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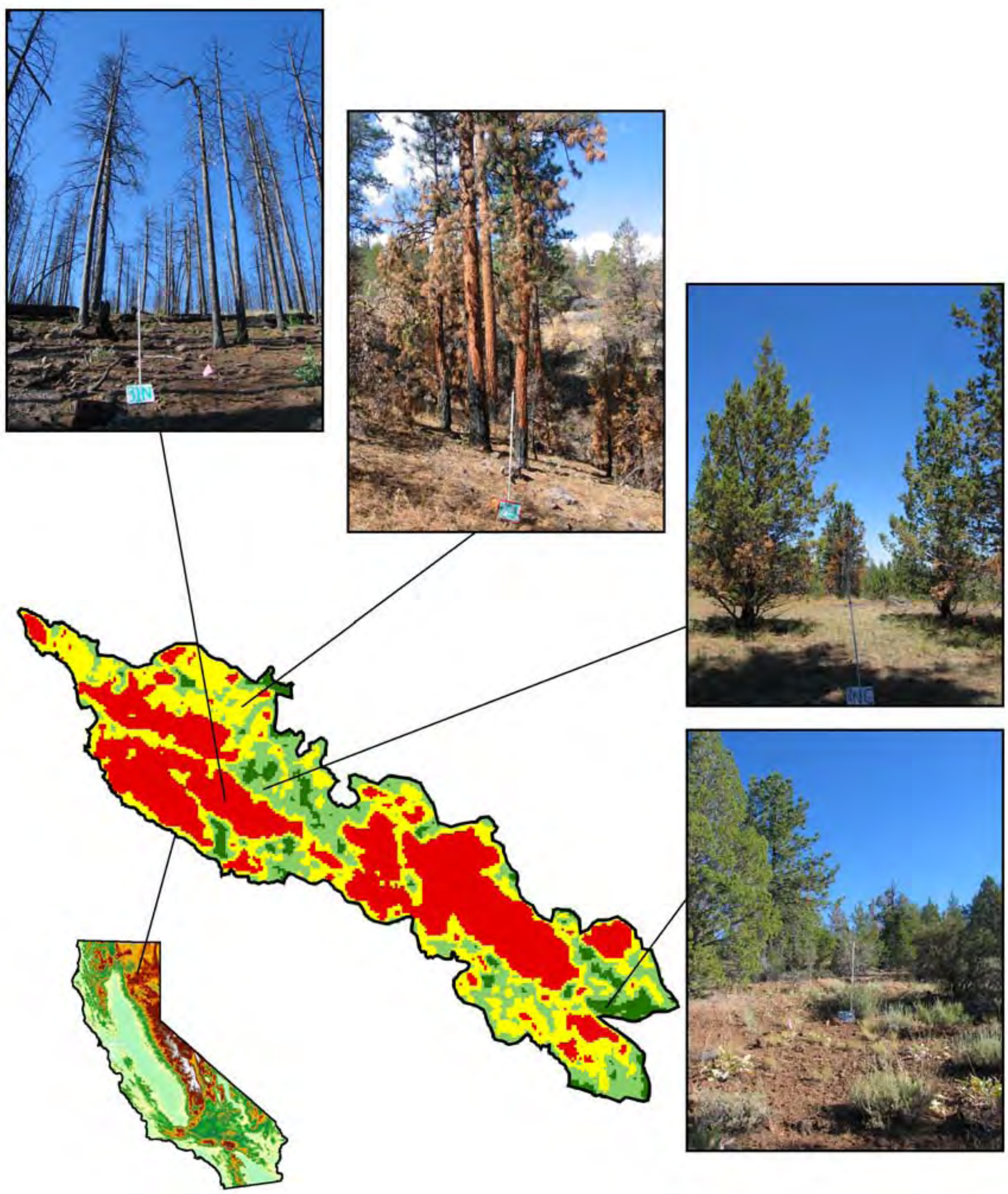
Sierra Nevada Fire Severity Monitoring 1984-2004



Sierra Nevada

Fire Severity Monitoring 1984 – 2004

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Executive Summary

Background

This report presents the findings of the Sierra Nevada Forest Plan Amendment (SNFPA) Fire Severity Monitoring Program for the period 1984-2004. The Fire Severity Monitoring Program (FSMP) is a fundamental component of the SNFPA monitoring plan as originally outlined in the Final Environmental Impact Statement (USDA 2001) and confirmed in the Final Supplemental Environmental Impact Statement (USDA 2004). Data collected by the FSMP are important for addressing a number of pivotal resource management questions in the SNFPA area, as well as for validating underlying assumptions of the SNFPA.

Objectives

The primary objectives of this project were to: 1) reassess estimates of vegetation-based severity used in the Sierra Nevada Forest Plan Amendment Final Environmental Impact Statement (SNFPA FEIS) (USDA 2001) by directly mapping severity for a widespread sample of fires, and 2) quantitatively evaluate current spatial and temporal trends in fire regimes in the SNFPA area.

Approach

The basic approach was to develop a fire severity atlas for a large and representative sample of fires in the SNFPA area using satellite imagery and fire severity mapping methods based on existing US-Geological Survey and National Park Service protocols. Field plot data were collected one-year post-fire on fires at a variety of locations and in multiple vegetation types in order to calibrate the imagery to the Composite Burn Index (CBI) and tree basal area mortality.

In this report, fire severity data are reported in three ways. First, satellite acquired imagery is used to produce continuous distribution curves of vegetation-based severity by vegetation type over multiple fires. The distribution curves are compared to conceptual severity distributions assumed to be representative of different historical ("pre-settlement") fire regimes. Secondly, the continuous data are divided into four CBI-defined severity categories (high, moderate, low, unburned) for each fire. Proportional representation of the different severity categories from the sampled fires from 1984-2004 is compared to the severity assumptions produced by the SNFPA Final Environmental Impact Statement (FEIS). Trends from 1984-2004 are analyzed (1) in the proportional representation by area of high severity vs. other severity classes in a variety of vegetation types, and (2) in patch sizes of high severity fire in conifer forests. Wildland fires managed as Wildland Fire Use (WFU) fires since 2001 are also compared with wildfires (wildland fires not managed as WFU). Third, the continuous data are divided into seven fire severity categories based upon tree basal area mortality and are reported for each fire. All analysis by vegetation type, including patch size, was performed only on acres administered by the U.S.

Forest Service. We also report temporal trends in fire size and annual burned area between 1908 and 2006 for all fires in the FEIS analysis area using the fire history database for the state of California. Finally, we explore relationships of climate to percent high severity fire, number of fires, fire size, and annual burned area.

Findings

1. Both time series regression and ten-year moving averages document increases in the proportion of high severity fire in the majority of the area burned on U.S. Forest Service lands in the SNFPA area. However, the proportional area of fires burning at high severity showed strong interannual variability. At the beginning of the period of analysis, about 14% of the area affected in forest fires burned at high severity; by the beginning of the 21st century the high severity component had increased to over 23%. Different forest types showed different patterns within this general trend. The ten-year moving average for percent high severity fire in mixed conifer forest shows an increase from 17% of fire area on average on U.S. Forest Service lands to about 27% over the analysis period. Severity in forested areas dominated by white fir and black oak increased at the greatest rate, growing by 200-300% across the analysis period. Fires in lower to middle elevation evergreen (live) oak forests were only marginally more severe on average at the end than at the beginning of the period, and both high elevation forests and low elevation westside ponderosa pine showed no increase in the proportion of high severity fire.

2. The average size of contiguous areas ("patches") of stand-replacing fire within conifer forests almost doubled across the period of analysis, rising from a mean of about 7 ac. in the first ten-year period to about 13 ac. in the last period. High severity patch size was found to be positively related to fire size, which likely has roots in the close correlation between large fire incidence and extreme fire weather.

3. The actual proportion of high severity acres (vs. other severities) in 1984-2004 fires was less in conifer forest than the assumed proportions used in the FEIS analysis. The percentages for eastside pine forest were comparable, differing by only 5%, but estimates for the high severity component in mixed conifer, ponderosa pine, and white fir forests were 44-55% percent higher in the SNFPA FEIS. It is not surprising that the FEIS estimates were somewhat higher than the results presented here since existing vegetation maps were used to estimate severity as opposed to directly measuring severity as was done for this report. Assumptions were made during the FEIS analysis about vegetation structure that was not necessarily true. For example, it was assumed that all areas converted to plantations within fire perimeters had experienced stand replacing fire.

4. The percentage of high severity acres (vs. other severities) in WFU fires (since 2001) was 13% on average as opposed to 19% in non-WFU wildfires. The difference in severity between WFU

managed fires and wildfires was primarily mediated through differences in two vegetation types, eastside pine and mixed conifer. All fires that were compared occurred in similar vegetation types and at approximately the same elevation. However, only one WFU fire and one wildfire occurred in the same year. Therefore differences in antecedent moisture conditions may have influenced the results of the comparison.

5. The overall area burned in forest fires and number of fires larger than 100 ac. per year dropped from the 1930's through the middle of the century, but area burned has been increasing at a rapid rate since the 1970's and especially since the early 1980's. Mean and maximum fire size have both risen since the beginning of the fire record, but the increase has entirely occurred over the last two or three decades. Current values for mean and maximum fire size appreciably exceed those seen over the previous 80 years while annual number of fires over 100 ac. has remained relatively low.

6. Fire size and annual burned area in the first half of the 20th century were negatively correlated with winter precipitation and positively correlated with spring maximum temperatures, with the correlations shifting in the second half of the century to negative correlation with spring precipitation and positive correlations with summer temperatures. In similar fashion, the number of fires was also negatively correlated to winter precipitation in the first half of the century, and negatively correlated to spring precipitation in the second half of the century. However, unlike fire size and annual area burned, the number of fires remained positively correlated with summer maximum temperatures over the whole century. For all long-term fire variables, the strength of the climate-fire relationship increases considerably from the first to the second half of the record.

7. Mean annual precipitation over the analysis area increased by approximately 10 inches between 1908 and 2006. There were no temporal trends in mean maximum temperature, but mean minimum temperatures showed significant increases. Precipitation also explained more of the variation in fire size and annual burned area over time, while temperature explained less. It may be that higher fuel loads due to increased precipitation; longer growing seasons through warmer nighttime temperatures, and the general absence of fire has lead to conditions that are now less limiting to the occurrence of fire and higher severity fire in the low and middle elevation forests in the SNFPA area.

Discussion

The results presented here provide the first quantitative demonstration that the extent of forest stand-replacing fire is increasing across a significant part of the SNFPA area. Fires in most low and middle elevation forest types are currently burning at higher severity than before Euroamerican settlement, and the magnitude of that departure is increasing with time. Forest types most affected by increasing fire severity are those which 1) form the majority of the lands administered by the U.S. Forest Service; 2) support most remaining habitat for a suite of old-forest obligate carnivores and raptors whose declining populations led to the SNFPA in the first place [for example, California spotted owl (*Strix occidentalis occ.*), goshawk (*Accipiter gentilis*), and fisher (*Martes pennanti*)]; 3) see the heaviest human resource extraction and recreation use; and 4) are experiencing rapid growth in human population. Through their growing tendency to kill larger patches of canopy trees, contemporary fires are contributing to increasing levels of forest fragmentation. With continuing increases in the extent of high severity fire and high severity patch size, post-fire erosion, stream sedimentation, nutrient cycling and natural forest regeneration processes will also be increasingly impacted (Pickett and White 1985; Hobbs and others 1992; Sugihara and others 2006), and human safety is also a rising concern (USDA 2004). The magnitude of these effects is still buffered by the fact that most fires are controlled during initial attack (Calkin and others 2005), but the number, severity, and size of fires that exceed initial attack capability is increasing across the study region.

Using a 1970-2003 dataset, Westerling and others (2006) showed a dramatic increase in large fire frequency in the western US beginning in the mid-1980's, centered in the northern Rockies and northern California (our study area plus adjoining coastal forests). Our data, which are from a smaller spatial scale but much broader temporal scale and which include medium-sized fires, corroborate Westerling and others' (2006) findings and show that the post-1980 increase in fire activity is not restricted to fire frequency, but extends to fire size and annual burned area as well, at least in the SNFPA area. Although our fire severity dataset only begins in 1984, we hypothesize that the increases we see in the extent of forest stand-replacing fire in the study region are linked to these longer-term patterns. Like Westerling and others (2006) we find a significant relationship between climate and wildland fire activity, but the temporal extent of our fire perimeter dataset allows us to discern three important trends in the nature of this relationship over time. First, early in the 20th century fire size and annual burned area in the study region responded largely to winter precipitation and springtime temperature (which influences snowmelt), but these fire variables now respond more directly to precipitation and temperature during the fire season itself. Second, fire number, size and annual burned area - and, at least over the last quarter-century, fire severity - have been rising in the study region even as regional precipitation has increased. Third, we document a strong increase in the relative importance of precipitation and temperature in driving fire size and annual burned area over the last century. Heat, oxygen, and fuel are the fundamental extrinsic factors regulating fire combustion and maintenance. Precipitation has a direct influence on fire through the wetting of fuel. But warming nighttime temperatures lead to an earlier snowmelt, which in turn leads to drying of fuels earlier in the year and a longer fire season. Increasing annual precipitation and warmer nighttime temperatures also have an indirect positive effect on fire activity due to increased fuels resulting from a longer growing season and augmented vegetation growth. Additionally, across California current annual burning affects only 6% of the area burned annually before Euroamerican settlement (Stephens and others 2007). The temporal patterns we see in the climate-fire relationship are clearly due in part to increasing mean nighttime temperatures, but our results suggest a prominent role for increasing levels of forest fuels, presumably from a combination of fire suppression and increasing annual precipitation. With respect to fire severity, most of the forested landscape within the SNFPA area historically supported relatively high frequencies of low to moderate severity fire and thus fairly low fuel loadings. We hypothesize that the pattern of an increasing proportion of high severity fire in SNFPA conifer forests we have measured is to a large extent an effect of the current and continuing absence of an agent to remove forest fuels at a rate compatible with their accumulation.

Applications

A wide variety of Pacific Southwest Region organizations are using the fire severity data produced by this project. A partial list includes: the Stewardship and Fireshed Assessment process for post-fire revision of fuel data layers, and calibration of fire behavior and fire effects modeling; the SNFPA California fisher working group for calibrating and validating model outputs; the Regional Ecology Program for fire regime mapping and post-fire inventory stratification; the Remote Sensing Lab for updating vegetation maps after fire occurrence; the Regional Center for Post-fire Restoration, for rapid assessment of deforested acres within fire perimeters; for assessment of fuels treatment effectiveness to alter fire behavior.

Introduction

Background

Concerns about the effects of fires to communities, old growth forests, and wildlife species dependent on late seral conditions, such as the California spotted owl and California fisher, were primary reasons for the Sierra Nevada Forest Plan Amendment Final Environmental Impact Statement (USDA 2001) (SNFPA FEIS). Fire and fuels is the central issue to all seven of the other topic areas addressed in the FEIS: old forests; air quality; sociocultural conditions; soil productivity; noxious weeds; lower Westside hardwoods; and aquatic, riparian, and meadow habitats. The level of concern regarding threats on habitat for species at risk posed by fire and the effects of fire and fuels management is of particular concern. A monitoring plan to track vegetation-based fire severity from medium and large fires was developed by Andrea Thode and others to measure how the FEIS addressed these issues. We report here on (1) the initial fire severity atlas developed to characterize landscape level trends in fire severity for the SNFPA area, and (2) results from analysis of that atlas.

Fire 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 2005a). 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 and others 2006). Therefore in addition to CBI, we collected individual tree mortality data in our field plots and produced severity map products in units of CBI and percent tree basal area mortality.

Burned Area Emergency Response (BAER) post-fire severity maps are based on severity to soils and hydrologic function (USDA 1995; Parsons 2003; Safford and others 2008). BAER soil burn severity maps differ in purpose from vegetation burn severity maps (such as those generated and analyzed here) whose main purpose is the identification of the extent of stand-replacing fire. Areas mapped as high, medium and low severity by a BAER soil burn severity map and a vegetation burn severity map will often not be coincident (especially at high severity), and even where they are, their focus is on different aspects of ecosystem response to fire (Safford and others 2008). For example, a forested area where all of the trees have been killed but the needles remain on the branch would be classified as high severity in a vegetation burn severity map, but as moderate severity in a soil burn severity map, because the needles will provide soil cover as they drop (Figure 1).

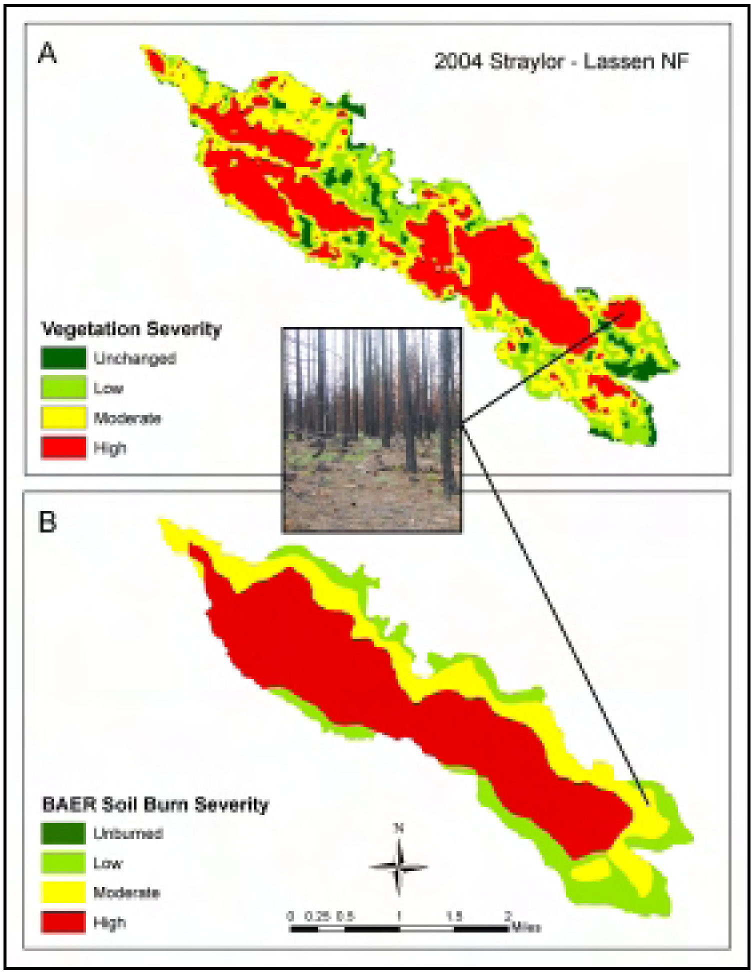

Figure 1. Comparison of BAER soil burn severity map to vegetation based severity map.

Beginning in 2006 the Wildland Fire Leadership Council sponsored the national interagency funded (USDI and U.S. Forest Service) Monitoring Trends in Burn Severity (MTBS) program. The data presented in this report were collected following the general MTBS methodology (developed by USGS and the National Park Service), with a few basic differences (Key and Benson 2005b). First, the national program is limited to fires greater than 1,000 ac., whereas our effort sampled fires over 100 acres in size. Secondly, the mapping methods employed by MTBS follow the methods used by the Remote Sensing Applications Center (RSAC) to produce Burned Area Reflectance Classification (BARC) maps for BAER teams, which do not correct for pre-fire cover and therefore can under represent stand-replacing fire (Miller and Thode 2007; Safford and others 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 Appendix A and in Miller and Thode (2007). Thirdly, 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 across the SNFPA area.
The results presented in this report are based upon a sample of fires over 100 acres that occurred in the SNFPA area from 1984 through 2004. The MTBS program will deliver data for all fires over 1000 acres for the State of California for 1984 through 2004 during Fy2008. Upon delivery of those statewide data, results presented in this report for the SNFPA area can be updated (if necessary), and methods used here can be applied to other regions of the state.

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 (2001), 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. Erman and Jones (1996) used fire occurrence data for an analysis of fire frequency on the Forests within the SNFPA area, but concluded that the hypothesis that larger fires were occurring more frequently was unsubstantiated for much of the SNFPA area. Recently Westering and others (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-1980's. Although there is substantial evidence for recent increases in fire size and frequency (Erman and Jones' results notwithstanding), 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 (Erman and Jones 1996; McKelvey and others 1996). The severity atlas produced for this report provides the first means for evaluating that question for SNFPA ecosystems, and indeed for any similarly sized area in the western United States.

Objectives

Analysis used to develop management options for the SNFPA FEIS (USDA 2001) estimated the percentage of lethal, mixed-lethal and non-lethal fire by vegetation type that occurred in the SNFPA area between 1974 and 1988 (Hermit 1996). Our primary objectives were to reassess those estimates by directly mapping severity for as many fires as possible and evaluate current trends in fire regimes for the SNFPA area. Additional objectives were to evaluate how well the remote sensing approach developed by Key and Benson (2005b) in Glacier National Park worked in SNFPA area and to develop a field data set to generate site specific calibration and interpretations of fire severity.

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 are detailed in Appendix A.

Spatial Extent and Time Period Covered

Our objective was to map all fires over 1000 acres that occurred at least partially on U.S. Forest Service administered lands in the SNFPA area between 2000 and 2004, and all fires over 100 acres between 1984 through 1999. We were not able to map all fires for the entire 1984 through 1999 period due to budget and time restraints. We mapped all fires greater than 100 ac. that occurred in the central SNFPA area between 1984 and 2004 covered by Landsat scenes P43R33, P43R34, and P43R34 (Figure 2). We added to this sample a subset of fires greater than 100 ac. that occurred elsewhere in the SNFPA area. We also included a complete coverage of all fires greater than 1000 acres that occurred between 2000 and 2004. Figure 2 depicts the extent and time period covered by Landsat data acquired by the project. We only mapped fires that occurred at least partially on U.S. Forest Service administered lands.

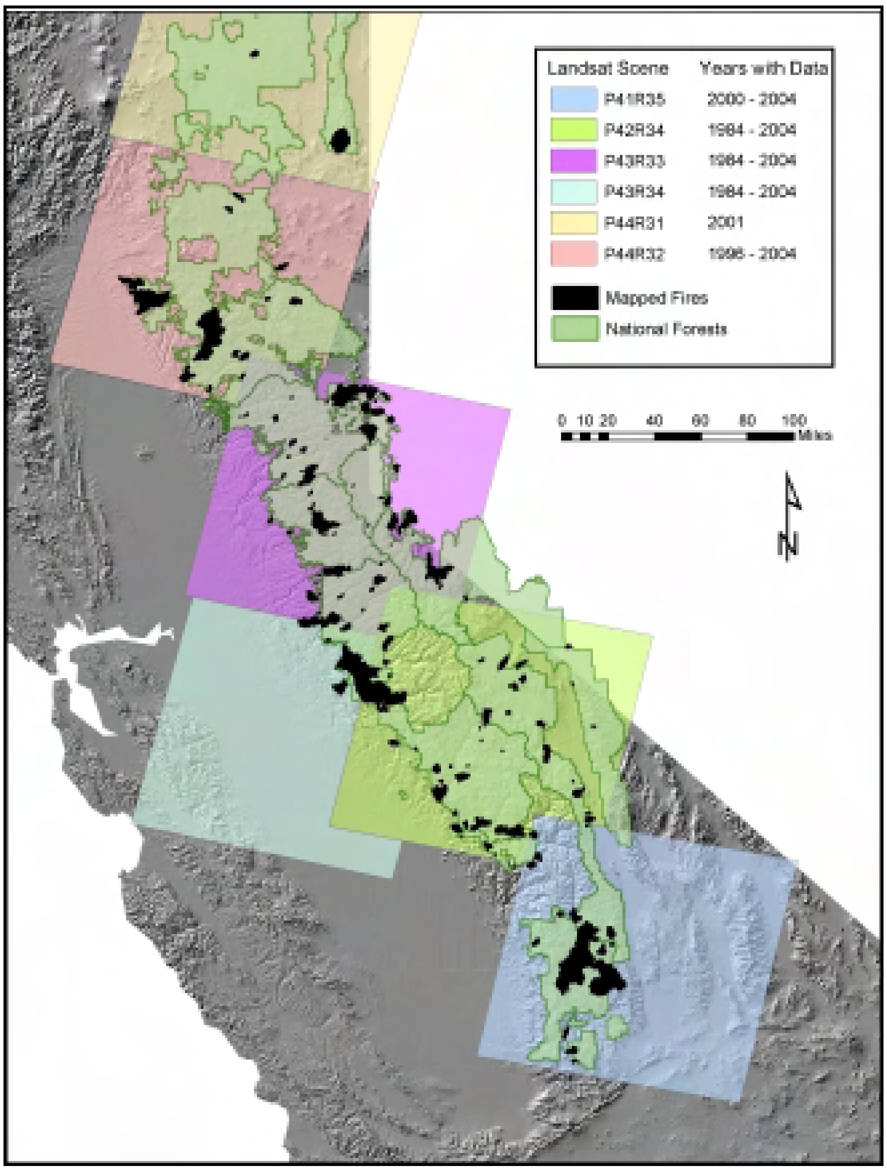

Figure 2. Location and time period of fires with respect to Landsat path/row location.

Considering only fires greater than 100 ac., the size-distribution of sample of fires we mapped is not significantly different from the complete fire history for the entire SNFPA area from 1984-2004 (χ^2 = 9.051, P = 0.249, df = 7), and mean fire sizes of our sample and the complete SNFPA area record are comparable (t = 1.172, P = 0.242, df = 614). There is also no latitudinal gradient in the severity of fires less than 1000 ac. in size (R^2 = 0.00003), that is, although our sample for fires less than 1000 ac. is more inclusive for the central study area, there is no systematic difference in fire severity for small fires between the north, central, and south study area that might bias our results. In short, there is no statistical reason to believe that our sample of fires is not representative of the entire population of fires that occurred in the SNFPA area during the 1984-2004 period. We mapped a total of 197 fires, totaling 1,192,627 ac. and accounting for 59% of the total area burned in the 1984-2004 time period across the SNFPA area. Of the sampled fire area, 71% occurs on U.S. Forest Service (USFS) lands, 29% on lands of other jurisdictions (Table 1). We did not include any fires that overlapped (3% of the total mapped area) in the analysis involving forest type since we did not have vegetation maps updated at sufficiently frequent intervals to capture fire-related vegetation changes. As a result, analyses carried out under the forest type stratification use data from 177 of the 197 total fires. All mapped fires were used in all remaining analyses.

Table 1. Number of acres by ownership in mapped fires

Ownership	Area (ac)
Private Lands	236,577
State Lands	26,789
Other	2,033
BLM	57,849
NPS	23,897
USFS	847,792

There were no temporal trends in precipitation 1984-2006. Based on means for the Sierra Nevada, the 1984-2006 period was at the 112-yr mean for precipitation (mean annual precipitation 1984-2006 divided by 112-yr mean = 1.002) and precipitation variability (average of annual standard deviations from 112-yr mean = 0.327; 1984-2006 mean of standard deviations = 0.326). Mean maximum temperatures did not change significantly 1984-2006; with respect to the mean minima, only the mean for June-August increased (+1.7° C, R^2 = 0.177, P = 0.046).

Wildland Fire Use fires

Fires mapped for this report included fires that were both suppressed as wildfires, and fires that were managed as Wildland Fire Use (WFU) fires. WFU fires account for about 4% of the area within all the fires mapped for this report. Considering only fires greater than 100 ac. in size, WFU fires account for about 3% of the SNFPA area burned as recorded in the state fire history database for the same time period. Fires analyzed for this report therefore are representative of the entire population of fires on a whole. About 2,900,000 ac. of U.S. Forest Service lands in the SNFPA area are managed as WFU areas, where naturally ignited fires may be allowed to burn without direct suppression, depending on a variety of factors including weather, fire location, staffing and budget. In addition, about 80% (approx. 1,000,000 ac.) of Yosemite and Sequoia-King Canyon National Parks are managed as WFU. Across the broader study region, about 13% of all lands are managed under WFU authority, but since these areas are in almost all cases high elevation wilderness areas with low fuel loads, WFU fires tend to remain small. Since relatively few fires are managed as WFU, the total area burned in WFU fires is very small as well. Two studies using similar methodologies to our own have recently demonstrated increased severities of fire in WFU-managed areas in Yosemite National Park and the Gila Wilderness in New Mexico. The Yosemite study – which is nested within our larger study region – measured a large increase in fire severity in the mid-1980's, but little subsequent rise (Collins 2007). The probability of a fire re-burning a previously burned area was limited by the time since last fire, suggesting that natural fire processes in the studied watershed were limiting fuels. This is very different from most of the study region as a whole, where long-term fire suppression has generated a fuels-rich environment. In the Gila study, Holden and others (2007) also saw a significant rise in fire severity in the period 1984-2004, but could not rule out precipitation effects in their analysis.

Ecological Stratification for Reporting

Fires were stratified geographically by latitude for reporting purposes. The three broad latitudinal regions (northern, central, and southern, as shown in Figure 3) correspond to latitudinal breaks between CALVEG ecological zones North Interior, North Sierran, and South Sierran (USDA 2005). The number of fires that fell within each latitudinal zone is listed in Table 2.

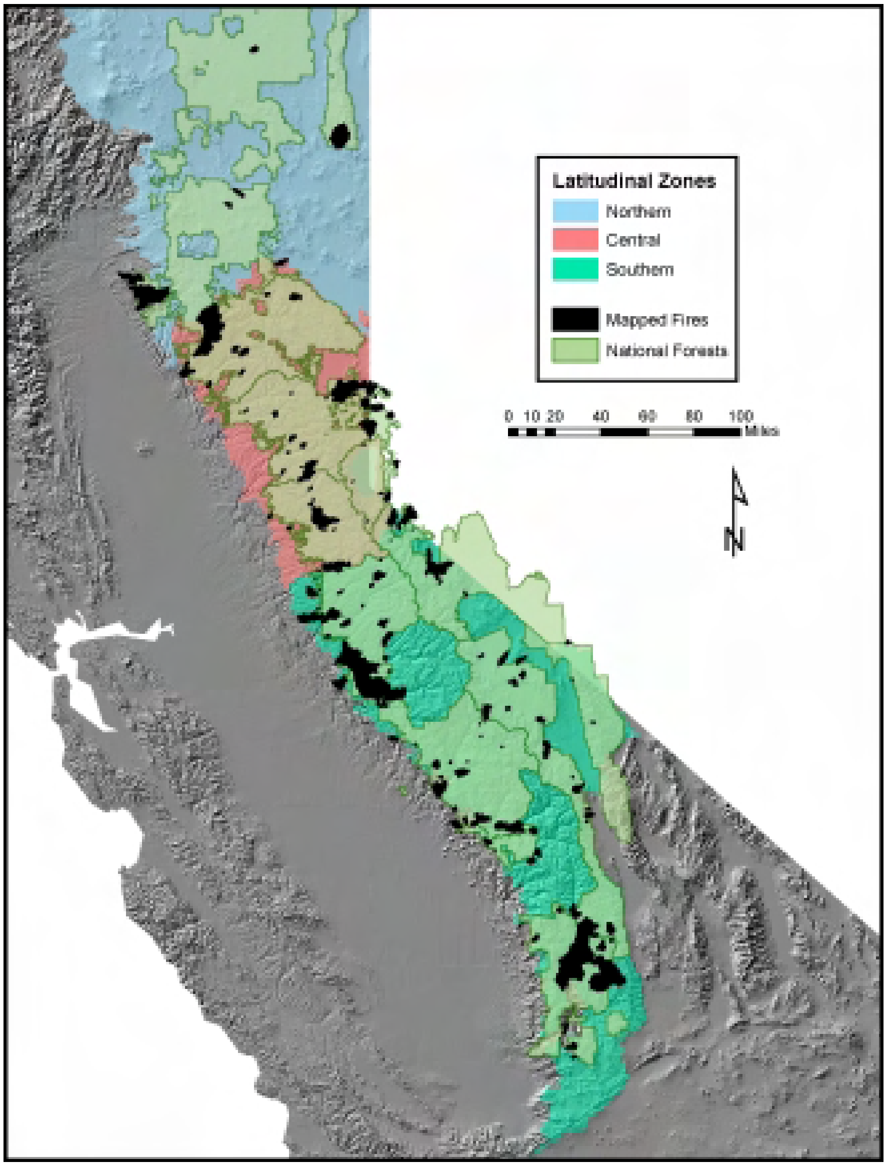

Figure 3. Stratification of fires corresponding to latitudinal ecological zones.

Table 2. Number of fires within each latitudinal zone

Latitudinal Zone	Number of Fires
Northern	9
Central	47
Southern	141

Remote Sensing and Field Calibration Data

Fire severity was mapped using imagery acquired by Landsat satellites. The Landsat data were converted to the relative differenced Normalized Burn Ratio index (RdNBR) which is correlated to fire effects on vegetation (Miller and Thode 2007). The "Normalized Burn Ratio" (NBR) is a measure derived using reflectance from Bands 4 and 7 in the Landsat TM 30-m satellite data (Key and Benson 2005b). 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 and others 2007). Where pre-fire images are available, the post-fire NBR measure can be subtracted from a pre-fire measure to give "delta" or "differenced" NBR (dNBR) (Key and Benson 2005b). The relative dNBR (RdNBR) is created by dividing the dNBR measure by the pre-fire NBR in order to remove the biasing effect of the pre-fire vegetation condition (Miller and Thode 2007; Safford and others 2008).

Satellite data obtained one year post-fire and one to two years pre-fire were used to calculate the RdNBR index. Field data collected on 14 fires in the SNFPA area during 2002 through 2005 were used to "calibrate" the satellite derived RdNBR index to a composite measure of severity and tree based severity data. Field data were collected utilizing the FIREMON composite burn index (CBI) methods (Key and Benson 2005a) with additional quantitative measures of effects to trees. CBI is primarily a measure of severity to vegetation and is calculated as the linear average of fire effects seen in all vegetation strata (understory, midstory and overstory), as well as exposed surface soil, and non-photosynthetic surface fuels. In addition to CBI, we collected individual tree mortality data in our field plots and produced severity map products in units of percent tree basal area mortality. The data are reported here in three different ways. First, a continuous measure of severity provided by the relative RdNBR index is used to produce severity distribution curves by vegetation type over multiple fires. Secondly, the RdNBR data are divided into four broad categories of severity for each fire based upon the composite burn index. Third, the RdNBR data for each fire are divided into seven categories of severity based upon tree mortality. The assumptions underlying the latter two measures are described in more detail below and in Appendix A.

Fire Severity Ratings Based on the Composite Burn Index

The satellite derived RdNBR index was calibrated to the field measured CBI through regression analysis. 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 and others 1998). Key and Benson (Key and Benson 2005a) 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 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. Table 3 lists the CBI thresholds used and generalized descriptions of the severity categories. Figure 4 depicts photos representative of each severity category taken from actual field validation plots. User map accuracies of high severity patches average about 76%, moderate about 63% and unchanged to low about 68% (see Appendix A for details).

Table 3. CBI based 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.

