Smoke Considerations Associated with Understory Burning in Larch/ Douglas-Fir

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INTRODUCTION

THE Lubrecht Forest fire study in which understory burning was done in mature Larch/Douglas-fir has been described earlier in this proceeding[1]. This paper discusses the effect of atmospheric conditions and fuel consumption on smoke. The research to date has determined quantitative relationships between pre-burn conditions and fire effects. Preliminary results indicate that it may be possible to predict the effects of various types of fires on the vegetation, on the site, and on the local atmosphere. Prescriptions can now be prepared for burning in this forest type that will produce the desired fuel reduction, duff removal, and nutrient availability, and result in known changes in atmospheric quality.

METHODS

Burning was done in the spring and fall of 1973 on 20, one-acre plots as described by Norum[1]. Weather and fuel conditions during

[1] Norum, R. Fire intensity—fuel reduction relationships associated with understory burning in Larch/Douglas-fir stands. (pp. 559-572.)

the study were constantly monitored. Fuel was measured by tallying all fuel particles intercepted by a 1-meter transect. The fuel particles were separated into five diameter classes; volumes and weights were determined by the method explained by Brown (1970).

Fuel mositure was measured immediately before burning by gravimetric means. Moisture samples consisted of litter, twigs, limbs, and green vegetation.

Air temperature and relative humidity were measured continually at the site by a hygrothermograph.

Wind velocity was measured with a 4-cup totalizing anemometer. Instantaneous readings of wind velocity are obtained from this instrument by counting the number of 1/60-mile contacts made during 1 minute of time. The average windiness condition during the 24-hour period was determined from this instrument because the output of the totalizing anemometer cup transmitter is displayed on a standard hygrothermograph weekly trace as 5-mile wind passages (Fischer, 1969).

Precipitation was measured with a recording rain gauge and checked against a standard Weather Bureau 8-inch funnel gauge.

Conditions aloft were measured with a standard radiosonde sent up just prior to each of the test burns. The base station was located 880 feet below the burn site about 3 miles away. The instrument package went to a height of 50,000 feet m.s.l. generally. A temperature vs. height profile was obtained from this instrument as well as wind velocity and direction at any desired elevation.

Smoke plumes were photographed from two locations 2 miles away from the fire so that the entire plume was visible. Two identical 16 mm movie cameras were set up so that photos could be made of the plume from two sides at right angles to each other simultaneously. This system allowed us to make three-dimensional measurements of the smoke plume. The cameras photographed the plume at 3-second intervals throughout the life of each fire. They were synchronized by radio pulses sent from one camera that triggered the shutter of the second one.

Measurements of the smoke plume dimensions were made on the paired sets of photos in order to obtain a determination of volume. Calculations were based on the assumption that the smoke plume resembled a geometric ellipsoid. This method did not give the total volume of the sky occupied by smoke, but it did provide a means of comparing smoke from one test fire with another. To determine the photo scale, large white cloth targets were positioned on the ground and their locations carefully plotted. The targets showed in the photographs and the photo distance between them was measured to provide the needed scale.

RESULTS

The total fuel loading varied from a maximum of 16.67 kg/m^2 to a mimimum of 5.55 kg/m^2 before burning. The average fuel loading for the nine spring fires was 12.75 kg/m^2 with 45 percent of the fuel being burned; and the average fuel loading for the fall fires was 9.34 kg/m^2 with 70 percent of the fuel burned (Table 1). Although more fuel was available for burning in the fall, a greater percentage was consumed than in the spring.

The fuel concentrations encountered on these burns varied from piles of fuel a meter deep to only grass and light burns. Because weight of fuel consumed does not adequately describe a fire in terms of smoke produced, a measure of the fire-blackened area was made to compare with smoke produced. The diversity of fuel, its moisture content, and ground wind combined to produce a burn pattern different for each fire. Figure 1 shows such a pattern. The percentage of area burned varied from 14 to 90. The average area burned for the spring fires was 35 percent and for fall fires 56 percent.

Fuel moisture determines how vigorously and how deep into the duff a fire will burn because of the tremendous amount of energy needed to convert water to vapor and then raise it to flame temperature. The most sensitive fuel element used for mositure determinations was the litter. Litter moisture varied from 13 to 70 percent in the spring and from 10 to 115 percent in the fall (Table 1). Fuel moisture in the large fuels was lower in the fall, probably accounting for the greater amount of fuel consumed at that time.

