Research Project Summary: Impact of summer and fall prescribed fires on fire-excluded, Sierran mixed-conifer forests in Kings Canyon National Park, California

Citation

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Figure 1—Giant sequoia-mixed-conifer forest before (left) and after (right) thinning and prescribed summer fire. The left-hand, fire-scarred tree is a giant sequoia. USDI, National Park Service photo by Harold Weaver.

SUMMARY

Restoration of historical stand structure and fire regimes is needed to preserve giant sequoia and other Sierran mixed-conifer forests in the long term. The prescribed fire program in Kings Canyon National Park was initiated in the late 1960s, along with studies on the effects of prescribed fire in Sierran mixed-conifer forests. These studies were conducted in giant sequoia-mixed-conifer and ponderosa pine-mixed-conifer forests on Redwood Mountain. Fire had been excluded on Redwood Mountain for at least 50 years prior. Large amounts of litter and duff had accumulated on the forest floor and an understory and subcanopy of white fir and incense-cedar had developed, creating ladder fuels. The shrub and herbaceous layers were scant. This Research Project Summary synthesizes results of related studies on Redwood Mountain.

Fire history studies conducted on and nearby Redwood Mountain found historical (1700-1867) fire-return intervals ranging from 4 to 20 years in giant sequoia-mixed-conifer forests and from 7 to 10 years in ponderosa pine-mixed-conifer forests. Fire intensity was historically low to moderate.

Objectives of the prescribed fires were to 1) reduce fire hazard and chances of crown fire on Redwood Mountain by reducing surface fuels and shade-tolerant seedlings and saplings that form ladder fuels, and 2) create openings in the canopy and expose mineral soil to promote establishment of early-seral plant species, particularly giant sequoia, sugar pine, and understory shrubs. The long-term goal was to develop a program of frequent prescribed fire that would ultimately restore historical stand structures and fire regimes to these forests.

Prescribed fires were set in midsummer 1969 and late fall 1970. The summer fires burned at higher intensities than the fall fires. Consequently, the summer fires killed more understory trees, consumed more surface fuels, and exposed more mineral soil. The fall fires increased relative density of giant sequoia and sugar pine compared to white fir, but they did not change relative density of ponderosa pine. Similar information was not provided for the summer fires. Both summer and fall fires increased density of the shrub layer. Establishment of giant sequoia and sugar pine seedlings was highest on summer burns, while establishment of deerbrush seedlings was highest on fall burns. Frequency of forbs was higher on fall-burned than on unburned control plots.

Kilgore [4] suggested that under fire weather and fuel conditions similar to those of the more intense summer fire, follow-up prescribed fire would be needed 7 to 10 years later. Under conditions similar to those of the less intense fall fire, he suggested conducting two prescribed fires in closer sequence, which would kill shade-tolerant saplings but consume large woody debris more gradually. After the second fire, follow-up burning could be conducted about every 10 years to remove surface fuels and woody debris. He suggested that lightning-ignited wildfires be allowed to burn in giant sequoia-mixed-conifer and ponderosa pine-mixed-conifer forests once current stand structure is more aligned with presettlement stand structure.

INTRODUCTION

This Research Project Summary synthesizes information from research projects conducted in the summer of 1969 and fall of 1970 in giant sequoia-mixed-conifer and ponderosa pine-mixed-conifer forest in Kings canyon National Park. It provides information on pre- and postfire fuel loads and fire weather; and postfire responses of giant sequoia, sugar pine, ponderosa pine, and deerbrush.
FEIS Research Project Summaries are intended to: 1) provide concise information about the effects of particular fire treatments on specific plant communities and 2) supplement FEIS reviews of individual species with detailed information on specific treatments and effects in a particular location.

The studies summarized in FEIS Research Project Summaries are selected based on their integration of fire effects information with relatively complete descriptions of burned and unburned vegetation, burning conditions, fire weather, and fire behavior.

Common names are used throughout this summary. For a complete list of the common and scientific names of species discussed in this summary and for links to FEIS Species Reviews, see the Appendix.

Sources

Unless otherwise indicated, the information in this Research Project Summary comes from the following sources: [3, 4, 5, 6, 7, 8].

