Impact of Prescribed Burning on a Sequoia-Mixed Conifer Forest

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THE significant role of fire in the coniferous forests of North America has been documented by many workers (Ahlgren and Ahlgren 1960; Hare 1961). Its general role in the giant sequoia-mixed conifer forest of the Sierra Nevada of California has been reported by Biswell (1961), Hartesveldt (1964), and Kilgore (1971c). Sierra Nevada forests were once considered to be nearly immune to continuous crown fire (Show and Kotok 1924). However, attempts to suppress all natural and man-caused fires in the sequoia-mixed conifer forest during the past half century or more have resulted in the accumulation of extreme quantities of dead and living fuels. This buildup has resulted in what has been termed the highest degree of fire hazard ever observed in sequoia communities (Hartesveldt 1964). In part to meet this challenge, the National Park Service at Sequoia and Kings Canyon National Parks has initiated special programs aimed at restoring fire, as nearly as possible, to its natural role in the forest (Schuft 1972; McLaughlin 1972).

The current management program for the giant sequoia-mixed conifer forests of Sequoia and Kings Canyon National Parks is based on the hypothesis that the giant sequoia exists today because of the role fire has played in its life cycle. Fire at intervals of probably 8 to 20 years reduced litter accumulations, limited the suc-

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cession of tolerant understory species, and provided suitable conditions for sequoia reproduction. At Redwood Mountain, where fire has been suppressed for at least 50 to 60 years, litter accumulations and young reproduction provide fuels that potentially can support fires of disastrous proportions. This condition is clearly intolerable, particularly in an area that is subject to frequent lightning. Fire must be carefully and sensitively restored to the sequoia forest. At the same time, research must determine more precisely the ecological role of fire so that management techniques can be guided by the best knowledge we can provide.

The present investigation attempts to record the impact of prescribed fire on certain biotic and abiotic elements of the sequoia-mixed conifer forest ecosystem by measuring these elements before and after burning.

STUDY AREA

In 1969, a burning management program was initiated on the ridge of Redwood Mountain which runs north and south within the 3,100-acre Redwood Mountain Grove of giant sequoias in Kings Canyon National Park (Fig. 1). To help interpret the impact of this program (Kilgore and Biswell 1971), we established a series of plots adjacent to the 1969 burn site which could be studied and then burned in 1970. The elevation along the ridge ranges from 6,400 feet at the saddle to nearly 7,000 feet near Sugar Bowl Grove, about 2 miles to the south. The climatic conditions on the ridge are quite similar to those previously reported for Grant Grove (Kilgore 1971a), 3.25 mi northwest at 6,600 feet elevation. Hygrothermograph records in 1970 from Redwood Saddle, about half a mile from the study area, showed a yearly low temperature of 17°F and a high of 82°F. July was the warmest month, with a mean minimum of 61°F and a mean maximum of 74°F. Temperatures in November, just before the burn, ranged from 32° to 58°F. Relative humidity was highly variable; summer readings were characteristically 20 percent or less, with occasional readings about 50 percent. During the week preceding the burn, relative humidity fluctuated between 30 and 80 percent, with higher values shortly after noon and lower values shortly before midnight. Winds in and near the study plots were moderate when present, varying from 0 to 5 mph.

Giant sequoia (*Sequoiadendron giganteum*), white fir (*Abies concolor*) and sugar pine (*Pinus lambertiana*) dominate the forest, with little incense-cedar (*Libocedrus decurrens*), ponderosa pine (*Pinus ponderosa*), and California black oak (*Quercus kelloggii*) represented except in the extreme southern plot and at somewhat lower elevation. Shrubs and herbs are present but rare, and grasses are almost absent. The study area thus seems to represent a moderately moist site by comparison with the more mesic Giant Forest area or the more xeric Whitaker's Forest (Rundel 1971, 1972).

Large portions of this grove, including the study plots, are found on soils derived from metamorphic schists (Ross 1958). Sequoia groves often occur on granitic soils such as the Shaver and Holland series found at Whitaker's Forest (Biswell, Buchanan, and Gibbens 1966).

Human Impact on the Study Area

Growing evidence suggests that Indian people living on the western slope of the Sierra Nevada had developed a cultural pattern which had profound influence on the vegetation of the entire area, particularly on the foothill brush, woodland, and mid-elevation mixed conifer zones (Reynolds 1959; Driver 1937). By burning periodically, the Indians kept successional stages at pre-climax levels, thus insuring their supply of plants that provided suitable foods and materials. Aboriginal man, therefore, probably augmented the frequency of fires ignited by periodic lightning strikes in the giant sequoia-mixed conifer forest. However, by the 1860's, the influence of Indian culture in the Sierra Nevada was nearly eliminated.

Logging of sequoias took place in the western portion of the Redwood Mountain Grove between 1873 and 1879 (Larson 1966). This activity, however, did not extend into the study area itself that lies on the eastern slope of the mountain. During the late 1800's and early 1900's, herds of sheep and cattle were driven through the western portion of the grove during seasonal moves between pasturelands in the central valley and mountain meadows. In modified form, cattle drives continue to this day.

FIG. 1. Prescribed burning in 1969 in the Redwood Mountain Grove of giant sequoias, Kings Canyon National Park. Fire consumes the accumulation of forest fuels, leads to a recycling of nutrients, and reduces wildfire hazard. During these early efforts, National Park Service crews used fire hoses as an added safety precaution. National Park Service photo by Bruce M. Kilgore

The Redwood Mountain area, except for a core of private lands, became part of the national forests in 1893, under the National Forest Reserves act. Fire suppression activities which began during this time continued after the grove became part of Kings Canyon National Park in 1940.

