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LOGGING SLASH FLAMMABILITY AFTER FIVE YEARS

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INTRODUCTION

This paper reports the final phase of research that has determined the flammability of slash for nine species of northern Rocky Mountain conifers[2] at three ages.[3] Visual characteristics, rate of fire spread, and fire intensity for 5-year-old slash were studied by essentially the same methods as had been used previously on freshly cut and 1-year-old material. Final experimental burning was done in July and August 1960 on a specially prepared site in the Priest River Experimental Forest in northern Idaho.

In the earlier stages of this study (*2, 3, 4, 5*),[4] rate of fire spread bore the same relation to relative humidity and quantity of fuel per acre for all species of freshly cut slash, increasing as relative humidity decreased and as fuel quantity increased. The relationship to fuel quantity did not change when slash aged 1 year, but the apparent effect of relative humidity became stronger. Rate of spread varied considerably with species, in response to variations in relative amount of fine fuel components and shape of branches. Aging 1 year reduced rate of spread 25 percent or more for all species except western white pine; greatest reductions were noted for species that lost their needles over winter. In general, fire intensity, as indicated by radiation measurements, was proportional to rate of spread. Presence of a moderate amount of fresh slash of any species raised the rate-of-spread component of fuel type to "Extreme." After a year the rating dropped to "High" for some species.

[1] For easy reference and comparison, this publication uses the same order and essentially the same format as "Logging Slash Flammability," Intermountain Forest and Range Experiment Station Research Paper 58.

[2] Western white pine (*Pinus monticola* Dougl.), lodgepole pine (*P. contorta* Dougl.), ponderosa pine (*P. ponderosa* Laws.), western redcedar (*Thuja plicata* Donn), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), Engelmann spruce (*Picea engelmannii* Parry), Grand fir (*Abies grandis* [Dougl.] Lindl.) and western larch (*Larix occidentalis* Nutt.).

[3] "Age" in this usage means time elapsed since cutting.

[4] Italicized numerals in parentheses refer to items in *Bibliography.*

SUMMARY

At the end of 5 years important changes in visual characteristics of fuel were: virtually total loss of needles by all species, concentration of needles on or near the ground, and compaction of the fuel bed (all species but hemlock). Incipient rot was apparent in the branchwood of all species, but advanced decay and appreciable breaking up of large limbs occurred only in grand fir. Average rate of fire spread for all species was 23 percent of that in fresh slash, ranging from only 18 percent in grand fir slash to 36 percent in lodgepole pine. Western white pine, ponderosa pine, and western hemlock showed essentially the same residual percentage as lodgepole, and larch the same as grand fir. Western white and lodgepole pine had the highest (and almost identical) rates of spread; following in decreasing order were hemlock, ponderosa pine, redcedar, Douglas-fir, Engelmann spruce, larch, and grand fir.

Quantity of fuel per acre had a somewhat less apparent effect on rate of fire spread in 5-year-old slash than in 1-year-old, and the apparent effect of relative humidity was nearer that determined for fresh slash than that for 1-year-old slash. These changes are not very significant, however, because only two weights could be burned, and the effects of fuel quantity were confounded with those of relative humidity on a few plots.

Fire intensity in 5-year-old slash was reduced further from that found for 1-year-old slash; the reduction was about the same in medium (20 tons per acre) as in heavy (32.5 tons per acre) slash. This finding supports an earlier one that fire intensity is essentially proportional to rate of spread in any given kind of fuel.

CHARACTERISTICS OF FIVE-YEAR-OLD SLASH FUEL COMPONENTS

Information on the characteristics of 5-year-old slash was obtained entirely from the 63 plots used for testing rate of fire spread and fire intensity. Representative plots were photographed, depth of slash was measured at four points on each plot, and a careful written description was prepared for each species.

In general, significant changes in slash fuels during the first 5 years after cutting were loss of foliage, sifting down of lost needles toward the ground line, and compaction of the entire fuel bed. Major exceptions were grand fir, which disintegrated rather spectacularly, and western hemlock, which appeared to undergo little change after the first year. From visual characteristics, comparative flammability was estimated as follows, by species in descending order: lodgepole pine, western white pine, western redcedar, western hemlock, Douglas-fir, Engelmann spruce, ponderosa pine, western larch, and grand fir. These ratings were based on examination of all medium and heavy plots; they did not take into account differences in quantity associated with species on cutover areas. Differences among the first four or five species appeared slight, and the ranking therefore was quite tentative. The following sections and figures 1 to 4 document slash characteristics in greater detail.

