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FIRE HISTORY OF A SEQUOIA-MIXED CONIFER FOREST[1]

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Abstract. Data on the years in which fires burned, on fire frequency, and on intensity and areal extent of fires were gathered from 935 scars on 220 stumps of mixed conifer forest species in an 1800ha-study area in the Sierra Nevada, California, USA. Before 1875, fires scarred clusters of living trees every 9 yr on west-facing slopes at Redwood Mountain and every 16 yr on east-facing slopes. Mean fire-free intervals between 1700 and 1875 varied by habitat phase from 5 yr in ponderosa pine on a dry ridge to 15-18 yr in more moist sites with white fir. For most 1-ha sites, the maximum time without fire was 14-28 yr.

From 1700 to 1875, fires of various sizes were found every 2-3 yr somewhere in a given drainage (not necessarily the same site) and every 5-9 yr in 3to 16-ha sites. This compares with fires every 8-18 yr in 1-ha clusters and every 11-39 yr on individual trees. Scar records of pre-1700 fires suggest intervals fairly comparable to those from 1700 to 1875. Evidence of fires diminished greatly after Indian burning was eliminated in the early 1870's, and such fire records became almost nonexistent after 1900, when fire suppression became more effective.

Most of the pre-1875 fires were small and of low intensity. Even the larger fires were usually confined to 1 slope or 1 drainage area. The short mean intervals between fires suggest that pre-1875 mixed conifer forests did not usually have heavy accumulations of litter or dense thickets of understory trees. Instead, small-acreage, low-intensity surface fires must have consumed accumulated litter at frequent intervals and at the same time killed most of the conifer regeneration which had become established since previous fires. Such frequent fires would have led to an intricate mosaic of age classes and vegetation subtypes which, in turn, insured that a subsequent fire would not burn large areas with great intensity. Intense fires which moved from crown to crown were absent in the study area for the past 400 to 2000 yr. If frequency of lightning ignition of fires over the past 50 yr is typical, ignitions by Indians must have augmented lightning-caused fires to yield the pre-1865 frequency of fires in the Sierra mixed conifer forest. Since 1900, the lack of frequent, low-intensity fires has resulted in a major increase in understory forest and fuels.

Key words: California; fire frequency; fire history, fire intensity; Indian burning; mixed conifer forest; Pinus ponderosa*;* Sequoiadendron giganteum*.*

INTRODUCTION

Fire has been a significant ecological force in the coniferous forests of the Sierra Nevada and particularly in the giant sequoia-mixed conifer forest (Hartesveldt 1964, Hartesveldt and Harvey 1967, Kilgore and Biswell 1971, Kilgore 1973a, b). Little is known, however, about the frequency, intensity, and areal extent of individual fires in these forest types.

Previous studies have described fire frequency in ponderosa pine forest (Weaver 1951, 1959, Cooper 1960, Soeriaatmadja 1966). Other authors have made general statements about fire incidence in Sierra Nevada coniferous forests (Boyce 1920, Show and Kotok 1924). These latter studies, conducted in central and northern California, failed to adequately describe the study sites; even information on aspect or exposure is lacking. Wagener (1961) reexamined the basal fire scar data from these earlier studies and drew general conclusions about fire origin, behavior, and frequency. Our study attempts to determine specifically the dates, frequency, intensity, and areal extent of past fires in a sequoia-mixed conifer forest. Probable ignition sources are also discussed. These investigations were conducted in Sequoia and Kings Canyon National Parks, California, USA, and on adjacent National Forest lands while the senior author was assigned as the parks' research bio1ogist and the junior author as a forest research technician. This research is a contribution from the natural science research program of the National Park Service between 1970 and 1972.

STUDY AREA

The study area covered =1800 ha of sequoia-mixed conifer forest in contiguous parts of 2 different drainage basins (Fig. 1). The northern portion, in the Sequoia National Forest, covered 770 ha of the Bearskin and Tenmile Creek drainages and included the small Bearskin Grove of giant sequoia *(Sequoiadendron giganteum).* These creeks are tributaries of the Kings River. The southern portion, in Kings Canyon National Park, covered 1030 ha of the Redwood Creek drainage and included much of the Redwood Mountain Grove of giant sequoia. This creek is a tributary of the Kaweah River. The 2 drainage basins are separated by a topographic divide which extends into the lower margin of the higher-elevation, red fir – Jeffrey pine type. A narrow band of this different forest type, or in some places an outcrop of bare granite, separates the 2 areas of sequoia-mixed conifer forest. Fires recorded in these 2 drainages were thus separated by different or discontinuous fuels.

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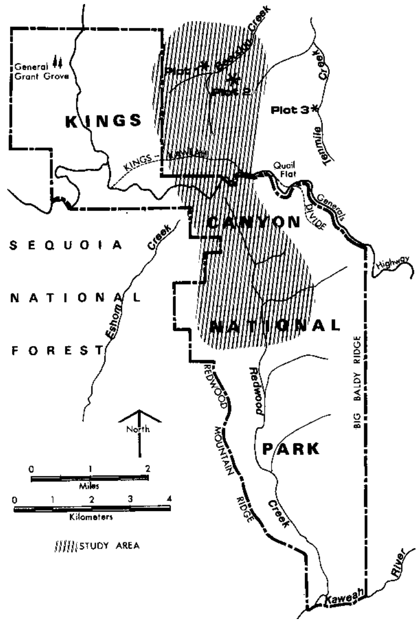

FIG. 1. Map of study area location, 80 km east of Fresno, California, USA


FIG. 2. Dense understory of white fir and incense cedar Canyon National Park, California beneath giant sequoia at Redwood Mountain, King

The Redwood Mountain Grove of giant sequoia is the largest of all giant sequoia groves, covering =1215 ha. It is situated on the west slope of the southern Sierra Nevada at elevations of 1700 to 2100 m. Usual associates with giant sequoia are white fir *(Abies concolor)* and sugar pine *(Pinus lambertiana)* (Fig. 2). On relatively dry sites, incense cedar *(Calocedrus decurrens)* and ponderosa pine *(Pinus ponderosa)* are associates. The latter is the dominant tree species in the zone below the sequoia – mixed conifer; red fir *(Abies magnifica)* and Jefferey pine *(Pinus jeffreyi)* are dominant in the zone above. There is great diversity in the mixed conifer forest, ranging from a relatively dry phase dominated by ponderosa pine with manzanita *(Arctostaphylos patula* or *Arctostaphylos viscida)* as an undergrowth component through several gradually more moist phases to a phase composed entirely of white fir.

