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THE FUEL COMPLEX IN 70-YEAR OLD LODGEPOLE PINE STANDS OF DIFFERENT DENSITIES

By

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Special thanks are extended to my wife Betty Ann, who maintained a cheerful disposition during a period of considerable inconvenience. Her encouragement and assistance played no small part in completing the program of studies.

TABLE OF CONTENTS

Page

LITERATURE REVIEW

METHODS

RESULTS

THE FUEL COMPLEX IN 70-YEAR
OLD LODGEPOLE PINE STANDS OF
DIFFERENT DENSITIES

by

A. D. KIIL

INTRODUCTION

Forest fires burn in trees, shrubs, herbs, litter and moss and occasionally consume a portion of the underlying humus. The intensity of combustion depends primarily on fuel weight, size, character of the fuel bed, and moisture content. Thus any fuel rating system in terms of fire behaviour must account for the relative importance of these and other fuel variables which exert a significant influence on the fire. An estimate of wood fibre content of fuel is of wider interest to students of forest productivity and utilisation.

Fuel classification in North America during the past 40 years has been based on estimates by experienced observers of the fuel complex in forest stands. The best known example of such a system is Hornby's (1935) division of forest areas "into units according to their characteristics respecting fire spread and difficulty of establishing and holding control lines". Such descriptions do not provide a quantitative measure of the amount or importance of each fuel variable.

Much of our knowledge about fuels is therefore incomplete and relative in the sense that observers' estimates of the fuel complex are only incidentally related to fire behaviour.

A quantitative approach to fuel measurement appears feasible particularly where the forests are comprised of relatively pure and evenaged stands of fire origin. In Alberta such stands are common and one approach would be to examine stand-fuel relationships in stands of different densities on similar landforms with similar site and growth conditions.

Fuel weight and size are major factors influencing rate of combustion and perhaps the easiest to measure; hence the first step will be to identify, measure and weigh individual fuel components comprising the fuel complex. Previous studies of individual forest fuel components in terms of weight and size have been reported by La Mois (1958), Fahnestock (1960), McArthur (1962), Muraro (1966) and Kiil (1967), but no single study has adequately described the entire fuel complex.

The second phase of the fuels research program will attempt to relate these and other variables in terms of their effect on fire behaviour. Finally the important fuel variables will be classified in terms of available fuel energy over a range of burning conditions.

The usefulness of the proposed system can be increased if it can be adapted for use with aerial photographs. Stand parameters such as crown cover, height, species and topographic features including landform, elevation, slope and aspect are all obtainable from aerial photographs. The feasability of classifying fuel variables on large-scale aerial photographs is the subject of a current research project.

The purposes of this study are to:

1. investigate how stand density affects weight-and-size distribution, and density of aerial and ground fuel components on one site, slope and exposure,

2. identify the stand parameters that can be used as predictors of fuel weight-and-size distribution,

3. attempt to provide a practical method whereby weight-and-size distribution of the fuel complex can be estimated from one or more stand parameters.

For purposes of this study, the fuel complex was separated into aerial and ground surface fuels. Aerial fuels comprise the entire standing tree crop, including standing snags, while ground surface fuels include all other fuels within 6 feet of the forest floor. The latter group includes shrubs, herbs, conifer regeneration less than one inch in diameter at breast height, forest floor litter, moss, and humus. Crown fuels are defined as all live and dead branchwood on standing trees whereas slash comprises the crown and the unmerchantable portion of the stem less than 4 inches in diameter. Fine fuels include all material less than ½ inch in diameter, medium fuels range from ½ to 2 inches, heavy fuels cover the range from 2 to 4 inches, and course fuels exceed 4 inches in diameter or depth.

LITERATURE REVIEW

Lodgepole Pine

In Alberta, lodgepole pine (Pinus contorta Dougl var. latifolia Engelm.) occurs in the western portion of the province, including the eastern slope of the Rocky Mountains and the foothills region. It occurs commonly in pure stands but also in mixtures with other species, including Engelmann spruce (Picea engelmannii Parry), white spruce (Picea glauca (Moench) Voss), black spruce (P. mariana (Mill) BSP.), alpine fir (Abies lasiocarpa (Hook.) Nutt), trembling aspen (Populus tremuloides Michx.) and balsam poplar (P. balsamifera L).[1]

Exposed bedrock in the lodgepole pine area ranges from the oldest hard Precambrian to the youngest, soft Tertiary strata. Land forms and soils are typically of glacial and glacio-fluvial origin, with depth of depositional material increasing progressively from the Subalpine to the Low Foothills Division (Smithers, 1961). Soil profile development varies from the typically grey wooded soil of the low foothills, through a podsolized grey wooded in the high foothills, to a brown or grey podsolic soil in the Subalpine Division. In west-central Alberta the tree occurs in even-aged stands on soils of glacial till, coarse gravelly alluvium, and lacustrine deposits (Duffy, 1962).

