Not for publication

CHANGES IN THE PHYSICAL CHARACTERISTICS AND MOISTURE CONTENT OF PINE AND SPRUCE-FIR SLASH DURING THE FIRST FIVE YEARS AFTER LOGGING

by

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Internal Report A- 14

Forestry Branch
July, 1968

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INTRODUCTION

The harvesting of forest crops creates varying amounts of debris, or slash, chiefly in the form of needles, branchwood, and unmerchantable tops. In west-central Alberta, clearcutting of mature, fully-stocked pine and spruce stands produces about 20 tons of slash per acre. Depending on stand condition and degree of utilization, other fuels such as forest floor duff and dead logs may increase the total fuel loading to 50 tons per acre, or more. The large fuel volumes and their exposure to the desiccating effects of the atmosphere combine to create a formidable slash fire hazard of several years's duration.

To reduce the high wildfire hazard in slash the Forests Act (1961) stipulates that all limbs be removed from trees when felled and the unmerchantable tops and the limbs shall be scattered and made to lie flat on the ground. Mechanical scarification may be applied in lieu of lopping and scattering. This policy for slash treatment is being enforced throughout the province, regardless of the type of forest cover, degree of utilization, or prevailing weather conditions. Lopping and scattering is based on the theory that when woody fuels are brought into direct contact or in the proximity of the ground surface they can absorb and retain moisture more readily than suspended slash, thereby having a salutary effect on rate of decay. While there is little doubt about the validity of the theory there is nevertheless considerable controversy among fire control personnel about the effectiveness of lopping and scattering as a method for reducing the wildfire hazard to an acceptable level. For example, it is possible that site, fuel, and weather conditions have a greater effect on fuel moisture and rate of decay than proximity of the fuel to the ground surface alone.

The purpose of this study is to determine the changes in the physical characteristics and moisture content of logging slash for a number of years after felling, thereby providing a background of knowledge for an objective assessment of slash fire hazard at various stages of decay. Emphasis is being placed on determining the rate of drying and the magnitude of the changes in selected physical characteristics of untreated, lopped and scattered, "walked over" with a bulldozer, and scarified slash. Clear-cut blocks with lodgepole pine and spruce-fir slash were chosen for the study because these species are commercially important in the study area. Field studies were limited to slash fuel components 4 inches or less in diameter because this represents the minimum top diameter utilized on the pulpwood logging operation. For purposes of this report, slash is comprised of logging residue in three diameter-classes, viz. (1) less than ½ inch (fine fuels), (2) ½ to 2 inches (medium fuels) and (3) 2 to 4 inches (heavier fuels). Forest floor fuels include litter, moss and humus (F and H layers). All fuel weights are given on an oven-dry basis.

LOCATION AND DESCRIPTION OF STUDY AREA

The study area is in the Upper Foothills Section (B 19.C) of the Boreal Forest Region (Rowe, 1959), approximately 15 miles north-west of Hinton (53°24'N, 117°37'W), Alberta. The forests are chiefly coniferous, dominated by white spruce (*Picea glauca* (Moench) Voss), black spruce (*P. mariana*) and alpine fir (*Abies lasiocarpa* (Hook) Nutt.) on the moister sites and pure lodgepole pine (Pinus contorta var. latifolia) on the drier sites. Both study sites are about 5,000 feet above sea level.

The climate is characterized by moderately warm summers and cold winters. Mean July temperature is about 60°F and mean January temperature about 10°F (Anon, 1964). Mean annual precipitation is about 20 inches, of which about 60 per cent falls during the 150-day growing season (Anon, 1965) when mean daily temperatures exceed 42°F. June, July and August are the rainiest months, each with over 2.5 inches, but droughts occur every 5 to 10 years. The year may conveniently be 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).

Two 40-acre blocks, clearcut in 1963 by North Western Pulp and Power Limited, were selected for the study. Both blocks are considered to be representative of slash conditions in other lodgepole pine and spruce-fir clearcuts in the Upper Foothills Section. The slash in both blocks is generally continuous except where it is broken by haulroads and log landings. Skidding of logs was done by horse.

The 90-year-old lodgepole pine stand of fire origin had 459 live stems per acre (Table 1). The soil on this site is a deep, well-drained podzol on a mixture of glacial drift and alluvial material. The organic soil horizon consists of a thin layer of moss and litter on top of 2 to 6 inches of decaying or entirely decomposed humus. Logging slash in the form of foliage, branchwood, and the unmerchantable top amounted to 15 tons per acre (Figure 1). The total fuel loading, including dead logs, litter, moss, and humus was about 40 tons per acre.

The over-mature spruce-fir stand had a stem-diameter range of from

1 to 30 inches at breast height. The soil on this site is a poorly-drained gleysol on compacted, nearly impermeable glacial till. The organic layer consists of a 2-inch thick carpet of moss overlying a deep layer of humus (F and H layers) (Table 1). Weight of slash fuels less than 4 inches in diameter was determined to be 18 tons per acre. Other material, including dead logs, moss, and humus increased the total fuel loading to over 100 tons per acre. A typical spruce-fir slash fuelbed is shown in Figure 1.

TABLE 1. SUMMARY OF SITE AND STAND CHATACTERISTICS FOR BOTH STANDS BEFORE CLEARCUTTING.

Category	Lodgepole Pine	Spruce-Fir
Average diameter of breast height in inches	7.3	8.8
No. of live stems per acre	459	336
No. of snags[1] per acre	170	110
Dominant height in feet	67.0	93.0
Basal area in square feet per acre	155.0	193.0
Moisture regime (est.)	dry, well-drained	moist, poorly-drained
Aspect and slope	level	5% northerly
Depth of organic soil layer in inches	4-6	12-24

[1] A snag is a standing dead tree.

Figure 1. Slash of lodgepole pine (upper) and over-mature spruce-fir (lower).

METHODS

Treatment Layout

Sampling was restricted to two 40-acre clearcut blocks, each with three slash treatments and an untreated area:

1) Lopped and scattered. All branchwood was lopped from the unmerchantable tops and scattered evenly over the area.
2) Scarified. A D-9 bulldozer with a special scarification blade developed by North Western Pulp and Power Limited was used.
3) Walked over. A D-9 bulldozer "walked over" the entire treatment area.
4) Untreated. Slash was left as cut. The merchantable portion of the bole however, was lopped as part of the logging operation.

Clearcutting of both blocks was completed by mid-summer of 1963. Three sets of untreated and lopped and scattered slash plots were established in each clearcut immediately after completion of logging. Scarification and "walking over" were applied in late summer of 1963, courtesy of North Western Pulp and Power Limited. The size and shape of each treatment area is shown in Figure 2.

Sampling

A weekly slash moisture sampling routine was initiated immediately after the application of each treatment. Composite samples, each weighing in excess of 25 grams, were taken of needles, and 3 size-classes of branchwood: 1) less than $\frac{1}{2}$ inch, 2) $\frac{1}{2}$ to 2 inches, and 3) over 2 inches in diameter.

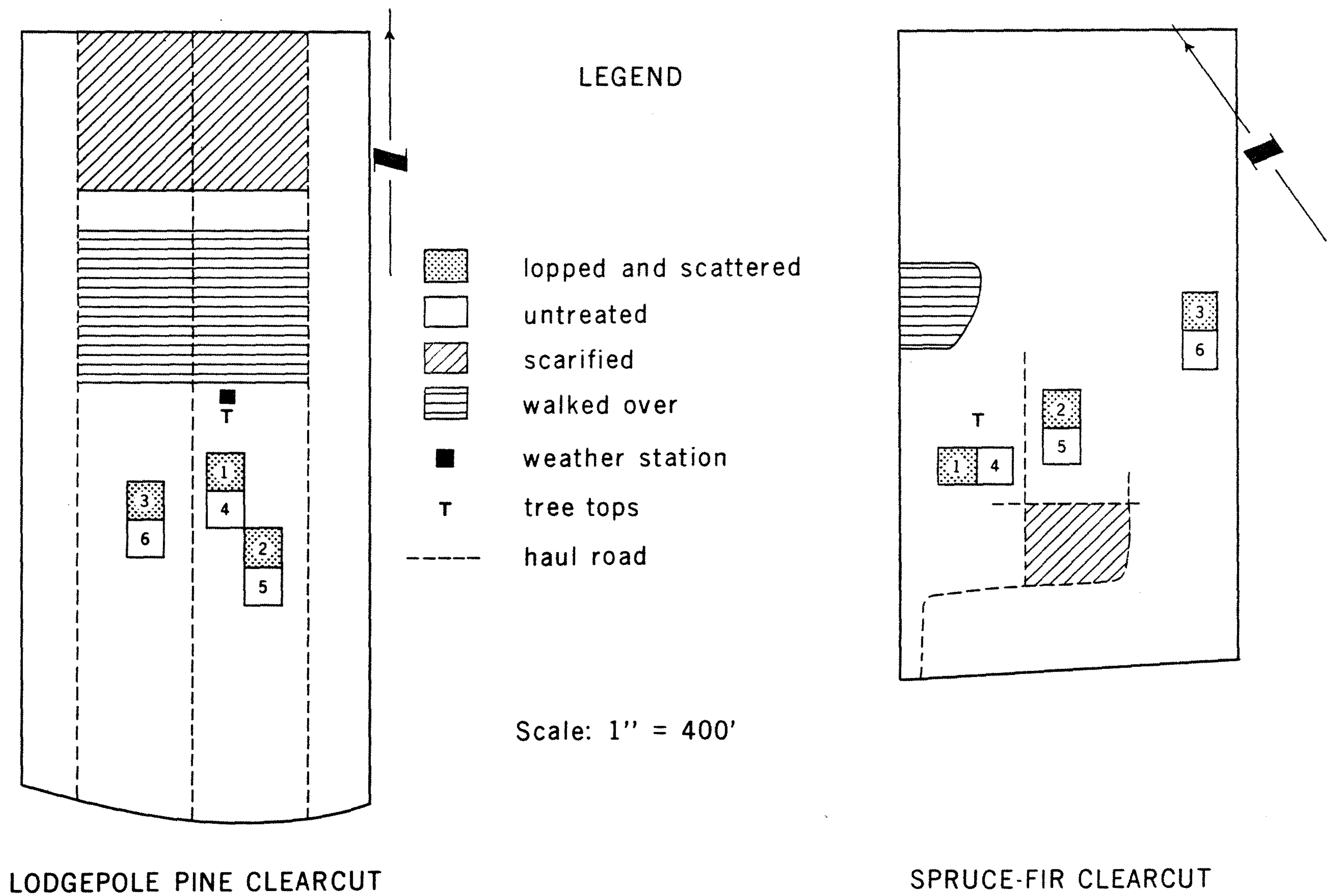

Figure 2. Layout of treatment areas in pine and spruce-fir clearcuts.