METHODS

Twelve 60-foot by 100-foot study plots were laid out about 600 feet east of the ridge of Redwood Mountain at an elevation of 6,300 feet. Two additional plots were established just below the saddle parking area as demonstration plots. These plots were selected as being representative of the range of vegetative and fuel conditions found on this east-facing slope of the mountain. Seven of the 12 plots and 1 demonstration plot were burned, while the remaining plots were retained as control areas.

For each plot, the following records were gathered before and after burning:

(1) species, diameter, and height class of trees more than 6 inches diameter at breast height (dbh) or 4.5 feet above the ground;

(2) numbers of white fir and sugar pine saplings per acre in four height classes. ("Sapling" is used for any tree less than 30 feet in height and includes most trees less than 6 inches dbh);

(3) extent and approximate height of white fir sapling thickets. ("Thicket," as used here, means a growth of young trees, usually of shade tolerant species, which is dense enough to make walking through the area difficult or to add significantly to the crown fire hazard in the area);

(4) coverage and frequency values (Daubenmire 1959) for herbaceous and shrub species;

(5) litter and duff weights;

(6) length and diameter of down trees;

(7) chemical light meter (Marquis and Yelenosky 1962) indices for light reaching the forest floor;

(8) appearance of vegetation as recorded by black and white and color photographs from 102 permanent photo points.

Before going into the field, locations of three 50-foot transects were systematically determined for each plot to sample the understory cover and ground cover. Sampling procedures followed were basically those used in earlier work with red fir (Kilgore 1971b), except that understory cover contributed by both small and large living trees and shrubs plus dead branches was estimated up to 12 feet. Light received over a 24-hour period at six points on each of the 14 plots, or 84 points, was measured simultaneously by the chemical light meter method as an index to overall canopy vegetation density.

To determine the impact of fire on surface litter and duff weights, samples of these two types of fuel were collected, dried, and weighed before and after burning. At each of 47 sites, a 2-foot-by-3-foot sampling frame was used and two sub-samples were taken. All branches, loose twigs, needles, and cones found within the frame made up the litter (L) sub-sample, while the partially decayed organic material found in one square foot unit made up the duff (F and H) sub-sample. Because of their large size and uneven distribution, down trees greater than 6 inches diameter were measured separately and converted to an estimated volume and oven-dry weight per acre.

To augment the coverage of these results, more widespread sampling of the total burn area, both inside and outside the intensively measured study plots, was conducted before and after burning. More than 100 readings were taken of (1) depth of litter and duff combined (L, F, and H layers); (2) coverage of twigs and branches in three size classes; and (3) mean depth of such branches and twigs. Sample readings were taken at 33-foot intervals along several transects parallel to the west boundary of the burn area.

In addition, using the technique of Gleason (1957), erosion spikes were installed at 15 points arranged systematically throughout each plot to allow determination of soil movement following fire. Temperatures attained at various levels of the understory vegetation and in the first 6 inches of the soil were measured by means of 163 tempilaq units (Fenner and Bentley 1960) installed at 14 sites throughout the burn area and at understory locations ranging from the base of small saplings to 30 feet up in larger white fir and sugar pine. Chemical compounds which melted at 200°, 250°, 350°, 500°, 750°, and 1000°F were used, allowing determination of the maximum instantaneous temperature reached between 200° and 1000°F. An indication of the energy output of the fire was obtained at the same 14 sites by use of 43 paint can fire analogs, each containing 3000 ml of water (Beaufait 1966). Kilogram-calories of energy at each point were calculated from temperature change and loss of water.

Burning Conditions and Prescriptions

When all pre-burn measurements had been made, a fire-line 2 feet wide was built along the two sides and the bottom of the proposed 5-acre burn area. The 1969 burn plots were immediately uphill from the site. No other preburn preparations were made, partially to hold down costs, but more importantly to study the impact of prescribed burning alone, without elaborate cutting of small trees, felling of snags, and construction of substantial fire-lines undertaken in the earlier burn (Kilgore 1970).

We began burning the study plots on November 23, 1970 (Figs. 2 and 3). During the week preceding the burn, maximum daily temperatures were about 56°F, with relative humidities of 20 to 56 percent, and fuel stick moisture levels of 11.0. On the day of the burn, the conditions were somewhat drier. The temperature reached 59°F, the relative humidity at 0850 was 20 percent and the fuel stick moisture level was 10. Essentially no winds were involved.

Burning indices* for 23 Nov. 1970 were as follows:

	forecast	*actual*	*prescription (range)***
fine fuel moisture	6	5	7–10
spread index	8	8	5–12
intensity index	59	56	37–49
timber burning index	5	5	3–5
ignition index	45	55	15–49

**Adapted from Schimke and Green, 1970.

After a test fire burned well at 0850, the plots were ignited at 0900 with a drip torch along the upper boundary of the burn area. With no wind and an average slope of 35 percent, the fire backed slowly downhill. To speed up the burn, we ignited small strips 30–60 feet wide and allowed the fire to run uphill. The fire burned briskly from 0900 to 1200, gradually becoming slower and more

*California Wildland System.

Fig. 2. National Park Service forestry foreman uses a drip torch to ignite forest litter under a canopy of giant sequoia and white fir. Fire will consume most of the litter and will kill some of the understory white fir trees which have grown here in the absence of fire during the past 50 or more years. National Park Service photo by Bruce M. Kilgore

smoky as the relative humidity rose and the sun left the east-facing slope. We discontinued ignition at 1300. Heavy fuels burned well, but light fuels, needles and small twigs, burned less readily unless some heavy fuels were nearby. A rising convection column from one unit of briskly burning fuels would pick up the tempo of burning in another adjacent fire that had been lagging. A smoldering type of combustion often continued in heavy duff fuels for many hours after the main surface fire had passed.

On the second day of the burn, 24 November, we re-ignited some unburned areas between 0900 and 1200, but the humidity again rose by noon and only large fuels burned into the afternoon and evening.