The Sierra Nevada has a warm, dry summer and cool, wet winter climate, with precipitation mostly as snow. The 3to 4-mo summer drought period is usually interrupted by several pulsations of thundershower activity which are accompanied by lightning discharges. These often result in many ignitions. Since the early 1900's, man's suppression of lightning fires has interfered with natural processes which affect plant succession (Kilgore 1973b).

METHODS

Living trees of many coniferous species operate as "recorders" of fires. When such trees are injured but not killed by fire, the healing process leaves accurate records as fire scars. Young trees are killed by even low-intensity fires while older trees may have thick bark which protects the cambium from being killed by most surface fires; no record is left either way. The tree's age, size, and species, and the intensity of the fire near the base of the tree determine whether an initial scar will be made. Once initial scarring takes place, the tree acts as a more sensitive recorder of later fires. The dating of scars, the intervals between scars, the geographical distribution of scarred trees in a given year, and the relationship between scarred and unscarred trees furnish data on fire dates, frequencies, areal extent, and probable intensity.

FIG. 3. Fire frequency is clearly documented by these fire scars on a sugar pine stump from Redwood Mountain.

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We examined fire scars and tree rings on 220 stumps. The sites chosen for data collection were determined by topographic exposure and availability of stumps. There were relatively few stumps in the Redwood Creek section because tree cutting is generally prohibited in a national park. The Bearskin Creek section in Sequoia National Forest had an abundance of available stumps due to a Forest Service timber sale in 1970 and 1971.

From 1970 to 1972, we made intensive surveys of 3 recently logged areas on these national forest lands. These were:
Plot 1: a 5.7-ha east-exposure site north of Bearskin Creek (Fig. 1),
Plot 2: a 16.2-ha northwest-exposure site south of Bearskin Creek, near Bearskin Grove,
Plot 3: a 3.2-ha northeast-exposure site west of Tenmile Creek near Lower Bauman's Cow Camp.

We gathered detailed information from 153 firescarred stumps on these plots. On the 2 smaller plots, we recorded data from 64 unscarred stumps. The absence of any scarring on trees present a short distance from scarred trees at the time of a given fire helped to interpret the probable intensity of that fire. Information on fire frequency, size, and intensity on these 3to 16-ha units was then used to interpret information gathered from more isolated stumps or clusters of stumps found throughout the entire study area. For the broader survey of fire scar dates, we used all available stumps in the Redwood Mountain Grove and selected multiscarred stumps outside the logged plots in the Bearskin Creek drainage.

Each scarred stump was inventoried, marked, measured, aged, and recorded on a topographic map. Scars were dated using methods and principles noted by Weaver (1951), Wagener (1961), and Heinselman (1973). Intervals between scars were cross-checked with intervals on nearby stumps. Slabs from stumps containing a relatively complete series of scars (Fig. 3) were carefully examined in the laboratory using a binocular microscope. Based on these model stumps, a master chronology (Table 1) was developed, using the technique summarized by Arno and Sneck (1977).

To determine fire dates, we first counted annual growth rings on a stump surface from an outer ring with known date (usually recent logging) to the ring which formed the earliest healing tissue on each scar. We next made the assumption that most fires burned in July to September, after the primary radial growth had been completed for the year (Fowells 1965). The first healing ring would have been added the year after the fire. Errors of 1 or 2 yr may occur in the date assigned to any particular fire scar or scar series (Wagener 1961, Houston 1973). Considering all variables and sources of possible error, we recorded only those fires for which we had good evidence. Thus, our records represent a conservative estimate of the number of fires.

The interval between fires is simply the time in years between successive fires. Such an interval may be expressed as fire frequency or as fire incidence. Frequency is technically the number of events per unit time; in this case, it would mean number of times per century that fire returns to a single point or to the same small piece of ground. "Frequency" is used here to mean interval between fires on the same piece of ground and was calculated from records found on a single tree or a cluster of trees growing fairly close together. Fire incidence, however, was the interval between fires which burned some place in a particular sized unit of the forest, such as a drainage, but not necessarily involving the same point. Frequency, therefore, reflects fuel, climatic, and ignition factors inherent in the ecosystem or forest type, while fire incidence is also related in a major way to size of area being observed. For fire incidence, obviously, the larger the unit, the greater the number of fires and the shorter the interval between them.

We obtained our most meaningful data on frequency by use of small clusters of trees. Out of the 37 stumps examined in the Redwood Creek drainage area, there were 28 stumps with 4 or more scars per stump. Eighteen of these stumps were grouped into 4 logical clusters, each of which has 4 to 6 stumps growing within 25 to 100 m of each other. Eight similar clusters were established for the 3 logged sites in the Bearskin Creek drainage. All trees in a cluster were used to establish the chronology for that location and slope exposure. Usually 1 or 2 trees in any cluster were the best recorders and registered most of the total scar record; the neighboring trees often added a few more dates that either extended the record in time or added a fire date. Thus a group of 2 to 6 trees usually provided a more complete fire frequency record than any single stump by itself (as in Houston 1973).

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TABLE 1. Master fire chronology for study area, showing the number of sample trees scarred during each fire year in the 6 geographic units from 1597 to 1970[a]

	Scars (N)							
	Redwood Creek		Bearskin Creek					
Year	W	E	Plot 1	Plot 2	Plot 3	Extensive	Total	Size[c] burn
	(12)[b]	(23)	(58)	(77)	(18)	(30)		
1597			2				2	
1615			2				2	
1632				2			2	
1654				2			2	
1661				3			3	
1673			2				2	
1675				2			2	
1677			3				3	
1693				2			2	
1696						3	3	
1703			2				2	
1705	2			1			3	
1709	3						3	
1711			3				3	
1719	1		3				4	
1726	4	1				2	7	
1728			2				2	
1730	3						3	
1732		2	1				3	
1733				6			6	
1737		1	5			2	8	
1741	2						2	
1747			3			2	5	
1750				4			4	
1752	5						5	
1756			10			2	12	
1759	2	1		1			4	
1763				4		1	5	
1765	5			2			7	
1768		1				4	5	
1772	4		1	2	3		10	
1778	1	3					4	
1779			3				3	
1782	5		9	13		1	28	D
1783		3			1	2	6	
1785	2	1			2	3	8	
1787		1	4			1	6	
1789			1	4		3	8	
1792	6		1			1	8	
1795		2	16	10		2	30	D
1797	8	9			8		25	
1798				4		3	7	C(bs)
1799						5	5	
1801				4			4	
1808		3				2	5	
1809	9						9	
1811		2					2	
1814		5	11	4		7	27	D
1815						4	4	
1816					6	2	8	
1819	2	1				1	4	
1820			2			1	3	
1821					5		5	
1829				26			26	C(bs)
1830			23		1	7	31	
1831	11	12					23	C(rc)
1832					1	4	5	
1835		3		4		7	14	C(bs)
1841			9				9	
1842					9		9	
1843	9	14					23	C(rc)
1844				14		4	18	C(bs)
1845						6	6	
1852						5	5	
1856			5			4	9	C(bs)

