Crown-Fire Potential in a Sequoia Forest after Prescribed Burning[1]

BRUCE M. KILGORE and RODNEY W. SANDO

Abstract. Prescribed burning in a giant sequoia-mixed conifer forest reduced the potential for high intensity surface fires and crown fires. Based on three burned plots and three control plots, fuels on the ground were reduced from 203.5 to 30.1 tonnes/ha, while live crown fuels were reduced from 18.0 to 7.8 tonnes/ha. The lowest segment of the forest crown having more than 45.4 kg of fuel per 30.5 cm per 0.4 ha increased from about 0.9 to 4.9 m. Fuel complex porosity for the unburned plots indicates little chance of a sweeping crown fire independent of a surface fire, but heavy ground fuels can support a fire of intensity sufficient to burn individual tree crowns. Under preburn fuel and severe weather conditions, a wildland fire spread mode1 predicted a forward rate of spread of 3.8 cm/sec for a ground fire and a reaction intensity of 28.8 cal/cm'/sec. After prescribed burning, the same model predicted a spread rate of 0.05 cm/sec and a reaction intensity of 0.25 cal/cm^2/sec. Surface fuels accumulate again rapidly. The longer term impact of prescribed burning was killing smaller trees and the lower levels of live crowns in larger trees, thus removing fuel from the intermediate layer between surface and crown fuels. Forest Sci. 21:83-81.

CROWN FIRE is a major threat to the continued existence of a giant sequoia-mixed conifer forest. The probability of a surface fire moving into the crowns of giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchh.) in a given mixed conifer forest is increased by an understory of young saplings – particularly white fir (*Abies concolor* [Bord. 4 Glend.] Lindl.). With their low-hanging branches, such saplings form an almost continuous fuel supply from ground level to their tops–3 to 15.3 m (10 to 50 ft) high. Frequently there are thickets beneath larger trees which extend to 30.5 m (100 ft) or more in height; these larger trees frequently reach the 1ower crown of mature trees (from 54.9 to 76.3 m or 180 to 250 ft tall). This ladderlike arrangement of fuels creates a high potential for a fire to pass from surface fuels into sequoia crowns. Unlike its close relative, the coast redwood (*Sequoia sempervirons* [D. Don] Endl.), the giant sequoia will not sprout; hence, if all needles are killed by crown fire, the tree will die.

In the past, small undergrowth trees were readily killed by light surface fires which regularly moved through these forests (Kilgore 1973b). A continuous fuel layer from ground to crown was thus largely prevented by the normal fire regime found in most of the Sierra Nevada mixed conifer forest. More effective wildfire suppression programs have prevented light surface fires which would have eliminated all-but a few young trees. Thus the fuel complex has changed (Biswell et al. 1968, Wilson and Dell 1971) and the potential for crown fire has increased.

It is important to distinguish two different forms of forest fires commonly referred to as crown fires. The first and most destructive occurs when fuel and weather allow fire to spread between individual tree crowns – either with or without surface burning. The second occurs when tree crowns burn individually and is commonly termed "crowning out" or "torching" (Davis 1959). Both forms pose a threat to the sequoia overstory.

Crown-fire potential is a function of the quantity and arrangement of fuels. Surface fuels play an important role in the development of crown fires. Van Wagner (1968a) concluded that crown fires in red pine plantations are extremely unlikely unless supported by fires in lower strata. On the other hand, fuel types with certain physical or chemical characteristics have been known to support crown fires independent of surface fires under extreme environmental conditions, usually including strong winds. The majority of crown fires, including those in sequoia-mixed conifer forests, generally burn in conjunction with surface fires.

The reduction of crown-fire potential in the sequoia forest may be accomplished by removing some surface fuels or intermediate level and crown fuels up to some ”safe” level not ignitable by fire in surface fuels. This may be accomplished by low intensity prescribed burning under weather and firing techniques that prevent crown fires.