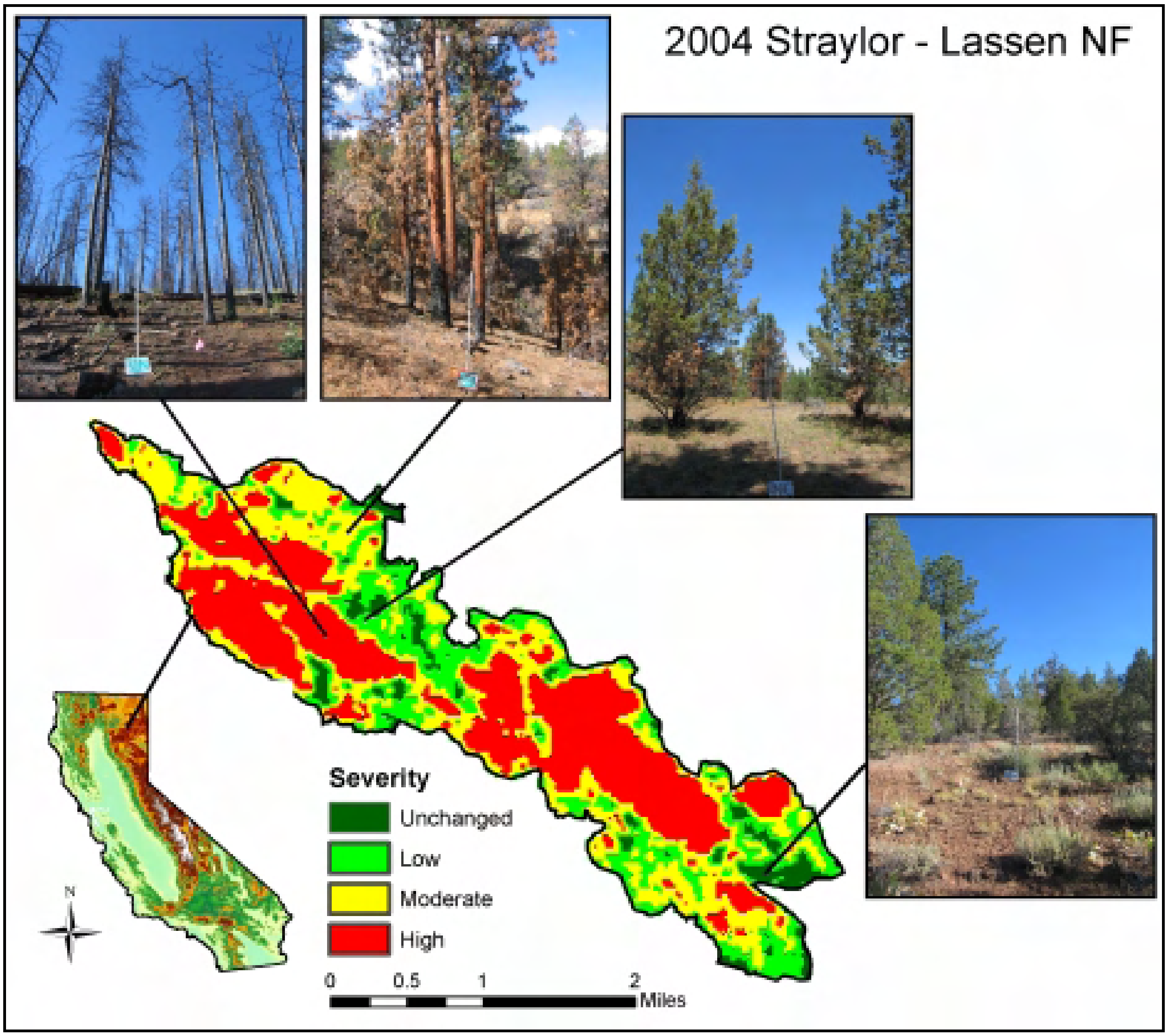

Figure 4. Example field plot photos of CBI based severity categories.

Fire Severity Ratings Based on Tree Mortality

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 and others 2006). We therefore also developed fire severity ratings based upon tree mortality, in contrast to the CBI approach described above. We measured tree mortality by size class one year post-fire in the same plots where we measured CBI to develop a regression model of percent tree basal area mortality to the RdNBR index. Percent tree basal area mortality was calculated as the proportion of total tree basal area of dead trees to pre-fire basal area. Data from plots with at least 5% pre-fire tree canopy cover were used in developing the regression model. A typical map of percent basal area mortality categorized into seven classes is shown in Figure 5. Characteristic of most fires, high severity patches are surrounded by rings of decreasing severity. The seven 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 [the U.S. Forest Service considers 10% to be the lower limit for defining forested areas (Brohman and Bryant 2005)], combining the seven categories into three broad classes accuracies for patches greater than 75% change in basal area average 80%; accuracies of areas with less than 25% change average about 70%, and areas between 25 and 75% change in basal area average only about 37% accurate, which is not much better than random (see Appendix A for details). Given the high accuracy at identifying high severity patches and the low accuracy for areas with 25-75% change, these maps should best be used only to locate and analyze areas of high severity fire.

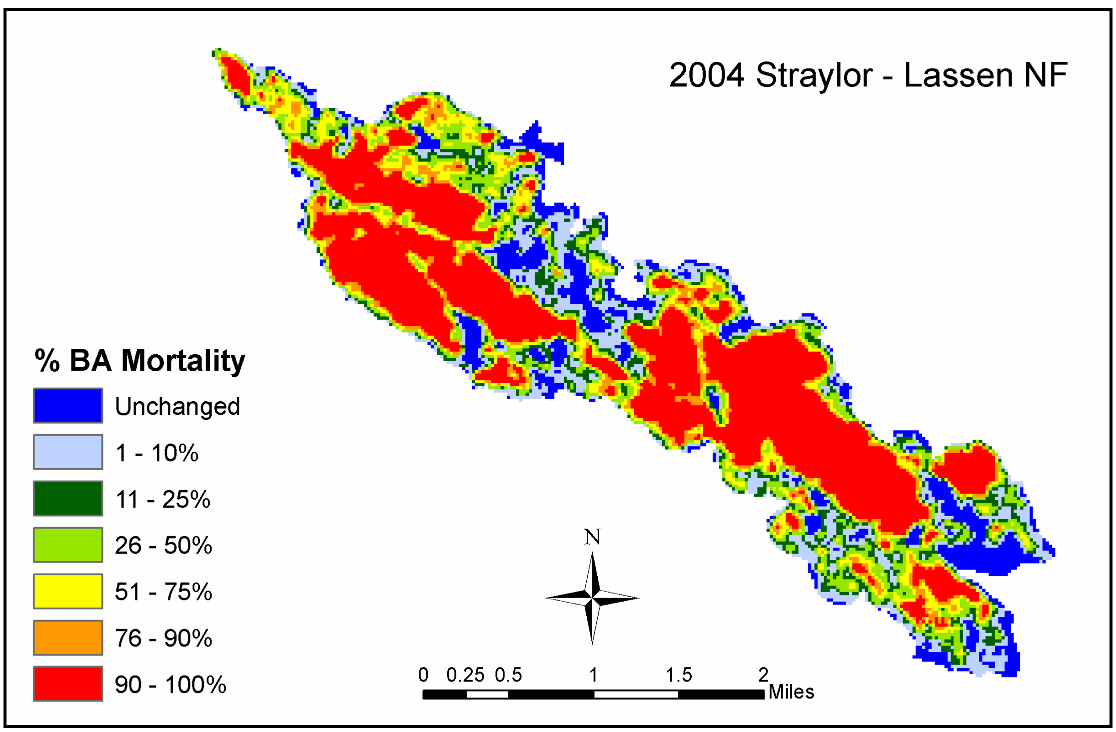

Figure 5. Typical map of percent basal area mortality.

Stratification by Vegetation Type

One of the primary objectives of this report was to reassess the analysis used in the SNFPA FEIS that estimated the percentage of lethal, mixed-lethal and non-lethal fire by vegetation type (Hermit 1996). That analysis used the first CALVEG vegetation maps developed for California through classification of Landsat imagery by the U.S. Forest Service Pacific Southwest Region Remote Sensing Lab (RSL) (USDA 2005). The vegetation types were comprised of CALVEG dominance types grouped into nine regional types: ponderosa pine, eastside pine, mixed conifer, white fir, pinyon-juniper, black oak, live oak, blue oak, and chaparral shrub. We used the most recent version of CALVEG to lump Dominance Type into the same nine types as were used in the FEIS and we added four more types: lodgepole pine, red fir, riparian and subalpine conifer (Table 4). Since one of the primary objectives of this report was to reassess the severity estimates made for the SNFPA FEIS, we aggregated CALVEG types into the same groupings that were used in the original FEIS analysis, even though ecologically those groupings may not make the most sense. For example, single-leaf pinyon pine and western juniper CALVEG types were lumped together for the FEIS analysis even though the two types have distinctly different distributions, and possibly different fire regimes. A description of each regional group including a range distribution map derived from CALVEG can be found in Appendix B of this report.

Table 4. CALVEG dominance type groupings

Dominance Type	Description	Regional Type	Code
QK	Black Oak	Black Oak	QK
QD	Blue Oak	Blue Oak	QD
PD	Gray Pine	Blue Oak	QD
QL	Valley Oak	Blue Oak	QD
CJ	Brewer Oak	Chaparral shrub	CS
CP	Bush Chinquapin	Chaparral shrub	CS
CC	Ceanothus Mixed Chaparral	Chaparral shrub	CS
CA	Chamise	Chaparral shrub	CS
CK	Coyote Brush	Chaparral shrub	CS
BM	Curlleaf Mountain Mahogany	Chaparral shrub	CS
FM	Curlleaf Mountain Mahogany (tree)	Chaparral shrub	CS
CI	Deerbrush	Chaparral shrub	CS
BX	Great Basin - Mixed Chaparral Transition	Chaparral shrub	CS
CG	Greenleaf Manzanita	Chaparral shrub	CS
CH	Huckleberry Oak	Chaparral shrub	CS
CQ	Lower Montane Mixed Chaparral	Chaparral shrub	CS
CE	Mountain Misery	Chaparral shrub	CS
CY	Mountain Whitethorn	Chaparral shrub	CS
CN	Pinemat Manzanita	Chaparral shrub	CS
CB	Salal - California Huckleberry	Chaparral shrub	CS
CS	Scrub Oak	Chaparral shrub	CS
CV	Snowbrush	Chaparral shrub	CS
CX	Upper Montane Mixed Chaparral	Chaparral shrub	CS
CM	Upper Montane Mixed Shrub	Chaparral shrub	CS

Dominance Type	Description	Regional Type	Code
CL	Wedgeleaf Ceanothus	Chaparral shrub	CS
CW	Whiteleaf Manzanita	Chaparral shrub	CS
EP	Eastside Pine	Eastside Pine	EP
JP	Jeffrey Pine	Eastside Pine	EP
WP	Washoe Pine	Eastside Pine	EP
QC	Canyon Live Oak	Live Oak	LO
QW	Interior Live Oak	Live Oak	LO
LP	Lodgepole Pine	Lodgepole Pine	LP
DP	Douglas-Fir - Ponderosa Pine	Mixed Conifer	MC
MF	Mixed Conifer - Fir	Mixed Conifer	MC
MP	Mixed Conifer - Pine	Mixed Conifer	MC
DF	Pacific Douglas-Fir	Mixed Conifer	MC
PJ	Singleleaf Pinyon Pine	Pinyon-Juniper	PJ
WJ	Western Juniper	Pinyon-Juniper	PJ
PP	Ponderosa Pine	Ponderosa Pine	PP
RF	Red Fir	Red Fir	RF
WW	Western White Pine	Red Fir	RF
QX	Black Cottonwood	Riparian	RI
SB	Buckwheat	Riparian	RI
QI	California Buckeye	Riparian	RI
QJ	Cottonwood - Alder	Riparian	RI
QF	Fremont Cottonwood	Riparian	RI
TA	Mountain Alder	Riparian	RI
QQ	Quaking Aspen	Riparian	RI
NR	Riparian Mixed Hardwood	Riparian	RI
NM	Riparian Mixed Shrub	Riparian	RI
QE	White Alder	Riparian	RI
QO	Willow	Riparian	RI
QY	Willow - Alder	Riparian	RI
QS	Willow - Aspen	Riparian	RI
WL	Willow (Shrub)	Riparian	RI
BP	Bristlecone Pine	Subalpine Conifer	SA
FP	Foxtail Pine	Subalpine Conifer	SA
SA	Subalpine Conifers	Subalpine Conifer	SA
WB	Whitebark Pine	Subalpine Conifer	SA
WF	White Fir	White Fir	WF

Using static vegetation maps to analyze severity by vegetation type over time is of concern since high severity events can cause vegetation type change. Ideally we would like to have used vegetation maps that pre-dated the first fires we mapped. The first CALVEG map was produced in 1978 by using photo-interpretation techniques with Landsat MSS imagery. The scale of that map is 1:250,000 and is therefore too broad-scale for the analysis performed for this report. The earliest CALVEG maps of sufficient scale date from the early 1990s and were first produced using 30m imagery and image classification techniques. Although CALVEG is used as an existing vegetation map, the mapping methodology calls for not removing any previously productive conifer forest land from the vegetation map – for example, when stand replacing events occur the tree density is set to zero but the primary dominance type is not changed (Ralph Warbington, personal communication). In essence then, the CALVEG map for California is at least partly a "potential vegetation" map. Additionally, the mapping methods used by the RSL have greatly improved since the first version of CALVEG, resulting in maps with higher accuracies. Based on these considerations, we decided to use the most recent CALVEG data to stratify all but one fire mapped for this report. The CALVEG data were inspected for each fire to determine whether fire patterns were reflected in the current vegetation map. In only two cases, the 2000 Manter Fire and the 1992 Cleveland Fire, was it felt that the current CALVEG data did not adequately represent the pre-fire condition. The1999-2000 version of CALVEG was used to stratify the Manter Fire (except for the fire area that occurred outside the Forest boundary, which was not mapped in 1999-2000). The 1992 Cleveland predated the first usable CALVEG map. The forested land surrounding the Cleveland is predominately classified as mixed conifer, but within the fire perimeter the high severity patches are currently classed as ponderosa pine since they were replanted with ponderosa pine. We therefore reset all ponderosa pine polygons within the fire perimeter to mixed conifer for this analysis. We also eliminated all fires that overlapped (3% of the total mapped area) from any vegetation type analysis, thereby minimizing any confusion in the analysis due to vegetation type change. A total of 197 fires were mapped for this report. After eliminating the overlapping fires, 177 fires remained for use in the analysis by vegetation type.

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 and others 2006). Although there are many attributes that can be used to characterize fire regimes, seven attributes are most commonly thought to be most important to ecosystem function: seasonality, fire return interval, size, spatial complexity, fireline intensity, type and severity (Sugihara and others 2006). This report concentrates primarily on characterizing severity, although trends in fire size and complexity are also examined. Sugihara and others (2006) present a set of conceptual distribution curves that describe the probability of occurrence for each fire regime attribute. For example, Figure 6 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 and others (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.

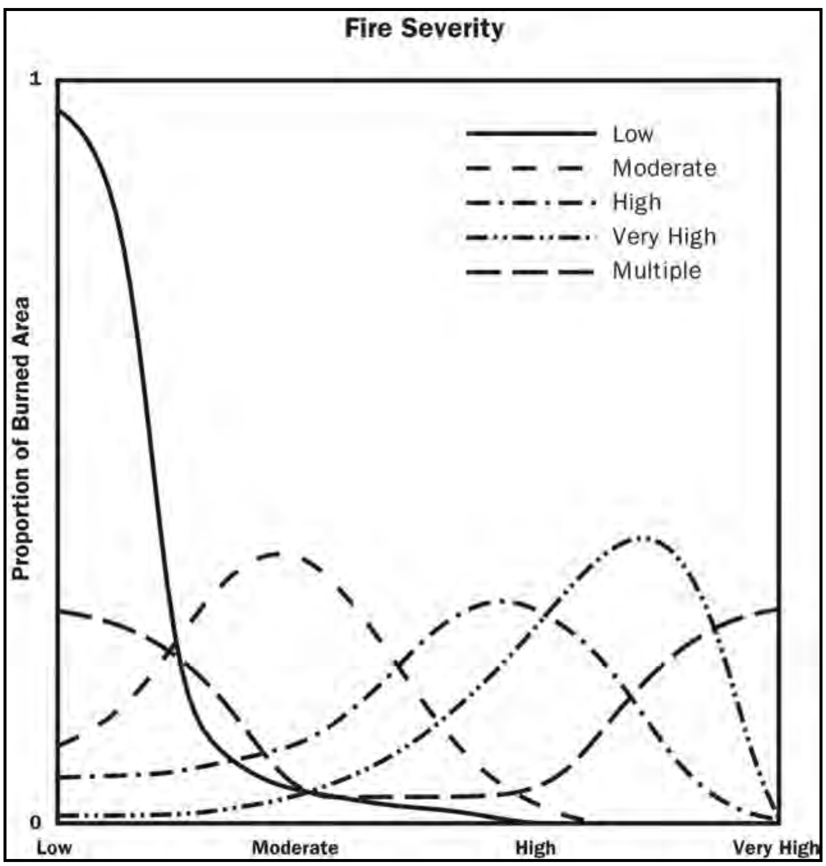

Figure 6. Hypothetical fire severity distribution curves describing the variation in severity for different fire regimes. (from Sugihara and others 2006)

Sugihara and others (2006) use the severity types above to describe - in a general sense - hypothetical historic (pre-settlement) fire severity attributes for major Sierra Nevada vegetation types. Table 5 lists the historic severity and fire type for each regional vegetation type used in this report except for the riparian type which was not discussed by Sugihara and others (2006). Mixed conifer, ponderosa pine, eastside pine, and subalpine conifers historically experienced predominantly surface fire at low or low-moderate severity in pre-settlement times (that is, as far back as the fire scar record goes). Although "surface fire" indicates that the fire front advances primarily through surface fuels, some of the area may experience torching of individual trees or groups of trees. According to Sugihara and others (2006), lodgepole pine, red fir and white fir historically experienced a range of both fire types and severities (Table 5).

Table 5. Historic fire regime types for SNFPA vegetation types (adapted from Sugihara et. al. 2006)

Vegetation Type	Severity	Fire Type
Black Oak	Low-Moderate	Surface
Blue Oak	Low	Surface
Chaparral Shrub	High	Crown
Eastside Pine	Low	Surface
Live Oak	Low	Surface
Lodgepole Pine	Multiple	Multiple
Mixed Conifer	Low-Moderate	Surface-Multiple
Pinyon Juniper	High	Active Crown
Ponderosa Pine	Low-Moderate	Surface
Red Fir	Multiple	Multiple
Subalpine Conifer	Low	Surface
White Fir	Multiple	Surface-Multiple

One of the major objectives of this project was to measure as directly as possible the current severity distribution curves and compare the distribution of severity for each vegetation type to the estimate made in the SNFPA FEIS. The fire severity distribution curves reported in Appendix B by vegetation type were derived by summing the Landsat based RdNBR index values over 177 fires from 1984 through 2004. The distribution curves were then summarized into four categories of severity (Table 3) 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 listed above as described by Sugihara and others (2006).

Results

Summary of Fires Mapped

Maps by U.S. National Forest displaying all fires mapped for this report are provided in Appendix C along with a summary list of all mapped fires. Year, fire name, and direct protection agency are listed for each fire. For each fire, Appendix C also gives the number of acres burned by CBI-derived severity category, the number of acres in three categories of percent tree basal area mortality, and the percentage of each category within the fire perimeter. A total of 2,012,230 acres burned in all fires that occurred at least partially on U.S. Forest Service lands in the SNFPA area between 1984 and 2004. The fires mapped for this report account for 1,192,627 acres, or 59% of the total number of acres burned during the 1984 through 2004 period.

Fires from 2000 through 2004

For this report we were only able to map a portion of the fires on U.S. Forest Service administered lands that occurred from 1984 through 2004 for the entire study area. The sample of fires mapped included all fires greater than 1000 acres only from 2000 through 2004. We are therefore only able at this time to compare acres burned during the 2000-2004 period. Figure 7 displays and Table 6 lists the number (and percent) of acres burned on U.S. Forest Service administered lands by severity category stratified by conifer vegetation type and latitudinal zone.

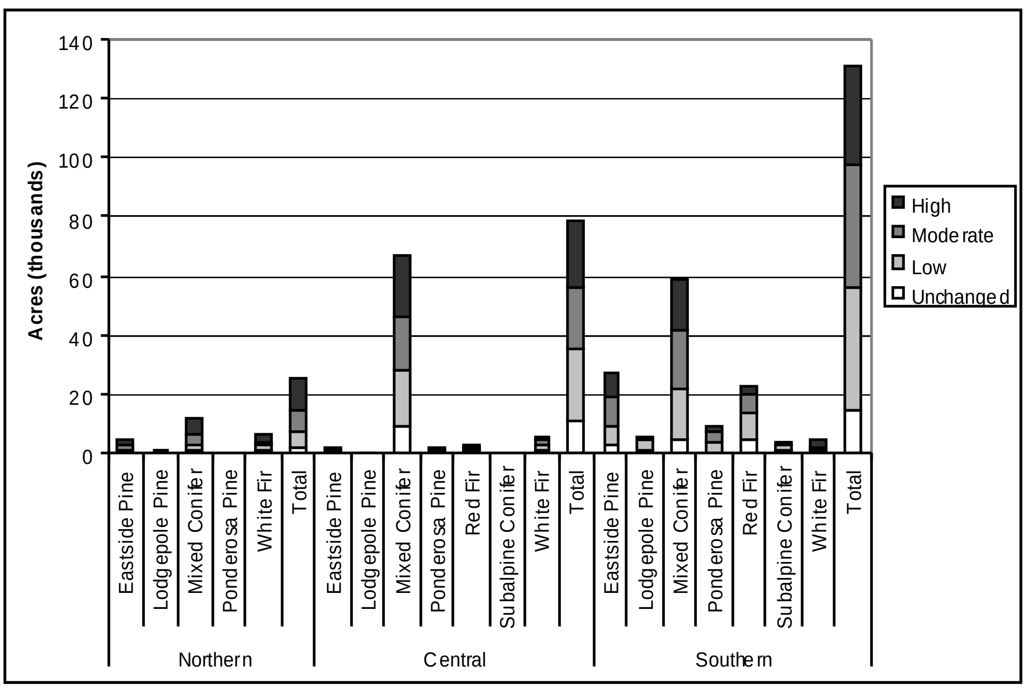

Figure 7. Number of acres burned 2000 through 2004 in conifer vegetation types by severity category.

Table 6. Number and percent acres burned 2000 through 2004 for conifer vegetation types by severity category.

Region	Vegetation Type	Unchanged (acres / %)	Low (acres / %)	Moderate (acres / %)	High (acres / %)	Total (acres)
Northern	Eastside Pine	270 / 5	945 / 19	1,610 / 32	2,130 / 43	4,955
	Lodgepole Pine	294 / 24	451 / 36	245 / 20	248 / 20	1,239
	Mixed Conifer	739 / 6	2,309 / 19	3,689 / 31	5,129 / 43	11,867
	Ponderosa Pine	7 / 12	27 / 46	20 / 33	5 / 9	60
	White Fir	850 / 12	1,572 / 22	1,567 / 22	3,010 / 43	6,999
	Total	2,161 / 9	5,306 / 21	7,131 / 28	10,522 / 42	25,120
Central	Eastside Pine	196 / 10	500 / 26	883 / 46	324 / 17	1,903
	Lodgepole Pine	91 / 26	189 / 53	52 / 15	25 / 7	358
	Mixed Conifer	9,070 / 14	19,507 / 29	17,665 / 26	20,542 / 31	66,784
	Ponderosa Pine	139 / 8	566 / 32	751 / 42	321 / 18	1,778
	Red Fir	771 / 32	884 / 37	506 / 21	213 / 9	2,374
	Subalpine Conifer	23 / 21	79 / 72	8 / 7	0 / 0	111
	White Fir	960 / 18	1,833 / 34	1,259 / 24	1,291 / 24	5,342
	Total	11,251 / 14	23,558 / 30	21,124 / 27	22,715 / 29	78,649
Southern	Eastside Pine	2,674 / 10	6,422 / 24	9,528 / 35	8,621 / 32	27,245
	Lodgepole Pine	1,389 / 25	2,813 / 51	993 / 18	335 / 6	5,530
	Mixed Conifer	4,330 / 7	17,391 / 30	19,384 / 33	17,125 / 29	58,230
	Ponderosa Pine	616 / 7	2,682 / 29	4,056 / 44	1,786 / 20	9,140
	Red Fir	4,576 / 20	9,311 / 41	5,550 / 24	3,296 / 14	22,733
	Subalpine Conifer	999 / 26	1,785 / 47	706 / 19	302 / 8	3,792
	White Fir	140 / 3	1,015 / 24	957 / 23	2,032 / 49	4,144
	Total	14,724 / 11	41,419 / 32	41,174 / 31	33,497 / 26	130,814
Grand Total		28,136 / 12	70,284 / 30	69,429 / 30	66,734 / 28	234,583

Severity by Vegetation Type

To the public, fires that are big and fires that are severe, and especially those that are big *and* severe, are 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 (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 variability (Agee 1993; Arno and Fiedler 2005). Table 5 provides some reference for the historic distributions of fire severities and types among major California vegetation types. As the Table makes clear, high severity fire was a major or minor component of fire regimes in many parts of the landscape, 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 the 1984-2004 period by major vegetation type in order to provide the proper contextual basis for understanding whether the current distribution of low versus high severity is indeed effecting undesirable changes to ecosystems in the SNFPA area.

Mapped fires from 1984 through 2004 were stratified into 13 regional vegetation types (Table 4). The Landsat based RdNBR index values were summed by vegetation type over 177 fires from 1984 through 2004 to create probability distribution curves of severity (see Appendix B). The distribution curves provide a measured estimate of the current fire regime severity attributes. Only the portions of the fires that occurred on U.S. Forest Service administered lands were included in the distributions. The number of acres mapped in each vegetation type for this report is listed in Table 7. The mixed conifer and chaparral shrub types were the best represented vegetation types, each with over 150,000 acres. Lodgepole pine, riparian and subalpine forests all had less than 7,500 acres. The severity distribution curves were summarized into percent area burned in three categories of severity (unchanged to low, moderate, and high) and are compared to the percentages listed in the SNFPA FEIS in the next section.

Table 7. Number of acres from mapped 1984-2004 fires analyzed by regional vegetation type on U.S. Forest Service administered lands.

Vegetation Type	Total Acres
Black Oak	14,623
Blue Oak	18,623
Chaparral Shrub	158,734
Eastside Pine	57,918
Live Oak	53,321
Lodgepole Pine	7,355
Mixed Conifer	240,306
Pinyon Juniper	39,274
Ponderosa Pine	61,054
Red Fir	29,849
Riparian	3,554
Subalpine Conifer	4,333
White Fir	23,853

Comparison of 1984-2004 fires with SNFPA FEIS analysis

The percentage of acres burned in each vegetation type by severity category was used in the SNFPA FEIS to evaluate the management alternatives presented in the Plan. Technology to directly map fire severity at the landscape scale did not exist at the time, however. The fire history GIS layer developed for the California spotted owl EIS was used in combination with the first comprehensive CALVEG map to estimate the number of acres burned by severity category. The CALVEG map, however, only represented post-fire conditions, and since no pre-fire vegetation data were available, fire severity could only be inferred from stand structure as mapped in CALVEG. Plantations and areas of non-stocked vegetation within known fire perimeters were assumed to have experienced high severity, stand-replacing events. Low density stands with an open canopy structure that showed signs of some loss of large trees were assumed to have experienced moderate severity fire. Areas within fire perimeters that had dense stands of large trees and full canopies were assumed to have been affected by low severity fire (Hermit 1996).

The average percentage of acres burned by CBI severity category during the 1984-2004 period and the percentages used in the SNFPA FEIS (USDA 2001) are shown in Table 8 for each regional vegetation type. Since the lowest severity category used in the SNFPA FEIS was "non-lethal", the unchanged and low CBI-based severity categories were added together to make one category for comparative purposes; low severity and non-lethal, moderate severity and mixed lethal, and high severity and lethal are all assumed for our purposes to be synonymous. Note that the SNFPA FEIS did not include estimates of severity for lodgepole pine, red fir, riparian, and subalpine conifer. We also do not have the raw acreages for the SNFPA FEIS analysis, and thus we cannot compute a statistical measure of the strength of the association (for example, χ^2) between the two datasets.

Qualitatively, eastside pine is the only vegetation type where the severity distributions from the 1984-2004 fires are very similar to the FEIS estimates (Table 8). Aside from pinyon pine, the percentage of high severity acres in all conifer forest types was estimated to be higher in the SNFPA FEIS than was actually measured in fires from 1984-2004. Correspondence between the SNFPA estimates and our measurements for high severity fire were fairly close for eastside pine, differing by only 5%. However, SNFPA estimates of high severity fire for the mixed conifer, ponderosa pine, and white fir vegetation types were 44-55% percent higher than in the actual 1984-2004 fire record; in these types, SNFPA estimates for non-lethal and mixed-lethal fire percentages were both lower than measured by our method. The percentage of high severity acres for blue oak agrees closely between the SNFPA FEIS and the 1984-2004 record, but black oak and live oak types differ by 78% and 47%, respectively. The SNFPA FEIS estimates also suggest that chaparral experiences almost exclusively high severity fire. In this case, we can't actually compare our estimates to SNFPA estimates: our measurements are biased by the dominance of resprouting shrubs since our mapping protocol calls for using imagery and field data acquired one year post-fire.

Table 8. The average percent of acres burned by regional vegetation type, fires 1984-2004 vs. percentages used for the SNFPA FEIS.

Regional	Fires 1984-2004			SNFPA FEIS		
Vegetation Type	**Unchanged to Low**	**Moderate**	**High**	**Non-Lethal**	**Mixed**	**Lethal**
Black Oak	40	37	23	10	85	5
Blue Oak	77	21	2	95	4	1
Chaparral Shrub	31	41	28	1	4	95
Eastside Pine	31	32	37	26 (25)*	37 (35)*	42 (40)*
Live Oak	48	34	18	40 (36)*	60 (55)*	10 (9)*
Lodgepole Pine	73	18	9			
Mixed Conifer	40	31	29	34	21	45
Pinyon Juniper	32	25	43	9 (9)*	85 (83)*	8 (8)*
Ponderosa Pine	37	37	26	30 (30)*	31 (31)*	38 (39)*
Red Fir	64	23	13			
Riparian	61	24	15			
Subalpine Conifer	76	17	7			
White Fir	42	24	34	33	18	49

* SNFPA-FEIS columns do not all add up to 100% (for example, in Live Oak they add to 110%). This is a feature of the original table and we have left it as originally published (USDA 2001) – the values in parentheses are those values which result if the published errors are standardized.

Current versus pre-settlement patterns in severity

For the most part, current patterns in fire severity are very different from those patterns which characterized SNFPA area forests before Euroamerican settlement in the mid 19th century (Sudworth 1900; Leiberg 1902; Skinner and Chang 1996; Weatherspoon and Skinner 1996; Sugihara and others 2006). Figure 8 shows the average severity in fires during the period 1984-2004 versus “reference” conditions, idealized severity distributions from the pre-Euroamerican settlement period, derived from modeling carried out for the interagency LANDFIRE program. Based on a multiyear series of regional workshops with fire scientists, LANDFIRE built nonequilibrial, aspatial state and transition models of idealized pre-settlement disturbance regimes to feed national- and regional-scale assessments of current departures from pre-settlement “reference” conditions (LANDFIRE; The Nature Conservancy and others 2006; Rollins and Frame 2006). One output of the LANDFIRE reference models is an estimate of the proportion of fires occurring at low, moderate and high severity. We used these proportions as a tentative best-estimate of pre-settlement conditions, and compared them to the area proportions of fire severity classes we sampled in the SNFPA area from 1984 to 2004. We also compared our overall severity proportions (summing all forest types) for the northern SNFPA area against 19th century values reported in 1902 by Leiberg (1902) for the area between 38º 55’ N and 40º 10’ N latitude. Leiberg (1902) suggests that much of the high severity fire he recorded was due to miners who carelessly let fires go, and his description suggests that pre-settlement fires may have had even less high severity than what he tallied. In Figure 8, the most “departed” forest systems are those at lower to middle elevations which were historically dominated by yellow pines (Jeffrey pine, ponderosa pine) and characterized by high frequency/low severity fire regimes; currently, the mean percent area of fires burning at high severity in these forest types is 5 to 8 times greater than in the pre-settlement reference models. Lower to middle elevation fir-dominated forests (for example, white fir) on moister sites are also burning at different severities and frequencies than before settlement, but to a lesser degree than the pine systems. On the contrary, contemporary high elevation forests (for example, red fir) appear to be burning within or near the historic range of variability for severity (Figure 8). These results further confirm general patterns reported from different forest types across western North America (Agee 1993; Weatherspoon and Skinner 1996; Schoennagel and others 2004; Arno and Fiedler 2005; Noss and others 2006; Sugihara and others 2006). Comparing our composite results for the northern SNFPA area against Leiberg (1902), who published an estimate of 19th century fire severity patterns in 1902, we find an almost 300% increase in the occurrence of stand replacing fire over the last two centuries.

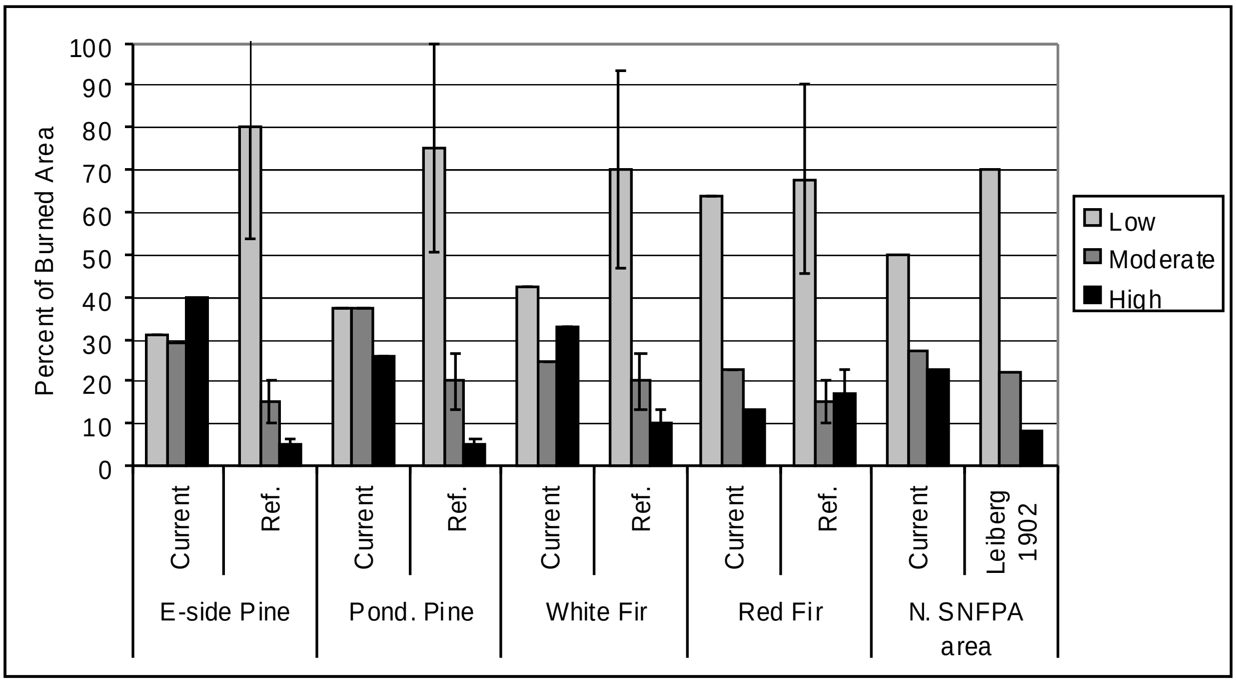

Figure 8. Comparison of average severity measured in fires 1984-2004 vs. history conditions for three major forest types in the SNFPA area, and a composite for the Northern SNFPA area. Error bars are +/- 33% of the mean.