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TABLE 1 (CONTINUED)

Year	Scars (N) Redwood Creek W	E	Bearskin Creek Plot 1	Plot 2	Plot 3	Extensive	Total	Size[c] burn
1858	11			38			49	D
1859			20				20	
1860				15		4	19	C(bs)
1863			1			4	5	
1865				4			4	
1866		16					16	C(rc)
1871			17	2		5	24	C(bs)
1872		1			16		17	
1873	9						9	C(rc)
1874		4				5	9	
1875			1	3			4	
1877				2			2	
1881		2		4		2	8	
1888				2		1	3	
1893				3		1	4	
1898		2					2	
1939				2			2	

[a] Two or more stumps contained a scar record in at least one unit before the date was included in this table.
[b] Number of sample trees in parenthesis.
[c] Larger sized fires occurred in years in bold type. D = multi-drainage fire; C = drainage-wide fire; bs = Bearskin Creek drainage; rc = Redwood Creek drainage. See text for detailed treatment of size of fires.

Confidence limits were calculated for the drainage wide fire incidence figures (Table 2). Data were transformed to natural logarithms to assure normality and retransformed to produce the confidence limits shown (Brownlee 1965).

The scar data were reviewed for evidence on the size of area covered by fires before Anglo-man arrived. Four categories evolved based on the minimum size of fire represented by the scars for a given year:

Spot fire.– Recorded only by a single tree or a single cluster of trees; ranged in size from 0.001 to 1 ha.

Small fire.– Recorded throughout 1 of the Bearskin drainage plots or from several clusters in Redwood Mountain; ranged from 1 to 16 ha.

Moderate-sized fire.– Recorded on several Bearskin plots and in the extensive Bearskin survey or on both the east and west-facing Redwood Mountain sites; ranged from 16 to 800 ha.

Large fire.– Recorded in both the Bearskin Creek drainage and in the Redwood Creek drainage in a given year; ranged from 800 to 2000 ha or more.

In evaluating the scar record for intensity information, we made 2 assumptions about how our 220 recorder trees were affected by fire: (1) At =50 yr of age, mixed conifer forest species appear to record moderately intense surface fire without being killed. This assumption is based on how these species grow, the age and size of 64 study trees when they were first scarred, and the results of experimental fires of different intensities in this area (Kilgore 1973a). Intensity and thus impact varies with amount and kind of fuel found at the base of a tree and with weather conditions which vary both seasonally and from day to night. (2) Once the initial scar had been made, the tree (having an exposed wound) was more sensitive to scarring even by subsequent low-intensity fires. This is partly due to the thinness of bark covering previous wounds (Gill 1974). In addition, resin or pitch found on a pine catface provides fuel for the next fire which comes near the base of the tree (Lachmund 1921) and encourages burning which can lead to another scar.

RESULTS

We found fire scars on stumps in every part of the study area. While all 6 coniferous species showed scars, pines generally yielded the best fire records. Incense cedar occasionally provided good sequence records, and because some individual trees were older than 600 yr, this species usually yielded the oldest scars and scar series. Firs were least valuable as recorders of past fires. Sequoia stumps were not used in the quantitative part of this study because of the special difficulties involved in data gathering (see Discussion).

Since our study area included much of the elevational range of mixed conifer forest from 1700 to 2200 m elevation, we were able to observe that the abundance of fire scars varied considerably among forest types. The upper elevation red fir – Jeffrey pine type yielded very few fire scars relative to the abundance of stumps. The lower elevation ponderosa pine type showed a much higher frequency of fire scars. Lightning is known to ignite fuels frequently in both types. We estimated that =20 to 25% of the stumps in the red fir type had fire scars and of these, <5% had 2 or more scars. In the mixed conifer type, 65~o of the stumps on Plot 1 and 38% of those on Plot 3 were scarred and the majority of these had 2 or more scars. While we worked only briefly in lower-elevation ponderosa pine, it appeared that well over 50% of the trees had been scarred by fire. The proportion of scars in these different forest types appeared to be a function of natural fuel buildup near the base of trees and general species susceptibility to scarring. It also seemed to reflect the kind of natural variations in fire history between types noted by Mutch (1970).

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The quality of data varied among the 220 stumps. Some had only 1 or 2 scars or had decayed wound areas which made the exact dates and intervals less precise. Others were sound and had several scars (some as many as 12 to 24) and provided nearly ideal conditions for determining intervals between fires. Ninety-six stumps had 4 or more scars, thus yielding a minimum of 3 intervals per stump. Great reliance was placed on these multiple-scarred specimens and particularly the clusters of such specimens in determining both dates of fires and intervals between fires.

TABLE 2. Mean interval between fires in various sized units in the Redwood and Bearskin Creek Drainages, 1700–1875

	Redwood Creek				Bearskin Creek			
			Interval in Years				Interval in Years	
Size of unit	Subunit	N^a	95% Confidence Limits	$\bar{x}$	Subunit	N^a	95% Confidence Limits	$\bar{x}$
Whole Drainage (777 to 1036 ha)		37	1.73–2.35	2.1		183	1.55–1.86	1.7
Logged sites (3.2 to 16.2 ha)					Plot 1	58		5.1
					Plot 2	77		5.9
					Plot 3	18		8.6
			Range				Range	
Cluster of trees (0.4 to 0.8 ha)	SW-facing	2/10	8.4–10.0	9.2	Plot 1	4/21	10.9–15.5	12.9
	SE-facing	2/8	14.9–17.8	16.4	Plot 2	3/13	14.1–16.1	15.0
			$\bar{x}$	12.8	Plot 3	1/2	...	16.7
					$\bar{x}$			14.9
			Range				Range	
Individual trees (10–50 m²)	SW-facing	9	11.0–16.0	12.8	Plot 1	17	14.0–38.6	24.3
	SE-facing	5	17.6–29.3	21.8	Plot 2	16	15.2–31.2	23.0
			$\bar{x}$	17.3	Plot 3	7	15.0–25.8	20.8
							$\bar{x}$	22.7

[a] The numerator in the N column under clusters shows the number of clusters, while the denominator shows total number of stumps involved in the clusters.

