weatherspoon and Skinner 1995, Odion et al. 2004, Alexander et al. 2006, Thompson et al. 2007). However, basic statistical principles caution against making broad extrapolations from limited datasets, especially when using data from years that can be confidently identified as atypical. In contrast, we report here on the first study that quantitatively assesses temporal trends and causal factors of high-severity fire effects using a complete census of all fires >1000 acres occurring on the four National Forests of NW California over a twenty-two year period (1987-2008).

Objectives

Our primary objectives were to determine the percentage of lethal, mixed-lethal and non-lethal fire by vegetation type and tree diameter size class, and assess temporal trends in severity and heterogeneity in all fires >1000 acres that occurred on the four NW California Forests between 1987 and 2008. Additional objectives included assessing longer-term trends in fire numbers, size and annual area burned over 1910-2008 using the fire perimeter history, and examining causal factors such as climate and ignition source.

Approach

A condensed description of the analysis methods and data are provided here to provide background for understanding the detailed results which follow this section. An expanded description of the analysis methods and data is provided in Appendix A.

Spatial Extent and Time Period Covered

We mapped severity for all fires over 1000 acres that occurred at least partially on the Klamath, Mendocino, Shasta-Trinity and Six Rivers National Forests in northwestern California from 1987 through 2008 (Figure 1). Adjacent fires that ignited on the same day during multiple lightning strike events were mapped as single fires to allow analysis of whole high-severity patches for a total of 132 fires. For fires that burned across NF boundaries, we only analyzed fires that burned at least 500 acres on a Pacific Southwest Region National Forest. The total burned area for all analyzed fires was approximately 1.6 million acres (87% due to lightning ignitions).

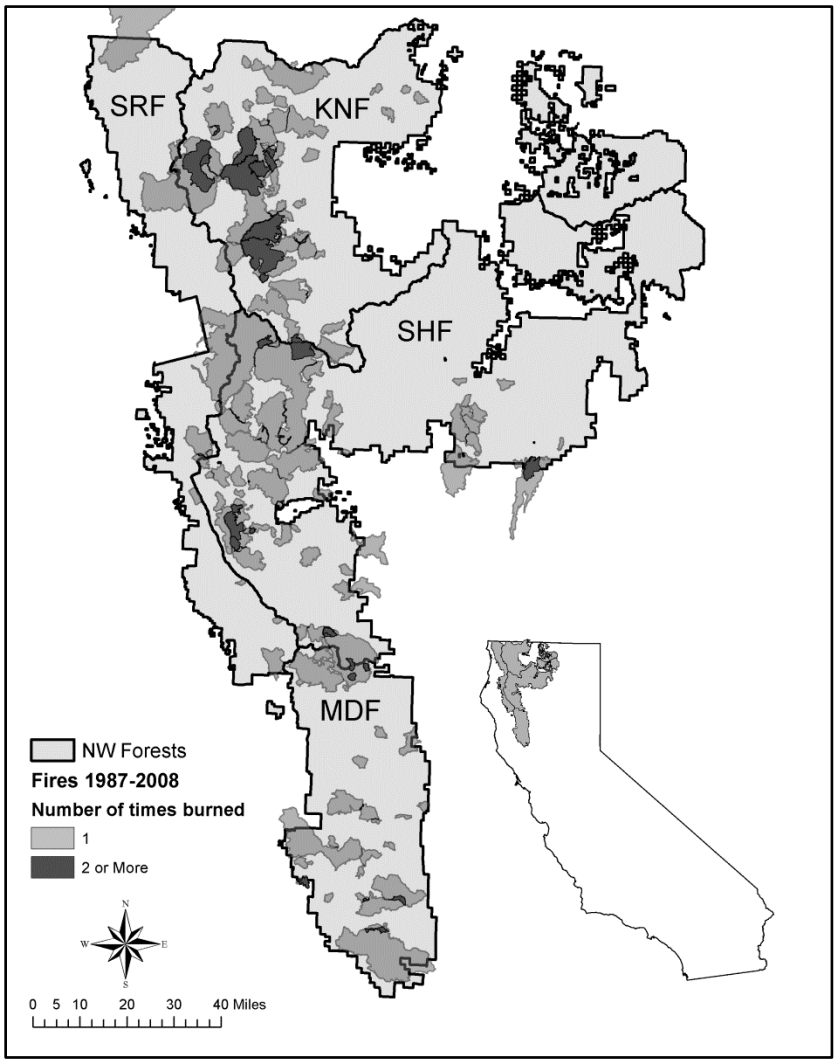

Figure 1. Map of the study area. Within the study region, areas demarcated in light gray and outlined in black listed clockwise starting from the top left are the Six Rivers (SRF), Klamath (KNF), Shasta-Trinity (SHF), and Mendocino (MDF) National Forests. Darker gray polygons represent 132 fires analyzed in the current study. Progressively darker fire polygons represent areas that burned more than once during 1987-2008.

Remote Sensing and Severity Data Calibration

Beginning in 2006, the Wildland Fire Leadership Council funded the Monitoring Trends in Burn Severity (MTBS) program to develop a historical fire severity atlas from satellite imagery to support the National Fire Plan and Healthy Forests Restoration Act (Eidenshink et al. 2007). The satellite data used to derive categorical severity data presented in this report were obtained from the MTBS program. However, the categorical data used in this report differ from those created by the MTBS program in two ways. First, the mapping methods employed by MTBS follow the methods first developed by the U.S. Geological Survey and National Park Service, and used by the U.S. Forest Service Remote Sensing Applications Center (RSAC) to produce Burned Area Reflectance Classification (BARC) maps for BAER teams. But, those methods do not correct for pre-fire cover and therefore can under represent stand-replacing fire (Miller and Thode 2007, Safford et al. 2008). The satellite data used for this report are processed slightly differently to remove the pre-fire cover bias; details of the methods used for this report are provided in Miller and Thode (2007). Secondly, categorical BARC maps produced for the BAER program are not calibrated or assessed for accuracy using field-sampled data, whereas maps presented in this report have been calibrated by field data collected in fires that occurred in the Sierra Nevada and validated with data collected in fires that occurred on the Klamath and Six Rivers National Forests in the Klamath Mountains of northwestern California (Miller et al. 2009a).

Severity is a measure of the consequences of fire to a given resource. The fire severity data presented here are based upon the correlation of satellite-acquired imagery with a field-measured composite burn index (CBI). The CBI protocol, developed by the USGS and National Park Service, incorporates eighteen vegetation related variables across all vertical strata (understory, midstory and overstory), four fuel variables, and one soil variable (Key and Benson 2006a). Given its heavy weighting toward measures of vegetation condition, the CBI is primarily a metric of fire effects on vegetation, rather than soil. Due to their view from above, satellites primarily measure conditions in the uppermost structural component of the vegetation community. For forested systems the uppermost structural component is the tree canopy. Variables that describe tree cover form a fundamental basis for mensuration, analysis, mapping and management of forest resources, and are often used as important variables in models of wildlife and plant species habitat (USDA 1992, Cade 1997, Zielinski et al. 2006). Therefore in addition to CBI, we collected individual tree mortality data in our field plots and produced severity data in units of percent change in canopy cover and tree basal area mortality. To be compatible with previous reports produced by the FSMP, all analyses in this report were conducted with the CBI calibrated data. The tree mortality data are available for subsequent analysis. The percent change in canopy cover data for the fires analyzed in this report are reported in Appendix B in four broad categories. The assumptions underlying the severity measures are summarized below. More detailed descriptions can be found in Miller and Thode (2007) and Miller et al. (2009a).

Fundamental limitations of satellite technology have several implications to the severity data used in this report. First, the satellite data are primarily sensitive to change in chlorophyll and have a spatial resolution of 30x30 meters. The severity data therefore represent a sum of effects, both vertically and horizontally, as seen from above. As a result, it is not possible to distinguish whether changes in chlorophyll represent effects to trees or inter-tree understory vegetation in open stands, or to understory vegetation under dense tree canopies. Secondly, it is often not possible to acquire optimal imagery immediately post-fire. Therefore, the post-fire imagery used for this report was acquired the summer after each fire occurrence. As a consequence, the severity data can reflect delayed fire effects such as additional tree mortality that may have occurred in the first year after a fire. In open stands, resprouting vegetation, e.g. shrubs, can mask tree mortality due to first order fire effects.

Fire Severity Ratings Based on the Composite Burn Index

The satellite data were calibrated to the field measured CBI through regression analysis (Miller and Thode 2007, Miller et al. 2009a). CBI, calculated as a linear average of the severity rating to vegetation (overstory, middlestory and understory), and to a much lesser extent the soil, results in a continuous variable ranging between zero (unburned) and three (highest severity). Severity is often mapped in broad categories to aid in interpretation (DeBano et al. 1998). Key and Benson (Key and Benson 2006a) however make no recommendation as to specific CBI values for delineating categorical severity ratings. Choosing which CBI values to use as thresholds between severity categories is therefore partially subjective judgment. Similar but distinct severity maps could be produced depending on management objective, analysis criteria, etc. For this analysis we chose to place the thresholds halfway between the values listed on the CBI data form for adjacent categories. For example, the CBI data form indicates a “moderate” severity fire occurs when CBI ranges between 1.5 and 2.0, and “high” severity occurs between 2.5 and 3.0. Therefore like previous analysis we have performed we use 2.25 as the threshold between “moderate” and “high” severity categories (Miller and Thode 2007, Miller et al. 2009a). The high-severity threshold also equates to approximately 95% change in live vegetated cover (Miller et al. 2009a). Since U.S. Forest Service vegetation classification standards requires a minimum of 10% tree cover to be the minimum for forested areas, the high-severity threshold provides a conservative estimate of conversion of forest to non-forest vegetation (Brohman and Bryant 2005). Table 1 lists the CBI thresholds used and generalized descriptions of the severity categories. Figure 2 depicts photos from field validation plots representative of each severity category. User map accuracies of high-severity patches average about 85%, moderate 50% and unchanged to low 44% for plots from the Klamath Mountains (Miller et al. 2009a).

Table 1. Composite Burn Index (CBI) severity categories.

CBI Value	Severity Category	Definition
0 – 0.1	Unchanged	One year after the fire the area was indistinguishable from pre-fire conditions. This does not always indicate the area did not burn.
0.11 – 1.25	Low	Areas where surface fire occurred with little change in cover and little mortality of the vegetation.
1.26 – 2.25	Moderate	A mixture of fire effects on vegetation, ranging from low to high, characterized by a "mosaic" spatial pattern.
2.26 – 3.0	High	Areas where high to total mortality of the vegetation occurred. This equates to a pproximately 95% change in the amount of canopy cover (Miller et al. 2009a).

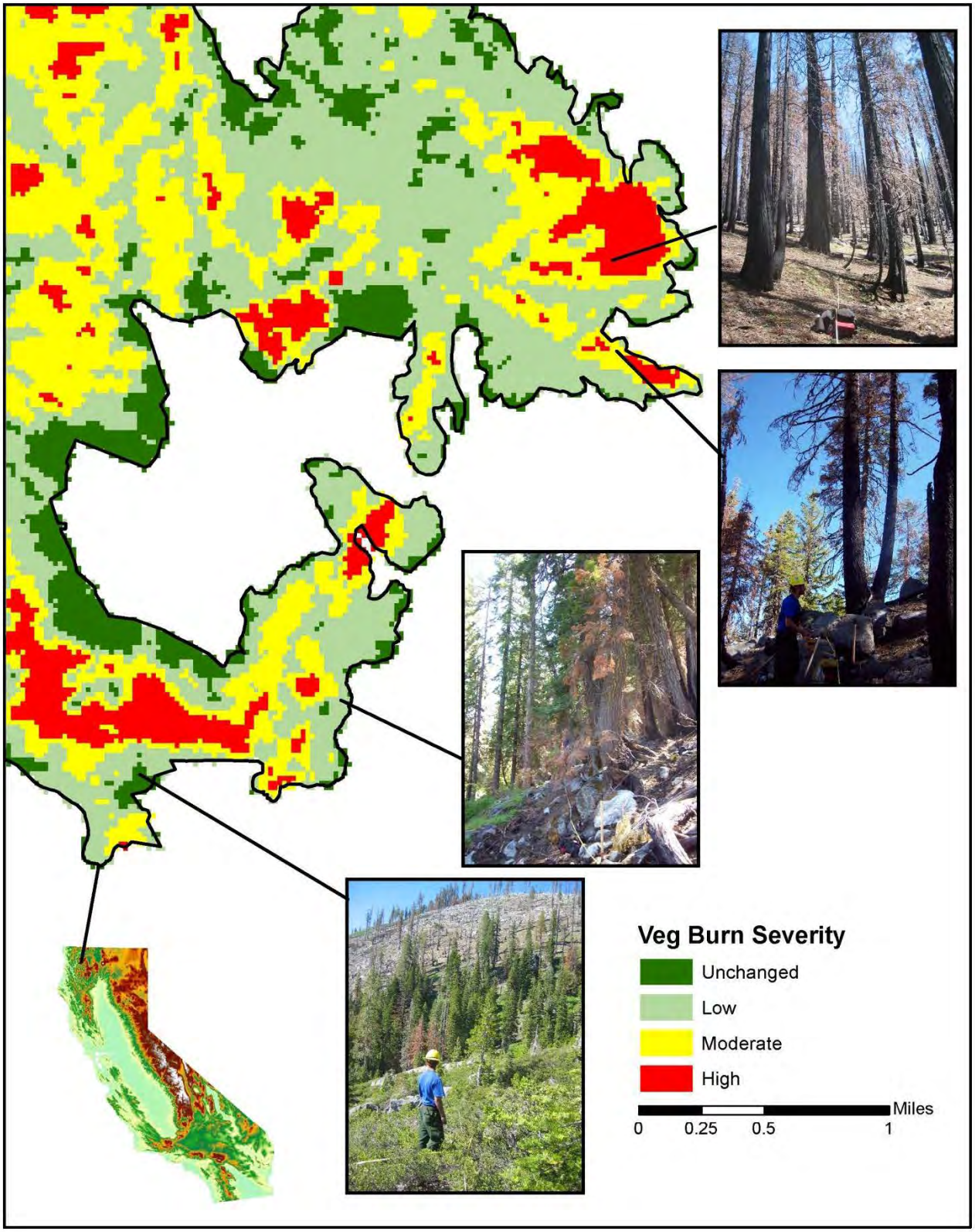

Figure 2. Example field plot photos for CBI severity categories, 2006 Hancock Fire.

Fire Severity Ratings Based on Percent Change in Canopy Cover

As noted above, measures of tree cover are a fundamental basis for mensuration, analysis, mapping and management of forest resources, and are often important variables in habitat models for wildlife and plants (USDA 1992, Cade 1997, Zielinski et al. 2006). We therefore also developed fire severity ratings based upon percent change in canopy cover in addition to the CBI approach described above. We measured tree mortality by size class one year post-fire to develop a regression model of percent change in canopy cover to the satellite image data. Percent canopy cover was calculated for pre- and post-fire conditions using the Forest Vegetation Simulator (FVS) (Dixon 2002). FVS-derived estimates of individual tree crown cover assume trees are healthy, but fire can modify dbh to canopy architecture relationships by raising crown-base-height; thereby reducing canopy width. Since there was no way to modify crown width inside FVS, we derived a crown cover correction factor as a function of the percentage of crown volume scorched (PCVS) using equations for modeling crown shape (Biging and Wensel 1990). Data from plots with at least 10% pre-fire tree canopy cover were used in developing a regression model of percent change in canopy cover to the satellite data since the U.S. Forest Service considers 10% to be the lower limit for defining forested areas (Brohman and Bryant 2005). A typical map of percent change in canopy cover categorized into five classes is shown in Figure 3. Characteristic of most fires, high-severity patches are surrounded by rings of decreasing severity. The five category map shows a steep change gradient typical in the transition area between high-severity patches and the surrounding low severity. When considering areas with at least 10% pre-fire tree canopy cover and combining the five categories into three broad classes, user's accuracies for areas with greater than 75% change in canopy cover average 87%; accuracies of areas with less than 25% change average about 61%, and areas between 25 and 75% change average only about 57% accurate [see Miller et al. (2009a) for details].

The Fire Regime Condition Class (FRCC) (www.frcc.gov) and LANDFIRE (www.landfire.gov) programs have used 75% change in vegetated cover as a definition of a stand-replacing fire regime. But that definition normally applies to the percent area that experiences vegetation type conversion over a larger landscape, such as within an entire fire, and not within a single 30 m pixel as portrayed in our satellite derived severity maps (Barrett et al. 2010).

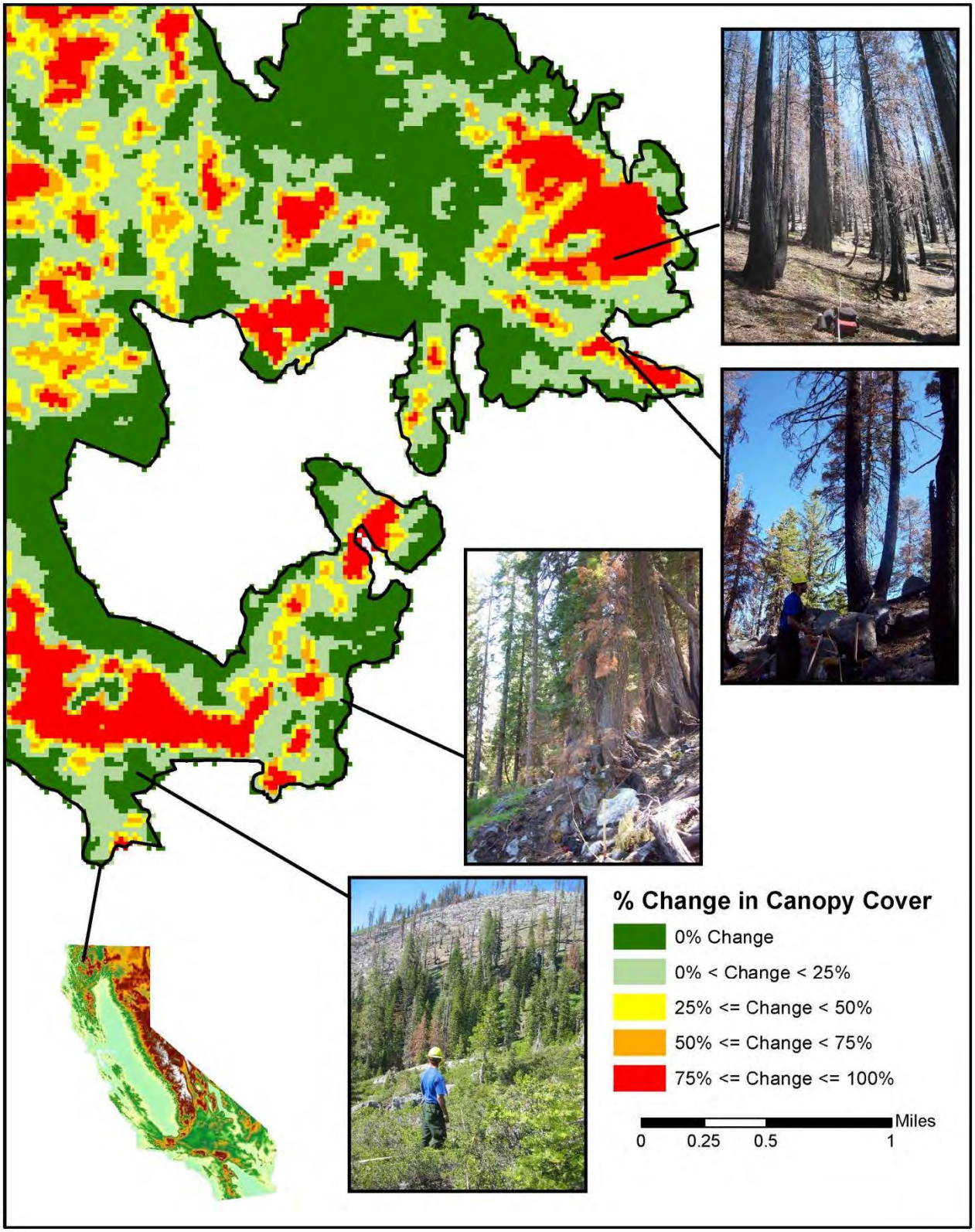

Figure 3. Example field plot photos for percent change in canopy cover severity categories, 2006 Hancock Fire.

Stratification by Vegetation and Cover Type

Using static maps of current vegetation to analyze severity by vegetation type over time can be problematic because high-severity fire events can cause vegetation type change. Vegetation stratification therefore must be based on standardized and frequently updated vegetation maps. CALVEG maps developed for Forest lands in California through classification of Landsat imagery by the US Forest Service Pacific Southwest Region Remote Sensing Lab (RSL) are the only available vegetation maps frequently updated for the study area (Franklin et al. 2000, USDA 2005). The earliest CALVEG maps of a scale matching Landsat imagery used to generate the severity data date from the early 1990s. Although CALVEG is used as an existing vegetation map, the mapping methodology specifies that productive conifer forest land be retained in the map to satisfy requirements of the National Forest Management Act of 1976. As a result, when stand replacing events occur in forested areas, tree density is set to zero and the primary vegetation type is not changed. In essence then, CALVEG is at least partly a "potential vegetation" map. However, approximately 15% of the area mapped for the severity analysis burned more than once after 1970 making it impossible to determine when areas converted from mature forest to early seral stages using the latest map. We therefore developed a pre-fire vegetation map. The first year that cloud-free imagery was available for the whole study area was 1987. Class categories in 1994 and 2004 versions of CALVEG were merged to match those used for our 1987 classification, thereby resulting in a consistent series of three vegetation maps that could be used for analyzing trends in severity by pre-fire vegetation conditions.

Rather than use all CALVEG categories, we mapped cover and vegetation types into broad categories. Cover types were generally divided along life form categories with the exception of conifer and mixed conifer/hardwood which were grouped together (Table 2). Conifer cover types were additionally subdivided into subcategories of percent cover and diameter size classes when these differences were of sufficient magnitude to influence fire behavior. Classification of vegetation type was trained using plots from the United States Department of Agriculture Forest Service (USFS) Forest Inventory and Analysis (FIA) program (USDA 1992). Vegetation types were lumped into seven broad categories (Douglas-fir, Gray pine, Mixed conifer, Fir/high-elevation conifer, Deciduous oak, Live oak, and Mixed hardwood) during the classification process based upon the ability of the classification algorithm to separate types into unique classes. The vegetation type classification was applied only to the areas mapped as either conifer or hardwood, excluding sapling/poles, produced in the cover type classification.

Table 2. Cover and vegetation types found within the study area and the amount of each burning (%, relative to total area burned) during the 1987-2008 period.

Type	Life form	Cover (%)	dBH (inches)	Percent area within fires 1987-2008
Cover type				
Barren (BAR)	Barren			
Conifer Closed Medium/Large (CCM)	Conifer/Mixed Conifer Hardwood	60 - 100	≥ 20	39.5
Conifer Closed Small (CCS)	Conifer/Mixed Conifer Hardwood	60 - 100	10 - 20	13.1
Conifer Open Medium/Large (COM)	Conifer/Mixed Conifer Hardwood	10 - 60	≥ 20	6.3
Conifer Open Small (COS)	Conifer/Mixed Conifer Hardwood	10 - 60	10 - 20	8.0
Hardwood (HDW)	Hardwood			10.7
Herbaceous (HEB)	Herbaceous			0.6
Sapling/Poles (SAPOL)	Conifer/Mixed Conifer Hardwood	10 - 100	1 - 10	11.5
Shrub (SHB)	Shrub			9.4
Water (WAT)	Water			0.0
Vegetation type				
Douglas-fir (DF)	Conifer/Mixed Conifer Hardwood	≥10	≥10	32.1
Gray Pine (GP)	Conifer/Mixed Conifer Hardwood	≥10	≥10	0.3
Mixed Conifer (MC)	Conifer/Mixed Conifer Hardwood	≥10	≥10	26.6
Fir/High Elevation Conifer (FIR)	Conifer/Mixed Conifer Hardwood	≥10	≥10	8.6
Deciduous Oak (DO)	Hardwood			4.3
Live Oak (LO)	Hardwood			5.7
Mixed Hardwood (MH)	Hardwood			0.7

Fire Regime Concept

Fire behavior is a complex function of weather, topography, and fuels. By examining many fires over time to account for variation in weather and topography, patterns of how fire interacts with vegetation communities can be discerned. Distilling those fire patterns into summaries known as fire regimes helps in understanding ecosystem processes at a landscape scale (Agee 1993, Sugihara et al. 2006). Although there are many attributes that can be used to characterize fire regimes, seven attributes are commonly thought to be most important to ecosystem function: seasonality, fire return interval, size, spatial complexity, fireline intensity, type and severity (Sugihara et al. 2006). This report concentrates primarily on characterizing severity, although trends in fire size and complexity are also examined. Sugihara et al. (2006) present a set of conceptual distribution curves that describe the probability of occurrence for each fire regime attribute. For example, Figure 4 depicts conceptual severity distribution curves for five severity types. The x-axis represents the range of values for severity and the y-axis the proportion of the burned area for each type: low, moderate, high, very high, and multiple. Sugihara et al. (2006) provide the following definitions of each severity type:

Low Fire Severity Most of the area burns in low-severity fires that produce only slight or no modification to vegetation structure; most of the mature individual plants survive….ponderosa pine, and blue oak woodlands are often examples of this fire severity pattern.

Moderate Fire Severity Most of the area burns in fires that are moderately stand modifying, with most individual mature plants surviving… Mixed conifer and giant sequoia are typical examples of this severity pattern.

High Fire Severity Fire kills the above ground parts of most individual plants over most of the burned area. Most individual plants survive below ground and resprout…many sprouting chaparral types are often examples of this fire severity pattern.

Very High Fire Severity Fires are mostly stand replacing over much of the burned area. All or nearly all of the individual mature plants are killed… Lodgepole pine … and non-sprouting chaparral types frequently display this fire severity pattern.

Multiple Fire Severity The area burned is mostly divided between two distinct fire types: low severity and high to very high-severity… red fir and white fir forests are often examples of this fire severity pattern.

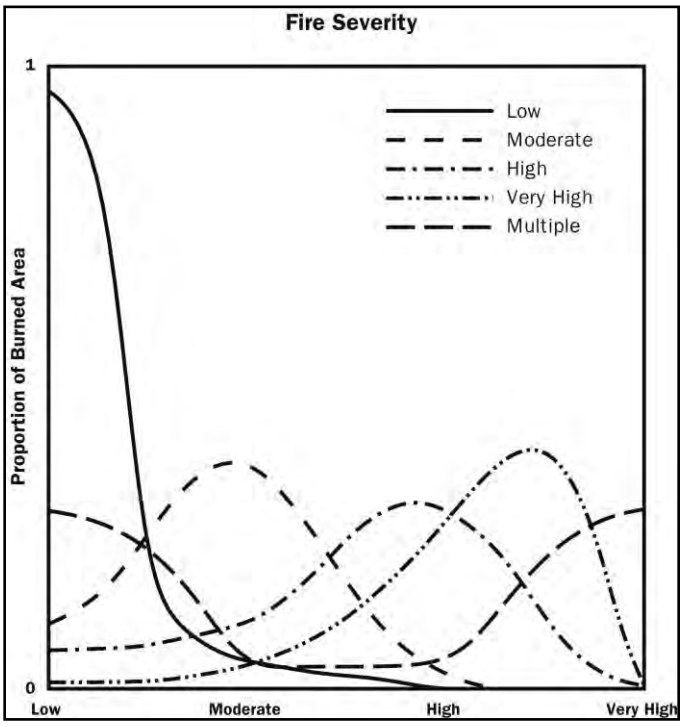

Figure 4. Hypothetical fire severity distribution curves for different fire regimes. (from Sugihara et al. 2006)

Sugihara et al. (2006) use the severity types above to describe - in a general sense - hypothetical historic (pre-settlement) fire severity attributes for major vegetation types of NW California. Table 3 lists the historic severity and fire type for each of the broad vegetation types used in this report except for mixed hardwood, which was not discussed by Sugihara et al. (2006). The fire severity data used for analysis in this report are summarized into four categories of severity (Table 1) and are reported in the Results section of this document. The high-severity category as used in this document combines the high and very high-severity categories as described by Sugihara et al. (2006).