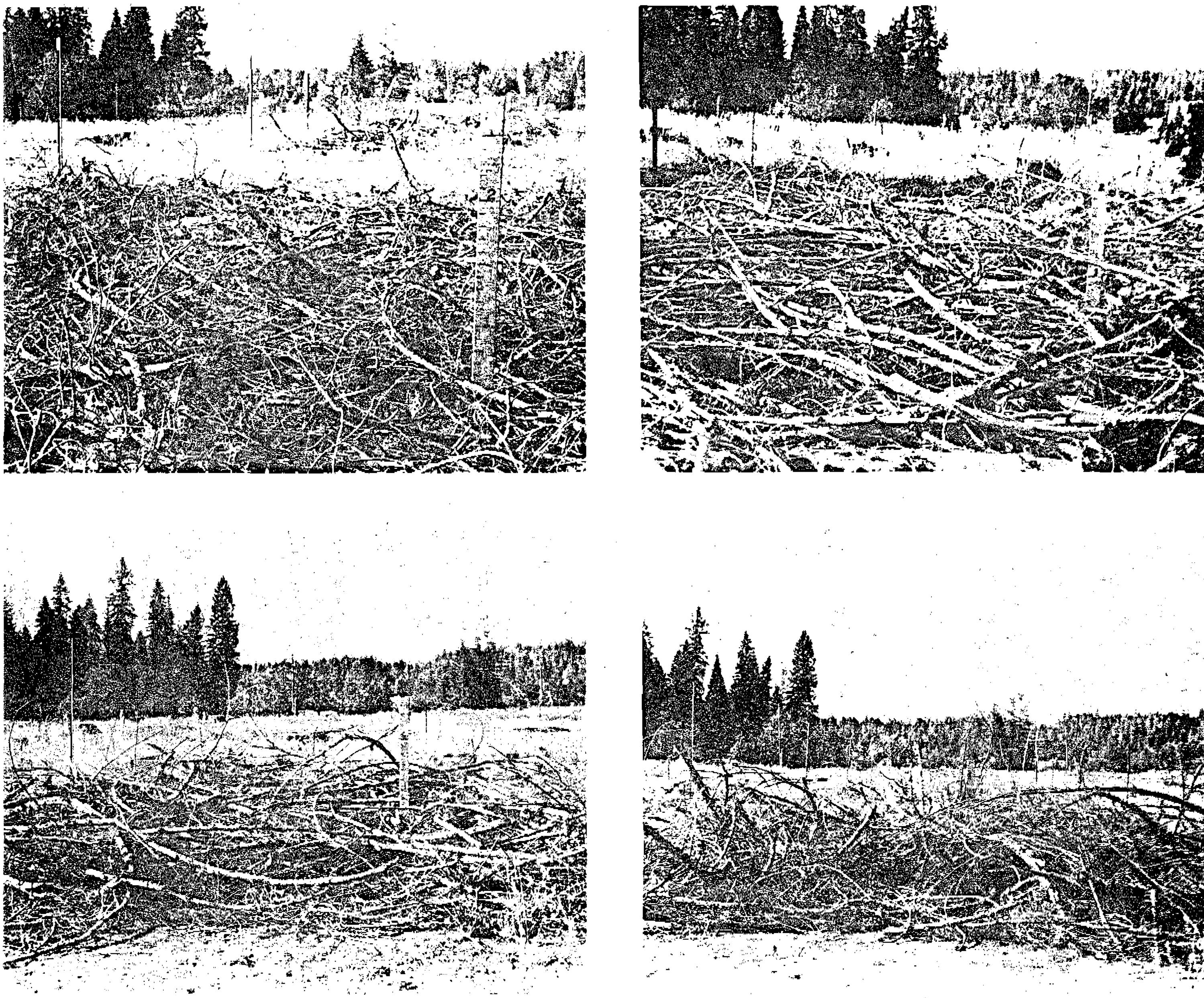


Figure 1. Five-year-old heavy slash (32.5 tons per acre) of: **upper left**, western white pine; **upper right**, western redcedar; **lower left**, Douglas-fir; **lower right**, western hemlock. Note retention of some needles by white pine, loose bark in redcedar and to a lesser extent in Douglas-fir, absence of appreciable compaction in hemlock [Cf. (3) figures 4, 5, 6, 7.]