The weather conditions that prevailed at the fire sites are shown in Table 2. Days and times of day to burn were selected when wind velocities were low to reduce the chance of spot fires and to restrict

Table 1. Fuel loading and fuel consumed.

Date	Litter Moisture Percent	Loading kg/m²	Burned kg/m²	Percent Burned weight	Percent Burned area
		SPRING			
5/11	15	14.92	4.57	31	17
5/23	9	16.67	10.16	61	18
5/30	11	16.17	10.46	65	38
6/6	10	12.65	2.86	23	55
6/13	11	10.02	1.68	17	46
6/20	9	10.46	5.65	54	37
6/21	11	14.72	5.59	38	39
6/26	11	11.83	9.05	76	30
6/29	9	7.35	2.15	29	33
Ave.	11	12.75	5.80	45	35
		FALL			
9/10	17	11.31	8.08	71	75
9/11	8	5.55	4.11	74	90
9/17	20	10.44	6.64	64	39
9/26	35	5.76	3.19	55	36
9/28	21	14.89	10.83	73	35
9/29	22	11.89	6.69	56	46
10/4	23	7.72	1.31	17	14
10/5	19	8.90	4.85	54	37
10/6	21	13.90	8.26	59	61
10/9	19	12.43	10.39	84	85
10/10	20	11.23	7.46	66	42
Ave.	20	9.34	6.53	70	51
Overall Average	16	10.88	6.20	57	44

variation among fires. Afternoons were chosen because the atmosphere had "heated out" and the smoke had a better chance of dispersing quickly. The added safety of evening's cooler temperature gave a little added protection in case a fire escaped. Wind velocities varied from 0 to 9 m.p.h. (4.5 m/sec.) with some gustiness.

The atmospheric conditions over the fire site influenced smoke dispersal. Radiosonde data indicate that the general flow of winds at the 500 mb. level was from the western quadrat. In the spring, southwesterly flow predominated and in the fall northwesterly flow predominated. No noticeable difference in smoke dispersal was noticed between directions in the upper air wind flow pattern. The wind speed at 500 mb. varied from 10 to 50 knots. Wind speeds at ridge height, 5,200 feet (1,585 m), varied from 1.8 m.p.h. (0.9 m/sec.) to 17.8 m.p.h. (8.9 m/sec.). Wind velocity at this height is im-

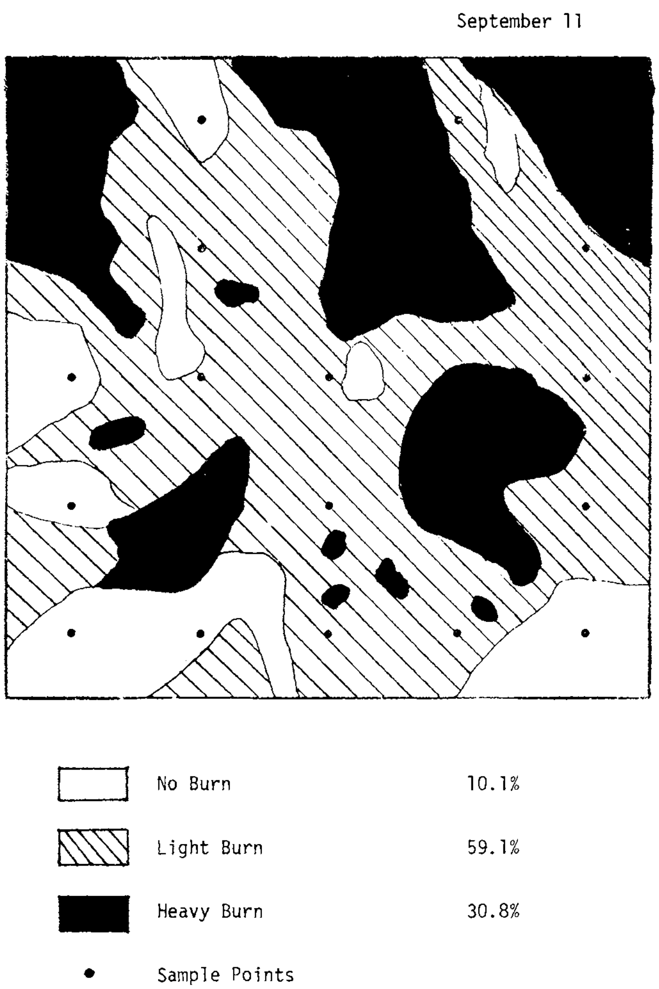

Fig. 1. Fire pattern—area burned map.