Table 3. Historic fire regime types for California vegetation types (adapted from Sugihara et. al. 2006)

Vegetation Type	Severity	Fire Type
Deciduous Oak	Low-Moderate	Surface
Live Oak	Low-Moderate	Surface
Mixed Hardwood		
Gray Pine	Low-Moderate	Surface
Douglas-fir	Low-Moderate	Surface
Mixed Conifer	Multiple	Surface
Fir/High Elevation Conifer	Multiple	Surface to crown

Results

Summary of Severity and Area Burned by Year, 1987 - 2008

Approximately 1,600,000 acres (including forested and non-forested vegetation) burned on the four U.S. Forests in NW California in fires over 1000 acres between 1987 and 2008. The four years when the most area burned were 1987, 1999, 2006 and 2008 (Table 4 and Figure **5**). In each of these four years, large fires were primarily caused by widespread lightning events and percent high-severity was between 15 and 16%, which was lower than all other years excepting 1990 and 1994 (Figure **6**). Percent high-severity was highest in 1992 at 49%, but only one fire larger than 1000ac burned more than 500 acres on National Forest land within the study area that year. No fires larger than 1000 acres occurred during 1993, 1997 or 1998.

Table 4. Total and percent area burned by severity category by year, 1987-2008 fires >1000 acres.

Year	Number of Fires	Unchanged (acres / %)	Low (acres / %)	Moderate (acres / %)	High (acres / %)	Total (acres)
1987	37	80,950 / 18	182,791 / 41	113,084 / 25	70,683 / 16	447,508
1988	3	2,339 / 17	4,119 / 30	4,054 / 29	3,425 / 25	13,937
1990	2	666 / 16	1,823 / 43	1,071 / 25	642 / 15	4,202
1991	2	121 / 6	506 / 25	751 / 37	645 / 32	2,023
1992	1	107 / 4	422 / 15	892 / 32	1,346 / 49	2,768
1994	4	6,563 / 16	17,928 / 43	10,485 / 25	6,647 / 16	41,623
1995	1	223 / 10	1,046 / 49	433 / 20	451 / 21	2,153
1996	2	3,588 / 5	12,627 / 16	32,650 / 42	29,088 / 37	78,221
1999	12	22,307 / 12	79,211 / 43	54,986 / 30	27,145 / 15	183,648
2000	4	426 / 7	1,542 / 27	2,476 / 43	1,273 / 22	5,717
2001	5	3,738 / 10	11,892 / 31	11,997 / 32	10,153 / 27	37,780
2002	3	823 / 2	3,516 / 10	16,419 / 48	13,209 / 39	33,966
2003	4	958 / 6	5,705 / 34	5,259 / 32	4,666 / 28	16,589
2004	3	1,433 / 13	2,777 / 25	3,167 / 29	3,692 / 33	11,069
2005	2	1,185 / 23	2,030 / 39	866 / 16	1,177 / 22	5,258
2006	10	22,947 / 13	83,154 / 48	43,053 / 25	25,559 / 15	174,713
2007	5	1,736 / 8	9,011 / 41	7,355 / 34	3,719 / 17	21,820
2008	32	59,980 / 11	249,844 / 46	150,073 / 28	82,031 / 15	543,539
Total	132	210,091 / 13	669,944 / 41	459,072 / 28	285,549 / 18	1,626,535

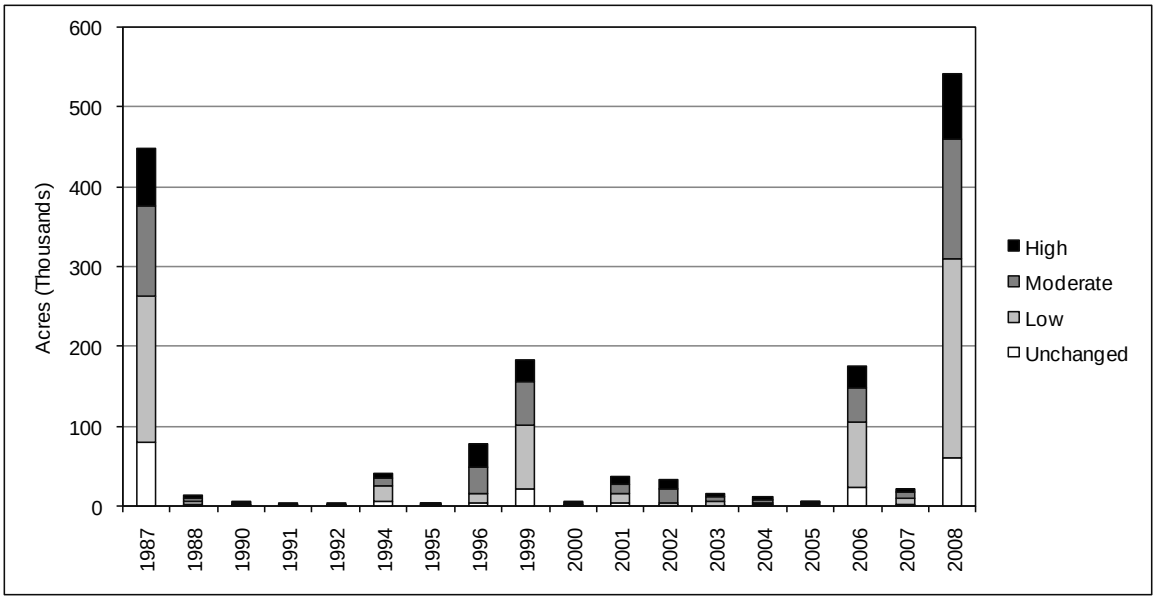

Figure 5. Area burned by severity category 1987-2008, fires >1000 acres.

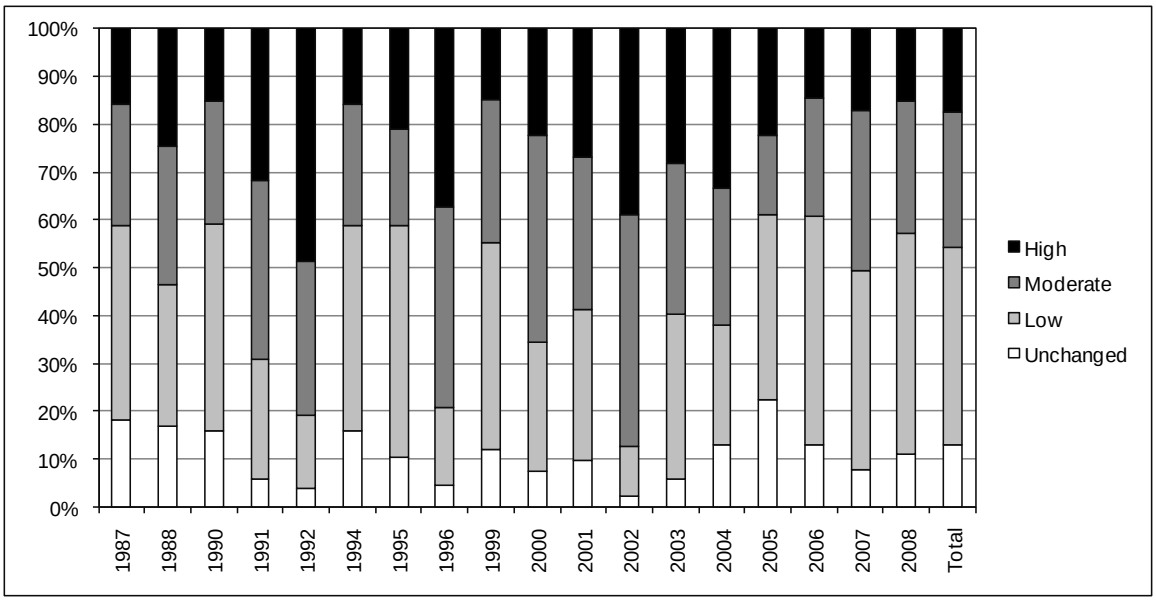

Figure 6. Percent area burned by severity category 1987-2008, fires >1000 acres.

A summary list of all fires mapped for this report is provided in Appendix B. For each fire, year, fire name, cause and direct protection agency are listed in addition to the number of acres burned by CBI-derived severity category, the number of acres in four categories of percent change in canopy cover, and the percentage of each category within the fire perimeter.

Severity by Vegetation and Cover Type, 1987 - 2008

To the public, fires that are big and fires that are severe, and especially those that are big *and* severe, are often perceived simply as "bad", without reference to the normal nature of fire in the vegetation type(s) in question. The Yellowstone fires of 1988 and the Southern California fires of 2003 are two cases where large, severe fire complexes caused huge public outcry, but – taking all variables into account, including weather and climate – fire size and severity in both cases were well within historical ranges for the their respective vegetation types (Romme and Despain 1989, Keeley and Fotheringham 2006). In other parts of the West, large, highly severe fires were indeed rare in pre-settlement times (for example, most yellow pine-dominated systems), and their occurrence today is probably correctly perceived as outside the range of historical variation (Agee 1993, Arno and Fiedler 2005). Table 3 provides some reference for the historic distributions of fire severities and types among the major vegetation types in this report. As the Table makes clear, high-severity fire was probably a minor component of fire regimes in NW California, but its representation clearly differed by vegetation type (with the vegetation type both affecting and being affected by the fire regime). In this section, we stratify fire severity over 1987-2008 by major vegetation and cover type in order to provide a contextual basis for understanding whether the current distribution of low versus high-severity is indeed effecting undesirable changes to ecosystems.

Mapped fires from 1987 through 2008 were stratified into seven broad forest vegetation types (Table 3). Cover types were divided along life form categories, with the exception of conifer and mixed conifer/hardwood which were grouped together. Conifer cover types were additionally subdivided into subcategories of percent cover and diameter size classes (Table 2). The percentage of the fire area burning at high-severity ranged from 10% to 27% (Table 5 and Figure 7). Severity was lowest for areas dominated by Douglas-fir and closed conifer forests of medium to large diameter (class "CCM"); severity differences between the other forest and cover types were not especially pronounced. CCM forests experienced the largest area of high-severity closely followed by mixed conifer forests (Table 5 and Figure 8). CCM forests experienced the most acres of high-severity primarily because they accounted for 51% of the forested area burned (Table 6 and Figure **9**). Percent high-severity was at least qualitatively highest in gray pine-dominated stands (which are often associated with chaparral shrubs or steep south- and west-facing slopes). For conifer cover types, percentage of high-severity increased with smaller mean tree diameter and lower percent cover. Among the hardwood types, severity levels were very similar, with deciduous oak experiencing somewhat higher severity than live oak and mixed hardwood. High-severity fire may be under-reported for sprouting hardwood types since severity data were derived from imagery acquired the year after fire. Post-fire sprouting by hardwood species may reduce the apparent severity level by decreasing the difference in live biomass between post- and pre-fire images.

Table 5. Percent and total area burned by severity category for forest vegetation and cover types, fires >1000 acres 1987-2008.

Type	Unchanged (acres / %)	Low (acres / %)	Moderate (acres / %)	High (acres / %)	Total * (acres)
Cover Type (Totals)					
Conifer Closed Medium/Large (CCM)	89,731 / 14	320,844 / 50	145,635 / 23	86,479 / 13	643,251
Conifer Closed Small (CCS)	21,748 / 10	97,503 / 46	59,403 / 28	34,384 / 16	213,216
Conifer Open Medium/Large (COM)	11,741 / 11	41,349 / 40	43,906 / 31	17,846 / 17	102,478
Conifer Open Small (COS)	13,893 / 11	46,287 / 35	43,906 / 34	26,212 / 20	130,442
Hardwood (HDW)	23,744 / 14	62,916 / 36	51,915 / 30	34,746 / 20	173,561
Sapling/Poles (SAPOL)	22,915 / 12	63,140 / 34	61,529 / 33	38,622 / 21	186,430
Forest Vegetation Type / Cover Type					
Douglas-fir (Total) **	71,936 / 14	279,304 / 53	119,517 / 23	54,582 / 11	519,415
CCM	51,120 / 15	181,235 / 55	67,858 / 20	31,603 / 10	331,816
CCS	13,348 / 11	64,166 / 51	32,845 / 26	14,858 / 12	125,217
COM	3,514 / 13	12,550 / 48	7,206 / 27	2,946 / 11	26,216
COS	3,764 / 11	15,120 / 44	10,940 / 32	4,632 / 13	34,457
Gray Pine (Total) **	292 / 7	909 / 22	1,764 / 43	990 / 24	4,056
CCM	8 / 4	79 / 40	56 / 28	41 / 21	184
CCS	67 / 15	114 / 25	148 / 32	116 / 25	444
COM	59 / 7	208 / 26	347 / 44	171 / 22	784
COS	120 / 5	419 / 17	1,169 / 48	660 / 27	2,368
Mixed Conifer (Total) **	48,910 / 11	175,319 / 41	122,811 / 28	83,815 / 19	431,167
CCM	30,146 / 13	107,042 / 46	56,994 / 24	39,317 / 17	233,499
CCS	6,926 / 9	28,356 / 38	22,763 / 31	16,075 / 22	74,120
COM	5,642 / 10	19,913 / 36	18,249 / 33	11,627 / 21	55,431
COS	5,888 / 9	19,439 / 30	23,991 / 37	16,349 / 25	65,667
Fir/High Elevation Conifer (Total) **	16,626 / 12	57,511 / 41	38,124 / 27	26,757 / 19	139,473
CCM	8,457 / 11	32,488 / 42	20,728 / 27	15,519 / 20	77,191
CCS	1,408 / 11	4,867 / 36	3,647 / 27	3,336 / 25	13,257
COM	2,526 / 13	8,678 / 43	5,676 / 28	3,103 / 15	19,984
COS	4,120 / 15	11,309 / 41	7,803 / 28	4,569 / 16	27,800
Deciduous Oak	9,276 / 13	23,142 / 33	21,599 / 31	15,288 / 22	69,318
Live Oak	12,986 / 14	35,108 / 38	27,167 / 29	17,178 / 19	92,548
Mixed Hardwood	1,476 / 13	4,664 / 40	3,149 / 27	2,279 / 20	11,685

* Sum of severity category acres do not equal totals due to unmapped areas within fires.

** Totals include areas of unknown diameter and density in CALVEG.

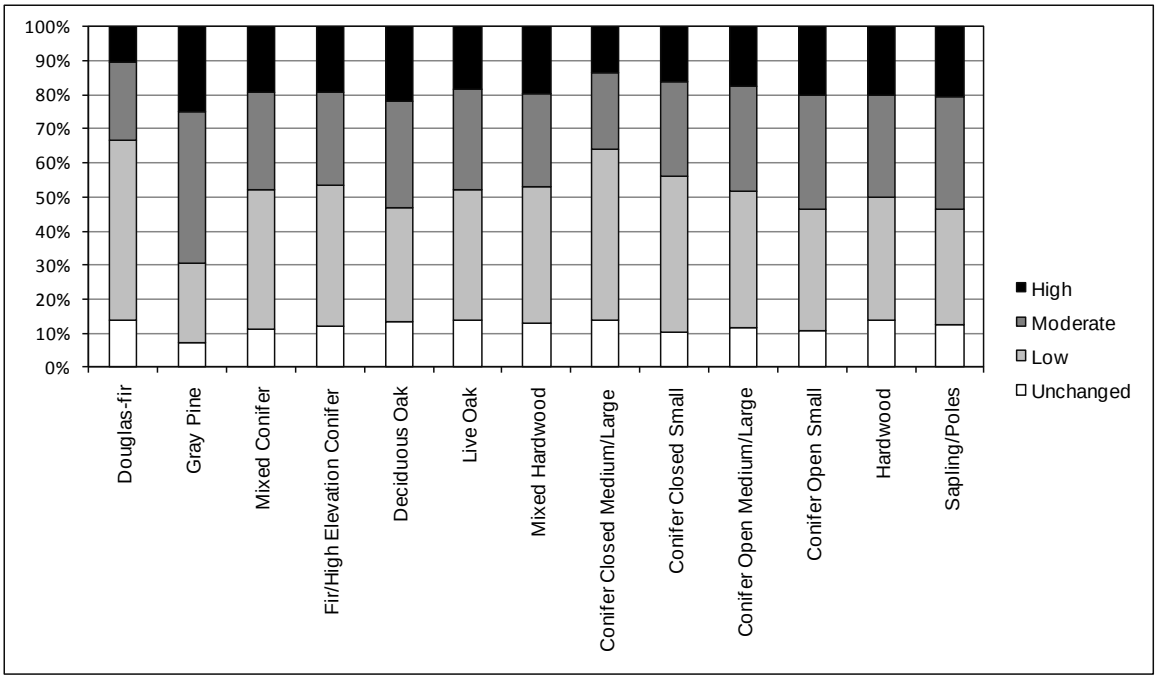

Figure 7. Percent total area burned by CBI severity category for forest vegetation and cover types, fires >1000 acres 1987-2008.

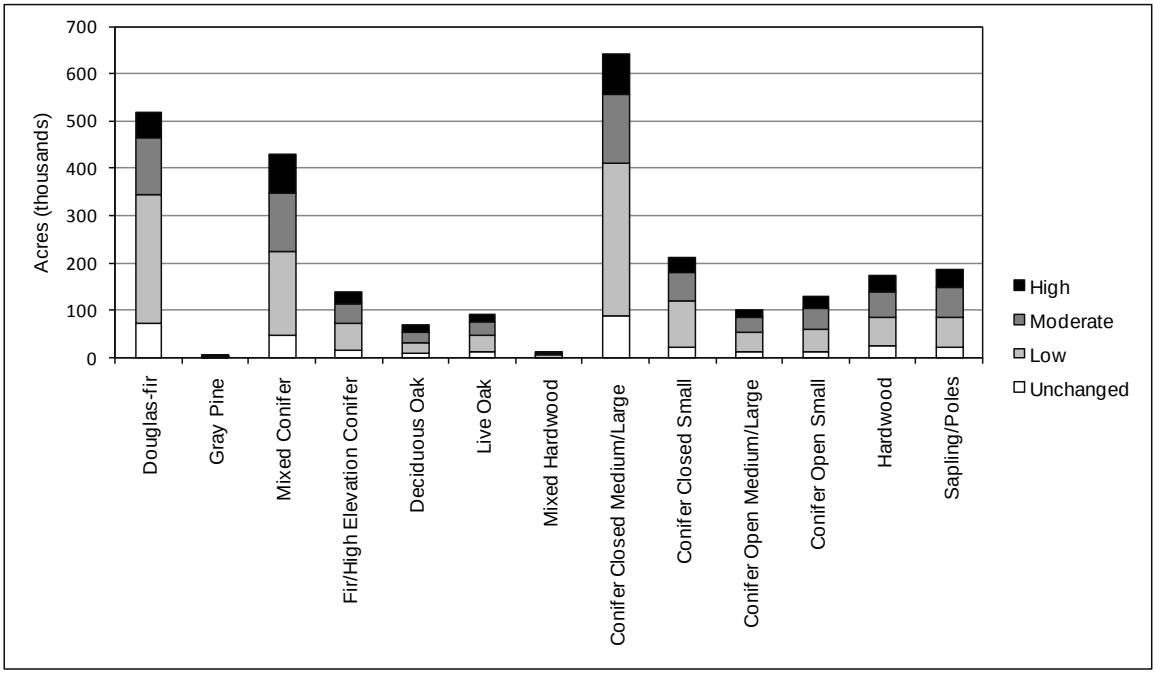

Figure 8. Total area burned by severity category for each forest vegetation and cover type, fires >1000 acres 1987-2008.

Table 6. Number of acres burned by all forest cover and vegetation types, fires >1000 acres 1987-2008.

Vegetation Type	Conifer Closed Medium/Large	Conifer Closed Small	Conifer Open Medium/Large	Conifer Open Small	Unknown*	HDW	Total
Douglas-fir	331,861	125,223	26,231	34,468	1,633		519,415
Gray pine	199	457	789	2,438	174		4,056
Mixed Conifer	233,720	74,194	55,438	65,675	2,139		431,167
Fir/High Elevation Conifer	77,472	13,342	20,021	27,854	785		139,473
Deciduous Oak						69,318	69,318
Live Oak						92,548	92,548
Mixed Hardwood						11,685	11,685
Total	643,251	213,216	102,478	130,435		173,552	1,262,932

* Diameter and density not mapped in CALVEG.

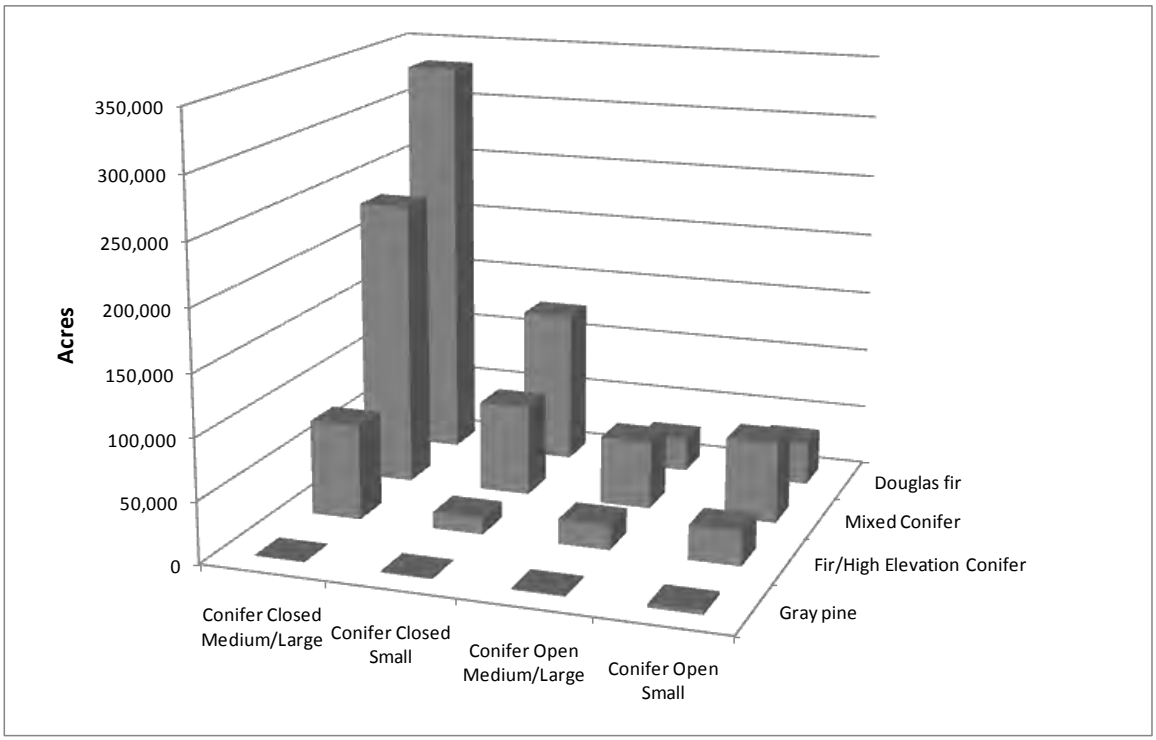

Figure 9. Number of acres burned by conifer cover and vegetation types, fires >1000 acres 1987-2008.

The percentage of high-severity at which a given vegetation type will burn can differ among fire events, in part because of weather conditions. We therefore used an Analysis of Variance (ANOVA) to examine the percentage of high-severity by forest vegetation and cover type per fire. Percentage of high-severity in areas that burned the first time after 1986 differed between the three major conifer types (9, 16, and 19% for Douglas-fir, mixed conifer and fir/high elevation conifers respectively) (Table 7), but there were no differences between types when reburned within 1-30 years (10, 12, and 11%; significance not shown). Among the hardwood types, deciduous oak experienced significantly higher severity than mixed

hardwood the first time burned (13 vs.8%), but was not significantly different from live oak (14%). Stratified by cover type, percentage of high-severity was lower in conifer forests with trees of medium to large diameter (both closed and open classes CCM and COM) than in forests of small diameter tress (classes CCS and COS). Among forest cover types, percentage of high-severity was highest in sapling/poles (SAPOL) at 16%. Percentage of high-severity in hardwoods (HDW) was significantly less than SAPOL, but high-severity may be under-reported for sprouting hardwood types since the severity data were derived from imagery acquired the year after fire. Post-fire sprouting by hardwood species may reduce the apparent severity level by decreasing the difference in live biomass between post- and pre-fire images.

In areas that burned twice during 1910-2008, the percentage of high-severity first time burned and second time burned differed between forest and cover types (Table 7). Douglas-fir (DF) forests that had not experienced fire since at least 1910 (the beginning of our fire occurrence dataset) but then burned after 1986 (i.e., during the period for which we have severity data, 1987-2008), did so at an average of 9% high-severity. In areas where we had record of a previous fire in DF before 1987, a second fire occurring between 1987 and 2008 tended to burn at similar levels of high-severity (10%) if the fire occurred within 30 years of the first fire. Second burns occurring in DF more than 30 years after the initial fire were significantly less severe however (5% for both 31-60 years and >60 years). In contrast, percentage of high-severity the second time mixed conifer (MC), fir/high elevation conifers (FIR), and the closed conifer cover types (CCM and CCS) burned was generally less than the first time burned regardless of interval between first and second time burned. The exceptions were MC and CCS at intervals of 61-98 years between fires (MC was close to significant at $P = 0.053$), and FIR at the 31-60 year interval (due to the small amount of area burned). Although there was generally a significant difference between first and second time burned, there were no differences between any of the second time burned intervals for MC or FIR (significance not shown). For CCM the percentage of high-severity for the 61-98 year interval was less than the 1-30 year interval (7 vs. 10% respectively, significance not shown). Percent high-severity the first time burned for any hardwood type was not significantly different than any interval the second time burned, except for the mixed hardwood (MH) 31-60 year interval, which is likely not reliable due to the small area.

There were differences in percentage of high-severity between the three major forest vegetation types when stratified by cover type (Table 8). For closed forests (CCM and CCS), DF showed no significant difference between first time burned and second time burned within 1-30 years. However, MC and FIR closed forests burned with a significantly lower percentage of high-severity the second time burned (within 1-30 years) than the first time burned. Results were less clear for open forests, with only two of the six comparisons (MC small and FIR medium/large) having a significantly lower percentage of high-severity when burned a second time, compared to the first. The reliability of the statistical tests for the open forest and FIR CCS types is limited due to the small number of acres burned. Similarly, differences between types when burned a second time were not tested due to the small number of acres.

Two factors should be considered when interpreting the reburn analysis in this report. We do not know the severity in fires prior to 1987, nor did we track the history of individual sites and therefore did not determine how severity in prior fires altered forest structure, thereby affecting severity in subsequent fires. We have confidence that areas mapped as CCM in our pre-fire maps were forested for the entire time period. These areas were most likely not altered by severe fire or they would not have retained the CCM state in the pre-fire maps. The degree and time frame within which other areas may have been altered is unknown. For example, areas classed as Sapling/poles (SAPOL) obviously did not retain that type throughout the full 1910-2008 period. Instead, they represent areas that either burned at high-severity the first time they burned (possibly prior to 1987) and then were planted or re-established from seed before burning a second time, or were harvested and planted prior to burning.

Table 7. Total number of acres (ac) burned, analysis of variance (ANOVA) estimates and standard errors for percentage of high-severity by fire for forest vegetation and cover types for all fires >400 ha 1987-2008. For areas that burned twice during the 1910 to 2008 period and the second time within the 1987 to 2008 period that fire severity data is available for, the data are broken down into different intervals between the first and the second burn. Less than 4% of the study area burned three or more times during the 1910 to 2008 period; data for more than two burns is therefore not shown.

