Prescribed Fire as the Minimum Tool for Wilderness Forest and Fire Regime Restoration: A Case Study from the Sierra Nevada, CA

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Abstract

Changes in forest structure were monitored in areas treated with prescribed fire in Sequoia and Kings Canyon National Parks. Five years after the initial prescribed fires, tree density was reduced by 61% in the giant sequoia-mixed conifer forest, with the greatest reduction in the smaller trees. This post-burn forest structure falls within the range that may have been present prior to Euroamerican settlement, based on forest structural targets developed with input from research, historic photos and written accounts. The results from this monitoring program provide an example of prescribed fire being used successfully both to reduce fuel hazard and to restore forest structure. This example may be particularly interesting to managers of other parks or wilderness areas where fire is considered the most appropriate means for restoring and managing ecosystems.

Introduction

Fire has been a pervasive and important process in many ecosystems for thousands of years, but humans have disrupted fire regimes over the past century. Proponents of allowing natural processes to function in wilderness areas maintain that natural fire regimes should be restored to many of these areas. After decades of fire regime disruption, however, altered fuel and vegetation conditions throughout many Western forests have increased the risk of severe wildland fires, which could result in undesirable fire effects (Hardy and Arno 1996; Vankat and Major 1978; van Wagtendonk 1985).

Heavy amounts of surface fuels have accumulated after nearly a century of fire regime disruption. In addition, small trees have increased in the understory, many of which would have been thinned by fire in the past. Some believe that forest structure in these areas should be

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restored before reintroducing natural fire regimes, thus minimizing the potential for unnaturally severe ecosystem effects from fire (Bonnicksen and Stone 1985; Fule and others 1997).

In the giant sequoia-mixed conifer forest of the Sierra Nevada, pre-Euroamerican fires burned at intervals ranging from 2-30 years, as evidenced by fire scars in the giant sequoia annual ring record dating back nearly 2,000 years (Kilgore and Taylor 1979; Swetnam 1993). This record does not distinguish fires by ignition source, and therefore, includes fires ignited by lightening, as well as those that may have been set by Native Americans (Lewis 1973). The increase in surface fuels and stand density after the century-long disruption of the fire regime are well-documented in this forest type (Kilgore 1972; Parsons 1978; Stephenson 1996, in press; Vankat and Major 1978).

One way to restore forest structure quickly is to mechanically remove trees, thereby increasing the space between tree crowns and reducing the risk that future fires will spread through the crowns. Using mechanical means to thin forests may have unacceptable consequences in wilderness areas, including new road construction and impacts of heavy equipment (such as high noise levels, soil compaction, heavy erosion and possible increases in certain pathogens). Even with mechanical thinning, surface fuels would need to be burned before natural fire regimes are restored. One method for restoring forest structure that is more compatible with wilderness values and legislation is prescribed fire; however, whether prescribed fire alone can accomplish the needed restoration has been questioned (Bonnicksen and Stone 1985).

To determine whether prescribed fire alone can restore forest structure, changes in fuel load and forest structure are monitored in areas treated with prescribed fire in Sequoia and Kings Canyon National Parks. The Parks have had an active program of prescribed fire since 1969. The long-term monitoring program began in 1982 to assess objective achievement and document changes in fuel and vegetation in burned areas.

Until recently, the Parks' prescribed fire management program focused first on reducing heavy surface fuel loads and then on restoring and maintaining the natural fire regime where possible. The initial fire planned in an area, called a 'restoration burn', has the primary objective of reducing the heavy accumulation of surface fuels that expose park developments and cultural and natural resources to damage from severe wildland fire. For the past three decades, the Park staff has concentrated on restoration burns, in part because of the extent of the recognized fuel hazard. Initial objectives of 60-80% total fuel reduction are consistently met with the current burn prescriptions in the giant sequoia-mixed conifer forest (Keifer 1998; Keifer and Manley, in press). In addition, large changes in stand structure occurred following prescribed fire (Keifer 1998) but there were no specific targets for stand structure, making it difficult to assess goals related to forest structural restoration.

Recently, the Park staff has developed preliminary targets for structural conditions in all vegetation types where stand structure is likely to have been greatly altered over the past century. These target conditions have been determined using the best available information, including research data, historic photographs, written accounts and expert opinion. To determine whether the prescribed fire program is making progress toward achieving forest structural goals, stand density results from the Parks' fire effects monitoring program is compared with the newly developed targets. If these and other structural target conditions are attained, the program can progress more readily toward restoring and maintaining the natural fire regime, where appropriate. If the target conditions are not achieved, changes to the prescribed fire treatment or reanalysis of the target conditions may be needed before natural fire regimes can be readily restored.