SITE DESCRIPTION AND STUDY DESIGN

Site Description

The study site was located just off the ridgetop of Redwood Mountain in the Kings Canyon portion of Sequoia-Kings Canyon National Park. The ridge is located within the 3,100-acre (1,250-ha) Redwood Mountain Grove area, which contains the largest grove of giant sequoias in the world [4, 6]. The ridge is oriented north-south. Elevation along the ridgetop ranges from 6,400 to 7,000 feet (2,000-2,100 m). Slope on the study site averages 35%; aspect is east facing. Mean annual temperatures range from a winter low of 17 °F (-8 °C) to a summer high of 82 °F (28 °C). Mean annual temperatures in midsummer (time of 1st prescribed fire) range from 61 to 74 °F (16-23 °C); in November (time of 2nd prescribed fire), they range from 32° to 58 °F (0-14 °C). Soils are derived from metamorphic schists [4].

Study Design

Separate studies were initiated for the summer [6] and fall [4] burns, and study design and plot sizes differed between the studies. Different approaches make comparisons between the studies unfeasible.

Summer Fires

Before ignition, a 100-acre (40-ha) block was divided into 13 sectors and thinned. Each sector was surrounded by small, hand-built firelines. Two-foot-wide (0.7-m) handlines were built around most giant sequoias. In each sector, white fir and incense-cedars <9 inches (23 cm) DBH were felled and left onsite. All snags except giant sequoia snags were felled [6].

Four study plots were established on the 100-acre site: three burn plots and an unburned control. Plots were roughly 4 to 6 acres (1.6-2.4 ha) (table 4). One transect was run through each plot. To measure conifer seedling and shrub densities, fifty 4- x 4-foot (1.2 x 1.2 m) microplots were established at 25-foot (7.6-m) intervals along each transect [6].

Fall Fires

Twelve 60- x 100-foot (18- x 30.5-m) study plots were established within a 5-acre (2-ha) area of the giant sequoia-mixed-conifer forest, just east of the ridgetop at 6,300 feet (1,900 m) elevation; an additional 60- x 100-foot plot in ponderosa pine-mixed-conifer forest was established at a lower elevation. No prefire thinning was conducted. Seven of the 12 giant sequoia-mixed-conifer plots and the ponderosa pine-mixed-conifer plot were burned; the other 5 plots were designated as untreated control plots. Three 50-foot (15-m) transects were run along each plot. Microplots of 2 x 3 feet (0.6 x 0.9 m) were established within each plot to measure conifer seedling and shrub densities (n = 210 total microplots on burn plots and 150 total microplots on control plots) [4].

PREFIRE PLANT COMMUNITY AND FUELS

Prefire Plant Community

The cover type is Sierran mixed-conifer forest. Giant sequoia, white fir, and sugar pine codominated upper-elevation study sites (hereafter, giant sequoia-mixed-conifer). Relative density of trees >12 inches

(30 cm) DBH averaged 55% for white fir, 29% for giant sequoia, and 8% for sugar pine [4]. All giant sequoias were ≥12 inches DBH [4], and some exceeded 2,000 years of age [6]. About 90% of the sapling size class (<30 ft (9 m) tall) was white fir and about 10% was sugar pine. Ponderosa pine, California black oak, and incense-cedar were sparse except in the ponderosa pine-mixed-conifer site [4].

Large cohorts of conifers had established between 1873 and 1907; roughly, the period when burning by American Indians was eliminated [4]. Before European-American settlement, the Yokut and Western Mono (Monache) tribes had permanent settlements in the area. The tribes apparently set fires frequently to maintain California black oak, which produces acorns favored for making meal [8]. At the time of prescribed burning, the cohorts that established from 1873 to 1904 had reached the 6- to 12-inch (15-30 cm) DBH class. Cohorts that established in the 1920s to the 1940s—when fire suppression was becoming increasingly effective—were <15-foot (4.6 m) tall [4].

The shrub and herbaceous layers were scant. Forbs were present in the herbaceous layer but grasses were absent [4].

Figure 2—Dense understory and subcanopy of white firs and incense-cedars beneath a giant sequoia at Redwood Mountain, Kings Canyon National Park, California. USDI, National Park Service photo [8].

Prefire Fuels

Fire had been excluded on Redwood Mountain for at least 50 years prior to these prescribed fires [4]. Large amounts of litter and duff had accumulated on the forest floor and an understory and subcanopy of white fir and incense-cedar had developed, creating ladder fuels [4].

Since study designs and plot sizes differed, effects of summer vs. fall fires on fuel loads cannot be compared. For summer plots, control and burned plots were compared, and litter and small woody fuel loads were combined. For fall plots, pre- and postfire fuels were compared.

Summer Fires

Fuel loads of control and postfire burned plots were assessed on the 4- x 4-foot microplots. Excepting logs >12 inches (30 cm) in diameter, dry biomass of fuels on control plots indicated a surface fuel load of 12 tons of fine and small woody fuels/acre (30 t/ha) and 36 tons of duff/acre (89 t/ha) for the giant sequoia-mixed-conifer forest [6]. Control and postfire fuel loads are shown in table 7.