Severity in Wildland Fire Use (WFU) vs. Wildfires (WF)

Wildland fire use (WFU) became a regularly used management strategy in the SNFPA area in 1999. Most fires managed as WFU do not typically occur in the same years as wildfires (WF) not managed as WFU since antecedent weather conditions factor into the decision whether to allow a fire to be managed as WFU or not. Additionally, our database is limited in the number of WFU fires due to the short time WFU has been implemented on U.S. Forest Service administered lands in the SNFPA area. All fires that were managed as WFU during the 1999 through 2004 period occurred on the Stanislaus and Sequoia National Forests. It is therefore difficult to directly compare fire effects between the two management strategies under the exact same conditions, but some preliminary observations can be made. Severity in WFU fires from 1999 through 2003 (no WFU fires occurred in 2004) was compared with severity in wildfires from 1988 through 2004.The wildfires used in this comparison occurred at approximately the same elevation and in the same geographic region as the WFU fires (Table 9). The percentage of acres in WFU fires that experienced high severity averaged 13% as opposed to 20% in WF fires (Figure 9). Eastside pine and mixed conifer were the two regional conifer vegetation types where the WFU vs. WF difference was most pronounced (Table 10). The high severity component was approximately equal between WFU and WF fires in red fir and subalpine conifer. There were not enough acres burned in either WFU or WF fires for lodgepole pine, ponderosa pine or white fir to make comparisons.

Table 9. Fires used in WFU vs. WF comparison

Year	Fire	WFU
1999	Deer	Yes
1999	Hiram	Yes
2003	Albanita	Yes
2003	Cooney	Yes
2003	Hooker	Yes
2003	Kibbie	Yes
2003	Mountain Cmplx	Yes
2003	Mud	Yes
2001	Silver	Yes
2003	Summit	Yes
2003	West Kern	Yes
2003	Whit	Yes
1997	Choke	No
2004	Crag	No
1988	Desk	No
1988	Fawn	No
1990	Lily	No
1988	Obelisk	No
1992	Rainbow	No
2002	Spi3Sourgrass	No
2001	White	No

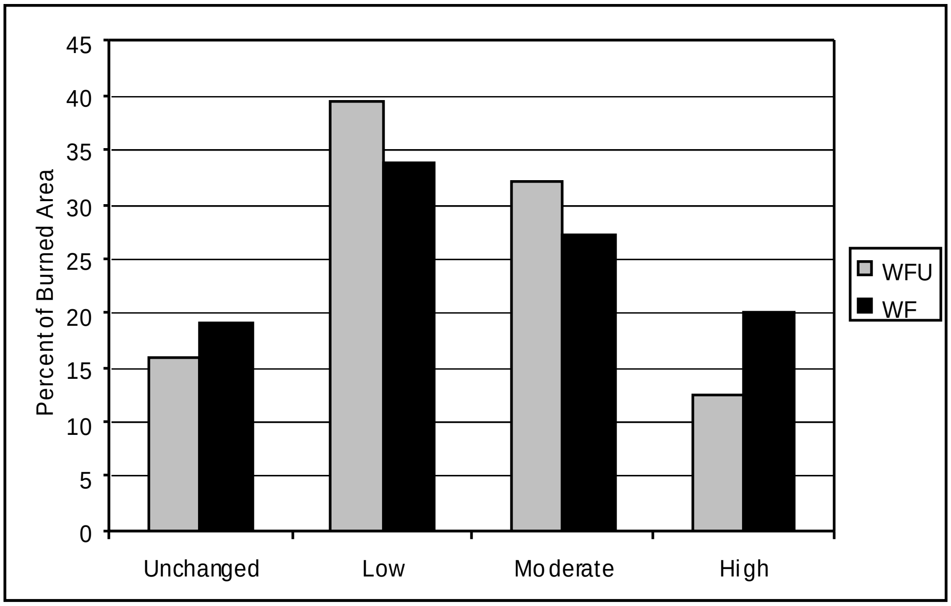

Figure 9. Comparison of average percent of acres burned by severity category in each WFU and WF fire.

Table 10. Number and percent of acres burned for conifer vegetation types by severity category in WFU and WF fires on U.S. Forest Service administered land.

Regional Vegetation Type	WFU Fires				WF Fires			
	Unchanged to Low(%)	**Moderate (%)**	**High (%)**	**Acres**	**Unchanged to Low(%)**	**Moderate (%)**	**High (%)**	**Acres**
Eastside Pine	53	38	9	2479	36	29	35	636
Lodgepole Pine	66	26	8	1448	77	22	1	73
Mixed Conifer	56	35	9	10220	54	26	20	9614
Ponderosa Pine				0	59	35	6	210
Red Fir	56	31	13	8855	71	19	11	2837
Subalpine Conifer	63	31	5	656	94	5	1	307
White Fir	100	0	0	10	9	65	26	8

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 and others 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 first 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 1984 through 2004. We also examined trends from 1908 through 2006 in number of fires and fire size using the Pacific Southwest Region fire history database.

Trend in Severity by Vegetation Type 1984-2004

We examined the trend in percent high severity acres by regional vegetation type from 1984 through 2004. We do not include the regional chaparral shrub type because rapid resprouting of many chaparral species makes pre- vs. one year post-fire comparisons difficult. Autoregressive Integrated Moving Average (ARIMA) time series regression (Box and Jenkins 1970; Shumway 1988) was used to calculate trends in the percent of fire area burning at high severity per year and high severity patch size over the 1984-2004 period. We transformed all percent severity data by arcsin-square root and all area data by log to meet statistical assumptions of normality, and therefore the linear models appear curve-linear in the figures. Because of the high interannual variability in most of these datasets, we also portray results using a ten-year running mean of the annual data for graphic depiction of the decadal trend. The running means smooth the annual data and effectively removes the effects of cyclical and seasonal variability (Porkess 1991). In our discussion, we use ten-year running means to only compare average values at the beginning and end of the analysis period. All statistical significance reported in the discussion is based on time series regression analysis. Only U.S. Forest Service administered lands are considered; private lands and lands managed by other public agencies are not included. Note that total burned area varies widely among the different regional vegetation types (Table 7), and certain types simply did not experience enough fire between 1984 and 2004 to develop a robust statistical pattern. As a rule of thumb, we feel that a sample size of about 15 fires (N = 15) and 20,000 acres burned (or 3% of the total burned area) is an approximate minimum for development of a "meaningful" pattern and therefore did not develop rigorous statistical time series models for vegetation types that fell below that level (Lodgepole pine, riparian, and subalpine conifers).

Trends in the proportional area of fires burning at high severity showed strong interannual variability, demonstrated by the gray squares in Figure 10. However, the increasing slope of the time-series regression [solid line in Figure 10; $R^2 = 0.353$; P(linear)=0.011; Table 11] documents significant increases in fire severity in forest types that make up the majority (~70%) of the burned area we surveyed. At the beginning of the period of analysis, a 10-yr average (the 10-yr mean is depicted with white squares in Figure 10) of about 14% of the area affected in forest fires in the broader study area burned at high severity (forest stand replacement); 21 years later the high severity component was approaching 23% of fire area. The pattern of inter-annual variability in severity is robust and not a result of the sample of fires we mapped, which can be discerned from number of acres mapped each year as shown by the white diamonds in Figure 10. Different forest types showed different patterns within this general trend, with the proportion of high severity fire increasing at an average-or-above rate for most low- and middle elevation forest types (for example, mixed conifer, white fir, black oak), but at a below-average rate or not at all for high elevation forest types (for example, red fir). Therefore in the following sections we discuss trends for each regional vegetation type in groups based upon elevation zone.

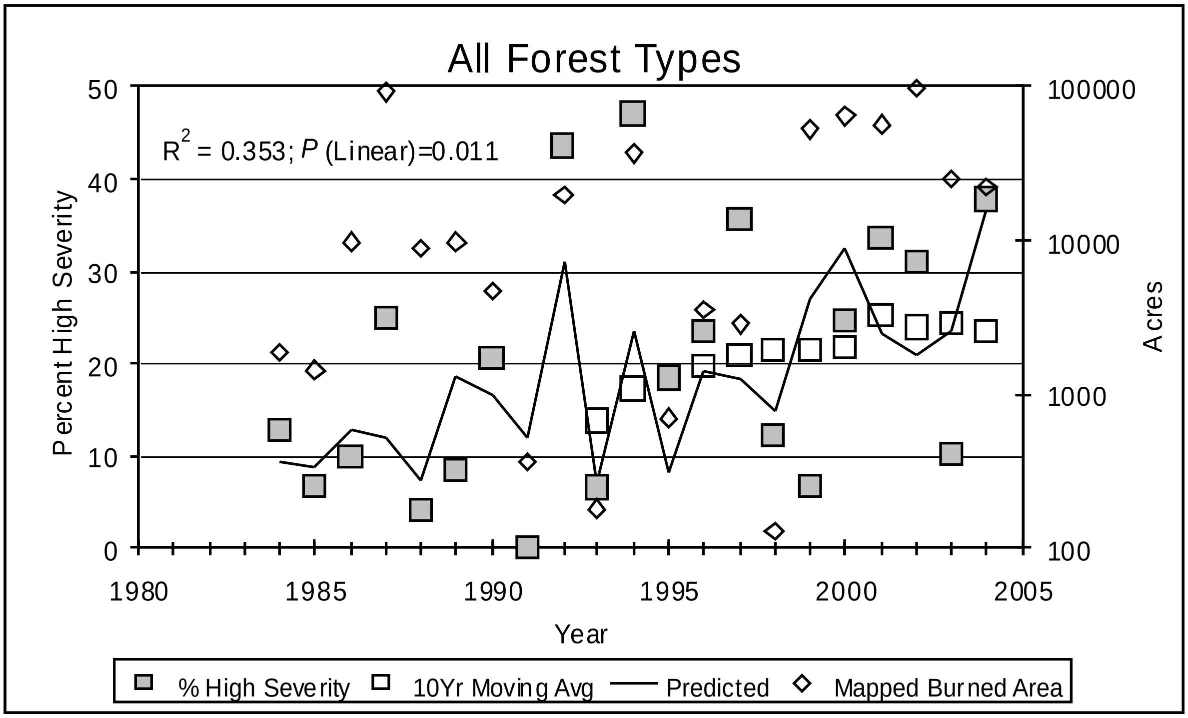

Figure 10. Temporal trend in percent area burned at high severity for all forest types combined (except pinyon-juniper) 1984-2004 with the best-fit regression function, 10-yr moving average for % high severity, and burned area mapped (right-hand Y-axis). Pictured *P* value refers to the linear trend. The data were best fit by a 1st order autoregressive function, $P_{(AR1)}$ = 0.035, adj. R^2 = 0.281.

Table 11. Regression statistics for results of ARIMA time series modeling of trends in high severity fire and high severity patch size, 1984-2004.

	All Forests	Mixed Conifer	Ponderosa Pine	Eastside Pine	Red fir	White fir	Black oak	Blue oak	Live oak	Pinyon Juniper	Mean Patch Size	Mean Max Patch Size
N	20	20	19	17	14	14	16	15	18	12	19	19
dfe	17	17	17	15	12	8	14	11	16	10	17	17
Parameter estimates												
Sigma-sq	0.011	0.017	0.022	0.035	0.138	0.016	0.092	0.008	0.010	0.025	0.116	0.472
Intercept	0.191	0.197	0.255	0.138	0.315	0.003	0.069	0.011	0.143	-0.019	0.505	0.952
Linear	0.008	0.008	-0.001	0.010	0.007	0.019	0.013	0.013	0.008	0.018	0.036	0.077
AR1	-0.473	-0.546	-0.611			-1.284		-1.198				
AR2						-1.585		-0.755				
AR3						-1.174						
AR4						-0.786						
P (linear)	0.011	0.025	0.789	0.152	0.237	<0.0001	0.002	<0.0001	0.059	0.021	0.011	0.007
P (AR1)	0.035	0.017	0.006			0.000		<0.0001				
P (AR2)						0.001		0.002				
P (AR3)						0.003						
P (AR4)						0.001						
Statistics of fit												
Mean square error	0.009	0.019	0.019	0.031	0.019	0.023	0.008	0.012	0.009	0.020	0.104	0.422
Root mean square error	0.097	0.016	0.139	0.175	0.138	0.151	0.092	0.109	0.094	0.143	0.322	0.650
Mean absolute % error	26.948	53.077	31.557	56.254	30.869	52.279	28.070	269.487	33.186	106.104	40.336	38.877
Mean absolute error	0.078	0.106	0.111	0.158	0.095	0.108	0.070	0.093	0.076	0.118	0.273	0.525
R-SQ	0.353	0.356	0.252	0.158	0.114	0.462	0.522	0.249	0.214	0.426	0.325	0.354
adj R-SQ	0.281	0.281	0.158	0.074	0.040	0.126	0.488	0.044	0.165	0.368	0.286	0.316
Akaike Information Criterion	-92.164	-77.194	-68.883	-55.190	-53.694	-40.948	-74.468	-58.466	-80.993	-42.658	-39.073	-12.382
Schwarz Baysian Criterion	-89.030	-74.206	-66.050	-53.524	-52.416	-37.113	-72.923	-55.633	-79.213	-41.688	-37.184	-10.493

Percent high severity by vegetation type was arcsin-square root transformed before analysis, patch size was log transformed.

Foothill and Woodland Vegetation Zones

All four regional vegetation types that fall in the foothill and woodland zones exhibit increasing trends in the percentage of high severity fire between 1984 and 2004 (Figure 11). However, the blue oak type trend line is largely influenced by the 2000 Highway fire where 8 out of a total of 18 acres in the blue oak type were high severity. If the Highway fire were considered an anomaly, the trend line for blue oak would be flat. Only five fires mapped between 1984 through 1995 occurred in the pinyon juniper type and nine years had no fires mapped. We did not map any fires between 1984 and 2000 on the Modoc or Sequoia National Forests where a significant amount of the pinyon juniper type exists (Figures 2 and B-9). Fires mapped from 1995-2004 were typically 20-40% high severity; the increasing trend may be a mapping anomaly, given the spatial coverage of the mapping and that pinyon juniper is thought to typically experience a stand replacing fire regime (Table 5; Sugihara and others 2006). Although oak species in the SNFPA area resprout after fire, increasing severity in oak dominated vegetation may be of some management concern, as hardwood species are a centerpiece of the SNFPA FEIS (USDA 2001) and the success of stump sprouting is known to relate negatively to fire severity (Plumb and Gomez 1983). At the same time, increasing severity may also benefit oak species by decreasing conifer competition

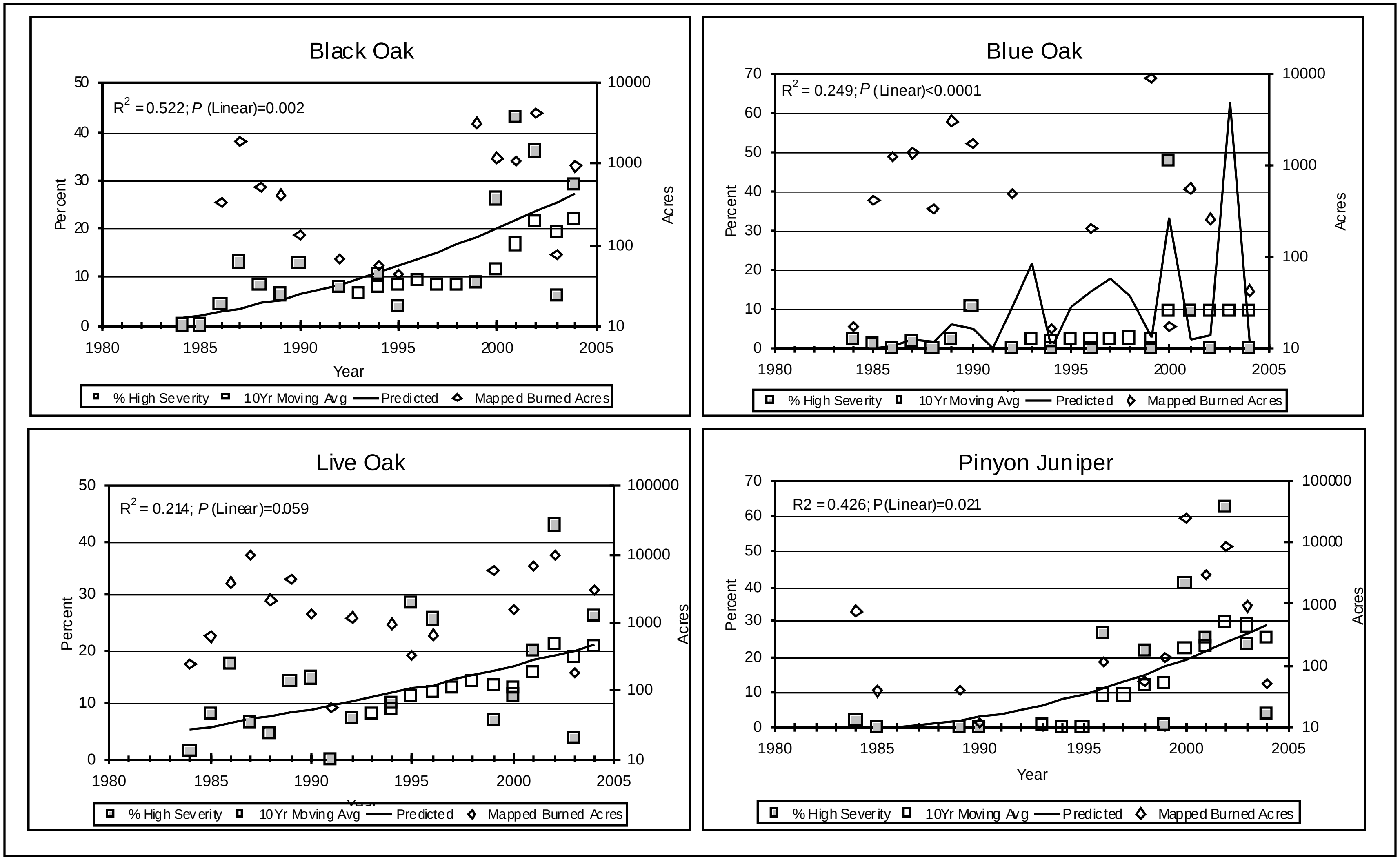

Figure 11. Trends in percentage of high severity acres for Foothill and Woodland vegetation types 1984-2004 with the best-fit regression function, 10-yr moving average, and burned area mapped (right-hand Y-axis). Percent high severity data were transformed by an arcsin-square root transformation before computing the regression. Pictured *P* value refers to the linear trend. Black oak and Live oak were best fit by linear functions; Blue oak with a 1st order autoregressive function.

Montane Zone

Mixed conifer and white fir vegetation types both saw increasing trends in the percentage of high severity fire between 1984 and 2004 (Figure 12). Trends of high severity fire in eastside pine, red fir, ponderosa pine and riparian types were generally weak or flat (Figure 13). We felt the riparian type had too few acres mapped to form a meaningful trend (Table 7), and therefore did not perform a rigorous statistical analysis of the trend. Mixed conifer and white fir had the strongest and most robust statistical relationships to increasing severity and these type make up almost half (47%) of the burned forested area we surveyed (Table 7). It is thought that mixed conifer historically experienced predominantly low to moderate fire severity (Table 5; Sugihara and others 2006). A temporal trend toward higher severity fire in the mixed conifer type would be of management concern as it is the dominant conifer type in the SNFPA area and serves as primary habitat to most of the species of concern addressed by the SNFPA FEIS (USDA 2001). Eastside pine and red fir time series were best fit with linear models (Table 11). Ponderosa pine time series was best fit with a 1st order autoregressive function ($P = 0.006$). Although the slopes of the models for eastside pine and red fir are positive, and slightly decreasing for ponderosa pine, none of the slopes are statistically significant and therefore may not represent actual trends. The lack of trend in westside ponderosa pine appears to contradict well-documented patterns of increasing fire severity in ponderosa pine forest in other parts of the Southwest (Allen and others 2002; Schoennagel and others 2004; Arno and Fiedler 2005). Ponderosa pine in the SNFPA area is generally a seral species, and in-growth of shade-tolerant conifers due to fire suppression is resulting in a steady loss of forest classified as "ponderosa pine"; some of the pattern may thus be artifactual. In addition, ponderosa pine forest occupies the most heavily populated elevation belt of the SNFPA area, which results in rapid response times for fire control agencies and relatively few fires exceed initial attack capability. Ponderosa pine and eastside pine are thought to have historically experienced a low severity surface fire regime (Sugihara and others 2006). Since the current distribution of high severity fire for both types is much higher than what occurred pre-settlement (Figure 8), it is likely that these types were already out of their historical range before 1984. Red fir however, appears to have experienced a percentage of high severity fire typical of historic conditions (Figure 8). The slight upward, but not statistically significant, trend over the analysis period may be an anomaly due to the larger amount of acres mapped later in the analysis period, which in turn may be due to an increase in the number of acres burned under WFU since 2000 (Table 9 and Table 10).

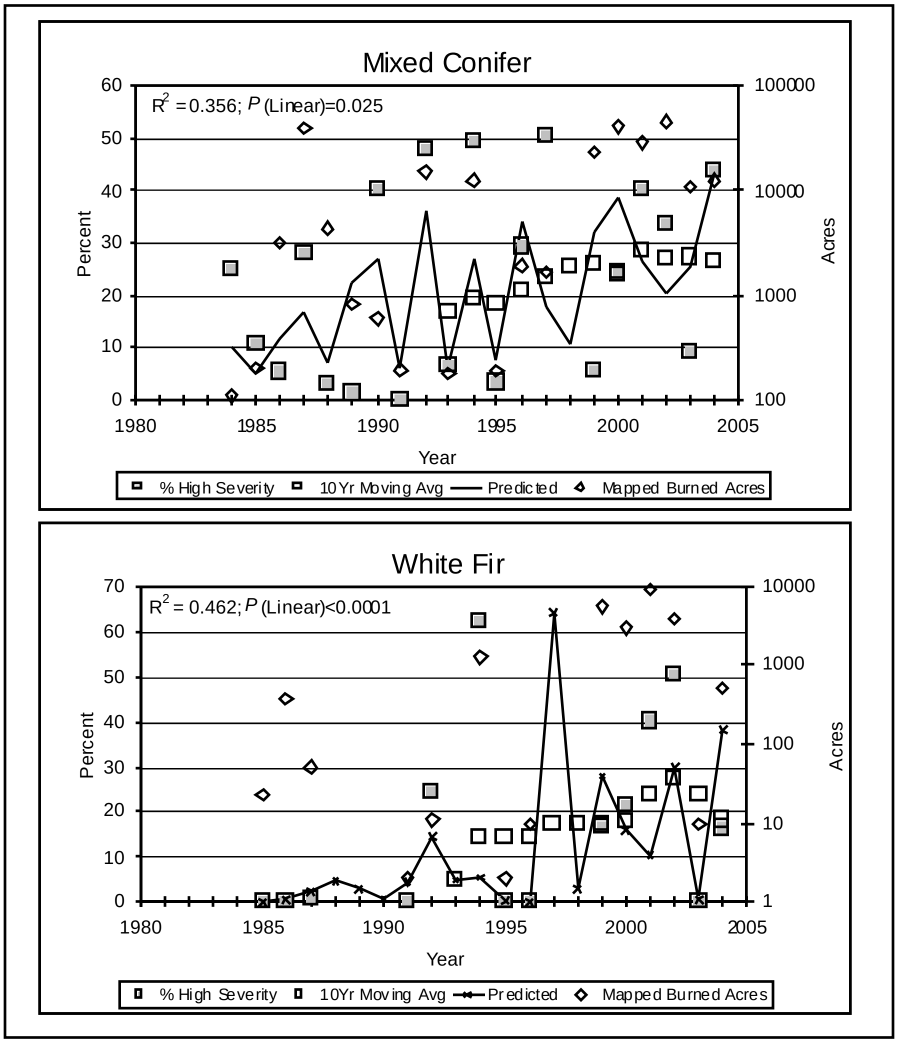

Figure 12. Trends in percentage of high severity acres for mixed conifer and white fir types 1984-2004 with the best-fit regression function, 10-yr moving average, and burned area mapped (right-hand Y-axis). Percent high severity data were transformed by an arcsin-square root transformation before computing the regression. Pictured *P* value refers to the linear trend. Mixed conifer was best fit by 1st order autoregressive function; white fir with a 4th order autoregressive function.

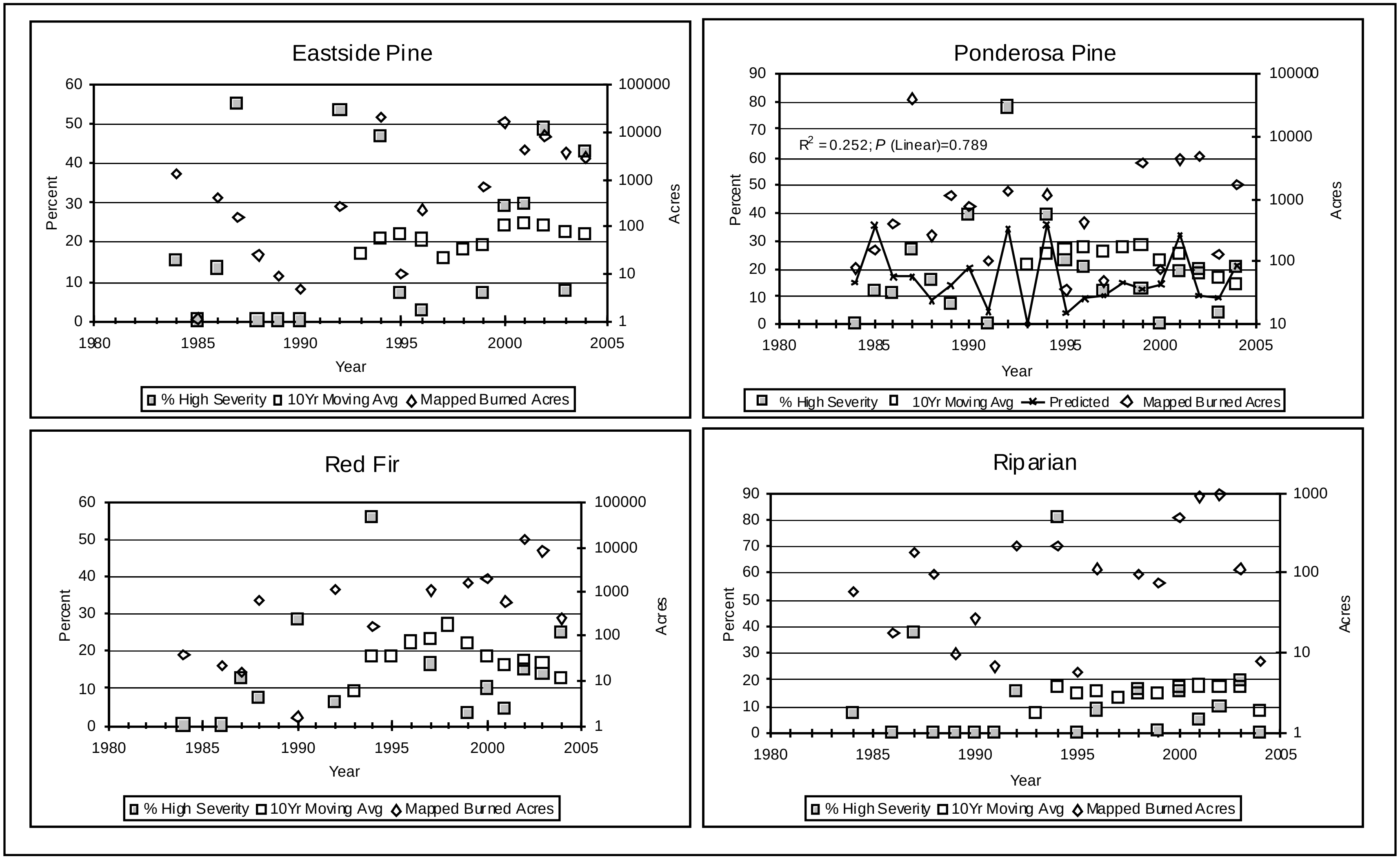

Figure 13. Trends in percentage of high severity acres for four Montane vegetation types 1984-2004 with the best-fit regression function, 10-yr moving average, and burned area mapped (right-hand Y-axis). Percent high severity data were transformed by an arcsin-square root transformation before computing the regression. Pictured *P* value refers to the linear trend. Eastside pine and red fir its were best fit with linear trends that were not significant; riparian had too few acres mapped; ponderosa pine was best fit with a 1st order autoregressive function (*P*=0.006).

Subalpine Zone

Area and sample size are very low for both subalpine conifer and lodgepole pine (Table 7) and do not permit a rigorous statistical analysis of the temporal trend in high severity.

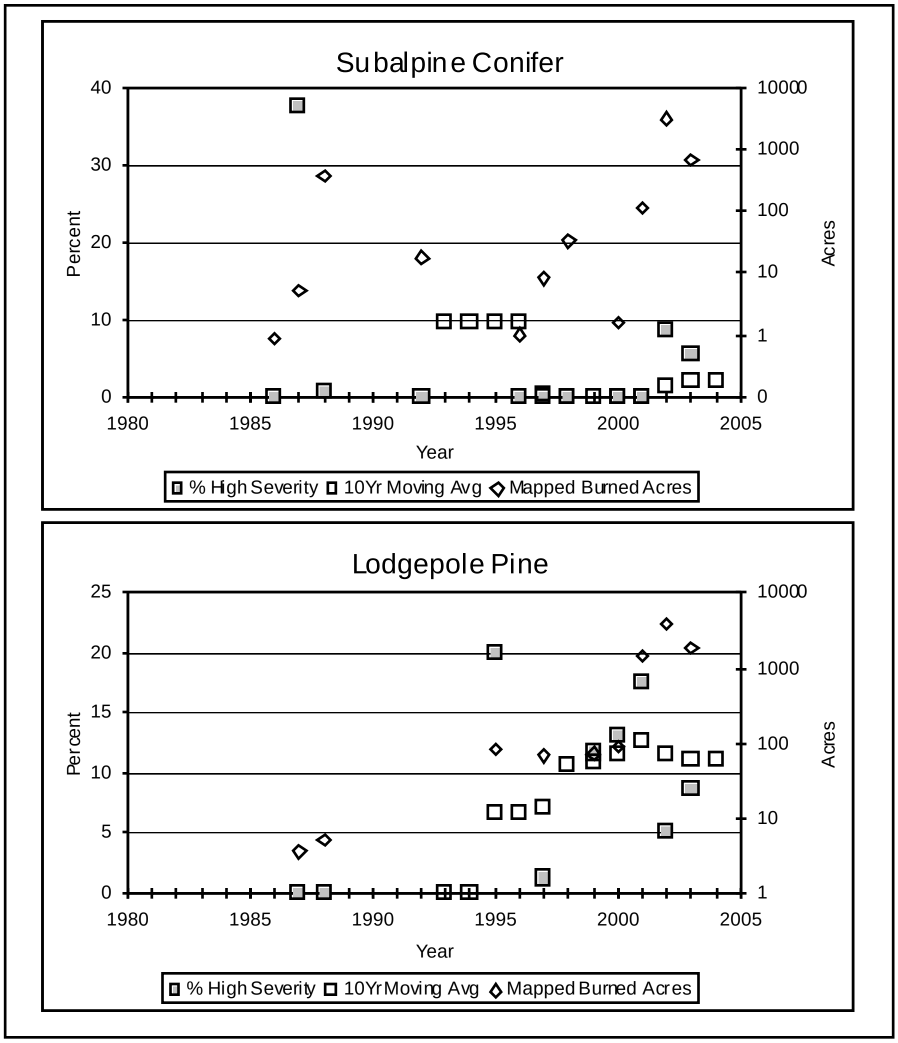

Figure 14. Percentage of high severity acres for subalpine conifer and lodgepole pine vegetation types 1984-2004, 10-yr moving average, and burned area mapped (right-hand Y-axis).

Trend in Fire Size and High Severity Patch Size 1984-2004

Fire management policy in the SNFPA area since the beginning of the 20th century has been to limit the number of acres burned (Husari and McKelvey 1996). Fire frequency and size have long been the preferred quantitative measures of fire patterns (for example McKelvey and Busse 1996), since they are easy to determine from suppression perimeters. However, the percentage of high severity acres in the 1984-2004 mapped fires only correlates weakly with fire size (Figure 15).

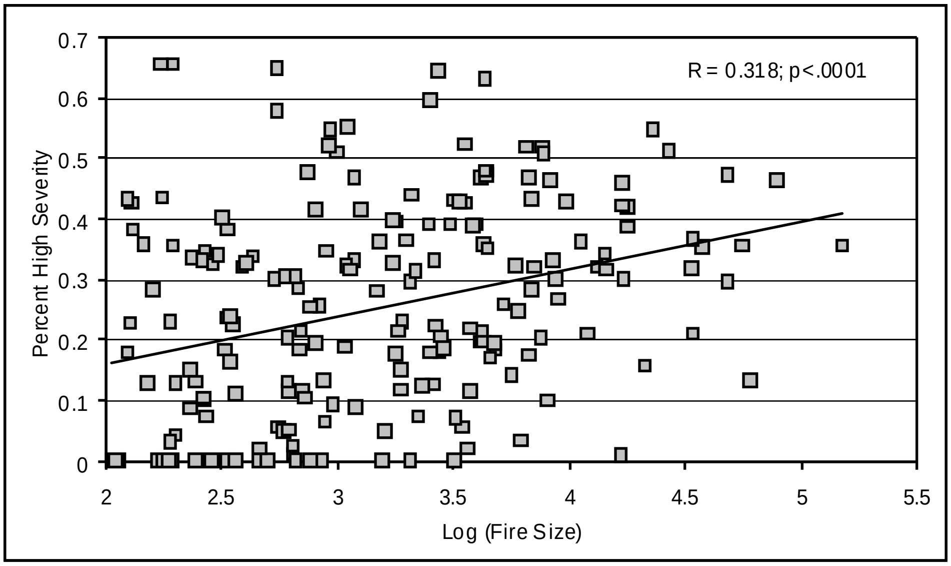

Figure 15. Percent high severity vs. fire size for 1984-2004 mapped fires. All acres in each fire were included. Percent high severity data were transformed by a standard arcsin-square root transformation and area data log transformed before computing the regression.

Fire size alone is most likely not the fire regime variable of most concern. All regime variables are interrelated and fully understanding how fire interrelates to ecosystems can only be accomplished by examining as many regime variables as possible (Sugihara and others 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 patch dynamics, which can have very important connections to propagule flow, sedimentation, habitat availability, 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 and others 1998). By most accounts, before Euroamerican arrival fires in most conifer forests in the SNFPA area were not typified by large patches of high severity fire (Sudworth 1900; Sugihara and others 2006). However as shown in Figure 16, the size of the maximum high severity patch in conifer forests was fairly well correlated with fire size for the fires mapped from 1984-2004 for this report. Ponderosa and eastside pine historically experienced primarily low severity and low complexity fires with very few small high severity patches. Subalpine conifers saw low severity fire with few high severity patches. Lodgepole pine, white fir and red fir were thought to have experienced at least some fire with large high severity patches (Sugihara and others 2006). However lodgepole pine, white fir and red fir were minor components of the total conifer acres mapped for this report (Table 7).

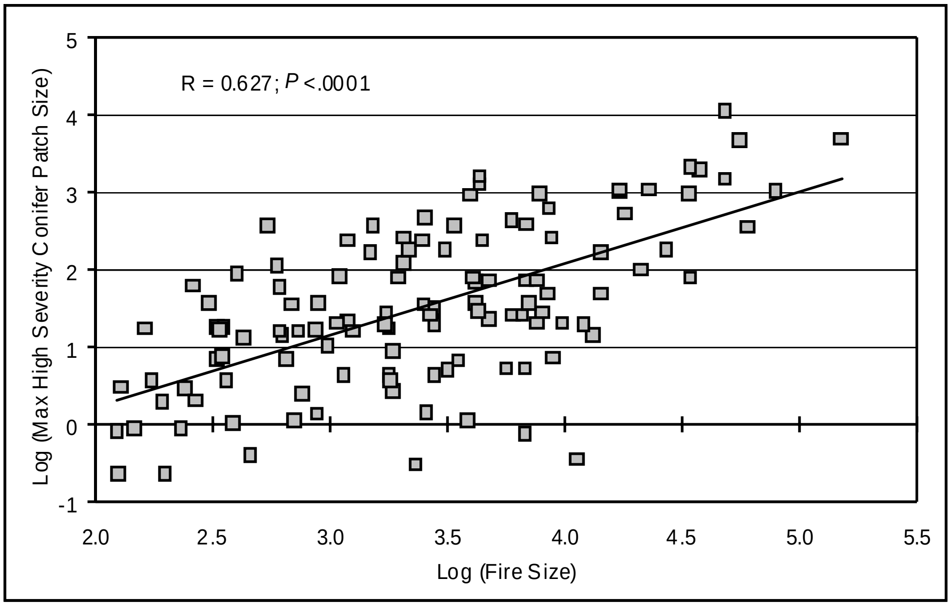

Figure 16. Maximum high severity conifer patch size on U.S. Forest Service administered lands from each mapped fire vs. fire size. Both axes are Log transformed.

