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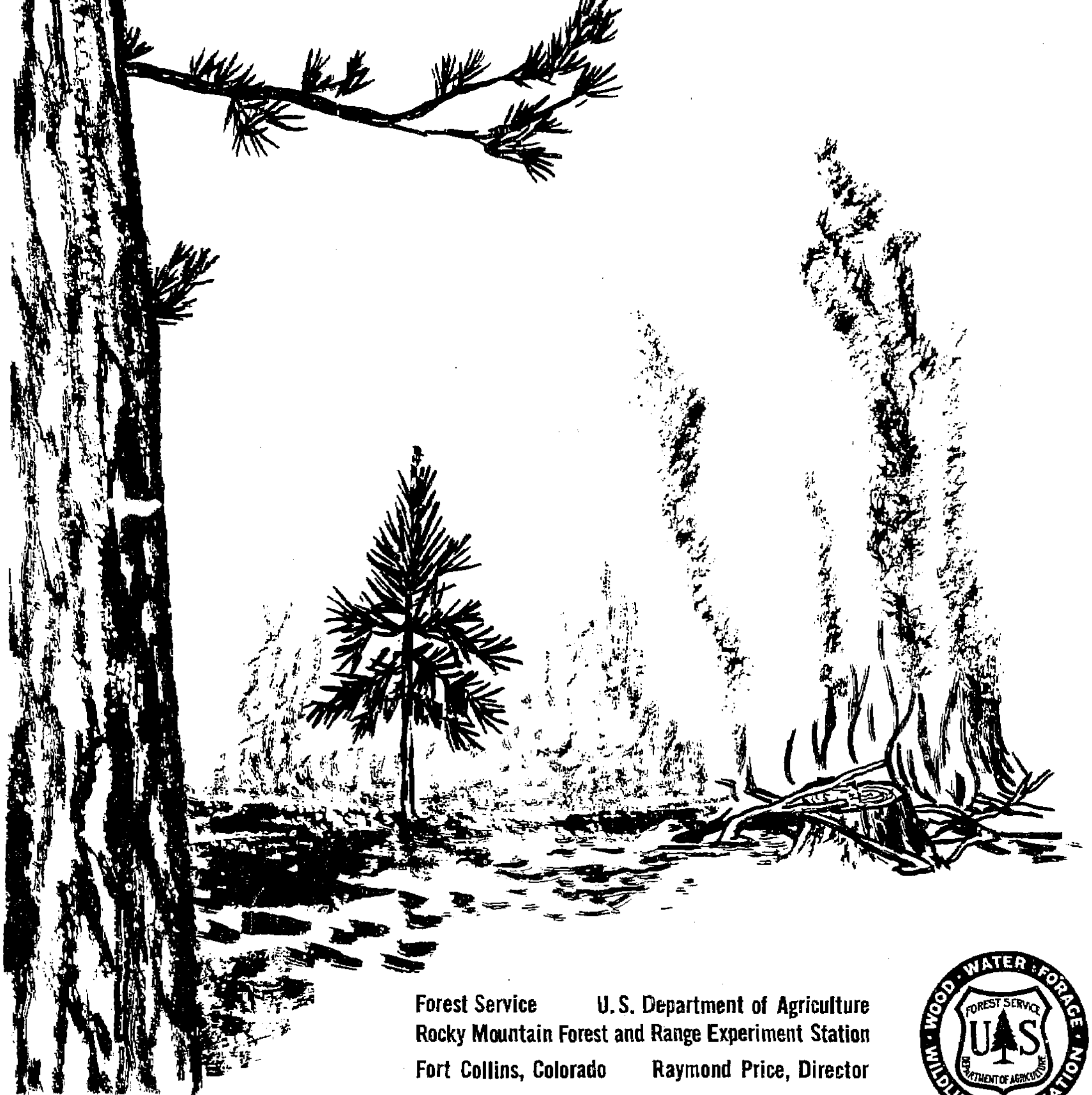
A Survey of Effects of Intentional Burning on Fuels and Timber Stands of Ponderosa Pine in Arizona

by

A. W. Lindenmuth, Jr.



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Rocky Mountain Forest and Range Experiment Station
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A SURVEY OF EFFECTS OF INTENTIONAL BURNING ON FUELS AND TIMBER STANDS OF PONDEROSA PINE IN ARIZONA[1]

by

A. W. Lindenmuth, Jr.[2]

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[1] The survey was a joint undertaking of the Bureau of Indian Affairs, U. S. Department of the Interior; the Southwest Lumber Mills, Inc.; the Southwestern Region of the U. S. Forest Service, and the Rocky Mountain Forest and Range Experiment Station.

[2] Project leader for forest fire research, Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, with headquarters at Colorado State University in Fort Collins.

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INTRODUCTION

Limited intentional burning of ponderosa pine timberlands to achieve net benefits has been going on for years. Many statements of results have been published. Most statements have been based on small plot records or subjective observations. Hence, the statements have been questioned by some readers and have led to debate over the merits of intentionally burning ponderosa pine timberlands.

The intentional burning of approximately 27,000 acres of ponderosa pine timberlands on the Fort Apache Indian Reservation in east-central Arizona in the fall of 1956 provided an opportunity to learn more about results. The burning was done by experienced men during weather that they considered favorable.

The burn was surveyed in the fall of 1957, using 6,666 sample points uniformly distributed over the area. The survey was concerned only with the influence of the burning on fuels and timber stands, and not with the influence of the burning on other resources of the land.

THE STUDY AREA

The area studied consisted of two geographic units. One unit of approximately 15,000 acres surrounds the town of McNary, Arizona, at an elevation of about 7,300 feet. The topography is relatively gentle. The timber is commercial ponderosa pine that was selectively cut 35 years before the intentional burning. About 5 miles to the east of the McNary unit, are the Blue Mountain plots studied by Gaines, Kallander, and Wagner (1958).

The other unit of approximately 12,000 acres surrounds the community of Maverick, about 30 miles airline from McNary. It lies at an elevation of about 7,800 feet. The climate is somewhat cooler and wetter than in the McNary unit. Spruce and fir are mixed with the ponderosa pine on some sites. The topography, although somewhat rougher than in the other unit, is still relatively gentle. About 54 percent of the area in this unit was selectively cut in 1950, 1952, 1953, 1955, and 1956 before the fire. The other 46 percent of the area had never been cut. Data for the Maverick unit are separated by area cutover and area uncut, and are referred to as the Maverick cut unit and Maverick uncut unit.

Past management practices influenced the stands and the fuels on the three areas in a way that may have affected the results of burning. Partial cutting of the McNary unit 35 years earlier had apparently permitted the understory trees to grow larger than on the Maverick units (table 1). The Maverick cut unit contained slash 1 to 6 years old; the uncut unit was virgin.

Table 1. --Distribution of potential crop trees [1] by size classes, burned area only

Study area	Size class: 0-4.5 ft. high	4.6+ ft. high, 3 in. d.b.h.	4 to 7 in. d.b.h.	8 to 11 in. d.b.h.	Total	Trees sampled
	Percent					No.
TYPICAL STANDS						
McNary	5.9	21.6	40.6	31.9	100.0	1,848
Maverick, uncut	19.3	28.0	34.3	18.4	100.0	798
Maverick, cut	14.8	35.2	33.0	17.0	100.0	851
DENSE STANDS						
McNary	5.4	31.0	47.8	15.8	100.0	297
Maverick, uncut	18.5	42.0	32.5	7.0	100.0	157
Maverick, cut	8.8	43.8	35.0	12.4	100.0	216
ALL STANDS						
McNary	5.8	22.9	41.6	29.7	100.0	2,145
Maverick, uncut	19.1	30.3	34.0	16.6	100.0	955
Maverick, cut	13.6	36.9	33.4	16.1	100.0	1,067

[1] Potential crop trees were understory trees needed to utilize growing space (see table 3).

