Fuel load and tree density changes following prescribed fire in the giant sequoia-mixed conifer forest: the first 14 years of fire effects monitoring

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ABSTRACT

Understanding both short- and long-term effects of prescribed fire is critical for successful fire management. Fire effects monitoring results are used to assess fire management objective achievement for Sequoia and Kings Canyon National Parks. Forest floor fuel load and tree density in a network of 0.1 hectare permanent plots are monitored prior to and following prescribed fires in the parks. In the giant sequoia-mixed conifer forest, total fuel load was reduced by 71% immediately following prescribed fire; the duff component was reduced by 93% while woody fuels were reduced by 56%. Woody fuel load nearly doubled in the 10 years following prescribed fire, slightly exceeding prefire woody fuel load. This increase was a result of fire burning in dense, prefire stands, killing branches and small understory trees that later fell to the forest floor. Duff accumulated at a slower rate, reaching only 28% of prefire levels 10 years after fire. After 10 years, total fuel load reached 75% of prefire levels, indicating subsequent fires may be needed as soon as 10-years postfire to further reduce fuels. After much of the woody debris downed after the initial fires is consumed, successive fires for fuel reduction may then need to be less frequent, as reduced stand density should result in less tree mortality to contribute to forest floor fuels. Prefire tree species composition was generally dominated by white fir (***Abies concolor*** [Gordon & Glend.] Lindley), especially in the smaller diameter classes, demonstrating white fir's relative success where fire has been excluded for at least the last 80 years. White fir, red fir, and total tree densities (three dominant species combined) were reduced following prescribed fire. Giant sequoia (***Sequoiadendron giganteum*** [Lindley] Buchholz) relative density increased, with a marked increase in young giant sequoias 10 years following prescribed fire.

KEY WORDS
fire effects monitoring, giant sequoia, fuel load, fuel reduction, tree density, prescribed fire, fire management, Sierra Nevada, Sequoia and Kings Canyon National Parks

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INTRODUCTION

Fire has been a part of Sierra Nevada ecosystems for thousands of years (Kilgore 1972, Vankat and Major 1978). In the giant sequoia-mixed conifer forest, pre-Euro-American fires burned at intervals ranging from 2-30 years as evidenced by fire scars in the giant sequoia (***Sequoiadendron giganteum*** [Lindley] Buchholz) annual ring record dating back nearly 2,000 years (Kilgore and Taylor 1979, Swetnam 1993). Recently however, as a result of nearly a century of attempted fire exclusion, unnaturally heavy fuels have accumulated in some of the parks' fire-adapted vegetation types (Kilgore 1972, Parsons 1978). In addition, an increase in small trees in the understory, limited by fire in the past, has resulted in an increase in stand density (Vankat and Major 1978). These altered fuel and vegetation conditions increase the risk of unusually severe wildland fires.

To start to address these changes, Sequoia and Kings Canyon National Parks began an active program of management-ignited prescribed fire in 1969. The goals of the parks' fire management program include restoring or maintaining the natural fire regime to the maximum extent possible so that natural ecosystems can operate essentially unimpaired by human interference. A specific objective of the prescribed fire program is to reduce heavy fuels that expose park developments and cultural and natural resources to damage from severe wildland fire. A long-term fire effects monitoring program, which began in 1982, is designed to: 1) determine if fire management objectives are being met, 2) assess ways to refine the prescribed fire program if objectives are not met, and 3) document visual, physical, and ecological effects of fire.

The parks' management staff is interested in restoring or maintaining natural conditions throughout all the parks' vegetation communities. However, the perpetuation of the giant sequoia-mixed conifer forest is particularly important due to its limited distribution and unique and revered nature. To specifically address the heavy fuel accumulation, the primary objective for the initial prescribed fire in this forest type is 60-80% total fuel reduction. Fire effects monitoring plots are therefore used to assess fuel reduction as well as to examine short- and long-term changes in giant sequoia-mixed conifer stand structure following prescribed fire.