The purpose of this study was to determine how the potential for crown fires in a sequoia-mixed conifer forest was affected by the moderately intense prescribed burning conducted in November 1970, at Redwood Mountain, Kings Canyon National Park, California (Kilgore 1973a). The study area, the methods employed, and the results obtained, are described together with a discussion of the short-term and long-term potential for crown fires following prescribed burning.

Study Area and Methods

Data related to crown fire potential were collected in 1971 and 1972 on six of the 18.3 x 30.5-m (60 X 100-ft) study plots described in earlier work (Kilgore 1973a). Three were control plots and three plots had been burned in the November 1979 prescribed burn. The plots were slightly east of the ridge of Redwood Mountain, Kings Canyon National Park, California, at 2013 m (6600 ft) elevation. The climate, soils, vegetation, and previous human impact on the area were described in the earlier work. In general, this largest grove of giant sequoias includes the usual southern Sierra mixed-conifer forest species, namely white fir, sugar pine (*Pinus lambertiana* Dougl.), ponderosa pine (*Pinus ponderosa* Laws.), and some incense-cedar (*Libocedrus decurrens* Torr.) and California black oak (*Quercus kelloggii* Newb.).

The method of describing the crown fuel complex was that of Sando and Wick (1972) in which bath weight and volume of crown fuel and its physical location are determined. Trees in two diameter categories – more than and less than 2.5 cm (1.0 in) dbh – were measured on six 0.004-ha (0.01-acre) subplots systematically located within each macroplot; mature giant sequoia were not included. Each tree was identified by species, and measurements were made of diameter, height, and crown length and -crown width. These measurements were used to supply data for species

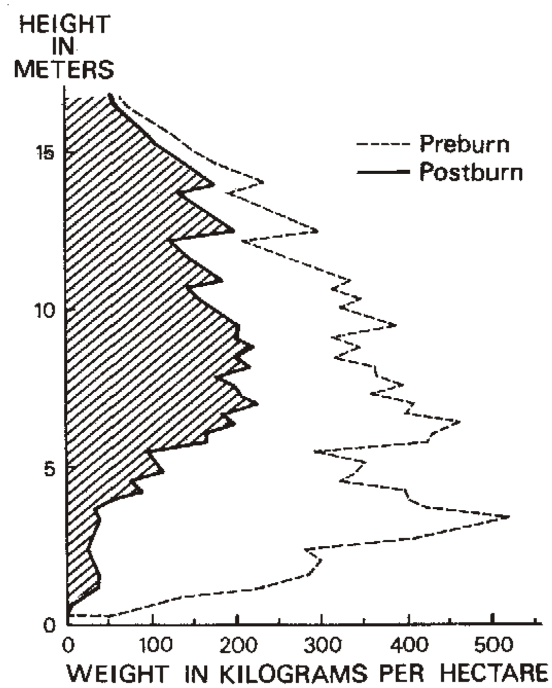

FIGURE 1. *Vertical distribution of oven-dry crown weight before and after burning in a giant sequoia-mixed conifer forest.*

regressions that predict oven-dry weight of crown material (Storey et al. 1955, Fahnestock 1960). The final weight values were apportioned depending on the physical dimensions of each tree and then graphed by computer (Fig. 1), thus giving a graphica1 representation of the vertical distribution of live crown materials less than 6.4-cm (2.5-in) diameter. The assumptions involved in this method are noted in Sando and Wick (1972).

In order to convert these data from a graphical form to an integrated quantitative form, two indices are used: the crown volume ratio (CVR) and the mean height of crown base (MHCB). CVR is defined as the ratio of the total space from ground to treetop level to the space occupied by the live tree crowns themselves. MHCB is defined as the height below which no 0.3-m (1-ft) interval has more than 112.4 kg/ha (100 1bs/acre) of crown fuel.

Surface fuels were sampled 8 months after the November 1970 fire using the line intersect method,(Van Wagner 1968b). Some post-fire accumulation had already occurred. Eight transects, 7.6 m (25 ft) long, were run in each macroplot. The

TABLE 1. Weights of ground fuels before and after prescribed burning in a giant sequoia-mixed conifer forest.