THE FIRE

Burning continued in all units from November 5 through December 7, 1956, but possibly not every day. The exact areas burned by dates is unknown. Weather conditions are shown in table 2.

Although 1956 was a year of extreme drought in the Southwest, the study area was not abnormally dry during the burning period. Nearly 1 inch of rain on October 28-30 had moistened the fuels. As fuels dry slowly in November and December, especially with the low temperatures that prevailed, both coarse and fine fuels were relatively moist throughout the burning period. No additional precipitation fell except for a trace at McNary on November 20.

Drought Index was constant at 77 on a scale of 100 points by the 2-index system for rating fire danger (table 2). That is at the boundary between the "moderate" class, in which coarse fuels do not burn readily, and the "high" class, in which coarse fuels burn readily. At this level of Drought Index partial and spotty combustion in coarse fuel is normal fire behavior.

Rate-of-Spread Index, the second independent 100-point index of the 2-index system, was "low" (0-15) on all but 2 days, on which it was "moderate" (20-35) (table 2). When Rate-of-Spread Index is "low" fires burn litter slowly or not at all; when it is "moderate" fires show some aggressiveness during midday. Both indexes represent conditions during the midday burning period, which is relatively short in November and December.

The general plan of burning was to ignite the higher elevations to induce the fire to burn downhill. Few, if any, special firebreaks were constructed; natural barriers were relied on. The fire, once ignited, was allowed to burn day and night, within the boundaries of the area to be burned. Where the fire went out it was reset from time to time until the area inside the prescribed boundaries was generally burned over.

Table 2.--Weather conditions during the burning period

Date	Temperature: McNary unit, Maximum	Temperature: McNary unit, Minimum	Temperature: Maverick unit, Maximum	Temperature: Maverick unit, Minimum	Wind velocity,[1] both units	Drought Index, both units	Rate-of-spread Index,[2] both units
	°F.	°F.	°F.	°F.	m.p.h.		
November							
5	45	15	63	10	5-10	77	5
6	57	21	64	20	4- 6	77	5
7	61	27	64	15	--	77	--
8	60	24	62	17	3- 6	77	5
9	58	29	65	15	0	77	5
10	62	20	67	14	1- 3	77	5
11	67	21	69	15	3- 6	77	5
12	68	22	67	14	--	77	--
13	67	22	56	17	8-12	77	5
14	57	23	51	15	--	77	--
15	51	12	54	-1	--	77	--
16	49	11	53	5	--	77	--
17	51	14	58	7	4- 6	77	5
18	57	15	53	7	4- 8	77	5
19	58	17	44	11	16-20	77	25
20	46	16	35	-1	16-20	77	20
21	33	7	57	3	0- 2	77	5
22	52	18	61	8	0- 8	77	5
23	55	17	61	18	3- 5	77	5
24	56	16	53	8	--	77	--
25	53	16	59	15	--	77	--
26	54	15	54	11	2- 3	77	5
27	54	14	55	6	0- 2	77	5
28	57	16	53	10	3-12	77	5
29	45	12	56	5	--	77	--
30	50	15	58	10	0- 4	77	5
December							
1	56	13	62	5	4- 6	77	5
2	62	16	54	9	0- 8	77	5
3	60	15	49	11	0- 6	77	5
4	47	12	52	8	2- 4	77	5
5	50	20	47	15	4- 6	77	5
6	50	35	44	34	0- 8	77	5
[3] 7	43	30	43	16	4- 8	77	5

[1] Visual observations based on Beaufort Scale.
[2] Based on maximum wind velocity.
[3] Rain started in both units.

THE SURVEY

The survey was made in the last week of October 1957, about 1 year after the fire. Main roads were used as base lines from which survey lines were run at quarter-mile intervals in a direction at right angles to the general topography. Observations were made at 2-chain intervals along the survey lines. Thus, on an average, there is one observation for each 4 acres.

At each point the observer:

1. Classified fuel as it probably existed before the fire on a 1/50-acre plot with the observation point as the center. Fuel was classified with respect

to its potential for carrying fire:

a. Not enough fuel to carry fire.
b. Enough continuous surface fuel to carry surface fire; understory not dense enough to carry crown fire except during extreme burning conditions.
c. Enough continuous surface fuel to carry surface fire; understory dense enough to carry crown fire during moderate and high burning conditions. (Any community of pine trees dense enough to be called a stand might support crown fire during extreme burning conditions.)

2. Classified the intensity of the fire, on the same 1/50-acre plot, as indicated by the amount of fuel consumed:

a. Not burned.
b. Light surface fire--$\frac{1}{4}$ inch or more of the litter left; no crowning that created openings 8 feet or more in minimum dimension or enlarged existing openings.
c. Hot surface fire--all litter consumed; no crowning that created openings 8 feet or more in minimum dimension or enlarged existing openings.
d. Crown fire--fire burned over at least 51 percent of the surface of the plot and also flared up into tree crowns enough to create openings 8 feet or more in minimum dimension or enlarged existing openings.

3. Recorded the factor or circumstance that probably caused crowning, where there was enough evidence to identify the cause.

4. Classified the observation point as stocked or unstocked in both overstory and understory before the fire.

5. For each observation point that was stocked before the fire, recorded whether the fire left the stocking unchanged, damaged, or killed.

6. For each potential crop tree, recorded the size of the tree and whether it needed release, and if it did, whether it was released.

Specifications and guides used in classifying sample points were as follows:

Fuels and surface-fire intensities were classified on the basis of condition on 51 percent or more of each 1/50-acre plot.

Stocking was classified independently for both overstory and understory. Trees in the 12-inch d.b.h. class and larger were considered overstory; smaller trees were considered understory. An observation point was classified as stocked if one tree that was living at the time of the fire was close enough to the point to utilize the site. The distance depended on the size of the tree (table 3).

Where more than one tree was close enough to "stock" a point, the observer selected the best tree that qualified, in either or both the overstory and understory, on the basis of dominance, size, vigor, and spacing. The best understory tree that qualified was also considered to be a potential crop tree.

Table 3.--Space that can be utilized fully by trees of different diameters[1]

Size range	Radius of circle	Trees per acre	Basal area equivalent[2]
	Feet	Number	Square feet
Overstory:			
30 inches or larger d.b.h.	33	13	--
20 to 29 inches d.b.h.	26	20	64
12 to 19 inches d.b.h.	18	43	53
Understory:			
8 to 11 inches d.b.h.	13	82	36
4 to 7 inches d.b.h.	9	171	24
4.6+ feet high; 3 inches d.b.h.	6	385	--
Less than 4.5 feet high	3	1,541	--

[1] U. S. Forest Service. A measure of stocking by size classes. Southwest. Forest and Range Expt. Sta. Ann. Rpt. 1950: 16-19, illus. (Processed.) This is not the same as silvicultural optimum stocking. When quality as well as quantity is part of the management objective, more basal area per acre than that shown usually is considered desirable.

[2] Based on median diameter for each class.