METHODS

Study Area

Sequoia and Kings Canyon National Parks are located in Tulare and Fresno Counties, California, in the southern Sierra Nevada. The giant sequoia-mixed conifer forest is located at elevations from 5400-7200 feet (1650-2200 meters), 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 areas monitored are dominated by mature white fir (***Abies concolor*** [Gordon & Glend.] Lindley), red fir (***A. magnifica*** Andr. Murray), and giant sequoia, but also include 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 white fir and incense cedar. The forest floor is typically sparse, with few herbs, and <20% shrub cover.

Burning Conditions

All plots in this study were burned between 1982 and 1995 within the same range of burning conditions specified for the giant sequoia-mixed conifer forest (U.S. Department of Interior, National Park Service 1992a). Fuels are best described by Northern Forest Fire Laboratory (NFFL) Fuel Model 8 (Albini 1976). The time since the last fire in all plots was greater than 40 years. Temperatures ranged from 40-75EF (4-24EC), relative humidities from 25-

50%, and mid-flame wind speeds from 0-6 miles per hour (0-10 kilometers per hour). Fuel moisture ranges were as follows: 1-hour time lag fuel moisture (TLFM), 3-13%; 10-hour TLFM, 4-14%; 100-hour TLFM, 5-15%; 1,000-hour TLFM, 10-20%. The range of backing rate of fire spread was 0-66 feet/hour (0-20 meters/hour) with flame lengths from 0-2 feet (0-0.6 meters). Head fire rates of spread ranged from 132 to 594 feet/hour (40-180 meters/hour) with flame lengths from 0-5 feet (0-1.5 meters).

Data Collected

Fire effects data were collected from a network of plots 20 x 50 meters permanently marked, established with a stratified-random sampling design within the park areas designated for management-ignited prescribed fire. Within each forest plot, fuel load and tree density were recorded prefire, immediately postfire, and 1-, 5-, and 10-years postfire.

Fuel load was measured using the planar transect method (Brown et al. 1982). Total fuel load includes: duff (the consolidated, decomposing organic layer above mineral soil), 1-hour (0-0.24 inches [0-0.61 centimeters] in diameter), 10-hour (0.25-0.99 inches [0.62-2.53 centimeters]), 100-hour (1.0-2.99 inches [2.54-7.59 centimeters]), and 1000-hour (<3 inches [7.6 centimeters]) TLFM woody fuels. For tree density, all trees >4.8 feet (1.47 meters) height are tagged, mapped, identified to species, measured for diameter, and recorded as live or dead (U.S. Department of Interior, National Park Service 1992b).

For immediate postfire fuel reduction, 27 plots that burned in 16 different prescribed fires between 1982 and 1995 were analyzed. To examine long-term postfire fuel accumulation and changes in tree density over time, 7 plots that reached the 10-year postfire stage were evaluated. These plots burned in 3 separate prescribed fires, 1982 (4 plots), 1984 (2 plots), and 1985 (1 plot).

RESULTS

Fuel Reduction

Prefire mean total fuel load ± 1 standard error of the mean for 27 plots was 64.0 tons/acre ± 6.0 (23.0 tonnes/hectare, **Figure 1**). The total fuel load was reduced by 71% to 18.8 tons/acre ± 3.2 (6.8 tonnes/hectare) immediately postfire. A much larger proportion of duff (93%) was consumed compared with the woody fuel component (56%). Woody fuels were reduced from 38.8 tons/acre (14.0 tonnes/hectare) prefire to 17.0 tons/acre (6.1 tonnes/hectare). Prefire duff of 25.7 tons/acre (9.3 tonnes/hectare) was reduced to 1.8 tons/acre (0.6 tonnes/hectare, **Figure 1**).