We examined the mean and mean maximum patch size by year for high severity patches in conifer forests, excluding pinyon-juniper, in the mapped fires from 1984-2004 (Figure 17). Only conifer acres on U.S. Forest Service administered lands were 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. Regressions of patch size were significantly influenced by the 1994 Cottonwood fire. We removed the 1994 Cottonwood Fire from the patch size analysis as an outlier, as its mean patch size was nine standard deviations higher than the 1984-2004 mean and the maximum high severity patch was more than twice the size of any other high severity patch measured in the mapped fires (Table 12). The average size of contiguous areas ("patches") of stand-replacing fire within conifer forest fires almost doubled across the period of analysis, rising from a mean of about 7 ac. in the first ten-year period to about 13 ac. in the last period (area data log-transformed, $R^2 = 0.325$, $P = 0.011$). Assuming circular patch geometry, the average radius of these high severity patches has increased from about 320 ft to about 420 ft. The mean maximum high severity patch size has also increased over the period of record, from about 110 ac. at the beginning of the record, to 290 ac. in the most recent ten year period (area data log-transformed, $R^2 = 0.353$, $P = 0.007$).

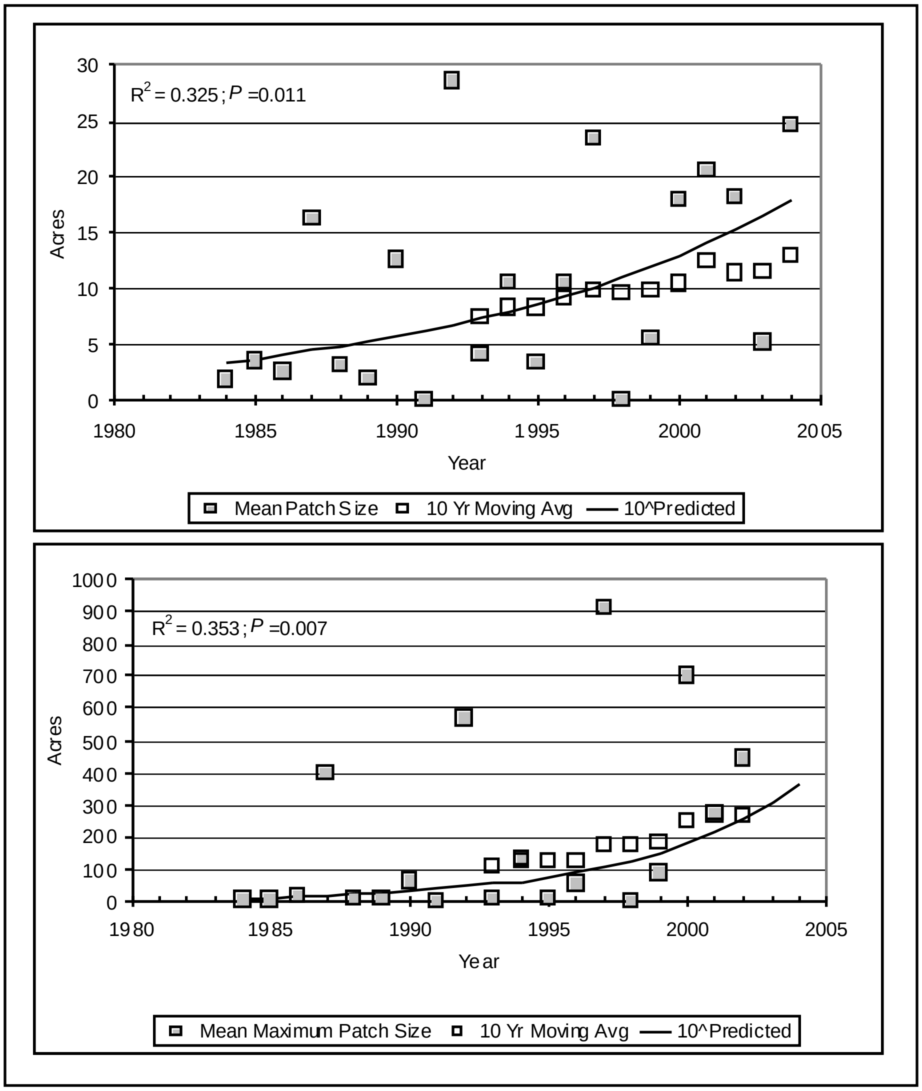

Figure 17. Mean and mean maximum high severity conifer patch size on U.S. Forest Service administered lands in the 1984-2004 mapped fires excluding the 1994 Cottonwood fire. Ten year moving average is for previous 10 years, displayed only for visual comparison. Patch size data log-transformed before computing the regression. Pictured *P* value refers to the linear trend.

Table 12. Contiguous high severity conifer patches greater than 1000 ac. on U.S. Forest Service administered lands in 1984-2004 mapped fires.

Year	Fire Name	High Severity Patch Size (ac)
1994	Cottonwood	10736
2002	McNally	4751
2000	Storrie	4544
2002	McNally	3282
2001	Blue	2086
1987	Paper Cmplx	1856
2002	McNally	1557
2001	Stream	1553
1987	Larson Cmplx	1438
2002	McNally	1362
1994	Cottonwood	1275
1992	Ruby	1242
1992	Cleveland	1059
2004	Power	1049
2001	Star	1032
2000	Manter	1021

Trend in Fire Size and Burned Area 1908-2006

Since our capability to directly measure percent high severity and high severity patch size for past fires is tied to the launch date of Landsat, 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 examine trends in number of fires and fire size. There are known problems with that database, such as sizes of all fires are not accurate and many fires less than 10 ac. are not included. However, the number of fires over 100 ac. and sizes of the largest fires are most likely accurate enough for a SNFPA area wide trend analysis. We began our trends analyses in 1908, as the data for 1906 and 1907 are very incomplete, and we restricted our analyses to fires greater than 100 ac, as small fires tend to be under-reported in the database (McKelvey and others 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 eleven Forests within the SNFPA area during the 1908-2006 period, which totaled 2,170. We used 10-year running means of the log-transformed dependent variables to graphically explore long-term trends. Figure 18 shows the number of fires per year for the SNFPA area from 1908 through 2006. The ten 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 1970s the number of fires has been increasing. While more than one factor may have contributed to the 30 years of relatively few 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 fire count (Pyne 1982). There also appears to be a reduction in the running average of the maximum fire size over the same 30 year period with an increasing trend in maximum size beginning either in the 1970s or 1980s (Figure 19). Interestingly, the ten year running average in Figure 19 shows a temporal oscillation in average fire size (with a periodicity of 15-20 years) ending in an upward trend from the early 1980s through present. Between 1940 and 1970 there does not appear to be a reduction in average fire size with the reduction in maximum fire size and number of fires, indeed the overall trend for the whole 1908-2006 period is up (R^2=0.089; P=0.003). This would be consistent with the idea that human management of disturbances is most likely to affect the tails of the distribution rather than the mean. Although more muted, the oscillation pattern can also be seen in the ten year running average of the maximum fire size and number of fires. Fire activity in the Sierra Nevada has been shown to be coupled to interannual and interdecadal climatic variability such as the Pacific Decadal Oscillation (PDO) and El Niño-Southern Oscillation (ENSO) (Swetnam 1993; Taylor and Beaty 2005). The oscillations evident in the ten year moving averages may therefore be related to climate variability. The upwards trend in maximum fire size since the mid to late 1980s appears to be uncharacteristic when compared to the beginning of the century (Figure 19).

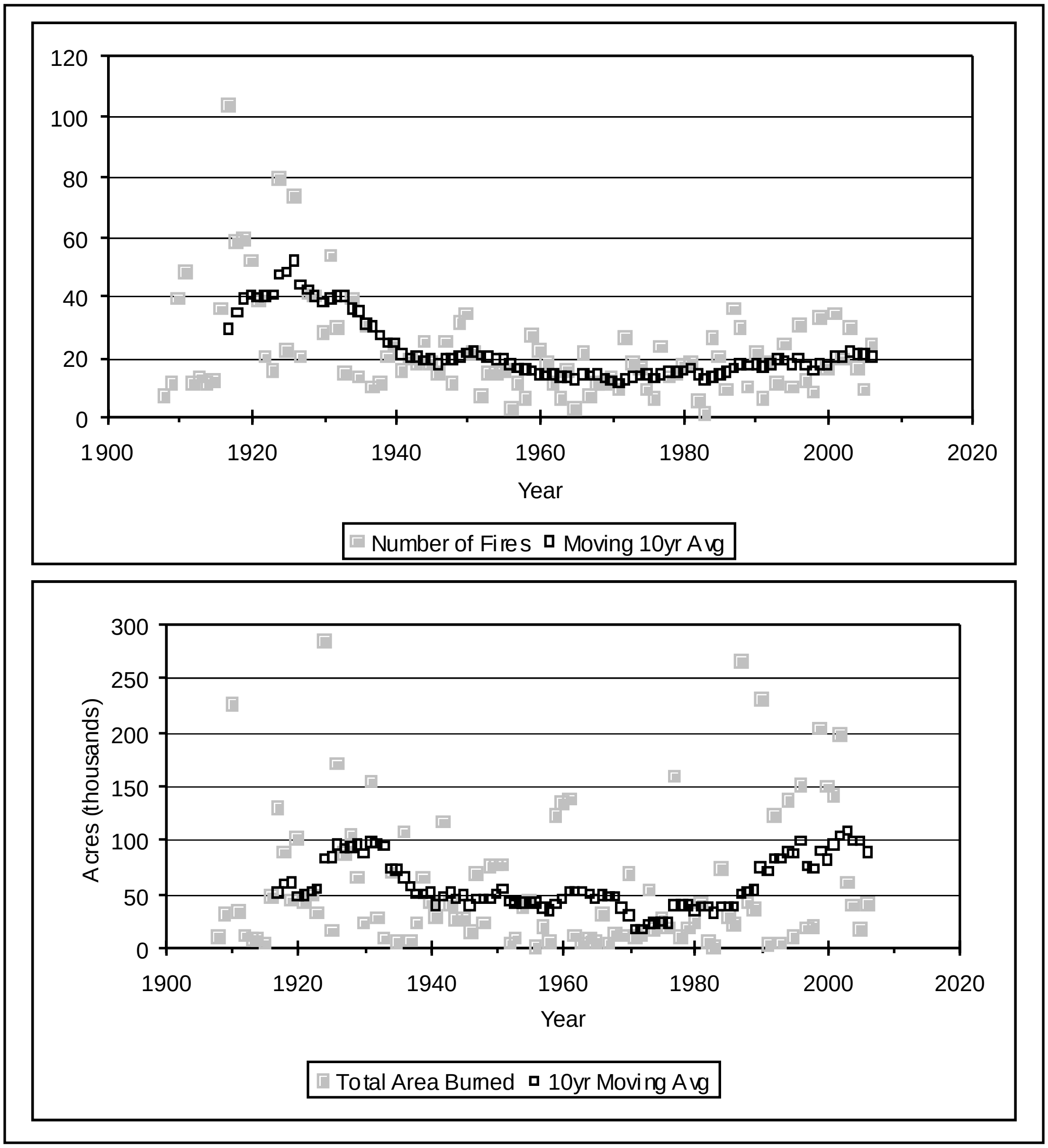

Figure 18. Number and total area of fires greater than 100 ac. per year 1908-2006 for the eleven SNFPA Forests. Ten year moving average is for previous 10 years, displayed only for visual comparison.

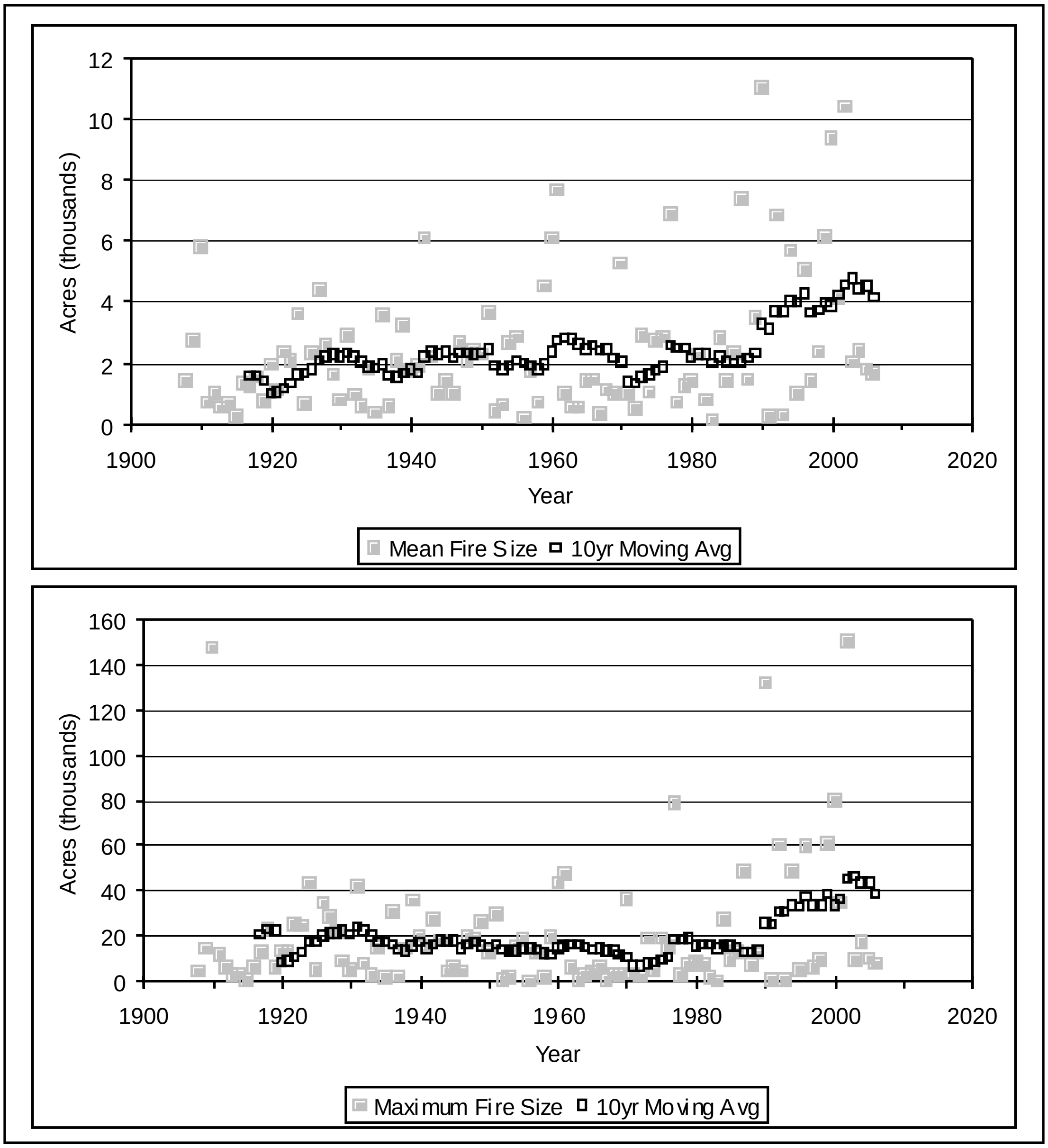

Figure 19. Mean and maximum fire size per year 1908-2006 for the eleven SNFPA Forests. Ten year moving average is for previous 10 years, displayed only for visual comparison.

Fire Correlations with Climate

Research into climate change has shown that global air temperature has been increasing (Brohan and others 2006). When normalized to the 1961-1990 mean, the global air temperature record is above the mean and rising since the beginning of 1980's (Figure 20). Westerling and others (2006) have recently shown that changes in climate have lead to increased large fire occurrence in the western U.S. since the early to mid 1980s. These changes in climate and fire occurrence appear to coincide with the increases we see in the maximum and average fire size in the SNFPA area (Figure 19).

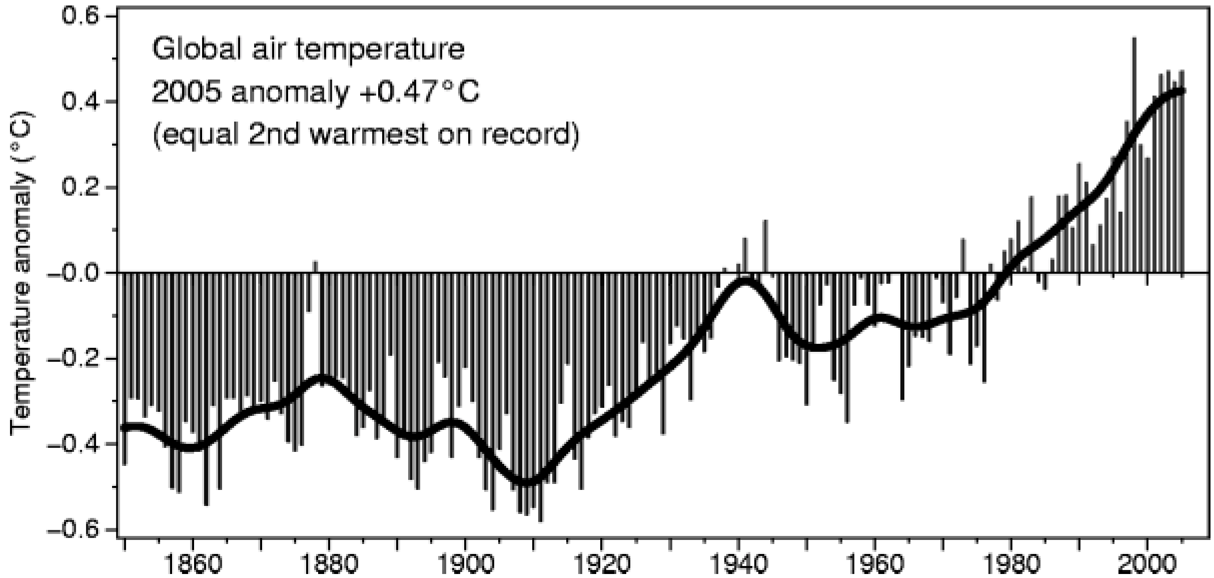

Figure 20. Global air temperature record normalized to the 1961-1990 average. (from University of East Anglia, UK; http://www.cru.uea.ac.uk/cru/info/warming/)

To more closely examine fire-climate relationships we acquired the California region D climate data from the Western Regional Climate Center which covers the western slope of the Sierra Nevada (Figure 21). 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 (1908-1956), late (1957-2006) and very late (1982-2006) portions of the study period; these temporal groups were generated by splitting the data set in half and then in half again, and were not made based on any *a priori* assumptions. Regressions were performed on the climate variables against the number, maximum and mean fire size, and total burned area for the years 1908 through 2006, and percent high severity fire seen in the major conifer forests 1984-2004 (Table 13). In the 1984-2004 period, fire severity in yellow pine-dominated forests in the SNFPA area (ponderosa pine, dry mixed conifer, Jeffrey pine) was best explained by springtime temperature minima, while severity in moister and higher elevation forest types dominated primarily by fir species (moist mixed conifer, true firs, subalpine) was best explained by spring and summer precipitation (Table 13). Climatic correlations were strongest for forest types with a fir component. Between 1908 and 2006, the annual number of recorded fires, fire size and annual burned area in the study region were all positively related to summer temperatures and negatively related to winter precipitation. Annual number of fires was also negatively related to spring precipitation. However, splitting the temporal record into early (1908-1956), and late (1957-2006) periods shows that a shift in climate correlations has occurred. In the early period, most fire variables were characterized by negative correlations with winter precipitation and positive correlations with spring temperatures, shifting in the late period to negative correlations with spring precipitation and positive correlations to summer temperatures (Table 13). Exceptions were mean fire size which was correlated with only spring temperatures in the early period and annual number of fires which was positively correlated to summer temperatures for both early and late periods. For all four fire variables, the strength (R^2) of the climate-fire relationship increases considerably from the first to the second half of the record (Table 13). Across the 99 year record, the proportion of variance in the fire variables explained by climate has more than doubled, from 11-27% in the early record to 34-52% in the late record. Fire size and burned area are increasing in concert with rising temperatures and precipitation, but whereas variance in fire size and annual burned area was primarily explained by winter precipitation and spring temperatures at the beginning of the record, it is now primarily explained by spring precipitation and summer temperatures (Table 13). Regional annual average precipitation during this period has increased approximately 10 inches (Figure 22), with most of the increase occurring in the spring (3.2 in, R^2=0.036, P=0.06) and fall (3.5 in, R^2=0.07, P=0.008). There were no temporal trends in mean maximum temperature over the 1908-2006 period (Figure 23), but all four seasonal measurements of mean minimum temperatures showed significant increases led by June-August (+3.16º F, $R^2 = 0.299$, $P < 0.001$).

Heat, oxygen, and fuel are fundamental factors controlling fire combustion. Precipitation's direct influence on fire is negative, through the wetting of fuel, and overall precipitation is increasing in the study area (Figure 22). But increasing amounts of precipitation is falling in the form of rain due to increasing temperatures. Increasing nighttime minimum temperatures are leading to earlier snowmelt, which in turn deepens the summer drought, drying fuels earlier in the year and lengthening the fire season. Increasing annual precipitation and warmer nighttime temperatures also have an indirect positive effect on fire activity due to increased fuels resulting from a longer growing season and augmented vegetation growth. All of which in concert with effective fire suppression is resulting in an increase in the percentage of high severity fire in middle and low elevation xeric conifer forests. Conversely, the percentage of high severity fire in mesic and high elevation conifer forests is primarily directly related to the amount of spring precipitation. It appears that the trend in precipitation and temperature occurred over the entire century, yet mean and max fire size, and annual area burned have increased primarily since the 1980's to levels higher than those seen during the period of modern suppression methods while number of fires has remained relatively low (Figure 18 and Figure 19). It may be that higher fuel loads due to increased precipitation; longer growing seasons through warmer nighttime temperatures, and absence of fire has lead to conditions that are less limiting to fire size.

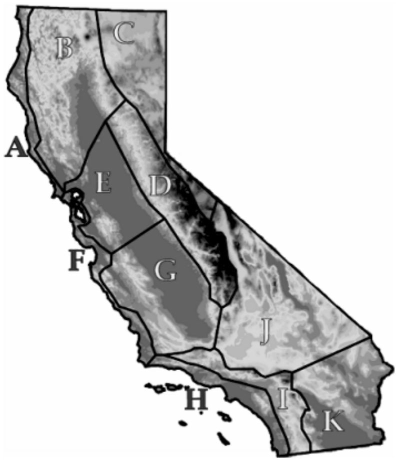

Figure 21. Western Regional Climate Center climate regions for California. (from Western Regional Climate Center http://www.wrcc.dri.edu/monitor/cal-mon/index.html)

Table 13. Fire-climate regression results

Dependent Variable*	Period	Winter precip	Spring precip	Spring max temp	Spring min temp	Summer max temp	Summer min temp	*P*	R^2
Dry Mixed Conifer	1984-2004				0.715			0.000	0.512
Ponderosa Pine	1984-2004				0.495			0.023	0.245
Jeffrey Pine	1984-2004				0.380**			0.089	0.144
Moist Mixed Conifer	1984-2004		-0.732					0.000	0.537
Red Fir	1984-2004		-0.539					0.011	0.290
Subalpine	1984-2004		-0.537					0.012	0.287
Number of Fires	1908-2006	-0.232	-0.288			0.359		0.000	0.359
	1908-1956	-0.397				0.331		0.001	0.266
	1957-2006		-0.424			0.532		0.000	0.523
Mean Fire Size	1908-2006	-0.215		0.323			0.264	0.000	0.253
	1908-1956			0.328				0.021	0.108
	1957-2006		-0.351			0.368		0.000	0.339
Max Fire Size	1908-2006	-0.222		0.244		0.313		0.000	0.278
	1908-1956	-0.296		0.349				0.004	0.217
	1957-2006		-0.424				0.413	0.000	0.396
Annual Burned Area	1908-2006	-0.253		0.345		0.320		0.000	0.388
	1908-1956	-0.360		0.360				0.001	0.269
	1957-2006		-0.462				0.499	0.000	0.523

* Dependent variable for forest types 1984-2004 is percent area of fires burning at high severity.
Values in climate columns are standardized regression coefficients.
All predictor parameter estimates are significant at $P < 0.05$ except **.
Winter = Dec-Feb, Spring = Mar-May, Summer = Jun-Aug, Fall = Sep-Nov

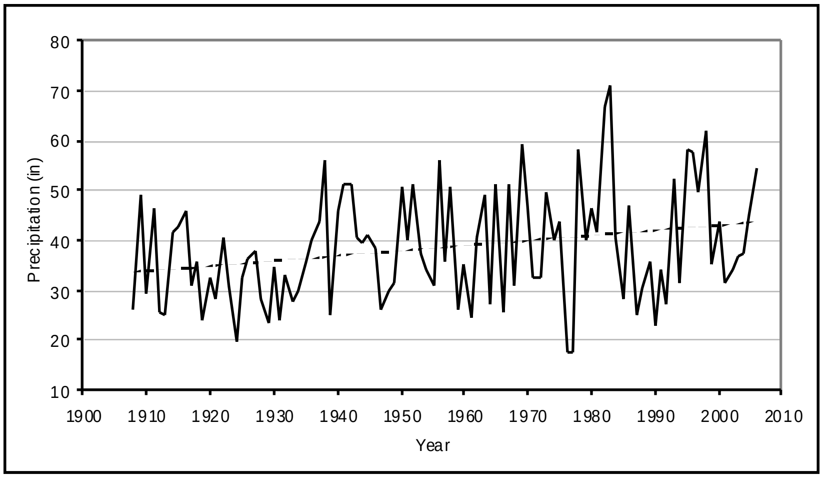

Figure 22. Sierra Nevada region D total precipitation for 1908-2006. Dashed line indicates linear trend (R^2=0.068, P=0.009).

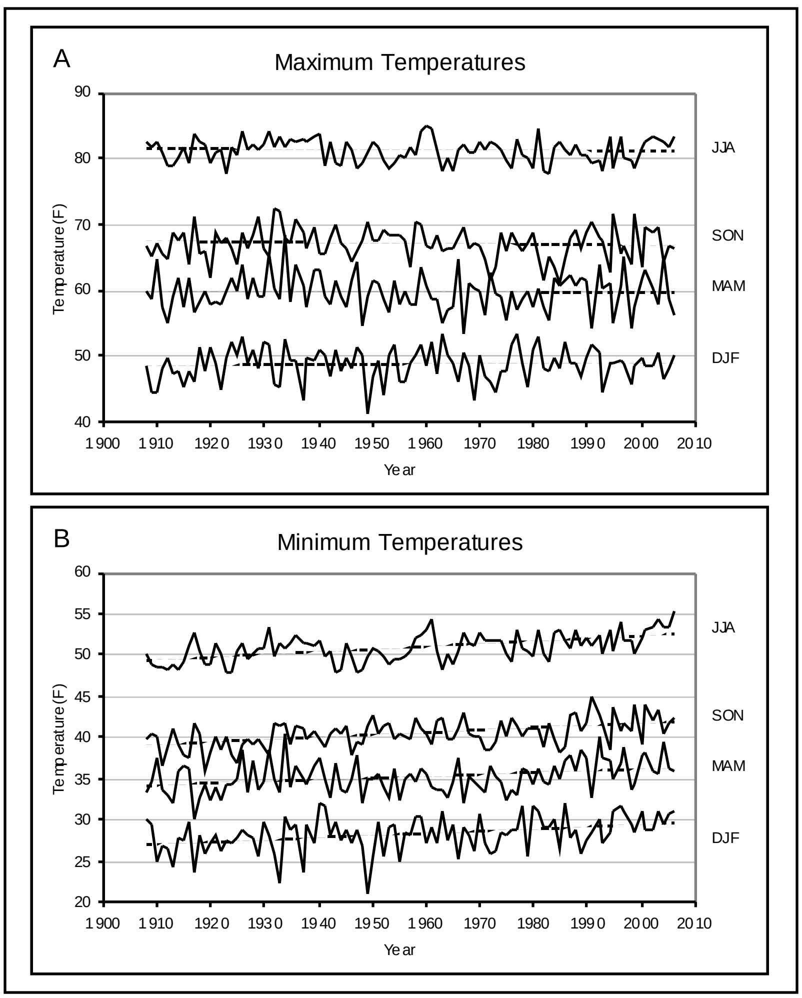

Figure 23. Sierra Nevada region D seasonal average temperatures (a) maximum, (b) minimum. JJA=June-August, SON=Sept-Nov, MAM=March-May, and DJF=December-February. Dashed line indicates linear trend.

Applications of Fire Severity Data

While vegetation based fire severity mapping is useful for measuring patterns of fire severity and trends over time, the greatest utility is in addressing important resource management questions. Current uses of vegetation based severity maps, both within Region 5 and nationally, include updating fuels and wildlife habitat layers to evaluation of vital underlying assumptions in project to regional scale planning analysis for NEPA. These assumptions include: effectiveness of fuel treatments, changes in wildlife habitat and vegetation structure and composition from fire, fire behavior and effects modeling, and fire regime condition class modeling. Another application is the broad scale evaluation of fire effects of WFU fires in comparison with wildfires. A limited comparison has been provided in this report. There is also the potential to improve information available for post-fire restoration and salvage related to vegetation, since most current BAER mapping is more focused on soils and hydrologic function. Since the middle of 2006 the Region 5 reforestation silviculturist has been using maps calibrated in units of percent tree basal area mortality developed for this report for post-fire reforestation planning within one month post-fire. Post-fire reforestation planning methods developed in Region 5 are currently being deployed in other regions. There are several on-going applications of the vegetation based fire severity mapping by the Stewardship and Fireshed Assessment process. They are utilizing the severity maps to modify fuels layers post-fire as well as vegetation structure and composition. They are also utilizing the severity maps to calibrate their fire behavior and fire effects modeling assumptions. An obvious application that is currently under utilized is the objective evaluation of the effectiveness of fuel treatments. Examples of how severity data produced by this project can be used for assessing fuels treatment effectiveness to alter fire behavior can be found in Fites and others(2007), and Finney and others (2005). Using severity maps from historic fires to validate a fire risk model for determining the placement of fire fighter safety zones is a novel application being developed on the Salmon-Challis NF. Occurrence of crown and lethal surface fire was correlated to vegetation structure, topography, historic fire regime, and fire regime condition class to develop a predictive model of where extreme fire behavior could occur on the landscape. The resulting model of extreme fire risk was then validated by comparing areas of high risk from crown fire to severity patterns mapped in historic fires.

The above examples are only a sample of management questions that could be addressed using vegetation severity data. Many more applications will be envisioned when more people become acquainted with the data. Below are examples of additional questions that we believe could be addressed using severity data.

- Ecosystem / Landscape level monitoring – Through historical severity data determine where and why high severity fire occurring. For example, does high severity fire occur in stands of large trees (old growth), or is it in young stands? What are the implications to the usage of suppression tactics and placement of fuels treatments?

- EIS and NEPA planning – Use the distribution of fire severity by category (low, moderate, and high) in past prescribed fires to predict effects in future prescribed fires for NEPA planning.

- Wildlife habitat monitoring - Severity data can be used to monitor how fires (severity and acres burned) are affecting habitat quality parameters; snag recruitment for Black-backed Woodpecker, for example.

Appendix A: Methods

Satellite Derived Index

Recently the normalized burn ratio (NBR) has gained considerable attention, mostly in the United States, for mapping fire scars (Miller and Yool 2002; Brewer and others 2005; Epting and others 2005; Key and Benson 2005b). Most often a post-fire NBR image is subtracted from a pre-fire NBR image in a change detection methodology to derive the differenced NBR (dNBR) (Key and Benson 2005b). 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 and others 2007). 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 2005b; Zhu and others 2006; Miller and Thode 2007). 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; Safford and others 2008). An additional advantage to RdNBR is that a single set of thresholds (calibrations) can be used to develop categorical classifications for fires (at least those occurring in similar vegetation types) without acquiring field data on each fire (Zhu and others 2006; Miller and Thode 2007).

Data processing of the Landsat data included converting raw digital numbers to at sensor reflectance as described by Chander and Markham (2003). Pre- and post-fire image pairs were matched by anniversary date as close as possible to minimize sun angle effects and differences in phenology. Images from June through August were used to map 96% of the fires mapped for this project. All post-fire images were acquired one growing season after fire occurrence to match the date of field sampling (Key and Benson 2005a). No atmospheric scattering algorithm was applied to the data since the NBR employs only near and middle infrared wavelengths that are minimally affected by atmospheric scattering (Avery and Berlin 1992). Satellite values were not corrected for topographic shading since NBR is a ratio and topographic effects cancel when atmospheric scattering is minimal (Ekstrand 1996). NBR values were multiplied by 1000 and converted to integer format to match procedures established by Key and Benson (2005b). A focal mean algorithm was used to average pixel values in a 3x3 pixel window to match the 90 meter diameter field plots. The dNBR for each fire was normalized to account for inter-annual differences in precipitation by subtracting the average dNBR value sampled from an unburned area outside the fire perimeter.

Field Data

Field data collected on 18 fires in the SNFPA area during 2002 through 2005 were used to "calibrate" the satellite derived index. The field protocol measured fire effects primarily to vegetation in 90 meter diameter circular plots. Field measurements employed the composite burn index (CBI) protocol developed by Key and Benson (2005a) 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 basal area mortality. CBI values were not collected the first field season (four fires). The qualitative measurements were made on all fires. 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) Based Classification

The CBI was developed by Key and Benson (2005a) 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 and others 2006); and 2.) CBI does not result in a measurement that is familiar to most resource managers.

The CBI based 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 (Parsons 2003; Safford and others 2008). 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 based 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.

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 therefore difficult sometimes 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 30m x 30m 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 and others 2007).

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 =**						Σ=
Litter/Light Fuel Consumed	Unchanged	--	50% litter	--	100% litter	>80% light fuel	98% Light Fuel	
Duff	Unchanged	--	Light char	--	50% loss deep char	--	Consumed	N =
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	X̄=
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 =**						Σ=
% Foliage Altered (blk-brn)	Unchanged	--	30%	--	80%	95%	100% + branch loss	
Frequency % Living	100%	--	90%	--	50%	< 20%	None	N =
Colonizers	Unchanged	--	Low	--	Moderate	High-Low	Low to None	
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High change	X̄=
C. TALL SHRUBS AND TREES 1 TO 5 METERS:								
Pre-Fire Cover =		**Enhanced Growth Factor =**						Σ=
% Foliage Altered (blk-brn)	0%	--	20%	--	60-90%	> 95%	Signifcnt branch loss	
Frequency % Living	100%	--	90%	--	30%	< 15%	< 1%	N =
% Change in Cover	Unchanged	--	15%	--	70%	90%	100%	
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High Change	X̄=
D. INTERMEDIATE TREES (SUBCANOPY, POLE-SIZED TREES)								
Pre-Fire % Cover =		**Pre-Fire Number Living =**			**Pre-Fire Number Dead =**			Σ=
% Green (Unaltered)	100%	--	80%	--	40%	< 10%	None	
% Black (Torch)	None	--	5-20%	--	60%	> 85%	100% + branch loss	N =
% Brown (Scorch/Girdle)	None	--	5-20%	--	40-80%	< 40 or > 80%	None due to torch	
% Canopy Mortality	None	--	15%	--	60%	80%	%100	X̄=
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 =**			Σ=
% Green (Unaltered)	100%	--	95%	--	50%	< 10%	None	
% Black (Torch)	None	--	5-10%	--	50%	> 80%	100% + branch loss	N =
% Brown (Scorch/Girdle)	None	--	5-10%	--	30-70%	< 30 or > 70%	None due to torch	
% Canopy Mortality	None	--	10%	--	50%	70%	%100	X̄=
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.