Fall Fires

Biomass of duff, litter, and woody debris was assessed before and after fire, using 2- x 3-foot (0.7- x 0.9-m) sampling frames (*n* = 47 fuel samples). Within each frame, duff was measured in a 1-foot^2 (0.3-m^2) subframe. Woody debris >6 inches (15 cm) diameter was measured separately. To augment these measures, more widespread sampling was conducted at 33-foot (10-m) intervals along "several" transects. Fuel loads are shown in table 8 [4].

HISTORICAL FIRE REGIME

Giant sequoia-mixed-conifer forests historically experienced frequent, low- to moderate-intensity surface fires. Kilgore [7] stated that prior to fire exclusion in the early 1900s, large crown fires were "almost unknown".

Preliminary fire history studies in the Redwood Mountain Grove found historical (1778-1867) fire-return intervals in giant sequoia-mixed-conifer stands averaged 7 to 9 years and ranged from 4 to 20 years on 7- to 10-acre (2.8- to 4-ha) plots [8]. In the ponderosa pine mixed-conifer stand, they averaged 7 to 10 years [4, 8].

A later fire history study at Redwood Creek (a watershed on Redwood Mountain) found that historical (1700-1875) mean fire-return intervals in the giant sequoia-mixed-conifer forest ranged from 2 to 39 years. Sample sizes for this cover type were small (*n* = three 1-ha areas). On the southeast-facing slope, fire-return intervals averaged 14.9 years and ranged from 4 to 35 years. On the northwest- and northeast-facing slopes, fire-return intervals averaged 10.9 to 16.7 years and ranged from 2 to 39 years. For the ponderosa pine-mixed-conifer forest, fire-return intervals on the dry ridge averaged 5.5 years and ranged from 2 to 12 years. On the southeast-facing slope, fire-return intervals averaged 8.8 years and ranged from 2 to 23 years [8].

Fire-return intervals for giant sequoia-mixed-conifer forests at two sites at Bearskin Creek (a watershed nearby Redwood Mountain) averaged 14.9 years and ranged from 10.9 to 16.7 years. Intervals were similar between east- and northwest-facing slopes [8].

Combined, the study site at Redwood Creek and the two at Bearskin Creek covered about 4,500 acres (1,800 ha). Historically, this landscape apparently experienced a variety of fire sizes. From 1782 and 1858, there were three fires large enough to scar conifers on all three study sites. During the same period, moderate-sized fires burned an average of every 11.5 years at Redwood Creek and 8.9 years at

Bearskin Creek. From 1726 to 1881, small fires burned somewhere on the three study sites at average intervals of 3.5 years, and “spot” fires averaged intervals of 1.2 years. Small fires were classified as those burning 2.5 to 39.5 acres (1-16 ha) and scarring multiple single trees or multiple tree clusters in the drainage; spot fires were classified as those burning 0.002 to 2.5 acres (0.001-1.0 ha) and scarring only a single tree or a single tree cluster. Kilgore [8] rated fire intensity low to moderate.