FIG. 3. Prescribed fire burning near the base of a giant sequoia. As the fire consumes ground litter and kills small fir trees, it also prepares a seedbed suitable for sequoia. National Park Service photo by Bruce M. Kilgore

Burning was essentially complete by late afternoon on the second day. Rain began falling on the early morning of 25 November, followed by snow which ended the burning season for 1970.

RESULTS

TEMPERATURES AND HEAT ENERGY

Some 94 percent of the 210 2-foot by 3-foot microplots sampled for vegetative change showed evidence of the impact of fire; 80 percent burned almost completely, while 14 percent burned partially or lightly. Despite the relatively mild nature of the overall burning intensity, only 6 percent of these microplots remained unburned.

Records obtained at 14 temperature measurement stations indicated great variation in both temperature and energy output of the fire over short horizontal and vertical distances. This is true despite the fact that all plots were situated on east-facing slopes just below the ridge with broadly homogeneous mixed conifer forest fuel conditions. The presence or absence of heavy fuels (6 inches diameter or more) appeared to be a major factor in determining both energy output and maximum temperature and hence fire intensity and vegetative impact. Specific slope characteristics and flash fuels were apparently of lesser significance.

High readings of energy output, as measured by water loss from the 43 fire analogs, were almost always associated with burning of heavy fuels. In general, the larger the fuel particles, the longer the time of intense burning and the greater the water loss. Where logs from 18 to 36 inch diameter or more burned on plot 8 (Figs. 4 and 5), the loss was greater than the water can analogs could measure (more than 1860 kg calories of energy). In sites having fine materials up to 6 inches deep, but involving no heavy fuels, water loss was often zero. The heat energy released through burning a 1½ inch deep layer of sugar pine needles was not recorded, and little heat energy was recorded when smaller than 1-inch diameter remnants of old manzanita bushes burned on plot 10.

Readings from tempilaq units at various levels in sapling white fir and sugar pine suggest that temperatures at short distances up in the canopy are likely to be better indices of probable mortality than surface bark temperatures at the base of the tree. A convection column of heat from burning heavy fuels beneath the crown canopy may be at least as significant a factor in fir and sugar pine mortality as direct burning at the base of a tree, short of girdling. While 150°F or less is considered lethal for most plant tissues (Hare 1961), basal bark temperatures of more than 1000°F did not always kill even small trees. But with few exceptions, when air temperatures 6 feet above the ground reached 250°F, white fir and sugar pine less than 12 inches dbh were killed; generally, of course, these trees had also recorded temperatures more than 500°F at their base. No measure-

Fig. 4. Experimental plot 8 before (above) and after (below) prescribed burning at Redwood Mountain in Kings Canyon National Park. The fire consumed ground litter and heavy log fuels and killed most of the white fir saplings seen in these photographs. Note the major reduction in the several large logs in the middle right of the before-burn photo on the uphill side of a 62-inch dbh sugar pine. National Park Service photos by Bruce M. Kilgore (above) and Dan Taylor (below.)

FIG. 5. Appearance of burn site above the large sugar pine shown in Fig. 4 immediately after the burn, while measurements are being made of water loss in paint can fire analogs. The ground is covered with a deep layer of ashes from the heavy fuels which burned here. National Park Service photo by Bruce M. Kilgore

ments were made of total heat received in the crown area. A number of fairly heavily burned trees in the 6 to 12 inch dbh class survived for a year after the fire, but died during the second post-fire year.

As an example of the variation in burning effects over short distances, fire in heavy fuels killed three saplings near a 68-in dbh sugar pine. Yet the large sugar pine received only some scorching of the lower bark and scorching of needles on the lower branches 60-feet above ground. There was some temporary evidence of bark beetle (*Dendroctonus valens*) activity near the base of this large tree and perhaps some cambium was killed there, but the tree continues to appear vigorous and sound.

Our temperature records in this site show a very close correlation with the distribution of heavy fuels. At two surface locations involving heavy fuels, the total energy output ranged from 1,612 to more than 1,860 kgm-cal. Just 10-feet away, around the base of the large sugar pine in fine litter and duff, 6 inches deep, less than 24 kgm-cal was recorded. Fifteen feet downhill in another fine fuel site (twig, needle, and duff, 3 inches deep) no energy output (water loss) was recorded. On one of the three saplings, a 20-foot tall white fir in which fire ignited the crown, temperatures reached 1000°F at 8 inches and at 5 feet above ground, 500°F at 11-feet, and 250°F at 16-feet. Temperatures on a second killed sapling, a 7-foot tall sugar pine, reached 750°F at ground level on the downhill side of the tree, 500°F at 3 feet, and 250°F at 6 feet.

Generally temperatures higher than 200°F did not penetrate below the top 2 inches of soil except under heavy fuel conditions, where long burning would cause a gradual rise in soil temperatures at greater depths. The highest soil temperature recorded was 750°F at a soil depth of 1¾ inches beneath a dense pile of heavy fuels and litter in plot 8. At this same point, temperatures of 200°F were recorded at a depth of 7 inches. The soil structure here was extremely loose immediately after the burn, giving the impression that all organic material had been consumed. A similar change in soil structure was evident on plot 9 where a 42-inch diameter sequoia log had been completely converted to ashes over the entire burning period. Temperatures of 500°F were recorded at a depth of 4 inches. Here the newly burned soil took on a pronounced reddish hue, in strong contrast with the chocolate brown color of adjacent lightly burned and unburned soil.

Impact on Vegetation

Although giant sequoia overtop all other species in canopy height, white fir is the dominant tree in density in a sequoia-mixed conifer forest (Table 1). Both before and after the burn, about 55 percent of the trees more than 12 inches dbh were white fir, while 29 percent were sequoia and only 8 percent were sugar pine. Only one tree in this size class was killed by the burn, a 17-inch dbh fir which was adjacent to a large sequoia log completely consumed during the fire.