Fire chronology

Fire dates from the 220 stumps in the 2 drainages ranged from 1478 to 1939. While there were a scattering of dates from the 1500's and 1600's, the scar records are more numerous from ~1700 to 1875. After 1875, fire-scar evidence declined abruptly and is nearly absent after 1900. The master fire chronology for the study 'area is shown in Table 1. This chronology – from 1597 to 1939 – contains 81 fire dates selected because 2 or more stumps in the same geographic unit recorded a fire for those particular years. Some of those dates were found on >1 of our study sites. More often, however, different patterns were found in the Redwood Mountain and Bearskin Creek areas. The fewer numbers of scars before 1700 are mostly a reflection of the natural life span of the tree species involved. Only, trees older than 300 yr could have recorded fires in the 1600's, and only trees more than 400 yr old in the 1500's. Of the 220 recorder trees, only 43 were living in the 1500's and 104 were living in the 1600's. Incense cedars in Plot 1 made up the bulk of the trees in the oldest age group.

TABLE 4. Fire frequency in years (from cluster data) by historical time periods in various geographic units

	1500–1699[a]		1700–1799		1800–1875		1876–1899[b]		1900–1971[b]	
Geographic unit	N^c	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$
Redwood Creek										
SW-facing	1/1	10.2	2/10	8.0	2/10	11.8	2/10	...	2/10	...
SE-facing	...	...	2/8	14.3	2/8	20.1	2/8	...	2/8	...
$\bar{x}$	...	...	...	11.2	...	16.0	...	...	...	
Bearskin Creek										
Plot 1	1/2	12.6	4/21	10.4	4/21	14.0	4/21	...	4/21	...
Plot 2	...	...	3/13	16.1	3/13	14.2	3/13	...	3/13	...
Plot 3	...	...	1/2	12.5	1/2	18.8	1/2	...	1/2	...
$\bar{x}$	...	...	...	13.0	...	15.7	...	...	...	...
Both Areas										
Totals	2/3		12/54		12/54		12/54	...	12/54	
$\bar{x}$		11.4		12.1		15.9		...		...

[a] These data are not as complete as the 1700 to 1971 data. They are based on minimal records obtained from the relatively few trees which recorded pre-1700 fires, usually a few older incense cedar or sugar pine.

[b] Post-1875 scar dates were spotty, from a few isolated trees, and were apparently the result of a number of small fires. See text for comment.

[c] The numerator in the N column shows the number of clusters, while the denominator shows total number of stumps involved in the clusters.

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Intervals between fires

The variations in fire behavior in a sequoia-mixed conifer forest (Kilgore and Sando 1975) suggest that measurements leading to any single mean time interval between fires would be misleading. Instead we chose to describe the variations in intervals in 6 ways: (1) fire frequency by exposure, (2) fire frequency in different habitat phases of the mixed conifer forest, (3) fire frequency during various historical time periods, (4) incidence of fires in various-sized units of the forest, (5) incidence of fires of different sizes, and (6) incidence of fires of different intensities.

Frequency by exposure. – Data from the clusters of trees (Table 2) indicate a mean fire frequency on southwest-facing slopes at Redwood Creek of 9.2 yr, which contrasts sharply with 16.4 yr for the southeast facing slopes. Cluster chronologies from the generally north-flowing Bearskin Creek drainage reveal that frequency between fires ranged from 10.9 to 16.7 yr, with a mean of 14.9 yr. No sharp contrast was found in the Bearskin Creek drainage between the generally east facing Plot 1 and the generally northwest-facing Plot 2. The east-exposure site, however, was a fairly flat situation with incense cedar as a significant component; hence, this was not a typical, more-moist site.

Fire-free intervals for the individual mixed-conifer forest clusters ranged-from 3 to 22 yr on the southwest-facing slope and from 4 to 35 yr on the southeast-facing slope of Redwood Creek and from 2 to 39 yr in Bearskin Creek. Mean frequencies for all the clusters ranged from 8 to 18 yr (Table 3). Thus, between 1700 and 1875, in sites <0.8 ha in size, in a sequoia-mixed conifer forest, the maximum time without fire was 39 yr, but the majority of clusters show a maximum fire-free interval of 14-28 yr.

TABLE 3. Fire frequency (from cluster data) for 1700–1875 by habitat types and phases

Habitat types and phases	Trees in cluster (N)	Cluster Intervals (in years) Min.	Max.	$\bar{x}$
Ponderosa pine				
Dry ridge	2	2	12	5.5
SE slope	4	2	23	8.8
Mixed-conifer forest				
SW-facing slope				
Ppo/Pla/Cde[a] dry knoll	6	3	14	8.4
Pla/Aco/Sgi Mod. moist, lower slope	4	3	22	10.0
NW and NE slopes				
Cde/Pla				
Plot 1a	6	2	26	10.9
Plot 1b	6	2	27	12.1
Plot 1c	3	5	19	13.1
Plot 1d	6	9	22	15.5
Pla/Aco/Cde				
Plot 2a	3	5	28	14.4
Plot 2b	5	5	34	14.5
Plot 2c	5	9	39	16.1
Plot 3a	2	9	30	16.7
SE-facing slope				
Sgi/Pla/Aco Mod. moist				
Cluster a	4	4	35	14.9
Cluster b	3	12	23	17.8

[a] Symbols for tree species are: Ppo = *Pinus ponderosa* (ponderosa pine); Pla = *Pinus lambertiana* (sugar pine); Cde = *Calocedrus decurrens* (incense cedar); Aco = *Abies concolor* (white fir); Sgi = *Sequoiadendron giganteum* (giant sequoia).