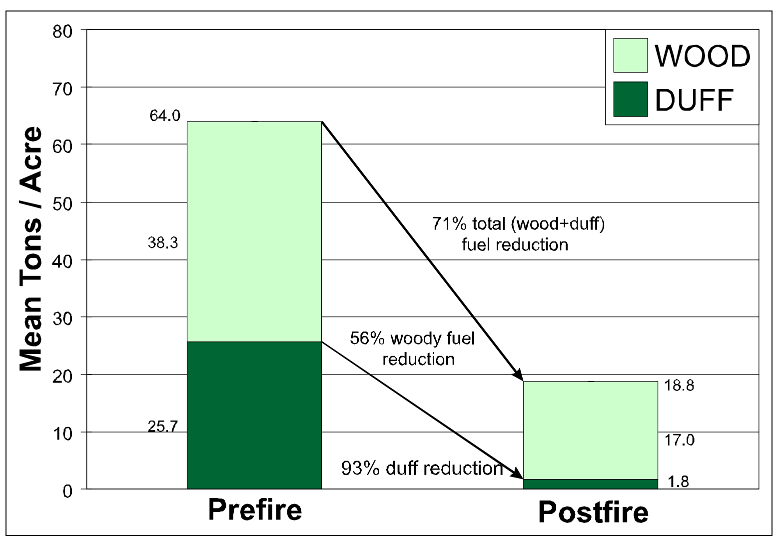

Figure 1. Fuel load (mean tons/acre) in giant sequoia-mixed conifer forests before and immediately following prescribed fire (n=27 plots). Mean values for duff and wood components and mean total fuel load +/- 1 standard error of the mean are included.

Postfire Fuel Accumulation

Ten-years postfire, mean total fuel load ± 1 standard error of the mean for 7 plots increased to 42.6 tons/acre ± 4.1 (15.3 tonnes/hectare), nearly doubling the immediate postfire level of 22.8 tons/acre ± 6.6 (8.2 tonnes/hectare, **Figure 2**). Woody fuels accumulated faster than duff, with 10-year postfire woody fuels (36.6 tons/acre [13.2 tonnes/hectare]) slightly exceeding the prefire level (35.7 tons/acre [12.9 tonnes/hectare]). Ten years following fire, duff reached only 28% of the prefire amount (21.1 tons/acre [7.6 tonnes/hectare] prefire, 6.0 tons/acre [2.2 tonnes/hectare] 10-years postfire, **Figure 2**). Mean total fuel load approached 75% of prefire levels 10 years following fire (56.8 tons/acre ± 4.3 [20.4 tonnes/hectare] prefire, 42.6 tons/acre ± 4.1 [15.3 tonnes/hectare] 10-years postfire).

Figure 2. Fuel accumulation over time following prescribed fire in giant sequoia-mixed conifer forests (n=7 plots). Mean values for duff and wood components and mean total fuel load +/- 1 standard error of the mean are included.

Tree Density

Total tree density (three dominant species) was reduced from 1230 trees/acre (498 trees/hectare) prefire to 729 trees/acre (295 trees/hectare) 1 year after prescribed fire (**Figure 3**). Changes in the relative densities of the three dominant tree species varied (note that relative densities do not total 100%, as other species are present in small amounts). White fir comprised 60% prefire and decreased to 56% 1-year postfire. Giant sequoia relative density increased from 7% to 12%. Red fir decreased only slightly 1-year postfire. The species' relative densities changed little 1- to 5-years postfire. Ten years after burning, the relative density of white fir had decreased by 9% (from 60% prefire to 51%) while giant sequoia relative density more than tripled (from 7% prefire to 23%; **Figure 3**).

Examining each species by diameter class is useful to assess the change in stand structure following fire. The density of white fir in the smaller diameter classes (0-10 and 10-20 centimeters) showed the greatest decrease following fire (**Figure 4**). Less mortality occurred