More than 84 percent of the trees in the 6 to 12 inch dbh class were white fir, with the remainder being sugar pine. No sequoia less than 12 inches dbh were found on the study plots. About 38 percent of this size class was killed during the burn, but the proportion of white fir to sugar pine remained nearly the same.

Among saplings, burning caused a change in the proportion of white fir to sugar pine. Prior to burning, white fir made up nearly 90 percent of the sapling population, while sugar pine was only 10 percent. The fire killed more than 87 percent of the trees in this size class, causing a drop from 1,348 to 172 saplings per acre. The relatively few remaining saplings appeared to be somewhat more evenly distributed between fir and sugar pine (Table 1). This resulted in a shift in relative species density of all size classes on the study plots from 88 percent white fir and 11 percent sugar pine to 65 percent fir and 30 percent sugar pine. This reduced per-

TABLE 1. CHANGES IN NUMBERS OF TREES PER ACRE AND RELATIVE SPECIES DENSITY IN DIFFERENT SIZE CLASSES BEFORE AND AFTER BURNING.

Size class and species	Before		After	
More than 12″ dbh	#/acre	Rel. Dens.	#/acre	Rel. Dens.
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
6″ to 12″ dbh				
White fir	93.3	84.1	57.0	82.1
Sugar fir	17.6	15.6	12.4	17.9
Ponderosa pine	—	—	—	—
Giant sequoia	—	—	—	—
Less than 6″ dbh				
White fir	1210.0	89.7	103.7	60.0
Sugar pine	138.3	10.3	69.1	40.0
Ponderosa pine	—	—	—	—
Giant sequoia	—	—	—	—
Totals – all size classes				
White fir	1325.1	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:	1498.6	100.0%	280.5	100.0%

centage of white fir in the forest seems to more nearly approximate the proportion of white fir found in the size class greater than 12-inches dbh. This suggests a possible adjustment in the successional pattern toward the numbers of white fir which naturally survived under pre-fire suppression conditions prevailing when the older, non-sequoia trees germinated, roughly between 1670 and 1870.

Ages were determined for a sample of 35 white fir ranging from 3 to 15 feet in height, growing in thicket or dense understory conditions. These saplings ranged from 15 to 49 years old, averaging 33.8 years. A smaller sample of sugar pine yielded nearly the same range of ages. Another sample of 82 white fir in the 6-inch to 12-inch dbh size class ranged from 63 to 97 years old and averaged 79.9 years. On the 0.27 acre area of plots 7 and 8, only 3 trees now living were present 100 years earlier in 1870. Beneath these two white fir (24 and 46-inch dbh)and one sugar pine (62-inch dbh), an understory strongly dominated by white fir has come in during the last century, with 49 fir and 10 pine between 5 and 13-inches dbh. The smaller saplings are even more strongly dominated by fir, with a fir:pine ratio of 10:1.

When the prescribed burn killed about 38 percent of the 6 to 12-inch dbh size class, trees germinating primarily between 1873 and 1907 were being thinned out. This period corresponds roughly with the time of high white fir germination and survival which followed elimination of Indian burning (Vankat 1970). The burning program also killed a major portion of saplings less than 15 feet tall, trees that apparently germinated primarily in the 1920's, 30's, and 40's when federal fire suppression activities were becoming increasingly effective on these Park lands.

The understory foliage of trees and shrubs 1 to 12 feet high covered about 35 percent of these plots. Following burning, such understory cover had decreased to less than 16 percent (Figure 6). Accompanying this decrease in cover on burn plots was a corresponding small relative increase in amount of sunlight reaching the forest floor. The change was not as great as that found in red fir forest studies (Kilgore 1971b), however, because the very tall and almost complete canopy provided by mature giant sequoia, sugar pine, and white fir was little affected by the burning program. A graphic

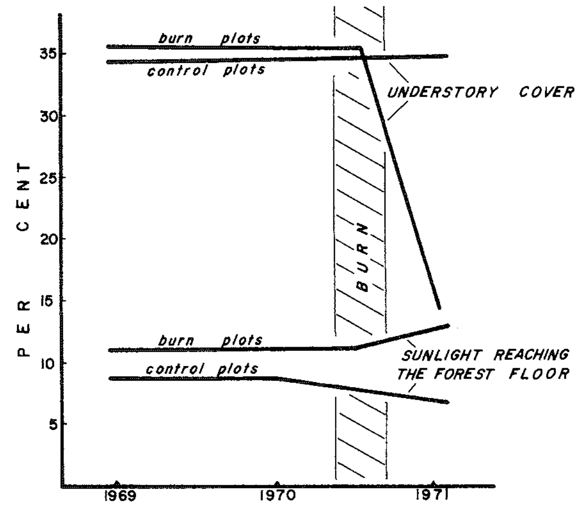

FIG. 6. Changes in percent of understory cover and in percent of full sunlight reaching the forest floor before and after burning.

representation of changes in area covered by white fir thickets is shown in Figures 7 and 8.

Essentially no tree seedlings of any species were found during the first year following this November 1970 burn. This is in sharp contrast with the nearly 22,000 sequoia seedlings per acre found on the previous, more intense August-September 1969 burn on the ridge itself (Kilgore and Biswell 1971). This difference presumably resulted largely from the timing of the burn, wherein rain and snow fell the day after the burn was completed, preventing sequoia seeds from reaching the loose mineral soil and ash bed created by the fire. The 1969 burn, however, was also hotter because the many young saplings which were felled added considerably to surface fuels available during the fire.