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[1] Canada, Department of Northern Affairs and National Resources, Forestry Branch, Native Trees of Canada, Bulletin 61, Fifth Edition.

Fire is the most important event in the development of lodgepole pine forests. The intensity of fire varies considerably, a fact which greatly influences forest composition (Horton, 1956). Sometimes it takes the form of a light ground surface fire which will skip haphazardly through a stand leaving some parts untouched, some scarred in varying degrees and others completely denuded. However, intense ground surface and crown fires are more usual in these regions. They sweep quickly over an area, scorching and thereby killing most or all vegetation.

Trees in mature stands fruit prolifically and bear mostly serotinous cones (Crossley, 1956a). Cones which remain closed do so because of a resinous bonding material which seals the scales together and forms a vapour-resistant protective coating over the entire cone (Beaufait, 1960). Temperatures exceeding 113°F are required for melting this bonding material and freeing the scales (Clements, 1910; Cameron, 1953). Beaufait (1960) found that jack pine (<u>Pinus</u> <u>banksiana</u> Lamb.) cones responded consistently by opening in a range from 80 seconds at 200°F to two seconds at 1300°F. The cones ignited in 60 seconds at 700°F; in only two seconds at 1300°F. Cones which ignited retained no viable seeds while unignited cones suffered but little reduction in the germinative capacity of their seeds. According to Beaufait, the results suggest that the high temperatures incurred in the crowns of standing trees during prescribed burns will not impair the viability of the seeds in serotinous cones, but should aid in their dispersion. While a great seedflight directly follows a fire there is considerable evidence that an appreciable amount of seed remains in semi-open cones to be disseminated periodically for several years afterward, according to fluctuating weather conditions (Smithers, 1961). Regenerated pine stands therefore usually have an age range of several years, though for practical purposes they may be called even-aged. The abundance of stored seed which is freed and the ideal germinating conditions for pine in recent burns account for the high density levels which often exist.

The usual course of stand succession proceeds from initial stocking of pine to a spruce-fir climax. If an adequate seed supply is available, the spruce will become established over a 40-year period following fire, or until the pine overstory becomes so dense that initial establishment of this species is precluded (Horton, 1956). While proximity to a seed source and favourable seedbed conditions are basic requirements for the initial establishment of both spruce and fir, the latter species is more tolerant and increases in abundance with stand age. The spruce understory is initially suppressed, but in contrast to the pine it maintains a steady growth rate and at 100 to 125 years becomes dominant. From this point on, spruce becomes increasingly important and pine is on the decline, successionally speaking.

As with other species, diameter growth of lodgepole pine responds to changes in stand density (Smithers, 1957). Dominant height of lodgepole pine increases with decreasing number of stems per acre (Smithers, 1956). Cubic foot volume, average height and average diameter are all strongly influenced by the number of stems per acre regardless of the physiographic site on which the stands occur. Basal area appears to be the one exception to this tendency. Thus, basal area in mature fully - stocked stands shows definite indications that it is predetermined by the physical characteristics of the site. Typically, basal area in fully-stocked stands increases rapidly during the first 40 years of stand development; culmination of this curve then takes place and stand basal area continues at a relatively uniform level consistent with site quality (Meyer, 1938, Smithers, 1954).

The species composition of ground vegetation varies with site, density of the pine canopy, and stand age (Horton, 1956). This would seem to concur with the concept of the vegetational continuum, which envisages a continually varying series of species occurring on an environmental gradient largely controlled by vegetational interactions. In the lodgepole pine community the most important interaction is succession which is primarily dependent on fire. Typical pine stands in a height range of from 30 to 60 feet have ground vegetation varying in density and composition with the density of the tree cover (Cormack, 1953). In general, mosses are abundant and grasses scarce in dense stands; while mosses are scarce or absent and grasses, fireweed and other plants are abundant in open stands. A noteworthy feature of the ground vegetation is the thin, almost continuous understory of low shrubs such as dry ground cranberry (<u>Vaccinium</u> <u>Vitis-Idaea</u> L.), dwarf blueberries (<u>V</u>. <u>Caespitosum</u> Michx., <u>V</u>. <u>oreophilum</u> Rydb.) and grouseberry (<u>V</u>. <u>scoparium</u> Leiburg).