Fuel	Preburn			Postburn		
	Weight per hectare	S.D.	$SE_{\bar{x}}$	Weight per hectare	S.D.	$SE_{\bar{x}}$
	Tonnes			Tonnes		
Litter	3.8	1.5	0.2	0.8	1.0	0.1
Duff	94.4	50.1	3.2	11.7	14.7	1.0
Class I[1]	1.2	.9	.1	.4	.3	(2)
Class II[1]	2.4	1.7	.1	.5	1.1	.1
Class III[1]	4.2	7.3	.6	1.7	5.0	.4
Greater than 6.4 cm	97.5			15.0		
Total	203.5			30.1		

[1] Mean diameters used for particle size classes are as follows: Class I, 0.38 cm; Class II, 1.22 cm; Class III, 3.51 cm.
[2] Less than 0.05.

diameter of each piece of fuel more than 6.4 cm (2.5 in) in diameter was recorded along all of the transects, while the smaller-sized fuels were measured only on the last 0.9 m (3 ft) of each transect. Small-sized surface fuels were grouped into three classes: (1) less than 0.64 cm (0.25 in); (2) 0.64 to 1.9 cm (0.75 in); and (3) 1.9 to 6.4 cm (2.5 in). Average diameters for each class are presented in Table 1. Larger surface fuels were put in the nearest 2.5-cm (1-in) diameter class. Depth and weight of duff were already available (Kilgore 1973a).

Results

The fire burned on November 23 – 24, 1970, when the air temperature was 14.4 C (58’F), relative humidity was 20 percent, fuel moisture levels were 10 percent, and there was essentially no wind (Kilgore 1973a) . Before burning, the forest floor was covered with a large volume of dead fuel. The surface litter layer was well developed from needles and small woody material. In addition, large fallen logs were abundant. The duff layer was also well developed and sometimes over 15.3 cm (6 in) deep. The weight of these surface fuels totaled 203.5 tonnes/ha (81 tons/ acre) before burning (Table 1) . These fuels accumulated in the absence of fire and provided ample fuel for an intense surface fire.

Live crown fuels in the lower 16.8 m (55 ft) of the stand were also abundant before burning (Table 2, Fig. 1) . The base of the live crown fuel complex was close to the ground as represented by the MHCB.

Following the fire, the fuels were substantially reduced (Tables 1 and,2) . Much of this change involved heavy ground fuels and duff which burned slowly after the main fire front had passed. Nevertheless, live crown fuels in the lower canopy were reduced more than half, and the MHCB increased substantially (Fig. 1 and Table 2).

Discussion

The impact of the prescribed burning on the live crown fuels is difficult to assess. The CVR was 108 before burning and 142 after burning, reflecting the open character of the fuel complex. By comparison, red pine plantations and jack pine stands described by Sando and Wick (1972) had CVR’s of 10.5 and 3.0 respectively. The packing ratio (B) or ratio of

TABLE 2. Crown fuel characteristics before and after prescribed burning in a giant sequoia-mixed conifer forest.

Characteristic	Preburn	Postburn
Live crown weight—		
Tonnes per hectare	18.0	7.8
Tons per acre	7.2	3.1
Crown volume ratio (CVR)	108	142
Mean height crown base (MHCB)—		
Meters	0.9	4.9
Feet	3.0	16.0

TABLE 3. Distribution of representative packing ratios in a sequoia forest before and after prescribed burning.

Height above ground		Packing ratio (B)	
Meters	Feet	Unburned	Burned
1.5	5	0.000177	0.000028
3.0	10	.000289	.000023
4.6	15	.000204	.000049
6.1	20	.000276	.000107
7.6	25	.000249	.000127
9.1	30	.000199	.000128
10.7	35	.000198	.000091
12.2	40	.000133	.000079
13.7	45	.000122	.000083
15.2	50	.000092	.000070

actual fuel volume to maximum possible fuel volume may be used to express fuel bed porosity (Countryman and Philpot 1970). We calculated the live crown packing ratio for each 1.52-m (5-ft) stratum in the lower 15.2 m (50 ft) of the stand before and after burning (Table 3). The low 8 values at all levels reflect the relatively low crown weights found in this stand.

