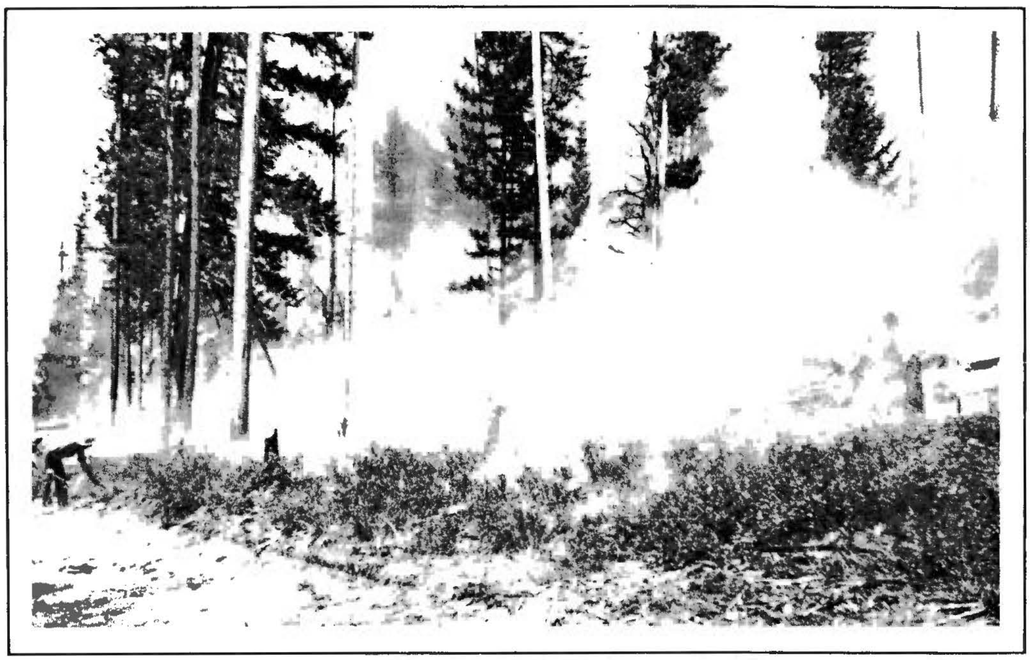
understory burning in larch/douglas-fir forests as a management tool



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Editor's Note—The Summer 1974 issue of Western Wildlands *carried an article entitled "New Fire Research Frontiers in Montana Forests," which described an experimental burning program being conducted at the University of Montana Forestry School's Lubrecht Experimental Forest. The study results showed that in mature larch/Douglas-fir forests, burning prescriptions can be prepared that will meet air quality requirements and yet successfully reduce fuel accumulations, remove duff, and improve nutrient availability. Below is a recap of the original article plus an update on the research results.*

RECAP

Fire occurs sometime during the life cycle of most forest species in the northern Rocky Mountains. It is an ecological force of great magnitude that has shaped and maintained the ecosystems we know today. A clear understanding of the influences of fire on the ecosystems is necessary if management decisions are to be biologically sound.

.Whereas fire once played a natural role in stabilizing the forests, its exclusion over several decades has allowed an abnormal increase in fuel accumulation. Diligent forest fire protection in the northern Rockies has been a mixed blessing, because the natural deposition of organic materials exceeds decomposition. For instance, it has been estimated that the fuel buildup during the life cycle of a Douglas-fir/western larch forest exceeds 300 tons per acre. The net accumulation of needles, twigs, branches, and fallen trees must inevitably be reduced by fire if it is not consumed in any other way. If this stored energy must be converted by fire, the fire should come at the time and under the conditions that best suit man's needs.