Fuel Measurement

Available fuel and the surface area for absorption of radiation are the two principal features of the forest for fire spread (Anon, 1961). The most important elements of a quantitative picture of the fuel complex are (1) total weight of fuel per unit area of ground, (2) the weight of the total mass within half an inch of a surface, (3) total fuel volume per unit ground area and (4) the surface area of the fuel per unit ground area. While item (2) is based on the assumption that fuels within half an inch of a surface are available for burning during average conditions, the actual depth of burn will vary with different burning conditions. A graphical description of the variation, with height, of the mean distribution, in planes parallel to the ground, of fuel mass and surface area are also needed.

A quantitative approach to fuel measurement was attempted by Kittredge (1944) who used both American and European data to estimate foliage weight from the periodic annual growth or from tree diameter at breast height. Recent studies have shown that crown weight can be predicted from stem diameter and crown length or total height of individual trees (Storey <u>et al</u>., 1955; Fahnestock, 1960; Wendel, 1960; Chandler, 1960; Young <u>et al</u>., 1964). Kiil (1967) developed crown weight and size tables for lodgepole pine and white spruce based on stem diameter and crown width of individual trees. A convenient estimate of slash weight after clearcutting of lodgepole pine and white spruce stands is obtainable from slash weight-volume ratios for a range of tree and stand diameters (Kiil, 1965; Muraro, 1966). Such quantitative measures of fuel weight and size are useful to forest managers interested in the application of fire for hazard reduction and seedbed preparation.

While one or more of stem diameter, crown length and crown width account for much of the variation in weight-and-size distribution of individual tree crowns, several attempts have been made to explore the relationships between site and stand factors and fuel weight. Examples are found in La Mois' (1958) work with ground fuel components, McArthurs' (1962) study of the relationship between surface fuel quantity, number of years since last burn and canopy cover, and Brown's (1965) study of individual crown weights in a range of site quality and stand density.

DESCRIPTION OF STUDY AREA

The study area lies in the Upper Foothills Section (B. 19c) of the Boreal Forest Region (Rowe, 1959). The town of Hinton is located in the study area at approximately 53° 24' north latitude and 117° 37' west longitude.

Frequent fires have resulted in extensive stands of lodgepole pine (Pinus contorta Dougl var. latifolia Engelm.) which, with white spruce (Picea glauca (Moench) Voss) and black spruce (P. mariana (Mill)BSP.) form much of the forest cover, particularly along the middle and top of slopes. Trembling aspen (Populus tremuloides Michx.) and balsam poplar (P. balsamifera L.) are represented at the lower elevations.

The lodgepole pine stands, owing to their fire origin are typically even-aged of variable density (Figure 1). White spruce is found in varying numbers, becoming dominant as the stands approach a climax stage. Common understory species found under most stands include Epilobium angustifolium L., Rosa acicularis Lindl., Linnaea borealis L., Cornus canadensis L., Ledum groenlandicum Oeder, and Vaccinium spp.[1] Alnus crispa (Ait.)

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[1] G. C. Cunningham, Forest Flora of Canada, Canada, Department of Northern Affairs and National Resources, Forestry Branch Bulletin 121.

Pursh may also be found in all stand densities but increases greatly in abundance with decreasing stand density. Feather mosses are abundant in most stands, but tend to increase with increasing stand density.

The study area is typified by high rounded hills reaching 6,000 feet in elevation and deep valleys at 3,500 feet. The rivers flow eastward in broad incised valleys. The bedrock is of Mesozoic and late Palaezoic origin and is overlain by glacial drift of variable composition (Rowe, 1959). The mature soils are classified as podzolised grey wooded or grey wooded soils on 4 to 6 feet of glacial till.

The climate of the study area has moderately warm summers and relatively cold winters. Mean July temperatures are 58.7°F at Edson and 59.4°F at Jasper, with both stations about 50 miles from Hinton (Anon, 1964). Mean January temperatures at the same two stations are 8.4°F and 11.5°F, respectively. The temperature rises rapidly from winter to summer and falls equally rapidly to winter. 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).