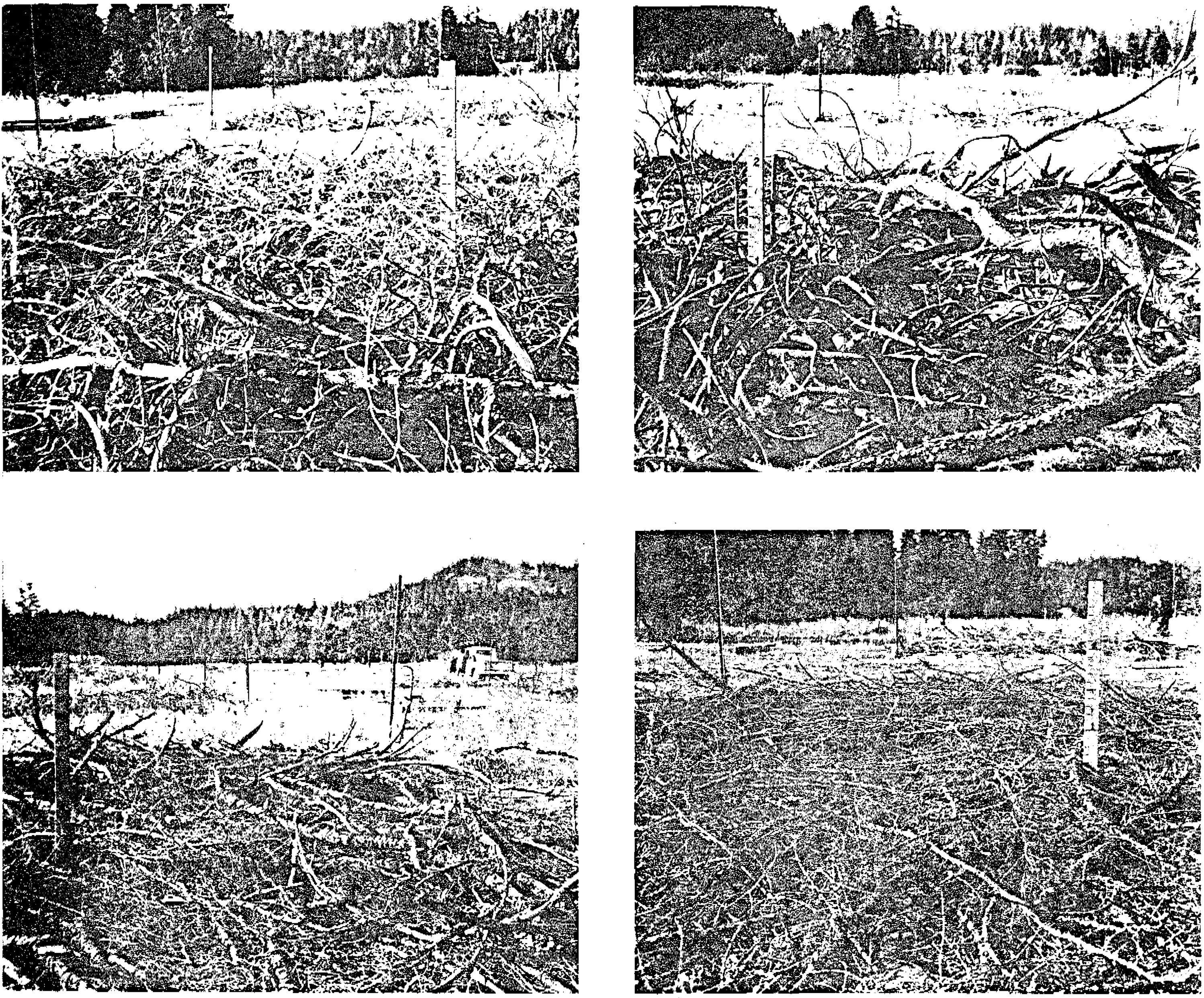


Figure 2. Five-year-old heavy slash of: **upper left,** lodgepole pine; **upper right,** ponderosa pine; **lower left,** Engelmann spruce; **lower right,** western larch. Almost total loss of bark from lodgepole pine twigs contrasts with minimal loss from those of ponderosa pine and larch. Note mat of needles and jumble of twigs on the ground in spruce slash.

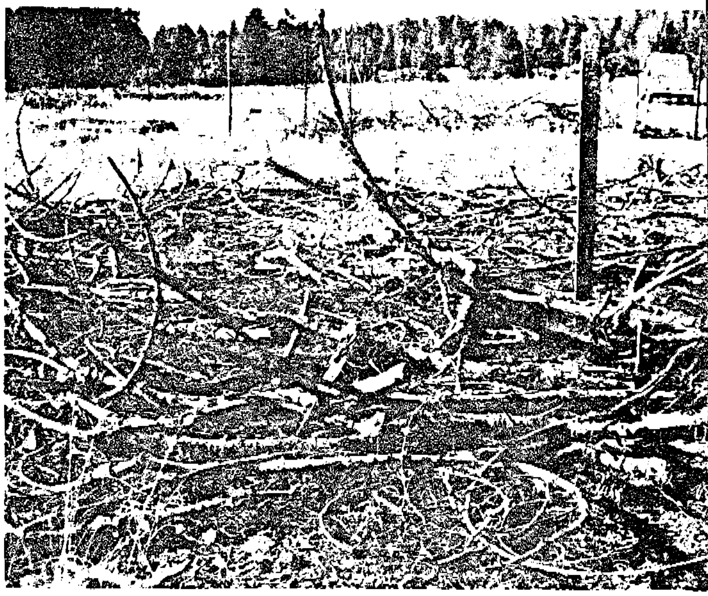
CHANGES DUE TO AGING

Foliage.—Nearly 25 percent of the white pine needles in the protected lower portions of the fuel beds remained attached to branches. All needles and foliage from the other eight species had fallen to the ground, creating layers or mats of varying thickness. Long needles often formed relatively loose mounds or hummocks on the ground. Foliage from the short-needled species lay in dense mats that frequently were bound together by fungus mycelium along the surface of the ground. These mats appeared likely to sustain only a smouldering fire while the looser layers of longer needles would permit surface fires to spread readily. Rotting of needles was negligible, and incorporation into the soil was not observed (it would hardly be expected on the study site).

Twigs and branches.—At the end of 5 years western white pine, lodgepole pine, Douglas-fir, western larch, and western hemlock retained approximately 75 percent of their twigs in the original state. Most of this fine material had fallen from slash of the other four species. Twigs from slash of Engelmann spruce, western redcedar, and grand fir contributed materially to depth and continuity of the surface fuels available for burning.

Bark.—Disintegration of bark on some of the species was quite pronounced, but on ponderosa pine and western larch most of the bark was still intact. Lodgepole pine had lost the most bark; an estimated 75 percent had fallen to the ground. The bleached appearance of twigs and branches on the lodgepole pine plots was distinctive. Bark remaining on twigs and branches promoted spread of fire in the plots of western redcedar. Split lengthwise and hanging loosely in conspicuous strips, this bark added a considerable volume of flashy fuel. Douglas-fir slash also had considerable loose bark.

Wood.—Advanced stages of cubicle rot were evident in the branchwood of grand fir. The appearance of the grand fir plots at the end of the 5-year period indicated that this species decomposed more rapidly than any of the others. Branchwood was well broken up and mostly close to the ground. The twigs and branchwood of ponderosa pine showed little external evidence of decay, but when the bark was removed, considerable dry rot could be seen. Western larch, Douglas-fir, and western redcedar had the least amount of incipient decay.