For the material in excess of 2 inches, sampling was restricted to the surface three-quarter inch. To reduce the variation in fuel moisture owing to position of the fuel relative to the ground surface, samples were taken only in a 6 to 12-inch zone previously found to contain 50 per cent or more of the slash by weight. To facilitate comparison of moisture content data within and between sampling days, both clearcuts were visited at the same time and in the same order each rainfree afternoon.

All fuel samples were taken to a field laboratory for weighing and ovendrying to a constant weight at a little more than 212°F.

The seasonal fluctuation in the moisture content of lodgepole pine and white spruce needles was determined on the basis of weekly samples taken from selected trees. Composite samples, each weighing at least 25 grams, were taken from 3 selected trees and oven-dried for moisture content determination. The moisture content of needles, branchwood, and the unmerchantable portion of the bole on standing trees was available from a concurrent study of crown weights (Kiil, 1967).

To study the effect of partial shade on fuel moisture, 24 trees - 12 lodgepole pine and 12 white spruce - were selected and felled in the stand adjacent to the lodgepole pine clearcut. Of each species, six tops were left under the stand canopy and six were set out in the adjacent clearcut. Every second top at each location was lopped and the branches scattered. The fuel moisture sampling routine was similar to that for slash plots.

Fuel compaction was assessed on the basis of yearly measurements of slash depth. Each 100-foot square slash plot was sampled using a 36-point reference grid on 20-foot centres. In 1965, the vertical distribution of fuels was determined from a fuel count utilizing a wooden U-frame 3 feet wide. All fuel pieces intersected by the vertical plane of the U-frame were tallied in three classes, viz. 1) direct ground contact, 2) within 6 inches of the ground surface but not touching it, and 3) 6 inches or more above the ground surface, and three size-classes, viz. 1) up to ½ inch, 2) ½ to 2 inches and 3) 2 to 4 inches in diameter. A total of 48 randomly-located U-frame counts were made in the two clearcuts.

The specific gravity of wood is the ratio between the oven-dry weight of a piece of wood and the weight of an equal volume of water; hence, it can be used as an indicator of heat value of wood. Sampling for specific gravity was carried out in conjunction with the U-frame fuel count, and consisted of three fuel pieces in each size and height class. Specific gravity of each wood piece was determined using the immersion technique (Brown, _et_ _al_. 1949).

Clearcutting increases the hazard of slashfires by leaving the ground littered with needles, branches and unmerchantable tops, and by exposing these fuels to the dessicating effects of the atmosphere. The slash fire hazard is transitory, decreasing with increasing decay and disintegration. Experience has shown, however, that a purely quantitative comparison of fuels is inadequate for purposes of estimating fire hazard; often site conditions, fuel distribution, and the quantity and condition of minor vegetation have a greater effect on the fire hazard than slash quantity alone. Periodic observations were therefore made on the study areas and other comparable clearcuts to document the changes in site condition, vegetation, and fuels which did not lend themselves easily to quantitative determination. Notes were kept on general moisture relations at each site, soil type, drainage, slope and aspect, the type and density of incoming minor vegetation, and general changes within the slash fuelbed (needle-drop, condition of bark, location of fruiting bodies, and disintegration of fuel particles).

Analysis of Data

The moisture content of each fuel sample was computed and tabulated according to date, age of slash, treatment, size, and exposure (full sun or partial shade). Mean moisture content of fresh slash was determined by species and size of material. Mean depth of slash was calculated by year and slash treatment. Slash volume was estimated using a borrow-pit method described by Skelton (1949). Fuel-count and specific gravity data were summarized according to size of material and position with respect to the ground surface.

Students t-tests and analyses of variance were performed to determine if there were any significant differences in moisture contents, slash depths, and specific gravities of various slash fuel components between treatment and exposure.

RESULTS

Physical characteristics of slash components

For a given combination of diameter at breast height and crown width, white spruce branchwood weighs more than that of either lodgepole pine or alpine fir (Table 2). This difference is attributed primarily to the relatively long and dense crowns of spruce trees. Lodgepole pine crowns are typically short and open, with heavy branches and needles borne in clumps. The crown of alpine fir is of medium length and has a relatively open appearance.

TABLE 2. CROWN WEIGHTS FOR SELECTED DIAMETER AT BREAST HEIGHT AND CROWN WIDTH CLASSES.

Dbh (in.)	Crown width (ft.)	White spruce	Alpine fir	Lodgepole pine
		Oven-dry weight in pounds		
4	4	14	11	9
	6	23	18	16
6	4	25	20	16
	6	40	32	28
	8	56	43	41
8	8	59	47	41
	10	83	65	60
	12	103	84	83
10	8	113	90	81
	10	147	115	100
	12	183	141	—

The proportional weight of fine branchwood, including foliage, decreased with increasing diameter at breast height (Figure 3). For example, 92 per cent of the weight of live branchwood in a 4-inch lodgepole pine tree was in the form of fine branchwood. The corresponding figure for a 10-inch tree was 67 per cent. The proportional weight of fine branchwood in spruce crowns averaged about 10 per cent higher.

As expected, the proportional weight of foliage also decreased with increasing tree size. In a 4-inch lodgepole pine tree, foliage accounted

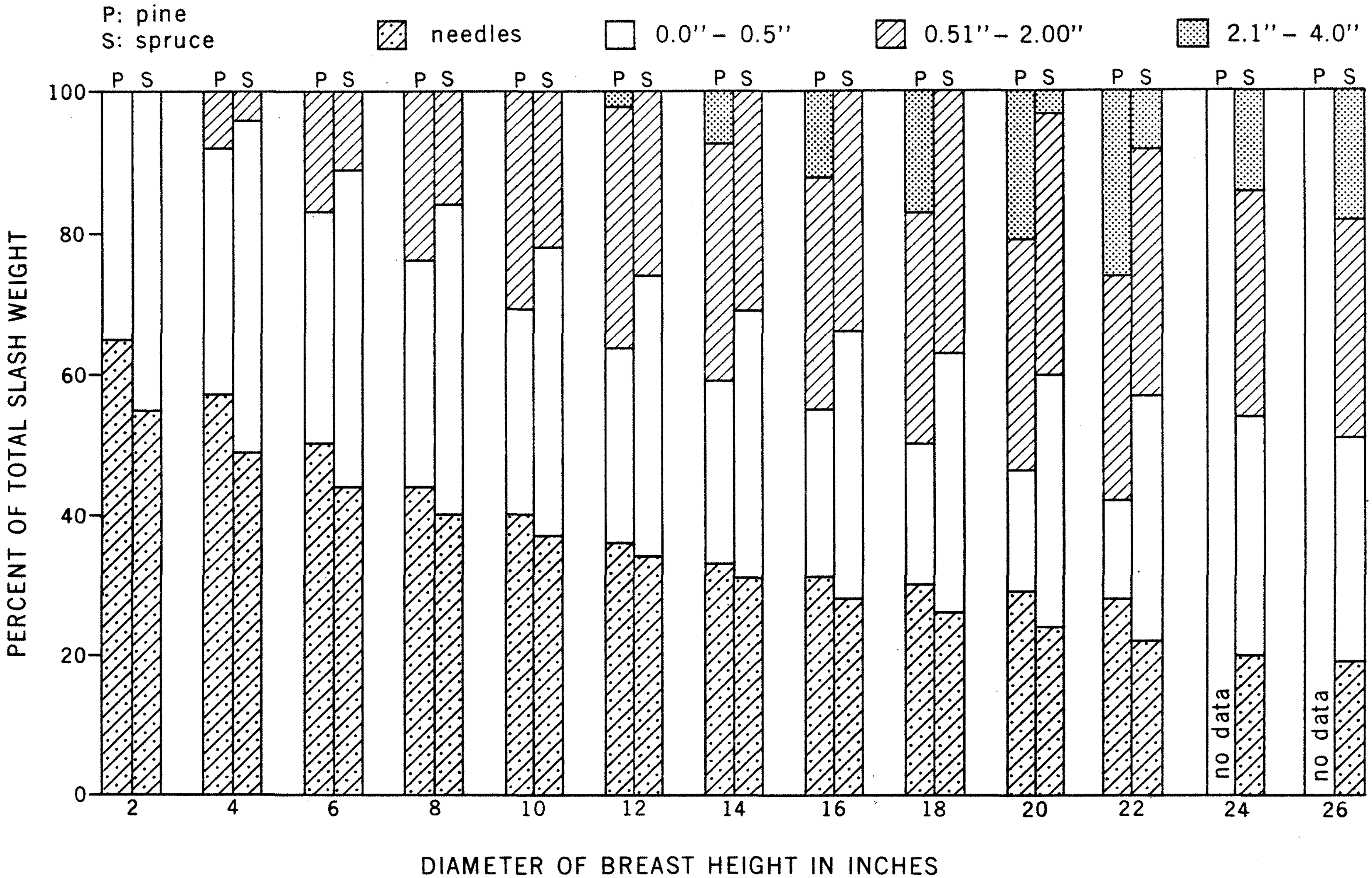

Figure 3. The proportional weight of white spruce and lodgepole pine slash components by size-classes. (Based on 36 spruce and 64 pine branches from selected trees.)

for about 55 per cent of live branchwood weight. The corresponding figure for a 10-inch tree was 40 per cent.