Mean annual precipitation at Edson is 20.85" and at Jasper 15.98", of which about 60 per cent falls during the 150-day growing season (Anon, 1965) when mean daily temperatures exceed 42°F (Anon, 1957). Periods of precipitation totalling less than 0.10 inch vary between seasons, ranging from 7 days in July and August to 12 days in May; hence, rainless periods tend to be shorter in summer than in spring.

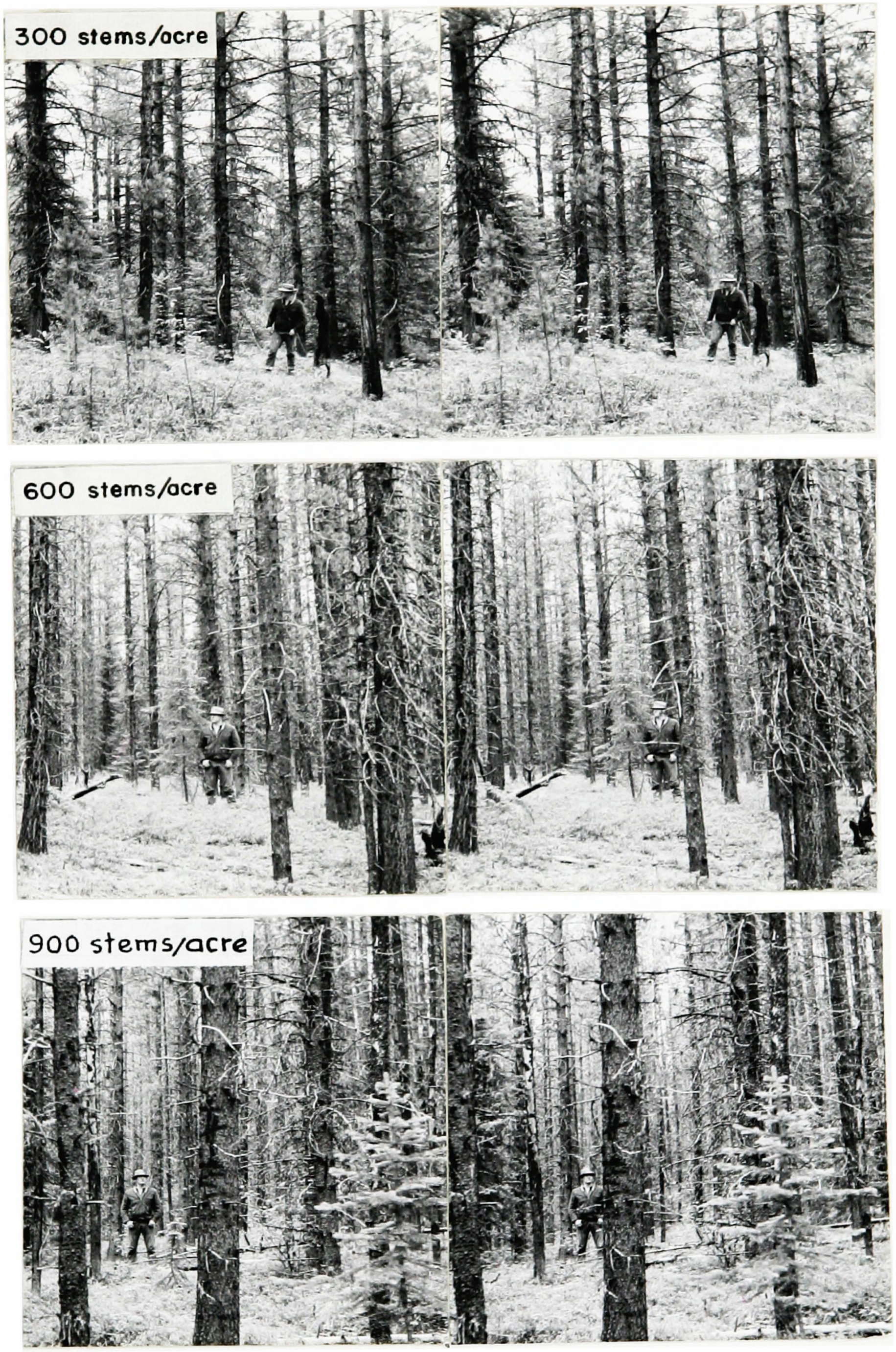

Figure 1. Stereograms of all three stand densities.