Type	All fires (ac / Est^2 / SE)	All first time burned† (ac / Est^2 / SE)	All first time burned Significantly different ‡	2nd time burned 1910-2008 (ac / Est^2 / SE)		
				Interval between 1st and 2nd time burned ‖		
				1-30 yr	31-60 yr	61-98 yr
Forest Vegetation Type						
Douglas-fir (DF)	513,739 / 9 / 0.15	381,448 / 9 / 0.15	GP, *MC, FIR, DO, LO*	54,752 / 10 / 0.19	19,241 / ***5*** / 0.24	24,497 / ***5*** / 0.22
Gray Pine (GP)	3,830 / 14 / 0.44	3,071 / 17 / 0.49	DF, MH	5 / **1**§ / 1.95	240 / 8 / 1.37	447 / 8 / 1.23
Mixed Conifer (MC)	424,855 / 15 / 0.16	345,634 / 16 / 0.16	*DF, FIR, LO*, MH	24,028 / **12** / 0.31	13,603 / **12** / 1.30	17,969 / 13 / 0.38
Fir/High Elevation Conifer (FIR)	137,084 / 18 / 0.15	116,116 / 19 / 0.15	*DF, MC, DO, LO, MH*	8,708 / **11** / 0.22	395 / 10 / 0.27	5,325 / **9** / 0.24
Deciduous Oak (DO)	68,520 / 14 / 0.17	60,376 / 13 / 0.18	*DF, FIR*, MH	2,100 / 12 / 0.59	2,911 / 12 / 0.50	1,932 / 14 / 0.61
Live Oak (LO)	91,804 / 14 / 0.17	65,659 / 14 / 0.17	*DF, MC, FIR*	6,457 / 8 / 0.35	7,529 / 11 / 0.33	5,100 / 9 / 0.39
Mixed Hardwood (MH)	11,490 / 11 / 0.28	6,738 / 8 / 0.35	GP, MC, *FIR*, DO	719 / 12 / 0.97	1,087 / ***27*** / 0.80	1,893 / 5 / 0.61
Forest Cover Type						
Conifer Closed Medium/Large (CCM)	638,270 / 12 / 0.15	499,998 / 13 / 0.15	CCS, COS, *SAPOL*	47,368 / **10** / 0.18	17,504 / ***8*** / 0.23	29,565 / ***7*** / 0.20
Conifer Closed Small (CCS)	211,139 / 14 / 0.15	153,054 / 15 / 0.16	CCM, COM	23,358 / ***10*** / 0.22	10,680 / ***7*** / 0.28	11,769 / 12 / 0.27
Conifer Open Medium/Large (COM)	101,329 / 12 / 0.16	83,998 / 13 / 0.17	CCS, COS, SAPOL	8,750 / 14 / 0.30	1,873 / **6** / 0.58	3,106 / 10 / 0.46
Conifer Open Small (COS)	128,769 / 14 / 0.16	109,229 / 14 / 0.16	CCM, COM	8,013 / 13 / 0.31	3,425 / 9 / 0.44	3,798 / 14 / 0.42
Hardwood (HDW)	171,814 / 14 / 0.15	132,777 / 14 / 0.16	SAPOL	9,278 / 12 / 0.29	11,527 / 13 / 0.27	8,925 / 11 / 0.30
Sapling/Poles (SAPOL)	184,045 / 16 / 0.15	125,142 / 16 / 0.16	*CCM*, COM, HDW	25,730 / 13 / 0.21	12,135 / **11** / 0.27	7,971 / 16 / 0.31

† First time an area burned after 1910 regardless of the number of times the area burned; does not include areas that burned before 1987.

‡ Differences of least squares means, t-test, α = 0.05; $P_{adj} < 0.05$

§ Estimate not significant at P < 0.05

‖ Bold indicates significantly different from "All first time burned"; differences of least squares means, α = 0.05, *P* < 0.05; when italicized *P* values are significant using a Tukey-Kramer adjustment.

Note: Estimates displayed are squared since the data were square-root transformed before running the ANOVA. Bold indicates significantly different from "All first time burned" (differences of least squares means; P < 0.05)

Table 8. Total number of hectares (ha) burned, analysis of variance (ANOVA) estimates and standard errors for percentage of high-severity by fire for forest vegetation type stratified by cover type for all fires >400 ha 1987-2008. For areas that burned twice during the 1910 to 2008 period and the second time within the 1987 to 2008 period that fire severity data are available for, the data are displayed for when the interval between the first and the second burn was less than 30yrs.

Forest Vegetation Type — Cover Type	All first time burned† (ac / % / SE)	All first time burned significantly different ‡	2nd time burned within 1-30yrs ‖ (ac / % / SE)
Douglas-fir (DF)			
Conifer Closed Medium/Large (CCM)	246,901 / 8 / 0.16	DFccs, *MCccm, MCccs, MCcom, MCcos, FIRccm, FIRccs, FIRcom, FIRcos*	31,574 / 8 / 0.20
Conifer Closed Small (CCS)	83,267 / 10 / 0.17	DFccm, DFcom, *MCccm, MCccs, MCcom, MCcos, FIRccm, FIRccs, FIRcom, FIRcos*	18,559 / 8 / 0.22
Conifer Open Medium/Large (COM)	21,994 / 8 / 0.21	DFccs, *MCccm, MCccs, MCcom, MCcos, FIRccm, FIRccs, FIRcom, FIRcos*	2,199 / 13 / 0.46
Conifer Open Small (COS)	29,286 / 9 / 0.19	*MCccm, MCccs, MCcom, MCcos, FIRccm, FIRccs, FIRcom, FIRcos*	2,422 / 11 / 0.44
Mixed Conifer (MC)			
Conifer Closed Medium/Large (CCM)	187,329 / 15 / 0.16	*DFccm, DFccs, DFcom, DFcos,* MCccs, MCcos, *FIRccm, FIRccs*	12,095 / **10** / 0.24
Conifer Closed Small (CCS)	58,871 / 17 / 0.17	*DFccm, DFccs, DFcom, DFcos,* MCccm, MCcom, *FIRccm, FIRccs*	3,897 / **11** / 0.36
Conifer Open Medium/Large (COM)	45,604 / 14 / 0.18	*DFccm, DFccs, DFcom, DFcos,* MCccs, MCcos, *FIRccm, FIRccs, FIRcom*	4,151 / 15 / 0.35
Conifer Open Small (COS)	53,830 / 17 / 0.18	*DFccm, DFccs, DFcom, DFcos, MCccm, MCcom,* FIRccs	3,884 / **12** / 0.36
Fir/High Elevation Conifer (FIR)			
Conifer Closed Medium/Large (CCM)	65,609 / 19 / 0.17	*DFccm, DFccs, DFcom, DFcos, MCccm, MCccs, MCcom,* FIRcos	3,699 / ***6*** / 0.39
Conifer Closed Small (CCS)	10,563 / 23 / 0.25	*DFccm, DFccs, DFcom, DFcos, MCccm,* MCccs, *MCcom,* MCcos, FIRcom, FIRcos	902 / **6** / 0.70
Conifer Open Medium/Large (COM)	15,792 / 17 / 0.22	*DFccm, DFccs, DFcom, DFcos,* MCcom, FIRccs	2,399 / **10** / 0.44
Conifer Open Small (COS)	24,154 / 16 / 0.20	*DFccm, DFccs, DFcom, DFcos,* FIRccm, FIRccs	1,707 / 15 / 0.51

† First time an area burned after 1910; does not include areas that burned before 1987.

‡ Differences of least squares means, α = 0.05, P < 0.05; when italicized P values are significant using the Tukey-Kramer adjustment

‖ Bold indicates significantly different from "All first time burned"; differences of least squares means, α = 0.05, P < 0.05; when italicized P values are significant using a Tukey-Kramer adjustment.

Note: Estimates displayed are squared since the data were square-root transformed before running the ANOVA.

Trend Analysis

Seven fire regime attributes that contribute in fundamental ways to ecosystem function are seasonality, fire return interval, fire size, spatial complexity, fireline intensity, fire type and fire severity (Sugihara et al. 2006). Most analyses of fire regimes in the past have concentrated on characterizing fire size through fire perimeter data, fire return interval through tree ring analysis of fire scared trees, and fire type by examining stand age. The severity atlas produced for this report provides the means for evaluating severity and spatial complexity at the landscape level. We examined the trend in percent high-severity acres and high-severity patch size from 1987 through 2008. We also examined trends from 1910 through 2008 in number of fires and fire size using the Pacific Southwest Region fire history database.

Because of high interannual variability in most of these datasets, we portray results using an eleven-year running mean of the annual data for graphic depiction of the decadal trend. The running means smooth the annual data and remove the effects of cyclical and seasonal variability (Porkess 1991). In our discussion, we use eleven-year running means to compare average values at the beginning and end of the analysis period. All statistical significance reported in the discussion is based on regression analysis of the raw data.

Severity by Vegetation and Cover Type

We examined the trend in percent high-severity acres by cover and vegetation types from 1987 through 2008. Common linear regression analyses of time series datasets are often inappropriate for trend analysis of ecological variables since errors about the regression line can be autocorrelated (Edwards and Coull 1987). We therefore used Autoregressive Integrated Moving Average (ARIMA) techniques that have been used in previous studies of trends in fire effects (e.g., Stephens 2005, Miller et al. 2009b) to calculate trends in the percent of fire area burning at high-severity per year and high-severity patch size over the 1987-2008 period. We square root transformed all percent severity data and log transformed all area data to meet statistical assumptions of normality, and therefore the models appear curvi-linear in the figures.

Regardless of cover or vegetation type stratification, there were no clear trends in percentage of high-severity. Time series regression modeling was unable to produce a model significant at $P = 0.05$ without inclusion of a quadratic component. After adding a quadratic component, three models were significant: CCS, All Forest, and All Conifer (Table 9). The All Forest model is typical of models with quadratic components where the modeled trend is convex, e.g. there is a lower percentage of high-severity fire at the beginning and end of the time period (Figure 10). The four years during 1910-2008 when the most area burned were 1987, 1999, 2006 and 2008, all of which are included in our fire severity dataset and the largest of which bracket the period of the severity dataset. In each of the four years, large fires were primarily caused by widespread lightning events and average percentage of high-severity in forested areas was inversely related to total forested area burned per year ($r^2 = 0.240$, $P = 0.039$). Overall fire severities

were relatively low during these four high fire activity years due to moderate meteorological conditions and many of the fires burned into the fall. As a result, time series models that were statistically significant included quadratic components with low values of severity at the beginning and end of the time series. It is possible that the coincidental timing of our severity dataset with the two years with the most area burned in the century precluded detecting any underlying trend in percentage of high-severity. For example, removing 1987 and 2008 from the time series analysis results in a significant decreasing linear trend without a quadratic component for All Forest ($R^2 = 0.557$, $P = 0.046$) because 1999 and 2006, the other two years with widespread lightning ignitions, occur in the latter half of the time series. These results underscore how wide-spread lightning events were a primary influence on severity over the 22 year period of the severity data.

Table 9. Percent severity 1987-2008 time series regression results

Parameter	Conifer Closed Small (CCS)	All forest*	All conifer**	Conifer mean patch size
N	18	18	18	18
dfe	12	12	12	16
Parameter estimates				
Sigma-sq	1.018	0.719	0.004	0.436
Intercept	-30.229	-23.029	-1.933	3.935
Linear	-1.790	-1.422	-0.115	-0.052
Quadratic	-0.022	-0.018	-0.001	
AR1	-0.159	-0.201	-0.254	
AR2	-0.270	-0.296	-0.313	
AR3	-0.674	-0.691	-0.729	
P (linear)	0.001	0.001	0.000	0.042
P (quadratic)	0.001	0.001	0.000	
P (AR1)	0.441	0.379	0.223	
P (AR2)	0.133	0.107	0.078	
P (AR3)	0.003	0.003	0.001	
Statistics of fit				
Mean square error (MSE)	34.630	23.959	0.140	9.094
Root mean square error (RMSE)	0.913	0.792	0.061	0.622
Mean absolute % error (MAPE)	14.296	13.592	15.297	16.473
Mean absolute error (MAE)	0.691	0.650	0.047	0.511
R-SQ	0.567	0.529	0.528	0.233
adj R-SQ	0.386	0.333	0.331	0.185
Akaike Information Criterion	8.715	3.588	-88.939	-13.069
Schwarz Baysian Info Criterion (SBC)	14.057	8.930	-83.597	-11.288

* All Forest includes hardwood and conifer cover types, excluding sapling/poles.

** All Conifer includes only conifer cover types, excluding sapling/poles.

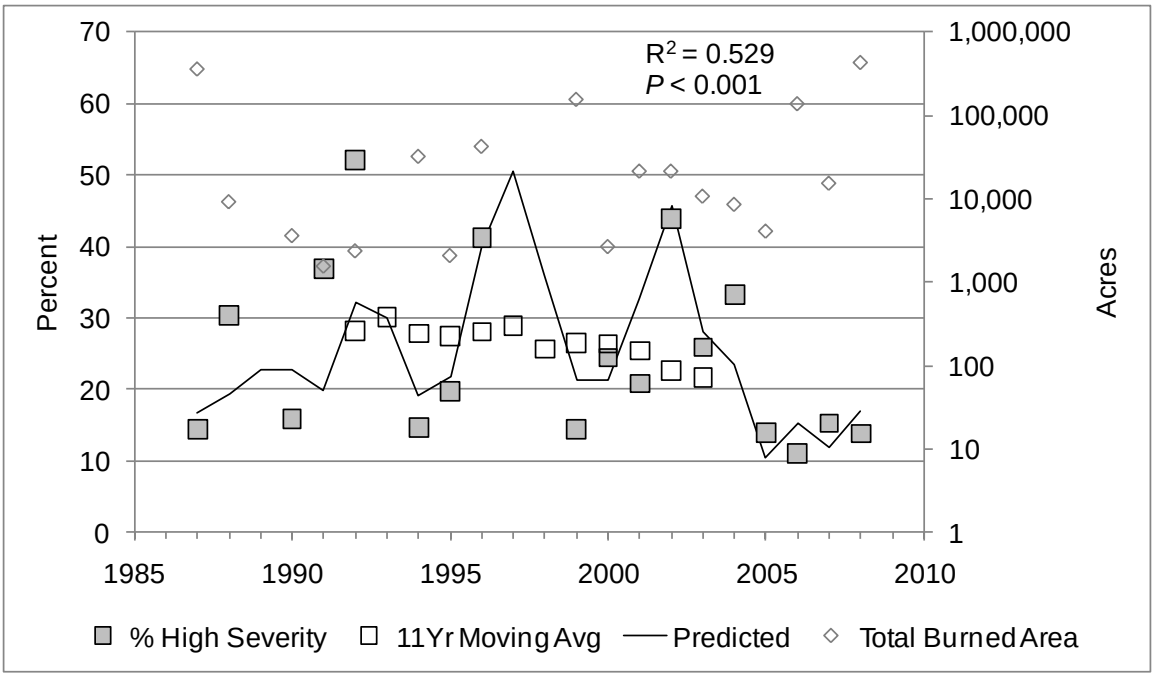

Figure 10. Temporal trend in percent area burned at high-severity for all forest types combined 1987-2008 with the best-fit regression function, 11-yr moving average for % high-severity, and burned area mapped (right-hand Y-axis). Pictured *P* value refers to the linear trend. The data were best fit by a 3rd order autoregressive function and quadratic, $P_{(AR3)}$ = 0.001, adj. R^2 = 0.331.

High-Severity Conifer Patch Size

Fire frequency and size have long been the preferred quantitative measures of fire patterns (e.g., McKelvey and Busse 1996), since they are easy to determine from suppression perimeters. However, similar to fires in the Sierra Nevada, the percentage of high-severity acres in the 1987-2008 mapped fires only correlates weakly with fire size (Figure 11; Miller and Safford 2008).

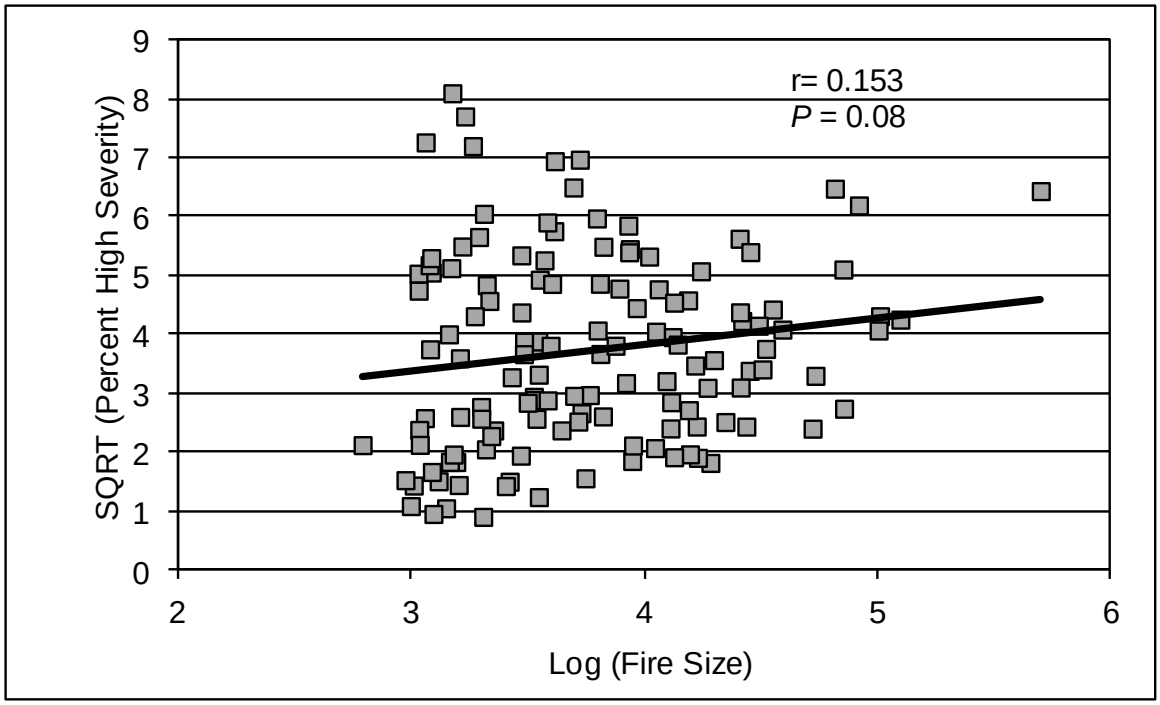

Figure 11. Percent high-severity vs. fire size for 1987-2008 mapped fires. All acres in each fire were included. Percent high-severity data were square root transformed and area data log transformed before computing the regression to meet normality assumptions.

Fire size alone is most likely not the fire regime variable of most concern. All regime variables are interrelated and fully understanding how fire affects ecosystems can only be accomplished by examining as many regime variables as possible (Sugihara et al. 2006). Severity may be the variable that bests describes fire effects to the biological and physical components of the ecosystem, but fire size and frequency are also critical to spatiotemporal vegetation patch dynamics, which can have very important influences on plant propagule flow, sedimentation, habitat availability, animal migration, etc.

High-severity patch size is probably a metric of more concern to post-fire recovery since patch size and severity control the number of surviving individuals and distance to seed sources, which in turn influences succession processes (Pickett and White 1985, Turner et al. 1998). By most accounts, before Euroamerican arrival fires in most conifer forests in NW California were not typified by large patches of high-severity fire (Sudworth 1900, Sugihara et al. 2006). However as shown in Figure 12, the size of the maximum high-severity patch in conifer forests was fairly well correlated with fire size for the fires 1987-2008, once again similar to the Sierra Nevada (Miller and Safford 2008).

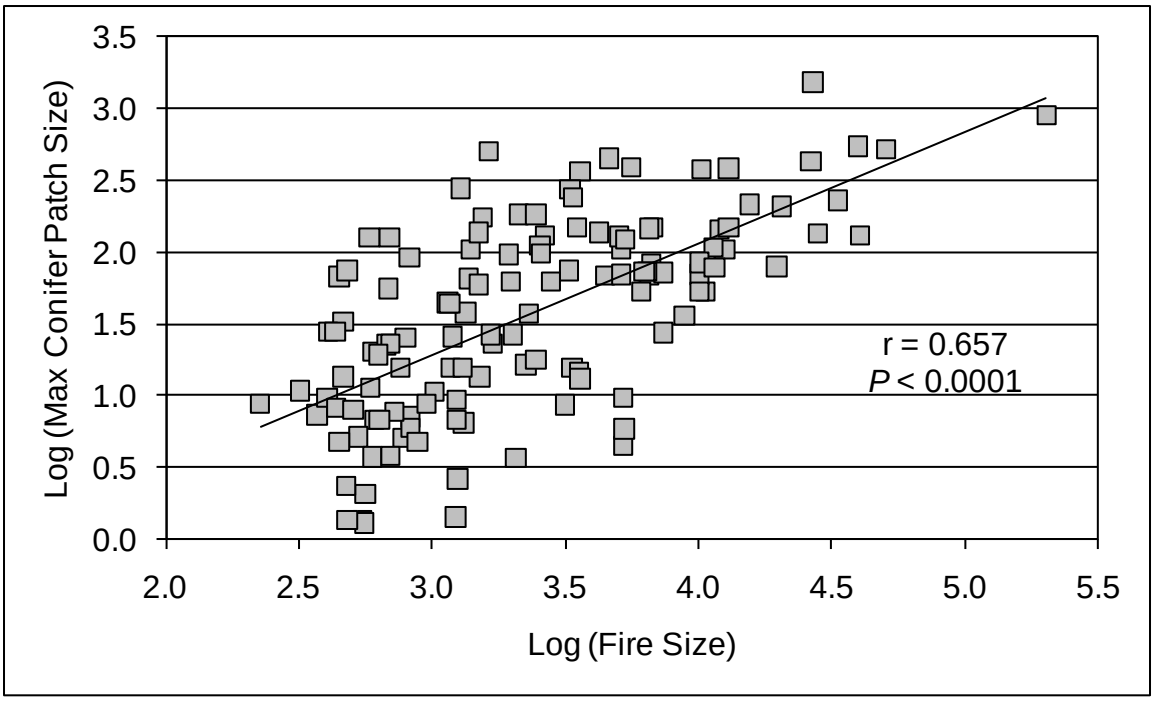

Figure 12. Maximum high-severity conifer patch size on U.S. Forest Service administered lands from each mapped fire vs. fire size. Both axes are Log transformed.

We examined the mean and mean maximum patch size by year for high-severity patches in conifer forests in fires from 1987-2008 (Figure 13). Only conifer forest on U.S. Forest Service administered lands was included in the analysis. Patches less than 900 m^2 were eliminated from the analysis since our minimum mapping unit was the Landsat 30m pixel size. ARIMA time series analysis found no autoregressive terms. We therefore report only linear regression results. Contrary to high-severity patches in the Sierra Nevada, which have increased in size, the average size of contiguous areas ("patches") of stand-replacing fire within conifer forest fires decreased by about 30% across the period of analysis, falling from a mean of about 34 acres in the first eleven-year period to about 24 acres in the last period. The mean maximum high-severity patch size remained relatively constant over the period at about 270 ac.

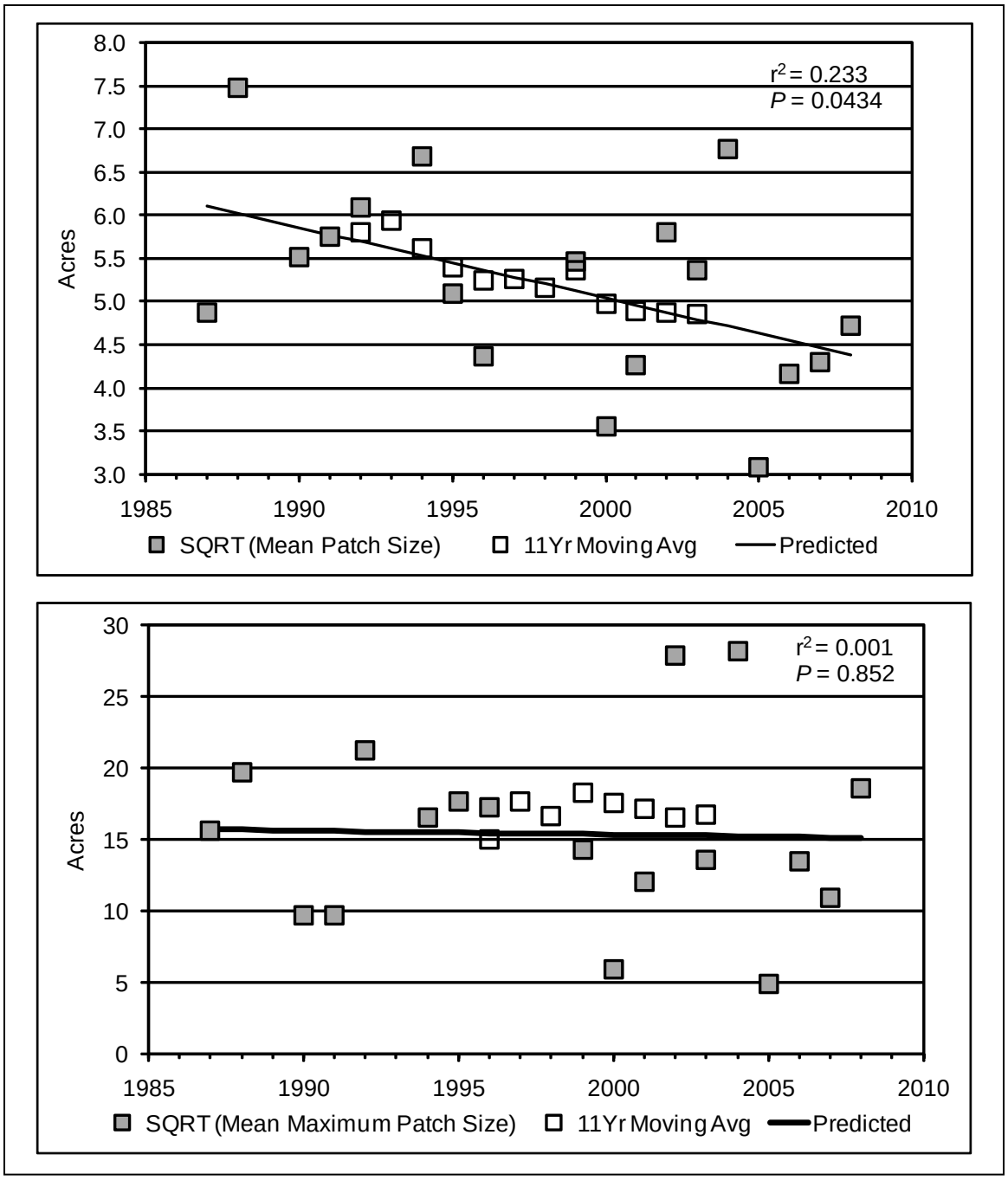

Figure 13. Mean and mean maximum high-severity conifer patch size on U.S. Forest Service administered lands in the 1987-2008 fires. Patch size data were square-root transformed before computing the regression. Pictured *P* value refers to the linear trend.

Fire Size, Number of Fires and Total Area Burned 1910 - 2008

Since our capability to directly measure percent high-severity and high-severity patch size for past fires is tied to the launch date of the first Landsat TM satellite, we are currently unable to examine longer term trends in severity, but we can examine longer trends in fire size and burned area. The most comprehensive data on fire activity available since the beginning of the settlement era are historical fire records kept by the land management agencies. Fortunately California has one of the best and most complete fire history databases in the U.S., with the earliest records dating from before the 20th century.

We used the California fire history database jointly maintained by the California Department of Forestry, U.S. Forest Service, and National Park Service to examine trends in number of fires and fire size. There are known problems with the database, such as some fire size inaccuracies and many fires less than 10 acres are not included. However, the number of fires over 100 acres and sizes of the largest fires are most likely accurate enough for a trend analysis. We began our trends analyses in 1910, the first year of a fire recorded for the study area, and we restricted our analyses to fires greater than 100 acres, as small fires tend to be under-reported in the database (McKelvey et al. 1996) and we were only interested in analyzing fires that exceed initial attack capability. We analyzed all fires greater than 100 acres in size that intersected the four NW California Forests during 1910-2008, which totaled 947. We use the FIRESTAT database to compare against results from the fire perimeter data to provide insight into fires cause, e.g. human vs. lightning ignitions. FIRESTAT contains records entered by the Forests of all ignitions regardless of fire size, but only contains data since 1970 for NW California, a total of 18,391 fire occurrences.

Figure 14 shows the number of fires per year for the study area from 1910 through 2008. The eleven year running average used to smooth the data clearly indicates a peak in the number of fires around 1920. There were significantly fewer fires between the early 1940s and early 1970s. Since the 1980s the number of fires has been increasing. While more than one factor may have contributed to the 30 years of relatively few large fires, the advent of modern fire fighting suppression techniques after the Second World War, including smokejumpers, air tankers, and a military styled fire suppression organization, most likely contributed to the reduction in the number of large fires (Pyne 1982). Running averages of total area burned, mean and maximum fire size all increased notably after the mid 1980s after remaining more or less unchanged for the previous seven decades (Figure 15).