Methods

Study Area

Sequoia and Kings Canyon National Parks are located in the southern Sierra Nevada, California. The giant sequoia-mixed conifer forest is located at elevations from 1,650-2,200 meters (5,400-7,200 feet), on all aspects, in drainage bottoms, broad upland basins and, occasionally, on steep slopes and ridgetops. Soils are coarse-textured and acidic, and soil depth ranges from shallow to very deep. The giant sequoia-mixed conifer forest is dominated by mature white fir (Abies concolor [Gordon & Glend.] Lindley), red fir (A. magnifica Andr. Murray) and giant sequoia (Sequoiadendon giganteum [Lindley] Buchholz), but also includes sugar pine (Pinus lambertiana Douglas), ponderosa pine (P. ponderosa Laws.), Jeffrey pine (P. jeffreyi Grev. & Balf.) and incense cedar (Calocedrus decurrens [Torrey] Florin) in small, varying amounts. Understory trees are primarily composed of white fir and incense cedar. The understory vegetation is typically sparse, with few herbs and <20 percent shrub cover.

Forest Structural Targets

In the giant sequoia-mixed conifer forest, research results (Bonnicksen and Stone 1982a; Stephenson 1994), examination of written accounts (Bonnicksen 1978), qualitative analysis of historic photos and expert opinion (both National Park Service and US Geological Survey scientists) led to development of target conditions for stand density. Recognizing that climate in the Sierra Nevada has changed over time (Graumlich 1993), the targets refer to the approximately 1,000-year time period prior to Euroamerican settlement, based on issues addressed by Stephenson (1996, in press). From age/diameter relationships, trees 80 cm or larger in diameter at breast height (DBH) were established almost exclusively prior to Euroamerican settlement (Finney and Stephenson, unpublished data).

The stand-level structural target for the giant sequoia-mixed conifer forest is to maintain the density of trees ≥80 cm DBH between 10-75 trees/ha and trees <80 cm DBH between 50-250 trees/ha, for a total tree density of 60-325 trees/ha. While species composition targets are also needed, the park staff focused on total tree density as a starting point for developing the stand density target conditions. Landscape-level target conditions include size and number of forest gaps and surface fuel load, which are not discussed in this paper.

Development of target conditions is ongoing, and any new knowledge gained about past conditions will be used to further refine target conditions. Additional information that will be useful in this process includes additional search for and quantitative analysis of historic photography and examination of existing park databases that contain information on the density of large trees by species (those present prior to Euroamerican settlement).

Burning Conditions

All areas in this study were burned between 1982 and 1997 within the range of burning conditions specified for the giant sequoia-mixed conifer forest (USDI National Park Service 1992a). Fuels are best described by Northern Forest Fire Laboratory (NFFL) Fuel Model 8 (Albini 1976). Time since the last fire in all plots was longer than 40 years and usually exceeded 100 years. Air temperature during prescribed fires ranged from 4-24 C (40-75 F), relative humidity from 25-50 percent and mid-flame wind speeds from 0-10 kilometers per hour (0-6 miles per hour). Fuel moisture ranges included: 1-hour time lag fuel moisture (TLFM), 3-13 percent; 10-hour TLFM, 4-14 percent; 100-hour TLFM, 5-15 percent; 1,000-hour TLFM, 10-20 percent. The range of backing fire rates of spread was 0-20 meters/hour (0-66 feet/hour), with flame lengths from 0-0.6 meters (0-2 feet). Head fire rates of spread ranged from 40-180 meters/hour (132 to 594 feet/hour) with flame lengths from 0-1.5 meters (0-5 feet).

Field Data Collection

Monitoring data were collected from a network of permanently marked 20 x 50 meter plots, established using a stratified-random sampling design within the Park areas designated for prescribed fire. Within each forest plot, fuel load and tree density were recorded pre-burn, immediately post-burn and 1, 2, 5, and 10 years post-burn. To obtain overstory tree density, all trees >1.37 meters (4.5 feet) in height were tagged, mapped, identified to species, measured for diameter and recorded as live or dead (USDI National Park Service 1992b).

We analyzed data from 27 plots that burned in 17 different prescribed fires between 1982 and 1991. Although the plots did not all burn during the same year, all analyses are direct comparisons of the same 27 plots at each post-burn stage. Some of the older plots were not monitored two years post-burn, so those data were not used in the analyses. To examine post-burn changes in stand structure, one-year and five-year post-burn mortality data were used because tree mortality resulting from the direct effects of fire is often not apparent immediately post-burn (Mutch and Parsons 1998).