If the best tree in either the overstory or understory was damaged or killed by the fire, then stocking was considered to be damaged. Therefore, the rating "damaged" could mean either that the best tree was damaged, or that it was killed and replaced by a smaller, less desirable tree. The stocking of a point was classified as "killed" only if all trees were killed that could qualify according to the specifications in table 3. Any tree living after the fire could qualify if within the prescribed distances irrespective of its size, condition, or position of dominance before the fire.

A potential crop tree was tallied as needing release if the average spacing between it and other trees of the same or higher position of dominance in the understory stand was less than that shown below:

Average stand size (Inches d.b.h.)	Average spacing (Feet)
5 or less	6
6	7.5
7	9
8	10
9	11
10	12
11	13.5

These spacing distances are based on an unreported study made at the Fort Valley Experimental Forest, Flagstaff, Arizona. A potential crop tree needing release was tallied as released if the fire killed one or more competing trees in the same or a higher position of dominance.

The thinning and stocking specifications differed. The stocking specifications were based on the maximum growing space an individual tree could utilize fully. The thinning specifications were based on the minimum growing space in which an individual tree could grow well. A 6-inch d.b.h. tree, for example, can utilize up to 254.5 square feet, according to the stocking specifications, but will do well in 176.7 square feet, according to the thinning specifications. When potential crop trees are spaced wider than the stocking specifications, some of the growing space definitely is not utilized by trees. In managed stands stocking usually is maintained at levels higher than shown in table 3. Estimates of reductions of stocking in this report therefore are minimum.

Eleven men employed by the cooperators in this study made the observations. They were trained to carry out the procedures uniformly.

OPPORTUNITIES FOR BENEFITS AND DAMAGES

Opportunities for two kinds of benefits from intentional burning were considered: (1) reduction of flammable fuels to lessen the chances of damaging wildfires later, and (2) release of potential crop trees in overly dense understory stands. The opportunities for benefits therefore depended upon the proportion of the total area that was occupied by flammable fuels and the proportion occupied by understory stands in need of thinning.

Opportunities for damages are closely related to opportunities for benefits. Neither benefits nor damages are possible on areas that will not carry fire. The intentional burning of fuels that can carry only light surface fire is not likely to cause much damage nor produce much benefit. On the other hand, opportunities for both benefits and damages are great where there is a potential for crown fire over a wide range of burning conditions. Such areas typically have abundant ground fuels and are covered by dense young stands in need of thinning. Benefits would be large if the potential for crown fire could be reduced or eliminated and if potential crop trees could be released from competition. If the intentional fire burns too hot, however, the young stand may be destroyed. If it burns too cool the potential for a future crown fire may be lessened only slightly, and thinning may be negligible.

The proportion of the areas considered to be in different potential fire-intensity classes before the fire is shown in table 4. Only the area within the borders of the fire was included.

The "unburnable" areas included such surface conditions as erosion pavement, rock outcrops, and interior service roads. There were few trees in these areas (table 5).

"Potential surface-fire" areas were the typical ponderosa pine stands composed of a mostly open overstory with scattered clumps of understory trees. The understory was judged to be too thin to support crown fire except during severest burning conditions. Such stands will be called typical stands in this report. Typical stands occupied 80-81 percent of all subdivisions of the area burned (table 4). From 8 to 15 percent of the potential crop trees of typical stands were in need of release (table 5).

Areas almost completely covered by understory trees were classified as "potential crown-fire" areas. Only openings small enough that crown fires could sweep over them were included. These dense stands, known locally as "dog hair" or "jack pine," were judged to be capable of crowning whenever burning was possible. In this report, they are referred to as dense stands. From 9 to 16 percent of the area to be burned was classified in this category (table 4); 20 to 51 percent of the potential crop trees of dense stands needed release (table 5).

Table 4.--Proportion of areas in three potential fire-intensity classes

Study area	Potential fire-intensity class: Unburnable	Surface fire	Crown fire	Total	Acres
	Percent				No.
McNary	10.3	80.9	8.8	100.0	14,532
Maverick, uncut	6.6	80.9	12.5	100.0	5,540
Maverick, cut	4.5	80.0	15.5	100.0	6,592
All units	8.1	80.7	11.2	100.0	26,664

Table 5.--Potential crop trees (sample trees only) in need of release grouped by potential fire-intensity classes and units

Study area	Potential fire-intensity class							
	Unburnable		Surface fire		Crown fire		All intensities	
	No.	Pct.[1]	No.	Pct.[1]	No.	Pct.[1]	No.	Pct.
McNary	4	4.9	332	15.1	139	50.7	475	18.6
Maverick, uncut	2	22.0	68	8.2	44	30.3	114	11.6
Maverick, cut	0	0	119	13.9	30	19.5	149	14.7
All units	6	6.2	519	13.4	213	37.2	738	16.2

[1] Total trees in the sample within each fire-intensity class in each unit = 100 percent.

The dense understory stands capable of supporting crown fire occupied such a small portion of the study area that even though 20 to 51 percent of potential crop trees needed release, they represented but 4.5 percent of the total number of potential crop trees on the nearly 27,000 acres. The growth that could be gained by releasing them or lost by not releasing them was a relatively small portion of the growth capacity of the study area.

RESULTS

Briefly, these are the overall findings of the survey for the total ponderosa pine timberland within the borders of the fire as determined from the sampling:

1. Fire intensity--

	Acres	Percent
Did not burn	5,724	21.5
Burned by light surface fire	14,708	55.2
Burned by hot surface fire	4,628	17.3
Burned by crown fire	1,604	6.0
Total	26,664	100.0

2. Potential crop trees that needed release--16.2 percent of the total number (4,554). Need for release was not tallied for 233 potential crop trees that were killed. Total number refers only to trees sampled, not the total number of trees on the area to be burned.

3. Potential crop trees released--3.5 percent of the total number (4,787).

4. Potential crop trees killed--10.9 percent of the total number (4,787).

5. Potential crop trees damaged--8.1 percent of the total number (4,787).

6. Sawtimber trees killed--0.8 percent of the total number (3,092).

7. Sawtimber trees damaged--6.9 percent of the total number (3,092).

8. Fuel reduction was proportional to fire intensity by definition of the fire-intensity classes.

The overall averages tell only part of the story. They do not show the distribution and variation of effects. For instance, they do not show whether potential crop trees were killed by both light surface fire and crown fire.

In the discussion of effects, the data in following sections are grouped by stand condition, potential fire intensity, actual fire intensity, stand density, and tree size.

ACTUAL FIRE INTENSITY

Eight percent of the ponderosa pine timberland within the borders of the fire was judged to be unburnable (see table 4). Main highways and rights-of-way, gravel pits, public roads, and other nontimberlands were not considered to be within the borders of the fire. Data for the land classed as potentially unburnable are left out of subsequent tables because this land was not affected by the fire.

Of the forest land judged to be burnable, 14.6 percent did not burn, even though the fire was repeatedly reset (table 6). This included 16.2 percent of the area expected to burn by surface fire and 3.2 percent of the area judged to be capable of supporting crown fire.

Data for area judged to be burnable but which did not burn are included in table 6 but are excluded from later tables. Effects on these unburned lands were nil.

Sixty percent of the total burnable area burned by fire of low intensity. Almost two-thirds of the area rated as having a surface-fire potential burned by light surface fire of low intensity. In contrast, only about one-third of the potential crown-fire area burned by low-intensity fire.