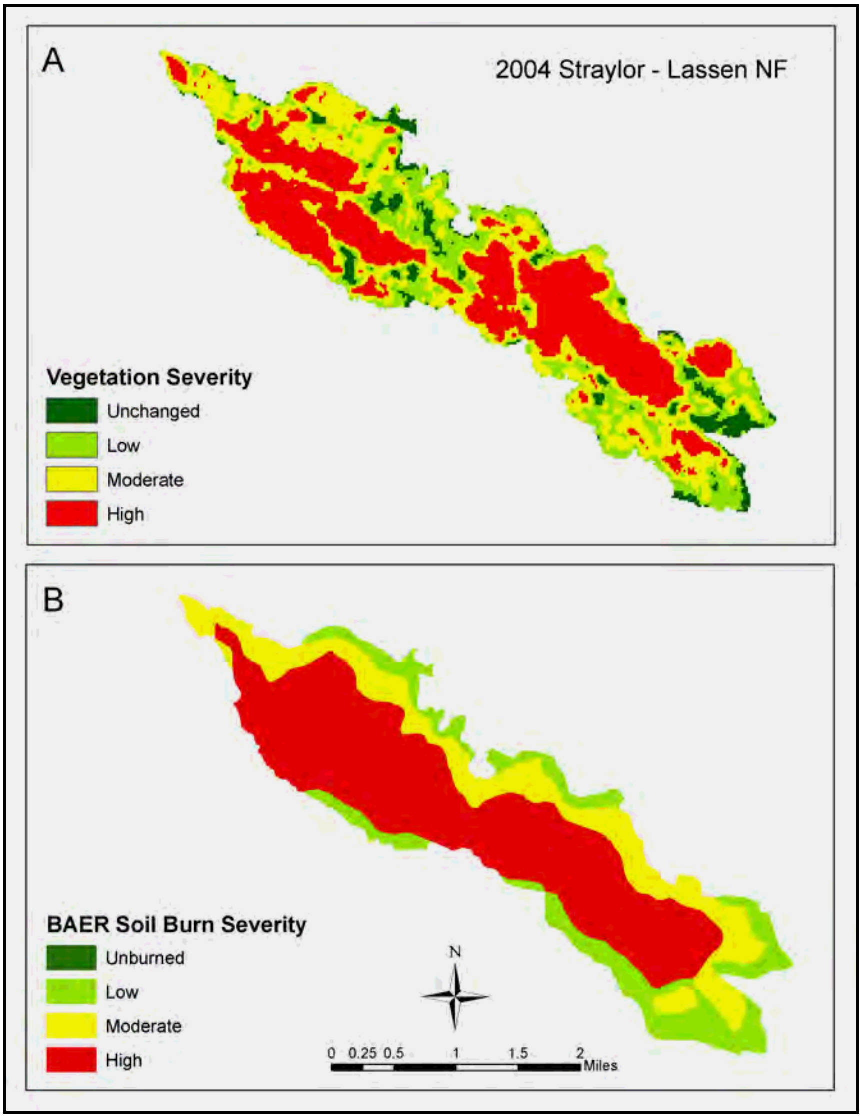

Figure A-2. Typical BAER and CBI based severity maps. A.) Severity map resulting from calibrating Landsat imagery with CBI data. B.) BAER burn severity map based upon soil characteristics.

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.

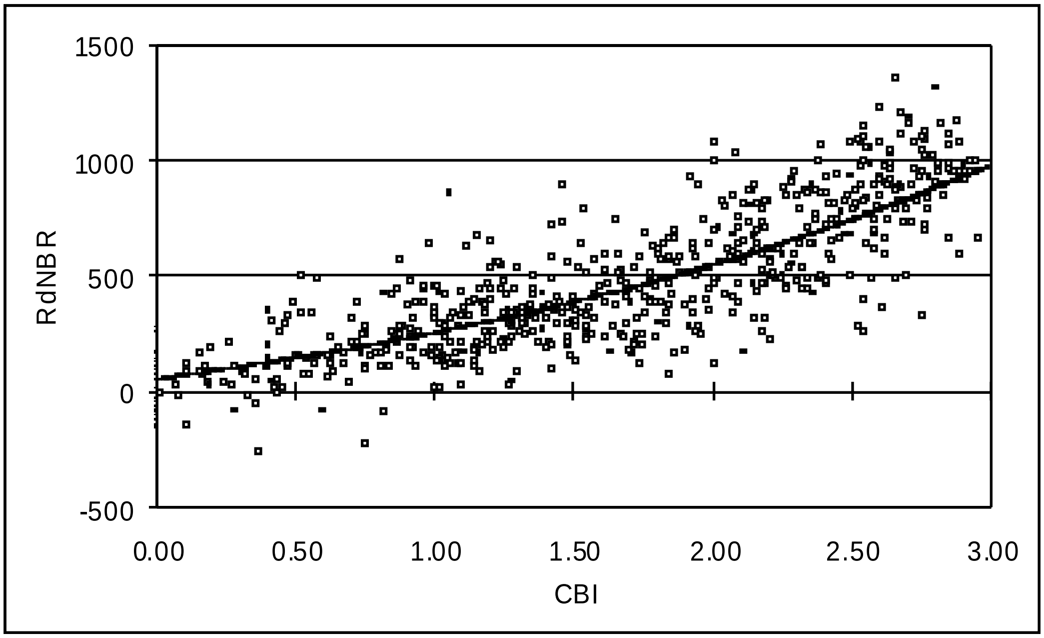

Figure A-3. Regression model of RdNBR to CBI overlaid with plots greater than 10% pre-fire tree cover.

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 Tree Basal Area Mortality Based 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 tree basal area mortality. Tree mortality by diameter size class was sampled in the same field plots where CBI data were collected. The mortality data were used to develop a nonlinear regression model of percent mortality of total tree basal area to the satellite derived RdNBR (Figure A-4; R^2 = 0.5528; P<.0001). The model was used to categorize percent basal area mortality into seven mortality categories shown in Table A-4. Figure A-5 compares a typical CBI based severity map to a map of percent basal area mortality. 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 seven 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 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 seven mortality categories were consolidated into three categories for reporting accuracies to more closely follow typical low, moderate and high classes, and since accuracies for the categories spanning the moderate severity range of 25-75% were poor. As with the CBI based values, the highest mortality category of greater than 75% basal area had the highest producer's and user's accuracies at about 80%. The moderate basal area mortality category of 25-75% had the lowest accuracies; lower than the accuracy of the moderate severity category of the CBI maps and not much better than would be expected by a random classification. The low accuracy of the 25-75% mortality category is not only due to the high spatial variability of moderate fire patterns, but of the high variability of tree versus shrub and herbaceous cover as reflected by the increase in user's accuracy as the percentage of pre-fire tree cover increases. The CBI is a composite measurement of severity accounting for all vegetation strata, where as the basal area mortality is only a measure of trees. Since the satellite index is highly sensitive to chlorophyll and is a measurement integrated over both horizontal and vertical space, CBI values more closely represent what is measured by the satellite except where tree canopy is dense enough to obstruct the view of the understory. Producer's accuracy is over 80% for the high severity category except when pre-fire tree canopy cover is less than 20% (Table A-6), due to the higher percentage of understory vegetation and soil exposed to view of the satellite when tree cover is low. Due to the low accuracy of the 25-75% category these maps should only be used to identify and analyze patches of high severity (>75% mortality).

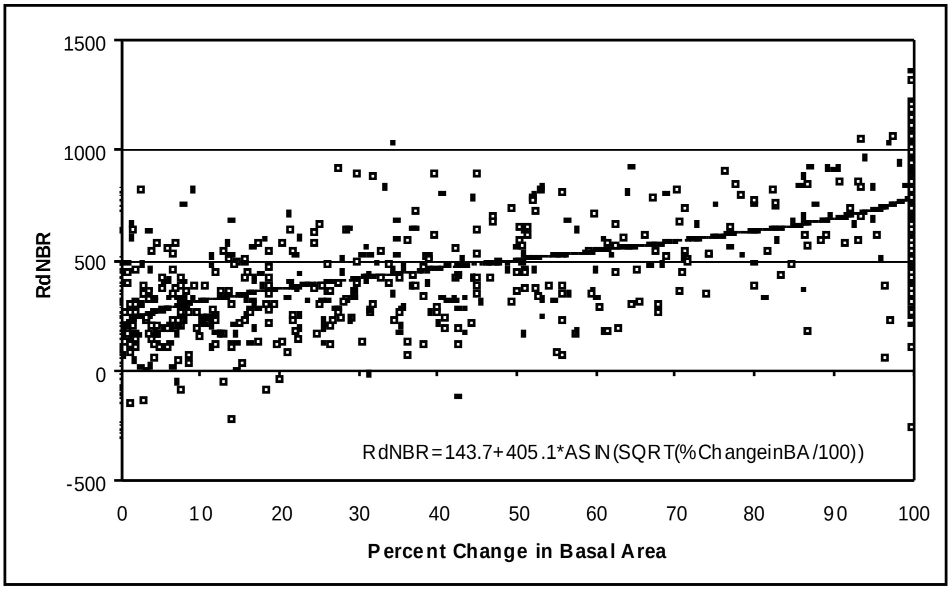

Figure A-4. Nonlinear regression model of RdNBR to field measured percent tree basal area mortality for plots with more than 5% pre-fire tree cover.

Table A-4. Percent change in tree basal area categories

Percent Tree Basal Area Mortality	RdNBR Threshold
0	Less than 144
1 – 10%	144 – 273
11 – 25%	274 – 355
26 – 50%	356 – 461
51 – 75%	462 – 567
76 – 90%	568 – 649
91 – 100%	Greater than or equal to 650

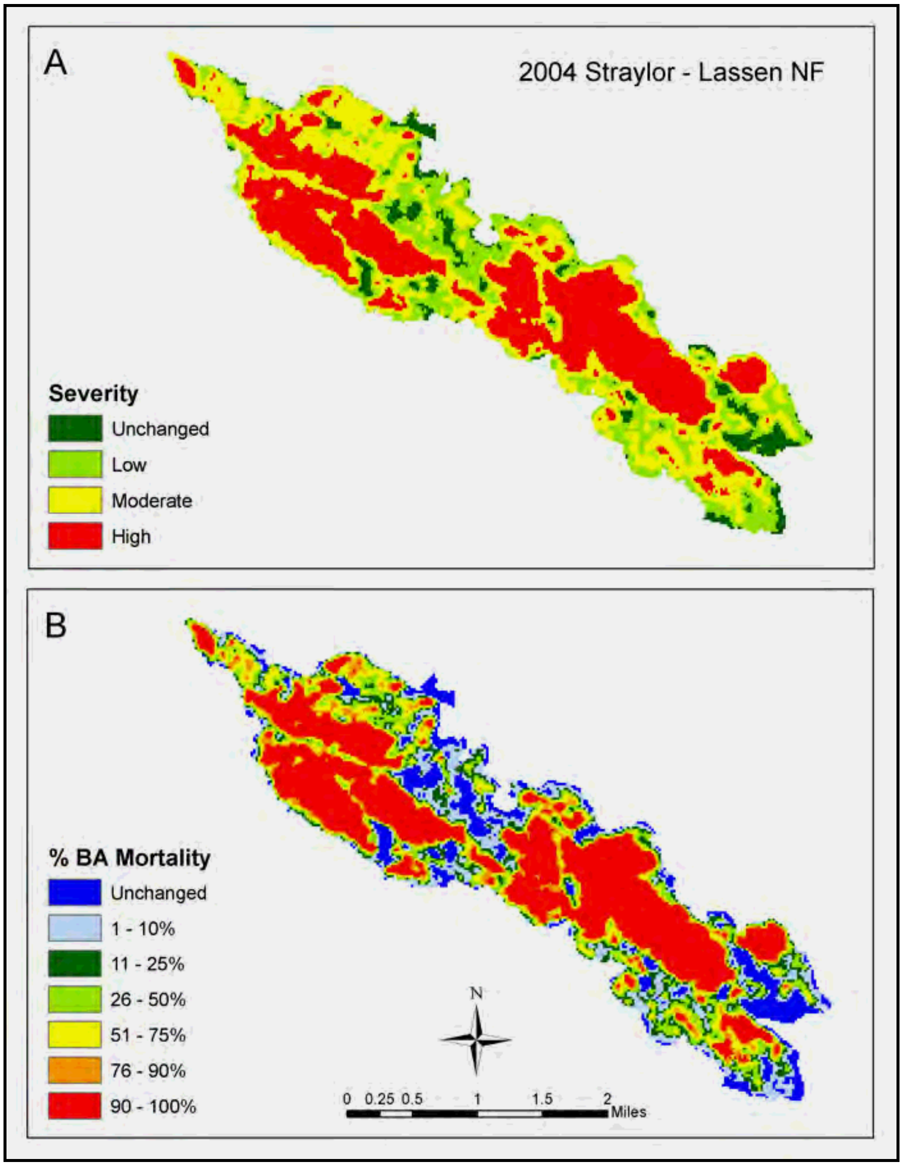

Figure A-5. Typical CBI based severity map compared to a percent basal area mortality map. A.) Severity map resulting from CBI derived thresholds. B.) Map of percent basal mortality resulting from a regression model of field measured mortality to RdNBR.

Table A-5. Percent change in tree basal area classification confusion matrix

Severity Category	<25%	25-75%	>75%	Total	User's Accuracy (%)
<25%	244	84	12	340	71.8
25-75%	76	79	47	202	39.1
>75%	23	50	278	351	79.2
Total	327	196	325	848	
Producer's Accuracy (%)	71.1	37.1	82.5		67.3

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

Table A-6. Percent change in basal area categories producer's and user's accuracies as a function of pre-fire tree canopy cover.

Pre-fire Tree Canopy Cover (%)	Producer's Accuracy			User's Accuracy		
	<25%	25-75%	>75%	<25%	25-75%	>75%
1-10	36	67	61	67	10	77
10-20	71	20	56	83	5	80
20-40	64	34	81	79	26	74
40-60	68	43	89	78	35	87
60-80	76	37	88	68	53	77
80-100	87	35	83	51	65	76

Note: Columns represent the number of plots with trees.

Trends in percent high severity and patch size, 1984-2004

Time series regression was used to calculate trends in the percent of fire area burning at high severity per year and high severity patch size over the 1984-2004 period, using SAS 9.1 (2003). We tested for data normality using Q-Q plotting and standard statistical tests (Lilliefors and Shapiro-Wilks). We transformed all percent severity data by arcsin-square root and all area data by log to meet statistical assumptions of normality. We fit Autoregressive Integrated Moving Average (ARIMA) time domain regressions to the severity data, using the Box-Jenkins (Box and Jenkins 1970; Shumway 1988) systematic technique for model identification and estimation. We fit linear trend models to severity data stratified by our regional vegetation types (including all forest types combined), and used Box-Jenkins techniques to determine if autoregressive, moving average, or difference operators improved the fit. We compared model adequacy using the Akaike Information Criterion (AIC) and Schwarz Bayes Criterion (SBC) as measures of goodness-of-fit (Shumway 1988). The patch size analysis only includes conifer forests, excluding pinyon-juniper. The minimum measurable patch size was 900 m^2, as our minimum mapping unit was the Landsat 30m pixel size. We removed one fire from the patch size analysis as an outlier, the Cottonwood Fire of 1994, as its maximum and mean high severity patch sizes were fully nine standard deviations higher than the 1984-2004 mean. Because of the high interannual variability in most of these datasets, we also portray results using a ten-year running mean of the annual data for graphic depiction of the decadal trend. We chose a ten-year window for our running mean calculation because (1) temporal autocorrelation statistics among the fire severity data showed a maximum at ten years, (2) 10 years is approximately the length of a half-cycle of the Pacific Decadal Oscillation, which has demonstrated temporal effects on fire activity in Northern California (Taylor and Beaty 2005), and (3) we wished to have at least 10 points to track mean trends across our analysis period.

Pre-settlement reference conditions for fire severity

Our graphs of idealized mean proportions of pre-Euroamerican settlement fire severities by vegetation type are based on nonequilibrial, aspatial state and transition models developed by the interagency LANDFIRE and FRCC programs for national and regional mapping of fuels and fire regimes (LANDFIRE; Hann and others 2005; The Nature Conservancy and others 2006; Long and others 2006;

Pratt and others 2006). The eastside pine reference conditions are based on LANDFIRE Biophysical Setting model BPS 0610310 (California Montane Jeffrey Pine Woodland), the ponderosa pine reference on model BPS 0310270 (Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland), the white fir reference on model BPS 0610280 (Mediterranean California Mesic Mixed Conifer Forest and Woodland), and the red fir reference on model BPS 061032b (Mediterranean California Red Fir Forest and Woodland).

Trends in area burned and fire occurrence, 1908-2006

We used the California fire history database jointly maintained by the California Department of Forestry and Federal land management agencies in California to investigate trends in number of fires, fire size and total burned area per year. This database contains fire perimeter (and other) information in GIS form for all fires greater than 10 ac. back to 1950, and somewhat larger fires (size depending on agency reporting the fire) before that date, back to 1906. We began our trends analyses in 1908, as the data for 1906 and 1907 are very incomplete, and we restricted our analyses to fires greater than 100 ac, as small fires tend to be under-reported in the database (McKelvey and others 1996) and fires over 100 ac. represent those fires that exceed initial attack capability. We analyzed all fires that intersected the eleven Forests within the SNFPA area for the 1908-2006 period, which totaled 2,170. We used 10-year running means of the log-transformed dependent variables to graphically explore long-term trends.

Climate analysis

To examine fire-climate relationships we acquired California Region D (Sierra Nevada) climate data summaries from the Western Regional Climate Center (WRCC 2007). Few of our fires occurred outside of Region D, so we used this climate dataset in all of our analyses. The monthly climate variables we included in our analysis included total precipitation, and mean minimum and maximum temperatures. The monthly data were grouped into seasons: Dec-Jan-Feb (winter), March-Apr-May (spring), June-July-Aug (summer), and Sept-Oct-Nov (fall). Stepwise linear regressions ($P_{(enter)} \leq 0.10$, $P_{(remove)} \leq 0.05$) for all subsets of the independent data were performed on the climate variables against the number, maximum and mean fire size for the years 1908 through 2006. We checked for data linearity through residual plotting and tested for normality using Q-Q plotting and standard statistical tests (Lilliefors and Shapiro-Wilks). Percent data were arcsin-square root transformed; fire number, size and area were log transformed; and precipitation variables were square root transformed. To assess data collinearity we examined variance inflation factors: in none of the final models did the VIF exceed 1.5 for any independent variable. The time series was also divided into two temporal groups of equal length to determine whether different climate variables were correlated to fire size and count in the early (1908-1956) and late (1957-2006) portions of the period of record; this split was not made based on any *a priori* assumptions.

Appendix B: Severity by Vegetation Type

One of the primary objectives of this project was to reassess the analysis used in the SNFPA FEIS (USDA 2001) to estimate the percentage of lethal, mixed-lethal and non-lethal fire by vegetation type (Hermit 1996). That analysis used the first CALVEG vegetation maps developed for California through classification of Landsat imagery by the U.S. Forest Service Pacific Southwest Region Remote Sensing Lab (RSL). The vegetation types were comprised of CALVEG dominance types grouped into nine regional types: ponderosa pine, eastside pine, mixed conifer, white fir, pinyon-juniper, black oak, live oak, blue oak, and chaparral shrub. The most recent version of CALVEG was used to lump Dominance Type into the same nine types as were used in the FEIS. In addition, we added four more types: lodgepole pine, red fir, riparian and subalpine conifer (Table 8).

Using static vegetation maps to analyze severity by vegetation type over time is of concern since high severity events can cause vegetation type change. Ideally we would like to have used vegetation maps that pre-dated the first fires we mapped. The earliest CALVEG maps of a scale matching Landsat TM used to generate the severity data date from the early 1990s and were the first produced using 30m imagery and image classification techniques. Although CALVEG is used as an existing vegetation map, the mapping methodology calls for not removing any previously productive conifer forest land from the vegetation map, for example, when stand replacing events occur the tree density is set to zero but the primary dominance type is not changed (Ralph Warbington, personal communication). In essence then, the CALVEG map for California is at least partly a “potential vegetation” map. Additionally, the mapping methods used by the RSL have greatly improved since the first version of CALVEG, resulting in maps with higher accuracies. Based on these considerations, we decided to use the latest CALVEG data to stratify all but one fire mapped for this report. The CALVEG data were inspected for each fire to determine whether fire patterns were reflected in the current vegetation map. In only two cases, the 2000 Manter Fire and the 1992 Cleveland Fire, was it felt that the current CALVEG data did not adequately represent the pre-fire condition. The 1999-2000 version of CALVEG was used to stratify the Manter Fire (except for the fire area that occurred outside the Forest boundary, which was not mapped in 1999-2000). The 1992 Cleveland predated the first usable CALVEG map. The forested land surrounding the Cleveland is predominately classified as mixed conifer, but within the fire perimeter the high severity patches are currently classed as ponderosa pine since they were replanted with ponderosa pine. We therefore reset all ponderosa pine polygons within the fire perimeter to mixed conifer for this analysis. We also eliminated all fires that overlapped (3% of the total mapped area) from any vegetation type analysis, thereby minimizing any confusion in the analysis due to vegetation type change. A total of 197 fires were mapped for this project. After eliminating the overlapping fires, 177 fires remained for use in the analysis by vegetation type.

The Landsat based RdNBR index values were summed by vegetation type over 177 fires from 1984 through 2004 to create probability distribution curves of severity. The distribution curves provide a measured estimate of the current fire severity that has occurred by vegetation type. Only the portions of the fires that occurred on U.S. Forest Service administered lands were included in the distributions to eliminate differences in management strategies between other Federal land management agencies, private owners, and the U.S. Forest Service.

The following sections describe the geographic distribution of each vegetation type within the SNFPA area and severity distribution curves for each vegetation type computed from the 1984-2004 fires. These distribution curves are summarized in Table 8 of the Results section of the main report. The distribution curves are derived by subtracting post-fire from pre-fire satellite images. Therefore, the vertical line on the x-axis represents zero, or where the pre- and post-fire images are equal. The x-axis to the right of the vertical line generally corresponds with the magnitude of fire severity (severity increases from left to right along the axis). The x-axis to the left of the vertical line represents areas where vegetation in image pixels was "greener" after the fire than before. Some of the pixels that fall to the left of the vertical line may have burned at low severity and actually experienced vegetation response that increased greenness one year after the fire. Other increases in greenness may be attributed to factors such as image noise and inter-annual variation in precipitation. An attempt is made during image processing to normalize the imagery so that pixels outside each fire have approximately the same image values.

Black Oak

The black oak regional vegetation type is composed solely of the black oak CALVEG type. Black oak occurs primarily in the lower montane zone on the west slopes of the Sierra Nevada. It is sparsely distributed and primarily found in areas of higher insolation and higher fire frequency (Barbour and Major 1988) (Figure B-1). Sugihara and others (2006) indicate that black oak historically experienced primarily low to moderate surface fire. The low to moderate mode seen in the probability distribution curve from the 1984-2004 fires shown in Figure B-1 corresponds broadly with that assessment, although 23% of burned acres did experience high severity fire (Table 8).

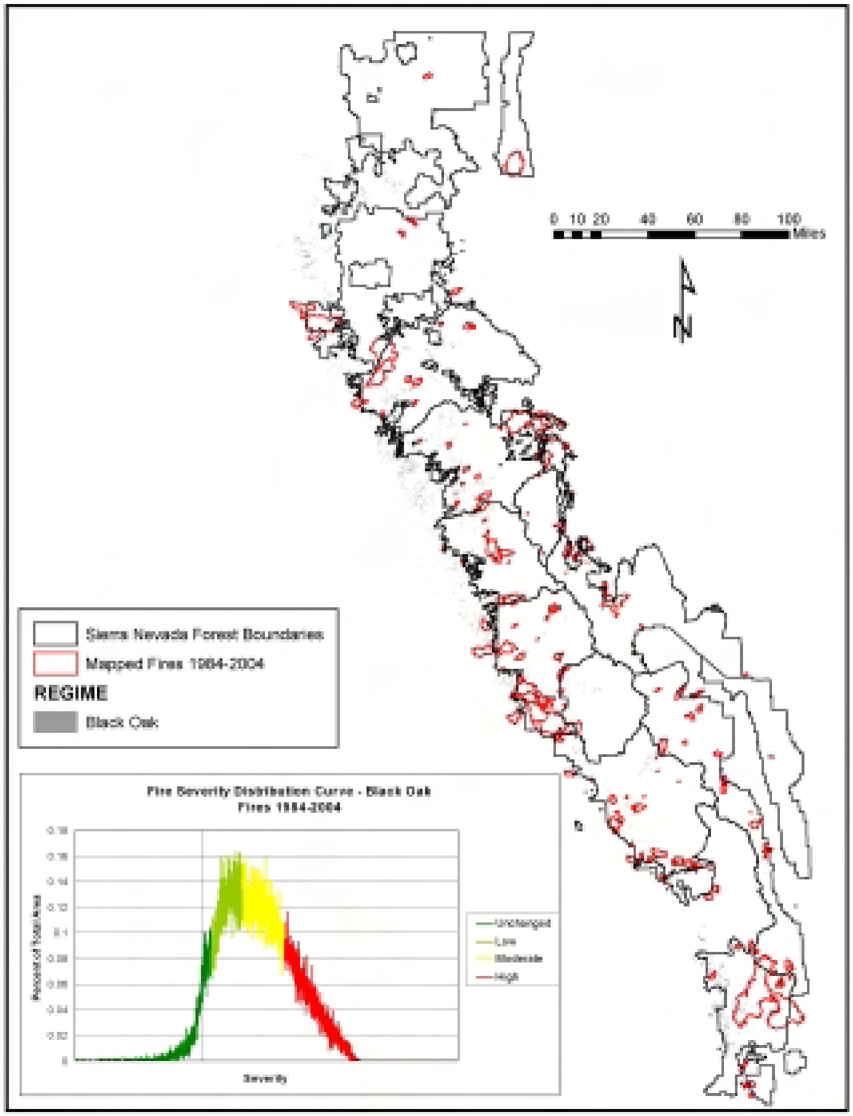

Figure B-1. Geographic distribution and fire severity probability distribution curve for the black oak regional vegetation type.

Blue Oak

The blue oak regional vegetation type is composed of the blue oak, valley oak, and gray pine CALVEG types; gray pine is included in this group because it is a common associate of blue oak, and only rarely dominates the canopy on its own (Barbour and Major 1988). These vegetation types occur at lower elevations in the foothill shrub and woodland zone on west side of the Sierra Nevada (Figure B-2). Sugihara and others (2006) indicate that blue oak historically experienced low severity surface fire. The low severity mode seen in the probability distribution curve from the 1984-2004 fires shown in Figure B-2 corresponds with that assessment.

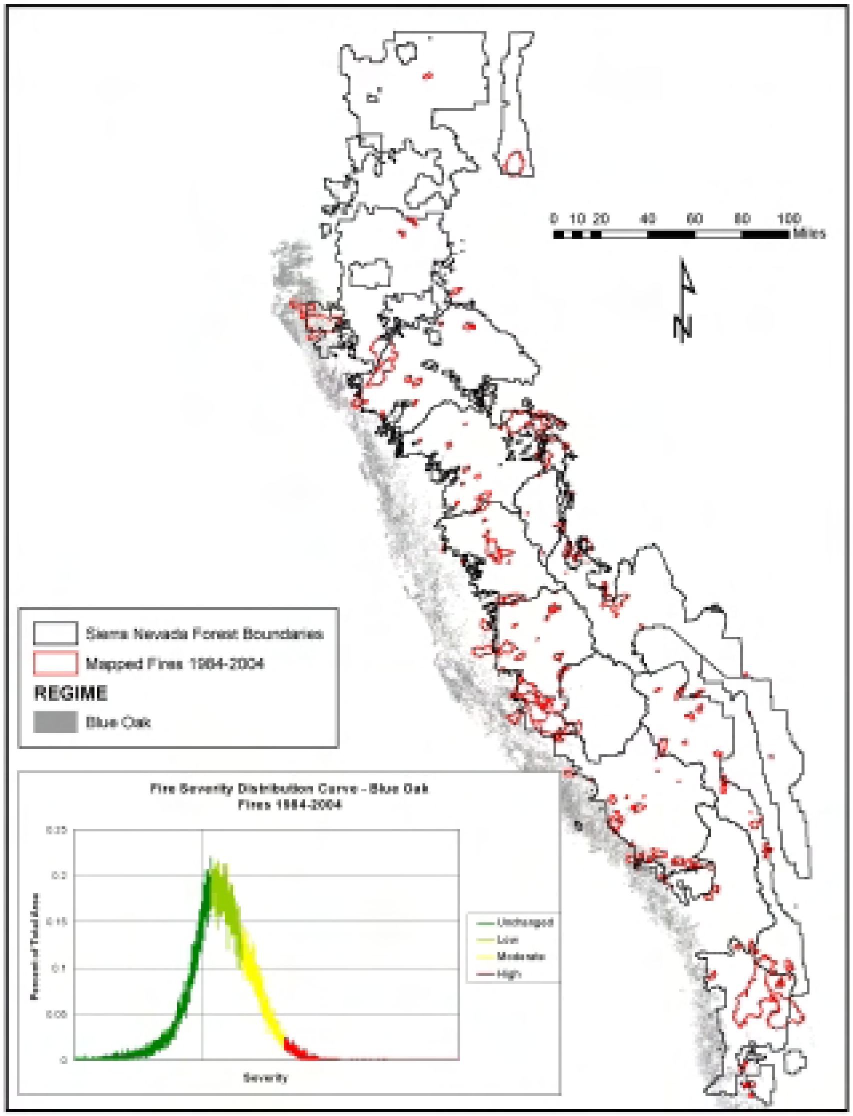

Figure B-2. Geographic distribution and fire severity probability distribution curve for the blue oak regional vegetation type.

Chaparral Shrub

The regional chaparral shrub type is composed of a very broad grouping of types as defined by CALVEG (Table 4), covering the entire elevation range of the Sierra Nevada (Figure B-3). Sugihara and others (2006) indicate that chaparral shrub types historically experienced primarily stand replacing fire. Therefore the historic severity probability distribution curve should have a mode in the high severity range. However, the distribution curve computed from the 1984-2004 fires has a mode in the upper moderate severity range. Many chaparral shrub species resprout after fire, although a number of species of manzanita and ceanothus do not. Since the severity data for this report were derived from one-year post-fire imagery, the distribution curve shown in Figure B-3 almost certainly under represents the amount of stand replacing fire experienced, as significant resprouting has usually occurred by that time. It is difficult to use our one-year post-fire measurements to make comparisons between our results and the SNFPA estimates for fire severities in chaparral. A better comparison would perhaps be made from severity assessments using immediate post-fire imagery.

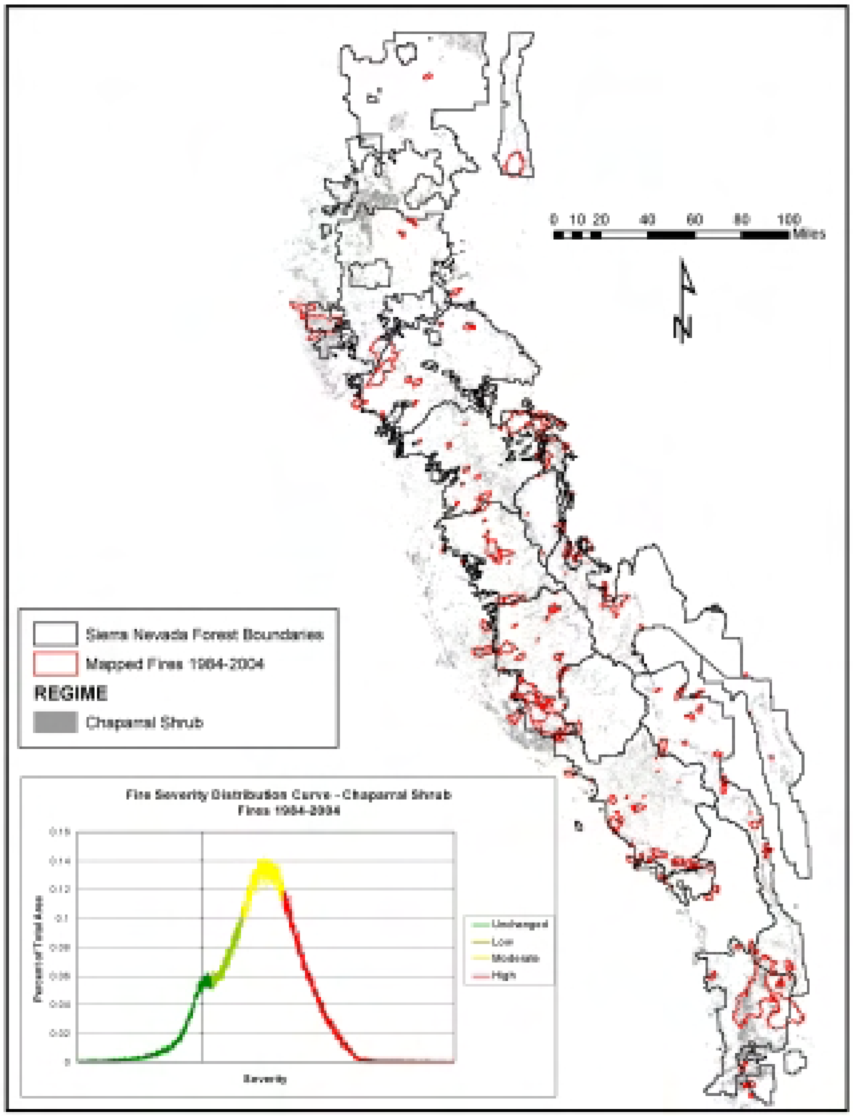

Figure B-3. Geographic distribution and fire severity probability distribution curve for the chaparral shrub regional vegetation type.

Eastside Pine

Eastside pine, Jeffrey pine, and Washoe pine CALVEG types were combined into one regional vegetation type. These types primarily occur in the montane zone on the east side of the Sierra Nevada and Modoc Plateau, but a minor component also occurs in the upper montane zone on the west slope (Barbour and Major 1988; Figure B-4). Sugihara and others (2006) indicate that eastside pine and Jeffrey pine historically experienced low severity surface fire. The low to low-moderate severity mode seen in the probability distribution curve from the 1984-2004 fires shown in Figure B-4 corresponds at least broadly with that assessment. However, west side Jeffrey pine is found primarily on rocky, low productivity sites, and historically supported a more mixed severity regime with longer fire return intervals. The low severity mode seen in the probability distribution curve from the 1984-2004 fires shown in Figure B-4 corresponds with that assessment. There is a secondary high severity mode in the 1984-2004 probability distribution curve, indicating that 37% of the area experienced high severity fire (Figure B-4 and Table 8). A variety of factors appear to have contributed to the high number of high severity acres (in comparison to the presumed historic condition [Sugihara and others 2006]). One is clearly the inclusion of west side Jeffrey pine stands with the east side types in our analysis (for example, the McNally Fire included 3200 acres of severely burned west side Jeffrey pine). Another is the well-documented in-growth of younger cohorts of Jeffrey pine and shade tolerant species like white fir into many east side pine stands, which can increase severity by "laddering" fire into the tree canopy. Finally, the eastside pine type is characterized by the presence of Great Basin shrubs such as sagebrush and bitterbrush which have a high severity regime (USDA 2005; Sugihara and others 2006), and in some places high densities of these shrubs may account for higher severities.