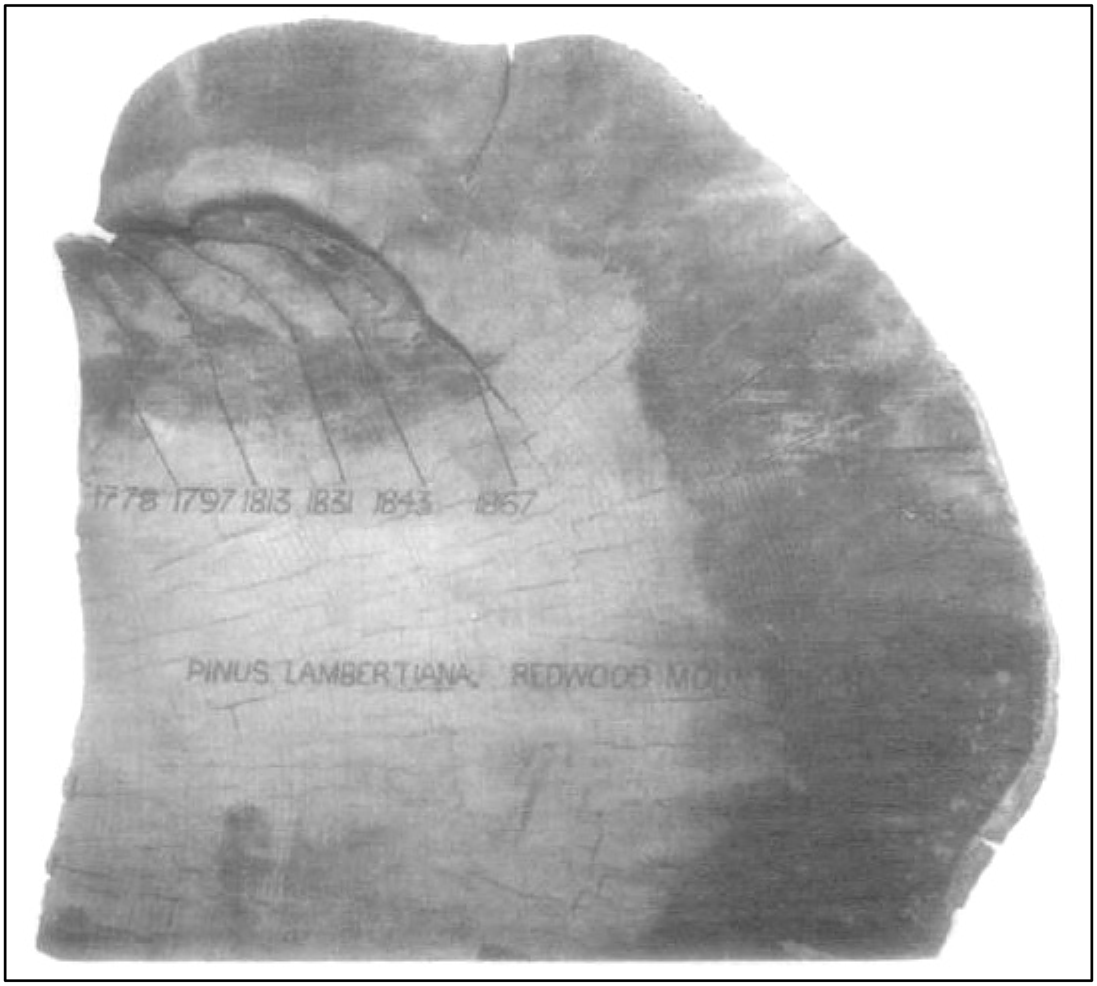

Figure 3—Fire frequency from 1778 to 1867 in the Redwood Mountain area of Kings Canyon National Park was determined from fire scars. Fires severe enough to scar this on this sugar pine stump occurred every 12 to 24 years. USDI, National Park Service photo by Dan Taylor [5].

LANDFIRE [9] classifies both giant sequoia-mixed-conifer and ponderosa pine-mixed-conifer communities in the Biophysical Setting listed in table 1. Their succession model for the mediterranean California dry-mesic mixed conifer forest and woodland Biophysical Setting applies to mixed-conifer forests in general, with and without giant sequoia [9]. Modeled historical fires severity and frequency value are shown below (table 1).

Table 1—Fire regime information for Sierran mixed-conifer communities. Fire regime characteristics are taken from the LANDFIRE Biophysical Setting Model [9]. This vegetation model was developed by local experts using available literature and expert opinion, as documented in the description of the Biophysical Setting Model listed below. Cells are blank where information was not available.

Vegetation Community (Biophysical Setting Model)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Mediterranean California dry-mesic mixed conifer forest and woodland (0510270)	Replacement	7	150		
	Mixed	30	35		
	Surface or low	63	17		

*Fire Severities:
Replacement=Any fire that causes greater than 75% top removal of a vegetation-fuel type, resulting in general replacement of existing vegetation; may or may not cause a lethal effect on the plants.
Mixed=Any fire burning more than 5% of an area that does not qualify as a replacement, surface, or low-severity fire; includes mosaic and other fires that are intermediate in effects.
Surface or low=Any fire that causes less than 25% upper layer replacement and/or removal in a vegetation-fuel class but burns 5% or more of the area [1, 10].

PLANT PHENOLOGY

At time of the summer fires, conifer cones were in the late stages of seed maturation. At time of the fall fires, conifer cones were dispersing seeds.

FIRE SEASON AND INTENSITY

Midsummer (19 August-11 September 1969), moderate to high intensity* [4, 6]
Late fall (23-24 November 1970), low intensity [4]

For the fall fire, a model [2] predicted a spread rate of 3.8 cm^2/sec for surface fire and a reaction intensity of 28.8 cal/cm^2/sec. After fire, the model predicted a spread rate of 0.05 cm^2/sec and a reaction intensity of 0.25 cal/cm^2/sec for the fall fires [7].