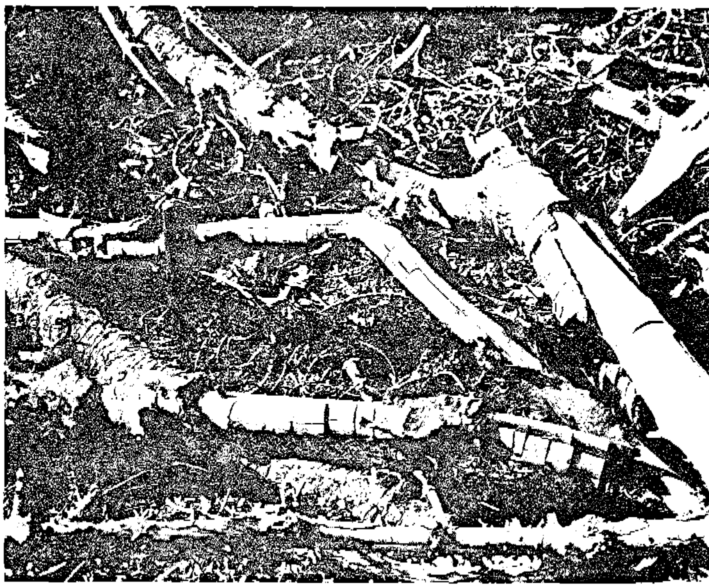


Figure 3. Five-year-old heavy slash of grand fir. **Upper,** general view showing disintegration of branches and concentration of fuel near the soil surface; **lower,** closeup showing typical rotted condition of large branchwood.

FUEL BED CHARACTERISTICS

Continuity.—By the end of 5 years the originally sparse fuel of the light (7.5-ton) plots had become so scattered that fire obviously could not spread continuously. Disintegration of aerial components virtually destroyed their ability to burn, and fuel added at the ground level as a result of this disintegration was negligible in comparison with the area to be covered. The thin, intermittent layer of needles was hardly distinguishable from the surface of the mineral soil. Some needles had been scattered by wind and animals, and some were becoming mixed with surface soil.

On the heavier plots gravitation of fine components toward the bottom of the fuel bed further reduced continuity of aerial fuels. The same process appeared to have increased continuity at the ground line. On both the medium and the heavy plots enough connected ground fuel appeared available to carry at least a smouldering fire over the entire plots under very dry conditions. The change in location of fines appeared likely to reduce the rate at which fire could spread but not the full extent of coverage.

Depth and density.—Depth of slash of all species except hemlock had decreased, as anticipated (tables 1 and 2). Hemlock branches continued to curl high above the ground, and apparent depth therefore was greater than at the first measurement. The greatest decreases in depth were in Engelmann spruce and grand fir; they resulted from the loss of most twigs and smaller branches. Density tended to increase in the lower portions of the fuel beds as depth decreased. The trend for all species but hemlock obviously was from an essentially aerial, though low, fuel toward a ground fuel having appreciable depth only in the heavier concentrations of the more durable species. Grand fir slash could be considered purely a ground fuel 5 years after cutting; larch and Engelmann spruce were virtually so.

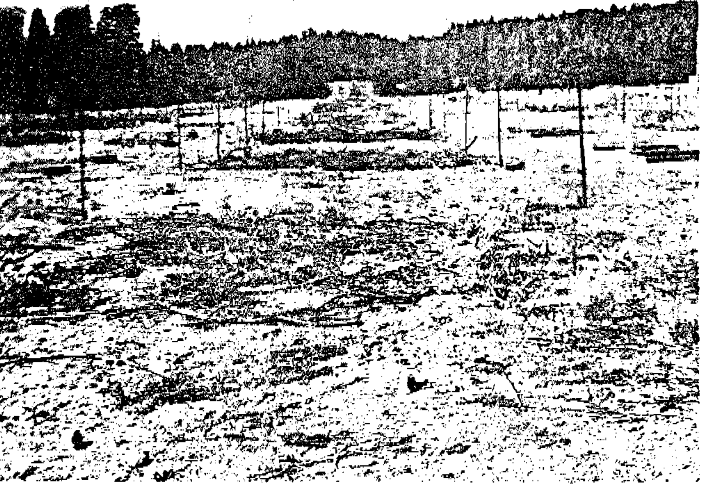
Table 1.--Depth (in feet) of evenly distributed, lopped slash in relation to species, age, and weight

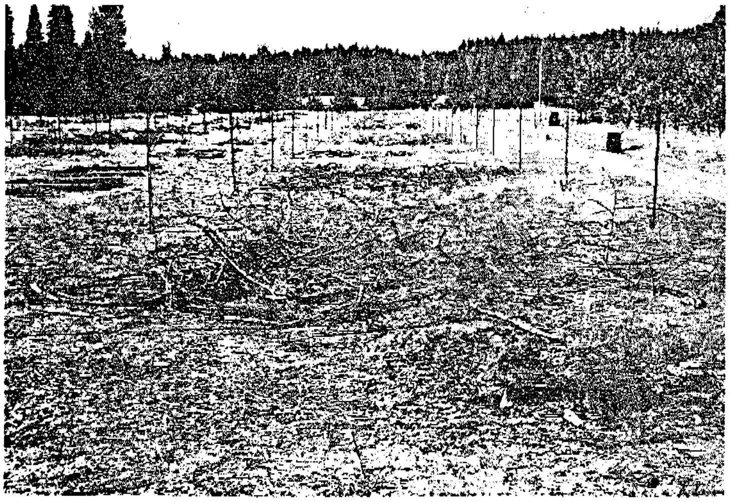
Species	Year of cutting			1 year old			5 years old		
	Tons per acre			Tons per acre			Tons per acre		
	7.5	20.0	32.5	7.5	20.0	32.5	7.5	20.0	32.5
Western white pine	0.51	0.80	1.00	0.32	0.54	0.78	0.12	0.35	0.55
Lodgepole pine	.51	1.04	1.29	.38	.66	.90	.18	.60	.70
Ponderosa pine	.34	.97	1.36	.44	.69	.96	.25	.32	--
Western redcedar	.35	.53	.84	.24	.66	.76	.30	.40	.60
Douglas-fir	.23	.63	.83	.23	.67	.72	.38	.60	.48
Western hemlock	.30	.62	.92	.31	.71	.88	.25	.82	1.12
Engelmann spruce	.49	.92	.96	.40	.58	.88	.08	.25	.32
Grand fir	.46	.76	.94	.26	.52	.74	.12	.20	.29
Western larch	.30	.78	.97	.26	.52	.70	.28	.22	.40