Although 7 shrubs, 1 grass, and 10 species of forbs were found on 1 or more study plots before burning, less than 1 percent of the preburn area of the sample microplots had living ground cover. The only postburn species showing more coverage than 1 percent was a moss which covered 1.6 percent of postburn plots. Almost no grasses were found on sample plots either before or after burning. *Carex* sp.,

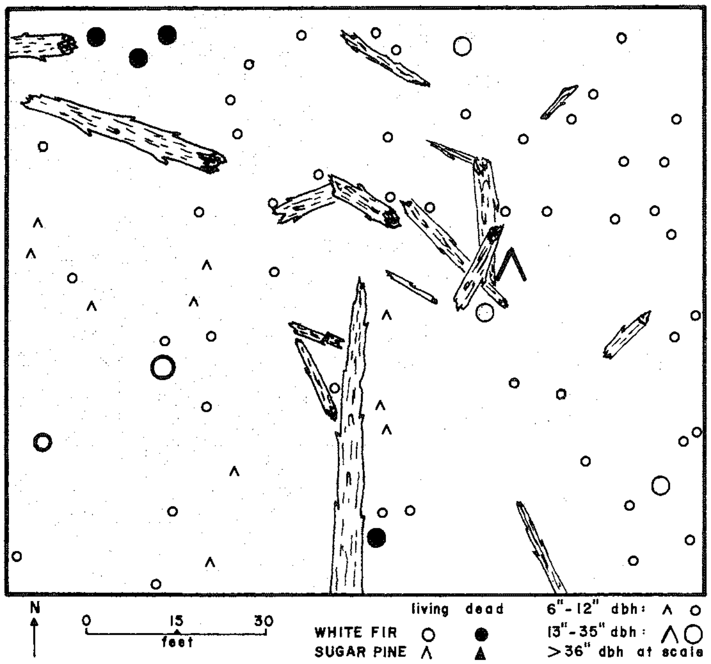

Fig. 7. Before burning, a white fir thicket covers all of this ¼-acre area, and heavy log fuels, weighing an estimated 4 tons, occupy a considerable amount of space. Note the numbers and distribution of living and dead saplings more than 6 inches dbh. Sketch by Dan Taylor

however, appears to be increasing on the adjacent, more open 1969 burn area.

Frequency values (Table 2) showed an increase following fire in such shrub seedlings as *Arctostaphylos patula*, *Ceanothus parvifolius*, *C. integerrimus*, and *Ribes roezlii* which in total appeared on 13 percent of the microplot samples. Mosses appeared with a frequency of 17 percent on postburn microplots, while none was found in control areas. Species which decreased in frequency following burning were *Goodyera oblongifolia* and *Pyrola picta*.

Fuels

Figure 9 compares the oven-dried weights of ground fuels before and after burning on control plots and burn plots. Weight for the

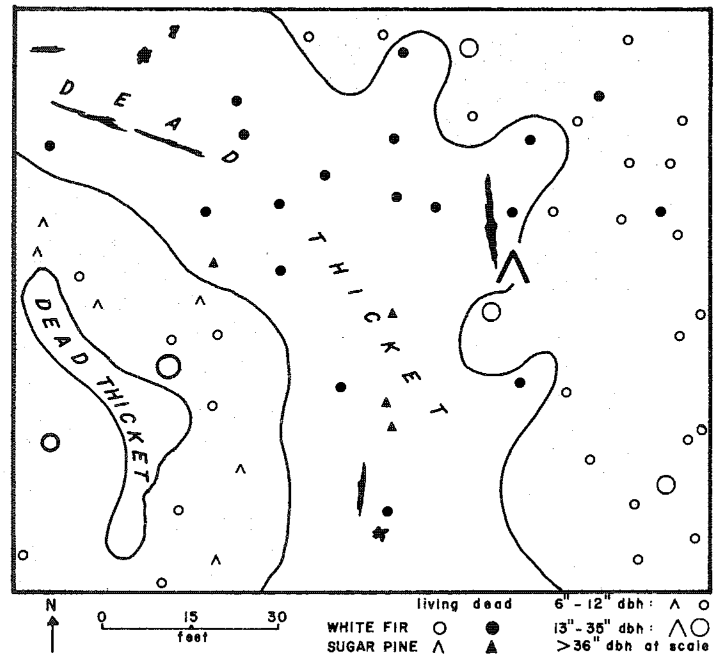

FIG. 8. After prescribed burning on the same ¼-acre area, understory trees have been killed in a swath where heavy fuels were located. In this particular area, heavy fuels were reduced by more than 80 percent, and about half of the understory canopy was opened. Snags were reduced to charred stumps or cavities. The photos in Figs. 4 and 5 were taken from the top of these sketches, looking south. Sketch by Dan Taylor

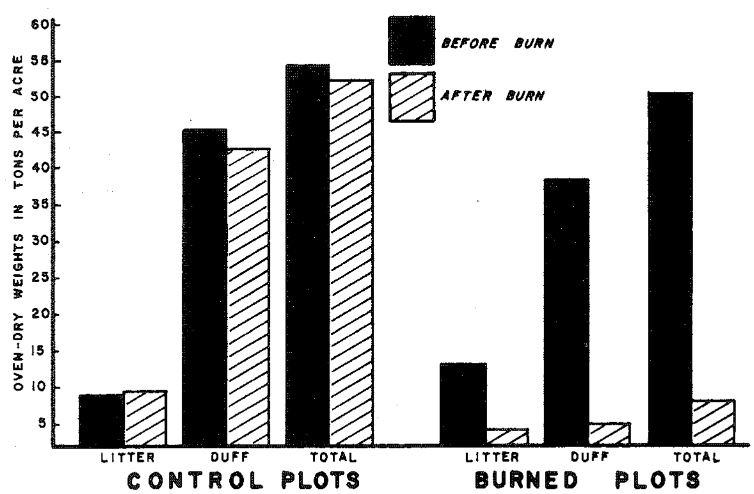

FIG. 9. Litter and duff weights before and after burning, Redwood Mountain.

