

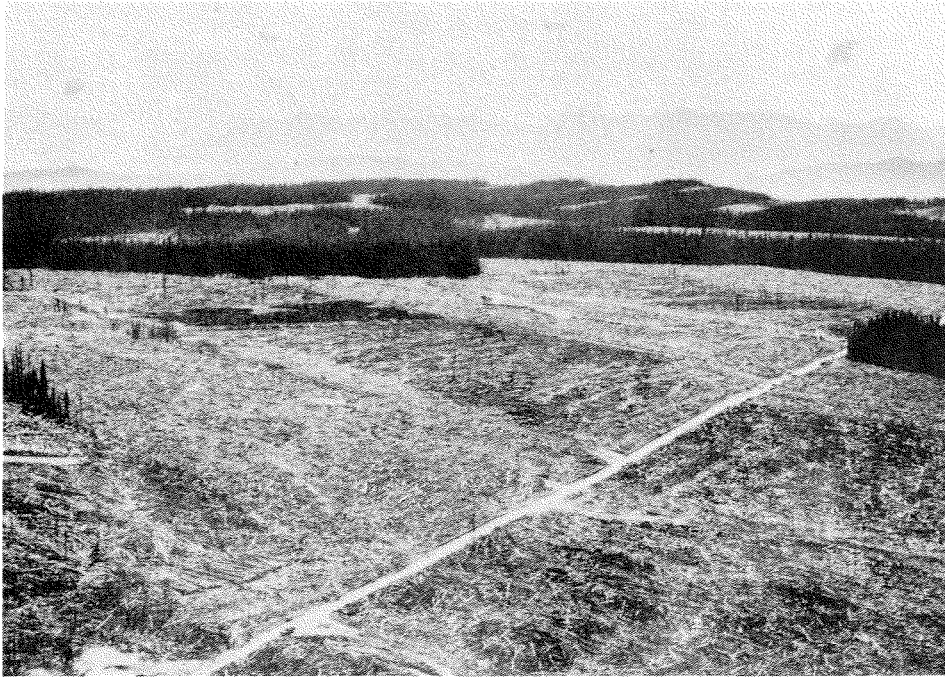
PREScribed FIRE EFFECTS IN SUBALPINE
SPRUCE-FIR SLASH

by

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Aerial view of shallow duff burning site near Hinton, Alberta.

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PREScribed FIRE EFFECTS IN SUBALPINE

SPRUCE-FIR SLASH

INTRODUCTION

Clearcutting of overmature spruce-fir (Picea glauca (Moench) Voss and Abies lasiocarpa (Hook) Nutt.) stands produces considerable woody material from unmerchantable tops, branches and decaying, unusable trees. This logging debris and the deep organic soil horizon typical of such overmature stands represent a formidable fire hazard and hinder planting-crew efficiency. The accumulation of 6 to 24 inches of unincorporated organic material is attributed largely to a continuous spruce-fir cover for centuries without interruption by wildfire, the high elevation and cold climate, and high moisture retention capacity of the soil.

Natural regeneration is, on the whole, inadequate following clear-cutting of these stands. Mechanical scarification and conventional and container planting are being appraised on such sites (Crossley, 1955; Ackerman et al, 1965) but hopes for success are not high owing to the presence of excessive accumulations of organic material including moss and mor humus. Even if survival of planted stock is satisfactory, it is unlikely that the process of site deterioration can be reversed unless the organic layer is greatly reduced.

The high fire hazard, unfavourable seedbed conditions for survival and growth of planted stock and the effect of slash fuels in reducing planting-crew efficiency led to a renewed interest in prescribed burning. In 1966, a co-operative study involving the Alberta Forest Service, North Western Pulp and Power Ltd., and the Canadian Forestry Service was initiated

in west-central Alberta to determine the potential role of prescribed burning in spruce-fir clearcuts. The purposes of this study are to:

1. provide burning prescriptions for hazard reduction,
2. determine if burning will improve planting-crew efficiency by reducing the physical barrier of slash accumulations,
3. evaluate the effect of burning on reversal of site deterioration by raising soil temperatures and generally encouraging activity of soil organisms.
4. investigate techniques and logistics of prescribed burning in this fuel type.

This paper presents the immediate results of fire-effects studies on four 20-acre burns in spruce-fir slash in 1968 and 1969. Results of a similar burn in 1967 have been published in a separate article (Kiil, 1969).

STUDY AREA

Physiography and Soils

The study area is in the transition zone between the Upper Foothills Section of the Boreal Forest Region and the East Slope Rockies Section of the Subalpine Forest Region (Rowe, 1959). The Mesozoic and late Palaeozoic sediments which form the bedrock are overlain by glacial deposits and colluvial material. The topography is rolling to mountainous with high rounded hills in excess of 6,000 feet above sea level and deep valleys at 3,500 feet above sea level. The burning sites are at an elevation of about 5,000 feet on a broad till-topped plateau 15 miles north-west of the town of Hinton (Lat. $53^{\circ} 24'$, Long. $117^{\circ} 37'$), Alberta.

Two sites, henceforth referred to as shallow and deep duff, were judged to be representative of the problem area and selected for the burning trials. The soil on the shallow duff site is a deep, well-drained podzolic developed on a mixture of glacial drift and alluvial material. The mineral soil is overlain by 4 to 8 inches of duff including moss and mor humus. The soil on the deep duff site is poorly gleysolic developed on a compacted, slowly permeable glacial till. The mineral soil is overlain by 6 to 24 inches of moss, partly decomposed organic material and black muck. Owing to the nearly impermeable sandy-clay parent material, moisture is perched on this layer and moves laterally through the alluvial layers. Also, drainage is impeded by frost which remains in the ground until June or July. This site is on a 5 per cent northwesterly slope.

Vegetation

The coniferous forest in the study area is characterized by over-mature spruce-fir stands (Figure 1). Extensive stands of lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) and black spruce (Picea mariana) occur in neighbouring areas but they are not an important constituent of the forests on the two burning sites. Stand statistics for both burning sites are given in Table I.

TABLE I. Summary of Site and Stand Characteristics for both Burning Sites.