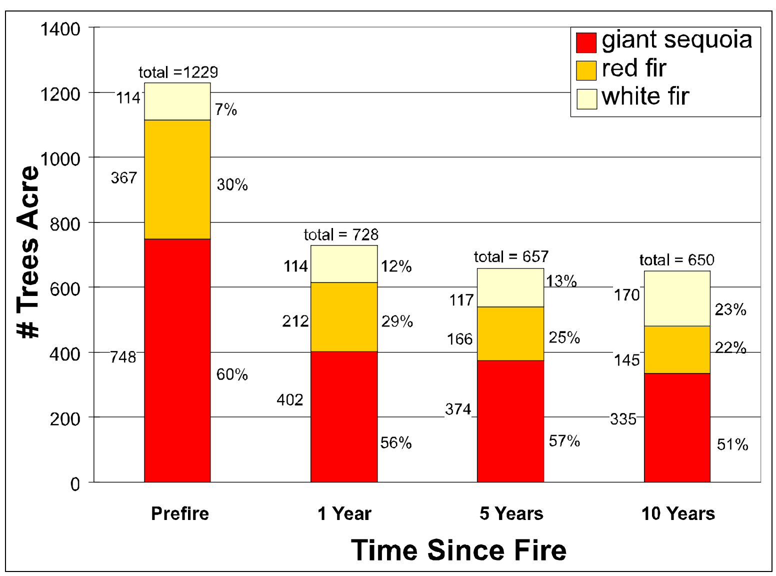

Figure 3. Density and relative density (% of total) of three dominant tree species over time following prescribed fire in giant sequoia-mixed conifer forests (n=7 plots).

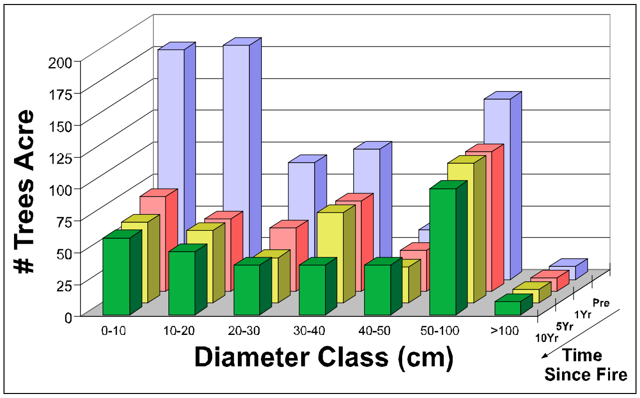

Figure 4. Density of white fir by diameter class over time following prescribed fire (n=7 plots).

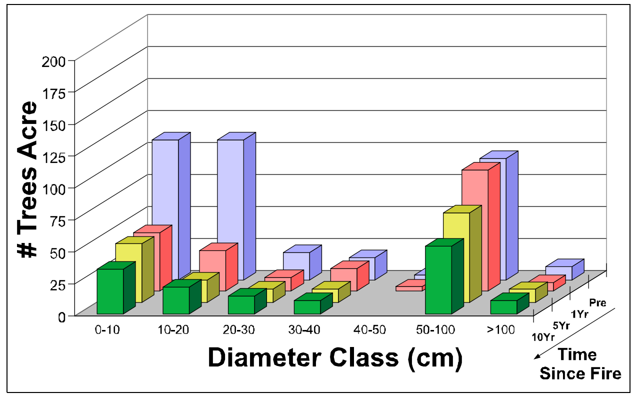

Figure 5. Density of red fir by diameter class over time following prescribed fire (n=7 plots).

in the larger, and more fire resistant, diameter classes. Little change occurred 5- and 10-years postfire. Similarly, red fir density decreased most notably in the smaller diameter classes (**Figure 5**). The density of giant sequoias in all size classes did not decrease over time, indicating their resistance to fire (**Figure 6**). Note that some changes in density within a size class indicate movement into a larger size class due to diameter growth over time. A marked increase in giant sequoia density in the 0-10 centimeter diameter class is evident 10-years postfire (**Figure 6**).

DISCUSSION

Fuel Reduction

The 71% reduction in total fuel load met the 60-80% fuel reduction objective for the giant sequoia-mixed conifer forest using prescribed fire under these conditions. Fuel reduction was nearly identical to that found in Yosemite National Park for NFFL fuel models 8 and 9 combined (70%, van Wagtendonk and Sydori k 1987).