Table 2.--Reduction of fuel volume during 1-year and 5-year periods

Species	Original weight	Original volume		Percent of original volume	
		Per acre	Per ton	After 1 year	After 5 years
	Tons/acre	- - Cubic	feet - -		
Western white pine	7.5	18,730	2,497)		
	20.0	33,977	1,699)	74	44
	32.5	48,352	1,488)		
Lodgepole pine	7.5	22,216	2,962)		
	20.0	44,867	2,243)	81	52
	32.5	55,757	1,716)		
Ponderosa pine	7.5	14,810	1,975)		
	20.0	42,253	2,113)	82	[1] 44
	32.5	59,242	1,823)		
Western redcedar	7.5	22,216	2,962)		
	20.0	26,136	1,307)	98	79
	32.5	38,768	1,193)		
Douglas-fir	7.5	11,326	1,510)		
	20.0	28,750	1,438)	105	79
	32.5	40,075	1,233)		
Western hemlock	7.5	11,761	1,568)		
	20.0	27,007	1,350)	120	112
	32.5	46,174	1,421)		
Engelmann spruce	7.5	21,344	2,846)		
	20.0	40,075	2,004)	89	28
	32.5	41,818	1,287)		
Grand fir	7.5	20,038	2,672)		
	20.0	33,106	1,655)	75	30
	32.5	40,946	1,260)		
Western larch	7.5	13,068	1,742)		
	20.0	33,977	1,699)	74	44
	32.5	42,253	1,300)		
All species	7.5	16,553	2,207)		
	20.0	34,412	1,721)	87	55
	32.5	45,738	1,407)		

[1] Based on 7.5- and 20-ton plots only.





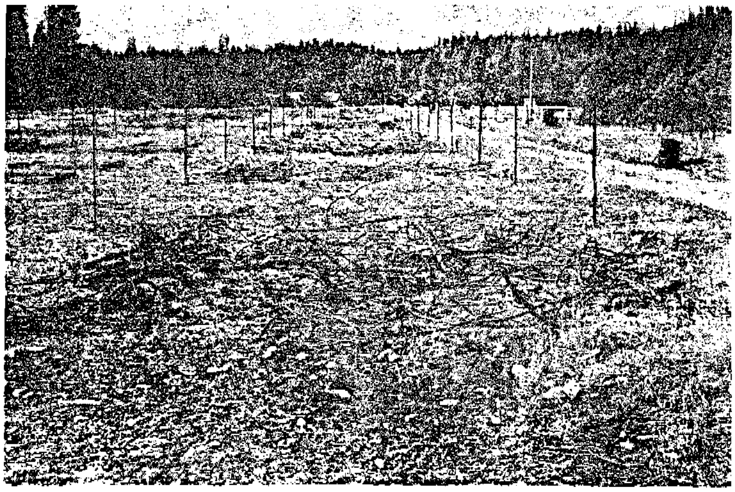


Figure 4. Five-year-old light slash (7.5 tons per acre) of: upper, western white pine; middle, western hemlock; lower, ponderosa pine. Aging has pretty well cancelled out original differences in fuel continuity. [Cf. (3) figure 9.]

FIRE SPREAD IN SLASH

RESEARCH METHODS

Experimental Design, Material, and Procedure

Investigation of fire spread in 5-year-old slash used the same techniques as the earlier experimental burnings of slash. In 1955, specially cut slash had been spread uniformly on 63 square 0.01-acre plots at per-acre rates of 7.5, 20.0, and 32.5 tons, representing fuel to be expected from light, medium, and heavy cutting, respectively. In this final phase of the study, the three plots per species of medium and heavy slash were burned during early evening between July 24 and August 13. Observers used remote pushbutton switches to mark an Esterline-Angus operations recorder chart when the fire edge passed 2-foot interval points on four diagonals radiating from the plot center. Usually, two plots were burned simultaneously.

Supplementary measurements included relative humidity, with a fan psychrometer at the start and end of each test fire; total air movement during each fire, with a directional vane anemometer; and fuel-stick moisture content at the start and end of each evening's burning. Time-lapse movies were taken of at least one fire in each species-weight combination of slash and black-and-white still shots of representative plots at peak fire intensity. Moisture content of slash was not sampled generally because in previous years the small number of measurements that were feasible had produced erratic, meaningless results.

No effort was made in 1960 to measure rate of fire spread on light plots because experience had shown that burning of such sparse fuel was erratic and most unlikely to yield usable results. Instead, these plots were burned during a warm, dry afternoon, and fire behavior was observed but not measured.