Stand or Site Characteristic	Shallow Duff			Deep Duff		
	Spruce	Fir	Total	Spruce	Fir	Total
No. of stems/acre	224	265	489	204	226	430
Average diameter at breast height in inches	9.7	5.9	7.9	10.5	6.7	8.3
Basal area in square feet/acre	115	50	165	102	55	157
Dom. height in feet	89	64	-	86	73	-
Age of dominants in years	300	150	-	300	150	-
Total volume in cu. ft./acre	2963	898	3891	2737	1062	3799
No. of snags ¹ /acre	-	-	174	-	-	112
Elevation of burning site in feet	4800			5200		
Slope and aspect	8% N			10% NW		
Soil	Well-drained podsolic on mixture of glacial drift.			poorly-drained gley- solic on compacted glacial till.		
Depth of duff layer in inches	4 to 8			6 to 24		

¹ Snag is a standing dead tree exceeding 10 feet in height.

In addition to the live trees, snags accounted for 37 and 27 square feet of basal area per acre in the shallow and deep duff sites, respectively. The large number of snags and ages of dominant spruce and fir trees reflect the overmature and decadent condition of these stands. Natural regeneration in these stands is spotty and consists mainly of slow-growing alpine fir. The moss and herbaceous cover is made up of Hylocomium splendens (Hedw.) BSG., Pleurozium schreberi (BSG.) Mitt., Hypnum crista-castrensis Hedw., Equisetum sylvaticum L., Ledum groenlandicum Oeder and Linnea borealis L. The shrubby vegetation is negligible, consisting of a few Alnus and Salix species.

The moss layer in these stands is continuous and averages about two inches in depth. The underlying F layer is well developed and consists of needles, mosses and other decaying woody material still identifiable as to original source. The H layer is highly variable in depth and contains varying amounts of mineral soil.

Climate

A continental climate with strong contrast between summer and winter temperatures prevails in the study area. Mean temperatures for January and July are about 10 and 60°F (Anon., 1964). Mean annual precipitation is about 20 inches (Anon., 1965), of which nearly 50 per cent falls during June, July and August. The year may be conveniently divided into 5 months winter (November to March), 5 months summer (May to September) and spring (April) and autumn (October) each one month (Kendrew and Currie, 1955). The climate at the 5,000-foot elevation is more severe than that reflected by available long-term averages. For

example, ground frost may persist into late June or early July and the period of active vegetative growth is usually less than 6 to 8 weeks.

METHODS

Selection and Preparation of Plots

Two study sites -- one in shallow duff, the other in deep duff -- were selected in fall of 1966 following an extensive field reconnaissance of the problem area. The selected sites were representative of similar site and stand conditions elsewhere in the East Slopes of the Canadian Rockies. Other selection criteria were ease of access and availability of an adequate supply of water for wetting of fuels prior to burning and for mop-up operations.

On each study site, three 10 to 25-acre burning plots and one control plot were established. A detailed stand inventory was carried out in late fall of 1966 (Table I). The plots were clearcut in winter of 1966-67 with utilization to a 4-inch minimum top diameter. Following delimbing, the tree-lengths were taken to roadside landings by rubber-tired skidders. Disturbance of the snow-covered forest floor was negligible (Figure 2).

Preparation of plots for burning included construction of 15 to 20-foot wide fireguards to mineral soil, excavation of water-holes, and felling of snags within 100 feet of the fireguards. Alberta Forest Service provided men and equipment on a standby basis in the event of fire excursions and assumed responsibility for mop-up operations as required.



Figure 1. Overmature spruce-fir stand with four-year-old slash in forefront.



Figure 2. Typical slash fuelbed in shallow duff site.

Fuel Inventory

Fuel sampling was carried out on four adjacent 1.6-acre plots by using a reference grid of 100 iron rods on 40-link centres in each plot. The weight of slash fuels was determined in three diameter classes - (1) up to $\frac{1}{2}$ -inch including foliage, (2) .51 to 2 inches and (3) 2.1 to 4 inches - by using crown weight tables (Kiil, 1967). The weight of logging residue and other dead logs on the forest floor in excess of 4 inches in diameter were sampled by using 200-foot-long line transects radiating from the centre of each plot at 60-degree intervals (Van Wagner, 1968). The mean depth and weight of three duff strata (L,F,H) and minor vegetation were determined from data collected from 30 2 x 3-foot and 56 one-square-foot plots established randomly in clearcuts and in adjacent stands. For the burns carried out in 1968 and 1969, 12 2 x 3-foot plots were extracted and measured to determine changes in depth and/or weight of litter (L) and minor vegetation. The ground-surface area covered by dead logs was determined from a fuel tally on four 1/10-acre plots in a stand adjoining the shallow duff site.

The depletion of logging debris and cull logs by fire was determined by measuring the diameter or size-class of fuel pieces intersected by the vertical plane of a sample line. For slash fuels less than 4 inches in diameter, 24 3-foot long wire frames were measured on each plot before and after burning. Consumption of fuel pieces in excess of 4 inches in diameter was determined by remeasuring the fuels intersected by the vertical planes of the 200-foot-long transects. The depletion of the duff layer by fire was determined by measuring the length of exposure of 120 8-gauge iron pins placed in groups of five at five-foot intervals

at the 24 wire frames. Depth of burn adjacent to three 3-, 6-, 9-, 12-, and 15-inch-diameter cull logs was determined by measuring the length of exposure of five pins placed at 3-inch intervals and at right angles to the length of each log. Each depth of burn measurement was based on the length of pin protruding above the ground surface after the ashes had been washed away by rain or removed by hand. The consumption of minor vegetation was determined by estimating the percent of plot area burned over.

For purposes of this study, moss consists of growing and dying plants and any spruce and fir needles and twigs therein. This composition lent itself very well to field sampling but extreme care was required to separate the fermentation (F) layer from the underlying mor humus (H). Fine fuels include needles and other woody material less than $\frac{1}{2}$ -inch in diameter. All weights in this report are given on an oven-dry basis.