Aside from a small market for chips, the only substantial market at present for forest products in this region is for sawlogs. Thus the opportunity for fuel reduction through marketable thinning is limited. Fire remains as the most economical and practical tool for reducing hazardous fuel accumulations and regenerating certain timber types. The usefulness of prescribed burning for slash disposal and fuel reduction under standing timber has long been recognized. Often in the past the objectives of burning were not met because fire was not properly applied. This was due at least in part to the fact that much past research concentrated on improving the techniques of fire application rather than on gaining an understanding of the physical and biological influences of fire.

Research conducted at the University of Montana Forestry School's Lubrecht Experimental Forest indicates that prescriptions can be prepared for burning under mature larch/Douglas-fir forests that will reduce fuels, remove duff, and improve nutrient availability, and still be within air quality requirements. Prescribed burns were conducted in the spring and fall of 1973 on 20 1-acre plots.

Intensive sampling was used to quantify the amount of down, dead material prior to burning, along with the living biomass in the understory. The dominant tree overstory was completely sampled (100 percent) by species, size, and location, and trees were classified as live or dead. Understory trees were sampled and similarly quantified. Sets of fuel samples were gathered at fire time to determine their moisture content, and continuous on-site weather records were kept. Temperatures and intensities were measured in the fire, using a grid array. Down, dead fuel loads ranged from 5 tons per acre to 47 tons per acre. Study plots covering this range were burned, on a random-selection basis, at moisture contents ranging from 8 to 28 percent during the months of May, June, July, September, and October. After burning, fuels and vegetation were inventoried again, and the immediate effects of the fires on the overstory were assessed.

Burning days and times were selected on the basis of wind velocity; low velocities reduce the chance of spot fires and reduce the variation in fire spread among the study fires. Afternoons were chosen because the atmosphere has "heated out" and the smoke has a better chance of dispersing quickly.

Wind velocity was measured with a totalizing anemometer, precipitation with an 8-inch standard rain gauge, and conditions aloft with a standard radiosonde sent up just prior to each of the test fires.

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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 simultaneous photos could be made of the plume from two sides at right angles to each other. This system made it possible to make three-dimensional measurements of the smoke plume. The cameras photographed the plume at 3-second intervals throughout the duration of each fire. They were synchronized by radio pulses sent from one camera that triggered the shutter of the second one.

The smoke plume dimensions were measured on the paired sets of photos to determine 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 that from 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.

Fuel Reduction

The total fuel loading varied from a maximum of 16.67 kg/m² to a minimum of 5.55 kg/m² before burning. The average fuel loading for the nine spring fires was 12.75 kg/m², with 45 percent of the fuel being burned; the average fuel loading for the fall fires was 9.34 kg/m², with 70 percent of the fuel being burned (table 1). A greater percentage of available fuel was consumed by fall burning than by spring burning. A possible method for predicting safe fuel consumption levels is as follows:

1. Measure weight of fuel in kg/m² on an average of 10 well-distributed sampling points per hectare (kg/m² x 4.46 = tons/acre).
2. Divide land by fuel load categories on a map.

Fuel class	Total fuel wt. (kg/m²)	Tons/acre[1]
Class I Light	0-6	0-27
Class II Medium	7-12	28-54
Class III Heavy	12+	54+

3. Choose a level of fuel reduction by fuel loading categories:

Fuel class	Safe fuel reduction (%)	Fuel moisture in lower duff (%)	Air temp. (°F)	Wind (mph)	Max. burning index[2]	Fuel moisture 0 to ¼ in. twigs (%)
I Light	75-100	10-45	60-85	5-12	40	8-13
II Medium	50-75	46-75	60-85	4-10	35	14-19
III Heavy	25-50	76-100	60-85	0-6	30	20-25

4. Choose a day with the following synoptic pattern:
   a. Atmosphere under the influence of small pressure change.
   b. No front predicted for at least 24 hours.
   c. 500 mb winds less than 60 knots.
   d. Ridgetops winds less than 5.3 m/sec (12 mph).