*Disclaimer: This study was initiated before the 1972 National Fire Danger Rating System was developed. Kilgore [4] estimated “probable fire intensity” based on fire-scarring patterns among overstory trees, usually sugar pines. Absence of any scarring on trees a short distance from scarred trees inferred low-intensity fire [8]. Fireline intensity was not measured.

FIRE DESCRIPTION

The objectives of these prescribed fires were to:

1) reduce fire hazard and chances of crown fire on Redwood Mountain by reducing surface fuels and shade-tolerant seedlings and saplings that form ladder fuels, and
2) create openings in the canopy and provide mineral soil seedbed for establishment of early-seral plant species, particularly giant sequoia, sugar pine, and understory shrubs [3, 4, 5, 6].

The long-term goal was to initiate a program of frequent prescribed fire that would ultimately restore historical stand structures and fire regimes in these forests [4].

The summer fires burned under drier weather conditions than the fall fires (tables 2 and 3).

Summer Fires

Fires were ignited on the ridgetop at noon [6]. Strip fires were used to increase fire spread and bring the fire downhill [4].

Table 2—Weather conditions for the summer fires. Data were only available for Sections 1 through 5 [4].

Variable	Range
Temperature (°F)	65-72
Relative humidity (%)	38-63
Wind (mph)	1-4
Fuel stick moisture (%)	9-10
Fine fuel moisture (%)	6-10
Spread index*	5-9
Ignition index*	11-49

*Indices from the California Wildland System (USDA Forest Service, unpublished document), not the National Fire Danger Rating System.

Fall Fires

Fires were ignited on 23 November at 9:00 am with a drip torch and burned downhill. To force uphill burning, 30- to 60-foot (9- to 18-m) strips were also ignited. The fires burned "briskly" from 9:00 am to 12:00. Ignition was discontinued at 13:00. Some unburned areas were reignited on 24 November. Rain, turning to snow, occurred on 25 November and ended the fire season. Postfire inspection found 80% of microplots burned almost completely; 14% burned partially or lightly [4].

Table 3—Actual and prescribed weather conditions for the fall fires [4]. Cells are blank where information was not provided.

Variable	Actual conditions on burning days	Range allowed under the fire prescription
Temperature (°F)	58	
Relative humidity (%)	20-38	
Wind (mph)	0	
Fuel stick moisture (%)	19	
Fine fuel moisture (%)	5	7-10
Spread index*	8	5-12
Ignition index*	55	15-49

*Indices from the California Wildland System (USDA Forest Service, unpublished document), not the National Fire danger Rating System.

Figure 4—The fall prescribed fire, approaching the bases of an understory white fir and an overstory giant sequoia. USDI, National Park Service photo by Bruce M. Kilgore [5].

FIRE EFFECTS ON PLANT COMMUNITY AND FUELS

Effects on Plant Community

Both summer and fall fires killed many shade-tolerant, young conifers. Air temperatures >250 °F (120 °C) at 6 feet (1.8 m) above ground—or temperatures >500 °F (260 °C) at trees bases—were sufficient to kill white firs and sugar pines <12 inches (30 cm) DBH. Generally, even fall fires produced temperatures >500 °F at tree bases [4]. Among plants species establishing after fire, giant sequoia and deerbrush established in highest numbers [4, 6].

Summer Fires

Summer fires charred some giant sequoias 50 feet (15 m) up the bole, and the convection column of heat killed needles on branches >100 feet (30 m) above ground on three giant sequoias [4]. Except for giant sequoia, data on damage and mortality of subcanopy and overstory trees were not provided.

Giant sequoia seedlings established in large numbers in postfire year 1. At that time, they averaged about 22,000/acre (54,000/ha). Through natural mortality, density of giant sequoia seedlings dropped to 2,614/acre (6,459/ha) in postfire year 2 and to 435/acre (1,077/ha) in postfire year 3 [5].

Highest establishment rates of giant sequoia seedlings were related to both parent tree density and fire intensity. Plot 3 had highest density of giant sequoia seedlings, with giant sequoia seedling densities exceeding 40,000/acre (99,000/ha) [3]. Fire intensity in the canopy and at the soil surface (soil temperatures based on Tempilaq® unit measurements) was highest on Plot 3 [6]. Convective heat dried out and opened giant sequoia cones >100 feet (30 m) above ground, contributing to heavy seedfall, and intense fire at the soil surface exposed more mineral soil on Plot 3 than on Plots 1 and 2 [3]. No giant sequoia seedlings occurred on control plots (table 4) [6]. A few white firs established on burned plots [6].