High-intensity fire capable of producing major effects (hot surface and crown fires) burned about 25 percent of the total burnable area. This included nearly 20 percent of the potential surface-fire areas and nearly 67 percent of the potential crown-fire areas. Of the area that had a crown-fire potential, 46 to 65 percent actually crowned.

Table 6.--Proportions of areas rated burnable that burned, by types of stands and fire-intensity classes

Study area	Fire-intensity class: Did not burn	Light surface fire	Hot surface fire	Crown fire	Total	Acres[1]
	- - - - - - - - - -	Percent	- - - - - - - - - -			No.
		TYPICAL STANDS				
McNary	21.8	62.4	15.8	--	100	11,760
Maverick, uncut	10.0	65.6	24.4	--	100	4,484
Maverick, cut	8.8	66.9	24.3	--	100	5,276
All units	16.2	64.1	19.7	--	100	21,520
		DENSE STANDS				
McNary	4.0	39.3	8.1	48.6	100	1,284
Maverick, uncut	2.3	34.7	17.3	45.7	100	692
Maverick, cut	2.7	15.7	16.5	65.1	100	1,020
All units	3.2	30.2	13.1	53.5	100	2,996
		TOTAL BURNABLE AREA				
McNary	20.1	60.1	15.0	4.8	100	13,044
Maverick, uncut	9.0	61.4	23.5	6.1	100	5,176
Maverick, cut	7.8	58.6	23.0	10.6	100	6,296
All units	14.6	60.0	18.9	6.5	100	24,516

[1] Acreage figures derived by multiplying the number of plots by 4, which is ratio of total acres to total plots.

The presence of slash in the recently cut unit may have contributed to an increase in the intensity of the fire in dense stands. In dense cutover stands the percentage that burned with light surface fire was lower than in the other units, but the percentage that crowned was higher.

Age of slash may also have influenced actual fire intensity. Although there were not enough observations in each year of cutting to provide a complete comparison by years, there were 456 observations in the 1950 cutting and 1,008 in the 1955 cutting. In typical stands, 36.0 percent burned with hot surface fire in the older slash compared with 18.1 percent in new slash. In dense stands, 78.5 percent of the area actually crowned in the older slash compared with 65.0 percent in new slash. The burn thus appeared more intense in the aged slash.

Crowning showed no consistent relation to size of understory trees (table 7). The percentage that crowned increased somewhat as tree size increased in uncut stands. The trend was opposite in the cut stand; there was a consistent and marked decrease in the percentage that crowned in the selectively cut Maverick unit as tree size increased.

The principal cause of crowning identified was density of understory, with presence of slash a secondary contributing factor. On a small number of plots abundant coarse fuel and favorable topography apparently triggered crowning, but on the large majority of plots the only cause appeared to be density of the understory stand.

Table 7. --Relationship between tree size and plots that crowned. (Total observations include all plots classed as dense that burned by fire of any type.)

Study area	Plots that crowned, by size class				
	0 to 4.5 ft. high	4.6+ ft. high, 3 in. d.b.h.	4 to 7 in. d.b.h.	8 to 11 in. d.b.h.	Average all classes
	Percent[1]				
Uncut units:					
McNary	43.8	50.0	50.0	51.1	49.8
Maverick	48.3	42.4	51.0	54.5	47.1
Average	46.7	46.8	50.3	51.7	48.9
Cut, Maverick	89.5	74.7	64.5	48.1	69.1
All units	59.4	57.3	54.3	50.6	55.4

[1] Total plots in each size class within each unit = 100 percent.

FUEL CONSUMPTION

As the actual fire-intensity classes were defined in terms of fuel consumption (see pages 3 and 4), the areas burned by fire of different intensities provide a measure of fuel consumption (table 6). The quantity consumed was appreciable only on the 25.4 percent of the total burnable area covered by hot surface or crown fire.

Consumption of fuel varied widely within the light surface fire-intensity class, but it was relatively constant within the other intensity classes. On a large part of the area covered by light surface fire, the consumption of litter was negligible, although around the base of trees the consumption of litter sometimes was the equivalent of that expected in hot surface fire. The hot spots within plots classed as light surface fire were too small to affect the overall classification of the plots.

Little or no coarse fuel was consumed by light surface fire. Where a substantial portion of the coarse fuel burned, all of the litter was normally consumed and the intensity was classified either hot surface or crown fire.

An appreciable residue of charred coarse fuel remained after the fire, especially in the recently cut unit, and this probably will rot slowly (Gill and Andrews, 1956).

RELEASE OF POTENTIAL CROP TREES

Opportunities for benefits from release of potential crop trees were limited. Of sample trees needing release, 620 (13.0 percent) were in the area that did not burn. In the burned area, 688 (17.5 percent) needed release and only 167 were released.[3] The 167 that benefited by release represented

[3] Information on need for release not tallied by three observers for all potential crop trees they tallied as killed (233); missing data do not represent specific conditions and therefore should not affect the distribution appreciably.

3.5 percent of the total number of potential crop trees tallied within the border of the fire, and only 4.2 percent of the total in the area that actually burned, or 24.3 percent of the total number needing release in the area that actually burned (table 8).

Need for release of potential crop trees differed with stand density, and it also differed among areas burned by fire of different intensities. More potential crop trees (20.8 percent) needed release in the McNary unit, which supported the largest understory trees, than in the Maverick units (12.0 and 15.3 percent). Dense stands in all categories contained a larger proportion of trees in need of release (37.1 percent) than typical stands (14.3 percent). Needs were greater in the area burned by crown fire (26.4 percent) than in areas burned by hot surface fire (14.9 percent) or light surface fire (17.4 percent).

The proportion of potential crop trees that were actually benefited by fire was influenced strongly by actual fire intensity and stand density. Light surface fire released only 11.9 percent; hot surface fire released 50.0 percent; and crown fire, 66.7 percent of those in need of release (table 8, fig. 1).

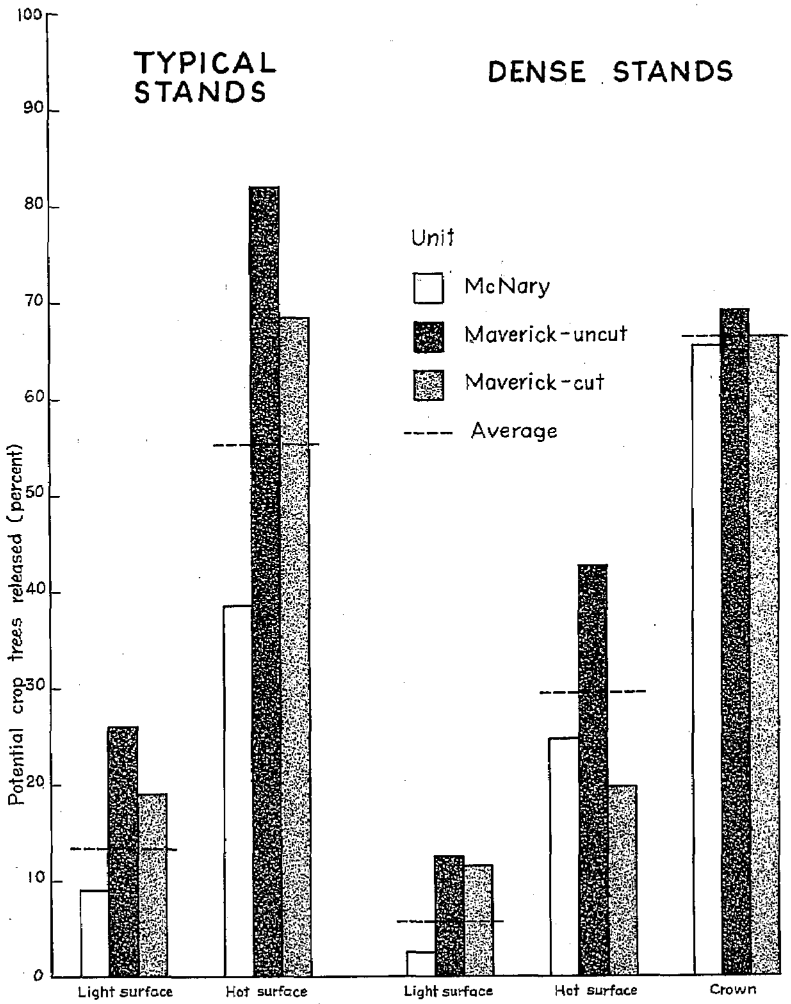

Figure 1.--Percentage of potential crop trees released by fire from among those needing release.