The ratio of branchwood weight to the weight of the unmerchantable top increased from 1:2 for a 4-inch pine tree to about 10:1 for a 10-inch pine tree. The unmerchantable top therefore accounts for a substantial part of total slash weight from dense, pole-sized stands but is a relatively insignificant source of fuel from mature stands with fewer trees per acre. For a given tree diameter, the unmerchantable top of a spruce tree weighs more than the corresponding pine or fir tree component. The differences, however, did not exceed 30 per cent of the weight of the lightest species.

The specific gravity of pine and spruce wood was found to increase with decreasing size of branchwood but the differences between the smallest and largest fuel components were generally less than 0.10. The specific gravity of pine and spruce twigs averaged about 0.50 and 0.55, respectively. The corresponding figures for medium branchwood were a little lower but the specific gravity of the unmerchantable top was up to 30 per cent lower. Three years after felling, the differences in specific gravity between treated and untreated slash fuels were about 0.03.

The dropping of needles from twigs and branches is the most striking physical change in spruce and pine slash during the first five years after felling. Spruce branches lost their foliage by the end of the first summer but pine branches retained most of their foliage for at least 3 summers (Table 3). In full sun, discolouration and loss of needles occurred earlier for lopped and scattered than for untreated slash. A similar relationship was observed for partially shaded slash but considerably more time was required for the discolouration and loss of needles to

TABLE 3. RATE OF DISCOLOURATION AND LOSS OF NEEDLES FROM UNTREATED AND LOPPED SLASH IN FULL SUN AND IN PARTIAL SHADE.

Date	Full sun				Partial shade			
	Untreated		Lopped		Untreated		Lopped	
	% needles brown	% needles dropped	% needles brown	% needles dropped	% needles brown	% needles dropped	% needles brown	% needles dropped
Lodgepole pine								
1964								
June 17	0	Nil	0	Nil	0	Nil	0	Nil
July 10	1	"	30	"	0	"	1	"
July 22	5	"	80	"	3	"	7	"
Aug. 4	9	"	85	"	3	"	25	"
Aug. 20	30	"	95	"	6	"	50	"
Sept. 1	50	"	95	"	6	"	50	"
1965	97	"	99	10	40	"	93	"
1967	100	80	100	90	100	60	100	75
White spruce								
1964								
June 17	N.A.	0	N.A.	0	N.A.	0	N.A.	0
July 10	"	99	"	10	"	1	"	30
July 22	"	100	"	35	"	3	"	70
Aug. 4	"	"	"	45	"	10	"	70
Aug. 20	"	"	"	85	"	10	"	—
1965	"	"	"	100	"	20	"	95
1967	"	"	"	"	"	100	"	100

take place. With both species, the needles fell through the network of twigs and branches and became part of the forest floor. They did not, however, lose their identity during the first few years after dropping from the branches.

Lodgepole pine branches were still intact five years after felling and retained their characteristic arching habit. Breakage of twigs was more noticeable with spruce than with pine slash, but the heavier branches remained intact. Splits and cracks were common in the heavier branchwood and the unmerchantable tops. Bark started to come loose during the second summer after felling but had not disintegrated appreciably by the end of the fifth summer. Unmerchantable tops lost their bark earlier than branchwood. At the end of the fifth summer, 30 per cent of the bark was off the untreated unmerchantable tops compared to 10 per cent for branchwood. A greater proportion of the bark was off lopped and scattered than untreated slash but the differences were generally less than 5 per cent. Untreated and lopped and scattered slash in partial shade retained its bark longer than slash in full sun.

Periodic observations of fungal activity in slash revealed that (1) the sporophores were most abundant on the shaded, lower surfaces of fuel pieces and (2) that the fruiting bodies attached to the bark seldom affected the wood. The position and extent of the sporophores varried from year to year but were still primarily confined to shaded slash at the end of the five-year study period. The shedding of bark was responsible for the separation of the fruiting bodies from the vicinity of the wood. Frequently the shedding of bark resulted in the rapid drying and case hardening of the newly-exposed wood, thereby making it difficult for fungi to get established.

Moisture content of fresh slash

The effect of species and fuel size on the moisture content of freshly-cut slash is shown in Figure 4. For all three species, the mean moisture content of foliage and branchwood ranged between 70 and 100 per cent of oven-dry weight. The initial moisture content of foliage was usually higher than that of branchwood and may account, in part, for the needles not reaching a highly flammable level until after the branchwood. The moisture content of the unmerchantable top usually exceeded 100 per cent. The moisture content values for the three species are not directly comparable owing to sampling not being carried out simultaneously but they are, nevertheless, believed to be indicative of general moisture levels in these species.

The seasonal variation in the moisture content of one-year-old, and older, pine and spruce foliage is shown in Figure 5. While pine needles contained more moisture than spruce needles, the seasonal fluctuations in these levels followed a relatively parallel pattern. The moisture content of new-growth spruce needles decreased steadily throughout the growing season from about 400 per cent in June to about 160 per cent in late August (Figure 6). The moisture content of one-year-old and old-growth needles fluctuated between 75 and 125 per cent.

A cursory examination of all moisture data indicated that for any one species, season, and size of fuel, tree age and position of the fuel in the crown accounted for most of the variation in the moisture content of fresh slash. The moisture content of branchwood decreased with increasing tree age but this is attributed to the thickening of the cell walls as the tree matures.

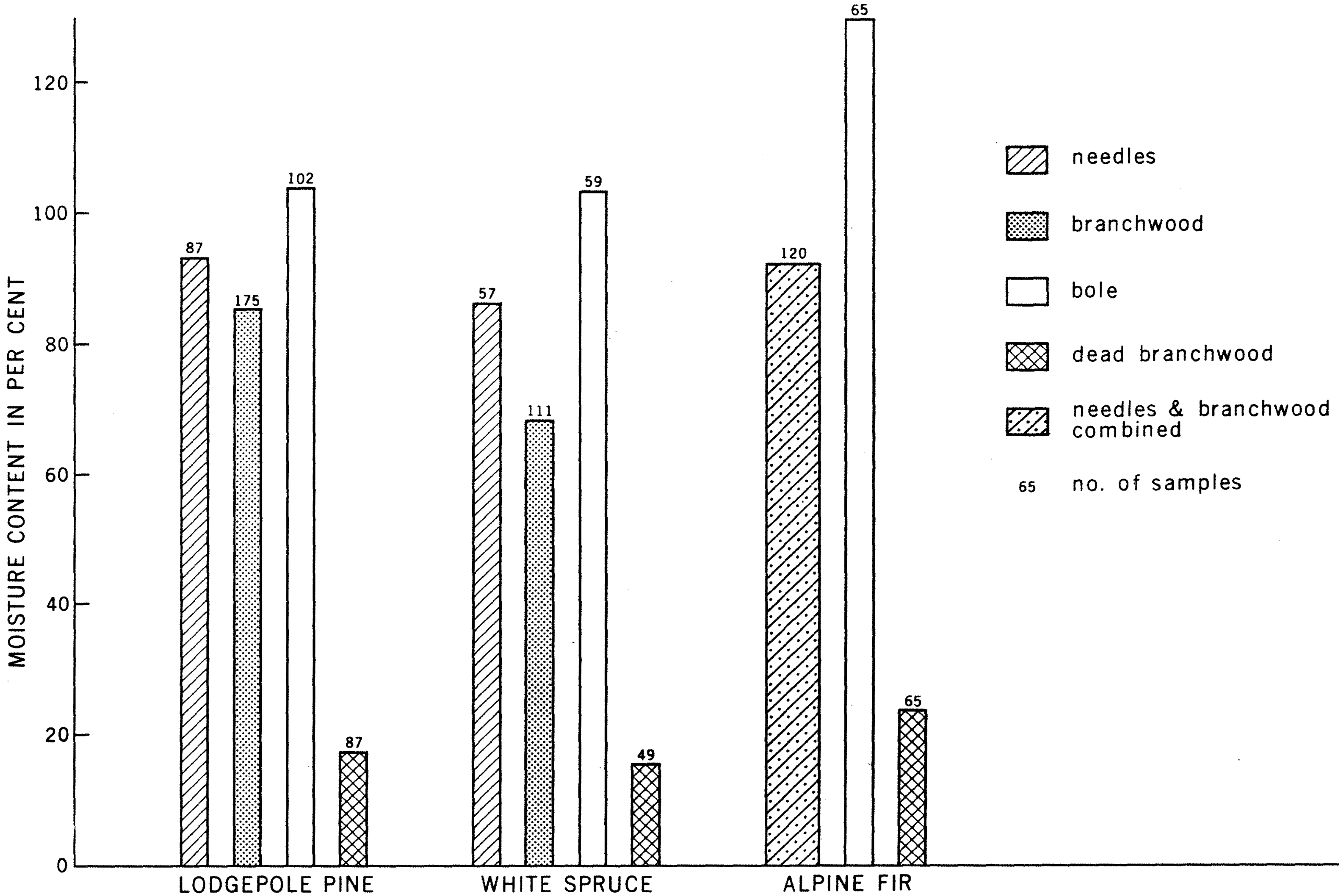

Figure 4. Moisture content of pine, spruce, and fir slash components.