METHODS

Selection of Study Area

Sampling was restricted to lodgepole pine stands of fire origin growing on land forms with similar site and growth conditions. The initial stages of the selection process consisted of a study of fire history, forest cover, site type and surficial deposits maps.[1] Areas considered suitable were inspected in the field to assess them in terms of study objectives.

A 100-acre area supporting 70-year old lodgepole pine stands of different densities was selected for sampling and stratified into three stand density classes on the basis of number of trees per acre. The three classes contain about 300, 600 and 900 live stems per acre and are hence referred to as sparse, medium, and dense stands, respectively (Figure 1). All three stands are on 7 per cent southerly exposures situated on the upper half of a main slope at an elevation of 4,300 feet.

The main considerations leading to the selection of the sample area were:

1. The surficial deposits in the sampling area are classified as glacial till deposits to bedrock.[2] Several soil profiles were examined in each stand density class and quantitatively characterized (Appendix I). The soils within the sampling area were classified as podzolised grey wooded soils on glacial fill. A typical soil profile is shown in Figure 2

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[1] Obtained from Forestry Department, North Western Pulp and Pow er Limited, Hinton, Alberta.

[2] Based on surficial deposits map prepared by the Forestry Department, North Western Pulp and Power Limited, Hinton, Alberta.

Figure 2. Typical soil profile in the study area.

and consists of an organic layer up to 9 inches in depth resting on top of 5 feet of weathered till. Leaching is concentrated throughout the top few inches of the mineral soil but occurs occasionally to a depth of 12 inches.

2. All three stands are classified as growing on Site Class 3 with a productive capacity of from 21 to 45 cords per acre.[1]

3. Examination of stump remains, fire scars on residual trees and the humus layer provided a reasonable picture of the former stand. Fire-scarred residuals indicated that the former stand had been relatively even-aged throughout the sampling area. Also, there was a seemingly greater abundance of charred logs buried in the organic layer in the sparsely stocked stand than in the denser stands. The sparse stand is nearest to the top of the slope whereas the stand on the other side of the ridge is older and was apparently not affected by the same fire. The inference made from the supporting evidence is that the species composition and distribution of the pre-fire stand, variable fire intensity, and the composition of the organic material remaining after the fire were responsible for the variation in stand density on the study area.

Experimental Design

To assess the effect of stand density on fuel weight-and-size distribution and fuel density on one site, slope and exposure, the sampling area was stratified into three stands supporting about 300, 600,

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[1] Based on site class map prepared by the Forestry Department, North Western Pulp and Power Limited, Hinton, Alberta.

and 900 stems per acre. A completely randomized hierarchial sampling design was used in each stand, and consisted of five one-tenth acre plots for aerial fuels and three 2 x 3 - foot subplots in each plot for ground surface fuels. Altogether a total of 15 one-tenth acre plots and 45 2 x 3 - foot subplots was sampled.

Mensurational Data

The following mensurational data were measured and recorded on each one-tenth acre plot:

1. Diameter at breast height of all live and dead standing stems over one inch by one inch diameter classes.

2. Width of all crowns to the nearest foot as represented by the average of two measurements taken at right angles to each other. Crown width is defined as the average length of at least three of the longest live branches on each side of the crown. A plumb-bob and tape were used to obtain the measurements.

3. Height of three lodgepole pine trees and three white spruce trees by one inch diameter classes.

4. Crown closure estimated by three observers to the nearest five per cent.

5. Average height from ground surface to lowest bridge fuels estimated by three observers to the nearest six inches.

6. A count of all coniferous regeneration less than one inch in diameter breast height.

7. Aspect and per cent slope using compass and Haga altimeter.

8. A quantitative soil description, based on an excavated soil pit (5 feet long and deep and 3 feet wide). One pit was excavated in each of the three stand density classes.

The sampling procedure on each 2 x 3 - foot subplot was carried out as follows:

1. Boundaries were established with the aid of a 2 x 3 - foot wooden frame divided into six one-foot squares. A vertical cut was made at the boundary of each subplot down to mineral soil and the adjacent organic material was removed.