Table 8.--Number[1] and percentage of potential crop trees needing release[2] and those released on the area actually burned

Study area and type of fire	Total of trees	Needed release	Released	Needed release	Released of total	Released of those needing release
	- - - - Number	- - - -		- - - - Percent	- - - -	
TYPICAL STANDS						
Light surface fire:						
McNary	1,479	255	24	17.2	1.6	9.4
Maverick, uncut	571	53	14	9.3	2.4	26.4
Maverick, cut	591	78	15	13.2	2.5	19.2
Total or average	2,641	386	53	14.6	2.0	13.7
Hot surface fire:						
McNary	345	47	18	13.6	5.2	38.3
Maverick, uncut	188	11	9	5.9	4.8	81.8
Maverick, cut	205	38	26	18.5	12.7	68.4
Total or average	738	96	53	13.0	7.2	55.2
Crown fire:	0	0	0	0	0	0
All fire intensities:						
McNary	1,824	302	42	16.6	2.3	13.9
Maverick, uncut	759	64	23	8.4	3.0	35.9
Maverick, cut	796	116	41	14.6	5.2	35.3
Total or average	3,379	482	106	14.3	3.1	22.0
DENSE STANDS						
Light surface fire:						
McNary	124	77	2	62.1	1.6	2.6
Maverick, uncut	55	24	3	43.6	5.4	12.5
Maverick, cut	35	9	1	25.7	2.9	11.1
Total or average	214	110	6	51.4	2.8	5.5
Hot surface fire:						
McNary	23	12	3	52.2	13.0	25.0
Maverick, uncut	23	7	3	30.4	13.0	42.9
Maverick, cut	22	5	1	22.7	4.5	20.0
Total or average	68	24	7	35.3	10.3	29.2
Crown fire:						
McNary	118	44	29	37.3	24.6	65.9
Maverick, uncut	63	13	9	20.6	14.3	69.2
Maverick, cut	92	15	10	16.3	10.9	66.7
Total or average	273	72	48	26.4	17.6	66.7
All fire intensities:						
McNary	265	133	34	50.2	12.8	25.6
Maverick, uncut	141	44	15	31.2	10.6	34.1
Maverick, cut	149	29	12	19.5	8.0	41.4
Total or average	555	206	61	37.1	11.0	29.6
ALL STANDS						
Light surface fire:						
McNary	1,603	332	26	20.7	1.6	7.8
Maverick, uncut	626	77	17	12.3	2.7	22.1
Maverick, cut	626	87	16	13.9	2.6	18.4
Total or average	2,855	496	59	17.4	2.1	11.9
Hot surface fire:						
McNary	368	59	21	16.0	5.7	35.6
Maverick, uncut	211	18	12	8.5	5.7	66.7
Maverick, cut	227	43	27	18.9	11.9	62.8
Total or average	806	120	60	14.9	7.4	50.0
Crown fire:						
McNary	118	44	29	37.3	24.6	65.9
Maverick, uncut	63	13	9	20.6	14.3	69.2
Maverick, cut	92	15	10	16.3	10.9	66.7
Total or average	273	72	48	26.4	17.6	66.7
All fire intensities:						
McNary	2,089	435	76	20.8	3.6	17.5
Maverick, uncut	900	108	38	12.0	4.2	35.2
Maverick, cut	945	145	53	15.3	5.6	36.6
Total or average	3,934	688	167	17.5	4.2	24.3

[1] Number refers to the size of the sample, not the total number of trees in the area burned.

[2] Information on need for release not tallied by three observers for all potential crop trees they tallied as killed (233); missing data do not represent specific conditions and therefore should not affect the distribution appreciably.

More release was apparently accomplished by surface fire in typical stands than in dense stands where most needed. Light surface fire released 13.7 and 5.5 percent of trees needing release, and hot surface fire 55.2 and 29.2 percent in typical and dense stands, respectively.

Release of potential crop trees was substantially greater in the Maverick units (35.2 and 36.6 percent) than in the McNary unit (17.5 percent). This may have been related to the larger average size of understory trees on the McNary unit. If so, however, it was due to the preponderance of area burned by light surface fire. Amount of thinning done by hot surface and crown fires was not consistently related to tree size (table 9).

Table 9.--Influence of tree size and fire intensity on percentage of potential crop trees released, for burned area only

Type of fire	Sample trees needing release	Tree size class				
		0 to 4.5 ft. high	4.6+ ft. high, 3 in. d.b.h.	4 to 7 in. d.b.h.	8 to 11 in. d.b.h.	Average all classes
	No.	Percent				
Light surface fire	496	15.4	16.2	8.3	9.0	11.9
Hot surface fire	120	50.0	57.5	51.5	16.7	50.0
Crown fire	72	83.3	55.6	69.0	80.0	66.7
All fire intensities	688	26.5	27.5	23.0	18.0	24.3

The presence of slash in the selectively cut Maverick unit apparently did not affect thinning. The percentage of trees released in both Maverick units was approximately the same.

Age of slash may have been a factor, however, in the distribution of thinning. In typical stands with 1950 slash, 54.3 percent of the potential crop trees needing release were released compared with 26.0 percent in areas with 1955 slash. In dense stands 66.7 percent were released in 1950 slash compared with 23.8 percent in 1955 slash.

TREES DAMAGED OR KILLED

The damages sustained in terms of needed potential crop trees that were damaged or killed exceeded the benefits from thinning. Of the 4,787 total potential crop trees tallied within the borders of the fire, 390 were damaged and 521 were killed (table 10). The 911 damaged and killed represent 19.0 percent of the total number of potential crop trees within the borders of the fire, or 21.9 percent of the total in the area that actually burned. The 521 potential crop trees that were killed is more than 3 times greater than the 167 released. When the trees that were damaged are added to those killed, more than 5 trees were damaged or killed for each tree released.

The percentage damaged or killed increased as fire intensity increased. The proportions damaged were 5.0, 18.5, and 22.0 percent for light surface, hot surface, and crown fires, respectively. The proportions killed were 4.3, 20.8, and 57.0 percent (table 10).