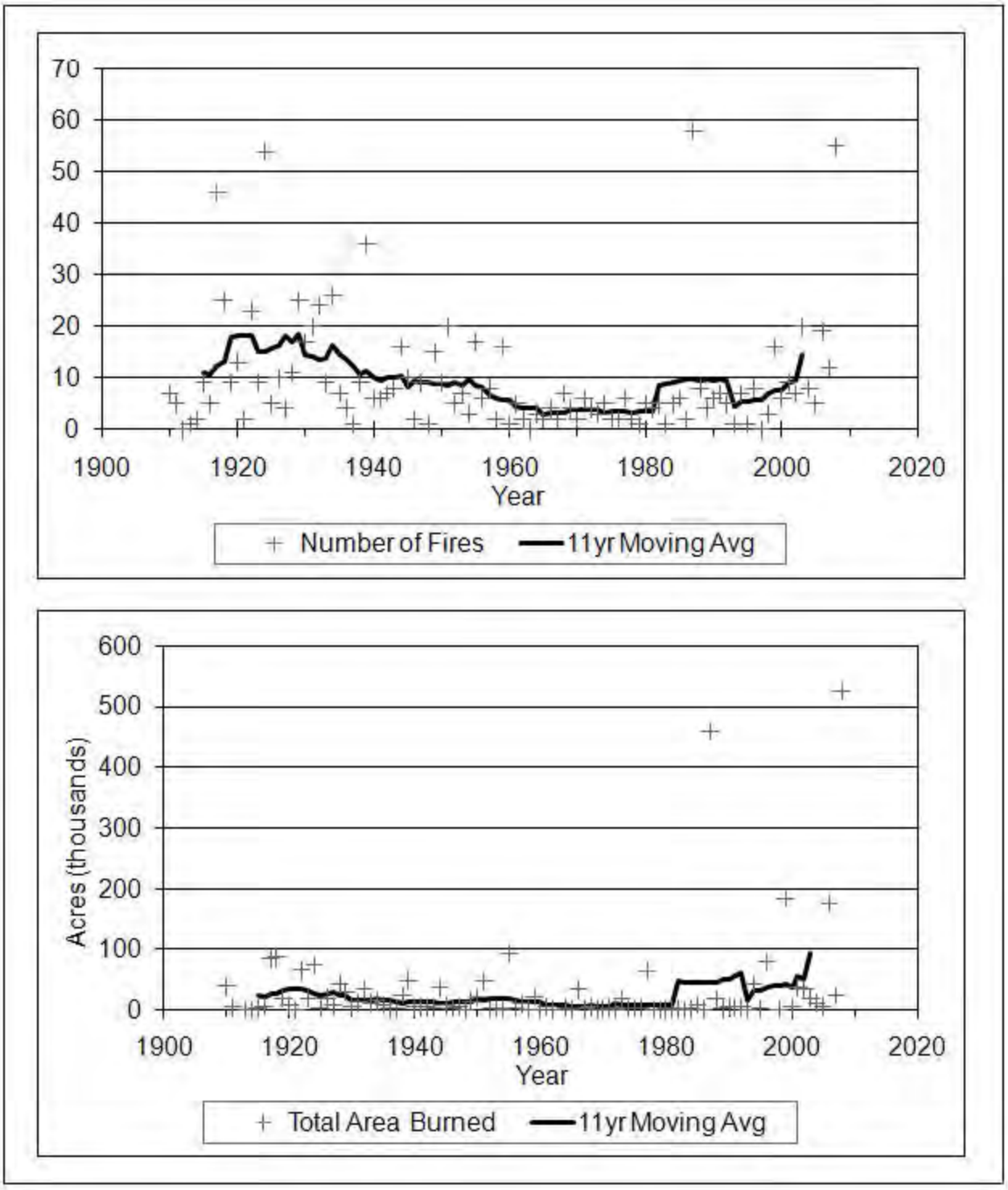

Figure 14. Number and total area of fires greater than 100 acres per year 1910-2008 for the four NW California Forests. Eleven year moving average is displayed only for visual comparison.

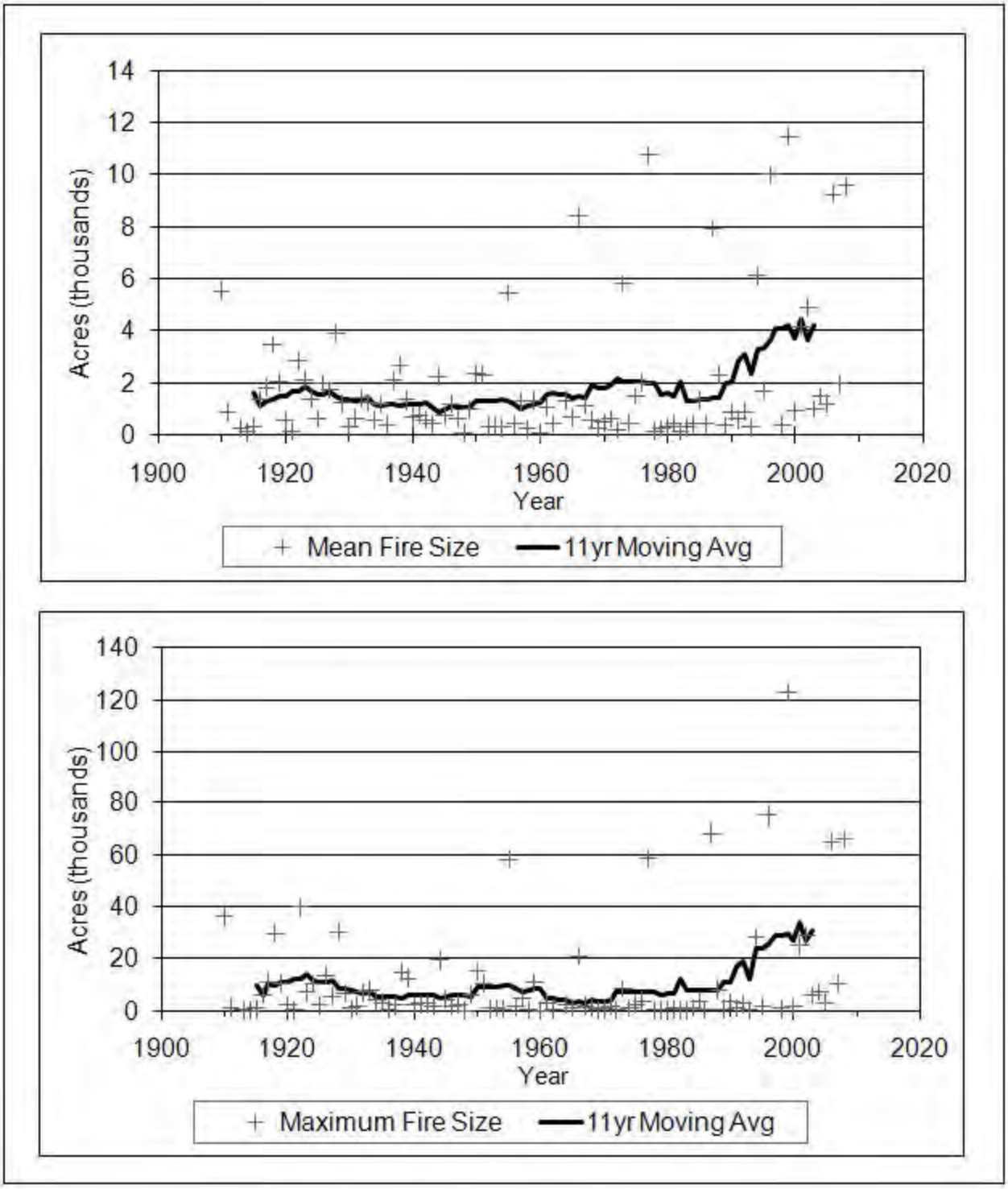

Figure 15. Mean and maximum fire size per year 1910-2008 for the four NW California Forests. Eleven year moving average is displayed only for visual comparison.

When examining trends in fire occurrences, ARIMA time series analysis found significant autoregressive terms only for all human ignitions. We therefore report linear regression results. Regardless, whether

using the fire perimeter data or occurrence data from FIRESTAT, analysis for fires since 1970 shows that number of fires >100 acres, maximum fire size and total area burned per year all increased significantly during the 1970-2008 period (r^2 = 0.106 to 0.210, all $P < 0.05$). An increase in mean fire size was found to be significant using the fire perimeters (r^2 = 0.107, P = 0.042) but was not significant using the FIRESTAT data. The number of lightning ignitions resulting in fires larger >100 acres increased (r^2 = 0.185, P = 0.006), but the total number of lightning ignitions remained constant. Conversely, the total number of human ignitions fell (r^2 = 0.265, P <0.001), while the number of human ignitions resulting in fires >100 acres remained constant.

Fire Rotation 1910 - 2008

"Fire rotation" is defined as the length of time necessary to burn an area equal to the area of interest (or in this case, our study area) and is calculated by dividing the time period of interest by the proportion of the study area burned in that time period (Heinselman 1973). In spatial analyses, fire rotation is a better descriptor of fire frequency than is fire return interval (Agee 1993). We calculated fire rotation for forested areas in our study region for the period 1910-2008 using a 25-yr moving window in order to allow comparison of landscape-level fire frequencies over the last century with published estimates from the pre-Euroamerican settlement period. Since we do not have pre-fire vegetation maps for fires before 1987, we used percentage of forested area within fires 1987-2008 as an estimate of forested area within fires prior to 1987. For this analysis, we define forested areas as all areas consisting of either conifer or hardwood vegetation types.

Approximately one third of the study area burned between 1910 and 2008 (Figure 16). Excluding water and barren areas, 33.5% burned at least once, 6.7% at least twice, and 1.3% three or more times. Fire rotation in forested areas in 1934, at the end of the first 25-yr interval, was 267 years and rotation steadily increased to a peak value of 974 years in 1984 (Figure 17). Rotation values fell to 256 years in 1987, the year with the second most area burned (Figure 14) and continued to fall to 95 years in 2008, the year with the most area burned. The 95-yr interval is between 3.7 and 6.3 times longer than the estimated mean pre-settlement rotations (15-26 years) for forests in NW California (Taylor and Skinner 1998, 2003). The rotation period for high-severity fire is somewhat more difficult to assess because high-severity fire tends to occur more often in some locations than others (Taylor and Skinner 1998), and therefore the expected rotation would be dependent upon geographic location. However, calculating high-severity rotation by dividing rotation period for all fire in forested areas by percentage high-severity measured 1987-2008 as a first order estimate (= 95/0.25), current rotation for high-severity fire over the last 25-year period for the entire study region (i.e., ignoring important geographic variability) would be somewhere between 350 and 400 years. We urge caution in interpretation of this number. Obviously, the temporal trend in high-severity rotation would follow the same decreasing trajectory as the overall fire rotation.

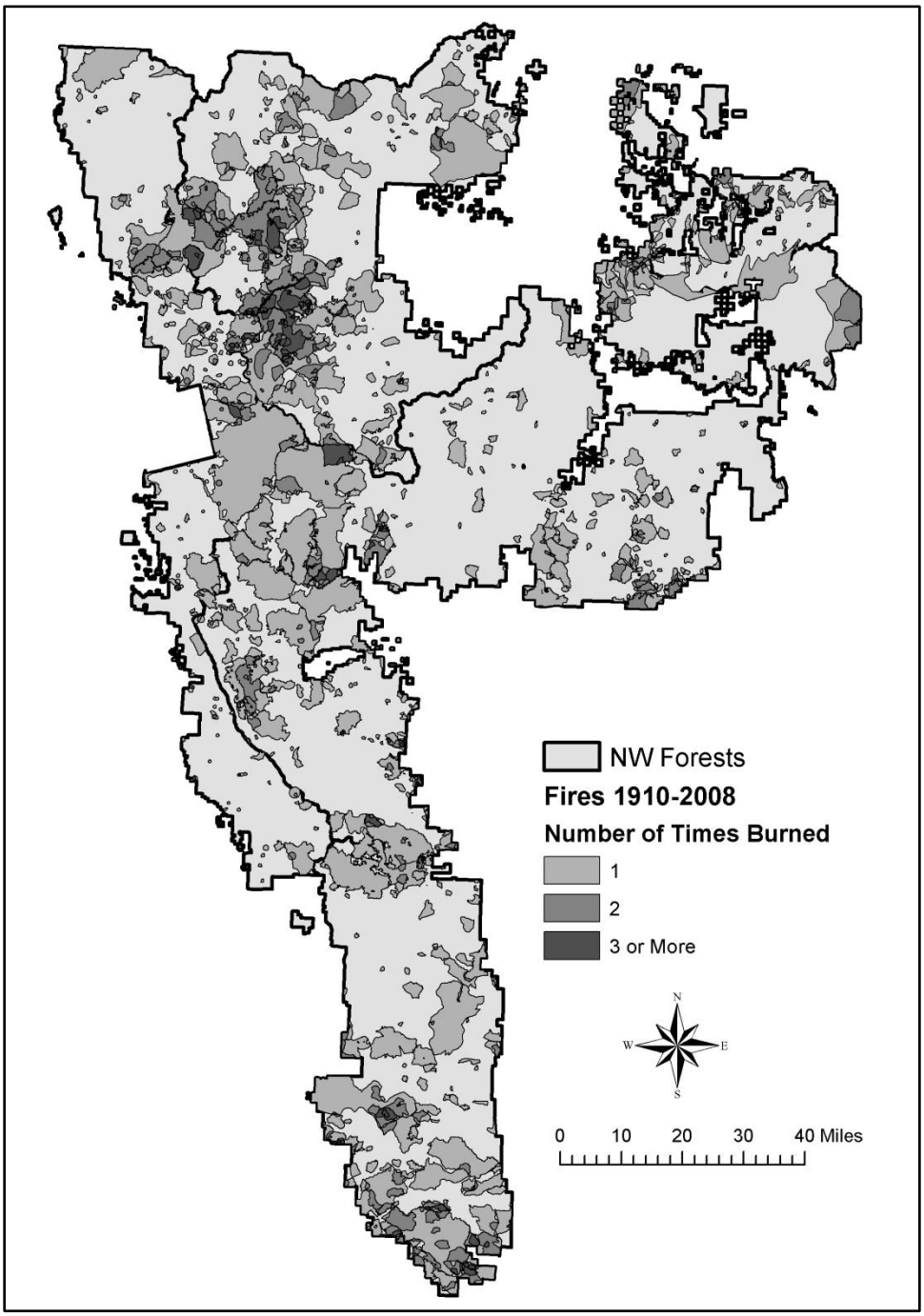

Figure 16. Number of times areas have burned 1910-2008. Derived from fire perimeters for fires larger than 100 acres, 33.5% of the study area burned at least once, 6.7% at least twice, and 1.3% three or more times.

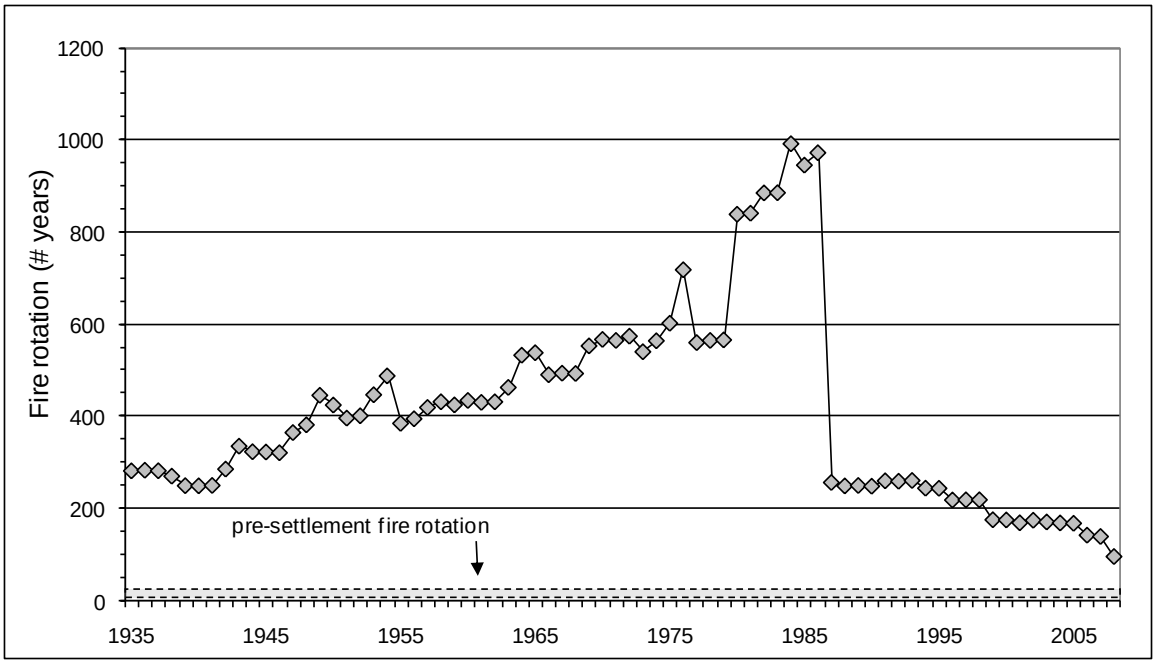

Figure 17. Fire rotation for forested areas, 1910-2008. Values are calculated for the sum of Forest area burned during the prior 25 years. For example, the point at year 2000 represents the fire rotation calculated for the entire period 1976-2000. The dotted lines represent range of pre-settlement fire rotation for northwestern California forests (Taylor and Skinner 1998, 2003).

Ignition Source 1970 - 2008

Regression analysis of ignition source from all ignitions in the FIRESTAT database over the 1970-2008 period shows that the number of human ignitions fell from an average of 235 to 187 ignitions year^{-1} (Figure 18). The number of lightning ignitions was highly variable and displayed no statistical trend, with the 11-year average ranging between 193 and 362 ignitions year^{-1}. However, the number of fires > 100 acres resulting from human ignitions remained fairly constant at about 3.5 fires year^{-1}while the number of fires > 100 acres due to lightning significantly increased, averaging from less than 1 to more than 9 fires year^{-1} (**Figure 19**).

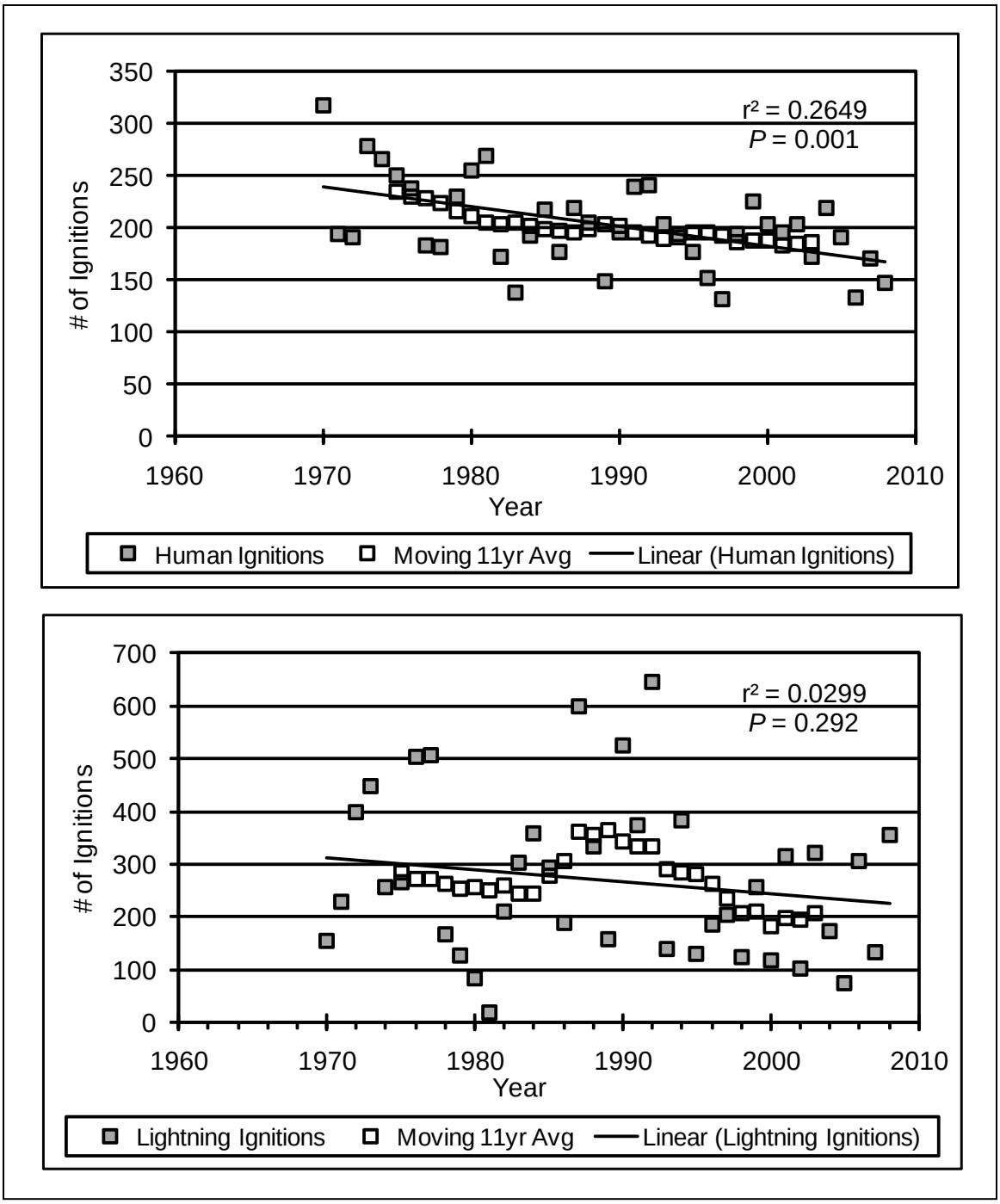

Figure 18. Number of ignitions, regardless of fire size, due to ignition source (human or lightning). Moving 11yr averages only shown for display purposes.

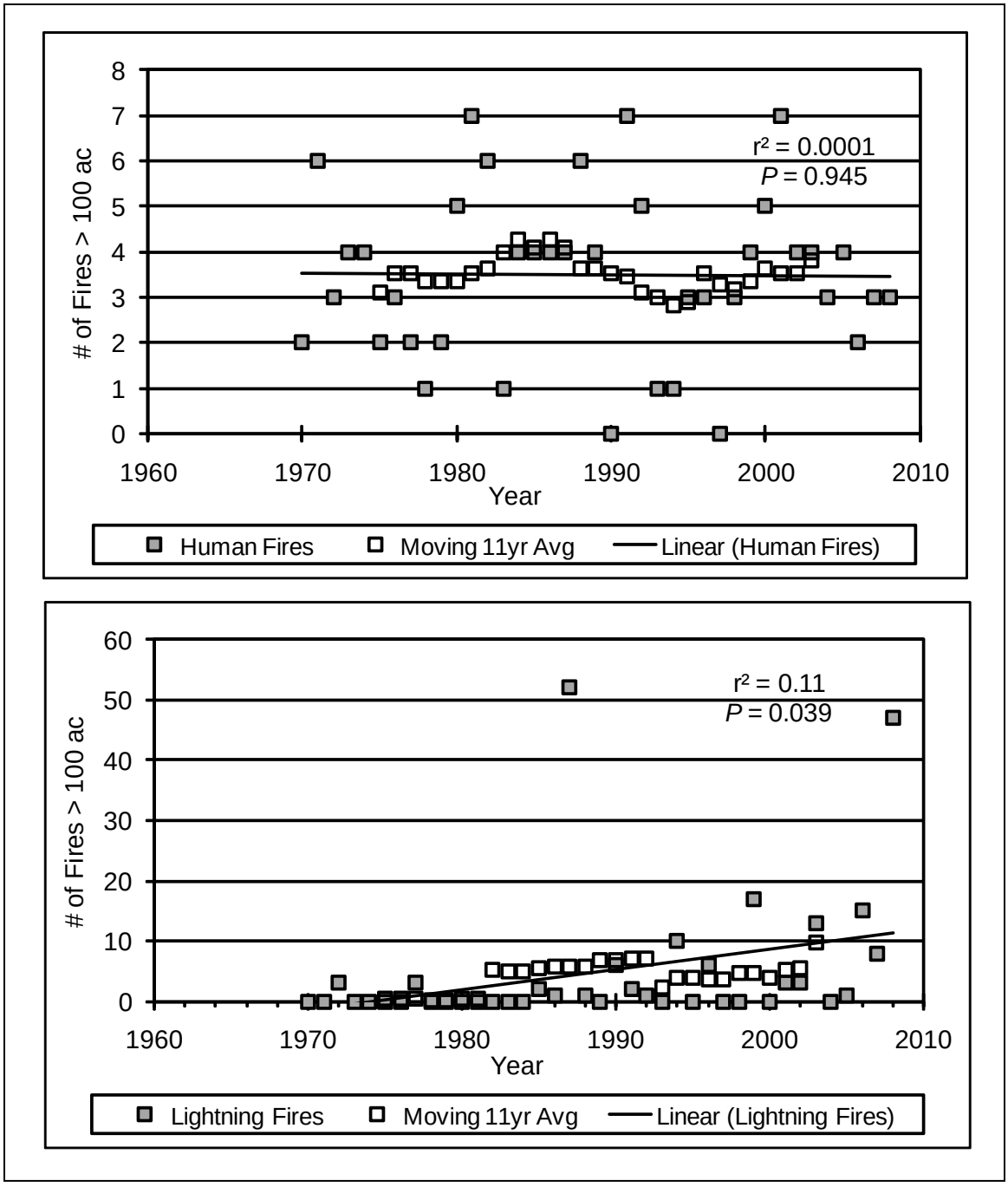

Figure 19. Number of ignitions resulting in fires > 100 acres by ignition source (human or lightning). Moving 11yr averages only shown for display purposes.

Underlying Relationships

Severity

Relationships between independent variables and fire severity variables were examined using multiple linear regressions. A full list of the independent variables examined can be found in Table A-15. In conifer

vegetation types, percentage of high-severity and high-severity patch size within single fires tended to be greatest: a) with larger fire size, b) in fires that ignited later in the year, and c) in years when less area burned across the study region (Table 10). Percentage of high-severity was inversely related to spring precipitation. Larger patches of high-severity fire tended to occur in forests closer to the Pacific coast. Although percentage of high-severity fire was more strongly (negatively) related to total area burned per year than fire size, the area of high-severity and high-severity patch size in each fire were more strongly related to fire size. Years with the greatest area burned and larger fires were characterized by less winter and spring precipitation than years with less total area burned and with smaller fires.

Table 10. Multiple regressions of fire effects variables for individual fires >100 acres 1987-2008 (Standardized regression coefficients significant at $P < 0.05$)

Dependent Variable	Spring Max Temp	Spring Precip	Ignition Day	Fire Size	Total Burned per Yr	Distance to Coast	*P*	R^2 (adj R^2)
Fire % High-severity		-0.212	0.238	0.231	-0.494		<0.001	0.252 (0.227)
Conifer % High-severity		-0.222	0.242	0.238	-0.492		<0.001	0.254 (0.230)
Mean Conifer Patch Size			0.197	0.226	-0.180	-0.189	<0.001	0.148 (0.120)
Max Conifer Patch Size			0.171	0.658	-0.161	-0.168	<0.001	0.500 (0.484)
Fire High-severity Area	0.110			0.873	-0.219		<0.001	0.722 (0.716)

Climate 1910 - 2008

To more closely examine fire-climate relationships we obtained the California region B climate data from the Western Regional Climate Center (Figure 20). Total precipitation, and mean minimum and maximum temperatures were grouped into standard seasons: Dec-Jan-Feb (winter), March-Apr-May (spring), June-July-Aug (summer), and Sept-Oct-Nov (fall). The time series was divided into three temporal groups to determine whether different climate variables were correlated to fire size and count in the early (1910-1959), late (1960-2008) and very late (1987-2008) portions of the study period; the first two temporal groups were generated by splitting the data set in half and were not made based on any *a priori* assumptions. The last time period was chosen to match the period of the fire severity data. Regressions were performed on the climate variables against the number, mean and maximum fire size, and total burned area for the years 1910 through 2008 (Table 11).

Splitting the dataset into early (1910-1959) and later (1960-2008) periods, correlations of fire variables shifted from inverse correlations with PDSI in the early period, to inverse correlations with summer precipitation in the later period (Table 11). Summer precipitation dipped below average from 1999-2008, the same period during which mean and maximum fire size, and total area burned were at their highest levels. Mean summer precipitation was lowest during the 1920s, yet number of fires was the only fire statistic that was larger during this period than during 1999-2008. Even though summer precipitation was low during the 1999-2008 period, mean annual precipitation during this period was more or less equal to the 99 year average (mean annual precipitation 1999-2008 divided by 99 year mean = 0.992). The

strength of the fire-climate relationship increased markedly from the beginning of the study period to the end. Variance in fire statistics explained by the climate regressions increased from an R^2 range of 0.268 to 0.366 in the 1910-1959 period, to an R^2 range of 0.413 to 0.599 in the 1987-2008 period (adjusted R^2 values).