Fuel Moisture Determinations

The moisture content of slash fuels was determined shortly before ignition in three size-classes - (1) less than $\frac{1}{2}$ -inch, (2) .51 to 2 inches and (3) the surface $\frac{3}{4}$ -inch of fuels 2.1 to 4 inches in diameter. Samples were taken also of needles and twigs on the forest floor and herbaceous vegetation. To determine the distribution of moisture in heavier logs, three 2-inch thick cross-sections were taken from selected cull logs in the 6-, 10- and 14-inch diameter classes. Immediately before each burn, three one-square-foot duff samples were extracted in each plot and in the adjacent stand, taken to a field laboratory and separated into L, F and H layers. All samples were oven-dried at about 105°C to a constant weight.

Standard 0.5-inch B.C. Forest Service fuel moisture indicator sticks were set out at the fire weather station and weighed at one-hour intervals on burning days.

Fire Weather and Burning Prescriptions

A weather station was maintained at both sites, and continuous records of rainfall, temperature, relative humidity and wind were kept. Wind speed and direction were measured 20 feet above the ground surface, temperature and relative humidity at 4.5 feet and rainfall 3 feet above the ground surface. Wind speed and direction were also measured 2 feet above the ground surface on the leeward side of each prescribed burn by using a sensitive cup anemometer. For the three shallow duff burns in 1968, the speed and direction of winds aloft was estimated by the use of a pilot balloon and a theodolite.

A special committee, comprised of representatives from Alberta Forest Service, North Western Pulp and Power Ltd. and the Canadian Forestry Service established a fire prescription for each burn. Each prescription specified the allowable ranges for fire hazard indices (Anon., 1970) and prevailing wind, temperature and relative humidity at the time of ignition. Maximum allowable wind speed at ignition was set as 12 mph. Weather and fire hazard indicators for all burns are summarized in Table II.

TABLE II. Weather and Fire Hazard Indicators

Plot	Burning Date	Time of Burn	Age of Slash (Mos.)	Temp. °F	R.H. in %	Wind in mph	$\frac{1}{2}$ -in. Moist. Sticks	FWI ¹	ADMC ²
Shallow Duff:									
Plot 1	Aug.16/68	3 pm	17	60	56	6	12.3	4	14
2	Jul. 3/68	8 pm	16	69	32	4	6.4	8	19
3	Jul. 8/68	7 pm	16	69	42	7	6.9	13	35
Deep Duff:									
Plot 4	Jul.23/69	2 pm	28	69	35	5	7.2	8	33

¹ FWI: Fire Weather Index

² ADCM: Adjusted Duff Moisture Code

Burning Procedures and Fire Control

Ignition was accomplished by a 4 to 8-man crew depending on ignition pattern and size of burn (Figure 3). Standard drip-torches were found most satisfactory for ignition but flame-throwers were utilized with good results where fuels were scarce or when rapid ignition was required along burn perimeters. Two-way radios were found satisfactory to inform members of ignition and standby suppression crews of fire behavior and to instruct them when the prescribed ignition pattern had to be modified to compensate for unexpected fire behavior and changing atmospheric conditions.

Centre-ignition with successive rings or strips of fire was used to ignite all blocks. In all cases, ignition of individual plots was completed within one hour. Some spotting occurred outside the fire lines during all burns but the firebrands were quickly extinguished by members of the standby suppression crew. The greatest danger to the safety and comfort of all personnel was the heavy smoke from the smoldering fire after the fine, fast-burning fuels had been consumed. The heavy drifting smoke reduced visibility and hindered spot-chasing on the leeward side of plot boundaries.

Flaming combustion lasted less than two hours but isolated hotspots developed towards noon of the following day. The outside perimeter of each plot was wetted down during the morning after a burn but the centre of each area was left undisturbed until all post-burn measurements had been taken. The deep duff plot was left smoldering for several days and a standby suppression crew was required to extinguish wind-carried fire-brands outside burn boundaries.

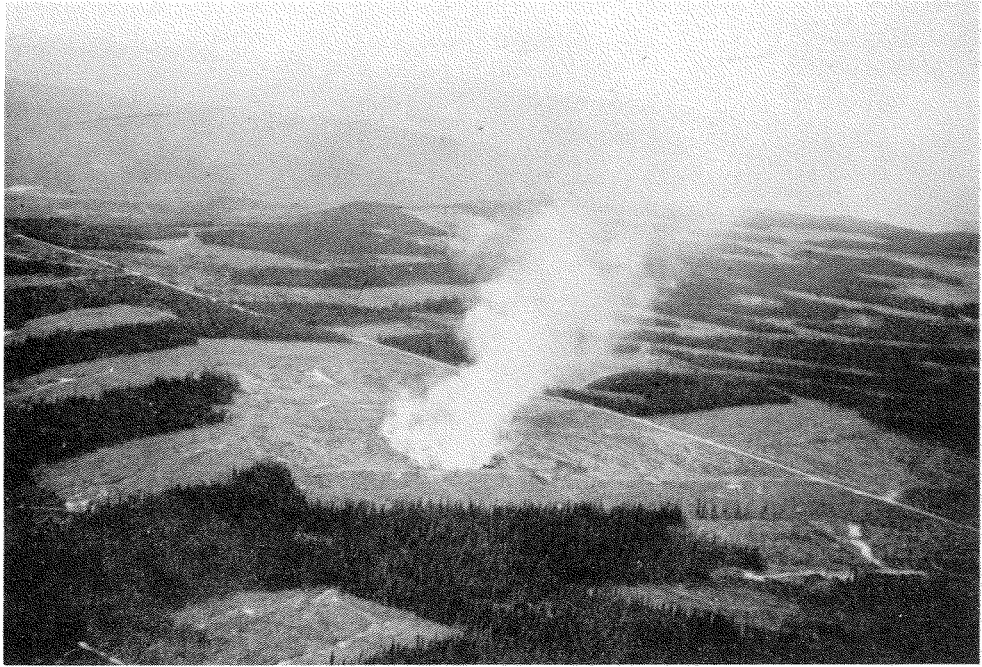


Figure 3. Prescribed burn in spruce-fir slash.