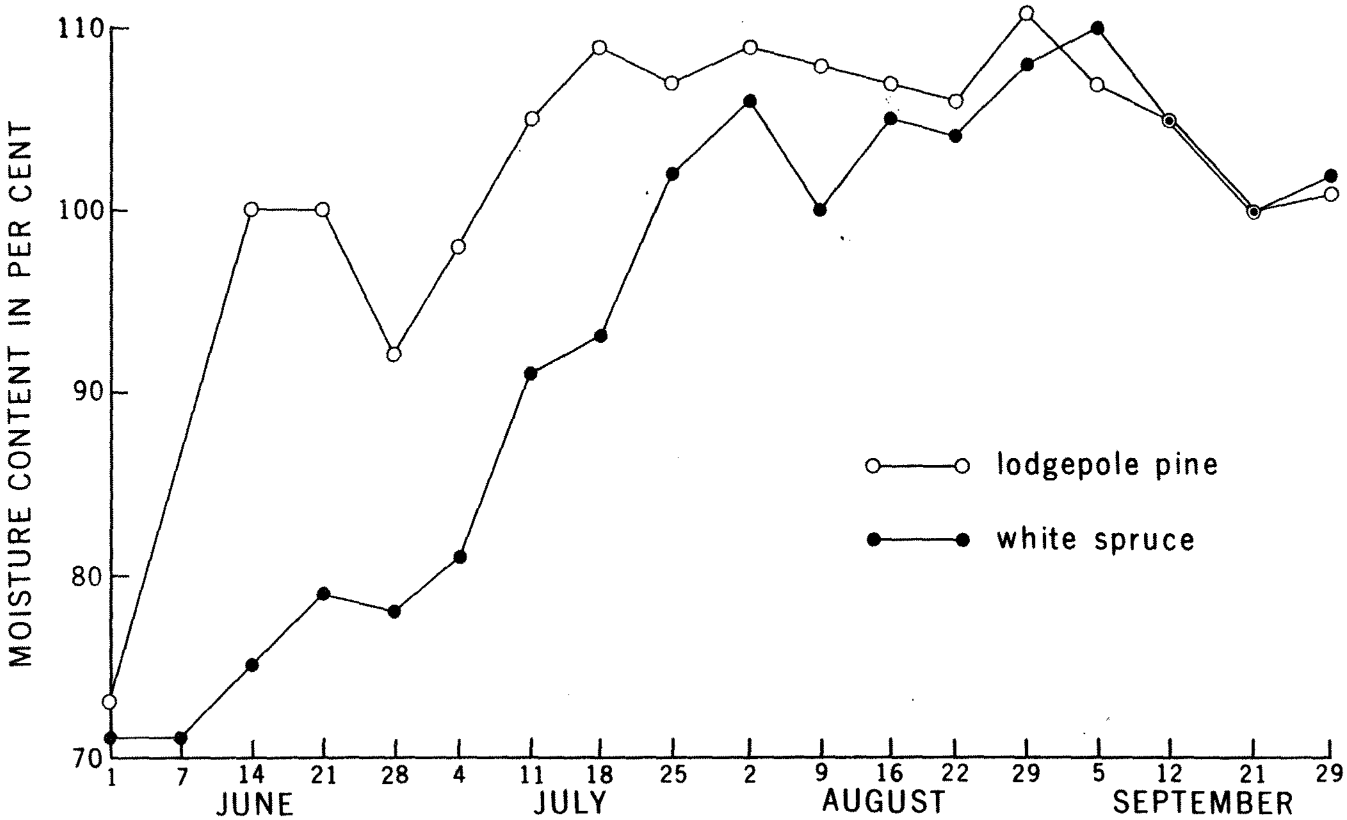

Figure 5. Moisture content of lodgepole pine and white spruce needles during 1964.

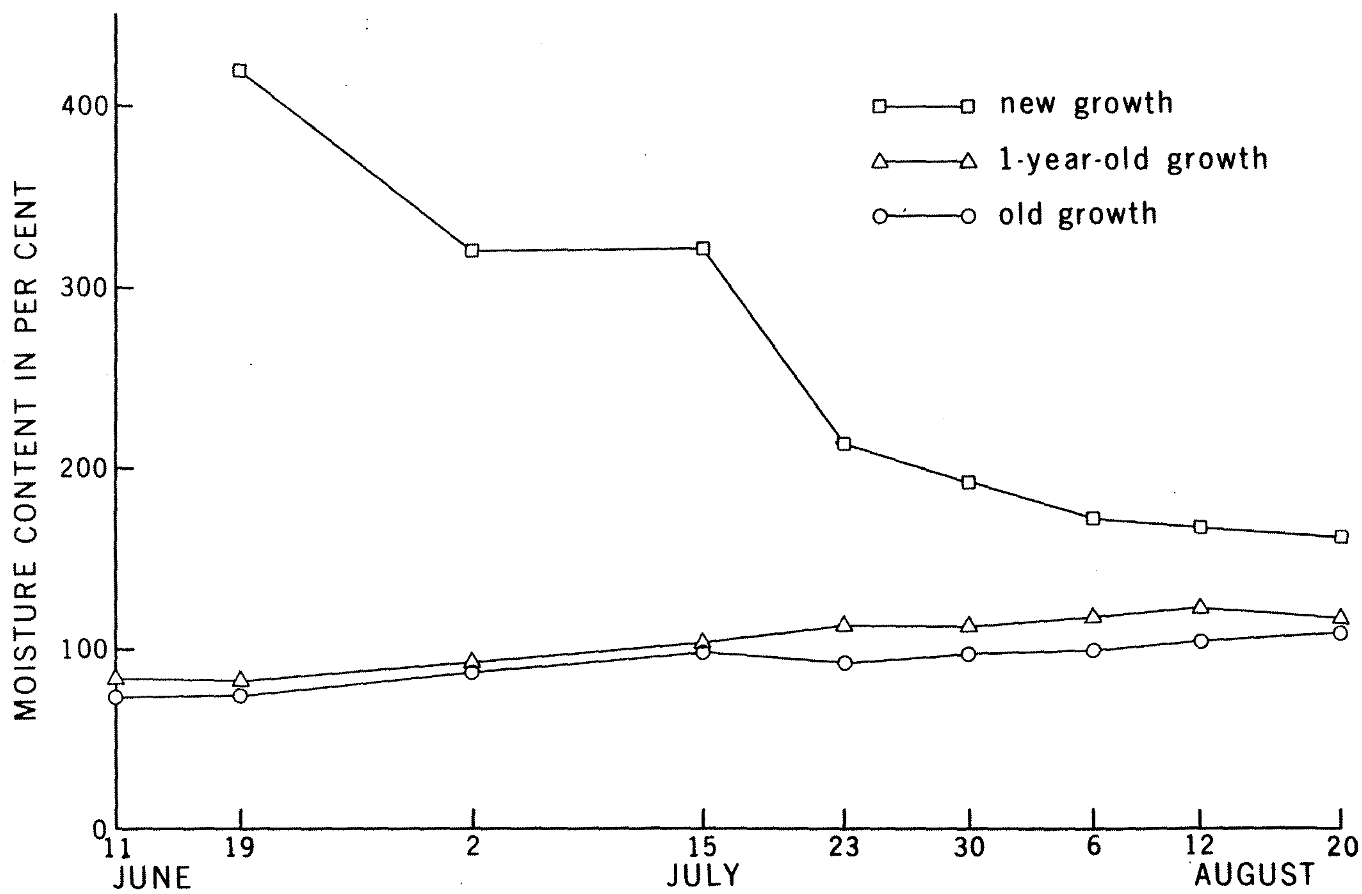

Figure 6. Moisture content of white spruce needles during 1965.

Similarly, the generally lower moisture content of the unmerchantable top in mature compared to younger trees is evidently owing to the increase in dry weight in proportion to moisture. There was a general increase in the moisture content of branchwood from the lower to the upper part of the crown but this difference seldom exceeded 10 per cent.

Effect of treatment and age on moisture content of slash components

Fine fuels, less than ½ inch in diameter

Lopped and scattered material dried faster than untreated slash (Figure 7). For example, the moisture content of pine and spruce needles on lopped branchwood dropped to 23 and 21 per cent in 11 weeks. The corresponding figures for needles on untreated branches were 38 and 36 per cent. After 11 weeks, the moisture content of lopped and untreated pine and spruce twigs had reached 20 and 14, and 38 and 16 per cent, respectively. Differences in moisture content between lopped and untreated fine fuel materials during the first year after felling were tested for significance using the null hypothesis that treatment did not affect fuel moisture. In general, the differences between lopped and untreated needles and twigs of both species were significant at the 5 per cent level. During the first summer after felling, the mean moisture content of lopped fine fuel materials was generally at least 10 per cent lower than for untreated fuel.