Table 2. Weather conditions on site.

Date	Temp. C o	Relative Humidity %	Wind Velocity m/sec	Remarks
		SPRING		
5/11	13	36	0.0	clear, calm day
5/23	19	48	1.3	high, thin overcast
5/30	21	35	1.3	some wind gusts
6/6	21	34	2.2	very steady wind
6/13	25	36	0.9	heavy, low overcast
6/20	21	32	0.9	broken clouds
6/21	27	27	0.0	calm, stable day
6/26	23	52	0.5	very steady wind
6/29	24	37	4.5	very gusty wind
Ave.	22	37	1.3	
		FALL		
9/10	27	40	0.0	calm, heavy air
9/11	27	30	2.7	gusty, variable wind
9/17	18	35	0.1	down slope wind
9/26	12	50	0.5	variable wind dir.
9/28	19	42	0.0	very calm day
9/29	23	34	1.3	gusty N.W. wind
10/4	14	28	2.2	steady wind
10/5	14	35	3.6	very gusty wind
10/6	13	41	0.0	calm, stable day
10/9	7	46	2.2	gusty winds
10/10	7	53	3.6	some strong gusts
Ave.	16	39	1.5	
Overall Ave.	19	38	1.4	

portant because it is this wind that is effective in dispersing smoke (Table 3).

The temperature lapse rates determined between 5,000 feet m.s.l. (1,524 m) and 8,000 feet m.s.l. (2,438 m) varied from 1.6°F./1,000 feet (3.6°C/km) to 6.3°F./1,000 feet (11.5°C/km). This represents a range from rather stable conditions to unstable conditions.

The Coldspan Company of Boulder, Colorado has developed a Dispersal Index (Table 4) which is a measure of the atmosphere's ability to disperse smoke and other pollutants. This index combines

Table 3. Weather conditions aloft.

Date	500 mb. Wind Knots	Temperature Lapse Rate* °C/km	—Wind at 1,646 m— Direction az. °	Velocity m/sec
		SPRING		
5/11	N. 30	6.6	270	2.2
5/23	S.W. 25	9.5	235	4.5
5/30	S.W. 25	8.6	200	4.5
6/6	W. 35	9.2	235	6.7
6/13	S.W. 45	9.2	180	4.5
6/20	S.W. 45	8.4	268	6.7
6/21	N.W. 25	6.6	280	4.5
6/26	W. 50	8.6	230	6.7
6/29	S.W. 45	9.5	240	8.9
Ave.	S.W. 36	8.5	238	5.5
		FALL		
9/10	S. 20	3.6	240	2.2
9/11	N.W. 10	8.5	175	4.5
9/17	N.W. 25	5.9	212	0.9
9/26	N.W. 25	9.2	237	4.5
9/28	W. 15	3.6	228	1.3
9/29	S.W. 10	6.6	207	4.0
10/4	N.W. 55	2.9	240	4.5
10/5	W. 50	8.5	213	7.2
10/6	S.W. 40	4.6	250	2.7
10/9	N.10	11.5	216	2.7
1-/10	N. 20	10.2	208	5.4
Ave.	N.W. 25	6.8	221	3.6
Overall Average	S.W. 30	7.6	228	4.5

temperature lapse rate, expressed as the mixing level, with wind speed to give a measure of dispersion ability. The lapse rate is a measure of the buoyancy of the atmosphere and the wind is very important as a dispersal agent. This index is the product of the mixing level, the wind velocity at a given height, and a constant, 9.66, all divided by 1,000. An index of 0 to 19 indicated poor dispersal conditions; 20 to 39, fair conditions; 40 to 59 good dispersal; and 60-plus excellent conditions.

Since all the test fires were conducted in the late afternoon when the mixing level was at least 8,200 feet (2,438 m) m.s.i., the dis-

Table 4. Atmospheric dispersal index.