TABLE 2. PERCENTAGE FREQUENCY* FOR HERBACEOUS AND SHRUB SPECIES BEFORE AND AFTER BURNING.

Species	Experimental plots 1969	Experimental plots 1971	Control plots 1969	Control plots 1971
Disporum Hookeri	0.5	—	4.0	3.3
Corallorhiza maculata	0.5	—	0.7	0.7
Goodyera oblongifolia	4.3	—	4.0	1.3
Habenaria unalascensis	—	—	0.7	—
Pyrola picta	5.7	1.0	2.0	0.7
Draperia systyla	2.4	5.2	0.7	0.7
Mertensia ciliata	0.5	—	2.7	1.3
Osmorhiza chilensis	—	—	0.7	—
Gallium sp.	0.5	—	1.3	0.7
Hieracium albiflorum	—	—	1.3	1.3
Unknown sp.	—	2.4	—	—
Unknown mosses	—	17.6	—	—
Grasses				
Carex sp.	—	—	—	0.7
Unknown grass	—	—	0.7	—
Shrubs				
Arctostaphylos patula	—	1.4	—	—
Ribes roezlii	0.5	4.3	—	—
Chamaebatia foliolosa	1.0	—	—	—
Rosa sp.	—	—	0.7	0.7
Ceanothus integerrimus	—	4.3	—	—
Ceanothus parvifolius	—	6.2	—	—
Symphoricarpos acutus	—	—	4.7	2.7

* Percent frequency values for 210 microplots in 7 burn plots and 150 microplots in 5 control plots.

47 6 ft^2 samples ranged from 84 to 413 ounces before burning.* After burning, control plot weights remained almost the same, while burned plot weights had decreased considerably. Preburn measurements indicated that the total litter and duff fuel was more than 50 tons/acre. Following burning, litter fuels were reduced by more than 75 percent and duff fuels by more than 85 percent, giving a total postburn weight of 7.7 tons/acre.

*Three samples which included buried, partially decayed log material ranged from 444 to 551 ounces.

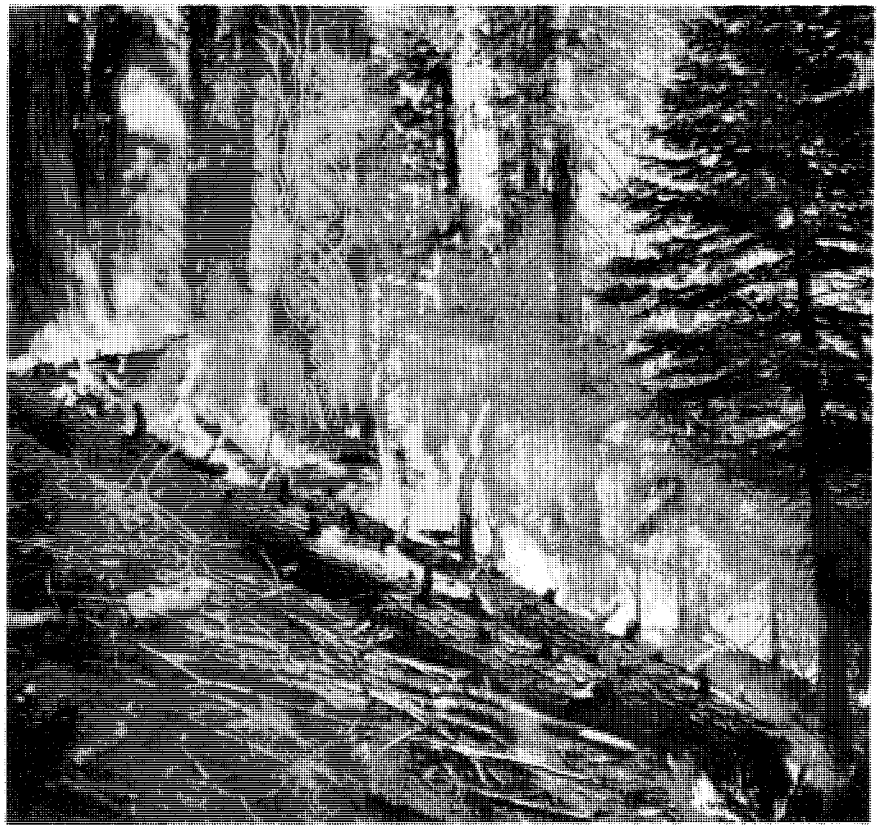

FIG. 10. Heavy fuels were consumed in the prescribed burns at Redwood Mountain causing a reduction in log fuel weights from 12.8 to 2.8 tons/acre. National Park Service photo by Bruce M. Kilgore

More extensive sampling showed the following changes:

	Preburn (1970)	Postburn (1971)
Mean depth of litter and duff	3.10″	0.51″
Mean depth of branches and twigs	2.01″	0.68″
Mean coverage of branches and twigs (in % of ground 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%

Depth of organic material on the forest floor had thus been substantially reduced. While most of the less than 1 inch diameter twigs and branches were consumed in the fire, the postburn coverage by such branches and twigs has remained fairly high because a considerable number of new small twigs have fallen from white fir killed in the burn.

Fire also reduced volume of big fuels, logs and branches more than 6 inches diameter, from 45 to 95 percent on most plots (Fig. 10). The estimated log fuel weights decreased from 12.8 to 2.8 tons/acre (Fig. 11).