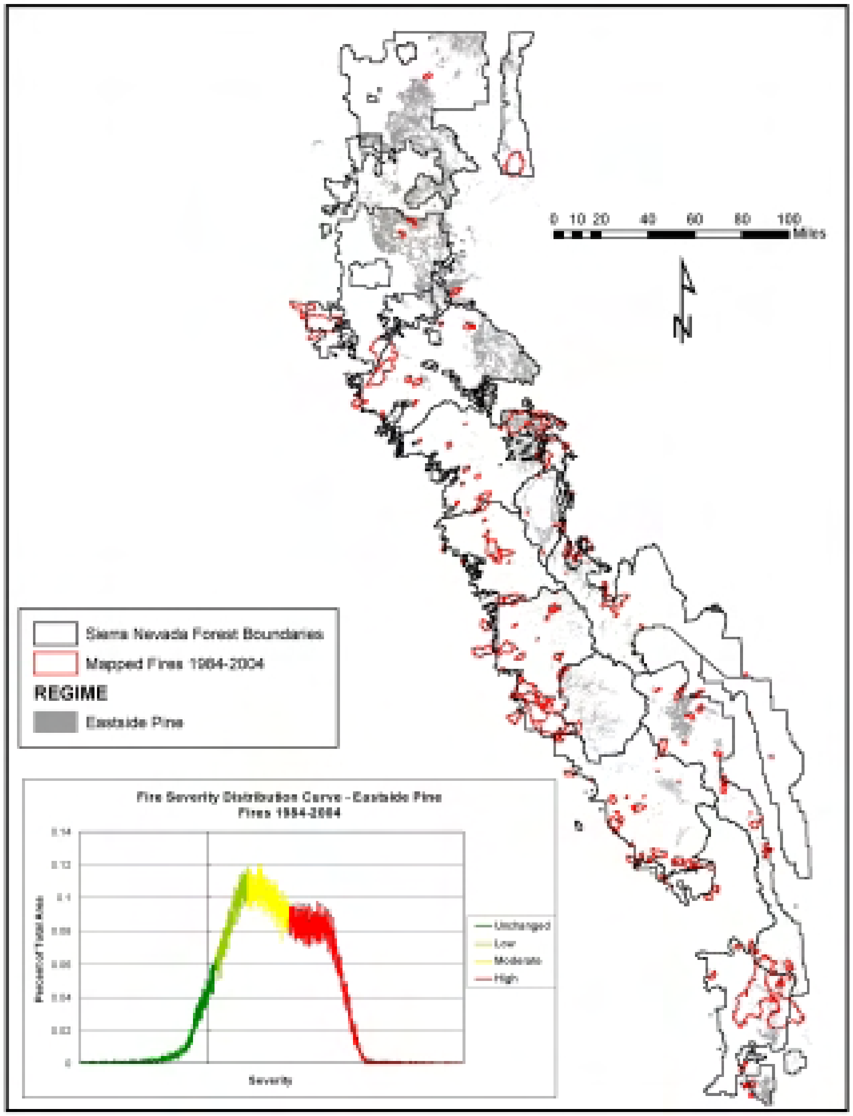

Figure B-4. Geographic distribution and fire severity probability distribution curve for the eastside pine regional vegetation type.

Live Oak

The live oak regional vegetation type is composed of the canyon live oak and interior live oak CALVEG types; these both occur in the foothill shrub and woodland zone on the west side of the Sierra Nevada (Figure B-5). The low severity mode seen in the probability distribution curve from the 1984-2004 fires shown in Figure B-5 agrees with the assessment made by Sugihara and others (2006) that live oak historically experienced low severity surface fire. Although a significant percentage of acreage also experienced moderate to high severity fire (Figure B-5 and Table 8), it should be noted that forty-four percent of those acres occurred in a single event, the 2002 McNally Fire.

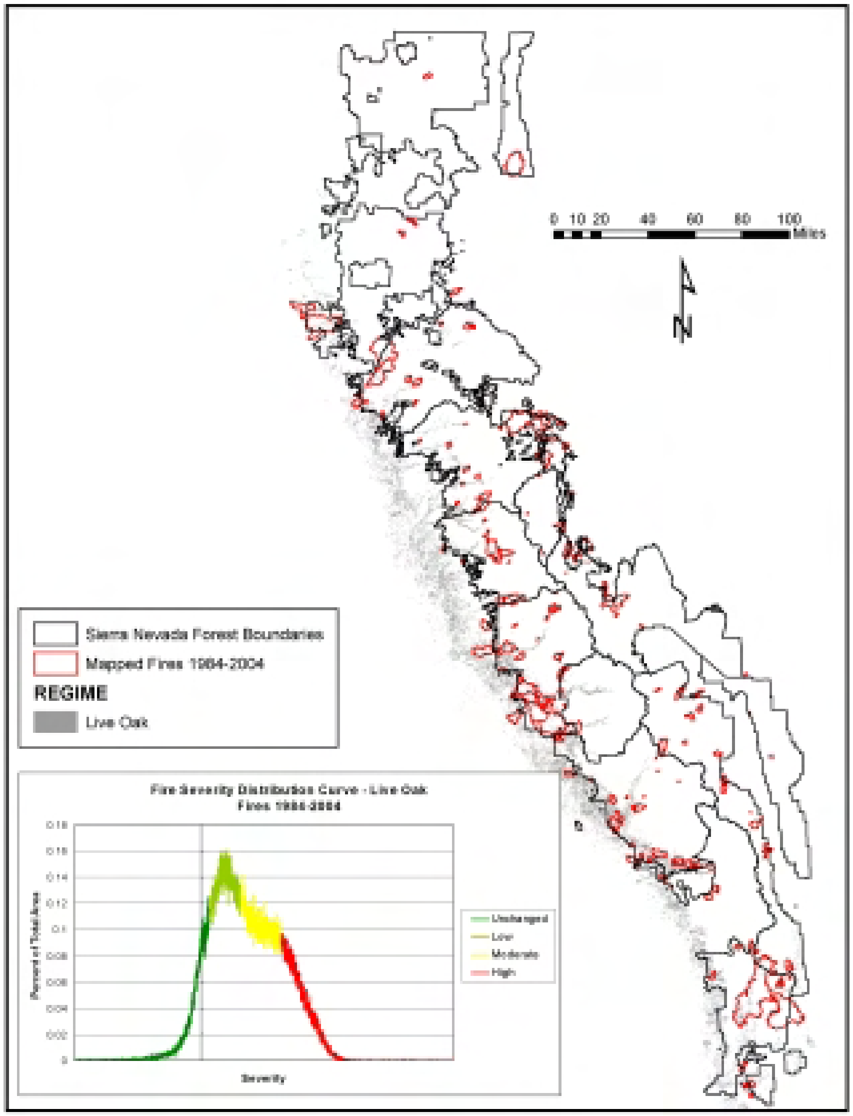

Figure B-5. Geographic distribution and fire severity probability distribution curve for the live oak regional vegetation type.

Lodgpole Pine

The lodgepole pine regional vegetation type is composed solely of the lodgepole pine CALVEG type. Lodgepole pine primarily occurs in the subalpine region in the Sierra Nevada (Figure B-6). Sugihara and others (2006) indicate that lodgepole pine historically experienced multiple severity and fire types, as opposed to a primarily low severity surface fire regime for other subalpine conifer forests (Table 5). We therefore placed lodgepole pine in a separate regional vegetation type from the other subalpine conifers for this analysis. The severity distribution curve in Figure B-6 indicates that lodgepole pine experienced primarily low severity fire in the 1984-2004 period, much like the other subalpine conifers (Figure B-7). It may be that our twenty year period of record is of insufficient duration to fully characterize the high severity component within the lodgepole pine fire regime, as fire return intervals for this type are estimated to be many decades to several hundred years (Keeley 1981; Sugihara and others 2006; Caprio 2007). It should also be noted that Sierra Nevada lodgepole pine is generally non-serotinous and the limited fire history data we do have, combined with modern fuel profiles, suggest that the "classic" high severity picture we have of Rocky Mountain lodgepole pine does not apply to the Sierra Nevada (Critchfield 1957; Parker 1986).

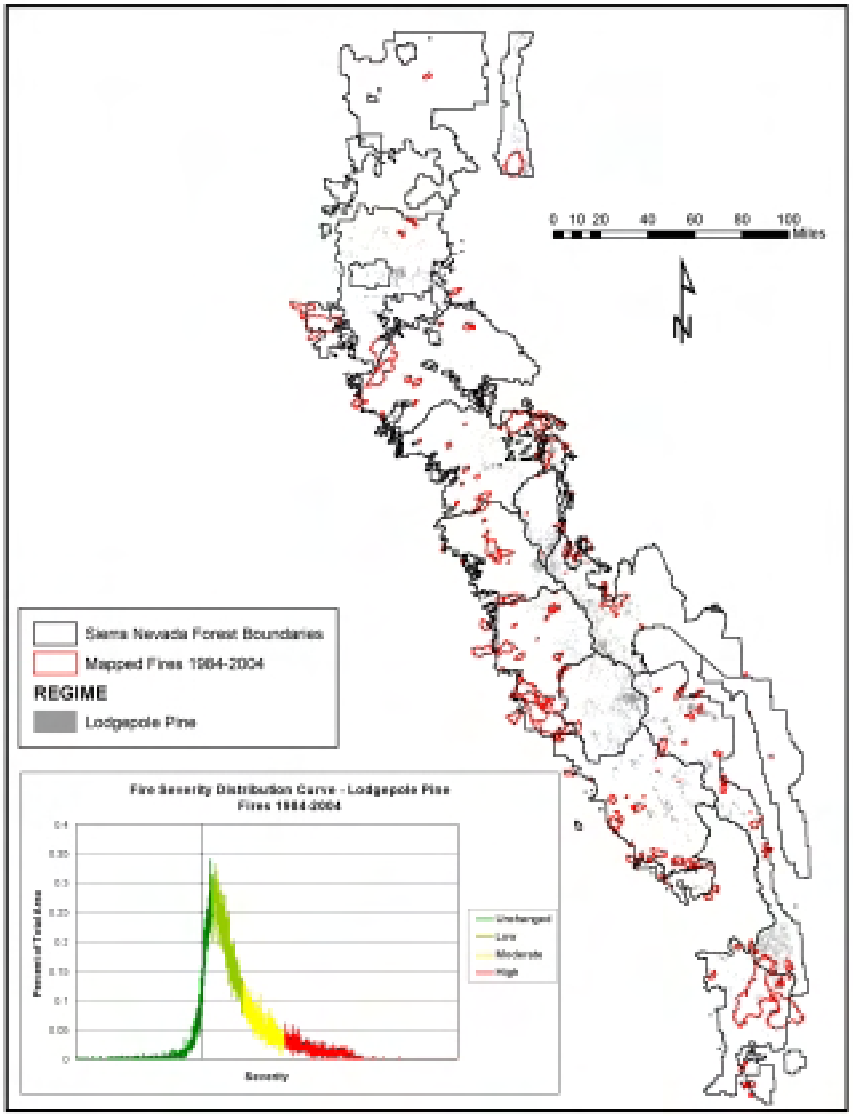

Figure B-6. Geographic distribution and fire severity probability distribution curve for the lodgepole pine regional vegetation type.

Subalpine Conifer

The subalpine conifer regional vegetation type includes subalpine conifers, bristlecone, foxtail, and whitebark pine CALVEG types. The subalpine conifers primarily occur in the subalpine region of the central and southern Sierra Nevada (Figure B-7). The severity distribution curve shown in Figure B-7 indicates that subalpine conifers experienced primarily low severity fire during the 1984-2004 fires, which corresponds with the presumed historical fire severity pattern as depicted by Sugihara and others (2006) (Table 5).

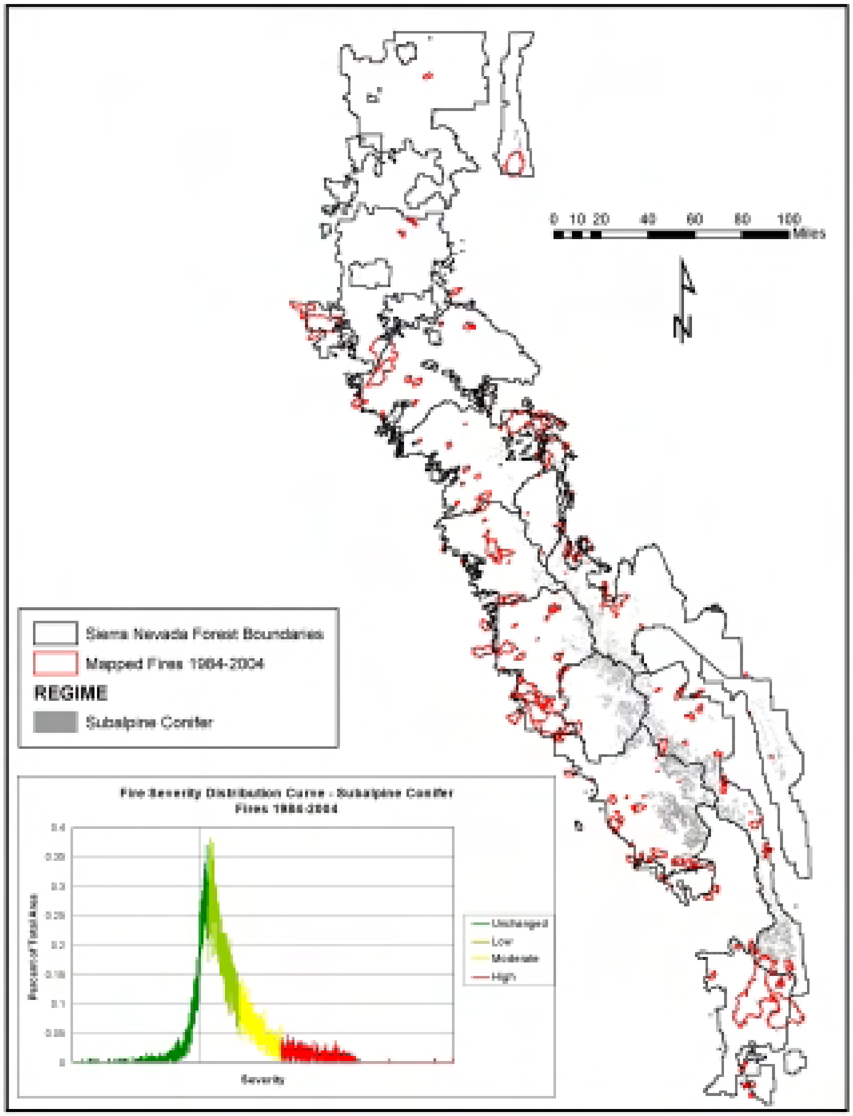

Figure B-7. Geographic distribution and fire severity probability distribution curve for the subalpine conifer regional vegetation type.

Mixed Conifer

The mixed conifer regional vegetation type includes the mixed conifer-fir, mixed conifer-pine, Douglas fir, and Douglas fir-ponderosa pine CALVEG types. The mixed conifer type is the most widespread conifer type, primarily occurring in the lower and middle montane zones of the Sierra Nevada. Mixed conifer stands occurring on the eastside were also included in this grouping (Figure B-8), although they show some differences in species composition and structure (Barbour and Major 1988). Sugihara and others (2006) indicate that mixed conifer historically experienced primarily low to moderate severity fire and surface to multiple fire types (Table 5). The severity distribution curve in Figure B-8 that although mixed conifer experienced primarily low to moderate severity fire during the period 1984-2004, 28% of the fire acres burned under high severity conditions (Figure B-8 and Table 8).

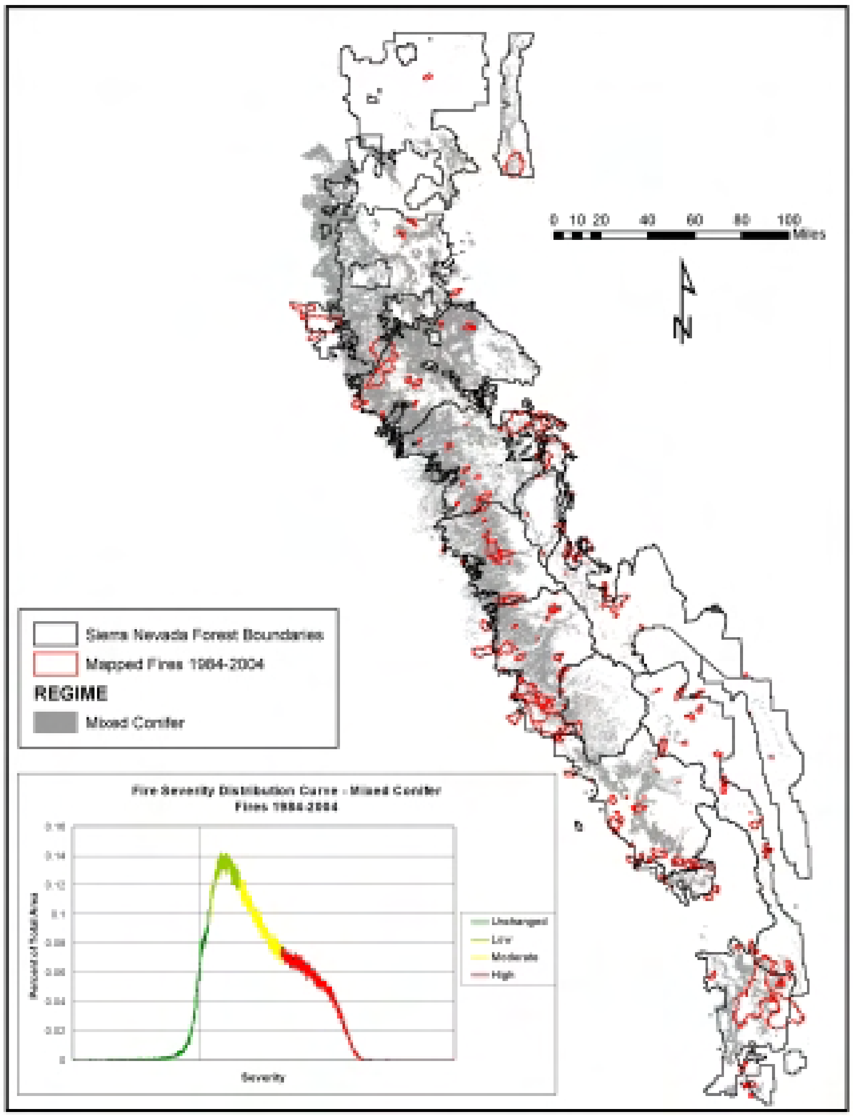

Figure B-8. Geographic distribution and fire severity probability distribution curve for the mixed conifer regional vegetation type.

Pinyon Juniper

The pinyon juniper regional vegetation type includes the single-leaf pinyon pine and western juniper CALVEG types. The single-leaf pinyon pine type occurs primarily on the eastside of the southern and central Sierra Nevada and the western juniper type occurs primarily on the Modoc Plateau and at upper elevations in the southern Sierra Nevada (Figure B-9). Sugihara and others (2006) indicate that pinyon pine historically experienced primarily high severity fire (Table 5). The severity distribution curve in

Figure B-9 indicates two modes of severity, one high severity and a lower mode at low to unchanged. Both pinyon pine and western juniper series typically occur either with shrubs, such as big sagebrush, or sparse understory vegetation (Barbour and Major 1988; Sawyer and Keeler-Wolf 1995). Where shrubs are absent, low severity fire may dominate unless winds are strong enough to promote active crown fire, which could result in the bimodal distribution shown in Figure B-9.

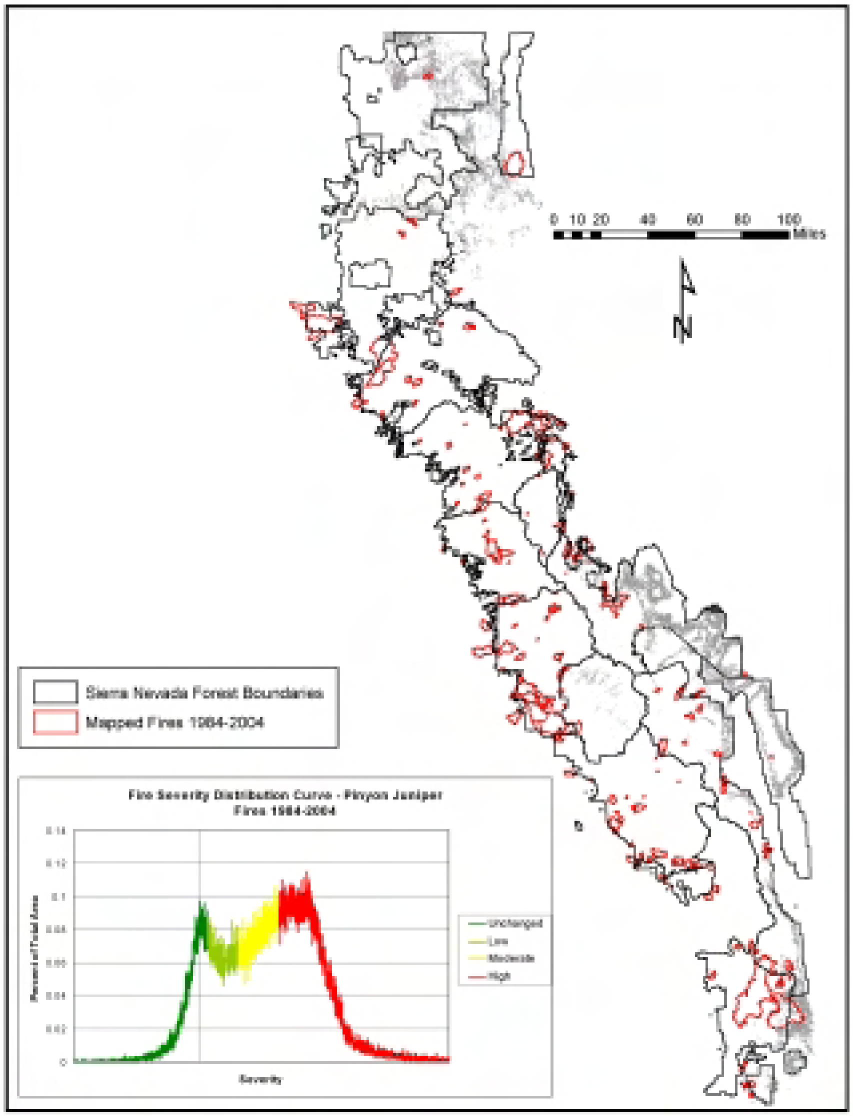

Figure B-9. Geographic distribution and fire severity probability distribution curve for the pinyon juniper regional vegetation type.

Ponderosa Pine

The ponderosa pine type includes only the ponderosa pine CALVEG type which occurs primarily in the lower montane zone on the western slopes of the Sierra Nevada (Figure B-10). Most of the ponderosa pine in the northern and central SNFPA area lies outside U.S. Forest Service boundaries: those acres are therefore not included in the distribution curve shown in Figure B-10. Sugihara and others (2006) indicate that ponderosa pine historically experienced low severity surface fire (Table 5). Current severity appears to be higher than under presumed pre-settlement conditions: our distribution curve indicates about 30% high severity between 1984 and 2004 (although most fire was low to moderate severity; Table 8). Note also that many areas historically dominated by ponderosa pine now support mixed stands of pine with shade tolerant species. These areas are currently mapped as mixed conifer (see above) and experience somewhat more high severity fire than those areas which continue to be dominated by ponderosa pine (Figure B-10).

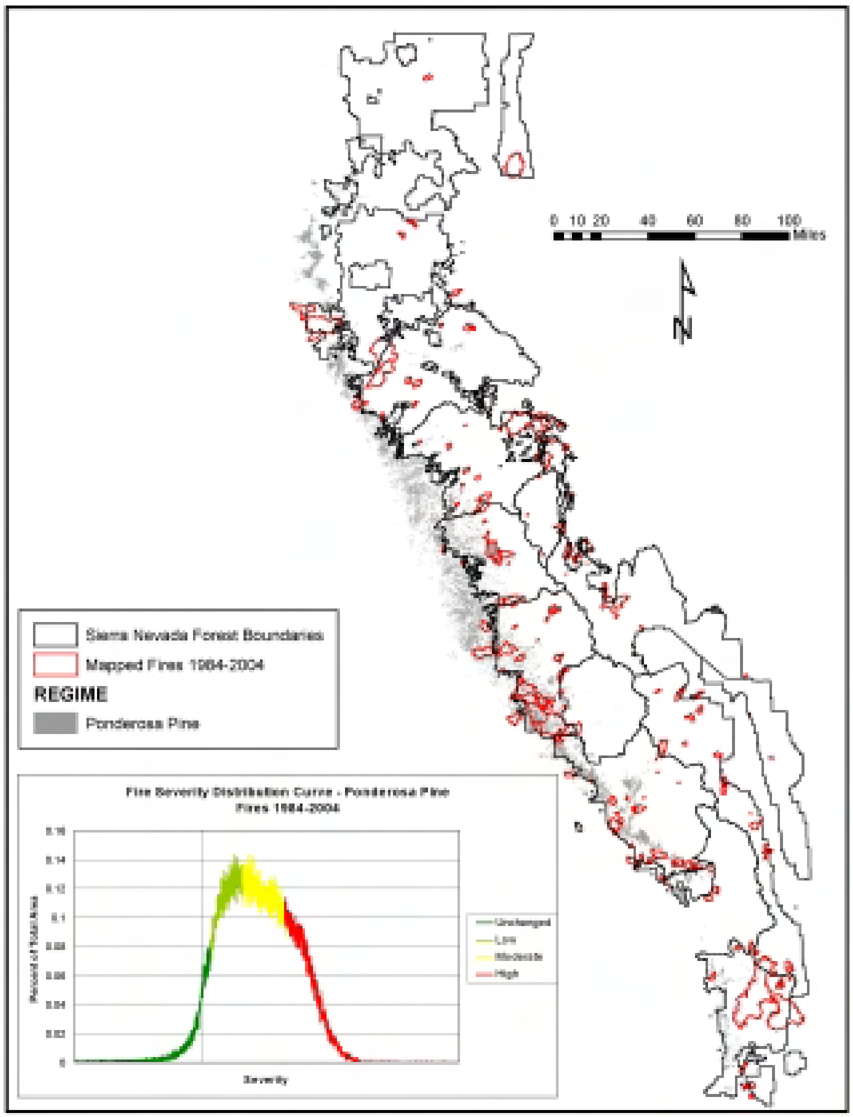

Figure B-10. Geographic distribution and fire severity probability distribution curve for the ponderosa pine regional vegetation type.

Red Fir

The red fir regional vegetation type includes the red fir and western white pine CALVEG types. The red fir type occurs in the upper montane zone of the Sierra Nevada (Figure B-11). Sugihara and others (2006) indicate that red fir historically experienced multiple severity and fire types (Table 5). The severity distribution curve from the 1984-2004 fires indicates red fir experienced primarily low severity fire during that time period. Thirteen percent experienced high severity fire, as evidenced by the small knee in the distribution curve (Figure B-11 and Table 8).

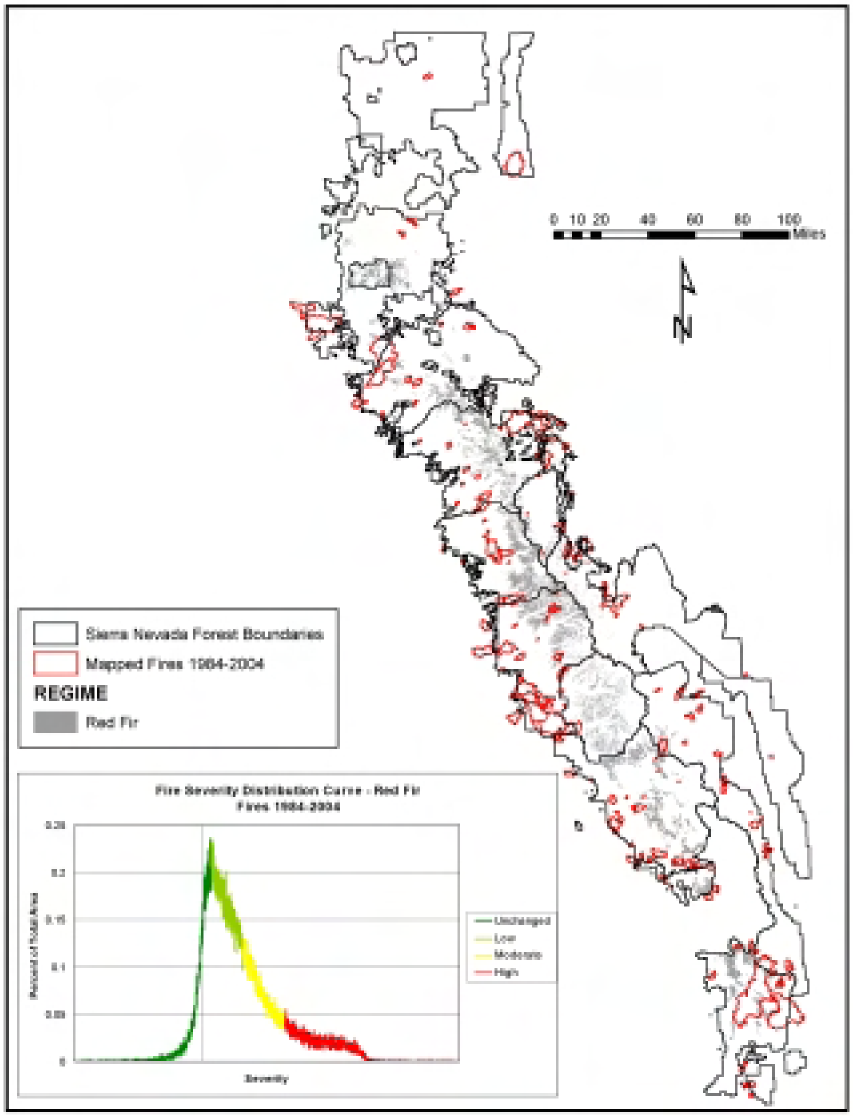

Figure B-11. Geographic distribution and fire severity probability distribution curve for the red fir regional vegetation type.

Riparian

The riparian regional vegetation type includes a large group of CALVEG types that normally occur in riparian zones (Table 4). The riparian zone types occur sparsely in the montane zone of the eastern Sierra Nevada (Figure B-12). Sugihara and others (2006) do not include any discussion of these vegetation types for the Sierra Nevada. The severity distribution curve from the 1984-2004 fires indicates that riparian types experienced primarily low severity fire although 39% experienced moderate to high severity during that time period (Figure B-12 and Table 8). The regional riparian type may not be adequately sampled to characterize its severity distribution curve: our sample consisted of only 3500 acres, the smallest area of any of the types we analyzed (Table 7).

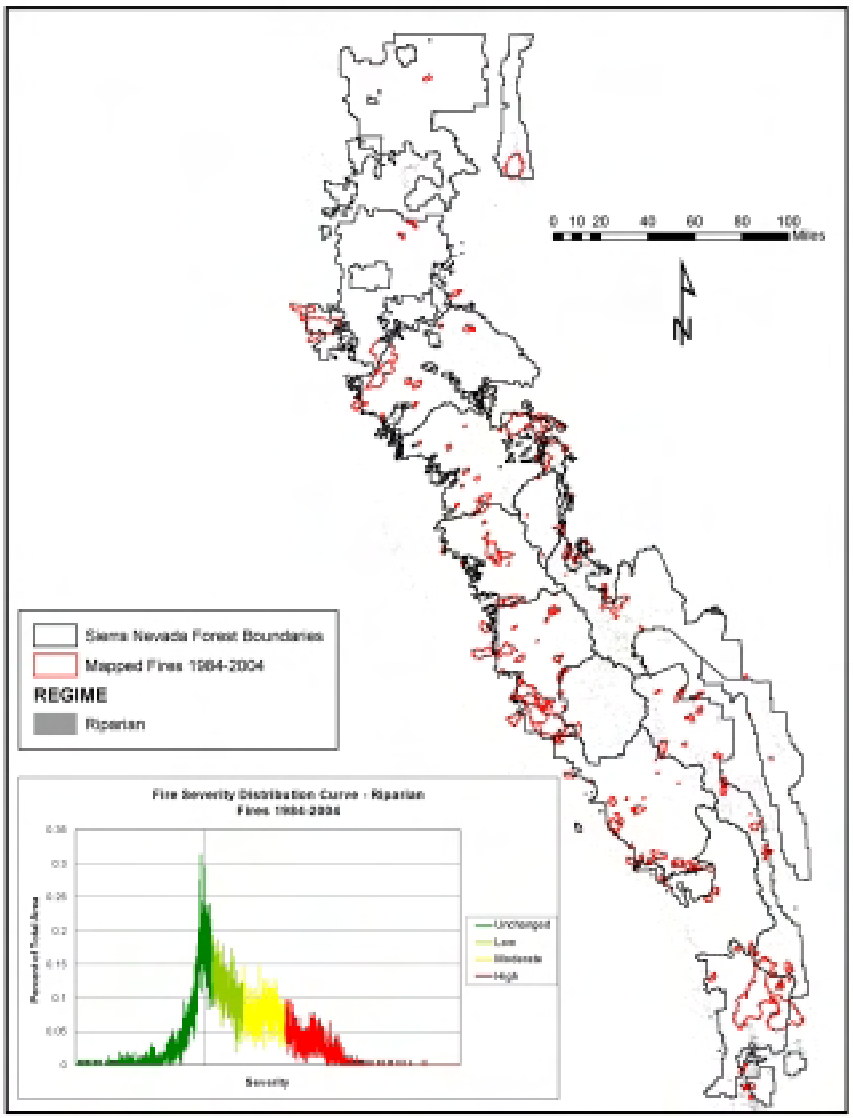

Figure B-12. Geographic distribution and fire severity probability distribution curve for the riparian regional vegetation type.

White Fir

The white fir regional vegetation type includes only the white fir CALVEG type. The white fir type occurs in the montane region in the northern and central Sierra Nevada and in the Warner Mountains (Figure B-13). Sugihara and others (2006) indicate that white fir historically experienced low to moderate severity and surface or multiple fire types (Table 5). The severity distribution curve shown in Figure B-13 indicates that white fir did experience primarily low severity fire during the 1984-2004 fires, but a secondary mode occurs in the distribution curve indicating that 34% experienced high severity (Table 8). The CALVEG white fir type is more or less pure white fir, described as being mostly in north-facing pockets and around lakes. It is mapped as occurring between the mixed conifer pine and mixed conifer fir types on south and west aspects, and between mixed conifer pine and red fir on north and east aspects (H. Gordon, pers. comm.). This tends to be a moister vegetation type than most mixed conifer and ponderosa pine stands and hence fire return intervals would be expected to be longer and severity skewed somewhat more toward mixed and high severity fire.