Date	Mixing Level M	Wind Speed m/sec	Dispersal Index	Dispersal Condition
		SPRING		
5/11	2650	2.2	56	good
5/23	2520	4.5	109	excellent
5/30	2800	4.5	122	excellent
6/6	3000	6.7	194	excellent
6/13	2550	4.5	111	excellent
6/20	3340	6.7	216	excellent
6/21	3110	4.5	135	excellent
6/26	3700	6.7	239	excellent
6/29	2790	8.9	240	excellent
Ave.	2940	5.5	158	excellent
		FALL		
9/10	2050	2.2	44	good
9/11	2880	4.5	125	excellent
9/17	3109	0.9	27	fair
9/26	3048	4.5	132	excellent
9/28	2560	1.3	32	fair
9/29	2012	4.0	78	excellent
10/4	3017	4.5	131	excellent
10/5	3865	7.2	199	excellent
10/6	2073	2.7	54	good
10/9	3139	2.7	82	excellent
10/10	2835	5.4	148	excellent
Ave.	2690	3.6	96	excellent
Overall Average	2802	4.5	124	excellent

persal index was in the "excellent" category most of the time and the smoke moved out of the burn area rapidly. The average dispersal index for the spring burns was 158 and for the fall burns 96.

The smoke plume measurements indicate a large variability in volume among fires. The average smoke plume volume for the duration of each fire is shown with its corresponding dispersal index, percent of area burned, and amount of fuel consumed (Table 5). The fire of 10/9, the highest intensity fire, burned over 85 percent of the total plot area, consumed 84 percent of the available fuel, but produced one of the lower average smoke plume volumes. The two fires

Table 5. Smoke volumes associated with dispersal index, area burned and fuel consumed.

Date	Average Smoke Volume $M^3 \times 10^3$	Dispersal Index	Percent of Area Burned	Percent of Total Fuel Consumed
6/20	159	216	37	54
6/21	323	135	39	38
6/26	83	239	30	76
9/17	713	27	89	64
9/28	1340	32	35	73
10/5	14	199	37	54
10/9	51	82	85	84
10/10	8	148	42	66

that produced the largest smoke volumes, i.e. 9/17 and 9/28, had dispersal indexes of 27 and 32 respectively, both in the "fair" dispersal range, whereas the fire of 10/9 burned under "excellent" dispersal conditions and produced less smoke.

DISCUSSION

Low-intensity fires in the understory usually do not produce enough heat to push smoke independently into the upper atmosphere where the winds aloft will dissipate it. Therefore, smoke movement is controlled by the conditions in the atmosphere from the ground up to about 5,000 ft. (1,524 m). If this layer of the atmosphere is very stable, smoke will not rise but will spread laterally and remain near the ground. If the layer is fairly unstable or even neutral, smoke has a chance of rising due to thermal buoyancy. This study showed that smoke from low-intensity fires burning in the understory of Larch/Douglas-fir was adequately dispersed by normal late afternoon winds in the mountains, even when the atmosphere was relatively stable.

This is significant because it allows the freedom to burn when the atmosphere is fairly stable with the assurance that smoke will be dispersed even by light winds. Further, from the safety standpoint, it is preferable to burn when the wind velocity is under 8 m.p.h. (4 m/sec.) and the atmosphere is stable because there is less chance of spot fires occurring outside the prescribed burn area.

Smoke columns are influenced by the forest fuels that are burning, their moisture content, and the rate at which these fuels are consumed. When the atmosphere was unstable, the fires produced visible smoke plumes of roughly 2 million cubic feet (50 x 10^3 cu.mtrs.) of space during the 2 hours of active burning. However, the smoke volume increased to 54 million cubic feet (1340 x 10^3 cu. mtrs.) under very stable conditions. Even though smoke plume volumes were considerably greater under stable atmospheric conditions, the wind dispersed the smoke adequately and no smoke accumulation was noticed in the valleys during the active burning periods.

The fuels in these mature Larch/Douglas-fir stands burned fairly rapidly and produced smoke in greatest quantity during the 2 hour period. Fuels tended to either burn up completely or fail to ignite, depending on their moisture content. However, large stumps and heavy duff frequently smoldered and produced lesser amount of smoke for longer times.

Forests of this type contain not only fuels of the current growing vegetation, but also remnant fuels from a past forest. These remnant fuels are stumps, logs, rotten wood, and snags. Often the remnant fuels contain pitch, which because of its extremely high heat content, is responsible for keeping much of the remnant fuel burning even when the moisture content is high and the pieces are large. If it were not for pitch, these same fuel pieces would probably go out and stop smoking when the main fire was over. These remnant fuels therefore burn slower than the fuels from the present forest, sometimes smoking for several days. A night-time atmospheric inversion can trap this smoke in valleys and cause air quality problems.

As forest management intensifies and as we begin to harvest younger stands, the amount of these "remnant" fuels will decrease, along with the problem of lingering smoke.

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