Deerbrush was the most common shrub seedling on burned plots, and it established in highest numbers where fire intensity was lowest (Plot 1). Littleleaf ceanothus and greenleaf manzanita seedlings also established on burn plots. No shrub seedlings occurred on control plots (table 4) [6]. Severe fire (Plot 3) apparently killed many shrub seeds in the soil seed bank [3], while less severe fires scarified the seed coats, removing seed dormancy and allowing germination to occur [3, 6].

Sedges were present and increasing in number in postfire year 1 [4].

Table 4—Mean densities of giant sequoia and deerbrush on control and thin-and-summer-burned plots. Data were collected in postfire year 1 [6].

Plot #	Plot size (acres)	Mature giant sequoias[a]		Giant sequoia seedlings		Deerbrush seedlings	
		#/plot	#/acre	#/transect	#/acre	#/transect	#/acre
Unburned control plot	5.30	31	5.8	0	0	0	0
Burned plots							
Plot 1	3.75	11	2.9	138	7,514	120	6,534
Plot 2	6.10	28	4.6	337	18,350	53	2,886
Plot 3	6.25	58	9.3	737	40,130	4	218

[a]Trees >6 feet DBH.

Fall Fires

The fall fires increased the relative densities of giant sequoia and sugar pine compared to white fir. Relative density of ponderosa pine remained about the same before and after the fires. The fires greatly increased density of the shrub layer. The fires killed about 87% of the sapling size class (stems 6 in-29 ft (15 cm-9 m) tall), reducing density from 1,348 to 172 saplings/acre (3,330 to 425/ha). The fire killed about 60% of 6- to 12-inch (15-30 cm) DBH conifers. Most were white fir; the relative proportion of white firs to sugar pines in that size class remained about the same before and after fire (table 5). Some 6- to 12-inch DBH trees survived through postfire year 1 but died in postfire year 2 [4]. Only one conifer

>12 inches DBH was killed: a 17-inch (43-cm) DBH white fir. Overall, the relative density of conifers of all size classes shifted from 88% white fir and 11% sugar pine before fire to 65% white fir and 30% sugar pine after. In contrast to the summer prescribed fires, no conifer seedlings were detected in postfire year 1 after fall prescribed fires (table 5). Kilgore [4] speculated that lack of conifer seedling establishment after the fall fires was because of snowfall immediately after the fires, which prevented conifer seeds from reaching mineral soil. Alternatively, the seeds could have dispersed prior to the fires, with fire killing the seeds.

Table 5—Conifer density before and after late fall prescribed fire. Data are means [4].

	Prefire		Postfire year 1	
Size class and species	Number/acre	Relative density (%)	Number/acre	Relative density (%)
<6” DBH				
white fir	1,210.0	89.7	103.7	60.0
sugar pine	138.3	10.3	69.1	40.0
ponderosa pine	0	0	0	0
giant sequoia	0	0	0	0
6” to 12” DBH				
white fir	93.3	84.1	57.0	82.1
ponderosa pine	0	0	0	0
giant sequoia	0	0	0	0
>12” DBH				
white fir	21.8	55.3	20.7	54.0
sugar pine	3.1	7.9	3.1	8.1
ponderosa pine	3.1	7.9	3.1	8.1
giant sequoia	11.4	28.9	11.4	29.8
Totals: All size classes				
white fir	1,325.1	88.4	181.4	64.7
sugar pine	159.0	10.6	84.6	30.2
ponderosa pine	3.1	0.2	3.1	1.1
giant sequoia	11.4	0.8	11.4	4.0
Grand totals	1,498.6	100	280.5	100

Before the fall fires, cover of understory trees and shrubs 1 to 12 feet (0.3-3.6 m) tall was about 35%. In postfire year 1, their cover was <16%. Cover of shrubs and herbs in postfire year 1 was negligible: the only herbaceous species with >1% cover was a moss [4]. Shrubs were increasing in frequency, however (table 6) [4]. Density of deerbrush seedlings decreased over the study period. In postfire year 1, density of deerbrush seedlings averaged 3,213/acre (7,939/ha); by postfire year 3, it had dropped to 200/acre (494/ha). Overall frequency of forbs was higher on burned than on control plots (table 6) [5].

Table 6—Frequency (%) of understory species on 2- x 3-foot microplots before and 1 year after fall prescribed fire. Data are means; *n* = 210 microplots on 7 burned plots and 150 microplots on 5 control plots [4].