RESULTS

Fuel Loading

The weight of slash, lesser vegetation and the forest-floor for all four burning plots are given in Figure 4 and Table III. Weight of slash fuels and lesser vegetation was similar for all plots but the deep duff site had substantially greater quantities of humus. There were roughly comparable amounts of slash under and over 4 inches in diameter. Needles and twigs less than $\frac{1}{2}$ -inch in diameter accounted for about 10 tons per acre on all plots. The ratio of spruce-fir slash was about 1.5 to 1 but nearly all spruce foliage had dropped off twigs and branches by the end of the first summer (1967) after felling.

Slash depth on all plots averaged one foot whereas dead logs on the forest-floor covered 12.5 percent of the ground-surface area. The depth of the L, F and H layers on the shallow and deep duff sites averaged 1.8, 3.1 and 1.6, and 2.4, 5.2 and 9.9 inches, respectively. The depths for these layers on both sites are indicative of duff conditions under standing timber prior to logging. Bulk density of the L, F and H layers averaged 0.03, 0.08 and 0.14 gms/cc.

Fire Weather Indices and Fuel Moisture Content

An exceptionally dry fall and winter of 1967-68 preceded the 1968 burns on the shallow duff site. In fall of 1967 several large wildfires occurred in west-central Alberta, which were followed by a snowfall about 75 per cent of normal. This lack of moisture and frequent chinook winds resulted in an unusually early severe fire season in late May of 1968. The Fire Weather Index (FWI) and Adjusted Duff Moisture Code (ADMC) for the summer of 1968 are shown in Figure 5.

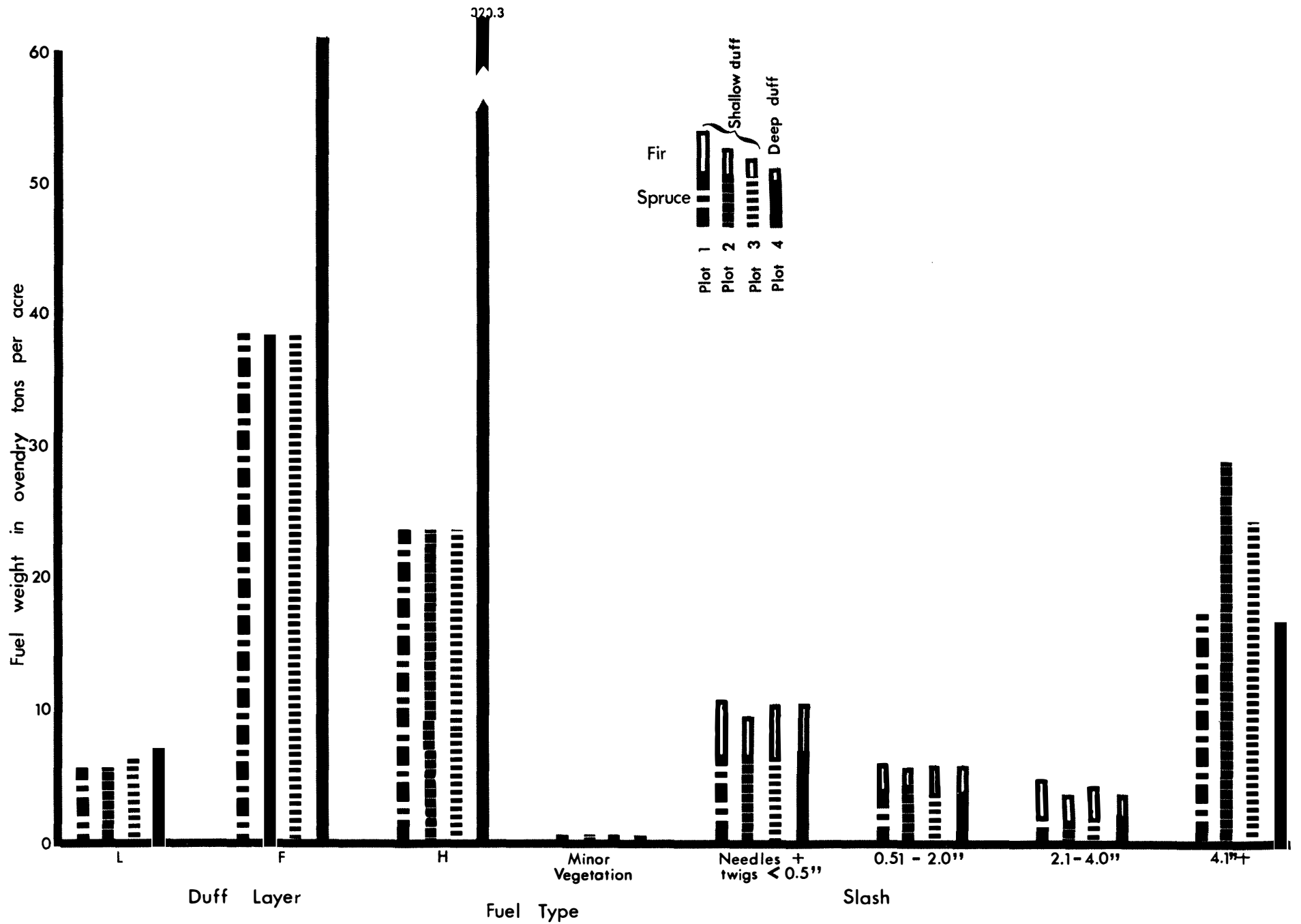


Figure 4. Fuel loading on shallow and deep duff burning plots by fuel components.

TABLE III. Fuel loading and consumption on shallow and deep duff sites by fuel components.