Duff Reduction

Reduction of duff depth is an important result of many prescribed fires. The remaining duff depth after the fire has a strong influence on what vegetation appears on the site after a fire. For instance, shallow duff depths favor larch seedlings, whereas Douglas-fir will germinate and survive better in a moderate amount of duff. Duff rarely dries enough in this forest type for fire to be carried by duff alone; hence, duff reduction depends on those factors above the duff surface that influence fire intensity. The following equations show the relationships among the most significant items affecting duff depth reduction:

Duff depth after spring fires (cm) = −2.0 + .433 (duff depth, prefire) +31.5 (reciprocal of lower duff moisture) −19.0 (pre-burn fuel weight of 1- to 3-inch pieces) −7.5 (pre-burn shrub weight)

[1]Total fuel weight includes shrubs, forbs, and grasses.
[2]Burning index as computed for National Fire Danger Rating System. Fuel Type G. (See Deeming et al. 1974. USDA Forest Serv. Res. Pap. RM-84. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, CO.

Duff depth after fall fires (cm) = 1.03 + .77 (pre-burn duff depth) −.03 (lower duff moisture) +14.0 (pre-burn shrub weight) +12.5 (pre-burn weight of grass and forbs)

Woody shrub weight acts as a deterrent to duff reduction in the spring and an aid in the fall. Grass and forb weights appear only in the fall equation because by fall they have cured and are more significant as a fuel then.

TABLE 1.—Fuel loading and consumption for 20 experimental fires on Lubrecht Forest.

Fire no.	Date	Loading *kg/m²*	Burned *kg/m²*	Percent burned Weight	Percent burned Area
29	5/11	14.92	4.57	31	17
30	5/23	16.67	10.16	61	18
9	5/30	16.17	10.46	65	38
26	6/6	12.65	2.86	23	55
25	6/13	10.02	1.68	17	46
2	6/20	10.46	5.65	54	37
6	6/21	14.72	5.59	38	39
5	6/26	11.83	9.05	76	30
28	6/29	7.35	2.15	29	33
	Average Spring	12.75	5.80	45	35
21	9/10	11.31	8.08	71	75
1	9/11	5.55	4.11	74	90
18	9/17	10.44	6.64	64	39
3	9/26	5.76	3.19	55	36
27	9/28	14.89	10.83	73	35
10	9/29	11.89	6.69	56	46
14	10/4	7.72	1.31	17	14
31	10/5	8.90	4.85	54	37
11	10/6	13.90	8.26	59	61
22	10/9	12.43	10.39	84	85
23	10/10	11.23	7.46	66	42
	Average Fall	9.34	6.53	70	51
	Overall Average	10.88	6.20	57	44

Nutrient Cycling

Lightly burned areas revegetated rapidly; almost no damage was done to rhizomes or roots, so that the original huckleberry, heartleaf arnica, Oregon grape, twin flower, grasses, and spiraea returned either the same or the next year. Light burns were completely successful in preventing erosion, but the temperatures (180 to 200°C) were too low to result in addition of significant amounts of nutrients. Added nutrients appeared in the tree root zone for only a few months following snowmelt, and were not sufficient to stimulate tree growth. On lightly burned areas, the weight of living shrubs per unit area after 3 years was 194 g/m².

Medium-intensity fires (surface temperatures between 200 and 300°C) made available more calcium, fluoride, potassium, magnesium, nitrate, sodium, phosphate, and zinc than did the light burns. Medium burns destroyed most of the shrubs, and up to half of the litter. The vegetation that returned was mostly huckleberry, spiraea, grasses, and fireweed. Revegetation was rapid and after 3 years the weight of living shrubs per unit area was 142 g/m². Revegetation was rapid enough to prevent erosion, but nutrient release was not adequate to stimulate tree diameter growth. Where the objective is to reduce accumulation of residual fuels in larch/Douglas-fir stands, medium-intensity burns produce the best overall results. Although they may not increase tree growth, they accomplish some fuel reduction, spare the mature trees, and result in minimal nutrient losses.