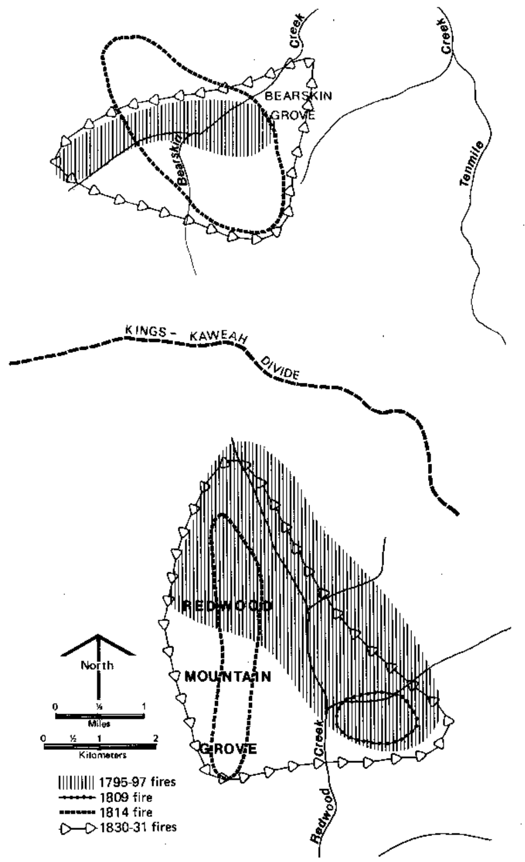

FIG. 4. Minimum sizes of certain larger fires in Bearskin Creek and Redwood Creek drainages are shown for selected years.

Frequency by habitat phase of the mixed-conifer type. – Table 3 shows frequency in clusters representing different habitat phases which vary on a dry to moist gradient. Overall, a sequoia grove tends to be more moist than areas outside a grove (Rundel 1972); yet there are apparent moisture variations among the various mixed-conifer 'habitat phases within and near groves. Two ponderosa pines on a dry ridge top at Redwood Mountain form a cluster which showed the shortest mean interval between fires, *5.5* yr. The gradient then ran through 2 west-slope pine clusters with frequencies in the 8to 10-yr range, 4 incense cedar and sugar pine clusters with 11- to 15-yr frequencies, to 4 sugar pine, white fir, and incense cedar clusters with 14- to 17-yr frequencies, and culminating with white fir, sugar pine, and sequoia clusters at Redwood Mountain with 15- to 18-yr frequencies. While numbers of clusters were too small to confirm results statistically, there appears to be strong indication that fires are more frequent on ridge tops, west-facing slopes, and other drier sites than on mid-slopes, east- facing slopes, and other more moist sites.

Frequency by historical time period. – Scar records from the 1500's to 1971 are compared in Table 4. The number of pre-1700 recorders were relatively few compared to post-1700 recorders, but those few old recording trees showed frequencies generally comparable to those for the 1700 – 1875 period.

Except for the fires in 1881 and 1898 recorded on 2 trees near the upper part of the basin, no other fires were recorded in the Redwood, Creek drainage after 1875. In Bearskin Creek, isolated fires occurred in Plots 1 and 2 at about the same intervals as prior to 1875. However, such isolated fires in Plot 1 occurred only during the 1884 – 1895 period; no fires were recorded thereafter. After 1900, the only study area in which scattered fires continued to be recorded was Plot 2; here a few fires burned from 1900 to 1939. No fires were recorded thereafter.

Another historical perspective is shown in Table 5. The numbers of fire scars per 100 rings of growth in Bearskin Creek dropped from >3.0 in the 1700 to 1875 period to 0.8 after 1876 and 0 after 1900. Thus, fire was much less frequent after 1875 than before that date. Only 5% (48) of the total of 935 scars found on all stumps between 1478 and 1939 were recorded after 1875, even though all 220 were living and susceptible to scarring during this nearly 100-yr period. This contrasts with 34% in the 1700's and 54% in the 1800 – 1875 period.

TABLE 5. Mean number of fire scars per 100 annual rings of growth by historical time period

Geographic unit	Sample trees (N)	Time periods[a]				
		1600–1699	1700–1799	1800–1875	1876–1899	1900–1971
Redwood Creek						
1. West-facing	10	2.3	10.5	7.1	...	...
2. East-facing	8	2.0	4.7	2.8	...	...
3. Ponderosa Ridge	2	3.5	15.2	8.7	2.1	...
4. Other[b]	17	1.2	6.6	5.7	1.5	0.1
Total	37	2.3	8.9	5.9	0.8	...
Bearskin Creek						
5. Plot 1	58	1.8	3.2	3.1	0.2	...
6. Plot 2	77	2.4	3.3	3.1	0.7	0.1
7. Plot 3	18	0.9	2.9	3.4	...	...
8. BS-Extensive	30	3.7	6.1	5.1	2.2	0.1
Total	183	2.2	3.9	3.7	0.8	...
Total both areas	220	2.2	6.4	4.8	0.8	...

[a] Numbers of scars calculated with respect to 100 annual rings of growth after an initial fire scar has made tree sensitive to low-intensity fires.
[b] Trees not part of east or west-facing clusters; usually more isolated.

Incidence by size of unit. – Table 2 shows that mean intervals between fires from 1700 to 1875 somewhere in a unit are shortest for the whole drainage and longest for an individual tree. Thus, a fire was recorded every 2 yr somewhere in each of the 770- to 1030-ha drainages; every 5 to' 9 yr somewhere in the 3.2- to 16.2-ha study sites; every 8 to 18 yr in each 0.4- to 0.8-ha cluster of trees; and every 11 to 39 yr (with means of 17 to 23 yr), on individual trees.

Incidence of different-sized fires. – Indications of the size of area covered by fires varied from instances where a single tree recorded a fire in years such as 1721 and 1769 to other cases where 38 stumps in 1 drainage and 11 stumps in another recorded a fire in the year 1858. In 1782 – 83, 1795-97, 1814, and 1858- 1859, fires burned in both drainages and represent our largest fire category (Table 1, Fig. 4). Between 1782 and 1858, at least, such large fires occurred every 25.7 yr. During this same period, moderate-sized fires or larger burned every 8-9 yr somewhere in Bearskin Creek and every 11.5 yr somewhere in Redwood Creek. Small fires (or larger) burned somewhere in the total study area every 3.4 yr between 1726 and 1881. Spot fires (or larger) were recorded every 1.2 yr somewhere in the study area.