FIG. 11. Tempilaq unit at the base of a 7-inch dbh white fir sapling during the prescribed fire at Redwood Mountain. The fire is burning in a thin veneer of limb, twig, and needle litter which overlies a duff layer. Flames of this intensity recorded 500°F and did not kill the tree. National Park Service photo by Dan Taylor

Erosion

Soil erosion appears to be negligible on all burn plots (Fig. 12). No evidence of rill or sheet erosion has been observed since the burn, and many of the 90 erosion spike installations have recorded no changes. About 19 percent of the spikes have recorded minor settling, up to ¼-inch. It is likely that a great deal of this is the result of the collapsing of pockets made by the combustion of organic matter in the soil. Ten of the spikes recorded soil movement from ½-inch to 1¼-inches. Six of these were on a 55 percent slope, but most likely movements were the combined result of exposure of the soil through burning, including some possible settling from raindrop impact, and soil trampling by researchers.

Cost of Burning

Research-related expenses on these study plots were considerable because of extensive preburn and postburn measurements of vegetative characteristics of the plots. Burning costs required in a similar management burn, however, would be far less. Such costs included 16 man-hours of preburn line cutting, 28 hours (7 men $\times$ 4 hours) during the burn itself, and 4 hours of night patrol. Assuming supervisory time as GS-9 ($5.84/hour) and other labor as GS-5 ($3.87/hour), labor costs were $178.16 or $35.63/acre. With vehicle costs and 15 gallons of torch fuel, the total prescribed burning costs ran about $38.43/acre. Costs on larger acreage burns should be less.

DISCUSSION AND CONCLUSIONS

We speak of "restoring natural environmental conditions" to the forest, but what are "natural conditions"? Can "natural conditions" be arbitrarily defined by a researcher or manager? Or are such conditions determined by the interaction of processes, some of which we can identify and some of which we cannot? Defining "natural conditions" seems difficult if not impossible. Our ultimate objective in the sequoia-mixed conifer forest, therefore, should not be to restore a certain abstract condition, but rather to permit all natural processes to operate.

The process most pertinent to this study, of course, is lightning

FIG. 12. Before burning (above) this site was covered with heavy limb, decaying log, and snag fuels. After burning (below) most of the heavy fuels had been reduced to ashes. Such a mineral soil and ash layer is ideal for germination of many tree seedlings, including sequoia. National Park Service photos by Bruce M. Kilgore (above) and Dan Taylor (below.)

fire. Before we can allow this process to again play its normal role, the man-caused increases in fuels in the sequoia-mixed conifer forest permitted by fire suppression now require man-caused reductions in such fuels, probably by prescribed burning. During this interim period, while we use prescribed burning to reduce fuels, there remain a number of important decisions confronting the wildland manager: How often should an area be burned? What prescription is appropriate? How much fuel accumulation indicates the need to prescribe burn again? What amount of habitat diversity is optimum for wildlife and what actions can best simulate "naturalness"?

A comparison which should be helpful in answering these questions is the difference in results obtained on a hotter 1969 management burn (Kilgore and Biswell 1971) as compared with the milder 1970 research burn reported here. An indication of the existing weather conditions and burning indices in the two cases is found in Table 3.

Some of the major differences on the hotter 1969 burn were: (1) many trees up to 24 inches dbh were killed and a larger proportion

TABLE 3. COMPARISON OF WEATHER CONDITIONS AND BURNING INDICES* INVOLVED IN DIFFERENT INTENSITIES OF PRESCRIBED BURNS IN A GIANT SEQUOIA-MIXED CONIFER FOREST.

Weather element or burning index	1969 burn: (8/19-9/11) Sector 1	2	3	4	5	1970 Burn (11/23-24)	RX Range
Temperature	65/70	67	72	70	68	58	
Rel. Humid.	63/49	49	38	51	49	20/38	
Wind	3/1	4	3	3	3	0	
Fuel Stick Moisture	9.5/9	9	8	9.5	10	10	
Fine Fuel Moisture	10/7	8	6**	8	8	5**	7 to 10
Spread Index	5/6	7	9	7	7	8	5 to 12
Intensity Index	45	45	53**	49	46	56**	37 to 49
Timber Burning Index	3	4	6**	2	4	5	3 to 5
Ignition Index	11/39	29	49	30	29	55**	15 to 49

* The indices used here are from the California Wildland System (USDA Forest Service Unpubl.) and not the more recent National Fire Danger Rating System (Deeming, et al. 1972).

** These elements were out of this particular prescription on the hot side.

of the 6 to 12 inch dbh size class were killed; (2) sizeable openings in the canopy were created and more sunlight could reach the forest floor; (3) surface fuels were more completely consumed. In 1971, sampling results on the 1969 burn revealed less fuels than found on the lighter 1970 burn, even though there had been an additional year of accumulation of needles and twigs; (4) crown fire potential presumably decreased to a greater extent (Fig. 13); (5) fire charred the bark on sequoia and other trees to a much greater height; (6) seedbed conditions for sequoia germination were better; (7) the higher intensity burn, coupled with preburn felling of small white fir, gave a more uniform appearance to the area, resulting in less diversity of habitat than is now found on the lighter burn; (8) smoke from the hotter burn presumably rose in a convection column which carried away particulate matter more effectively than under cooler, more moist conditions; and (9) burning costs were considerably greater because of intensive preburn preparation (Kilgore, 1970).

There are thus definite advantages to the hotter burn, but there are also disadvantages. Control of burning is more difficult under the hotter August-September conditions. Scorching of trunks of sequoias up to 50 feet probably has little adverse impact ecologically, but it may be unacceptable esthetically at this time to some segments of the public. The convection column of heat from heavy burning beneath sequoias on the hottest section of the 1969 burn apparently dried out and killed sequoia needles more than 100 feet up on three trees. While this may have helped open sequoia cones and contributed to heavy seed fall, such intense burning would seem to be at the upper margin of a reasonable prescription. With a hotter burn, it is possible that some mature sequoias could have been killed, an undesirable result in present prescribed burning programs.