Regional annual average precipitation increased approximately 11.8 inches during the 1910-2008 period ($r^2 = 0.069$, $P = 0.009$; Figure 21), with most of the increase occurring in the winter (6.01 inches, $r^2 = 0.031$, $P = 0.083$) and spring (3.25 inches, $r^2 = 0.036$, $P = 0.065$). Winter maxima and all seasonal minima temperatures increased over the 1910-2008 period (Figure 22) led by summer minima (+2.93° F, $r^2 = 0.426$, $P < 0.001$).

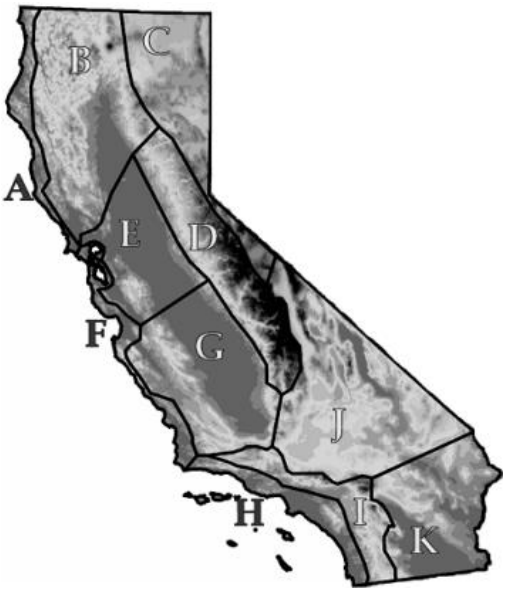

Figure 20. Western Regional Climate Center climate regions for California (WRCC 2009).

Table 11. Multiple regression of climate variables to fires >100 acres 1910-2008 (Standardized regression coefficients significant at $P < 0.05$)

Dependent Variable	Period	Winter Max Temp	Fall Min Temp	Summer Precip	Fall Precip	Summer PDSI	*P*	R^2 (adj R^2)
Number of Fires	1910-1959					-0.615	<0.001	0.378 (0.365)
	1960-2008			-0.280	-0.335	-0.368	<0.001	0.369 (0.336)
	1987-2008		0.310	-0.797			<0.001	0.637 (0.599)
Mean Fire Size	1910-1959	-0.300				-0.513	<0.001	0.328 (0.300)
	1960-2008					-0.394	0.005	0.155 (0.137)
	1987-2008			-0.664			<0.001	0.441 (0.413)
Maximum Fire Size	1910-1959					-0.532	<0.001	0.283 (0.268)
	1960-2008					-0.416	0.003	0.173 (0.155)
	1987-2008			-0.712			<0.001	0.507 (0.483)
Total Area Burned	1910-1959					-0.616	<0.001	0.380 (0.366)
	1960-2008				-0.265	-0.480	<0.001	0.288 (0.258)
	1987-2008			-0.748			<0.001	0.559 (0.537)

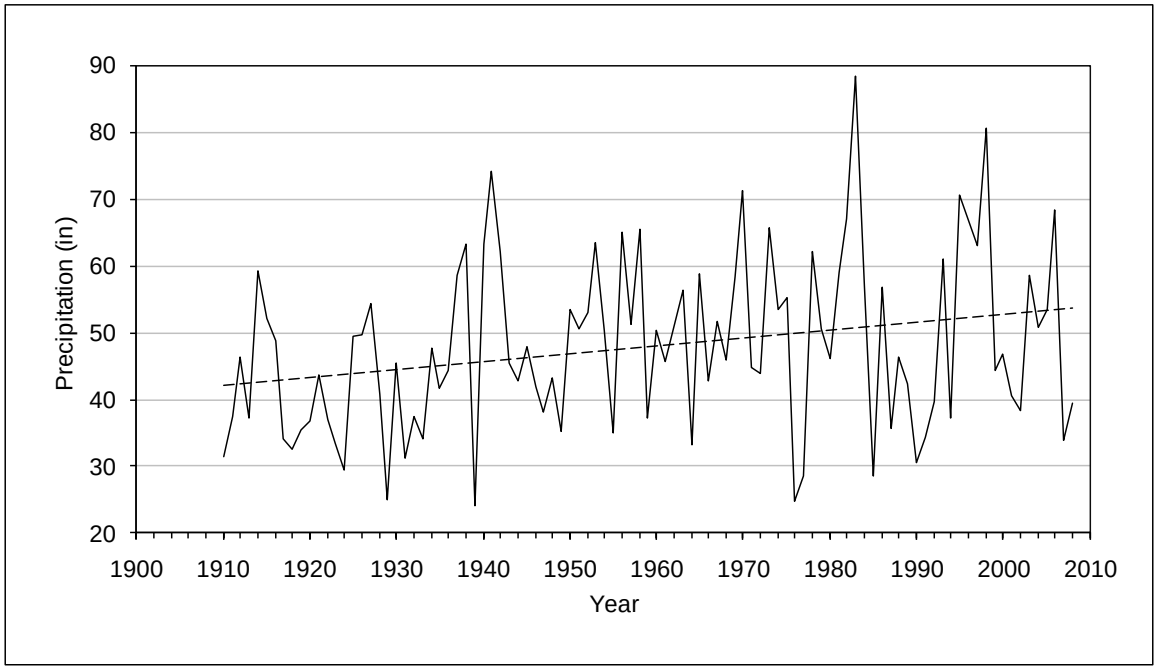

Figure 21. California region B annual precipitation for 1910-2008. Dashed line indicates linear trend ($r^2 = 0.069$, $P = 0.009$).

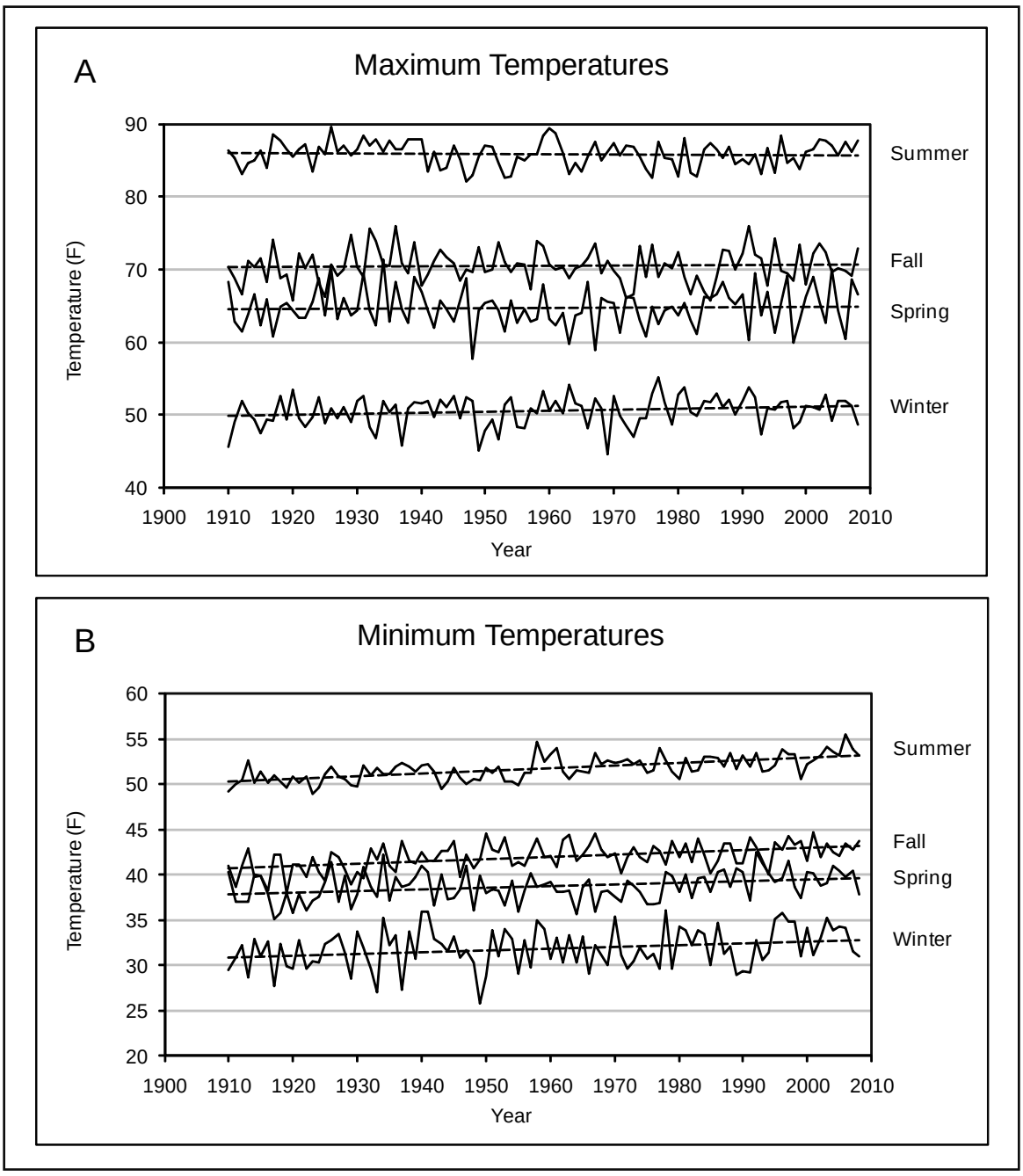

Figure 22. California region B seasonal average temperatures for 1910-2008, dashed line indicates linear trend. (a) Maximum spring, summer, fall not significant; winter $r^2 = 0.04$, $P = 0.046$, (b) Minimum, all significant r^2 between 0.06 and 0.42, all $P < 0.02$.

Lightning vs. Human Ignited Fires

For fires >100 acres, individual fire size, duration, number of fires, and total area burned per year were all significantly higher for lightning ignited fires than for human ignited fires; fire severity was lower in lightning-caused fires (Table 12; 11 vs. 28%). Human-ignited fires occurred closer to Wildland Urban Interface (WUI) or National Forest boundaries than lightning-ignited fires (1.2 vs. 2.2 miles respectively).

There were no significant differences in mean or maximum high-severity patch size or ignition dates between human and lightning caused fires. Lightning fires tended to occur under drier climatic conditions than did human caused fires, even though both tended to occur under drier than average conditions (mean PDSI = -1.83 and -0.78, and PNA = 0.49 and 0.33 for lightning and human ignitions respectively).

Table 12. Differences in fire variables due to lightning vs. human ignition sources. (H_0 (u_1-u_2) = 0)

Variable	Period	Mean difference (lightning - human)	SE	*P*
Fire % High-severity	1987-2008	-1.994	0.294	<0.001
Conifer % High-severity	1987-2008	-1.916	0.318	<0.001
Mean Conifer High-severity Patch Size (ac)	1987-2008	-0.198	0.170	0.315
Max Conifer Patch Size (ac)	1987-2008	0.059	0.362	0.878
Distance to WUI or Forest Boundary (mi)	1970-2008	1.089	0.256	<0.001
Fire Size (Fires >100 ac)	1970-2008	0.351	0.087	<0.001*
Fire Duration (Days, Fires >100 ac)	1970-2008	27.973	3.634	<0.001*
Ignition Day (Fires >100 ac)	1970-2008	-0.900	5.300	0.865*
PDSI (Fires >100 ac)	1970-2008	-1.045	0.195	<0.001*
PNA	1970-2008	0.158	0.064	0.016
Number of Fires >100 acres per year	1970-2008	0.605	0.043	<0.001
Total Area Burned per year	1970-2008	1.265	0.085	<0.001*

* F test indicated equal variances, *P* values are for unequal variances otherwise.

Appendix A: Methods

Satellite Derived Index

Recently the normalized burn ratio (NBR) has gained considerable attention, mostly in the United States, for mapping burned areas (Miller and Yool 2002, Brewer et al. 2005, Epting et al. 2005, Key and Benson 2006b). NBR is sensitive primarily to living chlorophyll and the water content of soils and vegetation, but it is also sensitive to lignin, hydrous minerals, ash and char (Elvidge 1990, Kokaly et al. 2007). Most often a post-fire NBR image is subtracted from a pre-fire NBR image in a change detection methodology to derive the absolute differenced NBR (dNBR) (Key and Benson 2006b). Absolute differenced images must be calibrated on each individual fire to ensure accurate results however, and absolute change images can under represent high-severity fire in heterogeneous landscapes (Miller and Yool 2002, Key and Benson 2006b, Zhu et al. 2006, Miller and Thode 2007, Safford et al. 2008). A relative dNBR (RdNBR) image created by dividing the dNBR measure by a function of the pre-fire NBR to remove the biasing effect of the pre-fire condition was therefore used to map severity to vegetation for this report (Miller and Thode 2007, Miller et al. 2009a). The RdNBR data for all fires larger than 1000 acres occurring during 1987-2008 in the study area were acquired from the Monitoring Trends in Burn Severity (MTBS) program (Eidenshink et al. 2007). The RdNBR data were converted to units of CBI and percent change in canopy cover based upon calibrations published in Miller et al. (2009a). Finally, a focal mean algorithm was used to average pixel values in a 3x3 pixel window to match the 90 meter diameter calibration field plots.

Field Data

Field data collected on eighteen fires in the Sierra Nevada area during 2002 through 2005 and six fires in the Klamath Mountains during 2006 were used to calibrate and validate the satellite derived index. The field protocol measured fire effects primarily to vegetation (Miller et al. 2009a). Field measurements employed the composite burn index (CBI) protocol developed by Key and Benson (2006a) supplemented with additional qualitative measures on trees: species; diameter breast height; tree height; canopy height; percent canopy torched, scorched and green; crown class; and char height. The supplemental measurements allowed us to derive specific vegetation related relationships to the satellite data like percent change in canopy cover or tree basal area. The qualitative tree data were the only data collected for the first four fires (2002) in the Sierra Nevada. The CBI protocol calls for sampling one year post-fire to allow for first year mortality due to fire effects and vegetation recovery, therefore all field data were collected the summer after each fire occurred.

Composite Burn Index (CBI) Classification

The CBI was developed by Key and Benson (2006a) as a field measure of the average burn condition found in a plot. The CBI protocol as depicted by the field data sheet in Figure A-1, records fire effects

derived from ocular estimates in five strata: 1) surface fuels and soils; (2) herbs, low shrubs and trees less than 1 meter; (3) tall shrubs and trees 1 to 5 meters; (4) intermediate trees; and (5) big trees. Each stratum incorporates four or five variables that are visually estimated and ranked between zero and three. Values for each stratum or all strata can be averaged to create a severity index value for understory and/or overstory components as well as the whole plot. Total CBI values used for this study were derived by summing scores from all measured values and dividing by the number of values measured. CBI values range between zero (unburned) and three (highest severity). Since the CBI is a field based protocol, regression analysis of field measured values to the satellite derived RdNBR index was used to develop categorical classes of severity (Miller and Thode 2007). The CBI protocol provides a consistent methodology for quickly assessing the relative severity at a location, allowing a larger number of locations to be evaluated than would a more quantitative protocol. Two major disadvantages of the CBI protocol however are: 1) variability in CBI values can be high since the measurements are ocular estimates (Korhonen et al. 2006); and 2) CBI does not result in a measurement that is familiar to most resource managers.

BURN SEVERITY -- COMPOSITE BURN INDEX (BI)

PD - Abridged	Examiners:			Fire Name:	
Registration Code		Project Code		Plot Number	
Field Date mmddyyyy	/ /	Fire Date mmyyyy	/		
Plot Aspect		Plot % Slope		UTM Zone	
Plot Radius Overstory		UTM E plot center		GPS Datum	
Plot Radius Understory		UTM N plot center		GPS Error (m)	
Number of Plot Photos		Plot Photo IDs			

BI – Long Form	% Burned 20 m Plot =	% Burned 30 m Plot =	Fuel Photo Series =

STRATA RATING FACTORS	BURN SEVERITY SCALE							FACTOR SCORES
	No Effect	Low		Moderate		High		
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	
A. SUBSTRATES								
% Pre-Fire Cover: Litter =	**Duff =**		**Soil/Rock =**		**Pre-Fire Depth (inches): Litter =**	**Duff =**	**Fuel Bed =**	∑=
Litter/Light Fuel Consumed	Unchanged	--	50% litter	--	100% litter	>80% light fuel	98% Light Fuel	N =
Duff	Unchanged	--	Light char	--	50% loss deep char	--	Consumed	$\bar{X}$ =
Medium Fuel, 3-8 in.	Unchanged	--	20% consumed	--	40% consumed	--	>60% loss, deep ch	
Heavy Fuel, > 8 in.	Unchanged	--	10% loss	--	25% loss, deep char	--	>40% loss, deep ch	
Soil Cover/Color	Unchanged	--	10% change	--	40% change	--	>80% change	
B. HERBS, LOW SHRUBS AND TREES LESS THAN 1 METER:								
Pre-Fire Cover =			**Enhanced Growth Factor =**					∑=
% Foliage Altered (blk-brn)	Unchanged	--	30%	--	80%	95%	100% + branch loss	N =
Frequency % Living	100%	--	90%	--	50%	< 20%	None	$\bar{X}$ =
Colonizers	Unchanged	--	Low	--	Moderate	High-Low	Low to None	
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High change	
C. TALL SHRUBS AND TREES 1 TO 5 METERS:								
Pre-Fire Cover =			**Enhanced Growth Factor =**					∑=
% Foliage Altered (blk-brn)	0%	--	20%	--	60-90%	> 95%	Signifcnt branch loss	N =
Frequency % Living	100%	--	90%	--	30%	< 15%	< 1%	$\bar{X}$ =
% Change in Cover	Unchanged	--	15%	--	70%	90%	100%	
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High Change	
D. INTERMEDIATE TREES (SUBCANOPY, POLE-SIZED TREES)								
Pre-Fire % Cover =	**Pre-Fire Number Living =**				**Pre-Fire Number Dead =**			∑=
% Green (Unaltered)	100%	--	80%	--	40%	< 10%	None	N =
% Black (Torch)	None	--	5-20%	--	60%	> 85%	100% + branch loss	$\bar{X}$ =
% Brown (Scorch/Girdle)	None	--	5-20%	--	40-80%	< 40 or > 80%	None due to torch	
% Canopy Mortality	None	--	15%	--	60%	80%	%100	
Char Height	None	--	1.5 m	--	2.8 m	--	> 5 m	
Post Fire: %Girdled =		**%Felled =**			**%Tree Mortality =**			
E. BIG TREES (UPPER CANOPY, DOMINANT, CODOMNANT TREES)								
Pre-Fire % Cover =	**Pre-Fire Number Living =**				**Pre-Fire Number Dead =**			∑=
% Green (Unaltered)	100%	--	95%	--	50%	< 10%	None	N =
% Black (Torch)	None	--	5-10%	--	50%	> 80%	100% + branch loss	$\bar{X}$ =
% Brown (Scorch/Girdle)	None	--	5-10%	--	30-70%	< 30 or > 70%	None due to torch	
% Canopy Mortality	None	--	10%	--	50%	70%	%100	
Char Height	None	--	1.8 m	--	4 m	--	> 7 m	
Post Fire: %Girdled =		**%Felled =**			**%Tree Mortality =**			

Community Notes/Comments:	CBI = Sum of Scores / N Rated:	Sum of Scores	N Rated	CBI
	Understory (A+B+C)			
	Overstory (D+E)			
	Total Plot (A+B+C+D+E)			

% Estimators: **20 m Plot:** 314 m^2 1% = 1x3 m 5% = 3x5 m 10% = 5x6 m
30 m Plot: 707 m^2 1% = 1x7 m (<2x4 m) 5% = 5x7 m 10% = 7x10 m

After, Key and Benson 1999, USGS NRMSC, Glacier Field Station.
Version 3.0 May 18, 2004

Strata and Factors are defined in FIREMON Landscape Assessment, Chapter 2, and on accompanying BI "cheat sheet". www.fire.org/firemon/lc.htm

Figure A-1. CBI data form.

The CBI maps are based on the severity to vegetation, in contrast to the Burned Area Emergency Response (BAER) team maps, which are focused on severity to soils and hydrologic function (Safford et al. 2008, Parsons et al. 2010). BAER severity maps can look similar to vegetation severity maps since fire intensity and severity are often correlated, but not always. Figure A-2 contrasts a typical BAER severity map with a CBI severity map. Since BAER teams focus on hydrologic function they can categorize areas of high vegetation mortality as low severity if the soil surface is not exposed, which can happen, for example, when dead conifers drop their needles.

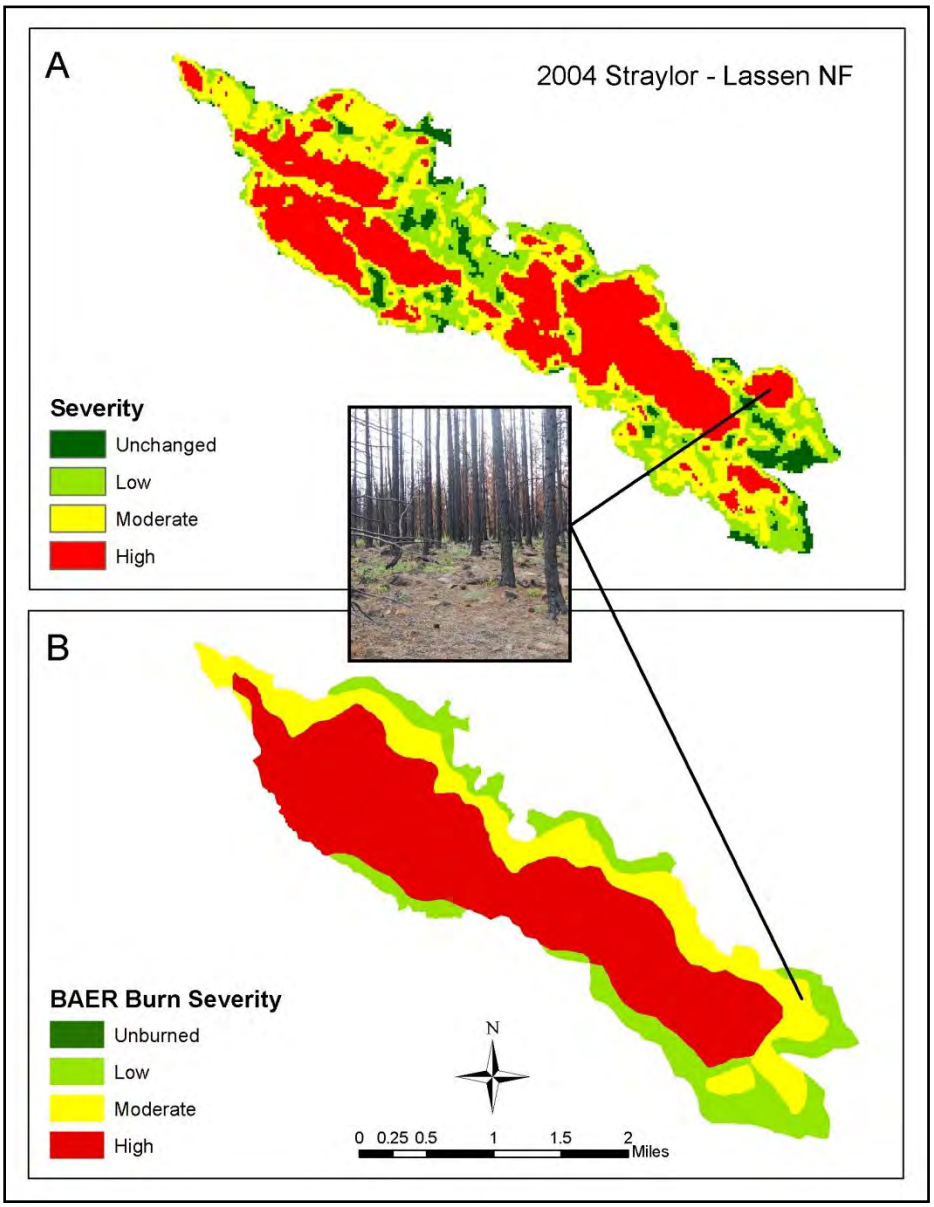

Figure A-2. Typical BAER and CBI severity maps. A.) Severity map resulting from calibrating Landsat imagery with CBI data. B.) BAER soil burn severity map based upon soil characteristics.

The vegetation severity categories reported in four categories of “unchanged”, “low”, “moderate”, and “high” are based upon CBI field data. We prefer to label the lowest severity class “unchanged” instead of “unburned”. Since we measure severity after one growing season, it is sometimes difficult to distinguish areas which have recovered after very low severity fire from unburned areas via satellite imagery.

Field measured CBI values range between zero (unburned) and three (highest severity). Choosing which CBI values to use as thresholds between severity categories is somewhat of a value judgment. Similar but distinct severity maps could be produced depending on management objective, analysis criteria, etc. For this report we chose to place the thresholds halfway between the values listed on the CBI data form for adjacent categories. For example, the CBI data form indicates a “moderate” severity occurs when CBI ranges between 1.5 and 2.0, and “high” severity occurs between 2.5 and 3.0. We therefore chose 2.25 as the threshold between “moderate” and “high” severity categories. The regression analysis of all CBI plot values with the satellite derived RdNBR index presented in Miller and Thode (2007) was used to determine thresholds for classifying satellite collected values into severity categories (Table A-1). Since the U.S. Forest Service considers a minimum of 10% tree cover to be the minimum to define forested areas we overlaid field plots with at least 10% pre-fire tree canopy cover with the regression model from Miller and Thode (2007) in Figure A-3 and computed the confusion matrix shown in Table A-2. The high-severity category had the highest producer’s and user’s accuracies, which is what we desire since the high-severity areas are where the greatest ecological impacts and most post-fire management activities occur. Producer’s accuracy, a description of map omission error, indicates the probability that a field plot had the correct class on the map; while user’s accuracy, a description of commission error, is the probability that the class of a pixel on the map actually represents that category on the ground. The accuracy of the moderate severity category is the lowest, which is not surprising considering the typically high variability of moderately burned areas, and that the satellite is looking down and summing fire effects both vertically and horizontally over a 30 x 30 meter area. Producer’s accuracy for the high-severity category is higher for areas with more than 20% pre-fire tree canopy cover (Table A-3). Mapping vegetation with sparse cover has historically been a remote sensing challenge since wavelengths used for the detection of vegetation are also influenced by the amount of exposed soil, parent substrate, soil water content, and in the case of fire post-fire ash cover (Huete 1988, Rogan and Yool 2001, Kokaly et al. 2007).

Table A-1. CBI Categories

Severity Category	CBI Threshold	RdNBR Threshold	Definition
Unchanged	0 – 0.1	Less than 69	One year after the fire the area was indistinguishable from pre-fire conditions. This does not always indicate the area did not burn.
Low	0.11 – 1.25	69 – 315	Areas where surface fire occurred with little change in cover and little mortality of the vegetation.
Moderate	1.26 – 2.25	316 – 640	A mixture of effects ranging between low and high on the vegetation in a mosaic pattern.
High	2.26 – 3.0	Greater than or equal to 641	Areas where high to complete mortality of the vegetation occurred. Approximately greater than 95% change in the amount of canopy cover (Miller et al. 2009a).