Conditions for Burning

The same burning conditions were sought as in previous years; namely:

1. Less than 0.2 inch of rain during preceding 5 days
2. No rain in preceding 2 days
3. Midafternoon air temperature 70° F. or higher
4. Minimum ½-inch fuel-stick moisture content 8 percent or less
5. Minimum relative humidity 40 percent or less
6. Mean wind velocity at time of burning not more than 2 m.p.h.

Burning was interrupted by 7 days of cool, cloudy, humid weather with some light rain; but by covering the plots it was possible to meet the prescribed conditions with the following exceptions:

1. Mean wind velocity was 2.2 m.p.h. when plots 12 (Engelmann spruce, 20 tons/acre) and 21 (western larch, 32.5 tons/acre) were burned.
2. Afternoon fuel-stick moisture content was more than 8.0 on August 2, when plots 55, 58, 60, and 62 were burned (lodgepole pine, grand fir, ponderosa pine, and western hemlock, respectively; all 20 tons/acre).
3. Burning was resumed August 9, the fifth day after a rain exceeding 0.2 inch.

The first exception was accidental, resulting from a temporary increase in wind velocity. The second two exceptions were deliberate. Number 2 was based on the assumption that the effects of exceptional dryness during preceding weeks offset the slightly too moist condition on August 2; number 3 on the fact that the plots had been covered during the rains.

Analysis

Average time (in seconds) required for fire to spread 1 foot radially was calculated for each plot. Table 3 summarizes the basic data for the entire life of this study. Average burning times shown in this table are based on plots for which five or more observations were recorded, and only these averages were used for subsequent analysis of the 1960 data.

The common logarithm of average burning time was used as the dependent variable (Y_5) in a multiple covariance analysis. Relative humidity and slash weight were the independent variables (X_1 and X_2 respectively). The prediction equation for 5-year-old slash is:

$$Y_5 = 2.1475 + .005788X_1 - .017390X_2.$$

Data for the three ages of slash were pooled to give the general prediction equation,

$$Y_{0+1+5} = 1.8957 + .006975X_1 - .020870X_2.$$

Rate-of-spread values calculated with this equation were expressed in the more familiar terms of chains' perimeter increase per hour. Differences were not tested for statistical significance because previous experience had shown that statistical comparisons were too insensitive to confirm any but the largest differences.

EVALUATION OF FACTORS AFFECTING RATE OF SPREAD

Weight and Relative Humidity

Effects of these two factors continued about the same in 5-year-old slash as in younger fuel. The reduction in the regression coefficient for weight (from .0225 to .0174) quite possibly resulted from absence of data for light 5-year-old slash. Thus the change is regarded as more apparent than real.

The regression coefficient for relative humidity in the equation for 5-year-old slash fell between those for fresh and 1-year-old material. This appeared to invalidate a tentative conclusion based on comparison of two coefficients derived earlier; namely, that relative humidity assumes greater importance as fuel becomes sparser with age (3). As was explained in this earlier publication, relative humidity was changing rapidly when nearly all plots were burned, and burning schedules confounded slash weight with humidity to a considerable extent in 1- and 5-year-old slash. These complications left little basis for a clear-cut conclusion that the effect of relative humidity varies with age of slash.

Species and Age

Table 4 summarizes rates of spread by species and age for the duration of this study. Adjusted means for fresh and 1-year-old slash differ slightly from those given previously (3, table 13) because of pooling the earlier prediction equations with those for 5-year old slash. Rankings are the same and relative values essentially so.

Flammability ratings assigned to species on the basis of visual examination (see p. 2) proved rather accurate. Measuring rate of spread changed only three rankings: ponderosa pine from sixth to fourth, western redcedar from third to fifth, and hemlock from fourth to third. The continued high flammability of hemlock had not been expected at the beginning of the study but was quite predictable from observations made in 1960 before burning. Cedar's intermediate position again supported the opinion that quantity of slash produced, resulting from both heavy tree crowns and methods of processing in the woods, is as important as inherent flammability in making slash of this species especially dangerous.

Table 3.--Results of experimental slash burning, by weight of slash per acre, age, and species, before analysis and adjustment

Age and species	Weight of slash (tons per acre)								
	7.5			20.0			32.5		
	Plots	Range of relative humidity	Mean rate of spread	Plots	Range of relative humidity	Mean rate of spread	Plots	Range of relative humidity	Mean rate of spread
		Percent	*Seconds per foot*		*Percent*	*Seconds per foot*		*Percent*	*Seconds per foot*
Fresh slash:									
Western white pine	3	58-62	80	3	34-86	32	3	30-65	18
Lodgepole pine	2	74-83	141	2	84-88	48	2	52-64	17
Ponderosa pine	([1])	--	--	2	60-85	71	2	54-91	33
Western redcedar	3	28-56	73	3	36-81	53	3	42-73	24
Douglas-fir	3	33-50	64	3	39-72	41	3	52-70	21
Western hemlock	2	51-67	87	3	47-74	41	3	27-66	28
Engelmann spruce	-	--	--	3	38-74	50	3	68-82	35
Grand fir	2	54-70	77	2	60-80	51	3	50-94	29
Western larch	2	76-77	67	2	62-68	24	3	70-82	19
All species	17	28-83	82	23	34-88	45	25	27-94	26
1-year-old slash:									
Western white pine	3	26-90	82	3	80-91	62	3	71-90	26
Lodgepole pine	3	28-31	120	4	73-92	89	4	54-93	33
Ponderosa pine	2	28-30	153	4	66-85	129	4	71-83	84
Western redcedar	2	26-67	117	3	34-71	52	3	63-82	46
Douglas-fir	-	--	--	2	25-28	45	3	61-70	70
Western hemlock	2	28-30	43	3	44-81	59	3	64-82	74
Engelmann spruce	-	--	--	2	57-82	95	2	72-82	57
Grand fir	2	30-31	130	4	60-78	229	4	54-89	124
Western larch	1	30	109	4	64-86	215	4	55-87	97
All species	15	26-90	107	29	25-92	119	30	54-93	70
5-year-old slash:									
Western white pine				3	35-74	123	3	59-89	81
Lodgepole pine				3	69-80	164	3	60-89	77
Ponderosa pine				2	69-74	184	3	35-83	107
Western redcedar				1	52	155	3	58-74	127
Douglas-fir				2	56-63	241	3	66-79	167
Western hemlock				3	61-79	168	3	57-83	88
Engelmann spruce				3	49-74	175	3	59-84	205
Grand fir				-	--	--	1	59	291
Western larch				1	52	200	3	49-58	152
All species				18	35-80	172	25	35-89	128