Fuel	Plot 1		Plot 2		Plot 3		Plot 4		1967 burn (Kiil, 1969)	
	Loading	Consumption	Loading	Consumption	Loading	Consumption	Loading	Consumption	Loading	Consumption
All weights in oven-dry tons per acre										
<u>Slash</u>										
Needles and twigs < $\frac{1}{2}$ " dia.	10.3	6.2	9.4	9.4	10.3	10.0	10.1	6.6	9.4	9.4
0.51-2.0"	5.7	3.8	5.4	5.3	5.5	5.3	5.5	2.9	4.5	3.7
2.1-4.0"	4.6	0.4	3.4	2.5	3.9	2.5	3.5	0.4	4.4	2.6
4.1" and over	17.3	7.6	28.9	12.1	24.0	12.2	16.5	8.9	27.1	7.0
Total slash	37.9	18.0	47.1	29.3	43.7	30.0	35.6	18.8	45.4	22.7
<u>Duff</u>										
L layer	5.5	1.5	5.5	4.0	6.1	5.6	6.9	2.7	4.8	4.0
F. layer	38.4	0.4	38.4	2.8	38.4	2.9	61.2	3.4	38.4	0
H layer	23.8	0	23.8	0.2	23.8	0.4	323.3	0.4	23.8	0
Total duff	67.7	1.9	67.7	7.0	68.3	8.9	391.4	6.5	67.0	4.0
Minor vegetation	0.3	0.1	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
Total all fuels	105.9	20.0	115.1	36.6	112.3	39.2	427.0	25.5	112.6	26.9

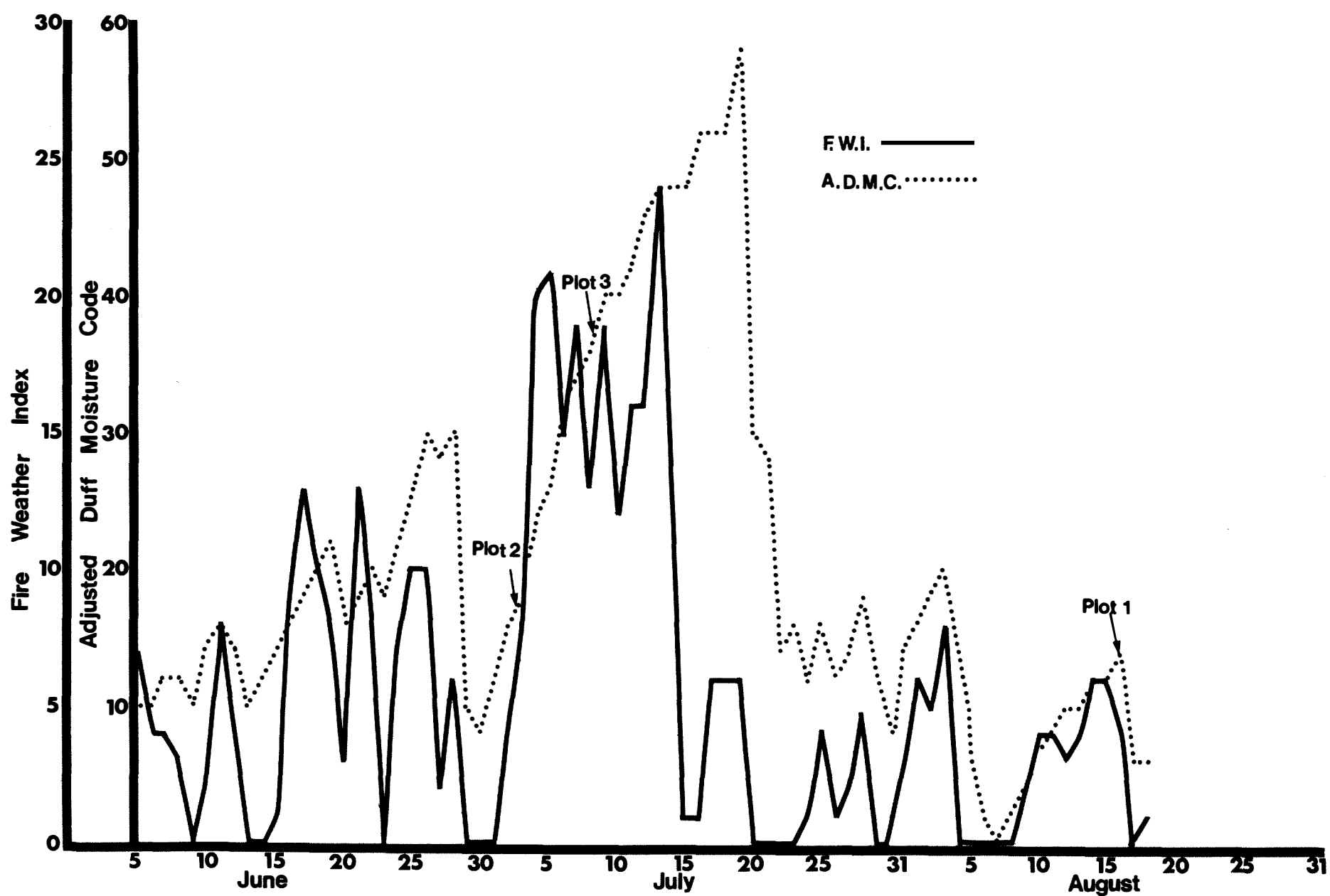


Figure 5. Fire behavior rating indices at shallow duff site, 1968.

Precipitation during the winter and early spring of 1969 was near-normal and there was no appreciable buildup of drought prior to the deep duff burn on July 23. The ADMC on the day of the burn was 33.

The moisture content of selected fuels on each burning day is given in Figure 6. For the three shallow duff plots, the moisture content of slash fuels less than two inches in diameter and the L layer decreased with increasing hazard but no definite trend was evident for the heavier logs and humus. Furthermore, the moisture contents of the heavier fuels on both duff sites may not be directly comparable as the samples were taken in different years. This possibility is attributed to age of slash and to differences in winter precipitation which are not considered in calculation of hazard indices.

Distribution of moisture in cull logs on the forest floor did not fluctuate appreciably between the three shallow duff burns. For all sizes of logs, the gradation in moisture content from the centre to the surface was usually less than 10 percentage points. Average moisture content for logs of all sizes ranged from 26 to 44 per cent and there was little evidence of consistent fluctuation in moisture from top to bottom of individual pieces. This condition is attributed to the relatively old age of the logs and case-hardening which appears to reduce penetration of moisture into the logs.