Freshly-cut and lopped fine material usually reached equilibrium with prevailing water vapour pressures after three months but untreated material required an additional 30 to 60 days to reach the same moisture condition. Having attained equilibrium moisture conditions with the pre-

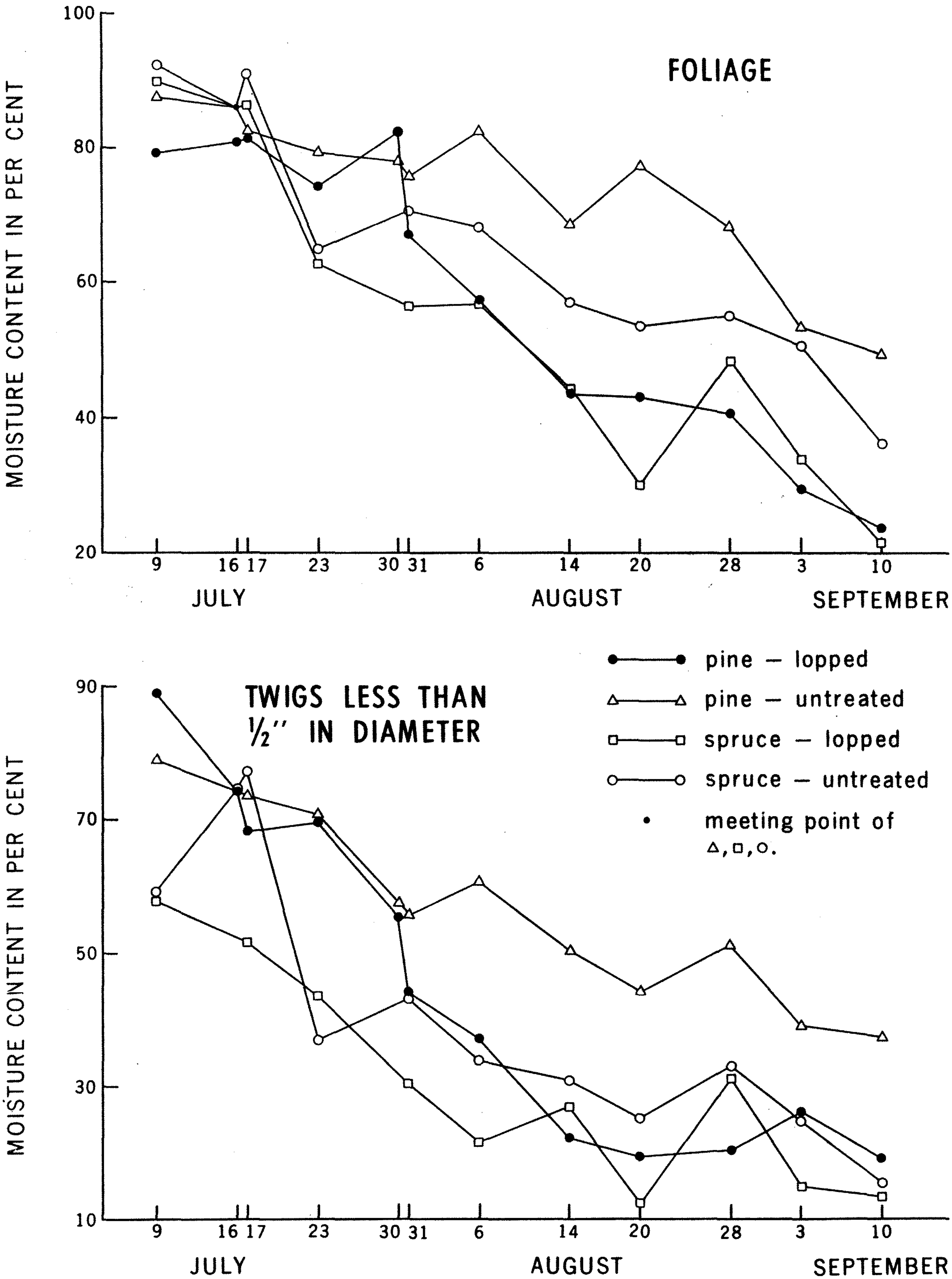

Figure 7. Drying rate of lopped and untreated lodgepole pine and white spruce foliage and twigs.

vailing water vapour pressures the moisture content of fine material fluctuated as in other dead fuels. During the second and third summers, differences in moisture content between lopped and untreated fuels were generally less than 4 per cent and attributed primarily to a slight increase in shade near the middle of the fuelbed where the samples were taken. For pine needles and twigs, the mean moisture departure of lopped from untreated material was -0.3 and 3.3 per cent. The mean moisture content of scarified and "walked over" fine fuels was 2.2 and 6.4 per cent higher than for untreated slash. Variations in fine fuel moisture between the various slash treatments were tested for significance using the null hypothesis that treatment did not effect fuel moisture. Generally, the differences between treatments for both species during the second and third summers were statistically not significant at the 5 per cent level.

The rate of drying and equilibrium moisture content levels of fine fuel components in clearcuts depends primarily on the treatment applied and on the macro- and micro-climate. Lopping and scattering increased the rate of drying of fine fuels above equilibrium moisture content levels. Once the fuels reached equilibrium with prevailing water vapour pressures their moisture content fluctuated as in other dead fuels, regardless of slash treatment. Aside from the direct effect of increasing the initial rate of drying of fine fuel components, all treatments influenced the moisture content of dead fuels by modifying the micro-climate within the fuelbed. In the study area, however, the shade from incoming lesser vegetation did not appear to have a significant effect on the moisture content and the rate of disintegration of fine fuels during the first five years after felling.

Medium (1/2 to 2 inches) and heavier fuels (2 to 4 inches).

Medium fuels are comprised primarily of branchwood whereas the heavier fuels consist primarily of unmerchantable tops. The amount of water that these and other woody materials can lose or gain depends, in part, on the surface exposed to sorption, on the relative vapour pressure of the sorbed material, on temperature, and on its chemical composition (Brown, et al. 1949). In the absence of rain, the rate at which the moisture content of slash fuels approaches equilibrium is dependent, to a large extent, on their diameter.

Drying curves for medium fuels are similar to those for needles and twigs (Figure 8). Lopped pine and spruce branchwood approached the 20 per cent moisture content level within 7 weeks of the application of the treatment. In comparison, untreated branchwood of the same species did not reach this moisture content level until early in the second year after felling. Results of t-tests indicated that the differences in moisture content between lopped and untreated branchwood for both species was statistically significant during the first summer. Generally the differences were not significant during the second and third summers after felling. During the two-year period the mean moisture departure of lopped from untreated medium-sized branchwood was 3.2 per cent. Somewhat surprisingly, the moisture content of medium-sized branchwood on scarified areas was generally lower than that for untreated slash. One explanation for this might be that only branches in full sun could be sampled on these areas as most of the shaded material was partially or fully covered by organic or mineral soil

The surface three-quarter inch of untreated unmerchantable tops dried at about the same rate as untreated medium-sized branchwood. In contrast to

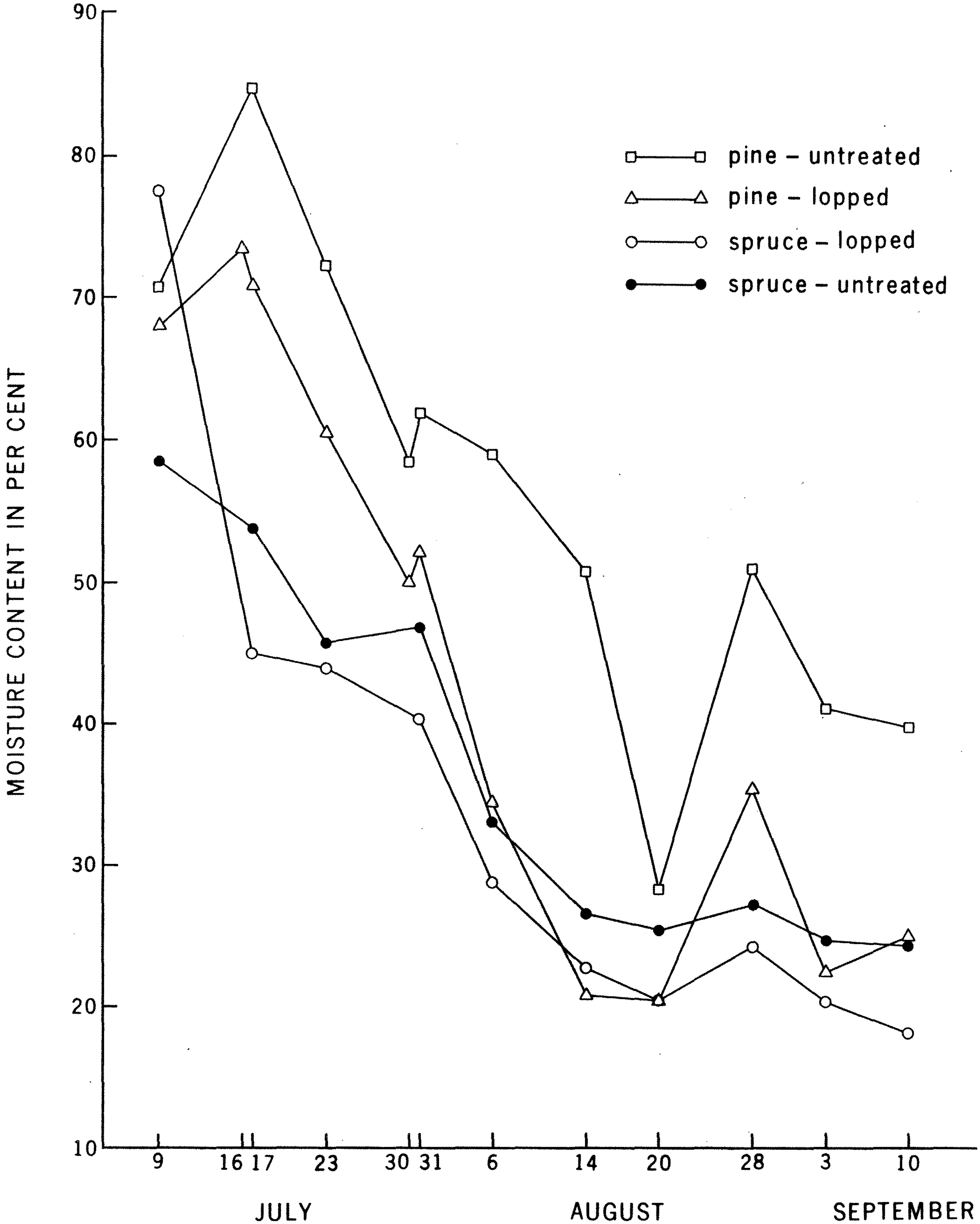

Figure 8. Drying rate of lopped and untreated lodgepole pine and white spruce branchwood (½ to 2 inches in diameter).

the general pattern of moisture loss from lopped material, the unmerchantable tops did not dry faster than untreated material. This deviation from the general pattern is attributed to (1) the absence of needles and branchwood through which moisture is lost and (2) the settling of the relatively heavy tops near to or on top of the ground surface where they are in the shade of the overlying needles and branches. The mean moisture departure of lopped, scarified, and "walked over" material from untreated tops was generally less than 10 per cent.