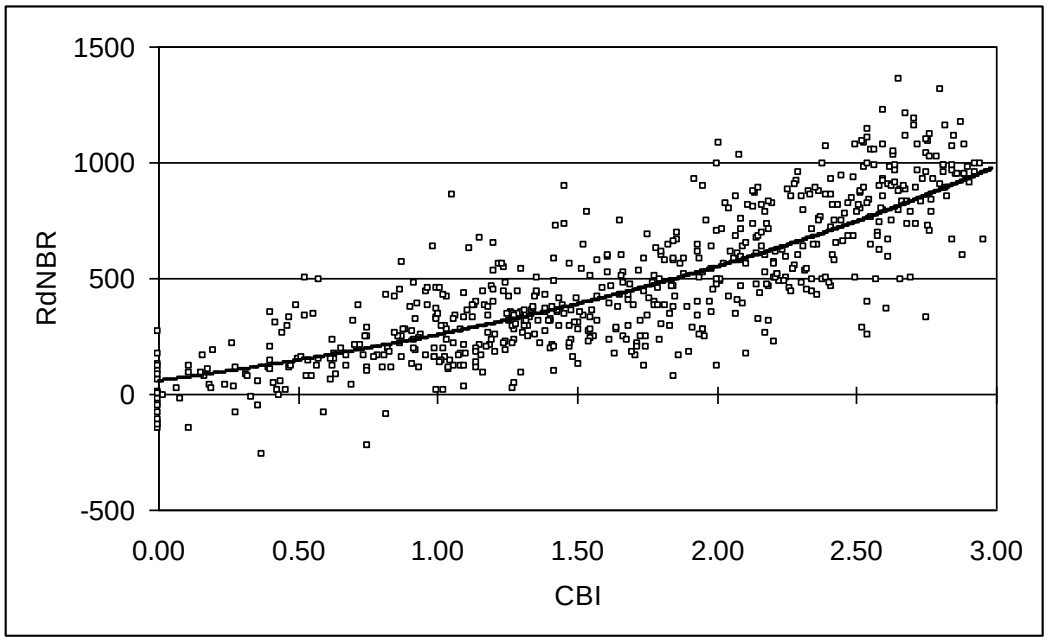

Figure A-3. Regression model of RdNBR to CBI overlaid with plots greater than 10% pre-fire tree cover (r^2 = 0.61, *P* < 0.0001).

Table A-2. CBI Classification confusion matrix

Severity Category	Low to Unchanged	Moderate	High	Total	User's Accuracy (%)
Low to Unchanged	153	70	2	225	68.0
Moderate	50	140	32	222	63.1
High	2	41	138	181	76.2
Total	205	251	172	628	
Producer's Accuracy (%)	74.6	55.8	80.2		68.6

Note: Columns = Reference (field collected CBI values in plots with at least 10% pre-fire tree canopy cover)

Table A-3. CBI severity map producer's accuracies as a function of pre-fire tree canopy cover.

Pre-fire Tree Canopy Cover (%)	Low to Unchanged	Moderate	High
1-10	83	52	45
10-20	85	43	56
20-40	79	58	73
40-60	70	62	80
60-80	63	76	83
80-100	51	68	74

Note: Columns represent the number of plots with trees.

Percent Change in Canopy Cover Classification

The CBI is a composite measure of severity from all strata of vegetation structure. However, many forest management activities are based upon fire effects to trees alone. We therefore also report severity in units of percent change in canopy cover. Tree mortality by diameter size class was sampled in the same field plots where CBI data were collected. We measured tree mortality by tree diameter size class one year post-fire to develop a regression model of percent change in canopy cover to the RdNBR index. Percent canopy cover was calculated for pre- and post-fire conditions using the Forest Vegetation Simulator (FVS) (Dixon 2002). FVS uses empirically derived allometric equations parameterized by species and dbh to model individual tree canopies. There are FVS variants for different geographic regions of the U.S. to account for regional differences in tree morphology. We used the northern California (NC) and western Sierra (WS) variants depending on fire location. FVS was configured to use random placement of trees and estimates of percent canopy cover were corrected for tree canopy overlap (Crookston and Stage 1999). We did not attempt to evaluate how random placement of trees affected the accuracy of canopy cover estimates, but other researchers have found that FVS calculated canopy cover can be more variable than field based measurements, and that FVS may underestimate cover for plots with highly regular spatial patterns and overestimate cover for plots with clustered patterns (Fiala et al. 2006, Christopher and Goodburn 2008).

FVS derived estimates of individual tree crown cover assume trees are healthy and unaffected by fire or disease. However, fire can modify dbh to canopy architecture relationships by raising CBH; thereby reducing canopy width. Since there was no way to modify crown width inside FVS, we derived a crown cover correction factor as a function of the percentage of crown volume scorched (PCVS). Equations for the Klamath variant of FVS (NC) were used to estimate an average tree height and crown width for all trees measured in plots from Klamath fires. We used equations for modeling crown shape for northern California conifer species from Biging and Wensel (1990) to derive the percent crown cover reduction factor (PctCCF) as a function of PCVS (Fig. 3) as follows:

$$\text{PCVS} = (V(h) \times 100)/CV$$

$$\text{PctCCF} = \quad 1 - PCVS \;\; 100 \;\times\; \frac{H - CBH}{H - h}$$

where CV is the total cubic crown volume computed using equation 1 from Biging and Wensel (1990); V(h) is the cumulative crown volume from the pre-fire CBH to a height h computed using equation 2 from Biging and Wensel (1990); and H is the total tree height. The percent canopy cover data modified for PCVS were used to develop a nonlinear regression model of percent change in canopy cover to the satellite derived RdNBR (Figure A-4; $r^2 = 0.52$; $P < 0.0001$) (Miller et al. 2009a). The model was used to categorize change in canopy cover into five mortality categories shown in Table A-4. Figure A-5 compares a typical CBI severity map to a map of change in canopy cover. Characteristic of most fires, patches indicated by the highest severity category are surrounded by rings of decreasing severity, sometimes only one pixel wide (pixels are 30m square). The five category map shows the steep change gradient typical in the transition area between high patches and the surrounding low severity. Table A-5 shows the confusion matrix using Klamath plots with more than 10% pre-fire tree canopy cover, since the U.S. Forest Service considers areas with at least 10% tree cover to be forested (Brohman and Bryant 2005). The five change categories were consolidated into three categories for reporting accuracies to more closely follow typical low, moderate and high classes. As with the CBI values, for validation plots in the Klamath Mountains the highest mortality category of greater than 75% change had the highest producer's and user's accuracies of 82.5 and 86.8% respectively after correcting for percent crown volume scorch. The moderate category of 25-75% change had the lowest producer's and user's accuracies of 50 and 57.1%.

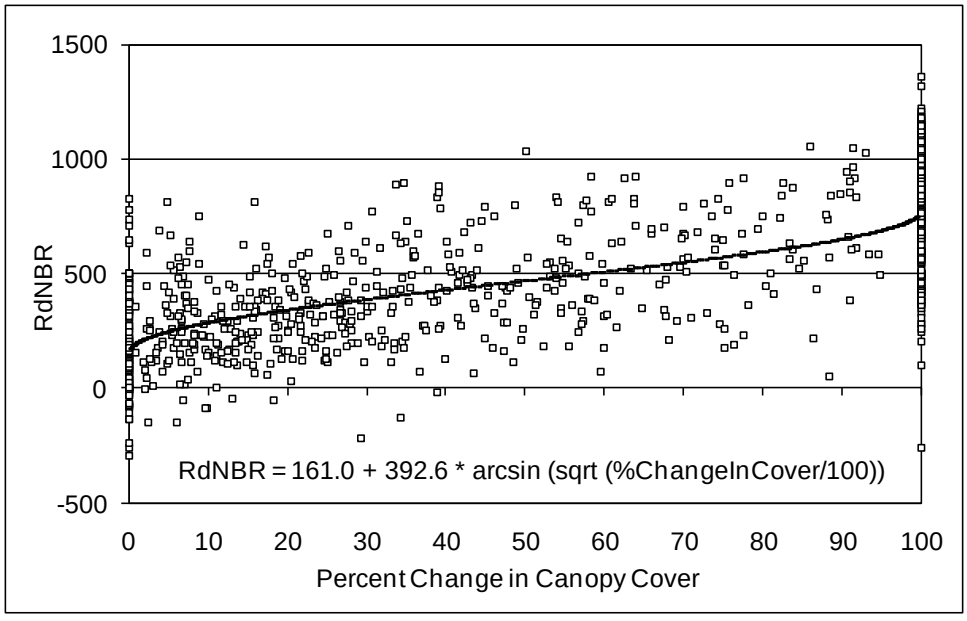

Figure A-4. Nonlinear regression model of RdNBR to field measured percent change in canopy cover for plots from the Sierra Nevada with more than 10% pre-fire tree cover ($r^2 = 0.52$, $P < 0.0001$).

Table A-4. Percent change in canopy cover categories

Percent Change in Canopy Cover	RdNBR Threshold
0	Less than 161
1 – 25%	161 – 366
25 – 50%	367 – 468
50 – 75%	469 – 571
75 – 100%	Greater than or equal to 572

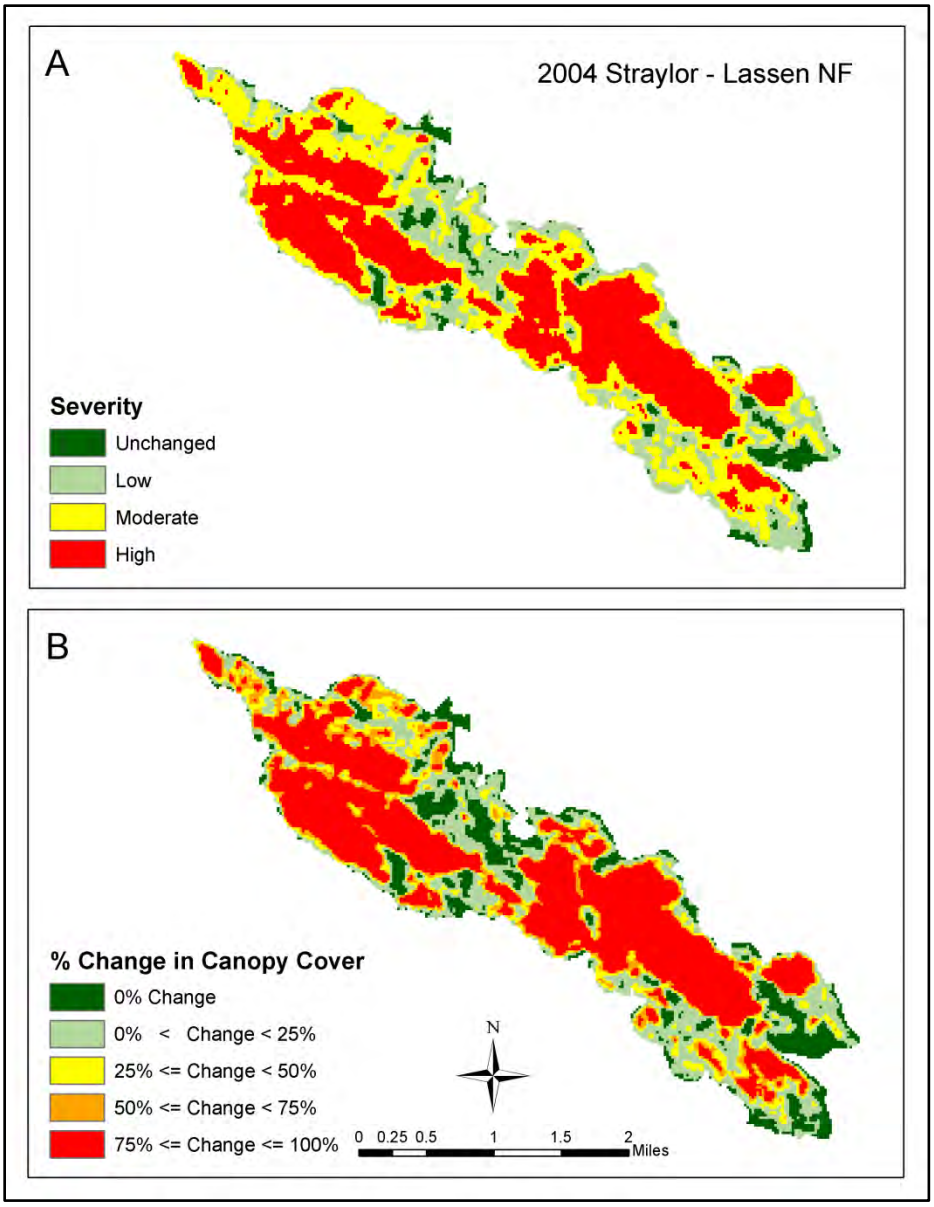

Figure A-5. Typical CBI severity map compared to a percent change in canopy cover map. A.) Severity map based upon CBI. B.) Map of percent change in canopy cover.

Table A-5. Percent change in tree canopy cover classification confusion matrix (Klamath plots corrected for CVS)

Severity Category	<25%	25-75%	>75%	Total	User's Accuracy (%)
<25%	17	7	4	28	60.7
25-75%	6	12	3	21	57.1
>75%	0	5	33	38	86.8
Total	23	24	40	87	
Producer's Accuracy (%)	73.9	50.0	82.5		71.3

Note: Columns = Number of plots with at least 10% pre-fire tree canopy cover)

Stratification by Vegetation and Cover Type

We used a series of three vegetation maps to stratify the severity data by vegetation and cover type. Two of the maps, based upon satellite imagery from 1994 and 2004 were derived using historic CALVEG data. In addition, to satisfy our requirement for a pre-fire vegetation map for fires before 1997 we developed a new vegetation map using 1987 imagery. We mapped cover and forest vegetation types into broad categories for our 1987 vegetation map. Cover types were generally divided along CALVEG life form categories with the exception of conifer and mixed conifer/hardwood which were grouped together (Table A-6). Conifer cover types were additionally subdivided into subcategories of percent cover and diameter size classes that should influence fire behavior. We first developed a cover type map through classification of three Landsat images (Figure A-6). The three classifications of cover type were restricted in extent to National Forest and ecoregion boundaries. Ecoregion boundaries were used to minimize confusion between cover types. We then performed separate classifications for the hardwood and conifer cover types to assign forest vegetation types. We used a variant of Classification and Regression Trees (CART) called Random Forests for all classifications (R Development Core Team 2009). CART analysis is a common tool used to develop vegetation maps and the Random Forests variant has recently been used in broad scale vegetation mapping projects (Breiman 2001, Rehfeldt et al. 2006, Evans and Cushman 2009). The advantage of the Random Forests algorithm is that it is designed to prevent over-fitting and has been shown to result in higher classification accuracies than other CART algorithms (Prasad et al. 2006).

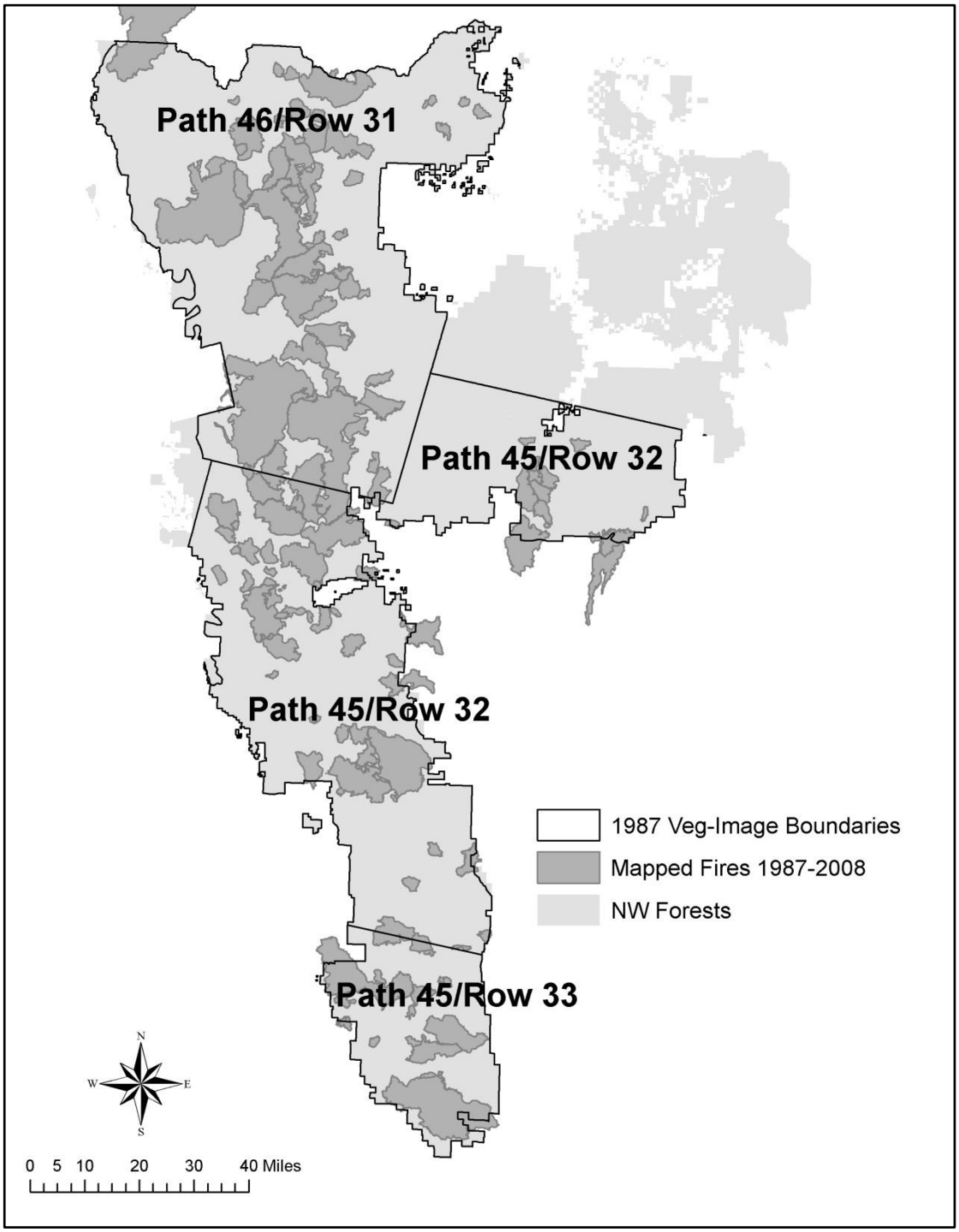

Figure A-6. Map of the overall study area. Northwestern California Forests demarcated in light gray and outlined in black listed clockwise starting from the top left are the Six Rivers, Klamath, Shasta-Trinity, and Mendocino National Forests. Darker gray polygons represent 132 fires that occurred 1987-2008 for which fire severity was analyzed in the current study. Outlined in black are the boundaries of three cover type classifications derived from Landsat images. Classification boundaries are a result of the intersection of National Forest, ecoregion, and image boundaries.

Table A-6. Vegetation cover types

Cover Type	Life form	Cover (%)	dBH (in)
Barren (BAR)	Barren		
Conifer Closed Medium/Large (CCM)	Conifer/Mixed Conifer Hardwood	60 - 100	≥ 20
Conifer Closed Small (CCS)	Conifer/Mixed Conifer Hardwood	60 - 100	10 - 20
Conifer Open Medium/Large (COM)	Conifer/Mixed Conifer Hardwood	10 - 60	≥ 20
Conifer Open Small (COS)	Conifer/Mixed Conifer Hardwood	10 - 60	10 - 20
Hardwood (HDW)	Hardwood		
Herbaceous (HEB)	Herbaceous		
Sapling/Poles (SAPOL)	Conifer/Mixed Conifer Hardwood	10 - 100	1 - 10
Shrub (SHB)	Shrub		
Water (WAT)	Water		

To carry out the cover type classifications, we first transformed the Landsat images to the Tasseled-Cap brightness, greenness, and wetness features to reduce the dimensionality and image noise of the Landsat data (Crist and Cicone 1984). The brightness, greenness and wetness features have been shown to be correlated to forest structure, stand age and vegetation biomass (Cohen and Spies 1992, Hansen et al. 2001). After transformation, the images were clipped to the study area and segmented into polygons delineating areas with uniform spectral characteristics. Image segmentation has replaced traditional pixel based classification algorithms in recent years and has been shown to increase accuracies for stand level classifications by taking advantage of contextual information (Wulder et al. 2004, Meddens et al. 2008). We used eCognition with a scale parameter of 9, a color to shape to ratio of 9, and compactness to smoothness of 5 to delineate segments (Definiens 2007). Polygon segments were labeled based upon the majority cover type from the 1994 CALVEG. Approximately 3500 to 6200 polygons outside of areas disturbed by fire were randomly chosen to be photo interpreted per Landsat image depending upon the amount of the study area covered by each Landsat image. The photo interpreted polygons were randomly split approximately in half for classification and accuracy assessment. The brightness, greenness, and wetness features combined with elevation and aspect derived from a 30m digital elevation model were averaged over each polygon and were classified to cover type. Three separate classifications, one for each Landsat image, were performed to derive a continuous map of cover type for the whole study area. Overall classification accuracies for the cover type classifications computed using the independent accuracy data from the three Landsat images ranged between 69.4 and 89.2% (Table A-7, Table **A-8**, and Table **A-9)**. Of the forest cover types, the conifer-closed-medium/large (CCM) category had the highest accuracies ranging between 82.6 - 88.9 for user's, and 89.1 – 97.3 for producer's. The hardwood (HDW) category had the second highest accuracies of all forest types except for the user's accuracy of the 45/33 image. The conifer-closed-small (CCS) accuracies were higher than the conifer open categories for the 46/31 and 45/32 images, but were lower for the 45/33 image. In general, the conifer closed categories were most confused with either the larger or smaller diameter category, e.g. CCM and CCS, for all image classifications. There were no similar patterns for the conifer open categories, which were confused with each other, the closed, as well as the shrub (SHB), sapling/poles (SAPOL) and HDW categories.

Table A-7. Confusion matrix of verification points for cover type classification of Landsat image from Path 46/Row 31

Class Name	BAR	CCM	CCS	COM	COS	HDW	HEB	SAP	SHB	WAT	Total	User's Accuracy (%)
Barren (BAR)	234	1		1	1		8	1	11	3	260	90.0
Conifer Closed Medium/Large (CCM)		754	92	33	8	16		6	4		913	82.6
Conifer Closed Small (CCS)		50	127	4	27	22		23	5	1	259	49.0
Conifer Open Medium/Large (COM)		14	10	24	10	3		6	4		71	33.8
Conifer Open Small (COS)	2	10	24	19	90	14	4	20	44		227	39.6
Hardwood (HDW)		3	14	5	10	149	2	38	20		241	61.8
Herbaceous (HEB)	5					1	49	3	9		67	73.1
Sapling/Poles (SAPOL)		6	9	8	18	67	5	293	28		434	67.5
Shrub (SHB)	19	7	6	9	63	10	33	47	396		590	67.1
Water (WAT)	1	1								29	31	93.5
Total	261	846	282	103	227	282	101	437	521	33	3093	
Producer's Accuracy (%)	89.7	89.1	45.0	23.3	39.6	52.8	48.5	67.0	76.0	87.9		69.4

Table A-8. Confusion matrix of verification points for cover type classification of Landsat image from Path 45/Row 32

Class Name	BAR	CCM	CCS	COM	COS	HDW	HEB	SAP	SHB	WAT	Total	User's Accuracy (%)
Barren (BAR)	48						2	4	2		56	85.7
Conifer Closed Medium/Large (CCM)		436	33	17	4	12		2	1	1	506	86.2
Conifer Closed Small (CCS)		13	46		2	8		2	5		76	60.5
Conifer Open Medium/Large (COM)		8	1	31	16	2		2	2		62	50.0
Conifer Open Small (COS)		3		12	32	4		6	5		62	51.6
Hardwood (HDW)		5	15	2	8	407	4	47	27		515	79.0
Herbaceous (HEB)	2	1				4	140	3	9		159	88.1
Sapling/Poles (SAPOL)		4	4	1	12	16	1	61	13		112	54.5
Shrub (SHB)	1	7		2	21	28	2	24	219		304	72.0
Water (WAT)										142	142	100.0
Total	51	477	99	65	95	481	149	151	283	143	1994	
Producer's Accuracy (%)	94.1	91.4	46.5	47.7	33.7	84.6	94.0	40.4	77.4	99.3		78.3

Table A-9. Confusion matrix of verification points for cover type classification of Landsat image from Path 45/Row 33

Class Name	BAR	CCM	CCS	COM	COS	HDW	HEB	SAP	SHB	WAT	Total	User's Accuracy (%)
Barren (BAR)	18	1			1				4		24	75.0
Conifer Closed Medium/Large (CCM)	1	249	9	5		5		8	3		280	88.9
Conifer Closed Small (CCS)		2	14			3		1	1		21	66.7
Conifer Open Medium/Large (COM)		1		9	2						12	75.0
Conifer Open Small (COS)				1	11	1					13	84.6
Hardwood (HDW)		2	8		1	122		15	16		164	74.4
Herbaceous (HEB)	4						83	5	12		104	79.8
Sapling/Poles (SAPOL)			1		2	11	3	111	12		140	79.3
Shrub (SHB)		1		5	4	13	8	19	949		999	95.0
Water (WAT)										12	12	100.0
Total	23	256	32	20	21	155	94	159	997	12	1769	
Producer's Accuracy (%)	78.3	97.3	43.8	45.0	52.4	78.7	88.3	69.8	95.2	100.0		89.2

To train a classification of forest vegetation type we used plots from the United States Department of Agriculture Forest Service (USFS) Forest Inventory and Analysis (FIA) program (USDA 1992). We did not withhold any plots for accuracy assessment due to the sparse sample of plots. FIA protocols call for a grid sampling that results in approximately one plot per 6000 acres, but the RSL enhances the number of FIA plots with additional field sampling. After including RSL enhanced plots and excluding plots that had been sampled in plantations and fires that had occurred since 1987, we ended up with 750 conifer and 53 hardwood plots. Forest vegetation type was assigned to plots based upon tree species in each plot using CALVEG classification rules used by the RSL. We initially grouped the CALVEG dominance types measured in the plots into 13 types that could exhibit unique fire regime characteristics (Table A-10). Independent variables used in a Random Forests classification consisted of variables computed from a 30m digital elevation model and climate variables from the DAYMET (http://www.daymet.org/) and PRISM (http://www.prism.oregonstate.edu/) datasets (Table A-11). Separate classifications were performed for conifer and hardwood life forms to minimize confusion between vegetation types.

Table A-10. Forest vegetation types for FIA plots within the study area and associated CALVEG types.

Initial Vegetation Type	Final Vegetation Type	CALVEG Type
Douglas-fir	Douglas-fir	Pacific Douglas-fir
Redwood	Douglas-fir	Redwood
Gray Pine	Gray Pine	Gray Pine
Jeffrey Pine	Mixed Conifer	Jeffrey Pine
Knobcone Pine	Mixed Conifer	Knobcone Pine
Mixed Conifer	Mixed Conifer	Douglas-fir/Ponderosa Pine
Mixed Conifer	Mixed Conifer	Douglas-fir/White Fir
Mixed Conifer	Mixed Conifer	Incense Cedar
Mixed Conifer	Mixed Conifer	Mixed Conifer/Fir
Mixed Conifer	Mixed Conifer	Klamath Mixed Conifer
Mixed Conifer	Mixed Conifer	Mixed Conifer/Pine
Mixed Conifer	Mixed Conifer	Ultramafic Mixed Conifer
Mixed Conifer	Mixed Conifer	Port Orford Cedar
Mixed Conifer	Mixed Conifer	Ponderosa Pine/White Fir
Ponderosa Pine	Mixed Conifer	Ponderosa Pine
Fir	Fir/High Elevation Conifer	Brewer Spruce
Fir	Fir/High Elevation Conifer	Red Fir
White Fir	Fir/High Elevation Conifer	White Fir
Subalpine Conifer	Fir/High Elevation Conifer	Mountain Hemlock
Subalpine Conifer	Fir/High Elevation Conifer	Subalpine Conifers
Subalpine Conifer	Fir/High Elevation Conifer	Western White Pine
Deciduous Oak	Deciduous Oak	Oregon White Oak
Deciduous Oak	Deciduous Oak	Black Oak
Deciduous Oak	Deciduous Oak	Valley Oak
Live Oak	Live Oak	Canyon Live Oak
Live Oak	Live Oak	Tanoak (Madrone)
Live Oak	Live Oak	Interior Live Oak
Mixed Hardwood	Mixed Hardwood	Interior Mixed Hardwood
Mixed Hardwood	Mixed Hardwood	California Bay
Mixed Hardwood	Mixed Hardwood	White Alder
Mixed Hardwood	Mixed Hardwood	Madrone
Mixed Hardwood	Mixed Hardwood	Bigleaf Maple
Mixed Hardwood	Mixed Hardwood	Quaking Aspen
Mixed Hardwood	Mixed Hardwood	Montane Mixed Hardwood

Table A-11. Independent variables used in the forest vegetation type classification

Acronym	Definition	Reference
YALBERS	Y-coordinate	
ELEV	Elevation	
ASPECT	Aspect	
SLOPE	Slope	
SLOPEPOS	Slope position	(Jenness 2006)
TCI	Topographic convergence index	(Beven and Kirby 1979)
TOTALRAD	Total radiation (ArcMap)	
COASTDIST	Distance to coast (ArcMap)	
GROWDAY	Number of growing days 1980-1997 (DAYMET)	(Thornton et al. 1997)
FFD	Frost-free days 1980-1997 (DAYMET)	(Thornton et al. 1997)
TMAXJAN	Average maximum temperature in January 1971-2000 (PRISM)	(Daly et al. 1994)
TMAXJULY	Average maximum temperature in July 1971-2000 (PRISM)	(Daly et al. 1994)
TMINJAN	Average minimum temperature in January 1971-2000 (PRISM)	(Daly et al. 1994)
TMINJULY	Average minimum temperature in July 1971-2000 (PRISM)	(Daly et al. 1994)
ATMIN	Average annual minimum temperature 1971-2000 (PRISM)	(Daly et al. 1994)
ATMAX	Mean annual maximum temperature 1971-2000 (PRISM)	(Daly et al. 1994)
GSP	Growing season precipitation, April-Sept 1971-2000 (PRISM)	(Daly et al. 1994)
APRECIP	Average annual precipitation 1971-2000 (PRISM)	(Daly et al. 1994)

The Random-forests classification of conifer vegetation type was unable to successfully separate the 10 conifer types as they were initially grouped (Table A-10). When more than 70% of the plots of any of the initial types were incorrectly classified the type was lumped in order to improve classification accuracy, with gray pine being the one exception. Only 16% of gray pine plots were correctly classified. Incorrectly classified gray pine plots were primarily confused with Douglas-fir, since elevation was the most important variable in the gray pine classification (Table A-12). We believe that fire regime characteristics of the gray pine and Douglas-fir are too different to justify combining those types. The final conifer vegetation type classification resulted in four types (Table A-10) with elevation being the most important factor for all conifer types (Table A-12). All three of the initial hardwood vegetation types remained in the final classification. Although we did not withhold plots for a true accuracy assessment, we did compute confusion matrices to get a sense for how well the classifications performed. The overall accuracies for the conifer and hardwood classifications were 71.7 and 64.2% respectively (Table A-13 and Table **A-14**). The final forest vegetation type classifications were applied only to the areas mapped as having either conifer or hardwood cover types, excluding sapling/poles, produced in the cover type classification described above.