Results and Discussion

Pre-burn mean density for trees <80 cm DBH was 625 trees/ha, which is two and a half times the maximum target value (fig. 1). The pre-burn mean density of trees ≥80 cm DBH was 46 trees/ha, well within the target range of 10-75 trees/ha. Tree density was reduced one-year post-burn, with 53% mortality of trees <80 cm DBH but only 4% mortality of trees ≥80 cm DBH. While large tree post-burn density remained within the target range, the density of trees <80 cm DBH (292 trees/ha) was still higher than the target maximum of 250 trees/ha (fig. 1).

By five years post-burn, the mean density of trees <80 cm DBH was further reduced to 222 trees/ha, which falls within the target range (fig. 1). The larger trees are only slightly reduced to 42 trees/ha by five years post-burn. Most of the density reduction occurred in the smaller trees, indicating that prescribed fire may reduce the potential for spread of crown fire in these forests by thinning smaller trees and ladder fuels, while minimizing effects on larger trees (8% reduction in density from pre-burn to 5-years post-burn). No mortality of large giant sequoia trees occurred within the monitoring plots following prescribed burning.

Although the Parks' preliminary target conditions do not yet include species composition, one of the indicators of successful fire regime restoration is the regeneration of fire-adapted species. Giant sequoia establishment and recruitment rely heavily on exposed mineral soil and canopy openings resulting from fire. Results from 12 giant sequoia-mixed conifer forest monitoring plots indicate that the relative density of giant sequoia has tripled 10 years after prescribed fire (Keifer 1998). This increase is primarily attributed to the successful recruitment of giant sequoia post-burn regeneration into the smallest tree diameter class, along with the fire-induced mortality of many of the small white fir (fig. 2). This regeneration of giant sequoia is in stark contrast to areas that have not burned, where giant sequoia regeneration is almost entirely absent (Stephenson 1994). Demographic models suggest that the amount of sequoia regeneration following prescribed fire may be roughly comparable to that prior to Euroamerican settlement (Stephenson, unpublished data).

The results from this monitoring program provide an example of prescribed fire being successfully used both to reduce fuel load and to restore forest structure in the giant sequoia-mixed conifer forest of Sequoia and Kings Canyon National Parks (see also Stephenson 1996, in press). Whether forest structure can be restored in other vegetation communities using prescribed fire depends on many site-specific factors, including the number of fire-return intervals missed and history of other disturbance. Some vegetation communities may be so greatly altered that using prescribed fire without first mitigating the altered structural conditions may result in unacceptable effects (Fule and others 1997). In some areas, several prescribed fires may be needed to completely restore fuel load and forest structure before natural fire regimes can be returned. This case study presents evidence that forest structure restoration using prescribed fire is possible in at least some forests where structure has been altered. Use of fire in forest restoration should be investigated in other areas where mechanical forest restoration is inappropriate or impractical, such as parks and wilderness areas.

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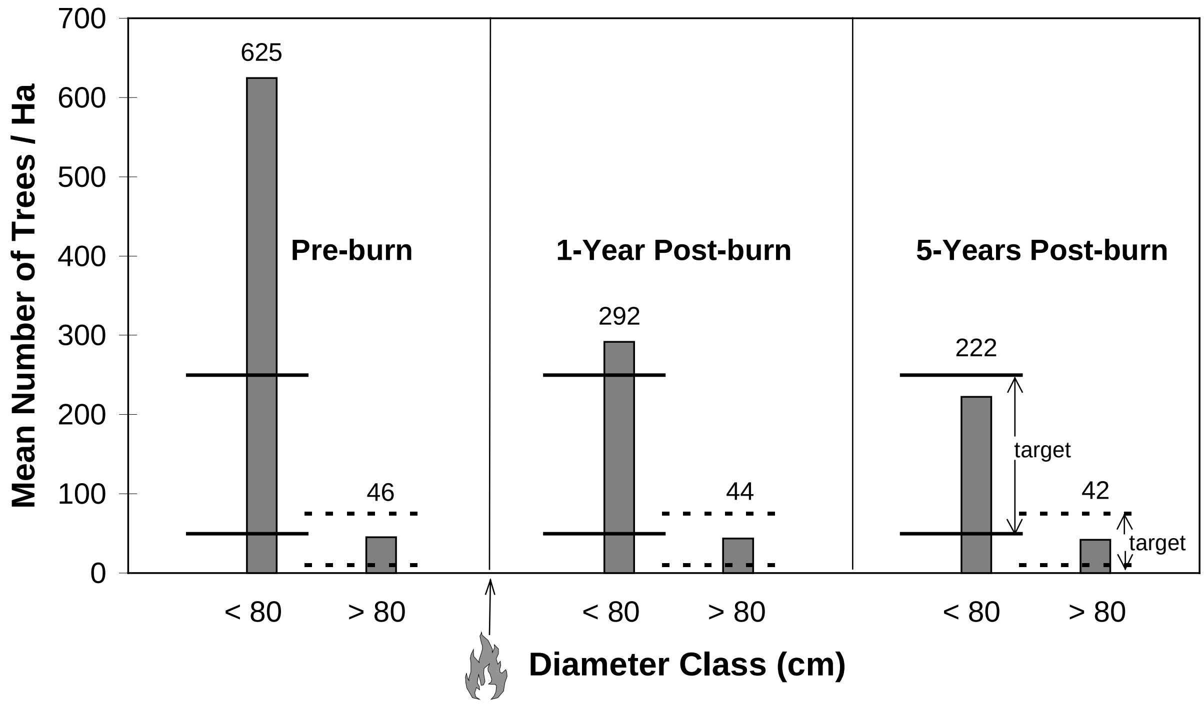