Postfire Fuel Accumulation

Ten years after fire, total fuel load was nearly 75% of prefire levels. While the duff component accumulated slowly (28% of prefire level), 10 years following fire, woody fuels slightly exceeded the prefire level. Only 56% of the woody fuels had been consumed in the fires, therefore, immediate postfire woody fuel load was already substantial. Postfire woody fuels then increased as a result of dead branches and stems killed by the initial prescribed fire that fell to the forest floor over time (Parsons 1978). Based on annual fuel accumulation rates obtained over 6 years, calculated fuel loads in Yosemite National Park would reach prefire levels approximately 11 years after fire (van Wagtendonk and Sydoriak

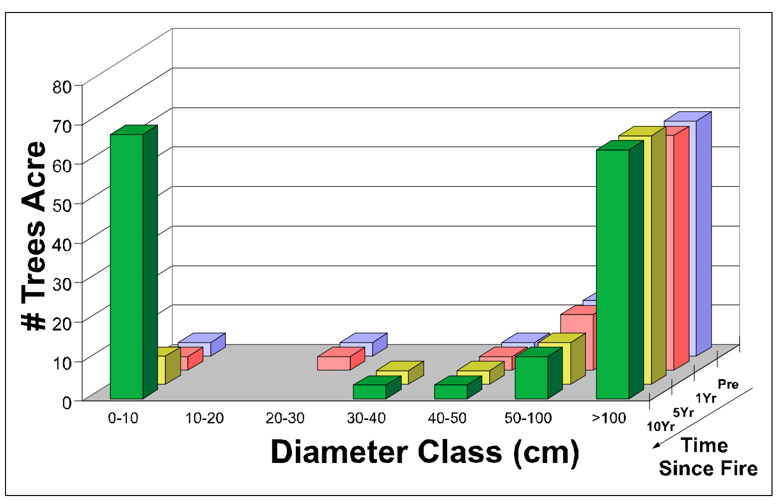

Figure 6. Density of giant sequoia by diameter class over time following prescribed fire (n=7 plots).

1987). The monitoring results presented here indicate somewhat slower postfire fuel accumulation, reaching 75% of prefire levels after 10 years.

By 10 years after the initial fire, a subsequent fire would be useful to reduce both the woody fuels that were unconsumed and those that accumulated as a result of the initial fire. Due to the high density of small trees in the understory, several burns may be necessary before postfire woody fuel accumulation is lessened. After much of the fallen woody debris from dead branches and stems downed after the first few fires is consumed, successive fires for fuel reduction may then need to be less frequent, as duff accumulates more slowly and reduced stand density should result in less tree mortality to contribute to forest floor fuels. Continued fuel accumulation information following successive fires, along with knowledge of historical fire return intervals, will be useful in determining when subsequent burns will be most effective for the restoration and perpetuation of giant sequoia-mixed conifer forests.

Tree Density

Very few smaller diameter class (0-30 centimeters) giant sequoias were present in the plots before the fire compared to white and red fir. This stand composition and structure is a result of the increased survival of shade-tolerant firs and the decrease in giant sequoia regeneration in the absence of fire. Prescribed fire reduced the mean total tree density in the giant sequoia-mixed conifer forest monitoring plots by 47% 10-years following the fire with the greatest reduction occurring in the smaller diameter trees. This reduced density may help limit the movement of surface fire into the overstory tree crowns by reducing ladder fuels.

Ten years after fire, the size structure of both white and red fir showed a much reduced density of smaller trees relative to larger trees. At the same time, an increase in young giant sequoias is consistent with earlier observations that prescribed fire facilitates the early stages of giant sequoia recruitment (Parsons 1978). Some, but not all, of these younger giant sequoia trees may reach the larger size classes. Over time, as the larger, older firs are lost to senescence, and if subsequent burning keeps the smaller trees in check, the density of firs relative to giant sequoia may be further reduced. In addition, if some of the smaller size class giant sequoias survive subsequent fires, the relative density of giant sequoia will further increase.

Thus, as the pre-Euro-American settlement fire regime in the giant sequoia-mixed conifer forest saw fires burning at intervals from 2-30 years, successive fires within these intervals may help restore relative tree densities within the range of those present before Euro-American settlement. Continued long-term monitoring is needed to determine future changes in stand structure and composition following these successive fires.

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