Table 10.--Number[1] and percentage of potential crop trees damaged and killed on burned area only, grouped by fire intensities and units

Study area and type of fire	Total of trees	Damaged	Killed	Damaged and killed	Damaged	Killed	Damaged and killed
	------ Number ------				---- Percent ----		
TYPICAL STANDS							
Light surface fire:							
McNary	1,493	55	29	84	3.7	1.9	5.6
Maverick, uncut	593	42	37	79	7.1	6.2	13.3
Maverick, cut	606	34	52	86	5.6	8.6	14.2
Total or average	2,692	131	118	249	4.9	4.4	9.2
Hot surface fire:							
McNary	355	53	36	89	14.9	10.1	25.1
Maverick, uncut	205	45	50	95	22.0	24.4	46.3
Maverick, cut	245	38	81	119	15.5	33.1	48.6
Total or average	805	136	167	303	16.9	20.7	37.6
Crown fire:	0	0	0	0	0	0	0
All fire intensities:							
McNary	1,848	108	65	173	5.8	3.5	9.4
Maverick, uncut	798	87	87	174	10.9	10.9	21.8
Maverick, cut	851	72	133	205	8.5	15.6	24.1
Total or average	3,497	267	285	552	7.6	8.1	15.8
DENSE STANDS							
Light surface fire:							
McNary	124	5	1	6	4.0	.8	4.8
Maverick, uncut	56	5	4	9	8.9	7.1	16.1
Maverick, cut	35	3	1	4	8.6	2.9	11.4
Total or average	215	13	6	19	6.0	2.8	8.8
Hot surface fire:							
McNary	25	11	2	13	44.0	8.0	52.0
Maverick, uncut	27	10	5	15	37.0	18.5	55.6
Maverick, cut	31	7	11	18	22.6	35.5	58.1
Total or average	83	28	18	46	33.7	21.7	55.4
Crown fire:							
McNary	148	42	64	106	28.4	43.2	71.6
Maverick, uncut	74	18	39	57	24.3	52.7	77.0
Maverick, cut	150	22	109	131	14.7	72.7	87.3
Total or average	372	82	212	294	22.0	57.0	79.0
All fire intensities:							
McNary	297	58	67	125	19.5	22.6	42.1
Maverick, uncut	157	33	48	81	21.0	30.6	51.6
Maverick, cut	216	32	121	153	14.8	56.0	70.8
Total or average	670	123	236	359	18.4	35.2	53.6
ALL STANDS							
Light surface fire:							
McNary	1,617	60	30	90	3.7	1.9	5.6
Maverick, uncut	649	47	41	88	7.2	6.3	13.6
Maverick, cut	641	37	53	90	5.8	8.3	14.0
Total or average	2,907	144	124	268	5.0	4.3	9.2
Hot surface fire:							
McNary	380	64	38	102	16.8	10.0	26.8
Maverick, uncut	232	55	55	110	23.7	23.7	47.4
Maverick, cut	276	45	92	137	16.3	33.3	49.6
Total or average	888	164	185	349	18.5	20.8	39.3
Crown fire:							
McNary	148	42	64	106	28.4	43.2	71.6
Maverick, uncut	74	18	39	57	24.3	52.7	77.0
Maverick, cut	150	22	109	131	14.7	72.7	87.3
Total or average	372	82	212	294	22.0	57.0	79.0
All fire intensities:							
McNary	2,145	166	132	298	7.7	6.2	13.9
Maverick, uncut	955	120	135	255	12.6	14.1	26.7
Maverick, cut	1,067	104	254	358	9.7	23.8	33.6
Total or average	4,167	390	521	911	9.4	12.5	21.9

[1] Number of trees in samples.

Both damaging and killing were greater in dense stands. The proportion damaged was 7.6 percent for typical stands and 18.4 percent for dense stands; the proportion killed was 8.1 percent for typical and 35.2 percent for dense stands.

The presence of slash was a factor; 33.6 percent of needed potential crop trees were killed or damaged in the selectively cut Maverick unit compared with only 13.9 and 26.7 percent, respectively, in the McNary and Maverick uncut units.

Age of slash apparently was not an important factor in the damaging or killing of needed potential crop trees. In 1950 slash, 10.6 percent of potential crop trees were damaged compared with 8.8 percent in 1955 slash. Those killed were 19.5 percent in the area selectively cut in 1950 compared with 24.0 percent in the "new" slash.

No consistent association was found between the percentage of potential crop trees damaged and tree size (table 11).

Table 11.--Relation of damaging and killing of potential crop trees to tree size and fire intensity, for burned area only

Type of fire and condition of trees	Tree size class				
	0 to 4.5 ft. high	4.6+ ft. high, 3 in. d.b.h.	4 to 7 in. d.b.h.	8 to 11 in. d.b.h.	Average all classes
	Percent				
Light surface fire:					
Damaged	2.4	5.5	5.3	5.0	4.9
Killed	21.3	6.4	0.8	0.3	4.3
Damaged and killed	23.7	11.9	6.1	5.3	9.2
Hot surface fire:					
Damaged	4.2	17.0	25.2	16.9	18.5
Killed	57.5	33.6	9.2	1.7	20.8
Damaged and killed	61.7	50.6	34.4	18.6	39.3
Crown fire:					
Damaged	10.5	13.8	32.2	25.6	22.0
Killed	73.7	69.6	47.3	32.6	57.0
Damaged and killed	84.2	83.4	79.5	58.2	79.0
All fire intensities:					
Damaged	3.5	8.9	12.2	8.1	9.4
Killed	35.2	19.8	7.0	2.0	12.5
Damaged and killed	38.7	28.7	19.2	10.1	21.9

Killing and tree size, on the other hand, were consistently related. The percentage of potential crop trees killed decreased as tree size increased. Approximately 8 percent of sawlog-sized trees were damaged and 1 percent were killed, as shown below:

Unit	Trees in sample (No.)	Damaged (Pct.)	Killed (Pct.)
McNary	1,223	5.4	0.7
Maverick, uncut	752	7.6	.9
Maverick, cut	781	11.4	1.2
All units	2,756	7.7	.9

UNDERSTORY STOCKING

The productivity of a forest is partly a function of stocking. Holes in the stand reduce productivity. Understory stocking of the area covered by the fire was reduced by 10 percent. An additional 7.4 percent of points that were stocked by undamaged trees before the fire, were stocked by damaged trees after the fire (table 12). In the recently cut Maverick unit, where understory trees were needed most, overall reduction in stocking was greatest (17.5 percent).

Table 12.--Percentage of burned area stocked with potential crop trees before and after the fire

Study area	Observation points	Condition of trees	Stocking before fire	Stocking after fire	Change
	No.		- - -	Percent	- - -
McNary	3,633	Undamaged	82.3	70.9	-11.4
		Damaged	0	6.4	+ 6.4
Total			82.3	77.3	- 5.0
Maverick, uncut	1,385	Undamaged	81.1	59.4	-21.7
		Damaged	0	10.2	+10.2
Total			81.1	69.6	-11.5
Maverick, cut	1,648	Undamaged	73.5	48.8	-24.7
		Damaged	0	7.2	+ 7.2
Total			73.5	56.0	-17.5
All units	6,666	Undamaged	79.6	62.2	-17.4
		Damaged	0	7.4	+ 7.4
Total			79.6	69.6	-10.0

DAMAGES AND BENEFITS IN UNDERSTORY STANDS

The amount of effective thinning accomplished by this burning increased with fire intensity. But damaging and killing of needed potential crop trees also increased with fire intensity. The relation between the proportion of trees damaged and killed and the proportion of trees released (some of which were damaged) is shown by figure 2. Where the fire killed only a small proportion of needed potential crop trees, it released only a small proportion of those in need of release. Where the fire released a high proportion of those in need of release, it killed or damaged a high proportion of the total potential crop trees.