[1] Absence of data indicates that plots did not burn sufficiently to provide five or more observations of fire spread. In all, the plots that did not burn were six fresh 7.5-ton, nine 1-year-old 7.5-ton, one 1-year-old 20-ton, nine 5-year-old 20-ton, and two 1-year-old 32.5-ton. No attempt was made to burn 5-year-old 7.5-ton plots because of the obvious futility of such an effort.

Table 4.--Rates of spread in nine species of fresh, 1-year-old, and 5-year-old slash

Species	Adjusted mean rate of spread [1]			Percent of rate in fresh slash	
	Fresh	1-year-old	5-year-old	1-year-old	5-year-old
	(Chains per hour perimeter increase)				
Western white pine	9.6	9.6	3.3	100	33
Lodgepole pine	9.0	5.9	3.2	66	36
Ponderosa pine	7.2	3.4	2.4	47	33
Western redcedar	8.0	6.0	1.9	75	24
Douglas-fir	8.9	3.8	1.6	43	18
Western hemlock	8.2	5.7	2.7	70	33
Engelmann spruce	7.2	4.9	1.6	68	22
Grand fir	9.2	2.3	.7	25	8
Western larch	14.5	2.4	1.3	16	9

[1] At 3-age mean relative humidity of 64.3 percent, mean weight of 23.3 tons per acre, as calculated by pooled regression for all three ages of slash.

On an average, rate of fire spread in 5-year-old slash was only 23 percent of that in fresh material. Changes from the rates for 1-year-old slash ranged from only 7 percent for larch, which had dropped 84 percent the first year, to 67 percent for white pine, which had shown no reduction the first year. Ponderosa pine, redcedar, Douglas-fir, and Engelmann spruce had low rates of spread comparable to those of grand fir and larch 4 years earlier. White pine, lodgepole pine, and hemlock at 5 years were about on a par with 1-year-old ponderosa and Douglas-fir. Burning 5-year-old larch slash yielded a mean rate of spread about twice that obtained for grand fir; for practical purposes this meant that experimental fires usually would spread in larch slash and usually would not in fir.

INTERPRETATIONS OF FINDINGS ON RATE OF SPREAD

Evaluation of Relative Flammability

Table 5 extends to 5 years an earlier sample calculation of composite relative rate of spread for a hypothetical cut of several species. The indication is that rate of spread based on slash alone would be down to only 19 percent of the possible maximum in fresh slash, or 22 percent of the fresh-slash rate for the mixture in the example.

Slash as a Fuel Type

Comparison of experimentally determined rates of spread with mean rates characteristic of Region 1 fuel types (*1, 6*) by methods used previously (3) showed that most 5-year-old slash would fall into the "Low" and "Medium" rate-of-spread types. Rather heavy cuts, yielding 15 tons or more of tree crown material, would put white pine and lodgepole in the "High" bracket. The amount of fuel needed to produce "High" ratings in other species would be 19 or more tons in hemlock, 22 or more in ponderosa pine, and 27 or more in redcedar. Actually about 20 tons per acre of cedar probably would produce high rate of spread if the operation involved peeling in the woods and splitting posts. *Five-year-old grand fir and larch slash would not exceed a "Low" to "Medium" rating regardless of quantity.* For all practical purposes the same is true for Douglas-fir and Engelmann spruce, since at least 30 tons of slash per acre would be required to produce a "High" rating. *Heavy to very heavy cuts of most species leave a fuel hazard that is high for 5 years or longer.*

Table 5.--Sample calculation of relative rate-of-spread ratings for a combination of species and quantities of slash

Species	Quantity		Rate-of-spread rating					
			Fresh slash		1-year-old slash		5-year-old slash	
	Tons per acre	Percent of total	Factor	Proportional rating	Factor	Proportional rating	Factor	Proportional rating
Western white pine	5	25	8	2.0	6.2	1.6	2.5	0.6
Western redcedar	4	20	8	1.6	6.2	1.2	1.5	.3
Douglas-fir	2	10	8	.8	3.6	.4	1.5	.2
Western hemlock	4	20	8	1.6	3.6	.7	2.5	.5
Grand fir	2	10	8	.8	2.0	.2	.6	.1
Western larch	3	15	12	1.8	2.0	.3	1.5	.2
Total	20	100		8.6 = Rating for area = 4.4				1.9

INTENSITY OF SLASH FIRES

Fires in 5-year-old slash were rather unspectacular and exhibited few of the more violent characteristics observed in earlier years. Flames seldom exceeded 6 or 7 feet in height and usually were much lower. Pronounced cones of solid flame, common in the early stages of fires in heavy fresh and 1-year-old slash, seldom appeared, and then they persisted for only short periods. For the less flammable species, fire characteristics differed less with weight of fuel than in younger fuel. Flame pulsations were observed a few times but were transitory and weak. Irregular fire spread was common, with accompanying fitful variation in intensity.