Figure 1. Stand density (all species combined) by diameter class in the giant sequoia-mixed conifer forest (n = 27 plots) pre-burn, and 1- and 5-years after prescribed fire. The target range for trees <80 cm is indicated by solid lines, and the target range for trees ≥80 cm is indicated by dashed lines.

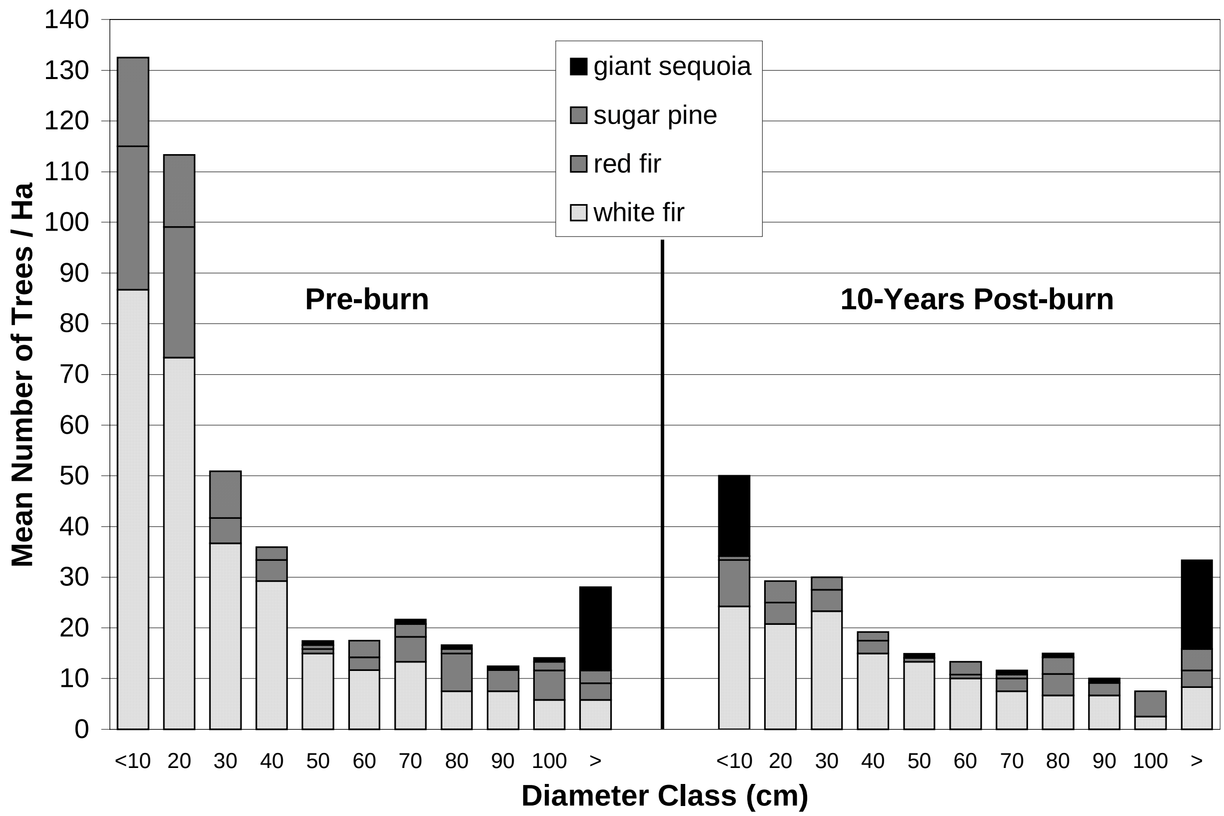

Figure 2. Pre-burn and 10-year post-burn stand density, by species and diameter class, in the giant sequoia-mixed conifer forest (n = 12 plots). Note the increase in giant sequoia in the smallest diameter class 10-years post-burn.