Incidence of different intensities of fires. – Different intensities are possible in forest fires: (1) low-intensity surface fires; (2) medium- to high-intensity surface fires with occasional "crowning out" or "torching" of individual trees; and (3) crown fires which spread between individual tree crowns, with or without surface burning. Evidence for burns of different intensities included: (1) Groves with sequoia trees >2000 yr old (Redwood Mountain and Bearskin Creek groves) grow and flourish. Hence, crown fires are ruled out for these groves. Individual standing dead sequoias are found, but even these are relatively few in number. (2) The fire-scarred trees on our plots have not been killed by the fires which scarred them; yet they regularly recorded fires for the past 200 to 500 yr. A crown fire or holocaust fire would have killed many of them. (3) Many trees near the scarred trees have been neither killed nor scarred (Fig. 5). Trees of similar age showing no fire-scar evidence were often found from 0.5 to 3 meters from scarred specimens. Only surface fires – from low to fairly high intensity, perhaps with occasional torching – have burned during their 100- to 500yr life span. (4) Fire scars are much more numerous in certain years than in others. In 15 different yr from 1782 to 1872, fires left records on 16 to 49 of the total 220 recorder trees (Table 1). Generally, the greater the number of stumps in a single plot or study area recording a particular fire year, the greater the expected intensity. Presumably, under usual circumstances, the higher-intensity fires

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would also be the larger fires, because of widespread fuel buildup and/or dry weather conditions, From 1782 to 1872, these apparently larger, higher-intensity fires burned at intervals of 1 to 17 yr somewhere in the study area. (5) In the present study, we found few trees whose first scar was made before age 50 to 100 yr (Table 6) or 25.4 cm diameter at breast height (dbh). Certain trees were first scarred but not killed when they were from 3.8- to 15.2-cm diameter at a height of 1.4 m (dbh). This provides evidence that fires were of relatively low intensity at the base of these small trees.

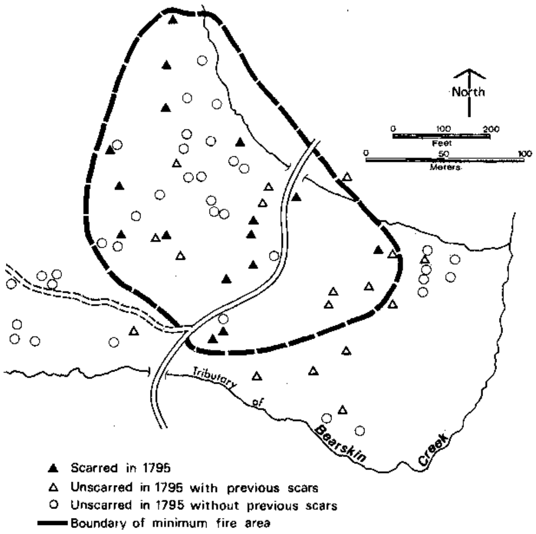

FIG. 5. Fire scar records from 1795 fire on Plot 1, showing both scarred and unscarred trees and outline of minimum size fire.

TABLE 6. Age of trees at first scar by species[a]

Species Common Name	N	Age at first scar (in years)			
		Min.	Max.	$\bar{x}$	SD
Sugar pine	23	23	292	102	64.1
Ponderosa pine	13	21	235	96	56.5
White fir	10	14	212	84	49.1
Incense cedar	19	38	338	162	81.4
Total	64				
$\bar{x}$		24	286	117	

[a] Data recorded only from 64 stumps having >3 scars per stump and where both age and diameter could be clearly determined.

To evaluate intensity for a specific site and year, we applied the criteria of minimum age and previous scar- ring (see Methods) to the 1797 fire at Redwood Mountain. Of the 37 trees studied, nearly 60% (22) had scars from previous fires; of these, 15 recorded the 1797 fire. Another 27% (10) were previously unscarred but were >50 yr old; only 2 of these were initially scarred by the 1797 fire. Thus, while 17 of the 37 study trees recorded the 1797 fire, 15 of these had been previously scarred and therefore could have recorded even a low-intensity burn. In addition, 7 previously scarred trees did not leave a 1797 scar record, and 10 other trees present in that year showed no initial scarring even though 2 of them were <50 yr old and presumably were especially vulnerable to being killed or scarred by a fire of more than low intensity. The 1797 fire appears to have been widespread, but of relatively low intensity, at least at the time it burned near the 17 trees which showed no record of its passing. A similar result was found on the intensively studied Plot 1 site in 1795 (Fig. 5) where previously scarred trees showed no evidence of this fire, even though they were within 10 m of other trees scarred in 1795.

Discussion

Fire behavior in a sequoia-mixed conifer forest is complex and variable. The characteristic summer drought enhances fuel flammability over substantial parts of the forest, and ignition sources (man and lightning) are usually more common during the summer. But variable arrangement, type, and volume of fuels, often augmented by topographic irregularities, lead to a diverse fire pattern and to considerable variations in frequency, areal extent, and intensity of fires.

Frequency and incidence

The results of our study of fire frequency and fire incidence in the southern Sierra Nevada are similar to findings of Boyce (1920), Show and Kotok (1924), Presnall (1933), Weaver (1951 and 1959), Wagener (1961), Biswell (1961), Hartesveldt (1964), and van Wagtendonk (1972). Those studies documented intervals between fires ranging from 2 yr on a 30-ha study area through 8 to 10 yr for large fires in the Sierra generally to 20 – 25 yr in a given locality of a sequoia grove. Variations are partly related to differing forest types or phases, exposures, and elevations, and partly to whether frequency or incidence was being measured. Previous studies have used "frequency" for both concepts.

We find positive evidence that fires have burned through the same area of mixed-conifer forest 4 and 5 yr after an earlier burn. Six different trees on the west-facing slope of Redwood Creek recorded both the 1792 fire and the 1797 fire'. Three trees showed 4-yr intervals, while 1 ponderosa pine on the ridge of Redwood Mountain showed a 3-yr interval between fires. Such intervals are fairly common in the cluster records (Table 3).

Brief examinations of 4 sequoia stumps 5 km west of our study area yielded 2 scars in the fifth century with a 5-yr interval, 7 scattered dates between the years 510 and 1620, and a series of 8 scars between 1620 and 1739 having a mean interval of 17 yr. While working conditions are difficult because of age, size, and height of sequoia stumps, additional studies should develop a fire chronology of 1000 yr or more. Such a chronology would be likely to confirm preliminary evidence that fires occurred in sequoia groves about as frequently as in mixed conifer forests.

Areal extent of fires

Fire in the Sierra usually burns small, irregularly shaped areas and does so with varying spread rates. This is probably related to variations in fuel-type pattern and fuel-moisture content as hypothesized by Kourtz and O'Regan (1971) and van Wagtendonk (1972) as well as to local variations in topography and weather. Fire – in combination with other factors such as exposure, slope, soil type, insects, and disease – results in a mosaic of age classes and vegetation types (Bonnicksen 1975). In turn, this contributes to the variability of fire behavior and tends to work against large areas burning simultaneously. This contrasts with the relatively large areas burned in certain dense and even-aged northern forests which develop after infrequent crown fires (Heinselman 1973).