Assuming that our ultimate objective is the restoration of natural enviromental processes, we have a choice in prescription and frequency of burning. We can burn fairly hot, using an approximation of the 1969 conditions, and then follow in about 7 to 10 years with a more moderate burn to clean up trees which have become part of the litter layer after being killed in the first burn. Or we can carry out two lighter burns, in closer sequence, under something like the 1970 conditions, in order to more gradually kill the young

FIG. 13. Highly porous fuel conditions before burning (above.) Besides the surface fuels, this site was characterized by partially suspended dead trees and by many dead lower limbs on living trees. Such fuel conditions can pose a serious crown fire hazard. After burning (below) there was a significant reduction in all types of fuels. Note the consumption of the big log in the left middle ground. National Park Service photos by Bruce M. Kilgore (above) and Dan Taylor (below.)

white fir and clean up heavy fuels. The first burn might kill most trees less than 15 feet tall, while the second burn under somewhat hotter conditions might make more impact on understory trees up to 12 or even 24 inches dbh, thus allowing development of larger openings in the forest. These burns would in turn need to be followed by a third burn in a decade or so to clean up boles of those trees that come down after the second of the two burns.

Once the abnormal fuel accumulation has been removed, the intervals between subsequent burns and the timing of burns could be set by nature or could follow patterns of intervals known to exist in pre-European man eras. Lightning-caused fires would no longer be regarded as a threat to this particular sequoia forest area. Rather, they might well be viewed as the important natural phenomena they are and be incorporated more reasonably into park interpretive programs.

The special problem of shrub response to a series of fires in this forest type is one which requires more study. In southern California chaparral, Vogl and Schorr (1972) found that mortality was high among ceanothus seedlings which germinated following burning; the authors concluded that these lower elevation species of ceanothus had a short life span and a life cycle controlled by fire. In coniferous forests, seedlings of nonsprouting shrubs like ceanothus may be killed by a second burn taking place before these plants have opportunity to grow seeds (Biswell 1967). If a fairly complete initial burn stimulates germination of most of the soil reservoir of ceanothus seeds, few may remain in the soil when a second burn takes place. Thus from a shrub-wildlife standpoint, an early second burn may prove undesirable. On the other hand, a fairly intense original burn provides a period of protection from another fire. A light second burn would likely create a patchwork of burned and unburned areas with shrubs surviving in the unburned spots. In any event, unless a sizeable opening is created in the forest canopy, shrubs seem to have relatively little chance to establish themselves in any major way. For example, in the heavily burned area just uphill from a 62-inch dbh sugar pine on plot 8, an area of dead understory roughly 70 feet by 70 feet was created (Fig. 8). This has potential for becoming the largest opening on the burned area. The opportunity for establishment and survival of shrub and herbaceous species is perhaps greater here than in any other area of the burn.

The above conclusions about prescriptions, timing of burns, and sequence of burns are based partly on results from this study; but they go beyond the facts gathered and incorporate the best subjective judgment available. As such these conclusions form part of a management hypothesis which must be continually checked in the field. Such monitoring of management program results will allow a gradual refinement of prescription to determine whether a somewhat hotter or cooler fire gives the best results. Studies now underway on fire frequency will offer better evidence about what interval in the hypothesized 8 to 20 year frequency range generally seems to result in a set of conditions which lead to burning in this forest type. In that the forest usually burns when conditions are "right," our task is to determine how often this happens in a sequoia-mixed conifer forest.

Practical considerations relating to air quality in the adjacent San Joaquin Valley will also temper prescribed burning programs carried out in Sequoia, Kings Canyon, and Yosemite National Parks. It has been pointed out before (Kilgore 1971c), however, that the possible additional contribution of particulates to the atmosphere cannot be reasonably used as an argument against prescribed burning.

The choice is not whether to burn or not to burn; the choice is merely when, how, and under what conditions. Fire *is* a part of the giant sequoia-mixed conifer forest ecosystem, regardless of what man may wish or attempt to do about it. In the absence of prescribed burning, wildfires will burn. If fuel levels and successional processes are returned as nearly as possible to that which was found prior to the impact of our fire suppression efforts, then perhaps lightning fires will once again be effective in maintaining the natural cycling of nutrients and energy within this ecosystem. But until this has taken place, prescribed burning in this forest type seems essential.

SUMMARY

A 5-acre experimental plot was burned in November 1970 under the following conditions: temperature, 58°F; relative humidity, 20

percent; fuel stick moisture, 10.0; wind, 0; slope conditions, 35 percent, east-facing. Basal temperatures of more than 1000°F were recorded on a number of small white fir and sugar pine; a more accurate index to lethal conditions for these small trees, however, seemed to be a record of temperatures reaching 250°F at 6 feet or more in the canopy.

This prescribed burn killed more than 87 percent of white fir and sugar pine saplings and 38 percent of trees between 6 and 12 inches diameter. Only one tree greater than 12 inches diameter was killed. This apparently adjusted the successional pattern by reducing the numbers of surviving white fir to more nearly approach the proportion found in the mature age class, a class which germinated under prefire suppression conditions. While understory cover diminished significantly, the amount of sunlight reaching the forest floor increased only slightly because of the almost continuous crown canopy provided by the mature overstory. No tree seedlings were found after this late fall burn because rain and snow immediately after the fire prevented seeds from reaching the mineral soil.

Coverage and frequency of shrubs, grasses, and herbaceous plants were extremely low, both before and after burning. The general scarcity of ground cover may be related to lack of fire during the past 60 to 80 years and the resulting closed canopy. Species which were obviously favored by conditions following fire included *Arctostaphylos patula*, *Ceanothus parvifolius*, *C. integerrimus*, and *Ribes roezlii*, the first three of which offer considerable potential as browse plants for deer.

Litter and duff fuels were reduced from a preburn 50 tons/acre to 7.7 tons/acre following burning. Combined with a major decrease in understory trees, this presumably caused a significant decline in the potential for crown fires in this giant sequoia-mixed conifer forest.

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