Table A-12. Importance variables from random forests classification of forest vegetation type

Type	YALBERS	ELEV	ASPECT	SLOPE	SLOPEPOS	TCI	COASTDIST	TMAXJULY	TMINJAN
Douglas-fir	0.63	1.87	0.76	1.20	0.70		1.58	1.67	1.16
Gray Pine	2.18	3.47	0.29	-0.60	-0.24		1.68	2.21	-0.27
Mixed Conifer	1.01	1.24	0.45	0.56	-0.25		0.82	0.86	0.43
Fir/High Elevation Conifer	0.30	3.53	1.40	-0.14	0.05		0.03	2.64	2.32
Deciduous Oak		1.55		2.55		0.68		0.24	2.11
Live Oak		-0.79		3.90		3.64		-1.12	-0.24
Mixed Hardwood		6.47		0.72		3.75		6.01	3.20

Table A-13. Conifer vegetation types confusion matrix from random forests classification.

Type	Douglas-fir	Fir	Gray Pine	Mixed Conifer	Total	User's Accuracy (%)
Douglas-fir	182		10	65	257	70.8
Fir		45		19	64	70.3
Gray Pine	1		2		3	66.7
Mixed Conifer	73	37	7	309	426	72.5
Total	256	82	19	393	750	
Producer's Accuracy (%)	71.1	54.9	10.5	78.6		71.7

Table A-14. Hardwood vegetation types confusion matrix from random forests classification.

Type	Deciduous Oak	Live Oak	Mixed Hardwood	Total	User's Accuracy (%)
Deciduous Oak	15	7	2	24	62.5
Live Oak	6	16	3	25	64.0
Mixed Hardwood		1	3	4	75.0
Total	21	24	8	53	
Producer's Accuracy (%)	71.4	66.7	37.5		64.2

Fire occurrence and area burned

For analysis of fire occurrence due to ignition source regardless of fire size, we used records from FIRESTAT (http://www.fs.fed.us/fire/planning/nist/firestat.htm), which archives fire reports filed by US Forest Service personnel. FIRESTAT spatial data are point features and cannot be used to carry out spatial analyses of burned area, although each report does include an estimate of fire size. FIRESTAT includes geographic locations of all ignitions regardless of size, but in our area it is complete only for fires since 1970 (total N = 18,391 fire occurrences).

For spatial analysis on burned area and to investigate trends in number of fires, fire size and total burned area per year for large fires over a longer 1910-2008 period we used the California fire history database jointly maintained by the California Department of Forestry and Federal land management agencies in California . This database contains fire perimeter (and other) information in GIS form for all fires greater

than 10 acres back to 1950, and somewhat larger fires (size depending on agency reporting the fire) before that date, back to 1910 for the Forests in NW California. For our study area it is considered complete for fires >100 acres back to about 1910. Except for fires smaller than 100 acres, there is no systematic exclusion of fires from the database that would bias an analysis of trends. Fire maps of older fires were acquired and digitized to create the original database in the early 1990s (McKelvey and Busse 1996). Some perimeters for fires between 100 and 1000 acres in size that occurred before 1950 are generalized, but retain size and location from fire records. Additionally, US Forest Service and Department of Interior staff have spent considerable time validating and updating the database over the last decade. In our analysis we included all fires >100 acres that were recorded within the study area 1910-2008 (total N = 947) because 1) smaller fires (< 100 ac) tend to be under-reported, and 2) fires >40 ha tend to represent those that escape initial attempts at containment. Fire perimeters were clipped to Forest boundaries for all analyses. We used 11-year running means of the log-transformed dependent variables to graphically explore long-term trends.

Trends Analysis

Time series regression was used to examine trends over time using SAS 9.2 (2008). Common linear regression analysis of time series datasets is often inappropriate for trend analysis of ecological variables since errors about the regression line can be autocorrelated (Edwards and Coull 1987). We therefore used Autoregressive Integrated Moving Average (ARIMA) techniques that have been used in previous studies of trends in fire effects (e.g., Stephens 2005, Miller et al. 2009b). We fit time domain regressions using Box-Jenkins techniques for model identification and estimation (Shumway 1988). All time series models included a linear component and some included quadratic terms. Autoregressive terms were added when Chi-Squared test statistics for the residuals series indicated that the residuals contained additional information that might be reasonably incorporated into a more complex model. For all time series analyses, percentage data were square root transformed, and number of fires greater >100 acres (excepting human caused ignitions), mean and maximum fire size, and area variables were Log transformed to meet normality assumptions.

Percent high-severity

We examined the time series trend in the percentage of fire area burning at high-severity per year 1987-2008, stratified by cover and vegetation type. For each year, percent high-severity fire was determined by summing the area burned at high-severity across all fires and dividing by the total burned area for that year. Severity data were square root transformed and area data Log transformed to meet normality assumptions. Due to high inter-annual variability in the datasets, we also graphically portray trends using an 11-yr moving average of the annual data.

The percentage of high-severity at which a given vegetation type will burn can differ between fire events. We therefore used an Analysis of Variance (ANOVA) to examine the percentage of high-severity of forest vegetation and cover types per fire. For areas that burned twice during the 1910 to 2008 period (with the

second time burned occurring during the 1987-2008 period for which we have fire severity data), we computed percentage of high-severity per fire stratified by cover and vegetation type for different intervals between the first and second time burned (1-30, 31-60 and 61-98 years). Shorter intervals yielded too few hectares for some vegetation and cover types to be meaningful. A 30 year interval also closely matches what is thought to be the historic fire rotation in NW California (Wills and Stuart 1994, Taylor and Skinner 1998, 2003, Stephens et al. 2007). We examined the effect of previous fire on the subsequent percentage of high-severity in two ways. First, stratifying by vegetation and cover type (Table 2) we compared the percentage of high-severity between the first time areas burned and the second time areas burned in each of three time intervals,. Second, we stratified the three major conifer vegetation types (Douglas-fir, mixed conifer and fir/high elevation conifers) by cover and diameter size class category (cover type categories in Table 2) and examined differences in high-severity for first time burned vs. second time burned within 30 years. We chose to examine only the first 30yr interval because the number of hectares in the remaining two 30 year intervals was too few to be stratified. Time interval, vegetation type and cover type were considered fixed effects, while fires were a random effect in our ANOVA. Severity data were square root transformed to satisfy normality assumptions. To satisfy the ANOVA requirement for equal variances we applied area burned as a weight. We used post hoc tests to compare differences in means between the first time vegetation and cover types burned, and between first time and second time burned. Statistical textbooks recommend that *P*-values should be adjusted to avoid type I errors when making multiple comparisons. However, there is significant debate in the literature whether those adjustments should be made when the data being examined are not random numbers but actual observations of ecological processes (Rothman 1990, Moran 2003, Meyn et al. 2010). We therefore base our results on non-adjusted *P*-values, but we also report significance of *P*-values using a Tukey-Kramer adjustment for comparison (Kramer 1956).

Patch size

Polygons of conifer small and medium/large cover types were merged to form contiguous patches and patch size was limited to >900 m^2 due to Landsat's 30×30 m pixel size. Sizes of all conifer high-severity patches, and maximum conifer high-severity patch per fire were averaged per year (giving the mean and mean-maximum patch size) and analyzed for temporal trends between 1987 and 2008.

Fire occurrence and area burned, 1970 - 2008

We used the FIRESTAT data to carry out ARIMA time series regression for number of all ignitions, lightning ignitions, and human caused ignitions, for all fires and for fires >100 acres in size 1970-2008. We also carried out ARIMA time series regressions for fire occurrence and area burned from the fire perimeter data for the period 1970-2008, matching the FIRESTAT period of record. Values were Log transformed when required to meet normality assumptions.

Underlying relationships

We examined relationships between multiple independent variables and fire response variables across three different time spans: 1987-2008 (fire severity data), 1970-2008 (FIRESTAT data and fire perimeter data corresponding to the FIRESTAT time period), and 1910-2008 (fire perimeter data). Percentage data were square-root transformed, and area variables were Log transformed; data collinearity was also assessed using variance inflation factors.

Stepwise multiple linear regressions ($P_{(enter)} < 0.15$, $P_{(remove)} > 0.05$) were used to examine relationships between independent variables (Table A-15) and the following variables derived from the severity data: percentage and area of fire area burned at high-severity per fire, percentage of high-severity in conifer vegetation per fire, and mean and maximum high-severity conifer patch size per fire for the 1987-2008 period (N = 132 fires). Three fires lacked information on containment date; therefore N = 129 for analyses where fire duration was an independent variable. In the patch size analyses N = 130, because two fires had no high-severity effects in conifer vegetation. Using two-sample t-tests we also compared differences between lighting and human ignition sources with respect to independent variables using fire locations from the FIRESTAT data 1970-2008 >40 ha (lightning N=191, human N=126), and using severity variables derived from the 1987-2008 fires (lightning N=102, human N=28). We used fire perimeters 1970-2008 to match the FIRESTAT period of record for analysis of distance to the nearest Wildland Urban Interface (WUI) or Forest boundary (USDA 2006).

To determine whether fire-climate relationships have changed 1910-2008, we examined the relationship of number of fires, mean and maximum fire size, and total area burned per year to seasonal and annual climate variables, the Palmer Drought Severity Index (PDSI) (Alley 1984), and the Pacific/North American circulation pattern index (PNA) (Wallace and Gutzler 1981) (Table A-15). We divided the fire perimeter dataset into three temporal groups and ran regressions for each period: early (1910-1959), late (1960-2008), and very late (1987-2008). The very late time period was selected to coincide with the fire severity data record, and the early and late periods were derived by dividing the whole period in half.

Table A-15. Independent Variables for the Multiple Regression Analysis and t-test Analysis

Acronym	Definition	Source
DJFppt, MAMppt, JJAppt, SONppt	Total precip. 1910-2008: Winter (previous Dec, Jan-Feb), Spring (Mar-May), Summer (Jun-Aug), Fall (Sep-Nov) (summary for CA north coast climate division)	(WRCC 2009)
ANNppt	Sum of DJFppt, MAMppt, JJAppt and SONppt (Precipitation year runs Dec-Nov)	(WRCC 2009)
ANNppt1	Annual precipitation lagged one year	(WRCC 2009)
DJFMAMppt	Winter and spring precipitation per year	(WRCC 2009)
DJFmaxT, MAMmaxT, JJAmaxT, SONmaxT	Avg. max temp. 1910-2008: Winter (previous Dec, Jan-Feb), Spring (Mar-May), Summer (Jun-Aug), Fall (Sep-Nov) (summary for CA north coast climate division)	(WRCC 2009)
DJFminT, MAMminT, JJAminT, SONminT	Avg. min temp. 1910-2008: Winter (previous Dec, Jan-Feb), Spring (Mar-May), Summer (Jun-Aug), Fall (Sep-Nov) (summary for CA north coast climate division)	(WRCC 2009)
PDSI	Palmer Drought Severity Index 1910-2008: indexed by year and month of fire start date	(NOAA 2009b)
PDSIjja	Avg. Palmer Drought Severity Index Summer (Jun-Aug)	(NOAA 2009b)
PNA	Pacific/North American circulation pattern index per year 1950-2008: average of Jan, Feb, previous year Dec	(NOAA 2009a)
IgnitionDay	Julian date of fire start	FIRESTAT
FireDuration	Containment date - ignition date	FIRESTAT
NFires40	Number of fires >40 ha per year	Fire perimeters
FireSize	Fire size	Fire perimeters
TotalBurnedYr	Total area burned per year in fires >40 ha	Fire perimeters
NLightning	Number of lightning ignitions per year	FIRESTAT
NIgnitions	Number of all ignitions per year	FIRESTAT
CoastDist	Distance to California coast from fire perimeter centroid	Fire perimeters
PrismANNPrecip	Annual avg. precip. at perimeter centroid	(Daly et al. 1994)

Appendix B: Individual Fire Results

Figures B-1 through B-4 display CBI derived four category severity data by National Forest for all fires mapped for this report. We only analyzed fires that burned at least 500 acres on a Pacific Southwest Region National Forest. When multiple fires occur in the same location the severity data for the oldest fire are displayed. Perimeters of all fires in the fire history database, regardless of size, that occur at least partially within Forest boundaries are shown. Fires that occurred between 1910 and 1986 are displayed in blue, while severity categories are displayed for fires on or after 1987. Table B-1 lists year, fire name, cause and direct protection agency for all fires included in this report. When fire names were not recorded in the fire history database the fire name was derived by concatenating year, state, unit, and local number. For each fire the number of acres burned by CBI derived severity category, number of acres in three categories of percent change in canopy cover, and percentage of each category within the fire perimeter that burned on Forest Service land in the Pacific Southwest Region are listed. Areas and percentages in some instances represent adjacent fires which occurred in the same year as reported in the statewide fire history database when those fires were analyzed as single fires for this report.

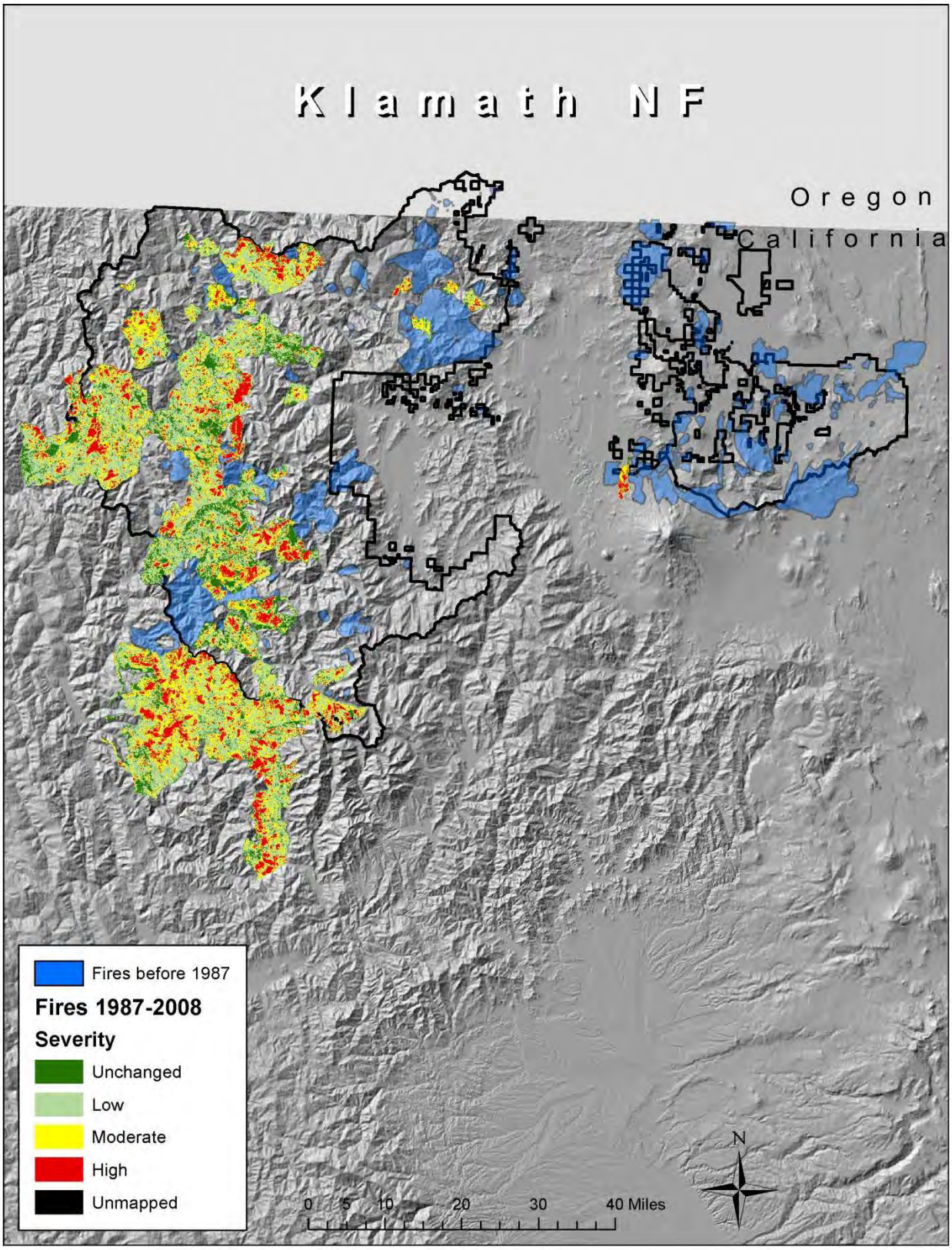

Figure B-1. Fires mapped on the Klamath NF.

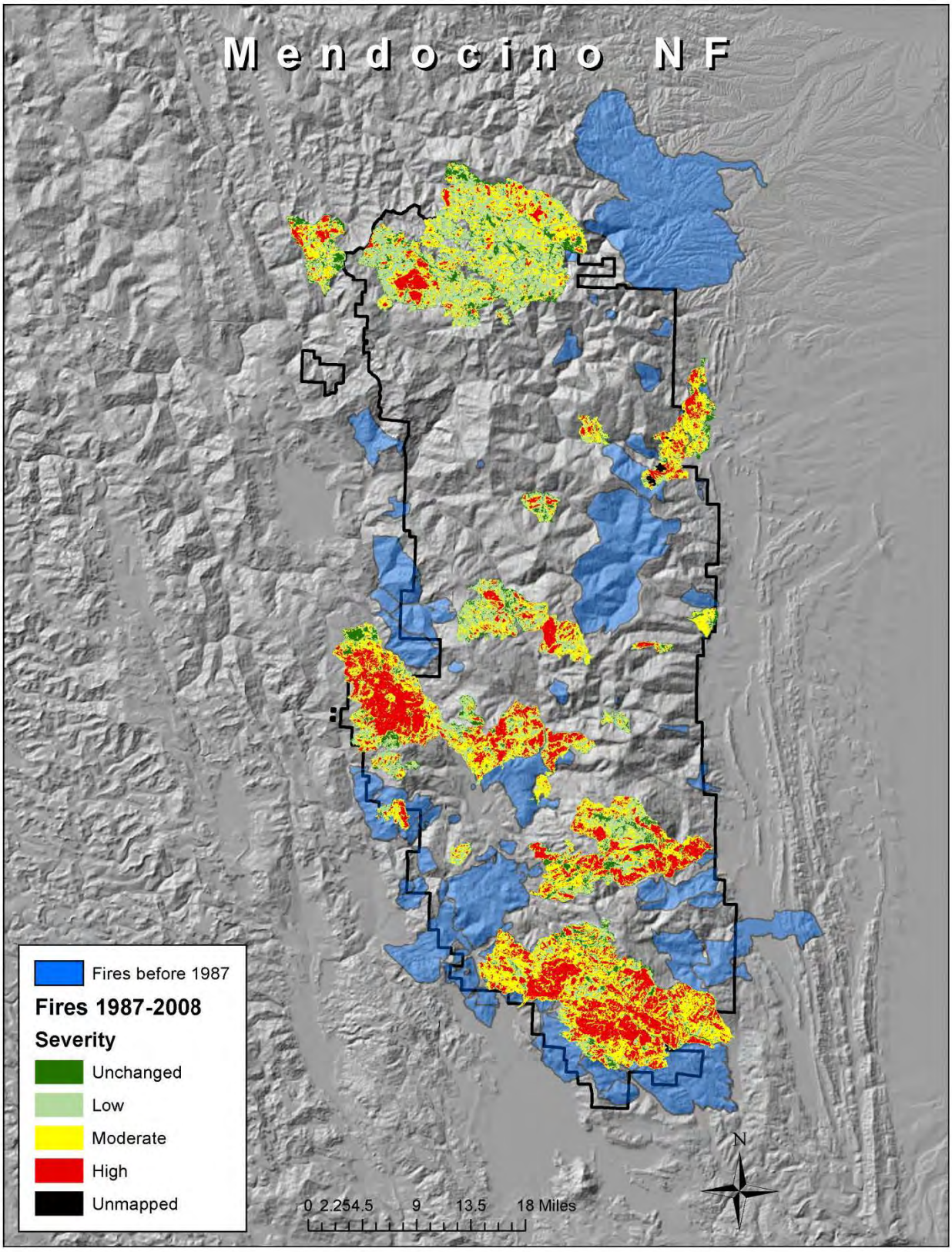

Figure B-2. Fires mapped on the Mendocino NF.

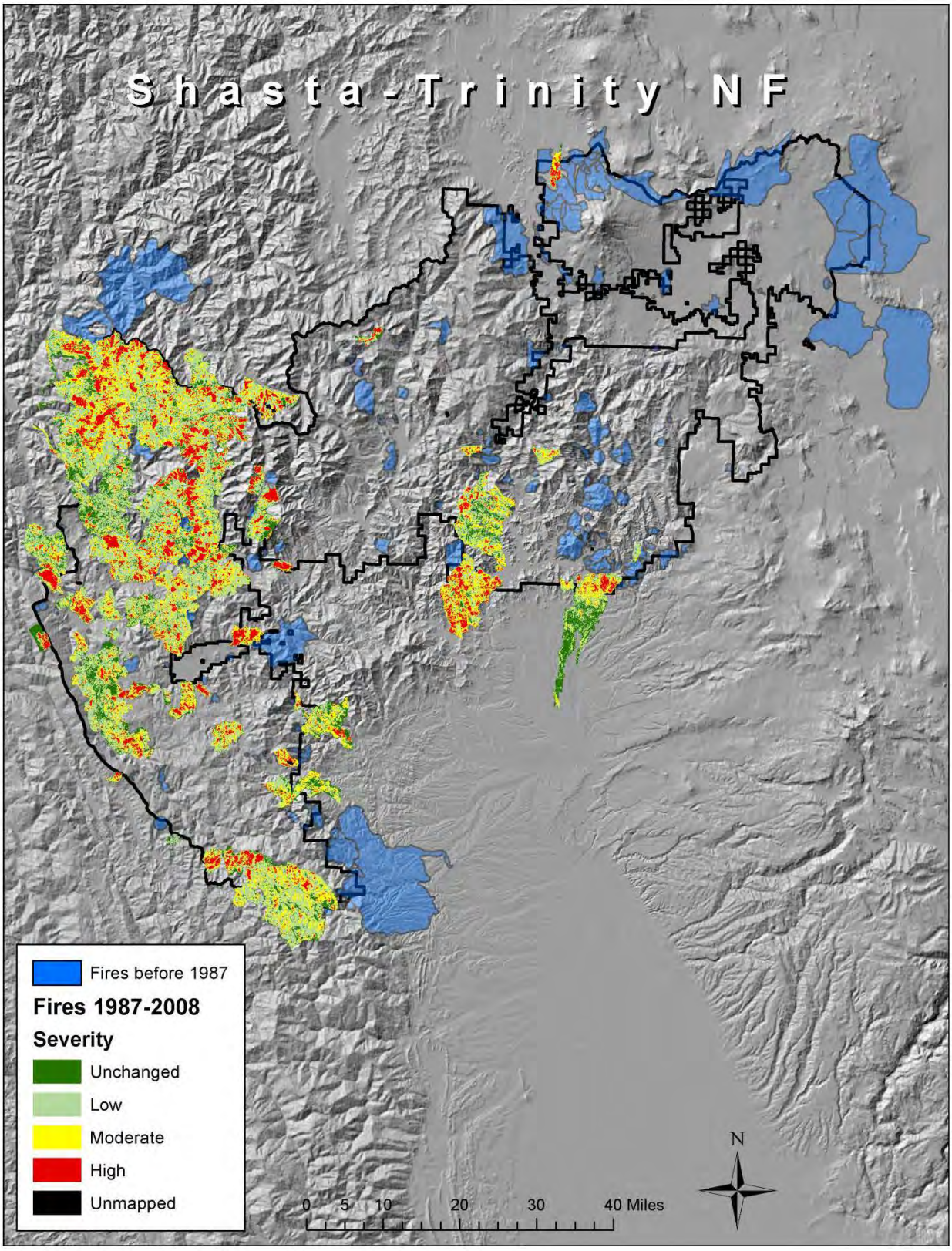

Figure B-3. Fires mapped on the Shasta-Trinity NF.

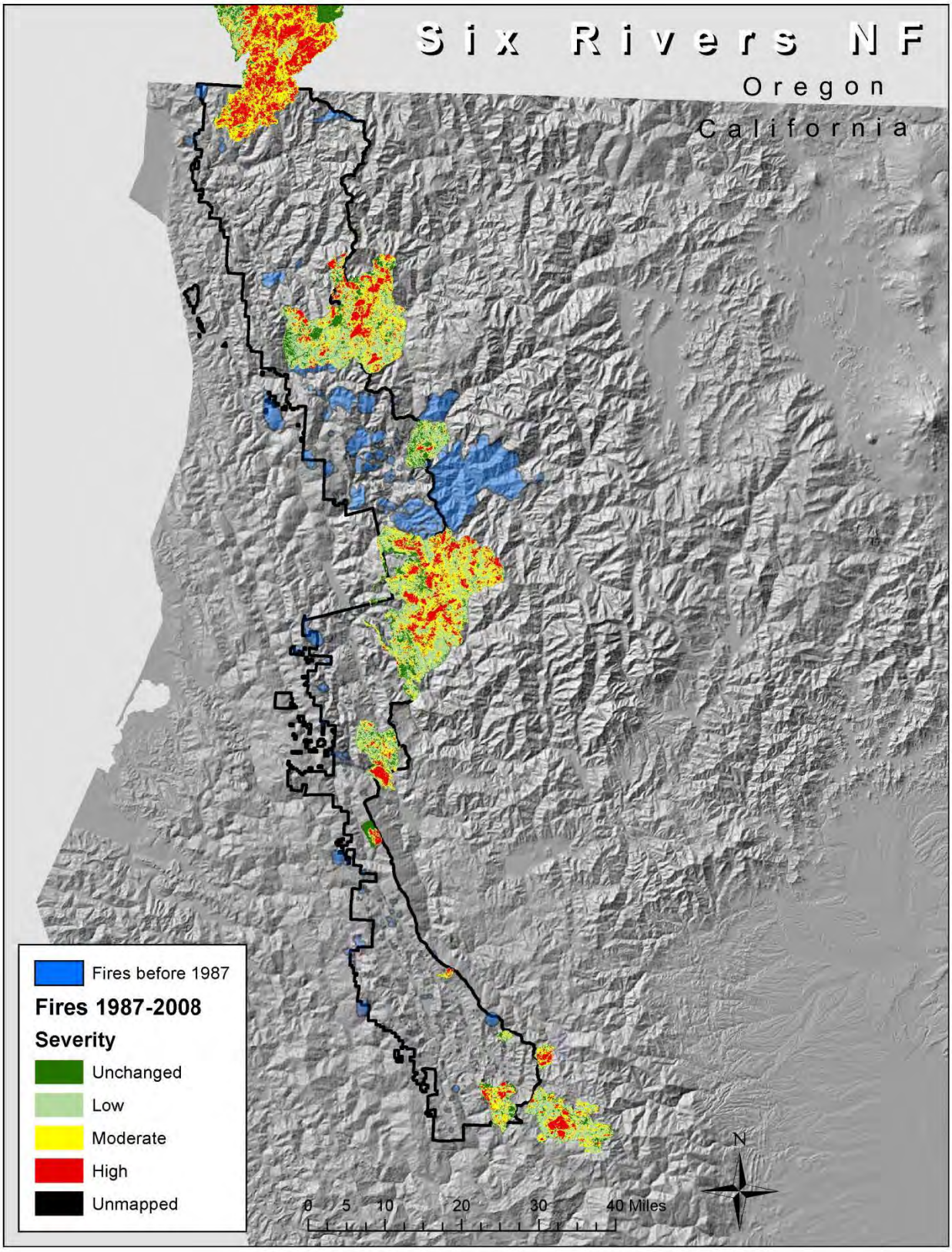

Figure B-4. Fires mapped on the Six Rivers NF.