Porosity values for the unburned stand and the relatively high CVR indicate there is probably little likelihood of a sweeping crown fire in this stand independent of a fire in surface fuels. However, surface fuels will support a fire of considerable intensity which might cause “torching” of individual tree crowns. Because of the restricted range and great age of giant sequoia, individual tree loss, when brought about by an abnormal accumulation of ground fuels, represents a critical threat.

Two important questions needing answers are: (1) what surface fire intensity will the fuels on the untreated area support under wildfire conditions, and (2) what impact on fuel reduction has been accomplished by prescribed burning? To answer these questions, we utilized the fire spread model developed by Rothermel (1972). Rothermel presented eleven different fuel models which may be used to represent most fuel types. The appropriate model for the sequoia forest is timber with litter and understory. The preburn reaction intensity of 28.8 cal/cm’/sec (6367 BTU/ ft’/min) derived from our data is somewhat higher than the

TABLE 4. Fire spread model results before and after prescribed burning in a giant sequoia-mixed conifer forest.

Item	Preburn	Postburn
Forward rate of spread—		
cm/sec	3.8	0.05
ft/min	7.5	0.1
Reaction intensity—		
cal/cm^2/sec	28.8	0.25
BTU/ft^2/min	6367	55

18.1-cal/cm’/sec (4000-BTU/ft’/min) reaction intensity derived for this fuel model under similar ambient conditions by Rothermel. This could be due both to fue1 type and accumulation under recent fire suppression policies of the area. It indicates potential for high intensity surface fires in the preburn sequoia stands studied and, combined with the low preburn height of the base of crown fuels, a consequent high potential for crowning out or torching of individual trees – including giant sequoia.

Using preburn and postburn ground fuel measurements (Table 1) and relatively extreme conditions for wildfires of 4 percent fine fuel moisture and a wind speed of 2.2 m/sec (5 mph), the Rothermel fire model predicted a substantial decrease in the forward rate of spread in ground fuels and reaction intensity following the prescribed burn (Table 4). These predictions represent essentially no forward spread under extreme conditions. Thus fuel reduction accomplished by the prescribed burning greatly reduced the potential for high intensity surface fires that could lead to crown fires – even under relatively extreme ambient conditions. The reduction of crown fire potential in these stands by prescribed burning has both short-range and long-range implications. Short-range reduction is accomplished through combustion of surface fuels. However, these fuels will promptly re-accumulate and will soon approach their former volume, perhaps in 5 to 8 years. Furthermore, the fuels from the standing trees killed by the fire will fall to the ground in 2 to 5 years and will accelerate the surface fuel accumulation process. This calls for multiple prescribed burns to reduce crown fire potential.

Long-range impact of the prescribed burning will be the reduction of live crown fuels at lower levels within the stand. The fires killed many small trees and lower crowns of larger trees (Fig. 1). The encroachment of shade tolerant species will continue in the absence of fire, of course. However, the fire removed much advance reproduction of shade tolerant species, and it may take 25 to 50 years for the fuels to develop to their former condition.

Conclusions

High intensity surface fires with associated ”crowning” or ”torching” of individual trees and clumps of reproduction threaten giant sequoia overstory. Although it has dramatic impact, a single prescribed burn is not sufficient to reduce this threat over a long time period. After long fire exclusion, several repeated burns, perhaps every 5 to 8 years, will be required to sufficiently reduce the existing volume of crown material in the understory, followed by periodic burns at longer intervals (probably 8 to 20 years) to prevent the development of dense growth of shade tolerant white fir so characteristic of a sequoia forest without fire. Ideally, initial efforts would be followed by prescribed burns or natural fires at intervals duplicating natural fire frequency.

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