High-intensity fires (temperatures considerably over 300° C) under standing timber can burn into mineral soil and kill roots and rhizomes. These fires normally burn out entire root systems, causing some physical changes in the soil. Logs are likely to be consumed, releasing large amounts of ash and readily leachable nutrients into the soil at one time. If the soil has sufficient clay or silt to slow drainage and hold the added nutrients, all is well. If the soil has too much clay, especially the expansive types, infiltration will be slowed and surface runoff may carry away nutrients. On some soils, compounds may form that reduce soil wettability. If the soil is highly permeable, as with a sandy loam, an excess of nutrients may wash through the soil and be lost for good.

A liverwort (*Marchantia*), fireweed, and abundant larch and Douglas-fir seedlings appeared on hotly burned sites within a year, and only minimal erosion occurred. The vegetation on heavily burned sites after 3 years weighed the most (253 g/m²) and had the highest nutrient content. Heavy burning resulted in greater nutrient losses than did the other burning treatments, but these losses are not significant in reducing the long-term productive capabilities of this young soil.

Measurements show that we could burn the vegetation on the forest floor (slash, brush, litter) once every 50 years with fire temperatures exceeding 300°C for something like 54,000 years before all of the potentially available calcium in the root zone would be exhausted. It would take 50,000 years to erode away the present root zone with the levels of erosion recorded following heavy burning.

These research results cannot be extrapolated directly to other areas, but some general trends are evident. In western Montana, fire poses little threat to long-term productivity of soils, especially those derived from argillite (based on total nutrients potentially available). The richer the parent material the less chance of lasting damage, with the exception of certain calcareous or dolomitic soils. With young soils, the greatest danger lies in too frequent harvest or too intense or frequent burning. This could cause losses of *available* biologically essential nutrients needed for day-to-day growth of trees. Removing too many of these essential nutrients can result in temporary shortages of calcium, phosphorus, or other ions, thus restricting tree growth for tens to hundreds of years. If brush takes over in the meantime, trees may be eliminated from the site until a major fire occurs. Removing needles eliminates a larger amount of nutrients from the decay cycle than removing wood. For sustained tree growth, it is essential to use burning and harvest treatments that do not deplete the available nutrients. Research is now needed on "nutrient shock" produced by too severe or frequent treatments.

Smoke Dispersal

Atmospheric conditions above the fire site influence smoke dispersal. Low-intensity fires in the understory usually do not produce enough heat to push smoke 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 feet (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 bouyancy. 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 mph (4 m/sec) and the atmosphere is stable, because there is less chance of spot fires occurring outside the prescribed burn area.

Radiosonde data indicated 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 differences in smoke dispersal were observed among directions in the upper-air windflow 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 mph (0.9 m/sec) to 17.8 mph (8.9 m/sec). Wind velocity at this height is important because it is this wind that is effective in dispersing smoke (table 2).

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TABLE 2.—Weather conditions aloft for 20 experimental fires on Lubrecht Forest.

Fire no.	Date	500 mb wind *knots*	Temperature lapse rate[1] *°C/km*	Wind at 1646 m Direction *az°*	Velocity *m/sec*
29	5/11	N 30	6.6	270	2.2
30	5/23	SW 25	9.5	235	4.5
9	5/30	SW 25	8.6	200	4.5
26	6/6	W 35	9.2	235	6.7
25	6/13	SW 45	9.2	180	4.5
2	6/20	SW 45	8.4	268	6.7
6	6/21	NW 25	6.6	280	4.5
5	6/26	W 50	8.6	230	6.7
28	6/29	SW 45	9.5	240	8.9
	Average Spring	SW 36	8.5	238	5.5
21	9/10	S 20	3.6	240	2.2
1	9/11	NW 10	8.5	175	4.5
18	9/17	NW 25	5.9	212	0.9
3	9/26	NW 25	9.2	237	4.5
27	9/28	W 15	3.6	228	1.3
10	9/29	SW 10	6.6	207	4.0
14	10/4	NW 55	2.9	240	4.5
31	10/5	W 50	8.5	213	7.2
11	10/6	SW 40	4.6	250	2.7
22	10/9	N 10	11.5	216	2.7
23	10/10	N 20	10.2	208	5.4
	Average Fall	NW 25	6.8	221	3.6
	Overall Average	SW 30	7.6	228	4.5

[1]Lapse rate between 1,524 m and 2,438 m.