Effect of shade on slash moisture

Both untreated and lopped branchwood dried faster in full sun than in partial shade (Figure 9), and reached their fibre saturation points by the end of the first summer. In contrast, the lowest moisture content values for untreated and lopped pine branchwood in partial shade were 53 and 37 per cent, indicating that considerable free water remained in the cell cavities by the end of the first summer. Pine foliage dried more slowly than branchwood. The general pattern of moisture loss from spruce slash was similar to that for pine.

For any one slash treatment, needles on shaded twigs and branches did not discolour as fast as those on fully exposed slash (Table 3). By the end of the first summer, only 6 per cent of the needles on untreated slash in partial shade had turned brown compared to 95 per cent for lopped slash in full sun. Needle-drop from shaded pine slash occurred chiefly during the fourth and fifth summers but was not complete by the end of the fifth summer. All spruce needles on shaded slash had fallen to the ground by the end of the third summer. In full sun, less than 90 days were required for all spruce needles to fall off twigs and branches.

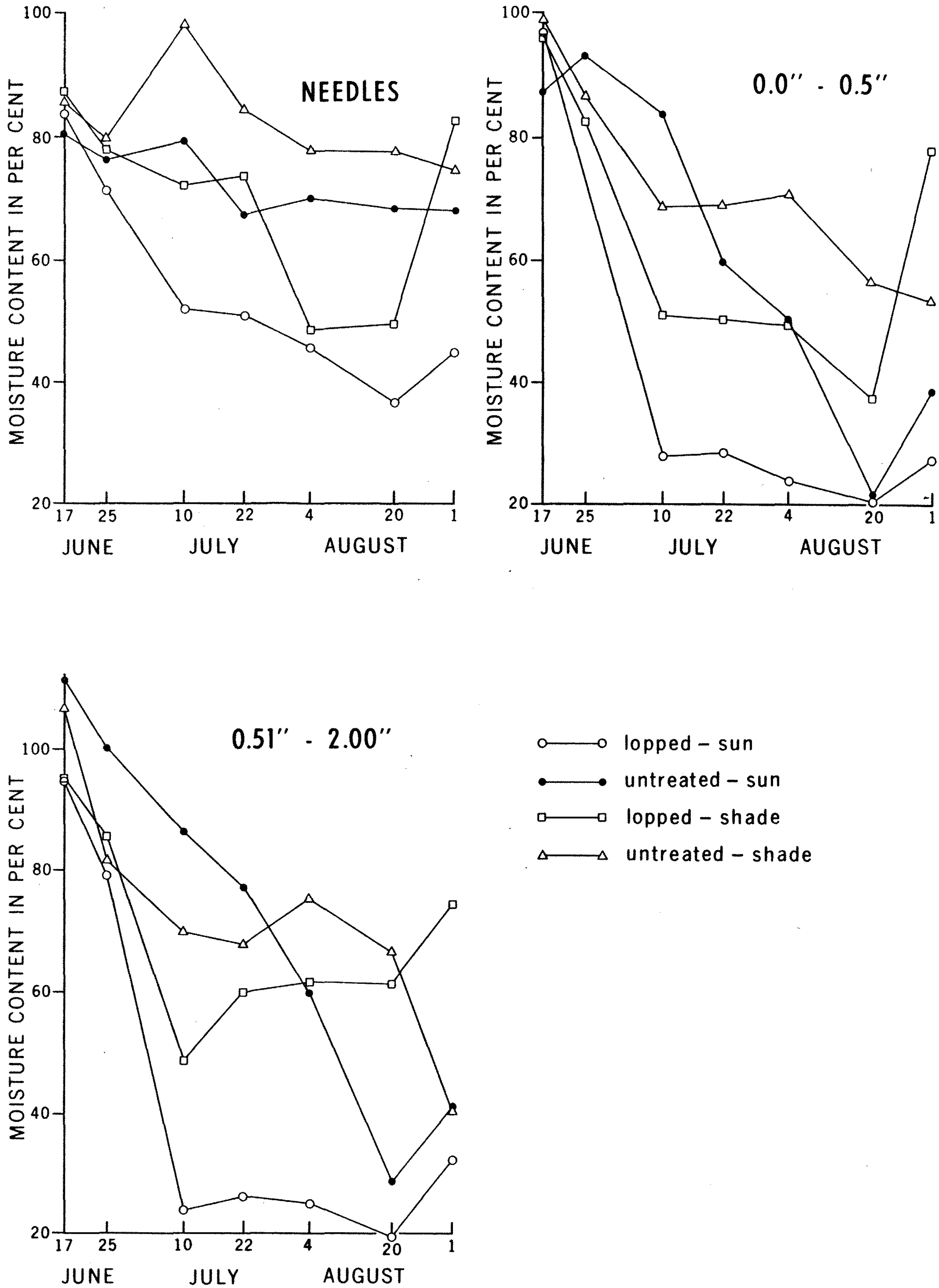

Figure 9. Drying rate of lodgepole pine foliage and branchwood in full sun and in partial shade.

The differences in moisture content of spruce slash in full sun and in partial shade were of the same magnitude as for pine slash but the former reached a lower moisture content by the end of 1964 (Figure 10). Even so, the lowest reading for shaded spruce slash was 32.4 per cent, indicating that all fuel components retained some water in the cell cavities. The generally lower moisture content of spruce slash is attributed, in part, to a lower initial moisture content.

The differences in moisture content of untreated and lopped slash in full sun and in partial shade are shown in Figure 11. Without exception, shaded slash of both species had a higher mean moisture content than fully exposed slash. Generally the mean moisture content departures of shaded from fully exposed slash were greater for lopped than for untreated fuels, at least during the first summer. A review of the data showed that the departures in moisture content of shaded from fully exposed slash decreased during the second summer but were generally higher than the differences between untreated and lopped slash in full sun or partial shade.

The moisture content of the surface three-quarter inch of untreated unmerchantable tops was lower than for the tops from which the branches had been lopped. By the second summer, lopped slash components in the shade had higher mean moisture content values than corresponding untreated slash. The differences ranged from less than 5 to over 40 per cent but averaged about 15 per cent. In general, the differences were greater for pine than spruce and tended to increase with increasing fuel particle size.

Effect of treatment and age on slash depth

Slash fuels become compacted with age, the rate of compaction being

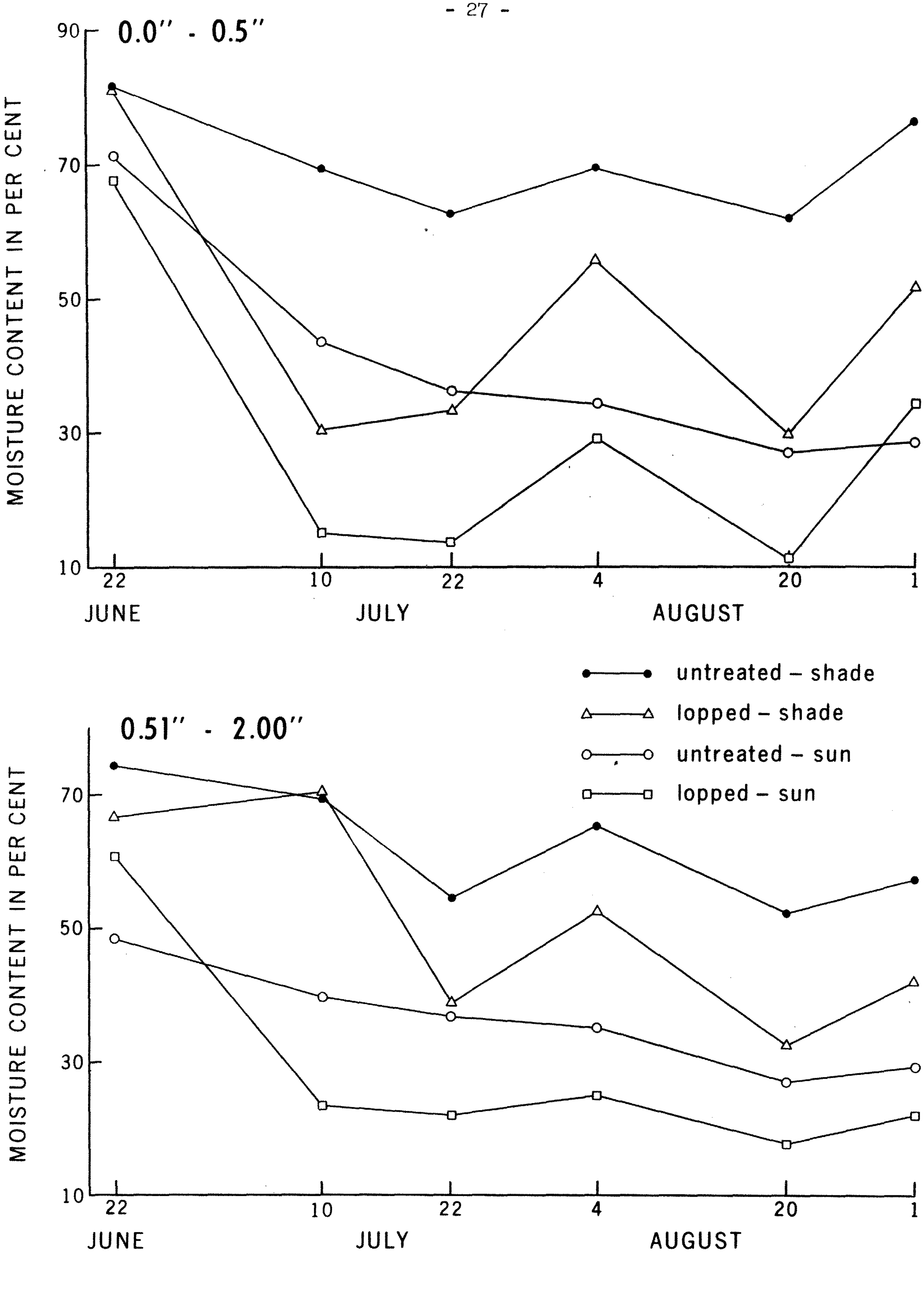

Figure 10. Drying rate of white spruce branchwood in full sun and in partial shade.