Species	Thin-and-fall-burned plots		Unburned control plots	
	Prefire	Postfire year 1	Prefire	Postfire year 1
Shrubs				
deerbrush	0	4.3	0	0
greenleaf manzanita	0	1.4	0	0
littleleaf ceanothus	0	6.2	0	0
mountain misery	1.0	0	0	0
rose	0	0	0.7	0.7
sharpleaf snowberry	0	0	4.7	2.7
Sierra gooseberry	0.5	4.3	0	0
Graminoids				
sedges	0	0	0	0.7
unidentified grass	0	0	0.7	0
Forbs				
bedstraw	0.5	0	1.3	0.7
drops-of-gold	0.5	0	4.0	3.3
slender-spire orchid	0	0	0.7	0
summer coralroot	0.5	0	0.7	0.7
sweetcicely	0	0	0.7	0
tall fringed bluebells	0.5	0	2.7	1.3
violet draperia	2.4	5.2	0.7	0.7
western rattlesnake plantain	4.3	0	4.0	1.3
white hawkweed	0	0	1.3	1.3
whiteveined wintergreen	5.7	1.0	2.0	0.7
Mosses				
unidentified moss	0	2.4	0	0

Effects on Fuels

Postfire sampling in 1971 showed the summer burn had fewer surface fuels and a lighter overall fuel load than the fall burn, even though the summer burn had an additional year to accumulate fuels. Potential for crown or severe surface fire was less on the summer than the fall burns because the summer fires burned live branches to greater heights, killed more trees in the 1- to 24-inch (2.5-61 cm) DBH class, and completely consumed surface fuels. By killing more understory conifers and consuming more litter and duff, the summer fires created a more favorable seedbed for shade-intolerant conifers than the fall fires [4].

However, Kilgore [4] stated that the summer fires were at the upper margin of acceptable intensity. A slightly more intense fire might have killed some giant sequoias.

Summer Fires

Summer fires reduced surface fuel loads by 80% compared to fuel loads on control plots [6]. Where logs burned for many hours, soil temperature surface (based on Tempilaq® units) often reached 750 ^{o}F (440 ^{o}C) [3].

Table 7— Mean fuel loads on control and thin-and-summer-burned plots in postfire year 1 [6].

Fuel class	Control[a]	Burned
Duff	36 tons/acre	7.5 tons/acre
Fine and small woody fuels	12 tons/ha	2 tons/acre

[a]Fuels on control plots were measured after thinning.

Fall Fires

The fall fires also reduced surface (table 8a) and crown (table 8b) fuel loads. For surface fuels, litter was reduced by >75% and duff by >85%. Most twigs and branches <1 inch (2.5 cm) in diameter were consumed, but because of postfire downfall, postfire loads of fine and small woody fuels were similar to prefire fuel loads postfire year 1. Fuel loads of logs and branches >6 inches (15 cm) diameter were reduced by 45% to 95% on most plots. Biomass of logs was reduced from about 12.8 tons/acre to about 2.8 tons/acre (29 to 6 t/ha) [4]. For crown fuels, live crown fuels in the lower canopy were reduced by more than half, and the base of the live fuel complex was raised an average of 13 feet (4 m) [7].

Table 8a—Mean surface fuel loads on burn plots before and after fall fires [4].

Fuel class	Prefire	Postfire year 1
Duff and litter	>50 tons/acre	7.7 tons/acre
Depth of litter and duff	3.10 inches	0.51 inch
Depth of twigs and branches	2.01 inches	0.68 inch
Woody fuel cover (%)		
<1-inch diameter branches	34.98	27.91
1- to 3-inch diameter branches	6.59	3.01
3- to 6-inch diameter branches	4.21	0.90

Table 8b—Mean crown fuel loads on burn plots before and after fall fires [7].

Characteristic	Prefire	Postfire year 1
Crown live weight	7.2 tons/acre	3.1 tons/acre
Crown volume ratio (CVR)*	108	142
Crown base height	3.0 feet	16.0 feet

*CVR is a complex measure of stand density depending on size and spacing of individual trees; it is not a direct measure of fuel quantity. Increases in CVR indicate a lowering of crown fire potential [7, 12].

FIRE MANAGEMENT IMPLICATIONS

These fires successfully reduced surface and ladder fuel loads; exposed mineral soil by reducing litter and duff; and killed many shade-tolerant seedlings and saplings in the understory. Prior to these prescribed fires, the litter and duff layers alone had >50 tons/acre (112 t/ha) of surface fuels. The fall fires in particular successfully reduced fuel loads, to 7.7 tons/acre (16 t/ha) or an 85% reduction. The number of shade-tolerant seedlings and saplings in the understory was greatly reduced by the summer thin-and-burn and fall burn treatments. In turn, this reduced the chances of crown or severe surface fire by reducing surface and ladder fuels. Decreased density of the understory and exposure of mineral soil promoted establishment of giant sequoia and shrub seedlings. Heat from moderately intense fire promoted rapid drying and opening of giant sequoia cones, while less intense fire scarified seed coats of shrub species [3]. The summer and fall fires killed few mature white firs or other shade-tolerant species in the subcanopy [7].