An average of 5.5 potential crop trees were damaged or killed for each potential crop tree released. There was some variation in the ratios with fire intensity--4.5:1 for light surface fire, 5.8:1 for hot surface fire, and 6.1:1 for crown fire; and with stand conditions--5.2:1 for typical stands, and 5.9:1 for dense stands. When classified by units and fire intensities, 12 out of 15 ratios were in the range of 3.0:1 to 6.3:1, a relatively narrow range considering the inherent variability in fire intensity from one spot to another, in tree size, and other factors affecting the susceptibility of trees to fire damage (table 13).

Figure 2.--Percentage of potential crop trees released and the percentage killed or damaged as related to fire intensity.

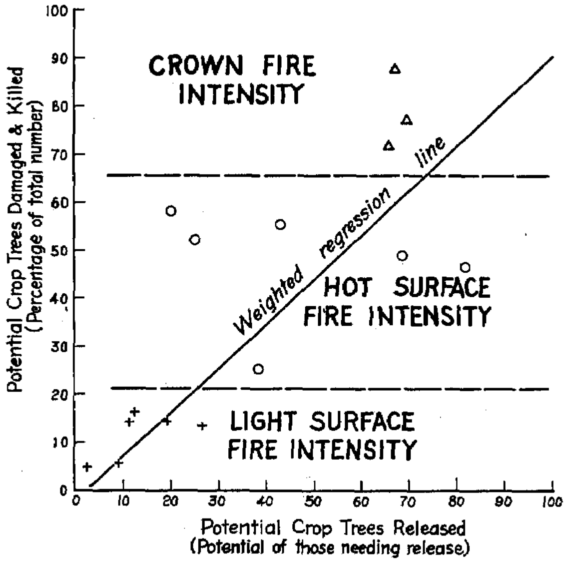

Table 13.--Damage-benefit ratios for potential crop trees in terms of number of potential crop trees damaged or killed for each potential crop tree released, for burned area only

Study area	Trees damaged			Trees killed			Trees damaged and killed		
	Typical stands	Dense stands	All stands	Typical stands	Dense stands	All stands	Typical stands	Dense stands	All stands
				LIGHT SURFACE FIRE					
McNary	2.3	2.5	2.3	1.2	0.5	1.2	3.5	3.0	3.5
Maverick, uncut	3.0	1.7	2.8	2.6	1.3	2.4	5.6	3.0	5.2
Maverick, cut	2.3	3.0	2.3	3.5	1.0	3.3	5.7	4.0	5.6
All units	2.5	2.2	2.4	2.2	1.0	2.1	4.7	3.2	4.5
				HOT SURFACE FIRE					
McNary	2.9	3.7	3.0	2.0	0.7	1.8	4.9	4.3	4.9
Maverick, uncut	5.0	3.3	4.6	5.6	1.7	4.6	10.6	5.0	9.2
Maverick, cut	1.5	7.0	1.7	3.1	11.0	3.4	4.6	18.0	5.1
All units	2.6	4.0	2.7	3.2	2.6	3.1	5.7	6.6	5.8
				CROWN FIRE					
McNary	0	1.4	1.4	0	2.2	2.2	0	3.7	3.7
Maverick, uncut	0	2.0	2.0	0	4.3	4.3	0	6.3	6.3
Maverick, cut	0	2.2	2.2	0	10.9	10.9	0	13.1	13.1
All units	0	1.7	1.7	0	4.4	4.4	0	6.1	6.1
				ALL FIRE INTENSITIES					
McNary	2.6	1.7	2.2	1.5	2.0	1.7	4.1	3.7	3.9
Maverick, uncut	3.8	2.2	3.2	3.8	3.2	3.6	7.6	5.4	6.7
Maverick, cut	1.8	2.7	2.0	3.2	10.1	4.8	5.0	12.8	6.8
All units	2.5	2.0	2.3	2.7	3.9	3.2	5.2	5.9	5.5

DISCUSSION

The motive for burning is to achieve net benefits. How well this burn accomplished objectives is documented in terms of fuel reduction and timber stand improvement.

From the standpoint of fuel reduction and future fire control the benefits left much to be desired. On 23.3 percent of the area there was a good cleanup of surface fuels, accompanied by an increase in dead aerial fuels. On 55.2 percent of the area, much of the litter and practically all the coarse fuel were left. On 21.5 percent of the area, fuels were untouched. This means that about three-fourths of the area can still support surface and crown fires. The other fourth will probably carry crown fire only during severest fire weather.

The fire released from competition 24.3 percent of potential crop trees that needed release (3.5 percent of total number). The released trees should grow faster. Offsetting these benefits, the already short supply of needed potential crop trees was reduced by 10.0 percent and an additional 7.4 percent were damaged. The area supporting neither understory nor overstory trees, and therefore completely idle from the timber production standpoint, increased from 15.4 percent before the fire to 18.8 percent after the fire.

The benefits and damages obtained from this burn may be evaluated differently by different land managers. But the burning demonstrated clearly that fire, as used, is an imperfect tool. Can anything be done to improve its effectiveness?

Fire was used with a minimum of controls. It burned day and night through all variations of stand and topography over a period of 33 days. Any area as large as 27,000 acres includes numerous combinations of stand conditions, fuel conditions, and topographic situations. A period as long as 33 days includes a considerable variety of fire weather.

There are many possibilities for varying the intensity of fire and therefore its effects. Fire can be made to burn uphill, downhill, or along contours. It can be made to burn against the wind, with the wind, or across the wind. Within limits, it is possible to select conditions of weather and fuel moisture for burning. Within the range of differences found in steepness of slopes, wind velocities, and fuel moistures, a considerable range of fire intensities can be developed.

Objectives of burning could undoubtedly be met more completely if the area to be burned were subdivided into units within which objectives were the same and over which a more or less uniform fire intensity might be developed. Within units having rather uniform fuels of a size that can be burned in a single burning period during relatively constant fire weather, it should be possible to achieve fairly uniform fire intensities. As more is learned about fire intensity from additional studies this will be increasingly true. But fire intensity is only part of the picture. Even light surface fire, about the lightest intensity fire that can ever be achieved, damaged or killed 4.5 needed potential crop trees for each tree released. The vulnerability of the trees must be considered too. This survey suggests that adjusting fire intensity to tree size (table 11) has good possibilities for controlling killing of trees. Different fire intensities might be prescribed for units containing different sizes of trees.

The type of burning practiced was inexpensive. Systematic application of specific intensities of fire to homogeneous units will cost much more: pre-burning surveys, detailed planning, extra firebreaks, special fire weather forecasts, and other special measures would be required. So while improved burning techniques may lead to more favorable results, they will also increase costs and overall net benefits may not improve materially.

One of the most important showings of this survey is the need for more research and documentation of what can be done toward attaining specific management objectives through systematic application of fire of prescribed intensities to homogeneous timber units. The large-scale application of fire that was practiced apparently had a low ratio of benefits to damages. More favorable results should be possible. But to learn the full potential for beneficial use of fire in ponderosa pine will require carefully controlled burning tests on uniform areas that are small enough to be burned in a single burning period under relatively uniform burning conditions.

SUMMARY AND CONCLUSIONS

A systematic survey of fire effects was made on two geographic units of ponderosa pine timberlands totaling approximately 27,000 acres that were intentionally burned in November and December 1956 by experienced men during conditions and by methods they considered favorable for success of such burning.