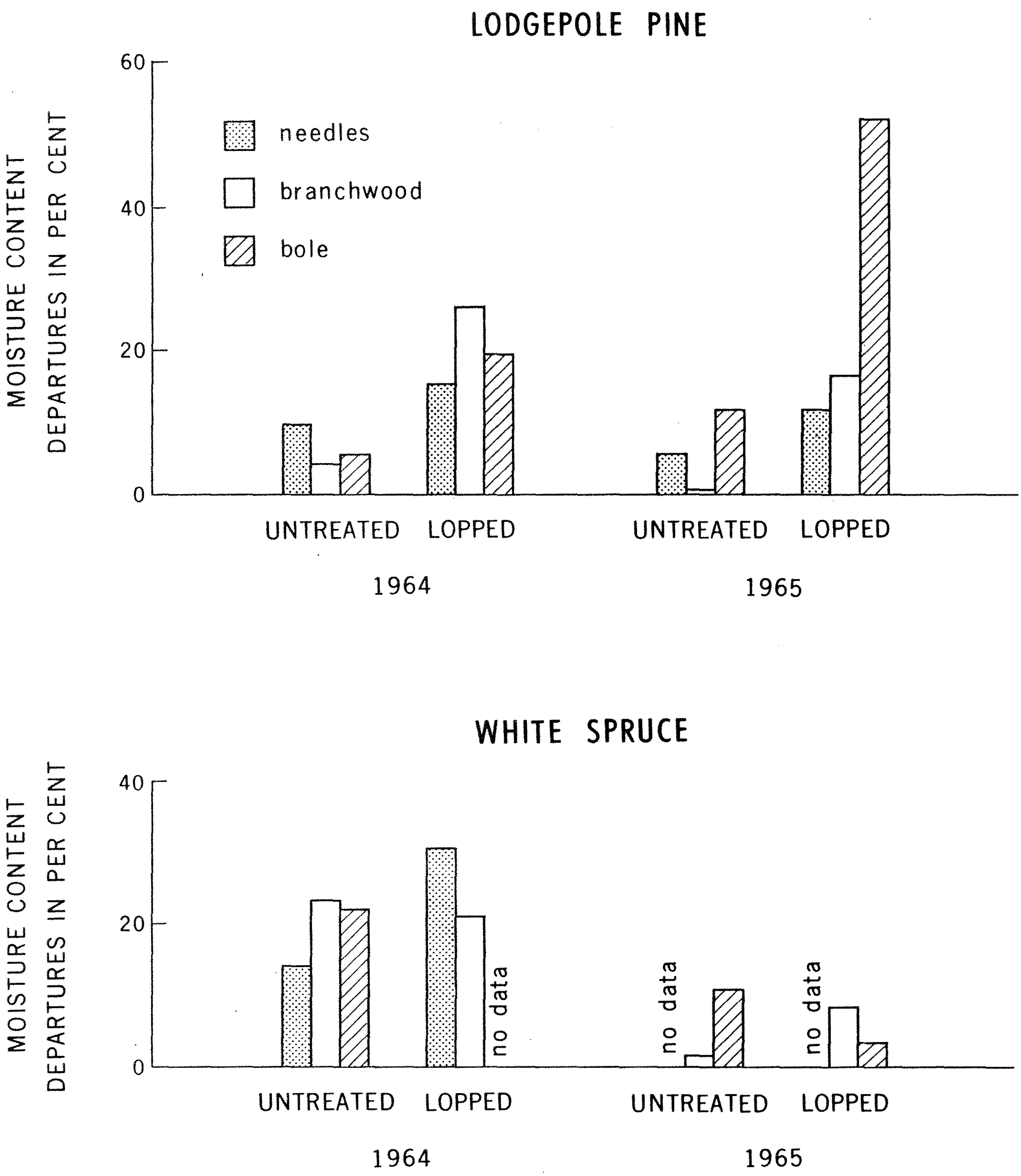

Figure 11. Mean moisture content departures of shaded from unshaded slash fuel components by treatment and year.

dependent on the rate of deterioration. This tendency for the fuels to settle is shown in Table 4. The mean depth of freshly-cut pine and spruce slash ranged between 0.8 and 1.4 feet. The increase in slash depth during the second and third summers is attributed to the loss of needles and the drying of twigs and branches so that they were able to assume a more vertical position. By the fourth summer, both untreated and lopped and scattered slash had settled appreciably and the mean depth varied from 0.65 to 0.81 feet. Five years after felling, mean slash depth was about 50 per cent of the original depth for both species.

Scarification and "walking over" reduced the slash to less than one-half of its pre-treatment depth. Little additional settling of scarified and "walked over" slash could be detected during the next three years. Scarification, in particular, effectively broke up slash continuity and actually reduced the available fuel for burning by mixing it into the organic and mineral soil.

TABLE 4. MEAN DEPTH OF SPRUCE AND PINE SLASH BY TREATMENT AND AGE.

	Untreated		Lopped & Scattered		Scarified		Walked over	
Year	Pine	Spruce	Pine	Spruce	Pine	Spruce	Pine	Spruce
	Depth in feet							
1963	0.85	1.35	0.90	1.10	—	—	—	—
1964	1.04	1.27	0.89	1.18	0.54	—	0.49	0.66
1965	1.11	1.33	0.86	1.03	0.43	0.44	0.38	0.57
1966	0.72	0.81	0.65	0.76	0.42	0.57	0.45	0.57
1967	0.60	0.61	0.54	0.62	0.42	0.46	0.39	0.63
Avg.	0.87	1.07	0.77	0.94	0.45	0.48	0.43	0.55

Three years after felling, more than 50 per cent of both untreated and treated slash components were within 6 inches of the ground surface. For both species combined the per cent of untreated, lopped and scattered, scarified, and "walked over" slash within 6 inches of the ground surface was 61, 77, 90, and 77, respectively. A slightly greater proportion of pine than spruce slash was in direct contact with the surface, indicating perhaps the heavier branching habit of pine.

Compaction reduces availability of oxygen and facilitates an increase in fuel moisture by increasing shade. The optimum air-fuel ratio for the rapid spread of fire through slash is not known but it is probably over 20:1. The total volume of the untreated fuelbed (including air space) ranged from 1500 to 2200 cu. yds./acre, decreasing to about 900 cu. yds./acre at the end of the fifth summer after felling. The air-fuel ratio decreased from a maximum of about 45:1 for fresh slash to less than 20:1 for five-year-old slash. The differences in the air-fuel ratios of five-year-old slash were of the same magnitude for untreated and lopped and scattered slash of both species. The air-fuel ratios of five-year-old scarified and "walked over" slash averaged about 15:1 and remained relatively constant throughout the study period.

Development of minor vegetation

Observation of vegetative condition on both clearcuts indicated important differences in the rate of development and species composition. Minor vegetation was very slow in invading the relatively dry pine site and no appreciable shade from this source developed until the fourth and fifth summers after felling. Five years after felling, minor vegetation covered about 60 per cent of the clearcut to a depth of 6 inches. The main plant species were Fireweed, Indian Paintbrush, Dogwood and grasses. The moss which covers over 50 per cent of the ground surface in the adjacent pine stand, had dried and shrivelled to a fraction of its original thickness.

The vegetative cover on the spruce-fir clearcut became relatively dense during the third summer after felling. By the middle of the 1967 growing season it covered 70 per cent of the area to a depth of 12 inches or more. This vegetative cover provided partial shade for the lower portion of the fuelbed during the growing season. Patches of live moss in the shaded areas reflected the effectiveness of minor vegetation for this purpose. The main plant species on this site included Horsetail, Fireweed, grasses, Cow - Parsnip, Wild Raspberry, and Prickly Rose.

PRACTICAL CONSIDERATIONS AND SUMMARY

This study has emphasized the measurement and description of the physical characteristics and moisture content of pine and spruce-fir slash during the first-five years after felling. The main objective has been to compare the rate of decay and disintegration of untreated and lopped and scattered slash but information has also been gathered on scarified and "walked over" slash. Other aspects of the study relate to the effect of shade on fuel moisture, seasonal fluctuation of moisture in conifer needles, and changes in slash depth. While an interpretation of the results of this study provides some useful clues about the probable slash fire hazard in pine and spruce-fir clearcuts, only a comprehensive experimental slash burning program can provide conclusive evidence about the actual fire hazard in these areas. In the interim, however, an examination of these and other findings as they relate to potential slash fire hazard seems appropriate.