Intensity

Bonnicksen (1975) draws the conclusion from Muir's (1901) observations of fire in Giant Forest in 1875 that (1) fuel accumulations in early mixed-conifer forests' were variable, but generally low, with large piles of debris widely scattered; (2) the forest was relatively open; (3) most fires were of low intensity, with flame heights <0.6 m, and burned along the surface; but (4) fire intensities were variable, and occasionally – where debris had accumulated – intensities would be severe enough that young sequoias up to 200 yr old would crown out and be killed. Our evidence agrees with this analysis. While obviously there were exceptions where heavy fuel accumulations had built up, the typical pre-1875 fire in the sequoia-mixed conifer forest was a low to moderate intensity surface fire. The paucity of fire scars on small trees suggests that understory tree populations were severely thinned by such periodic, low-intensity fires.

Climatic influences on size and intensity

The few early records of climatic conditions in California show some correlation between certain big fire years and known drought conditions. Drought years of 1862-64 and 1869-71 (Strong 1964, Vankat 1977) relate to a moderate-sized fire in 1863 and the major fire in 1871, recorded by 24 stumps in our study (Table 1). Dry climatic conditions in the low-elevation valleys also gave impetus to the grazing of sheep in high mountain meadows beginning in the 1860's. While driving their sheep out of the mountains each fall, herders commonly set fires to encourage better forage the following spring (Vankat 1977). The many sheep reported grazing in Sequoia Park in 1881 (Strong 1964) may thus tie in indirectly with fires recorded that year on 8 stumps in our study area.

In a number of instances, it appeared that the same weather and fuel conditions which led to fire in 1 basin also led to fires in the other basin, often in successive years. Thus, the multiple-basin fire in 1782 was followed by fire records in 1783 on the east-facing slopes in Redwood Creek and several additional scars in the Bearskin general survey. In 1795, a large part of Bearskin Creek drainage burned, leaving 28 scar records, with only 2 such records in upper Redwood Creek basin; 2 yr later in 1797, an additional 8 stumps in Tenmile Creek basin and 17 in Redwood Creek re- corded a fire, presumably caused by the same weather and fuel conditions, but not the same ignition source. Similar circumstances were apparently involved in the sequence of fires in 1814 – 1816, 1829 – 1831, 1841 – 1845, 1858-1860, 1865-1866, and 1871-1874 (Table 1).

Ignition factors

It is intriguing to speculate as others have done (Reynolds 1959, Burcham 1960, Wagener 1961) about the role of lightning *versus* the role of Indians as primary ignition sources for fires before 1875. Lightning ignitions have presumably not changed significantly in our study area over the years, while numbers of Anglos increased and numbers of Indians decreased dramatically during the last half of the 1800's. The sharp decline of fire-scar occurrence after the early 1870's in our study area suggests that native Indians may have been a significant ignition source.

In the southern Sierra Nevada, the contact of Anglo people with Indian people took place during the 1860's and the 1870's, when it was related at first to livestock grazing and then, in the 1880's, to logging. In general, Indian culture crumbled on contact with Anglo man (Cook 1951), and between 1865 and 1875, Indian burning of the areas adjacent to Redwood Mountain was presumably phasing out (Lewis 1973, Vankat 1977). Concurrently, a period of both planned and accidental fires by stockmen, loggers, and miners had begun (Strong 1964, Vankat 1977). During the years 1865 to 1900, an initial increase in burning by white man was followed by a gradual shift to suppression programs as General Grant Grove National Park was established in 1890, the Sierra Forest Reserve in 1893, and a newly created Forest Service began its fire control programs in the early 1900's. Several early stockmen in the area feel little effective suppression was carried out until the early 1920's.

Some hold that the artificially high levels of burning by prospectors, stockmen, settlers, lumbermen, and others during the 1850 to 1900 period led to the false impression that the original character of natural forests- in California was open and parklike. This view also contends that such Anglo burning led to the misguided belief that Indian burning contributed substantially to development of vegetation in chaparral and coniferous forests (Burcham 1960). Our evidence suggests a different view.

As Indian burning was gradually being replaced by Anglo burning from 1865 to 1875, our fire-scar record was very similar to the previous 165-yr period. Vankat (1977) concluded that, "much of the burning done by the herders... [was] an extension of the practice of- the Indians. Indeed, the 2 cultures burned for much the same reasons – to favor certain plant species and to open the forest." By 1875, when any artificially high levels of Anglo fires alone should have been creating more fire scars, our record shows a major decrease in scars (Tables 1, 4, and 5).

Lightning fires. – Fire suppression records indicate that between 1921 and 1972, lightning started fires in 15 different yr in Redwood Creek drainage and in 3 different yr in Bearskin Creek drainage. This may at first appear to resemble the pre-1875 intervals which were determined from fire scar data (Table 4). How- ever, the discontinuous fuel pattern we believe characterized the forest floor before 1875 would usually have led only to very localized, small fires. Few of these would have become more extensive fires and scarred trees in the various clusters we have studied.

For example, the 2 west-slope clusters at Redwood Mountain recorded pre-1875 intervals between fires of 8 to 11 yr. Yet since 1921, only 1 lightning fire (in 1956) has been suppressed here. Another was suppressed 1.6 km northeast and 213 m higher in elevation in 1926. However, under pre-1875 fuel conditions, this ignition would not likely have spread to the lower elevation cluster. All other ignitions on this slope were across creeks and higher up on the slope. It is unlikely any would have spread to the clusters.

The entire Bearskin Creek area reported ignitions in only 3 yr between 1921 and 1972. Each of these would have had to spread extensively in order to scar trees at anywhere near the frequencies recorded between 1700 and 1875. Hence the pre-1875 cluster frequencies of every 8 to 18 yr would not have been achieved during the past 50 yr by lightning ignitions alone.

Aboriginal burning. – Fire was an integral part of the daily existence of the Yokuts and Western Mono (Monache) tribes in the vicinity of Sequoia and Kings Canyon (Driver 1937, Gayton 1948). The Waksachi Monache had a permanent village site, Citatu in Eshom Valley (Gayton 1948), some 9.7 km southwest of our study area at 1,006 m elevation in the oak wood- land-chaparral zone. Other nearby lower-elevation tribes also traveled each summer to Citatu to gather acorns. Residents of this 25-house village with a population of perhaps 100 people, migrated each summer to the higher elevation coniferous forest zone near the Quail Flat area, at the head of Redwood Creek on the Kings-Kaweah Divide (Gayton 1948, Elsasser 1972).