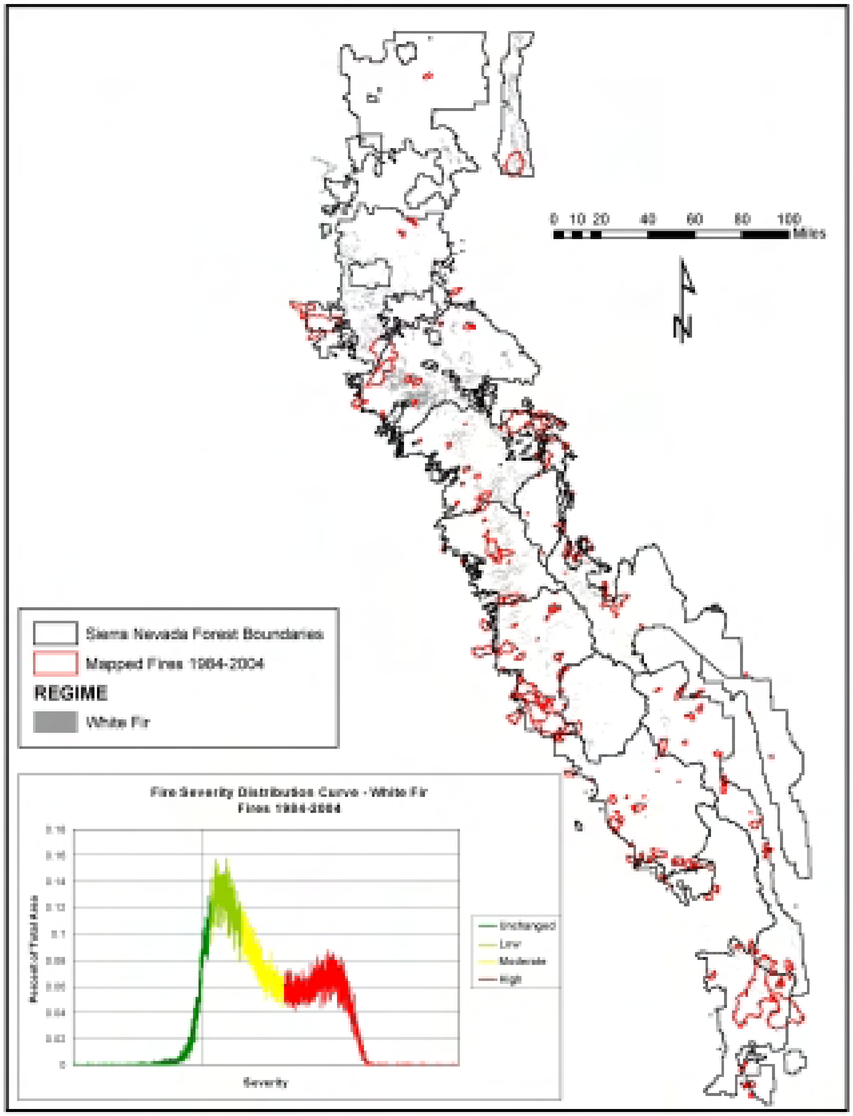

Figure B-13. Geographic distribution and fire severity probability distribution curve for the white fir regional vegetation type.

Appendix C: Individual Fire Results

Figures C-1 through C-10 display the four category severity data, by National Forest, for all fires mapped in the SNFPA area for this report. When multiple fires occur in the same location, the data for the oldest fire are displayed. Perimeters of all fires in the fire history database are shown for each Forest, color coded as to whether they occurred before or after 1984, the earliest date mapped by this project. Table C-1 lists all fires included in this report. Year, fire name, and direct protection agency are listed as identifying fields for each fire. Names were not recorded in the regional fire history database for all fires. When the fire name was missing a name was derived by concatenating year, state, unit, and local number. The number of acres burned by CBI derived severity category, number of acres in three categories of percent tree basal area mortality, and the percentage of each category within the fire perimeter are given for each fire.

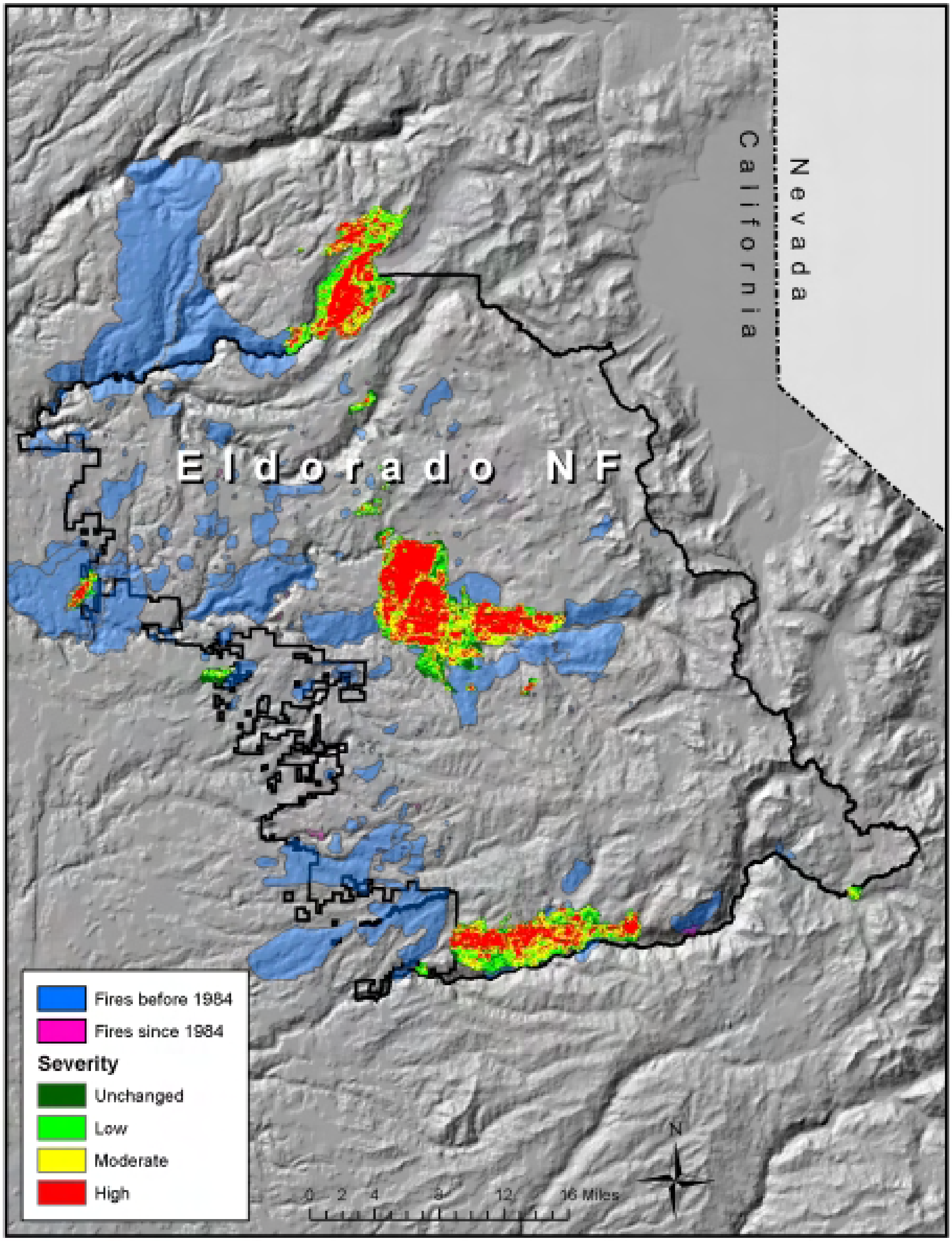

Figure C-1. Fires mapped on the Eldorado NF.

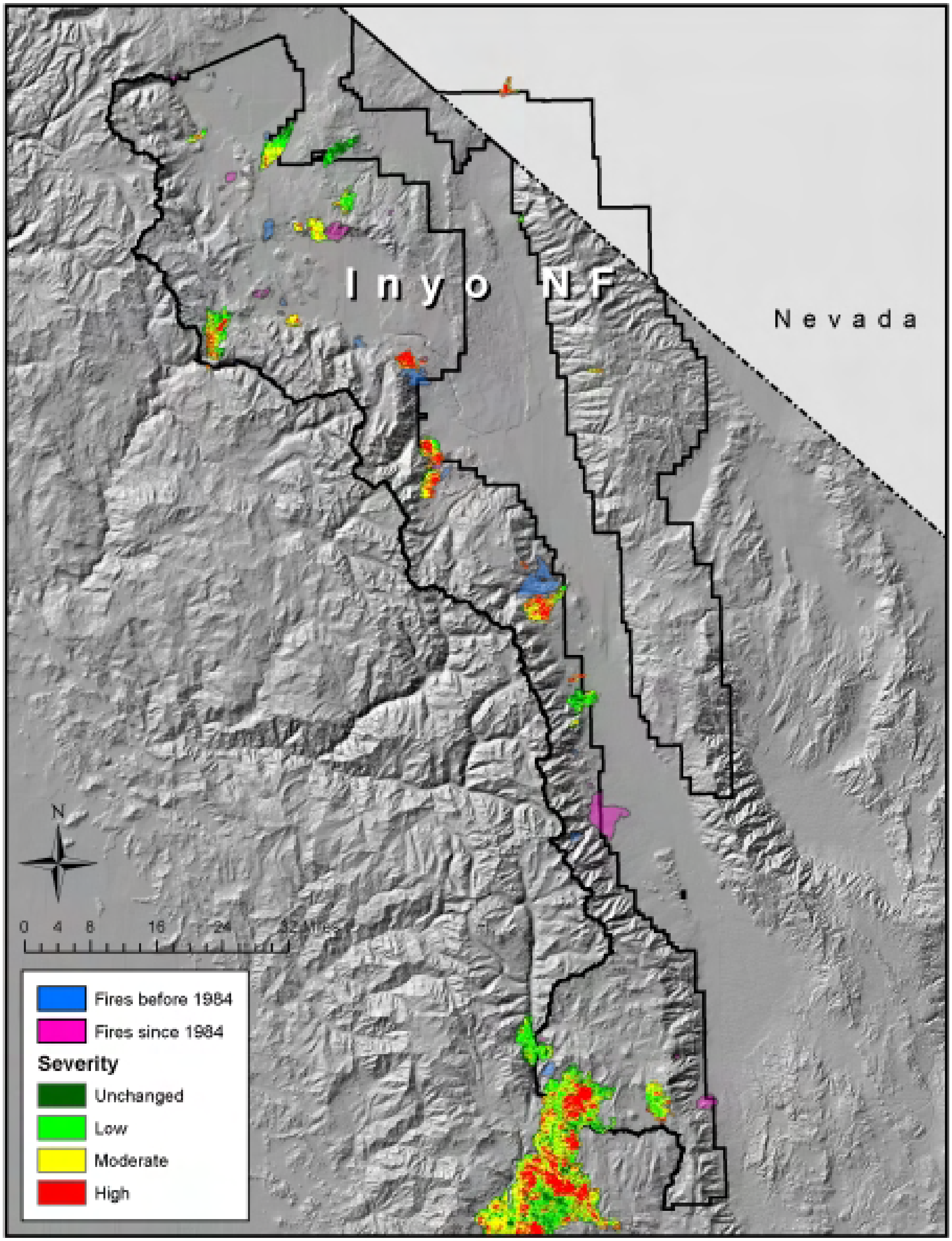

Figure C-2. Fires mapped on the Inyo NF.

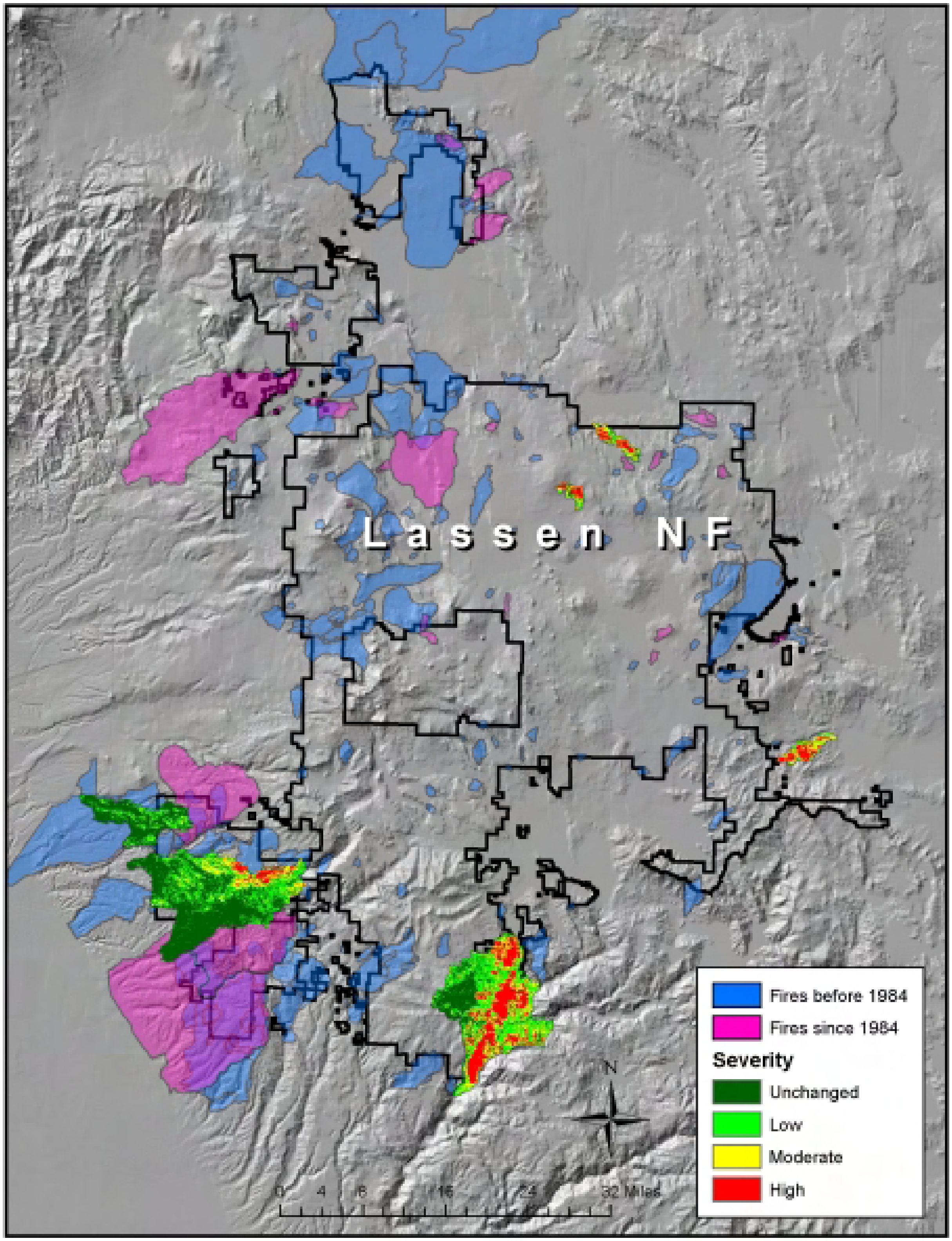

Figure C-3. Fires mapped on the Lassen NF.

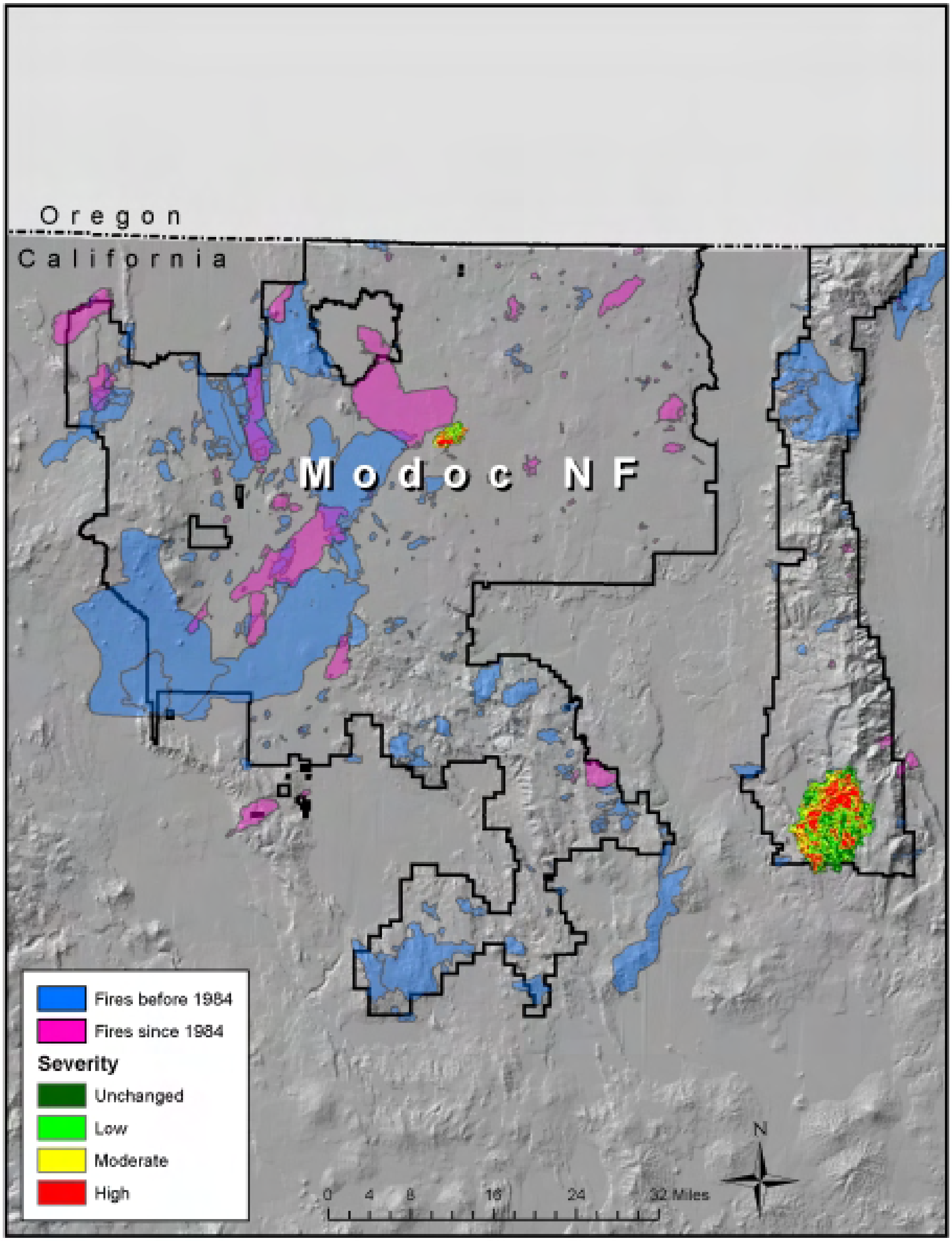

Figure C-4. Fires mapped on the Modoc NF.

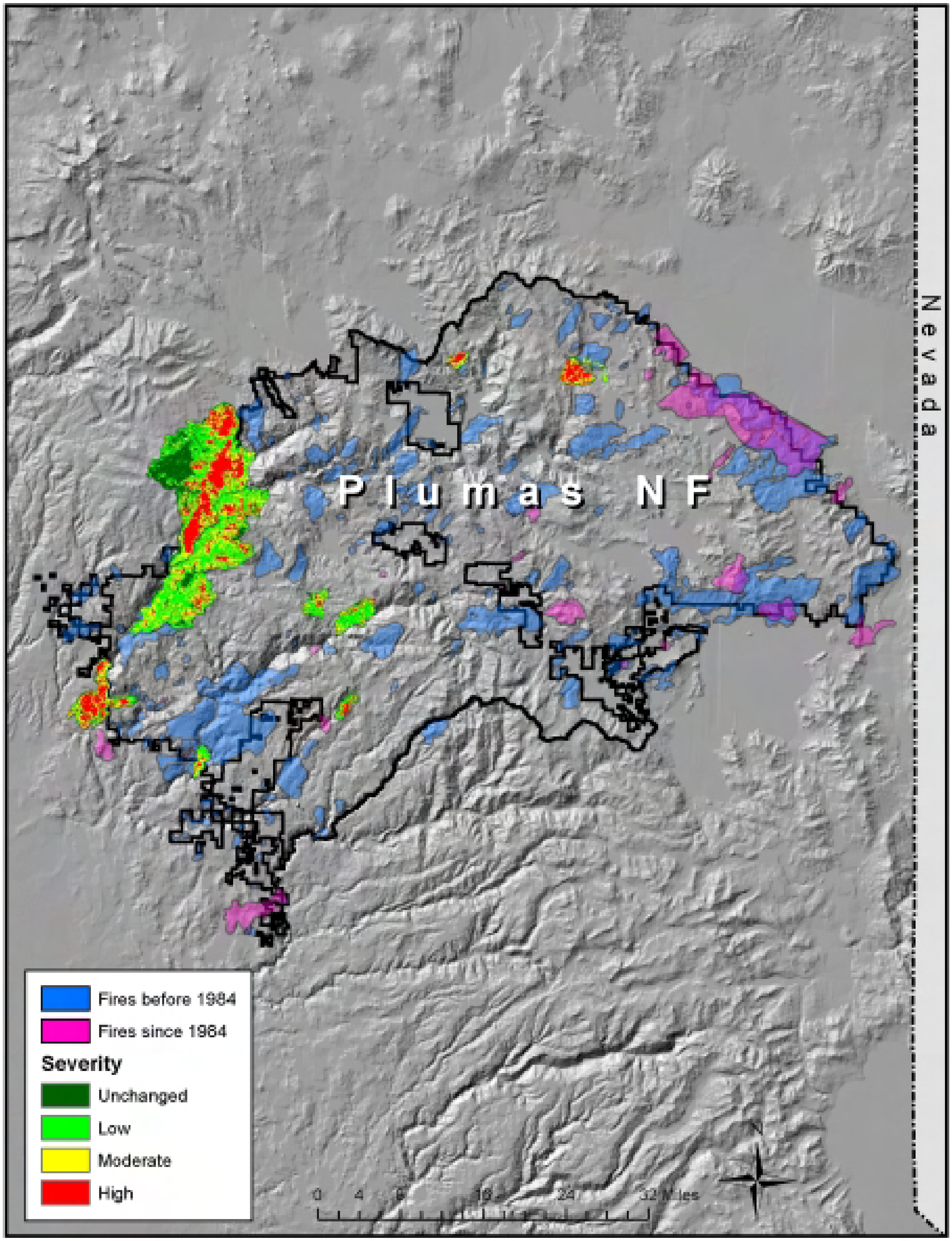

Figure C-5. Fires mapped on the Plumas NF.

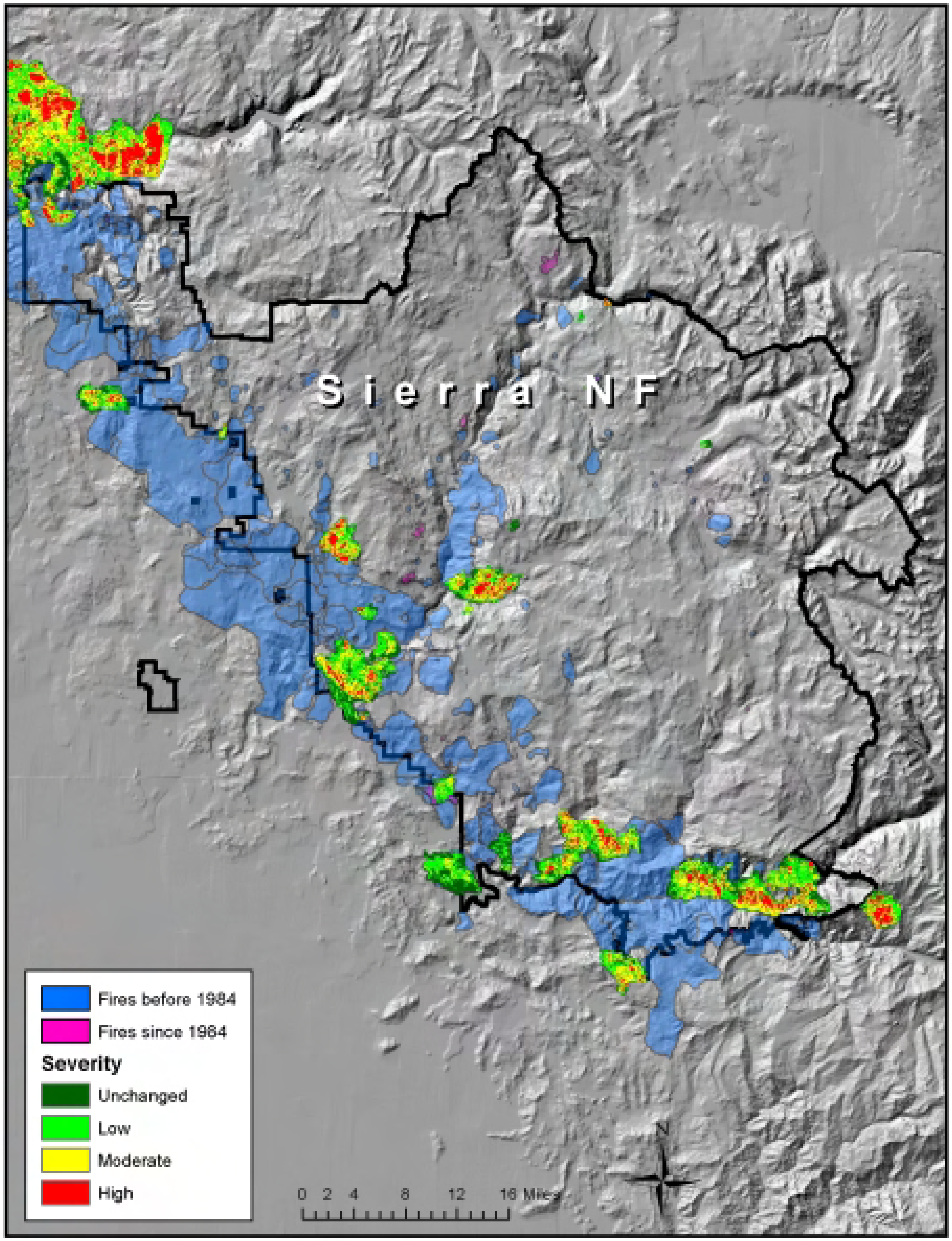

Figure C-6. Fires mapped on the Sierra NF.

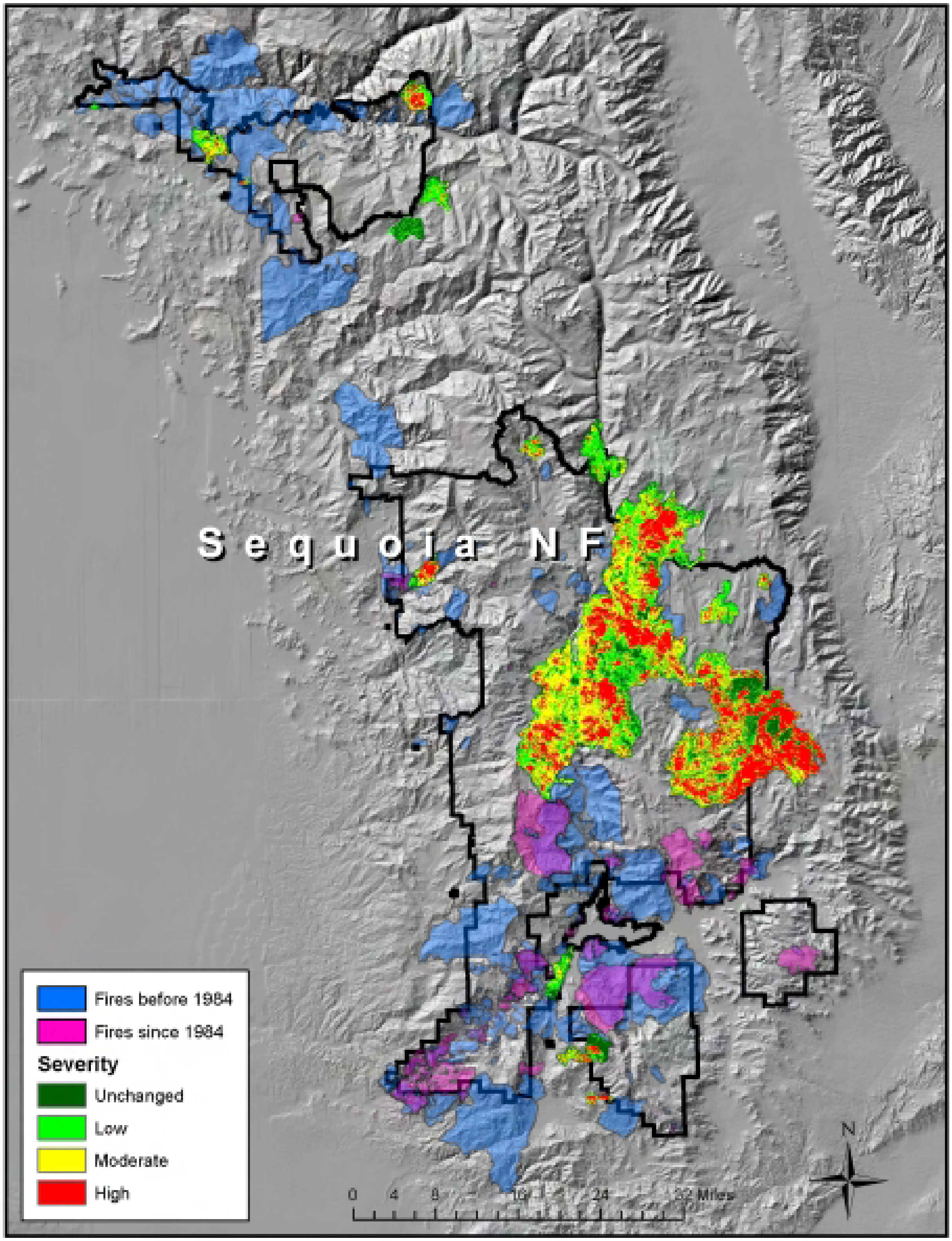

Figure C-7. Fires mapped on the Sequoia NF.

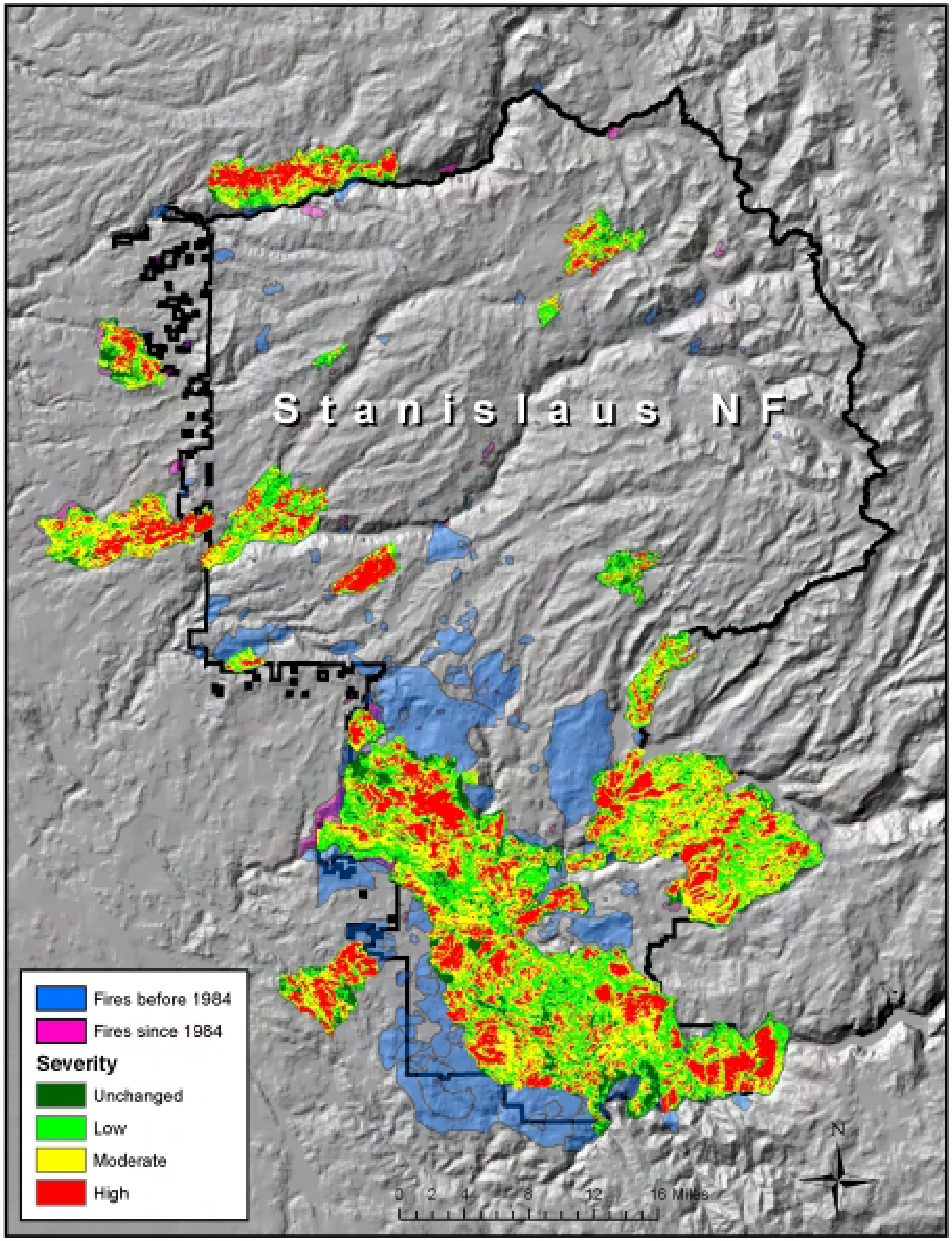

Figure C-8. Fires mapped on the Stanislaus NF.

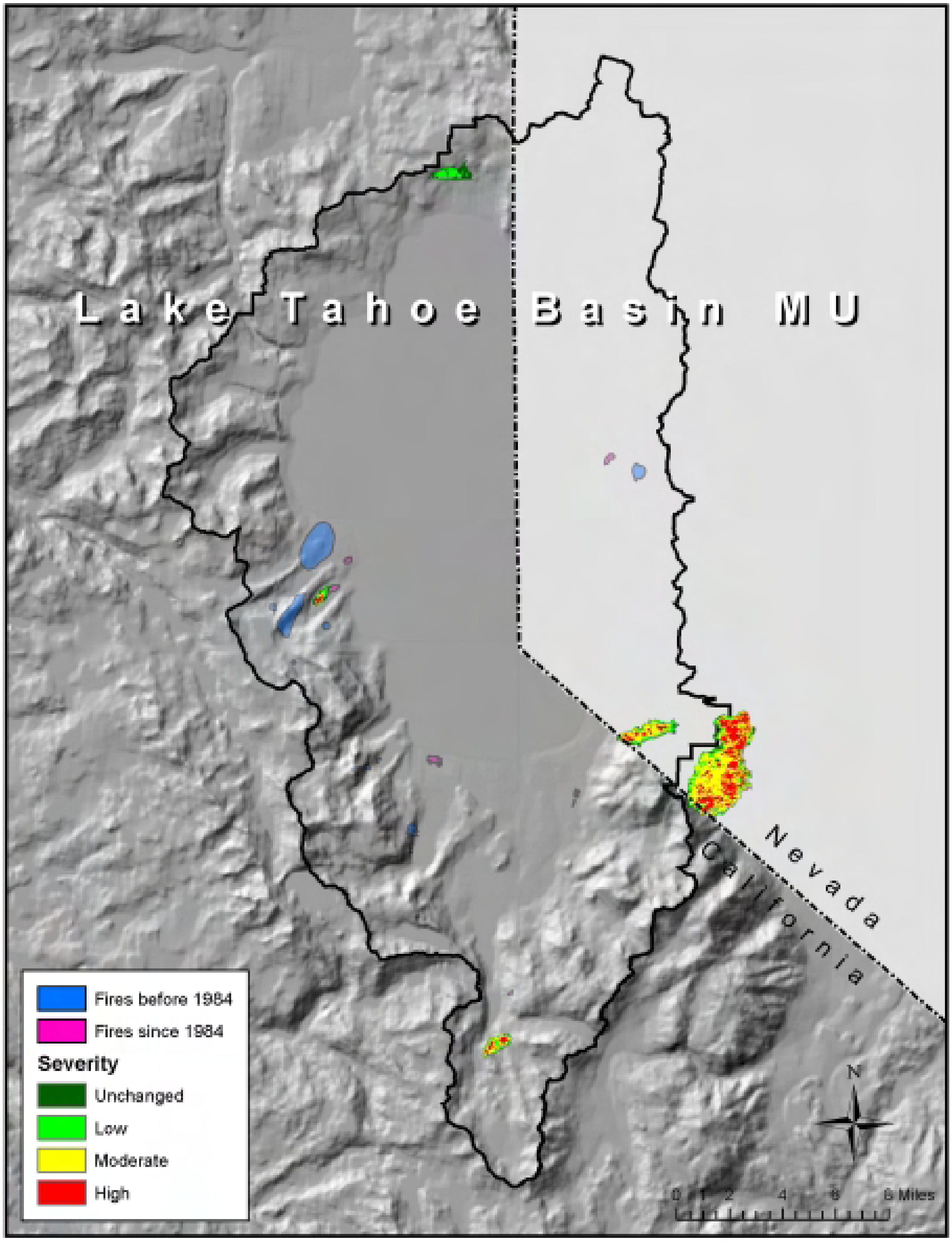

Figure C-9. Fires mapped on the Lake Tahoe Basin Management Unit.