Fuel Consumption

General Observations

All burns reduced the amount of slash, eliminated the aerial parts of lesser vegetation and consumed a portion of the duff layer. Post-burn fuels consisted primarily of charred logs on the forest floor and an ash-covered duff surface. With the exception of Plot 1, all burns greatly reduced

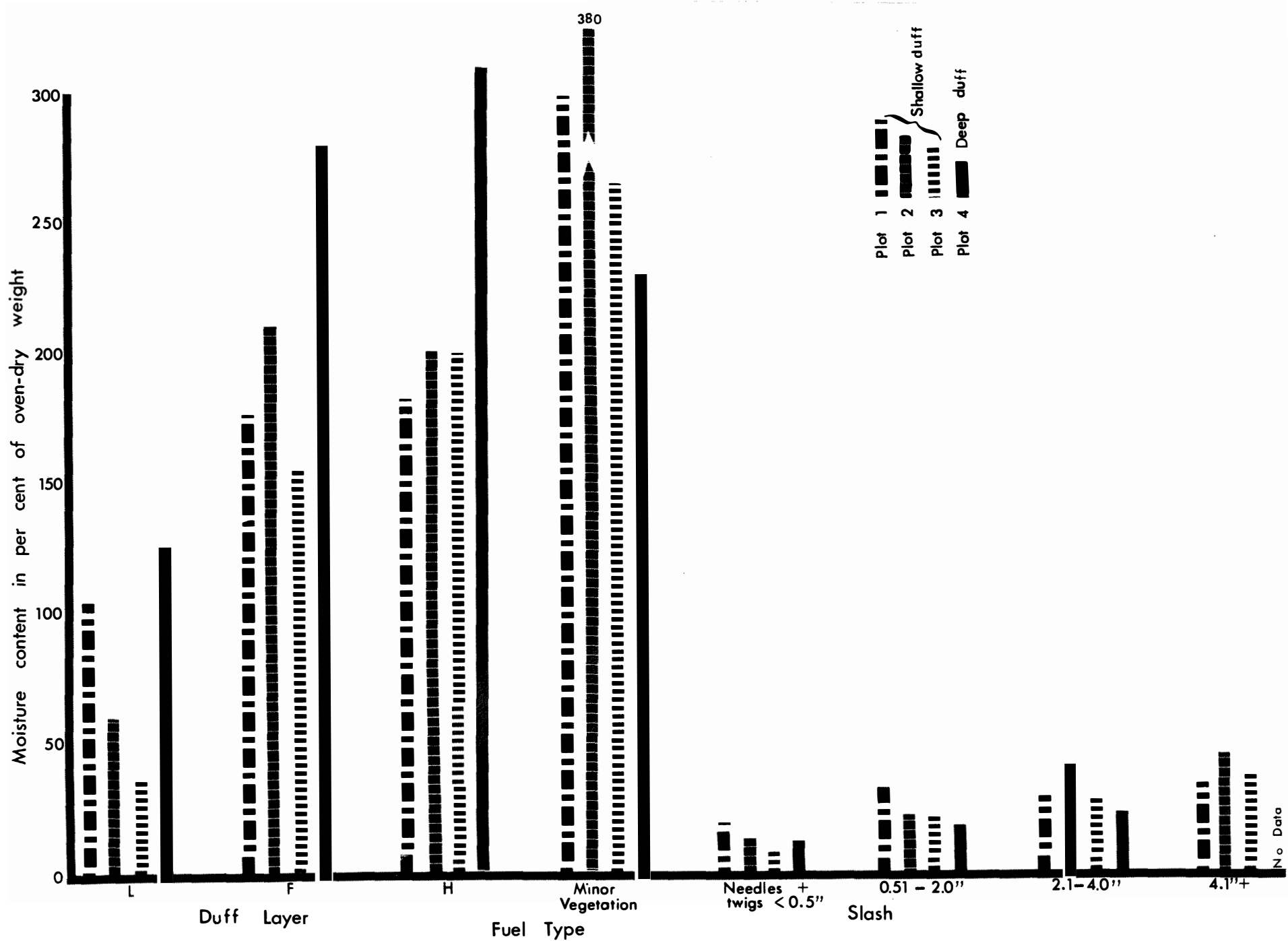


Figure 6. Moisture content of duff and slash fuels on shallow and deep duff sites.

the fine-fuel concentrations which are the main hindrance to increased conventional planting-crew efficiency. On Plot 1, a rain-shower of one-tenth inch appeared to have been triggered by the release of water vapour from the burn. This event prevented the fire from consuming all fine fuels.

Inspection of burned plots revealed that depth of burn was highly variable within plots but duff consumption was generally greatest adjacent to stumps and dead logs on the forest floor and under heavy slash concentrations. Mineral soil exposure was very spotty on all burns but did occur adjacent to stumps, heavy roots and large logs on the ground surface. Smouldering usually decreased during the first night after burning but increased considerably during the following morning and afternoon and resulted in flaming combustion after surface fuels had dried enough to support it. Furthermore, smouldering tended to be least on plots which had supported the most intense fire.

Slash

Slash consumption on each plot is indicated in Figure 7. All burns consumed at least 50 per cent of the fine fuels and usually upwards of 100 per cent when burning was continuous (Figure 8). Combustion of these fine fuels occurred during the passage of the fire front, whereas the heavier logs continued to burn or smoulder for several hours. An estimated 50 per cent or more of the fuel energy from logs over 5 inches in diameter did not contribute to the development of the convection column.