Bedrock mortars and obsidian chips have been found within our study area, at Quail Flat and at several other sites – 2 within 1.6 km of our west-slope Redwood Creek clusters (Purves 1975, Popelish 1976). The mortars indicate the people probably worked on acorns collected in the area; the long-term or repeated occupation of this site makes clear that acorns and oaks were regularly present during the time of aboriginal occupation. Because conifers are presently over- topping the black oak *(Quercus kelloggii),* fires set by the Waksachi and by lightning probably kept the vegetation more open and favored black oak in the past (see Reynolds 1959 for similar description in the Yosemite area).

Lewis (1973) studied anthropological and biological data and generalized that California Indians used fire in woodland-grass, chaparral, and coniferous forests as a significant form of environmental management which resulted in a dynamic balance of natural forces. Bonnicksen (1975) noted that, "Most descriptions of Indian burning were recorded from low-elevation areas and these were usually in grassland or brush .... There is a possibility that many, if not most, Indian-caused fires in the sequoia groves were the result of escapes from low-elevation areas."

Both Lewis (1973) and Burcham (1974) seem to agree that one of the impacts of Indian burning was the forming of openings within which there was a local concentration and increase of plant and animal re- sources. As Burcham (1974) concludes, "Their activities tended to maintain the distribution of certain plant species on a local scale, where [tribal] populations were most dense...." Lewis (1973) also notes that, "Large-scale burning would have reduced the complex of ecotones... the very 'spottiness' and much higher frequency of very localized Indian burning seems to have affected a much more complex overall ecosystemic pattern than would have been the case with only natural fires."

While establishing that a particular group of Indians burned vegetation in a particular site over a specified period of historic time is difficult, the weight of circumstantial evidence is heavy. Lewis (1973) cites the work by Stewart (1955) and Reynolds (1959) indicating that (1) almost every tribe in the western United States has used fire to modify its environment, and (2) that within California at least 35 tribes used fire to increase yield of desired seeds; 33 used fire to drive game; while others used fire to aid seed collection, to make vegetable food available, and to improve visibility. The ethnographic studies by Driver (1937) and Gayton (1948) combined with the more recent archeological evidence strongly suggest that the Waksachi Monache used fire in our study area during the past 500 to 1000 yr (Elasser 1972).

Further evidence that the Indians used fire comes from our fire-scar records. Fires burned through a given site every 8-18 yr. Such frequencies are greater than can be attributed to lightning fire ignitions alone. The only reasonable conclusion is that aborigonal ignitions- either in the coniferous forest itself or as escapes from the lower-elevation woodland, grass, or chaparrel fires- augmented the lightning-caused ignitions to give the frequencies we have found.

Interrelationships

Natural fire frequency coincided with levels of fuel accumulation that resulted in burns of relatively low intensity at frequent intervals rather than higher-intensity burns at infrequent intervals. After a minimum fuel buildup, the timing of mixed-conifer forest burns depends on the simultaneous occurrence of an ignition source and suitable weather conditions (van Wagtendonk 1972).

The main understory tree species in the sequoia-mixed conifer forest is white fir. These trees now occur in thickets in all parts of the Redwood Mountain Grove as well as elsewhere in the Sierra Nevada mixed-conifer forest. During our study on Redwood Mountain and vicinity, we obtained ages of many understory white fir growing in thickets near our large stumps. Usually they had become established within 10–30 yr after the last fire identified on nearby sugar pine stumps. It appears that the succession to white fir in a sequoia-mixed conifer forest type is very related to the absence of fire.

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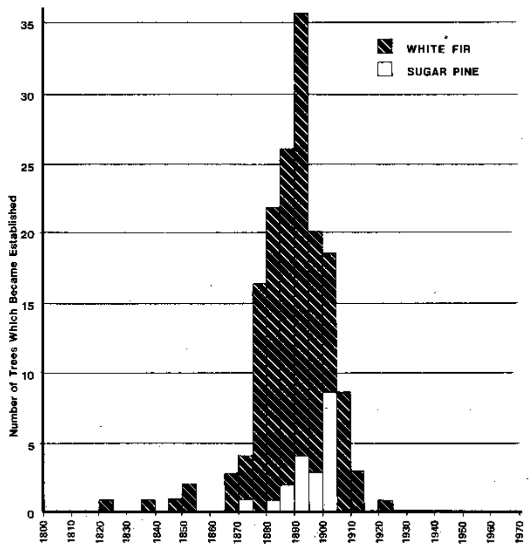

FIG. 6. Numbers of pole-size understory white fir and sugar pine which germinated and became established at different time periods between 1800 and 1970 on a 0.4-ha study area at Redwood Mountain. (Does not include the smaller saplings and seedlings established since 1910.)

Establishment dates of such understory trees offer an indirect indication of the impact of the frequency and intensity of the fires which burned in the Redwood Creek drainage in the 1700's and 1800's. On 0.4 ha of land intensively studied in connection with earlier work (Kilgore 1973*a*), some22 large trees of 4 species made up the overstory canopy, all of them being >200 yr old. The white fire and sugar and ponderosa pine started growing between 1700 and 1760 and ranged from 61 to 170 cm dbh. The giant sequoia had all obviously become established before 1700 and ranged from 112 to 239 cm dbh.

Beneath these overstory trees in 1760, white fir and sugar pine were germinating and becoming established, as they do now, in numbers which would fill most available sites during a few decades time. However, records on this east-facing slope also indicate that surface fires burned in such a way that they reached any given area every 15 to 18 yr between 1760 and 1870. Thus, many of the small trees which had started growing and survived the first few year N of summer drought were regularly killed by low-intensity surface fires.

As a result of this pre-1870 interaction between forces of seedling establishment and survival and fire and summer drought, only 8 white fir started growth between 1760 and 1870 and survived to become part of this 0.4-ha 1970 forest. In the absence of frequent, low-intensity fires during the following century from 1870 to 1970, 173 young fir and pine became established and survived to become pole-sized trees (6 to 32 cm dbh in 1970 (Fig. 6). These trees, together with >1200 seedling and sapling fir and pine (<6 cm dbh) formed a dense understory thicket which constituted a highly flammable fuel bed beneath the original, fairly open overstory. Lack of frequent, light fire had resulted in a major departure from conditions which normally evolved under giant sequoias during the past 1000 yr or more. Prescribed burning was carried out in parts of the Redwood Mountain Grove in 1969 (Kilgore and Biswell 1971) and in 1970 (Kilgore 1973a). These burns reduced fuels and therefore greatly reduced the potential for intense surface fires that could support crown fires (Kilgore and Sando 1975). They constitute a first step towards restoring the ecosystem to a condition which probably more nearly approximated the pre- 1875 forest.

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