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

The Colspan Company of Boulder, Colorado has developed a dispersal index (table 3) that is a measure of the atmosphere's ability to disperse smoke and other pollutants. This index combines 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 bouyancy of the atmosphere, and the wind is very important as a dispersal agent. This index is a product of the mixing level, the wind velocity at a given height, and a constant (9.66), all divided by 1000. An index of 0 to 19 indicates poor dispersal conditions; 20 to 39, fair conditions; 40 to 59, good conditions; 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 ft (2,438 m) msl, the dispersal index was in the "excellent" category most of the time and the smoke moved out of the area rapidly. The average dispersal index for the spring burns was 158, and for the fall 96.

Smoke columns are influenced by the forest fuels, their moisture content, and the rate at which these fuels are consumed. The measurements indicated a large variation among fires in smokeplume volume. Table 4 shows the average smokeplume volume for the duration of each fire, along with the corresponding dispersal index, percent of area burned, and amount of fuel consumed. Fire No. 22, the highest intensity fire, burned under excellent dispersal conditions and, even though it burned 85 percent of the total plot area and consumed 84 percent of the available fuel, it produced one of the smaller smoke volumes. Fires No. 18 and 27, which burned under dispersal indexes of 27 and 32, respectively, were both in the "fair" dispersal range and produced larger smoke volumes. Even though smoke plume volumes varied considerably because of fuel and atmospheric conditions, the wind dispersed smoke adequately during the approximately 2-hour-long active burning period.

TABLE 3.—Atmospheric dispersal index for 20 experimental fires on Lubrecht Forest.

Fire no.	Date	Mixing level *m*	Wind speed *m/sec*	Dispersal index	Dispersal condition
29	5/11	2,650	2.2	56	good
30	5/23	2,520	4.5	109	excellent
9	5/30	2,800	4.5	122	excellent
26	6/6	3,000	6.7	194	excellent
25	6/13	2,550	4.5	111	excellent
2	6/20	3,340	6.7	216	excellent
6	6/21	3,110	4.5	135	excellent
5	6/26	3,700	6.7	239	excellent
28	6/29	2,790	8.9	240	excellent
	Average Spring	2,940	5.5	158	excellent
21	9/10	2,050	2.2	44	good
1	9/11	2,880	4.5	125	excellent
18	9/17	3,109	0.9	27	fair
3	9/26	3,048	4.5	132	excellent
27	9/28	2,560	1.3	32	fair
10	9/29	2,012	4.0	78	excellent
14	10/4	3,017	4.5	131	excellent
31	10/5	2,865	7.2	199	excellent
11	10/6	2,073	2.7	54	good
22	10/9	3,139	2.7	82	excellent
23	10/10	2,835	5.4	148	excellent
	Average Fall	2,690	3.6	96	excellent
	Overall Average	2,802	4.5	124	excellent

TABLE 4.—Smoke volumes associated with dispersal index, area burned, and fuel consumed

Fire no.	Date	Average smoke volume m^3x10^3	Dispersal index	Percent of area burned *percent*	Percent of total fuel consumed *percent*
2	6/20	159	216	37	54
6	6/21	323	135	39	38
5	6/26	83	239	30	76
18	9/17	713	27	39	64
27	9/28	1,340	32	35	73
31	10/5	14	199	37	54
22	10/9	51	82	85	84
23	10/10	8	148	42	66