Heat radiation, as a measure of fire intensity, was measured on 48 of the 54 plots burned in 1960. Flat-plate, total-hemispherical radiometers were again employed, as in 1954 and 1955. Reduced fire intensity permitted placing all radiometers 28 feet from the plot centers; therefore, measurements were directly comparable, with no adjustment for instrument distance.

Table 6 summarizes radiation values for medium and heavy slash of five species at all three ages, and of all species at 1 and 5 years. Where data for all ages were available, mean intensity dropped to 36 percent of the fresh-slash level during the first year after cutting and to 27 percent by the end of 5 years. The changes were almost identical in medium and heavy slash. The average change between the first and the fifth years was about the same for all nine species as for the five with records running the full gamut of ages.

Although general average intensities declined consistently with age, higher values were measured for 5-year-old than for 1-year-old heavy slash of ponderosa pine, western redcedar, Douglas-fir, western hemlock, and Engelmann spruce. The 1960 figures were uncorrected instrument readings from the same type of radiometer at a single distance; hence they should be wholly reliable. Some of the earlier values were calculated to account for differences in instruments or instrument distances, or both; and two were based on a single plot. No satisfactory accounting could be made for the shape factor of the radiating surface, so the calculations were known to be only approximate. Therefore, the discrepant values for 1-year-old slash are unquestionably too low. Support for this conclusion comes also from knowledge that fire intensity is proportional to rate of spread (3). Average rate of spread in 1-year-old slash was 54 percent of the rate in fresh slash, appreciably above the apparent 36 percent for radiation; but overall mean rate of spread in 5-year-old slash was 23 percent of that in fresh fuel, quite close to the corresponding 27 percent calculated for radiation.

Table 6.--Average maximum radiation received[1] from slash of nine species at three ages and at two weights per acre

Species	Fresh slash				1-year-old slash				5-year-old slash			
	20.0 tons/acre		32.5 tons/acre		20.0 tons/acre		32.5 tons/acre		20.0 tons/acre		32.5 tons/acre	
	Plots	Heat	Plots	Heat	Plots	Heat	Plots	Heat	Plots	Heat	Plots	Heat
		$Btu/ft^2/hr$		$Btu/ft^2/hr$		$Btu/ft^2/hr$		$Btu/ft^2/hr$		$Btu/ft^2/hr$		$Btu/ft^2/hr$
White pine	-	--	-	--	2	193	3	628	3	128	3	293
Lodgepole pine**	2	523	2	2,003	3	317	3	885	3	150	3	499
Ponderosa pine**	2	359	2	1,245	4	142	4	297	3	45	3	356
Western redcedar	-	--	-	--	2	138	2	279	2	37	3	286
Douglas-fir	-	--	-	--	2	98	2	156	2	72	3	241
Western hemlock	-	--	-	--	2	110	1	176	3	69	3	264
Engelmann spruce**	3	245	3	317	2	130	1	60	3	94	3	158
Grand fir**	2	263	2	902	3	49	4	216	1	15	2	68
Western larch**	2	478	3	957	4	64	4	258	2	52	3	215
Mean **species		362		1,010		136		362		92		273
all species		--		--		136		364		82		272
Percent of fresh-slash **species intensity						38		36		25		27

[1] Received by radiometer adjusted to instrument distance of 28 feet from plot center.

CONCLUSIONS

The final phase of the slash flammability study added little new information, but it did strengthen conclusions drawn earlier. Rate of spread and fire intensity declined in the old slash of all species; the decreases were about what would be expected from the appearance of the slash. As in previous years, artificialities in research methods prevented absolute experimental values from being very meaningful, but results indicated satisfactorily clear-cut comparative ratings. Thus the general effect of aging 5 years was clearly brought out, and also the variation in this effect with species. *Persistence of high flammability under certain circumstances was the most important finding.*

"Logging Slash Flammability" discussed all aspects of slash flammability and need for slash treatment. The five ensuing conclusions draw upon all phases of the slash flammability study to emphasize considerations, both old and new, that bear significantly on the need for slash treatment.

1. Slash is hazardous in proportion to the quantity and durability of fine components, and to the length of time it is dry each year. Risk and accessibility of area to fire-control agencies are modifying considerations.

2. Given the same total weight per acre, slash flammability is proportional to the degree that fine material is elevated above the ground. Relative flammability per unit of weight therefore can be estimated rather reliably from visual examination. Weight must be known and can be calculated by methods developed earlier in this study.

3. Heavy to very heavy concentrations of western white pine, lodgepole pine, western redcedar, and western hemlock slash, and perhaps occasionally of ponderosa pine, Douglas-fir, and Engelmann spruce,

warrant a "High" rate of-spread rating after 5 years. Patches of "High" fuels can make hazardous an area that generally rates "Low" to "Medium."

4. Grand fir and western larch slash seldom require treatment. Grand fir disintegrates very rapidly; western larch is sparse, loses its highly flammable needles the first year, and lies close to the ground.

5. Slash treatment will buy the most protection per dollar spent where slash species and estimates of quantity point to a "High" rate-of-spread rating at 5 years. Extra protection in lieu of treatment has the best chance of success where the rating drops to "Low" or "Medium" by or soon after the end of the first year after cutting [see (3), p. 59].

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