Total slash-fuel consumption on Plots 1, 2, 3 and 4 amounted to 18.0, 29.3, 30.0 and 18.8 tons per acre, respectively. The corresponding weight for the 1967 burn (Kiil, 1969) on the shallow duff site was 22.7 tons per acre. Consumption of fine fuels on Plot 1 would have been similar to that on Plots 2

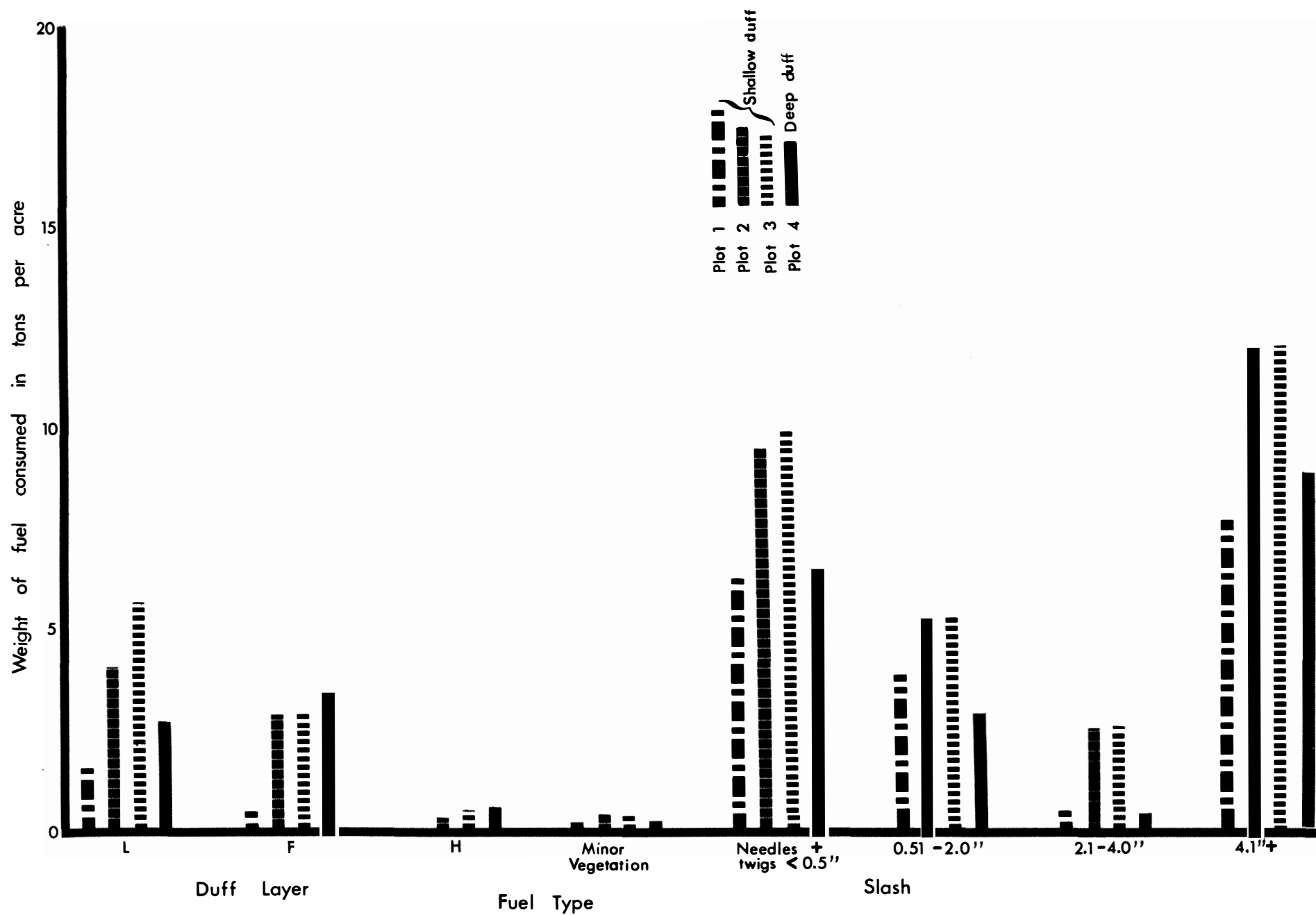


Figure 7. Fuel consumption on shallow and deep duff sites by fuel components.



Figure 8. View of plot after burning.
Note absence of fine fuels.

and 3 had the fire-induced shower not occurred prior to complete burning of these fuels. The lack of complete combustion of fine fuels on Plot 4 is attributed to the relatively patchy and compacted condition of slash fuels on the deep duff site. This condition and wet depressions prevented continuous spread of fire through the slash fuels.

Duff

A total of 1.9, 7.0, 8.9 and 6.5 tons/acre of duff was consumed on Plots 1, 2, 3 and 4, respectively (Table III, Figure 7). The corresponding depths of burn were 0.31, 0.99, 1.14 and 0.74 inches. Observations indicated that depth of burn was greatest adjacent to stumps, logs on the forest floor and under heavy slash piles. For Plots 2 and 3, depth of burn immediately adjacent to, and 3, 6, 9 and 12 inches from logs averaged 1.9, 1.9, 1.8, 1.5 and 1.4 inches, respectively. Mineral soil exposure was most frequent adjacent to stumps and heavy roots.

Effect of smouldering on fuel consumption

The effect of smouldering on fuel consumption was measured on 20 acres of the 60-acre deep duff block. Several days of smouldering increased the proportion of the plot surface burned from 44 to 60 per cent and duff consumption from 6.5 to 17.5 tons per acre. Average depth of burn increased from 0.74 to 2.12 inches, with maximum values in excess of 18 inches near stumps and dead logs on the forest floor.

DISCUSSION

These burning trials were carried out in late afternoon or early evening during July and August. With the exception of Plot 1, prevailing weather conditions were similar for all burns and differences in fuel consumption

are attributed primarily to drying conditions preceding the experimental burns. Given similar fire behavior rating indices, the season of burning is important in terms of predictability of weather conditions during burning, the duration of the diurnal burning period and the possibility of extended periods of drought following burning. The latter condition is particularly important in deep duff where carry-over fires may result in a formidable mop-up operation.

Slash weight was similar on all burning plots but the deep duff site had substantially more humus (Figure 4, Table III). Fire spread is related to fuel loading but equal loadings of differing size-class distributions will not necessarily result in the same rate of spread (Muraro, 1968). In addition, fuel fineness and compactness (Fons, 1946) affect rate of fire spread. The present study indicated that all fine fuels are consumed as long as fire spread is continuous. Similarly, most fuels in the 0.51 to 2.00-inch size class are consumed by a relatively low-intensity fire. The higher residual fuel loadings on Plots 1 and 4 are attributed primarily to a heavy shower during the burn and the spotty and compacted condition of the slash fuels, respectively.