Data taken at 6,666 observation points systematically distributed over the entire area lead to the following conclusions concerning fire effects on fuels and trees; effects on other values and on the protection of land values were not surveyed:

1. This fire was predominantly a low intensity or "cool" fire as could be expected with the low-level fire-danger indexes that prevailed during the burning period.

2. Of the burnable area, 21.5 percent did not burn. An additional 55.2 percent burned by light surface fire that produced small benefits and caused little damage.

3. Major changes in fuels and understory were found only on the 23.3 percent of the total area that burned by hot surface or crown fire.

4. Despite the low level of fire danger under which the fire burned, more than half the area that had a potential for crown fire actually crowned.

5. Fuel consumed, potential crop trees released, and fire intensity were directly correlated--the higher the intensity the greater the percentage of the fuel consumed and the larger the percentage of trees released.

6. The burning released 3.5 percent of the total number of potential crop trees, or 24.3 percent of the number of potential crop trees needing release.

7. For every potential crop tree released an average of 5.5 potential crop trees needed to utilize growing space were either damaged or killed.

8. Influence of tree size on damage to understory stands was limited chiefly to mortality; the percentage of potential crop trees killed decreased as their size increased.

9. The presence of slash apparently intensified results; where there was slash, a larger percentage of area burned, a larger percentage of area in dense stands crowned, a larger percentage of potential crop trees was killed, a larger percentage of sawlog-sized trees was damaged, and stocking was reduced more. Nevertheless, amount of thinning done was about the same within fire-intensity classes in both the recently cut and the other two units.

10. Before the fire, 15.4 percent of the area was unstocked with either sawlog trees or potential crop trees; after the fire, 18.8 percent. In the understory alone burning reduced stocking 10.0 percent by killing potential crop trees; another 7.4 percent of the remaining potential crop trees were damaged.

11. Intentional burning of ponderosa pine timberlands to treat fuels and timber stands presents many unsolved complex problems. More control over the intensity of fire will be necessary for consistently accomplishing specific objectives. Knowledge of desired fire intensities and practical techniques for controlling fire intensity are still limited.

An economic analysis of benefits and costs was not attempted. More must be known before it is reasonable to do this. For the time being, it is recommended that intentional burning continue to be considered experimental and that efforts be made to prescribe the fire intensities desired and the burning conditions that will produce them. Such experiment will be most productive if confined to small, reasonably uniform, burning areas.

BIBLIOGRAPHY

Anderson, Carl A., Arnold, Joseph F., Barr, George W., and others.
1956. Recovering rainfall. Arizona watershed program. Part II. Ariz. State Land Dept., Salt River Valley Water Users' Assoc., and Ariz. Univ. 218 pp., illus.

Biswell, H. H., and Schultz, A. M.
1956. Reduction of wildfire hazard--correct timing of prescribed burning of dead vegetation in timber reduces danger of uncontrolled fires in those areas. Calif. Agr. 10(11): 4-5, illus.

________ and Schultz, A. M.
1956. Removal of tinder in ponderosa--prescribed burning of forest brush during the wet season by tested methods effectively reduces hazard of wildfire. Calif. Agr. 10(2): 6-7, illus.

______, Schultz, A. M., and Launchbaugh, J. L.
1955. Brush control in ponderosa pine--technics of prescribed burns to encourage growth of desirable game browse in second-growth timber. Calif. Agr. 9 (1): 3, 14, illus.

Coston, Charles T.
1955. Prescribed burning in the northern Rocky Mountains. U. S. Forest Serv. Fire Control Notes 16 (1): 43-46, illus.

Davis, Kenneth P.
1959. Forest fire, control and use. 584 pp., illus. New York, Toronto [etc.].

Gaines, Edward M., Kallander, Harry R., and Wagner, Joe A.
1958. Controlled burning in southwestern ponderosa pine: results from the Blue Mountain plots, Fort Apache Indian Reservation. Jour. Forestry 56: 323-327.

Gill, Lake S., and Andrews, Stuart R.
1956. Decay of ponderosa pine slash in the Southwest. U. S. Forest Serv. Rocky Mountain Forest and Range Expt. Sta. Res. Note 19, 2 pp. [Processed.]

Kallander, Harry R.
1958. The watershed--protection of forests from wildfires by prescribed burning...of ponderosa pine, Fort Apache Indian Reservation, Arizona. In Preliminary economic considerations of the Arizona watershed program. Ariz. Watershed Program Proc. 2: 46-48, illus. [Ariz. Water Resources Com. and Ariz. State Land Dept.]

______ 1959. Controlled burning in ponderosa pine stands of the Fort Apache Indian Reservation. In Your Range--Its Management. Ariz. Agr. Expt. Sta. and Ariz. Ext. Serv. Spec. Rpt. 2, pp. 20-22.

______, Weaver, Harold, and Gaines, Edward M.
1955. Additional information on prescribed burning in virgin ponderosa pine in Arizona. Jour. Forestry 53: 730-731.

LeBarron, Russell K.
1957. Silvicultural possibilities of fire in northeastern Washington. Jour. Forestry 55: 627-630.

Morris, William G., and Mowat, Edwin L.
1958. Some effects of thinning a ponderosa pine thicket with a prescribed fire. Jour. Forestry 56: 203-209, illus.

Mowat, Edwin L.
1953. Thinning ponderosa pine in the Pacific Northwest. A summary of present information. U. S. Forest Serv. Pacific Northwest Forest and Range Expt. Sta. Res. Paper 5, 24 pp., illus. [Processed.]

Vlamis, J., Biswell, H. H., and Schultz, A. M.
1955. Effects of prescribed burning on soil fertility in second growth ponderosa pine. Jour. Forestry 53: 905-909, illus.

Wagle, Robert F.
1959. Prescribed burning--a few pros and cons. In Your Range--Its Management. Ariz. Agr. Expt. Sta. and Ariz. Ext. Serv. Spec. Rpt. 2, pp. 19-20.

Weaver, Harold.
1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. Jour. Forestry 41: 7-14, illus.

_____ 1946. Slash disposal on the Colville Indian Reservation. Jour. Forestry 44: 81-88, illus.

_____ 1947. Fire--nature's thinning agent in ponderosa pine stands. Jour. Forestry 45: 437-444, illus.

_____ 1947. Management problems in the ponderosa pine region. Northwest Sci. 21: 160-163.

_____ 1947. Thinning pine stands by prescribed burning. West Coast Lumberman 74: 111-112, 114.

_____ 1949. Shoals and reefs in ponderosa pine silviculture. Jour. Forestry 48: 21-22.

_____ 1951. Fire as an ecological factor in the southwestern ponderosa pine forests. Jour. Forestry 49: 93-98, illus.

_____ 1952. A preliminary report on prescribed burning in virgin ponderosa pine. Jour. Forestry 50: 662-667, illus.

_____ 1955. Fire as an enemy, friend, and tool in forest management. Jour. Forestry 53: 499-504, illus.

_____ 1956. Wild fires threaten ponderosa pine forests. Amer. Forests 62: 28-29, 52-55, illus.

_____ 1957. Effects of prescribed burning in ponderosa pine. Jour. Forestry 55: 133-138, illus.

_____ 1957. Effects of prescribed burning in second growth ponderosa pine. Jour. Forestry 55: 823-826, illus.

_____ 1959. Ecological changes in the ponderosa pine forest of the Warm Springs Indian Reservation in Oregon. Jour. Forestry 57: 15-20, illus.