Table B-1. Individual fire results

Year	Fire Name	Agency	Unit	Human or Lightning	Unchanged (ac/%)	Low (ac/%)	Moderate (ac/%)	High (ac/%)	% Canopy Cover Change <25% (ac/%)	% Canopy Cover Change 25-50% (ac/%)	% Canopy Cover Change 50-75% (ac/%)	% Canopy Cover Change >75% (ac/%)	Unmapped (ac/%)	Total (ac)
1987	Bear	USF	SHF	L	391 / 7	2990 / 56	1587 / 30	381 / 7	3984 / 74	541 / 10	331 / 6	493 / 9	0 / 0	5349
1987	Bearcat	USF	KNF	L	591 / 20	979 / 33	1256 / 43	111 / 4	1872 / 64	507 / 17	356 / 12	202 / 7	0 / 0	2937
1987	Blake	USF	SRF	L	1810 / 51	442 / 12	428 / 12	863 / 24	2345 / 66	128 / 4	142 / 4	927 / 26	0 / 0	3542
1987	China	USF	KNF	L	966 / 29	1294 / 39	790 / 24	290 / 9	2488 / 74	266 / 8	219 / 7	367 / 11	0 / 0	3340
1987	China	USF	SHF	L	589 / 6	4293 / 46	2522 / 27	1832 / 20	5697 / 62	831 / 9	639 / 7	2069 / 22	0 / 0	9236
1987	Cold	USF	SHF	L	5718 / 34	7026 / 42	2970 / 18	997 / 6	13764 / 82	1030 / 6	680 / 4	1238 / 7	0 / 0	16711
1987	East	USF	SHF	L	1909 / 20	3842 / 40	1614 / 17	2173 / 23	6286 / 66	524 / 5	386 / 4	2342 / 25	0 / 0	9538
1987	Elk Lick	USF	KNF	L	224 / 20	432 / 38	407 / 36	76 / 7	752 / 66	145 / 13	123 / 11	119 / 10	0 / 0	1138
1987	Flume	USF	SHF	L	2134 / 16	5215 / 40	3759 / 29	2067 / 16	8504 / 65	1332 / 10	941 / 7	2399 / 18	0 / 0	13175
1987	Fort Copper	USF	KNF	L	2083 / 6	15772 / 44	10652 / 30	6958 / 20	21241 / 60	3596 / 10	2644 / 7	7983 / 23	0 / 0	35465
1987	Fouts	USF	MNF	L	1748 / 10	5071 / 29	6117 / 35	4496 / 26	8121 / 47	1845 / 11	2005 / 12	5460 / 31	0 / 0	17432
1987	Friendly	USF	SHF	L	556 / 15	1109 / 30	1017 / 27	1029 / 28	1958 / 53	320 / 9	284 / 8	1150 / 31	0 / 0	3711
1987	Glasgow	USF	KNF	L	4392 / 29	4190 / 27	3544 / 23	3227 / 21	9446 / 62	1169 / 8	1047 / 7	3692 / 24	0 / 0	15353
1987	Gulch	USF	KNF	L	1443 / 13	6656 / 60	2492 / 23	477 / 4	9009 / 81	873 / 8	525 / 5	661 / 6	0 / 0	11067
1987	Gulch	USF	SHF	L	535 / 8	1873 / 28	2229 / 34	2006 / 30	2931 / 44	701 / 11	679 / 10	2333 / 35	0 / 0	6643
1987	Hotelling	USF	KNF	L	4668 / 25	8175 / 44	3969 / 21	1788 / 10	14119 / 76	1336 / 7	969 / 5	2175 / 12	0 / 0	18600
1987	Jessie	USF	SHF	L	313 / 9	1628 / 46	1179 / 34	387 / 11	2309 / 66	424 / 12	282 / 8	491 / 14	0 / 0	3506
1987	Kelsey	USF	KNF	L	809 / 18	2159 / 49	1175 / 27	248 / 6	3418 / 78	415 / 9	242 / 6	316 / 7	0 / 0	4391
1987	King Titus	USF	KNF	L	14145 / 20	37318 / 52	14835 / 21	5401 / 8	56397 / 79	4971 / 7	3606 / 5	6725 / 9	0 / 0	71699
1987	Lake	USF	KNF	L	6844 / 36	9373 / 49	2270 / 12	636 / 3	17085 / 89	783 / 4	467 / 2	789 / 4	0 / 0	19123
1987	Lauder	CDF	MEU	H	13 / 2	101 / 16	286 / 45	231 / 37	165 / 26	85 / 13	97 / 15	283 / 45	0 / 0	630
1987	Lazyman	USF	SHF	L	274 / 18	992 / 64	234 / 15	52 / 3	1361 / 88	68 / 4	50 / 3	72 / 5	0 / 0	1552
1987	Mendenhall	CDF	MEU	H	1630 / 4	8954 / 21	14210 / 33	17963 / 42	13422 / 31	4413 / 10	4814 / 11	20109 / 47	0 / 0	42758
1987	Nielon	USF	KNF	L	309 / 19	563 / 34	277 / 17	499 / 30	944 / 57	78 / 5	82 / 5	545 / 33	0 / 0	1648
1987	Peanut	USF	SHF	L	758 / 12	1720 / 27	2421 / 38	1520 / 24	3091 / 48	834 / 13	690 / 11	1802 / 28	0 / 0	6418
1987	Ripstein	USF	SHF	L	383 / 11	1232 / 35	705 / 20	1152 / 33	1785 / 51	221 / 6	222 / 6	1244 / 36	0 / 0	3473
1987	Saint Claire	USF	KNF	L	1333 / 15	5159 / 59	1964 / 22	302 / 3	7254 / 83	704 / 8	372 / 4	428 / 5	0 / 0	8758
1987	Slater	USF	KNF	L	1382 / 21	1527 / 24	2667 / 41	870 / 13	3390 / 53	866 / 13	979 / 15	1212 / 19	0 / 0	6447

Year	Fire Name	Agency	Unit	Human or Lightning	Unchanged (ac/%)	Low (ac/%)	Moderate (ac/%)	High (ac/%)	% Canopy Cover Change <25% (ac/%)	% Canopy Cover Change 25-50% (ac/%)	% Canopy Cover Change 50-75% (ac/%)	% Canopy Cover Change >75% (ac/%)	Unmapped (ac/%)	Total (ac)
1987	Slides	USF	MNF	L	157 / 15	671 / 66	170 / 17	21 / 2	922 / 90	52 / 5	17 / 2	27 / 3	0 / 0	1019
1987	Strause	USF	SHF	L	748 / 11	2216 / 33	1700 / 26	1976 / 30	3455 / 52	563 / 8	450 / 7	2172 / 33	0 / 0	6641
1987	Ten Bald	USF	KNF	L	1749 / 9	7659 / 39	7886 / 40	2526 / 13	11464 / 58	2857 / 14	2186 / 11	3313 / 17	0 / 0	19820
1987	Thompson	USF	KNF	L	1019 / 20	2703 / 53	1172 / 23	230 / 4	4143 / 81	424 / 8	258 / 5	300 / 6	0 / 0	5124
1987	Travis	USF	SRF	L	1887 / 17	3791 / 34	3664 / 33	1836 / 16	6626 / 59	1329 / 12	1021 / 9	2202 / 20	0 / 0	11178
1987	Trinity	USF	SHF	L	303 / 21	907 / 62	197 / 14	49 / 3	1291 / 89	65 / 4	39 / 3	62 / 4	0 / 0	1457
1987	USF05141987000282	USF	SHF	L	332 / 31	498 / 46	185 / 17	61 / 6	912 / 85	59 / 6	33 / 3	72 / 7	0 / 0	1076
1987	Wallow	USF	SHF	L	1221 / 35	1718 / 49	516 / 15	54 / 2	3129 / 89	195 / 6	110 / 3	76 / 2	0 / 0	3510
1987	Yellow #2	USF	KNF	L	15583 / 29	22545 / 42	10018 / 19	5896 / 11	40996 / 76	3301 / 6	2748 / 5	6998 / 13	0 / 0	54042
1988	Hermit	USF	SHF	H	1283 / 15	2297 / 27	2006 / 24	2914 / 34	4065 / 48	626 / 7	603 / 7	3206 / 38	0 / 0	8500
1988	Letts	USF	MNF	H	785 / 23	1309 / 38	823 / 24	494 / 14	2309 / 68	263 / 8	243 / 7	597 / 18	0 / 0	3412
1988	Powderhouse	USF	MNF	H	271 / 13	513 / 25	1224 / 60	17 / 1	1293 / 60	627 / 29	196 / 9	45 / 2	0 / 0	2025
1990	Bear	CDF	SHU	L	58 / 8	240 / 34	301 / 42	115 / 16	379 / 53	106 / 15	84 / 12	143 / 20	0 / 0	713
1990	Recer	USF	MNF	L	608 / 17	1583 / 45	770 / 22	527 / 15	2427 / 70	259 / 7	190 / 5	613 / 18	0 / 0	3489
1991	Bear	USF	MNF	H	48 / 5	352 / 40	437 / 50	40 / 5	568 / 65	154 / 18	93 / 11	62 / 7	0 / 0	877
1991	Rock	USF	SHF	H	73 / 6	153 / 13	314 / 27	606 / 53	275 / 24	88 / 8	113 / 10	670 / 58	0 / 0	1146
1992	Barker	USF	SHF	H	107 / 4	422 / 15	892 / 32	1346 / 49	716 / 26	274 / 10	301 / 11	1477 / 53	0 / 0	2768
1994	Bear	USF	KNF	L	595 / 28	606 / 29	405 / 19	492 / 23	1326 / 63	144 / 7	95 / 5	532 / 25	0 / 0	2097
1994	Jack #1	USF	KNF	L	3591 / 13	13965 / 50	7377 / 26	3233 / 11	19801 / 70	2485 / 9	1920 / 7	3960 / 14	0 / 0	28166
1994	Speciman	USF	KNF	L	2129 / 25	2304 / 27	1637 / 19	2501 / 29	4886 / 57	506 / 6	471 / 5	2709 / 32	0 / 0	8572
1994	Sugarfoot	USF	MNF	H	249 / 9	1053 / 38	1066 / 38	421 / 15	1584 / 57	342 / 12	308 / 11	554 / 20	0 / 0	2788
1995	Pony	USF	KNF	H	223 / 10	1046 / 49	433 / 20	451 / 21	1415 / 66	143 / 7	106 / 5	489 / 23	0 / 0	2153
1996	Fork	USF	MNF	H	2830 / 4	11465 / 15	32266 / 43	29028 / 38	18417 / 24	7522 / 10	12898 / 17	36754 / 49	0 / 0	75591
1996	Rock	USF	SHF	L	758 / 29	1162 / 44	384 / 15	60 / 2	2054 / 78	142 / 5	83 / 3	85 / 3	268 / 10	2631
1999	Bohemotash	USF	SHF	L	835 / 14	2376 / 41	2083 / 36	515 / 9	3836 / 66	761 / 13	516 / 9	696 / 12	0 / 0	5809
1999	East	USF	KNF	L	67 / 6	362 / 30	477 / 39	312 / 26	539 / 44	164 / 13	141 / 12	374 / 31	0 / 0	1218
1999	High	USF	SHF	L	198 / 6	1572 / 47	1303 / 39	281 / 8	2191 / 65	473 / 14	304 / 9	386 / 12	0 / 0	3354
1999	Jackass	USF	SHF	L	1673 / 30	2527 / 45	1226 / 22	136 / 2	4583 / 82	462 / 8	308 / 6	209 / 4	0 / 0	5562
1999	Jones	USF	SHF	H	97 / 4	725 / 27	1388 / 52	483 / 18	1677 / 42	716 / 18	649 / 16	989 / 25	0 / 0	2694
1999	Lunch	USF	SHF	L	308 / 15	1274 / 61	411 / 20	88 / 4	1732 / 83	152 / 7	85 / 4	112 / 5	0 / 0	2081

Year	Fire Name	Agency	Unit	Human or Lightning	Unchanged (ac/%)	Low (ac/%)	Moderate (ac/%)	High (ac/%)	% Canopy Cover Change <25% (ac/%)	% Canopy Cover Change 25-50% (ac/%)	% Canopy Cover Change 50-75% (ac/%)	% Canopy Cover Change >75% (ac/%)	Unmapped (ac/%)	Total (ac)
1999	Megram	USF	SHF	L	11496 / 9	50349 / 41	39649 / 32	22477 / 18	86879 / 70	9239 / 7	7092 / 6	20759 / 17	0 / 0	123970
1999	Onion	USF	SHF	L	4470 / 26	9704 / 57	2126 / 13	617 / 4	14943 / 88	716 / 4	479 / 3	779 / 5	0 / 0	16917
1999	Reptile	USF	SHF	L	161 / 9	613 / 33	743 / 40	347 / 19	972 / 52	247 / 13	207 / 11	438 / 24	0 / 0	1864
1999	Sheep #1	USF	SHF	L	2059 / 17	5995 / 49	2983 / 24	1270 / 10	9061 / 74	1054 / 9	689 / 6	1503 / 12	0 / 0	12307
1999	Sheep #2	USF	SHF	L	494 / 18	1317 / 49	585 / 22	289 / 11	1992 / 74	187 / 7	150 / 6	355 / 13	0 / 0	2685
1999	Sugar	USF	SHF	L	449 / 9	2396 / 46	2011 / 39	331 / 6	3439 / 66	704 / 14	530 / 10	514 / 10	0 / 0	5187
2000	Bark	USF	KNF	H	99 / 5	441 / 23	781 / 40	623 / 32	690 / 35	237 / 12	268 / 14	749 / 39	0 / 0	1944
2000	Cabbage	USF	MNF	H	77 / 5	411 / 27	966 / 64	58 / 4	695 / 46	348 / 23	325 / 21	145 / 10	0 / 0	1513
2000	Journey	USF	SRF	H	122 / 11	313 / 29	361 / 34	271 / 25	517 / 48	113 / 11	119 / 11	319 / 30	0 / 0	1068
2000	Town	USF	MNF	H	127 / 11	377 / 32	368 / 31	320 / 27	583 / 49	112 / 9	120 / 10	377 / 32	0 / 0	1192
2001	Hyampom	USF	SHF	H	84 / 7	487 / 40	300 / 25	341 / 28	665 / 55	105 / 9	69 / 6	373 / 31	0 / 0	1212
2001	Jones	USF	KNF	H	286 / 18	421 / 26	692 / 43	209 / 13	864 / 54	249 / 15	206 / 13	289 / 18	0 / 0	1609
2001	Oregon	CDF	SHU	H	29 / 3	137 / 12	290 / 26	668 / 59	208 / 18	80 / 7	109 / 10	726 / 65	0 / 0	1124
2001	Swillup II	USF	KNF	L	1489 / 18	3892 / 47	2086 / 25	840 / 10	6040 / 73	726 / 9	522 / 6	1019 / 12	0 / 0	8308
2001	Trough	USF	MNF	H	1849 / 7	6954 / 27	8630 / 34	8096 / 32	11046 / 43	2790 / 11	2475 / 10	9217 / 36	0 / 0	25529
2002	Biscuit	USF	SRF	L	576 / 2	1905 / 6	14799 / 50	12253 / 41	3604 / 12	3135 / 11	6531 / 22	16263 / 55	0 / 0	29532
2002	Forks	USF	KNF	H	92 / 6	484 / 33	512 / 35	389 / 26	705 / 48	159 / 11	157 / 11	455 / 31	0 / 0	1477
2002	Stanza	USF	KNF	L	155 / 5	1127 / 38	1108 / 37	567 / 19	1602 / 54	360 / 12	298 / 10	697 / 24	0 / 0	2957
2003	Deafy	UFS	MNF	L	62 / 1	1069 / 22	1721 / 35	2089 / 42	1501 / 30	546 / 11	541 / 11	2353 / 48	0 / 0	4940
2003	Happy Camp	UFS	MNF	L	196 / 12	1006 / 63	354 / 22	33 / 2	1350 / 85	128 / 8	58 / 4	54 / 3	0 / 0	1589
2003	Loma	UFS	SHF	H	605 / 16	2155 / 56	749 / 20	319 / 8	2990 / 78	266 / 7	179 / 5	393 / 10	0 / 0	3828
2003	Spanish	UFS	MNF	H	95 / 2	1475 / 24	2435 / 39	2225 / 36	2173 / 35	856 / 14	690 / 11	2512 / 40	0 / 0	6231
2004	Bear	CDF	SHU	H	587 / 10	1454 / 24	2231 / 37	1694 / 28	3844 / 51	785 / 10	771 / 10	2091 / 28	0 / 0	5967
2004	Eddy 54	USF	KNF	H	553 / 56	352 / 36	74 / 7	12 / 1	932 / 94	22 / 2	19 / 2	17 / 2	0 / 0	990
2004	Sims	UFS	SRF	H	293 / 7	970 / 24	863 / 21	1985 / 48	1498 / 36	279 / 7	234 / 6	2100 / 51	0 / 0	4112
2005	Deer	USF	MNF	H	257 / 14	306 / 17	317 / 17	950 / 52	626 / 34	85 / 5	103 / 6	1015 / 55	0 / 0	1830
2005	Wooley	USF	KNF	L	929 / 27	1723 / 50	550 / 16	227 / 7	2814 / 82	193 / 6	139 / 4	282 / 8	0 / 0	3429
2006	Bake Oven, Pigeon	USF	SHF	L,H	11900 / 12	45290 / 44	26079 / 25	19049 / 19	63215 / 62	9303 / 9	6964 / 7	22836 / 22	0 / 0	102318
2006	Hancock	USF	KNF	L	2991 / 13	12137 / 55	5652 / 25	1407 / 6	16889 / 76	1934 / 9	1440 / 6	1925 / 9	0 / 0	22187
2006	Harvey	USF	MNF	L	153 / 12	878 / 67	243 / 19	30 / 2	1108 / 85	96 / 7	53 / 4	46 / 4	0 / 0	1304

Year	Fire Name	Agency	Unit	Human or Lightning	Unchanged (ac/%)	Low (ac/%)	Moderate (ac/%)	High (ac/%)	% Canopy Cover Change <25% (ac/%)	% Canopy Cover Change 25-50% (ac/%)	% Canopy Cover Change 50-75% (ac/%)	% Canopy Cover Change >75% (ac/%)	Unmapped (ac/%)	Total (ac)
2006	Hunter	USF	MNF	L	1611 / 10	8172 / 50	4687 / 28	1991 / 12	10938 / 66	1703 / 10	1234 / 7	2585 / 16	0 / 0	16461
2006	Kingsley	USF	MNF	L	77 / 12	375 / 61	135 / 22	28 / 5	493 / 80	51 / 8	30 / 5	40 / 7	0 / 0	615
2006	Panther	USF	SRF	L	247 / 26	494 / 53	176 / 19	22 / 2	783 / 83	63 / 7	49 / 5	44 / 5	0 / 0	939
2006	Rush	USF	KNF	L	463 / 9	2780 / 56	1296 / 26	437 / 9	3748 / 75	442 / 9	252 / 5	532 / 11	0 / 0	4975
2006	Somes	USF	SRF	L	4175 / 27	9181 / 59	1675 / 11	607 / 4	14028 / 90	565 / 4	326 / 2	718 / 5	0 / 0	15637
2006	Titus	USF	KNF	L	779 / 12	2471 / 39	1985 / 32	1041 / 17	3755 / 60	641 / 10	583 / 9	1297 / 21	0 / 0	6276
2006	Uncles	USF	KNF	L	552 / 14	1376 / 34	1126 / 28	947 / 24	2242 / 56	399 / 10	297 / 7	1063 / 27	0 / 0	4001
2007	China	USF	KNF	L	417 / 14	1171 / 39	1033 / 34	408 / 13	1807 / 60	367 / 12	279 / 9	576 / 19	0 / 0	3029
2007	Elk	USF	KNF	L	68 / 6	569 / 47	393 / 33	169 / 14	724 / 60	146 / 12	108 / 9	220 / 18	0 / 0	1198
2007	King Creek, Titus, Wingate	USF	KNF	L	1057 / 8	5852 / 42	4900 / 35	2034 / 15	8039 / 58	1792 / 13	1313 / 9	2698 / 19	0 / 0	13842
2007	Little Grider	USF	KNF	L	181 / 8	1274 / 56	676 / 30	127 / 6	1614 / 71	242 / 11	183 / 8	219 / 10	0 / 0	2258
2007	Wallow	UFS	SHF	H	12 / 1	146 / 10	354 / 24	980 / 66	204 / 14	100 / 7	125 / 8	1064 / 71	0 / 0	1493
2008	Anthony Milne	USF	KNF	L	546 / 28	916 / 46	368 / 19	153 / 8	1560 / 79	140 / 7	83 / 4	200 / 10	0 / 0	1983
2008	Back	USF	MNF	L	36 / 2	890 / 55	577 / 36	109 / 7	1083 / 67	214 / 13	133 / 8	183 / 11	0 / 0	1612
2008	Big	CDF	MEU	L	133 / 19	313 / 44	222 / 32	37 / 5	480 / 69	78 / 11	67 / 10	75 / 11	0 / 0	705
2008	Bonanza	USF	SRF	L	12505 / 12	45823 / 45	25794 / 26	16734 / 17	64196 / 64	9249 / 9	6956 / 7	20455 / 20	0 / 0	100856
2008	Blue2, Dark, Mill, Three	USF	SRF	L	287 / 20	791 / 56	261 / 19	16 / 1	1176 / 84	109 / 8	41 / 3	28 / 2	48 / 3	1403
2008	Buckhorn	USF	SHF	L	3634 / 12	15113 / 49	6799 / 22	5329 / 17	20247 / 66	2321 / 8	1877 / 6	6430 / 21	0 / 0	30876
2008	Carey	USF	SHF	L	402 / 10	1461 / 37	1505 / 38	573 / 15	2145 / 54	514 / 13	465 / 12	817 / 21	0 / 0	3941
2008	Caribou	USF	KNF	L	756 / 6	4818 / 36	4206 / 31	2762 / 21	6540 / 49	1528 / 11	1103 / 8	3371 / 25	819 / 6	13361
2008	Cedar	USF	SHF	L	1542 / 6	12184 / 47	7000 / 27	4925 / 19	15305 / 60	2461 / 10	1889 / 7	5996 / 23	0 / 0	25651
2008	Deadshot	USF	SHF	L	63 / 10	301 / 46	146 / 22	148 / 23	397 / 61	46 / 7	39 / 6	173 / 26	0 / 0	658
2008	Deerlick	USF	SHF	L	316 / 25	465 / 37	402 / 32	73 / 6	868 / 69	144 / 11	116 / 9	129 / 10	0 / 0	1256
2008	Eagle	USF	SHF	L	2001 / 7	16100 / 53	8665 / 29	3528 / 12	20378 / 67	3214 / 11	2112 / 7	4591 / 15	0 / 0	30294
2008	Grouse	USF	MNF	L	353 / 5	3617 / 55	2190 / 33	452 / 7	4697 / 71	862 / 13	439 / 7	615 / 9	0 / 0	6611
2008	Gulch	USF	SHF	H	37 / 1	486 / 16	1385 / 47	844 / 29	702 / 24	456 / 15	456 / 15	1138 / 39	199 / 7	2951
2008	Half	USF	SRF	L	2866 / 19	8172 / 53	3282 / 21	1144 / 7	11886 / 77	1216 / 8	807 / 5	1556 / 10	0 / 0	15465
2008	Iron, Harvey, Slides, Thomes, Vinegar	USF	MNF	L	6601 / 13	26608 / 51	16276 / 31	3040 / 6	37903 / 72	6180 / 12	3732 / 7	4710 / 9	0 / 0	52525
2008	Ironside	USF	SHF	L	4424 / 33	6731 / 50	1718 / 13	493 / 4	11631 / 87	638 / 5	409 / 3	689 / 5	0 / 0	13366

Year	Fire Name	Agency	Unit	Human or Lightning	Unchanged (ac/%)	Low (ac/%)	Moderate (ac/%)	High (ac/%)	% Canopy Cover Change <25% (ac/%)	% Canopy Cover Change 25-50% (ac/%)	% Canopy Cover Change 50-75% (ac/%)	% Canopy Cover Change >75% (ac/%)	Unmapped (ac/%)	Total (ac)
2008	Jake	USF	KNF	L	4172 / 11	14693 / 38	13600 / 35	6517 / 17	21804 / 56	4881 / 13	3747 / 10	8549 / 22	0 / 0	38982
2008	Lime	USF	SHF	L	3852 / 14	15363 / 56	6448 / 24	1626 / 6	20955 / 77	2461 / 9	1524 / 6	2348 / 9	0 / 0	27288
2008	Mill	USF	MNF	L	401 / 13	1705 / 54	783 / 25	255 / 8	2288 / 73	281 / 9	213 / 7	362 / 12	0 / 0	3144
2008	Miners	USF	SHF	L	3645 / 14	13316 / 52	6356 / 25	2487 / 10	18630 / 72	2392 / 9	1524 / 6	3257 / 13	0 / 0	25803
2008	Monkey Rock	USF	MNF	L	491 / 25	1056 / 53	308 / 16	132 / 7	1641 / 83	108 / 5	66 / 3	171 / 9	0 / 0	1986
2008	Motion	CDF	SHU	L	168 / 2	2722 / 26	4452 / 43	3030 / 29	3605 / 35	1423 / 14	1407 / 14	3913 / 38	0 / 0	10372
2008	Noble	USF	SHF	L	833 / 14	2541 / 43	2032 / 35	480 / 8	3793 / 64	685 / 12	620 / 11	787 / 13	0 / 0	5886
2008	Panther, Merrill, Haypress	USF	KNF	L	4822 / 7	27865 / 39	19925 / 28	18585 / 26	36993 / 52	6914 / 10	5502 / 8	21788 / 31	0 / 0	71197
2008	Slide	USF	SHF	L	247 / 20	673 / 55	265 / 22	34 / 3	995 / 82	107 / 9	60 / 5	58 / 5	0 / 0	1220
2008	Stein	CDF	SHU	L	149 / 12	909 / 73	169 / 14	11 / 1	1113 / 90	67 / 5	30 / 2	28 / 2	0 / 0	1238
2008	Telephone	USF	SHF	L	551 / 7	3362 / 45	2490 / 33	1091 / 15	4556 / 61	886 / 12	626 / 8	1425 / 19	0 / 0	7493
2008	Trough	USF	SHF	L	227 / 6	969 / 25	1290 / 34	1333 / 35	1410 / 37	425 / 11	420 / 11	1564 / 41	0 / 0	3819
2008	Whiskey	USF	MNF	H	195 / 3	1109 / 19	2702 / 46	1351 / 23	1673 / 27	820 / 13	1147 / 18	2100 / 33	545 / 9	5902
2008	Yellow, Camp, Johnson	USF	MNF	L	3093 / 9	17331 / 52	8050 / 24	4689 / 14	22714 / 68	3014 / 9	1858 / 6	5575 / 17	0 / 0	33162
2008	Zeigler	USF	SHF	L	631 / 25	1442 / 57	408 / 16	52 / 2	2192 / 87	172 / 7	85 / 3	83 / 3	0 / 0	2532

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