If a reduction in rate of spread or fire intensity is accepted as the primary objective of burning for hazard reduction, a meaningful measure of the success of burning appears likely from pre and post-burn values of fuel weight up to an upper diameter of 3 inches. Results suggest that the residual slash-fuel loading in the 2 to 3-inch size-class is a particularly useful indicator of burning success for hazard reduction. Most of the fuels less than 3 inches in diameter are consumed during the passage of the fire front

and appear to be responsible for most of the variation in rate of spread and intensity.

Slash fuels in excess of 3 inches in diameter and the duff layer have a greater fire residence time and smouldering may proceed for hours, days or even weeks. Only a part of the available fuel energy may be released during the passing of the fire front; the remainder is released over a period of time and is not available for developing a strong convection column. Measurements taken on Plot 4 showed that duff consumption tripled after several days of smouldering. The residual weights of heavier slash and duff should serve primarily as indicators of expected resistance to control.

In the range of burning conditions tested, the trials demonstrated that prescribed burning cannot be expected to consume appreciable portions of the duff layer on these sites or to provide more than spotty mineral soil exposure around stumps and dead logs on the forest floor. Duff consumption on Plot 3 amounted to 8.9 tons per acre but this represents only 17 per cent of the weight of the entire organic soil mantle. Additional reduction of the duff layer may be achieved by a slow-burning duff fire. This possibility requires careful assessment of moisture distribution in duff, a reliable fire weather forecast for the duration of the burn and consideration of cost of standby suppression personnel and equipment.

ADMC values of over 20 resulted in generally continuous fire spread through the top layer of humus on the shallow duff plots. The results of this study and observations of fire behavior in similar fuelbeds indicate that effective hazard reduction on the shallow and deep duff sites is achieved when the FWI and ADMC exceed 7 and 10, and 10 and 20, respectively. Given a

continuous cured slash fuelbed with needles still attached to twigs and branches, effective hazard reduction can be achieved within a day or two after a saturating rainfall.

The experimental burning program in spruce-fir slash was carried out over a three-year period from 1967 to 1969. At the time of the 1967 burning trials (Kiil, 1969), the fir needles remained attached to the twigs and branches but most of the spruce needles had fallen to the ground. The moss layer had started to dry and compact but remained in a condition similar to that in adjacent stands. In 1968, the duff layer had compacted to about 75 per cent of its depth prior to felling. The compaction is attributed to drying and shrivelling of the moss layer, the inability of the dead root systems to hold the soil, and plugging of the non-capillary pores. On the deep duff site, the moister site conditions and shade from incoming minor vegetation resulted in only partial drying of the moss layer. Such changes in slash and duff condition need to be taken into account when planning and conducting prescribed burns. Owing to changes in compaction of the duff layer with depth below the ground surface and time since logging, fuel loadings for one-inch layers were determined and used for calculating fuel consumption.

The weather during the summer and fall of 1967 was extremely dry and resulted in critical burning conditions in west-central Alberta. Results of an ongoing study of moisture content in duff in clearcuts and under adjacent timber showed that the duff in the stand was drier than that in the clearcut. While this condition may be unique to overmature spruce-fir stands at high elevations with an appreciable portion of the root system imbedded in the duff layer, it does point to the need to carefully assess the potential for

fire spread in adjacent stands when conducting prescribed burning experiments. In 1967, the moisture content of the duff in the stand dropped below that in the clearcut when the ADMC approached 75. The Drought Code (DC) ranged from 250 to 350. The highly flammable fuels in adjacent stands, in conjunction with high wind speeds and spotting from prescribed burns, may represent a more serious fire control problem than the slash areas.

CONCLUSIONS AND RECOMMENDATIONS

The results of these operational-scale burning trials on deep duff sites indicate that prescribed burning is an effective method for reducing the slash fire hazard to an acceptable level. In the range of moisture regimes tested, prescribed burning cannot be expected to reduce more than 20 per cent by weight of the entire duff layer of six inches or more common on such sites. Similarly, the deep duff layers preclude any appreciable exposure of mineral soil even after moderately long periods of drought. The only exception to this rule is to let the fire smoulder for several days to eliminate the duff layer adjacent to stumps and root systems. The result from this study and experience gained during the course of the burning trials serve as the basis for the following recommendations:

- (1) Planning for prescribed burning should start at the cut layout stage to ensure that a clear definition of the objectives for the use of fire is based on a full consideration of both beneficial and adverse effects. Consideration of the management problem should relate to why, when and how fire can accomplish the desired objectives. The decision to burn leads to area, fuel and environmental considerations. Burning block boundaries should conform to topo-

graphic features and the block should be as close as possible to a circle or a square to maximize the area-perimeter ratio. The size of the burning block is highly variable but should be small enough so that ignition can be completed in one working period. A firing sequence to develop a strong central convection column is particularly effective when several hundred acres must be ignited in a single working period.

- (2) Prescribed burning for hazard reduction and site amelioration in the East Slopes of the Canadian Rockies appears feasible throughout the fire season but burning conditions are most suitable in late September and October. Spring and summer burning programs are limited primarily by the unpredictable weather conditions and by the possibility of carry-over fires in deep duff if a period of drought follows the burn.
- (3) Burning for hazard reduction is possible within a day or two following a saturating rainfall. Results of the present study and observations made on a number of sites indicate that the hazard has been reduced to an acceptable level if the weight of residual fuels less than 3 inches in diameter is less than 5 tons per acre or about one-third of the original loading.
- (4) Safe and economical prescribed burning on deep duff sites is not likely to result in appreciable exposure of mineral soil. Spotty mineral soil exposure is likely around stumps and large roots when the ADMC exceeds 30 but smouldering for several days is required to allow the fire to consume substantial amounts of duff. Burning

with ADMC in excess of about 75 is not recommended because the moisture content of duff in adjacent timber is likely to be lower than that in the clearcut.

- (5) The development of an operational prescribed burning program should be preceded by training sessions for the personnel involved. The key to safe and efficient burning lies in selecting and using an experienced crew for all burning operations. Such ignition crews could conceivably also be used for back-firing or "burning-out" operations on wildfires.

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