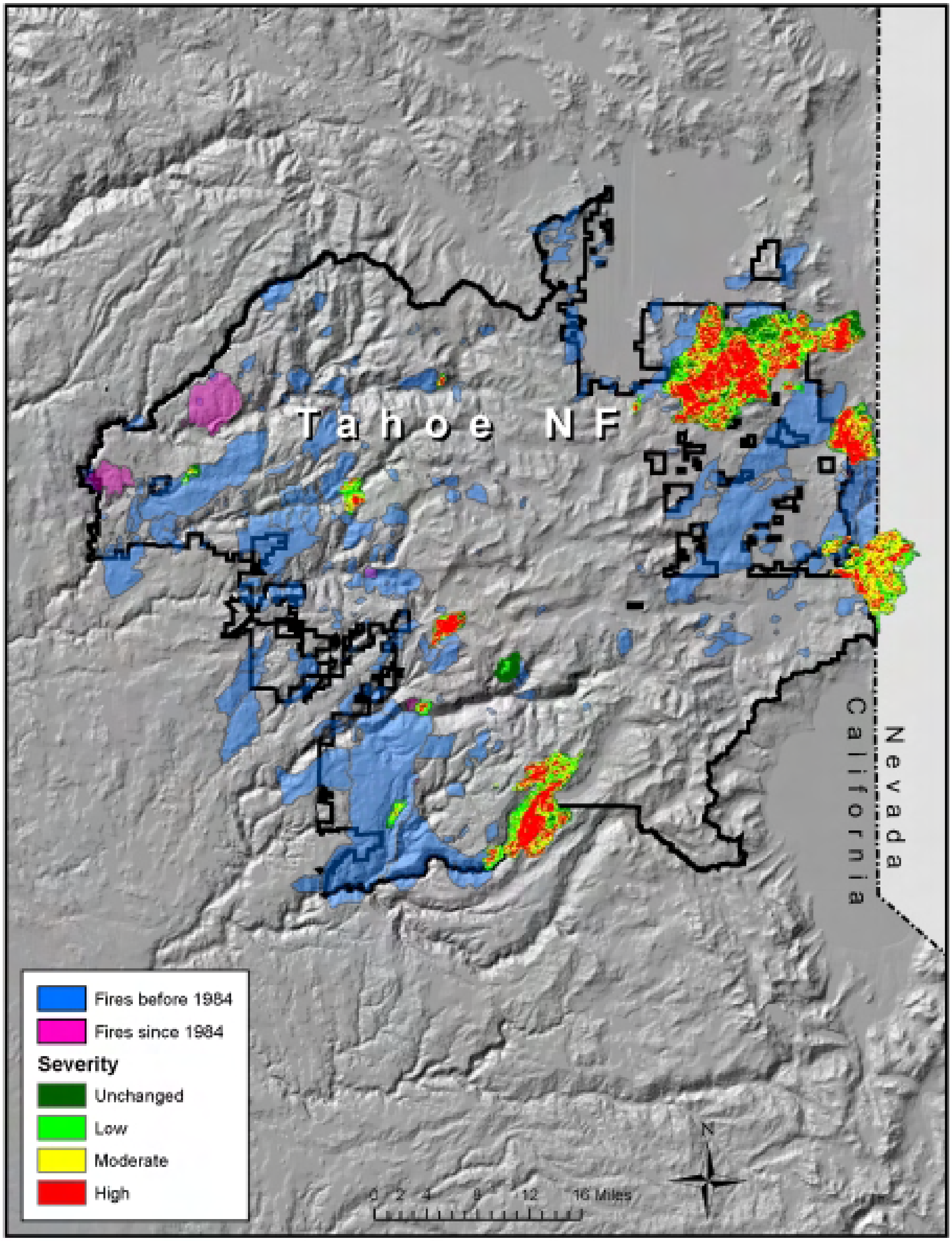

Figure C-10. Fires mapped on the Tahoe NF.

Table C-1. Individual fire results

Year	Fire Name	Protection Agency	Unit	Unchanged (ac/%)	Low (ac/%)	Moderate (ac/%)	High (ac/%)	%BA Mortality <25 (ac/%)	%BA Mortality 25-75 (ac/%)	%BA Mortality >75 (ac/%)	Total (acres)
1984	1984CATOI00000031	USF	TOI	1296 / 13	1920 / 20	2800 / 29	3799 / 39	3581 / 36	1873 / 19	4361 / 44	9815
1984	1984CATOI00000134	USF	TOI	4094 / 23	3958 / 23	5814 / 33	3620 / 21	8764 / 50	3862 / 22	4860 / 28	17486
1984	1984NVTOI00000136	USF	TOI	48 / 16	100 / 34	77 / 26	70 / 24	161 / 55	49 / 17	85 / 29	296
1984	BASIN	USF	SNF	228 / 40	257 / 46	74 / 13	4 / 1	507 / 90	48 / 9	8 / 1	563
1984	COW	CDF	BDU	2038 / 63	1183 / 37	4 / 0	0 / 0	3225 / 100	0 / 0	0 / 0	3225
1984	GREEN GULCH	CDF	NEU	55 / 6	135 / 14	213 / 23	536 / 57	210 / 22	142 / 15	588 / 63	940
1984	PIUTE	USF	STF	94 / 62	35 / 23	17 / 11	6 / 4	132 / 87	13 / 8	8 / 5	153
1985	1985CACCD0000J913	BLM	CCD	79 / 10	120 / 15	322 / 39	301 / 37	226 / 28	212 / 26	383 / 47	821
1985	1985CAENF00000066	USF	ENF	93 / 27	68 / 20	71 / 21	109 / 32	172 / 51	42 / 12	127 / 37	341
1985	1985CAINF00000070	USF	INF	62 / 27	103 / 44	56 / 24	13 / 5	174 / 75	40 / 17	19 / 8	233
1985	1985CAINF00005307	USF	INF	7 / 4	17 / 10	22 / 13	127 / 73	27 / 15	14 / 8	133 / 76	174
1985	1985CASTF00000112	USF	STF	56 / 28	77 / 38	60 / 30	8 / 4	142 / 70	40 / 20	19 / 10	201
1985	8 MILE	CDF	AEU	469 / 53	226 / 25	188 / 21	9 / 1	731 / 82	132 / 15	30 / 3	893
1985	BACKBONE	CDF	FKU	266 / 78	74 / 22	1 / 0	0 / 0	341 / 100	0 / 0	0 / 0	342
1985	BIG CREEK	USF	SNF	328 / 56	182 / 31	75 / 13	3 / 1	528 / 90	51 / 9	9 / 2	588
1985	MAMMOTH	USF	SNF	210 / 26	383 / 47	143 / 18	74 / 9	629 / 78	89 / 11	91 / 11	809
1985	RIVER	USF	STF	59 / 17	179 / 51	91 / 26	22 / 6	255 / 72	60 / 17	37 / 11	352
1986	1986CAENF00000082	USF	ENF	185 / 30	216 / 35	153 / 25	60 / 10	433 / 70	103 / 17	79 / 13	614
1986	1986CATNF00000013	USF	TNF	1816 / 88	247 / 12	13 / 1	0 / 0	2069 / 100	6 / 0	0 / 0	2075
1986	1986CATOI00000029	USF	TOI	84 / 2	535 / 15	1044 / 29	1919 / 54	756 / 21	692 / 19	2134 / 60	3582
1986	DEER	USF	SNF	2347 / 18	3175 / 24	4766 / 36	3105 / 23	6053 / 45	3169 / 24	4172 / 31	13394
1986	RIVERSIDE	USF	STF	30 / 24	44 / 35	42 / 34	10 / 8	81 / 64	30 / 23	15 / 12	126
1986	SYCAMORE	USF	SNF	1021 / 64	546 / 34	26 / 2	0 / 0	1577 / 99	15 / 1	1 / 0	1593
1987	1987CATNF00000176	USF	TNF	192 / 9	783 / 36	719 / 33	481 / 22	1087 / 50	471 / 22	617 / 28	2175
1987	1987CATOI00000119	USF	TOI	628 / 9	746 / 11	1776 / 27	3503 / 53	1518 / 23	1077 / 16	4059 / 61	6654
1987	BIG	USF	TNF	69 / 6	400 / 36	373 / 34	257 / 23	538 / 49	234 / 21	326 / 30	1098
1987	CHAWANAKEE	USF	SNF	175 / 10	746 / 41	745 / 41	136 / 8	1034 / 57	489 / 27	278 / 15	1801
1987	CHINA	USF	SNF	58 / 17	124 / 37	124 / 37	27 / 8	198 / 60	87 / 26	47 / 14	332

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1987	CLAVEY 87 CMPLX	USF	STF	1240 / 14	2249 / 25	3523 / 40	1850 / 21	3890 / 44	2323 / 26	2648 / 30	8861
1987	EVER	USF	STF	26 / 5	29 / 5	99 / 18	401 / 72	64 / 12	59 / 11	431 / 78	555
1987	HAMM 87 CMPLX	USF	STF	3134 / 9	9508 / 28	13609 / 40	7773 / 23	14348 / 42	8800 / 26	10875 / 32	34023
1987	HASLOE 87 CMPLX	USF	STF	193 / 3	1213 / 17	2821 / 40	2754 / 39	1673 / 24	1764 / 25	3545 / 51	6981
1987	JARREL	USF	STF	336 / 18	1050 / 56	425 / 23	65 / 3	1485 / 79	281 / 15	110 / 6	1876
1987	LARSON 87 CMPLX	USF	STF	4304 / 9	15377 / 32	19244 / 40	9676 / 20	22274 / 46	12946 / 27	13380 / 28	48600
1987	LAUREL	USF	INF	76 / 6	151 / 13	672 / 56	293 / 25	264 / 22	475 / 40	454 / 38	1193
1987	PAPER	CDF	TCU	522 / 11	1881 / 41	1863 / 41	313 / 7	2787 / 61	1261 / 28	531 / 12	4579
1987	PAPER 87 CMPLX	USF	STF	4284 / 11	10254 / 27	12884 / 34	10511 / 28	16299 / 43	8470 / 22	13165 / 35	37933
1987	RIVER II	USF	STF	251 / 34	278 / 38	190 / 26	20 / 3	572 / 77	128 / 17	40 / 5	739
1988	1988CAINF00005323	USF	INF	360 / 56	263 / 41	25 / 4	0 / 0	634 / 98	15 / 2	1 / 0	649
1988	1988NVTOI00000135	USF	TOI	777 / 41	631 / 33	257 / 14	238 / 12	1457 / 77	170 / 9	276 / 14	1903
1988	BACKBONE	CDF	FKU	229 / 92	20 / 8	0 / 0	0 / 0	249 / 100	0 / 0	0 / 0	249
1988	BRIDGE	CDF	TCU	1309 / 18	1675 / 23	2513 / 35	1656 / 23	3302 / 46	1673 / 23	2177 / 30	7152
1988	CLEARINGHOUSE	USF	STF	1076 / 41	823 / 32	596 / 23	103 / 4	1993 / 77	377 / 14	230 / 9	2599
1988	DESK	USF	SNF	145 / 57	96 / 38	13 / 5	0 / 0	245 / 96	9 / 3	1 / 0	254
1988	EL PORTAL	USF	SNF	49 / 29	73 / 43	48 / 28	0 / 0	132 / 77	38 / 22	0 / 0	170
1988	FAWN	USF	SNF	40 / 20	107 / 53	55 / 27	1 / 0	161 / 79	36 / 18	5 / 3	202
1988	GARNET	USF	SNF	1127 / 48	596 / 25	526 / 23	87 / 4	1808 / 77	364 / 16	165 / 7	2337
1988	LAKE	USF	SNF	212 / 79	54 / 20	0 / 0	0 / 0	267 / 100	0 / 0	0 / 0	267
1988	MIDDLE FORK	USF	STF	87 / 81	20 / 19	0 / 0	0 / 0	107 / 100	0 / 0	0 / 0	107
1988	OBELISK	USF	SNF	1862 / 24	2908 / 38	2114 / 28	754 / 10	5126 / 67	1397 / 18	1115 / 15	7638
1988	USFS ASSIST 3	CDF	NEU	319 / 51	167 / 27	121 / 19	20 / 3	505 / 80	86 / 14	37 / 6	628
1989	1989CATOI00000067	USF	TOI	49 / 38	40 / 31	25 / 19	16 / 12	94 / 73	16 / 12	20 / 15	129
1989	BALCH	USF	SNF	1389 / 15	2728 / 30	3365 / 37	1498 / 17	4600 / 51	2211 / 25	2169 / 24	8980
1989	BURROUGH	CDF	FKU	297 / 18	904 / 56	408 / 25	10 / 1	1321 / 82	270 / 17	27 / 2	1619
1989	POWERHOUSE	USF	SNF	3065 / 25	4179 / 34	3648 / 30	1277 / 10	7763 / 64	2312 / 19	2093 / 17	12168
1990	1990CATNF00000090	USF	TNF	88 / 27	59 / 18	63 / 20	112 / 35	154 / 48	38 / 12	131 / 41	322
1990	1990CATOI00000094	USF	TOI	65 / 28	90 / 39	74 / 32	4 / 2	169 / 72	55 / 23	10 / 4	234
1990	1990CATOI00000109	USF	TOI	8 / 4	48 / 25	84 / 43	54 / 28	66 / 34	45 / 23	84 / 43	195

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1990	A-ROCK	USF	YNP	985 / 5	4695 / 26	5699 / 31	6795 / 37	6508 / 36	3627 / 20	8039 / 44	18175
1990	COTTONWOOD	CDF	TCU	128 / 5	628 / 25	921 / 37	826 / 33	876 / 35	600 / 24	1026 / 41	2503
1990	KIRCH	USF	SNF	830 / 22	1385 / 36	1154 / 30	431 / 11	2387 / 63	764 / 20	649 / 17	3800
1990	LILLY	USF	SNF	7 / 4	34 / 20	64 / 37	70 / 40	49 / 28	41 / 24	85 / 48	176
1990	SAVAGE	USF	SNF	130 / 7	510 / 26	768 / 39	581 / 29	722 / 36	487 / 24	780 / 39	1989
1991	1991CAENF000012A2	USF	ENF	188 / 64	104 / 36	0 / 0	0 / 0	292 / 100	0 / 0	0 / 0	292
1991	1991CASTF00000003	USF	STF	131 / 68	58 / 30	4 / 2	0 / 0	192 / 99	2 / 1	0 / 0	194
1991	1991NVTOI00000091	USF	TOI	778 / 90	76 / 9	8 / 1	0 / 0	857 / 99	4 / 0	1 / 0	862
1992	1992CATOI00000160	USF	TOI	15 / 11	35 / 27	31 / 24	50 / 38	53 / 40	19 / 15	59 / 45	131
1992	ABERDEEN	USF	INF	5 / 1	48 / 9	157 / 28	343 / 62	64 / 11	79 / 14	411 / 74	554
1992	CLEVELAND	USF	ENF	1780 / 8	2726 / 12	5402 / 23	13176 / 57	5001 / 22	3356 / 15	14727 / 64	23084
1992	GULCH FIRE	CDF	TCU	914 / 5	2860 / 16	8460 / 47	5913 / 33	4458 / 25	5416 / 30	8273 / 46	18147
1992	ITALIAN	USF	SNF	808 / 36	950 / 42	457 / 20	30 / 1	1845 / 82	309 / 14	90 / 4	2245
1992	RAINBOW	USF	INF	1653 / 19	2686 / 31	2138 / 25	2106 / 25	4614 / 54	1377 / 16	2592 / 30	8582
1992	RUBY	USF	STF	60 / 1	389 / 9	870 / 20	3020 / 70	528 / 12	525 / 12	3286 / 76	4338
1993	1993CAINF00000035	USF	INF	10 / 2	49 / 9	366 / 68	111 / 21	70 / 13	202 / 38	265 / 49	536
1993	BACKBONE	CDF	FKU	100 / 91	10 / 9	0 / 0	0 / 0	109 / 100	0 / 0	0 / 0	109
1993	ROAD	USF	ENF	79 / 24	143 / 43	68 / 20	44 / 13	232 / 70	46 / 14	56 / 17	334
1993	WHITE DEER	USF	SQF	98 / 40	140 / 56	10 / 4	0 / 0	241 / 97	6 / 3	0 / 0	248
1994	BIG CREEK	USF	SNF	1141 / 19	1458 / 24	1982 / 33	1393 / 23	2852 / 48	1360 / 23	1761 / 29	5973
1994	BROKEN	USF	STF	42 / 31	25 / 19	24 / 18	42 / 32	69 / 53	15 / 11	48 / 36	132
1994	COTTONWOOD	USF	TNF	6630 / 14	7811 / 16	12298 / 25	22053 / 45	15859 / 33	7957 / 16	24976 / 51	48792
1994	CREEK	CDF	TCU	42 / 3	479 / 32	707 / 47	272 / 18	616 / 41	460 / 31	424 / 28	1500
1994	CRYSTAL	USF	TNF	647 / 8	871 / 11	2144 / 28	4100 / 53	1689 / 22	1315 / 17	4759 / 61	7763
1994	FOUR LANE	CDF	FKU	56 / 23	59 / 25	63 / 27	60 / 25	122 / 51	40 / 17	77 / 32	239
1994	GARLIC	USF	SNF	364 / 48	393 / 52	4 / 1	0 / 0	760 / 100	1 / 0	0 / 0	760
1994	HIRSCHDALE	USF	TNF	116 / 10	203 / 18	567 / 50	259 / 23	373 / 33	369 / 32	403 / 35	1145
1994	KELSEY	CDF	AEU	197 / 16	315 / 25	289 / 23	468 / 37	546 / 43	186 / 15	538 / 42	1270
1994	POWERHOUSE #2	USF	SNF	161 / 35	260 / 56	44 / 10	0 / 0	433 / 93	33 / 7	0 / 0	466
1994	SECATA	USF	SNF	300 / 45	265 / 40	102 / 15	0 / 0	594 / 89	72 / 11	0 / 0	666

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1995	HELESTER	USF	TNF	62 / 9	305 / 46	153 / 23	140 / 21	389 / 59	102 / 15	169 / 26	660
1995	MEEKS	USF	TMU	60 / 37	49 / 30	24 / 15	30 / 18	112 / 69	15 / 9	35 / 22	163
1995	MILL	USF	ENF	5 / 4	29 / 23	42 / 34	50 / 40	40 / 31	26 / 21	61 / 48	127
1995	POLE	USF	INF	501 / 11	679 / 15	1169 / 27	2036 / 46	1303 / 30	764 / 17	2317 / 53	4384
1995	POWERHOUSE #2	CDF	FKU	349 / 53	223 / 34	81 / 12	1 / 0	594 / 91	57 / 9	4 / 1	655
1995	WUKSACHI	NPS	KNP	2559 / 70	1069 / 29	50 / 1	3 / 0	3648 / 99	28 / 1	5 / 0	3682
1996	AUTUMN HILLS	USF	TOI	175 / 4	491 / 13	1961 / 50	1277 / 33	812 / 21	1209 / 31	1883 / 48	3905
1996	BELLI	USF	TOI	733 / 11	3399 / 50	2199 / 32	495 / 7	4590 / 67	1502 / 22	733 / 11	6826
1996	BIG CREEK	USF	STF	58 / 52	29 / 26	25 / 22	0 / 0	90 / 81	21 / 19	0 / 0	112
1996	COLEVILLE	USF	TOI	242 / 9	494 / 19	1263 / 48	652 / 25	843 / 32	827 / 31	981 / 37	2651
1996	COOKS	USF	PNF	12 / 1	191 / 16	451 / 38	538 / 45	262 / 22	300 / 25	629 / 53	1192
1996	MANUAL	CDF	TCU	157 / 34	226 / 48	83 / 18	0 / 0	401 / 86	58 / 13	7 / 2	467
1996	MT. JACKSON	USF	TOI	10 / 1	112 / 12	310 / 34	487 / 53	149 / 16	203 / 22	566 / 62	918
1996	ROGGE	USF	STF	4903 / 23	6566 / 31	8659 / 41	1247 / 6	12780 / 60	6292 / 29	2304 / 11	21376
1996	STUMPFIELD	CDF	MMU	1142 / 28	1442 / 35	1140 / 28	378 / 9	2743 / 67	731 / 18	628 / 15	4102
1996	TRIMMER2	CDF	FKU	3339 / 53	2223 / 36	669 / 11	16 / 0	5751 / 92	456 / 7	40 / 1	6247
1997	CHOKE	USF	SQF	394 / 10	1083 / 27	1194 / 30	1312 / 33	1637 / 41	772 / 19	1574 / 40	3984
1998	ROUGH	USF	SNF	91 / 9	406 / 42	450 / 46	21 / 2	617 / 64	312 / 32	39 / 4	968
1998	TOM	USF	INF	305 / 8	298 / 8	1614 / 45	1378 / 38	666 / 19	884 / 25	2045 / 57	3594
1999	BEAN CREEK	USF	PNF	137 / 7	830 / 45	671 / 36	201 / 11	1090 / 59	469 / 25	281 / 15	1840
1999	BUCKS	USF	PNF	3550 / 10	16275 / 47	11162 / 32	3589 / 10	21937 / 63	7345 / 21	5293 / 15	34575
1999	DEER	USF	STF	67 / 18	143 / 40	142 / 39	11 / 3	240 / 66	98 / 27	25 / 7	363
1999	DEHAVEN	CDF	TGU	12692 / 74	3816 / 22	560 / 3	3 / 0	16733 / 98	331 / 2	7 / 0	17071
1999	DEVILS GAP	USF	PNF	187 / 12	600 / 39	318 / 20	445 / 29	841 / 54	205 / 13	503 / 32	1550
1999	DIVISION	USF	INF	1061 / 32	1687 / 51	490 / 15	41 / 1	2876 / 88	327 / 10	76 / 2	3279
1999	FLORISTON	CDF	NEU	96 / 25	61 / 16	143 / 37	89 / 23	164 / 42	91 / 23	135 / 35	389
1999	GULLY	USF	TOI	12 / 6	153 / 81	24 / 13	0 / 0	177 / 94	12 / 6	0 / 0	188
1999	GUN II	CDF	TGU	37205 / 61	14569 / 24	6642 / 11	2683 / 4	53066 / 87	4273 / 7	3760 / 6	61099
1999	HIRAM	USF	STF	641 / 23	1091 / 39	813 / 29	284 / 10	1892 / 67	538 / 19	398 / 14	2829
1999	LIGHTNING #31	CDF	TCU	12 / 8	43 / 29	50 / 34	42 / 28	61 / 42	31 / 21	55 / 37	147

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1999	LOOKOUT	USF	PNF	336 / 12	1348 / 50	695 / 26	316 / 12	1823 / 68	453 / 17	419 / 16	2695
1999	PIDGEON	USF	PNF	523 / 11	2761 / 58	1075 / 22	431 / 9	3487 / 73	704 / 15	600 / 13	4791
1999	PILOT	USF	STF	364 / 9	674 / 16	1252 / 30	1872 / 45	1172 / 28	744 / 18	2246 / 54	4163
1999	WEST	USF	TOI	15 / 6	119 / 44	136 / 50	4 / 1	154 / 56	107 / 39	12 / 5	274
2000	ARROW CREEK	USF	TOI	401 / 14	1060 / 37	1201 / 41	237 / 8	1646 / 57	837 / 29	417 / 14	2900
2000	AZUSA	USF	INF	81 / 10	274 / 32	359 / 43	131 / 15	406 / 48	235 / 28	203 / 24	845
2000	GOLDEN2	USF	TOI	254 / 14	340 / 19	607 / 33	613 / 34	638 / 35	369 / 20	805 / 44	1813
2000	HARLEY	CDF	TCU	119 / 63	61 / 32	10 / 5	0 / 0	184 / 96	6 / 3	1 / 1	190
2000	HIGHWAY	CDF	FKU	81 / 11	256 / 36	294 / 42	78 / 11	380 / 54	208 / 29	120 / 17	709
2000	KING	CDF	KRN	2440 / 47	994 / 19	973 / 19	818 / 16	3566 / 68	640 / 12	1019 / 20	5225
2000	MANTER	USF	SQF	10756 / 14	12125 / 15	21564 / 27	35153 / 44	25223 / 32	14045 / 18	40330 / 51	79598
2000	MILLWOOD	USF	SQF	38 / 14	80 / 30	82 / 30	72 / 27	128 / 47	52 / 19	93 / 34	272
2000	MITCHELL	USF	TOI	143 / 23	180 / 29	302 / 48	4 / 1	361 / 57	214 / 34	54 / 9	629
2000	SAWMILL	USF	INF	25 / 7	92 / 26	197 / 55	43 / 12	129 / 36	121 / 34	106 / 30	357
2000	SENECA	USF	TOI	155 / 13	558 / 46	479 / 39	24 / 2	802 / 66	343 / 28	71 / 6	1216
2000	STORRIE	USF	PNF	12098 / 21	16633 / 29	12141 / 21	15785 / 28	30596 / 54	7880 / 14	18182 / 32	56657
2001	BELL	USF	MDF	414 / 13	613 / 20	1051 / 34	1035 / 33	1154 / 37	711 / 23	1249 / 40	3113
2001	BLUE	USF	MDF	8005 / 23	8183 / 24	8205 / 24	10284 / 30	17433 / 50	5430 / 16	11814 / 34	34678
2001	BRICEBURG	BLM	BLM	50 / 6	234 / 30	372 / 48	117 / 15	336 / 44	257 / 33	179 / 23	772
2001	CRATER	USF	INF	1090 / 19	2283 / 40	2053 / 36	276 / 5	3968 / 70	1288 / 23	447 / 8	5702
2001	CREEK FIRE	CDF	MMU	1455 / 13	2249 / 20	4381 / 39	3294 / 29	4128 / 36	2750 / 24	4502 / 40	11380
2001	DARBY	CDF	TCU	857 / 6	4685 / 32	5774 / 40	3260 / 22	6358 / 44	3922 / 27	4295 / 29	14575
2001	DEVIL	CDF	LMU	58 / 1	694 / 16	1659 / 38	1993 / 45	137 / 72	22 / 11	32 / 17	4404
2001	FLORISTON	CDF	NEU	76 / 40	54 / 28	37 / 19	24 / 12	530 / 21	259 / 10	1766 / 69	190
2001	GAP	USF	TNF	214 / 8	264 / 10	422 / 17	1655 / 65	2349 / 55	1116 / 26	782 / 18	2554
2001	HIGHWAY	USF	SQF	515 / 12	1579 / 37	1696 / 40	457 / 11	533 / 31	455 / 26	753 / 43	4247
2001	HIGHWAY 70	CDF	BTU	123 / 7	335 / 19	689 / 40	594 / 34	4461 / 31	4546 / 31	5448 / 38	1741
2001	MARTIS	CDF	NEU	880 / 6	2901 / 20	6886 / 48	3788 / 26	894 / 32	1424 / 51	479 / 17	14455
2001	MCLAUGHLIN	USF	INF	74 / 3	593 / 21	1919 / 69	211 / 8	517 / 84	62 / 10	36 / 6	2797
2001	MOORE	CDF	TCU	193 / 31	308 / 50	88 / 14	26 / 4	141 / 58	75 / 31	29 / 12	615

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2001	MUSIC	USF	SNF	30 / 12	94 / 38	111 / 45	10 / 4	1619 / 38	1109 / 26	1542 / 36	245
2001	NORTH FORK	USF	SNF	226 / 5	1162 / 27	1676 / 39	1206 / 28	2636 / 31	1535 / 18	4305 / 51	4270
2001	POE	CDF	BTU	694 / 8	1654 / 20	2398 / 28	3730 / 44	375 / 63	74 / 12	148 / 25	8476
2001	ROCK CREEK	USF	TNF	135 / 23	221 / 37	114 / 19	127 / 21	103 / 89	13 / 11	0 / 0	597
2001	SALT	USF	ENF	33 / 29	61 / 53	22 / 19	0 / 0	178 / 100	0 / 0	0 / 0	116
2001	SILVER	USF	SNF	65 / 37	112 / 63	1 / 1	0 / 0	5550 / 32	3197 / 19	8388 / 49	178
2001	STAR	USF	ENF	842 / 5	4001 / 23	4869 / 28	7423 / 43	1045 / 24	968 / 22	2338 / 54	17135
2001	STREAM	USF	PNF	312 / 7	576 / 13	1443 / 33	2019 / 46	186 / 46	91 / 23	127 / 31	4351
2001	TREASURE	USF	TNF	52 / 13	121 / 30	135 / 33	97 / 24	125 / 48	57 / 21	82 / 31	405
2001	WHITE	USF	STF	26 / 10	90 / 34	83 / 31	65 / 25	949 / 22	1087 / 25	2368 / 54	264
2002	BIRCH	USF	INF	182 / 7	154 / 6	444 / 16	1979 / 72	370 / 13	278 / 10	2111 / 77	2759
2002	BOREL	USF	SQF	1338 / 38	1565 / 45	574 / 16	26 / 1	3074 / 88	380 / 11	50 / 1	3503
2002	CANNON	USF	TOI	3096 / 11	3649 / 13	6520 / 24	14108 / 52	7321 / 27	4131 / 15	15922 / 58	27374
2002	CONE	USF	LNF	199 / 9	513 / 24	540 / 26	847 / 40	802 / 38	353 / 17	944 / 45	2099
2002	ELLIS 2	USF	ENF	71 / 27	130 / 49	59 / 22	7 / 3	212 / 79	41 / 15	14 / 5	267
2002	FULLER	USF	INF	373 / 5	950 / 14	2462 / 36	3044 / 45	1545 / 23	1615 / 24	3669 / 54	6829
2002	GONDOLA	USF	TMU	55 / 8	189 / 27	317 / 46	129 / 19	277 / 40	226 / 33	188 / 27	691
2002	HUNTER	USF	ENF	124 / 18	318 / 46	201 / 29	56 / 8	472 / 68	136 / 19	91 / 13	699
2002	MCNALLY	USF	SQF	15259 / 10	36922 / 24	57785 / 38	42830 / 28	59303 / 39	39187 / 26	54306 / 36	152796
2002	PAIUTE	USF	INF	60 / 14	101 / 23	161 / 37	111 / 26	181 / 42	104 / 24	148 / 34	433
2002	PIPER	USF	INF	11 / 6	19 / 10	22 / 11	143 / 73	33 / 17	14 / 7	149 / 76	196
2002	PLUM	USF	ENF	757 / 40	714 / 38	319 / 17	106 / 6	1529 / 81	205 / 11	161 / 9	1895
2002	ROCK CREEK 2	USF	SNF	252 / 51	239 / 48	6 / 1	0 / 0	495 / 100	1 / 0	0 / 0	496
2002	SAINT PAULI	USF	ENF	22 / 6	124 / 36	156 / 45	47 / 13	172 / 49	111 / 32	66 / 19	349
2002	SHOWERS	USF	TMU	8 / 3	81 / 26	139 / 45	80 / 26	104 / 34	97 / 31	108 / 35	309
2002	SPI #3 SOURGRASS	CDF	TCU	122 / 17	409 / 57	160 / 22	24 / 3	561 / 79	111 / 16	42 / 6	715
2003	ALBANITA_HOOKER	USF	SQF	514 / 11	2392 / 50	1527 / 32	385 / 8	3176 / 66	1041 / 22	601 / 12	4818
2003	BASIN	USF	SQF	47 / 5	164 / 16	275 / 28	512 / 51	248 / 25	187 / 19	564 / 57	999
2003	COD FISH	USF	TNF	179 / 20	439 / 50	222 / 25	38 / 4	659 / 75	156 / 18	63 / 7	878
2003	COONEY	USF	SQF	223 / 11	712 / 34	722 / 35	421 / 20	1045 / 50	476 / 23	558 / 27	2078

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2003	DEXTER	USF	INF	376 / 15	1360 / 54	596 / 24	195 / 8	1858 / 74	380 / 15	288 / 11	2526
2003	KIBBIE CMPLX	NPS	YNP	622 / 9	2058 / 30	2983 / 43	1278 / 18	3103 / 45	2067 / 30	1772 / 26	6942
2003	MOUNTAIN CMPLX	USF	STF	1269 / 29	1651 / 38	1003 / 23	397 / 9	3106 / 72	678 / 16	537 / 12	4321
2003	MUD	USF	STF	401 / 9	1117 / 25	1717 / 39	1223 / 27	1744 / 39	1179 / 26	1535 / 34	4458
2003	ROYAL	USF	TMU	188 / 52	175 / 48	0 / 0	0 / 0	363 / 100	0 / 0	0 / 0	363
2003	SAGEHEN	USF	INF	74 / 7	161 / 15	231 / 21	643 / 58	262 / 24	143 / 13	703 / 63	1109
2003	SALT	CDF	AEU	50 / 19	158 / 59	52 / 19	7 / 3	217 / 81	37 / 14	14 / 5	268
2003	SUMMIT	USF	INF	415 / 7	2301 / 38	2509 / 41	883 / 14	3176 / 52	1701 / 28	1232 / 20	6109
2003	WEST KERN	NPS	KNP	2252 / 28	4226 / 52	1452 / 18	199 / 2	6854 / 84	960 / 12	315 / 4	8129
2003	WHIT	USF	STF	78 / 7	527 / 49	387 / 36	90 / 8	683 / 63	261 / 24	137 / 13	1082
2003	WILLIAMS	NPS	KNP	847 / 23	2127 / 57	647 / 17	123 / 3	3151 / 84	418 / 11	175 / 5	3744
2003	WOODLOT	NPS	YNP	143 / 28	251 / 49	113 / 22	0 / 0	431 / 85	74 / 15	3 / 1	507
2004	CRAG	UFS	SQF	61 / 7	266 / 30	330 / 37	240 / 27	375 / 42	223 / 25	300 / 33	898
2004	DEEP	UFS	SQF	347 / 11	668 / 21	948 / 29	1261 / 39	1110 / 34	604 / 19	1510 / 47	3224
2004	EARLY	UFS	STF	87 / 5	450 / 25	811 / 46	422 / 24	644 / 36	521 / 29	605 / 34	1770
2004	FREDS	UFS	ENF	275 / 3	1060 / 13	2538 / 32	4024 / 51	1629 / 21	1669 / 21	4599 / 58	7897
2004	POWER	UFS	ENF	1119 / 7	3825 / 22	5722 / 33	6499 / 38	5689 / 33	3853 / 22	7623 / 44	17164
2004	STRAYLOR	CDF	LMU	227 / 7	751 / 22	1115 / 33	1325 / 39	1125 / 33	746 / 22	1546 / 45	3418
2004	TUOLUMNE	UFS	STF	21 / 3	105 / 14	282 / 37	347 / 46	149 / 20	181 / 24	426 / 56	756

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