It is generally recognized that slash concentrations from logging operations represent a serious problem to fire control personnel (Munger and Matthews, 1941; Williams, 1955; Fahnestock, 1960). Fire control organizations therefore often require that slash be treated or disposed of in a manner deemed satisfactory to reduce the fire hazard to an acceptable level. To accomplish this objective, it is necessary to decide (1) what is the acceptable level of fire hazard and (2) what is the fire hazard in the area being evaluted? Fuel, weather, and topographic conditions determine the potential fire hazard in an area but the acceptable level of fire hazard thereon relates to the policy and efficiency of the fire control organization. Any assessment of the effectiveness of a slash treatment method would be easier and more meaningful if the acceptable level of fire hazard could be defined in terms of rate of spread, difficulty of control, or fire intensity.

For purposes of this discussion slash fire hazard is defined in terms of probable ignitability, probable rate of spread, and probable resistance to control. Measuring the slash fire hazard relates directly to the physical and chemical characteristics, and moisture content of slash and other fuels contributing to the probable fire hazard. Other factors to be considered when assessing the need for slash treatment relate to climate, accessibility, risk, silvicultural considerations, aesthetics, soil and water conservation, the cost of the treatment, and the hazard in adjacent areas. A quantitative comparison of fuels and moisture content alone, therefore, does not necessarily reflect the total fire hazard. Slash-size and -distribution on an area with 15 tons of fuel per acre may result in a greater hazard than another area with 40 tons per acre. It is therefore of paramount importance to recognize local, rather than general fuel, weather, topographic, and related conditions when considering whether slash treatment is required and its potential effectiveness in reducing the fire hazard. Specific instructions for slash treatment and disposal over large regions should be avoided as much as possible and every effort made to ensure that the method is the most effective one for the particular area.

The following summary of changes in the physical characteristics and moisture content of untreated, lopped and scattered, scarified, and "walked over" slash during the first five years after logging is intended to serve as a basis for assessing the apparent effectiveness of each treatment in terms of reduced fire hazard in slash:

<u>First Year</u> Pine : Needles and small branches approached equilibrium moisture content levels but only lopped and scattered material becomes highly flammable. Nearly all needles on lopped and scattered tops turned brown, indicating that they had reached their fibre saturation point.

Spruce - fir : Needles and branches dried out and reached a lower moisture content level than corresponding pine slash. Regardless of the type of slash treatment, spruce needles fell off twigs and branches but fir needles remained attached. The time-lag in needle-drop between untreated and treated slash was in the order of a few weeks.

<u>Second Year</u> Pine : All foliage turned brown by the end of the year but remained attached to the twigs and branches. Medium and heavy branchwood dried out and those on untreated tops assumed a more erect position. The differences in the moisture content between lopped and untreated fuel components

were generally less than 4 per cent. Case-hardening was general where bark was loose. The incoming minor vegetation was sparse and did not provide shade for even the lower part of the fuelbed. The mean depth of scarified and "walked over" slash was about one-half of untreated slash.

Spruce-fir : All twigs and branches dried to a flammable level. Case hardening was general on exposed branchwood where bark was loose. Minor vegetation provided some shade for the lower part of the fuelbed. Sporophores were limited mainly to the lower surfaces of ground-contact slash.

<u>Third Year</u> Pine : All needles remained attached to untreated branchwood but 10 per cent of the needles dropped off lopped branches. The specific gravity values of various fuel components indicated no apparent reduction in the heat values of these fuels. Slash depth remained relatively constant but the incoming minor vegetation offered some shade for the lower part of the fuelbed. Some sporophore activity was noted, but decay was still of no apparent practical significance.

Spruce-fir : Shedding of bark was observed on all slash fuels, regardless of their size or position with respect to the ground. Lesser vegetation provided good shade for the lower portions of the fuelbed. Evidence of rot was negligible and fully exposed slash was dry and brittle.

<u>Fourth Year</u> Pine : Nearly all needles had fallen to the ground but retained their shape. Fruiting bodies were found mainly on the lower sides of ground-contact slash and were attached mainly to the bark. Slash had settled to about two-thirds of its original depth. The mean depths of untreated and lopped and scattered slash were similar but the latter was more uniformly continuous.

Spruce-fir : Minor vegetation covered over one-half of the area to a depth of about six inches. Fruiting bodies were still confined to the lower shaded parts of the heavier fuel pieces but rot was not prevalent. Settling of untreated and lopped and scattered slash reduced the fuelbed to just over one-half of its original depth. The spruce needles on the ground retained their original shape.

<u>Fifth Year</u> Pine : Fruiting bodies were not general and rot in five-year-old slash was negligible. About 30 per cent of the bark was off the untreated tops compared to about 40 per cent for lopped and scattered material. Over 80 per cent of the needles had fallen off both untreated and lopped and scattered material. The minor vegetation covered 60 per cent of the ground surface to a depth of about 6 inches and provided partial shade for most of the fuelbed.

Spruce-fir : Fruiting bodies were observed on the lower sides of the heavier fuel pieces. Slash was about one-half its original depth and more than one-half of it was in partial or complete shade. The depth of scarified and "walked over" slash remained unchanged but averaged less than that for lopped and scattered material. The minor vegetation covered 70 per cent of the ground surface to a depth of 12 inches. Most of the bark was loose and had fallen off one-third of the tops and larger branches. Disintegration of slash appeared minor even though some small twigs had broken off larger branches.

In Alberta, clearcutting leaves behind it between 15 and 20 tons of slash per acre. Dead logs and forest-floor fuels, including moss and humus, contribute as much, or more, to the total fuel loading. While slash quantity is considerably less here than in more productive forest areas, at least one-half of the slash fuels consist of fine fuels less than one-half inch in diameter (Figure 3). Thus a combination of slash weight - and size-distribution and the exposure of these fuels to the desiccating effects of the atmosphere produces a highly flammable concentration of fuels. In Alberta, the wildfire hazard in slash appears potentially serious in extensive clearcuts in excess of several hundred acres and in smaller clearcuts during periods of drought when the adjacent stands are in extremely flammable condition.

Clearcutting of merchantable pine and spruce-fir stands in the study area produces a relatively continuous slash fuel bed 1 to 2 feet in depth (Table 4). This level of fuel compaction has an air - fuel ratio of about 40 to 1, believed to be near-optimum for rapid fire spread. Needles account for about one-quarter of the total weight of freshly-cut slash. According to Muraro (1966) one pound of lodgepole pine needles present approximately 37.2 square feet of surface area compared to 5.2 square feet for fine branchwood having a maximum diameter of one inch. The loss of foliage therefore brings about a drastic reduction in the surface area - volume ratio of the fuel as well as a substantial reduction in the available suspended fuels for burning. The dropping of needles (Table 3) and the compaction of the fuelbed (Table 4) are believed to be mainly responsible for a substantial reduction in the rate of fire spread through five-year-old or younger slash. Visual observations of a large number of lopped and scattered and untreated clearcuts revealed that these changes may be significant in terms of reducing the rate of spread of fire through slash.

Needle-drop and the rate of compaction of the fuelbed was faster in lopped and scattered than in untreated slash areas but the differences were small and considered unimportant in terms of their effect on slash fire hazard. Scarification and "walking over" with a bulldozer had a much more pronounced effect on fuel compaction than lopping and scattering.

The incoming lesser vegetation is important in that (1) it provides partial or complete shade for the lower portion of the fuelbed and (2) increases fuel continuity when the vegetation is in a cured stage. The shade from this source creates a more favourable micro-environment for fungal activity and leads to higher fuel moisture levels. The kind and amount of lesser vegetation is primarily a function of site conditions but the effect of this vegetation on rate of decay and fuel moisture depends on the proximity of the fuel components to the ground surface. While a greater proportion of untreated than lopped and scattered slash was suspended above the ground surface no significant differences were observed in the incidence and spread of decay-producing fungi. It is conjectured that lesser vegetation becomes increasingly important in terms of its effect on rate of decay and fuel moisture as slash ages.

The mean moisture content of slash fuel components varied with species, size of material, and season (Figures 4, 5, and 6). The moisture content of live foliage was found to be highest during the growing season and lowest in the spring. The spring minimum is believed to be lowest in the east slopes of the Rockies where desiccating Chinook winds are a usual occurrence prior to the start of the growing season. It appears certain, however, that the differences in the moisture content between species, size of material, and season of freshly-cut slash are insignificant in terms of the time required for these fuels to reach a highly flammable level.

Lopped and scattered slash-fuel components dried faster than untreated fuels (Figures 7 and 8). The differences in moisture content between lopped and scattered and untreated fuels were generally statistically significant during the first year after felling but of little practical importance during succeeding years. Slash in partial shade dried more slowly than slash in full sun (Figure 9). Both lopped and scattered and untreated fuel components in full sun dried faster than the corresponding fuels in partial shade. Lopping and scattering appears most beneficial in partial cuts but the generally low slash fuel volumes and lack of fuel continuity do not represent a particularly hazardous fuel condition.

A meaningful interpretation of the results in terms of the slash fire hazard in the study area is difficult and inconclusive until an experimental slash burning program is carried out. The results of this study generally support the theory that lopping and scattering brings a greater proportion of the fuels into direct contact or in the proximity of the ground surface where they are in a position to absorb and retain moisture more readily than suspended slash. Temperature, water, and oxygen conditions in the study area, however, are generally unsuitable for rapid decay so that little is gained by bringing the fuels into direct contact or in the proximity of the ground surface. Both untreated and lopped and scattered slash remained unrotted for the first five years after felling. Hence, heat values of these fuels remained essentially the same as in freshly-cut wood. Furthermore, the results of the study do not indicate any important differences in other physical characteristics and moisture content values between treated and lopped and scattered slash.

Any real reduction in the slash fire hazard in the study area is attributed to (1) the loss of needles, (2) compaction of the fuelbed, and (3) incoming lesser vegetation. These changes occurred at about the same time and were of the same magnitude for both untreated and lopped and scattered slash. It should be stressed, however, that the rate of decay and disintegration of slash in the study area is extremely slow and the demonstration of differences in these factors is extremely time-consuming.

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