Results of these studies may apply to Sierran mixed-conifer forests of similar stand structure and plant species composition. A 2017 review reports similar build-up of surface and ladder fuels and loss of shrub and herbaceous cover on similar sites in Sequoia National Park and the southern Sierra Nevada [11].

Fuels

Kilgore [4] suggested that under fire weather and fuel conditions similar to those of the more intense summer fire, follow-up prescribed fire would likely be needed in 7 to 10 years. Intensity of the second fire could be less, with the objective of removing surface fuels that accumulated since the first prescribed fire. Under conditions similar to those of the less intense fall fire, he suggested conducting two prescribed fires in closer sequence, to kill shade-tolerant saplings and consume large woody debris more gradually. Under the fall fire scenario, the objective of the first fire would be to kill understory conifers <15 feet (4.5 m) tall. The second fire could be slightly more intense, with the objective of killing understory conifers 12 to 24 inches (30-61 cm) DBH and creating openings in the canopy [4]. Follow-up fire treatments every 10 to 20 years—depending on overstory species and fire history—can maintain stand structure and keep surface fuel levels low [3, 4].

Plant Community

In this study, an initial moderate- to high-intensity fire followed by low-intensity fire reduced the shrub layer more than two consecutive low-intensity fires. For shrubs with fire-stimulated germination—such as deerbrush, littleleaf ceanothus, and greenleaf manzanita—an initial intense fire may stimulate germination of most of their soil-stored seeds. If a second fire is conducted before the seedlings have matured enough to produce substantial amounts of seed, the second fire may kill the seedlings before the soil seed bank is replenished [4].

Restoration of historical stand structure and fire regimes is needed to preserve giant sequoia groves in the long term. Kilgore [3] concluded that these prescribed fires set back succession and promoted giant sequoia establishment in a “modest way” by killing white fir seedlings and saplings in the understory. He cautioned that the changes prescribed fires enacted were not equal to what frequent wildfire would have accomplished in a natural fire regime, but he stated that frequent prescribed fire "seems to be about the only way to get the job done efficiently and completely" [3]. He suggested allowing lightning-ignited wildfires to burn in Sierran mixed-conifer communities once current stand structure is more aligned with presettlement stand structure [5].

Sequoia-Kings Canyon National Park has continued their fire and fuels management program in giant sequoia- and ponderosa pine-mixed-conifer forests. In 2016, for example, 1,177 acres (476 ha) of the Grant Grove area were treated with prescribed fire and/or mechanical fuels treatments. See their Fire in the Parks website for details.

APPENDIX: PLANT NAMES

This Research Project Summary contains fire effects and/or fire response information on the following species. For further information, follow the highlighted links to FEIS Species Reviews.

Common name	Scientific name
Trees	
California black oak	*Quercus kelloggii*
giant sequoia	*Sequoiadendron giganteum*
incense-cedar	*Calocedrus decurrens*
ponderosa pine	*Pinus ponderosa* var. *ponderosa*
sugar pine	*Pinus lambertiana*
white fir	*Abies concolor*
Shrubs	
deerbrush	*Ceanothus integerrimus*
greenleaf manzanita	*Arctostaphylos patula*
littleleaf ceanothus	*Ceanothus parvifolius*
mountain misery	*Chamaebatia foliolosa*
rose	*Rosa* spp.
sharpleaf snowberry	*Symphoricarpos acutus*
Sierra gooseberry	*Ribes roezlii*
Graminoids	
sedges	*Carex* spp.
Forbs	
bedstraw	*Galium* spp.
drops-of-gold	*Prosartes hookeri* var. *hookeri (Disporum hookeri)*[a]
slender-spire orchid	*Piperia unalascensis (Habenaria unalascensis)*
summer coralroot	*Corallorhiza maculata*

sweetcicely	*Osmorhiza berteroi (Osmorhiza chilensis)*
tall fringed bluebells	*Mertensia ciliata*
violet draperia	*Draperia systyla*
western rattlesnake plantain	*Goodyera oblongifolia*
white hawkweed	*Hieracium albiflorum*
whiteveined wintergreen	*Pyrola picta*
[a]For species that have undergone scientific name changes, names in parentheses are those used in Kilgore's [4] research paper.	

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