2. The surface area covered by shrubs was estimated by three observers to the nearest five per cent.

3. Average height of shrubs was measured to the nearest inch.

4. The shrubs enclosed by the vertical plane of the subplot boundary were cut level with the top of the F layer, collected and weighed to the nearest 10 grams.

5. A representative sample was taken of the weighed material for moisture content determination and oven-dried to constant weight in the field laboratory for 24 to 36 hours at a little more than 212°F.

6. Steps 2, 3, 4 and 5 were repeated for each of 1) herbs, 2) twigs less than ½ inch in diameter, 3) dead forest floor fuels over ½ inch in diameter, 4) needle litter (L layer), 5) moss, and 6) humus (F and H layers).

7. A record was made of the main understory species.

ANALYSIS OF DATA

The stand growth data were compiled and summarized as follows:

1. Number of live trees and standing snags per acre for both species.

2. Basal area per acre for both species.

3. Crown closure in per cent.

4. Height-diameter curves for both species and all three stand densities.

5. Crown width-diameter curves for lodgepole pine and all three stand densities.

6. Total and merchantable stem volumes for both species using volume tables (Blyth, 1955; Anon, 1962).

7. Merchantable volume in cords per acre estimated by multiplying the basal area by the product of mean dominant height and the factor 0.05. This method for volume estimation was developed at North Western Pulp and Power Limited, Hinton, Alberta.

8. Reinike's stand density index (Chapman and Meyer, 1949).

9. Surface coverage of all ground fuels in per cent.

10. Height or depth of all ground fuels in inches.

11. Moisture content of all ground fuels in per cent.

The following oven-dry fuel weight data were summarized for the analysis:

1. Weight of branchwood, the unmerchantable portion of the stem and slash, was compiled using fuel weight tables (Kiil, 1967).

2. Weight of slash fuels by three size-classes, viz. (1) less than

$\frac{1}{2}$ inch, (2) $\frac{1}{2}$ inch to 2 inches and (3) over 2 inches in diameter was estimated from unpublished data (Appendices II A and II B).

3. Weight of the merchantable portion of the stem was calculated by multiplying stem volume by its specific gravity (Anon, 1951).

4. Weight of each ground fuel component was calculated using the formula:

$$\text{Oven-dry weight} = \frac{\text{green weight}}{1 + \frac{\text{percentage of moisture}}{100}}$$

5. Weight of each ground fuel component per acre-inch was calculated on the basis of the following formula:

$$\frac{\text{fuel weight per acre x 100}}{\text{percentage of surface coverage x depth or height in inches}}$$

Analyses of variance were performed to determine if there were any significant differences in weights of aerial and ground surface fuel components between and within stand densities. When differences were significant, the new Duncan's multiple range test was applied to determine whether the individual differences were significant (Steel and Torrie, 1960). Bartlett's test of homogeneity of variances was applied to determine whether the variances were from the same population (Snedecor, 1956: p. 286).

To utilize the supplementary information about the three stands, regression analysis was applied where analysis of variance indicated that differences between means were significant. Scatter diagrams were prepared to discover if there were straightline relationships between the independent variables (stand factors) and the dependent variables (fuel weight expressions). Combinations of independent and dependent variables exhibiting straightline relationships and uniform variances were subjected to regression analysis. Coefficients of correlation and determination and standard errors of estimate were determined for each regression equation and used to select the best estimator of the dependent variable.

RESULTS

Stand Description

The distribution of live stems and standing snags by plots is given in Figure 3. The pine-spruce ratio increased with increasing stand density as did the proportion of standing snags. Dominant height and crown closure in the sparse, medium, and dense stands averaged 59, 56, and 57 feet, and 41, 49, and 56 per cent, respectively.

The diameter distribution varied with stand density, the range of diameters decreasing with increasing density (Figure 4). The distribution of number of stems per acre, basal area, and stem volume all showed increasing proportions in larger diameter classes with decreasing stand density. The dense stand had the outward appearance of being well stocked and this was reflected by the scarcity of shrubs.

The relationships of height and crown width to diameter breast height are given in Figures 5 and 6. In the diameter range from 1 to 8 inches, height increased with increasing stand density. The seemingly contradictory increase in height of dominants with decreasing stand density is explained by the fact that all dominants were selected independently of tree diameter. Thus, mean dominant height in the sparse stand was based on larger trees than in the dense stand. Crown width increased

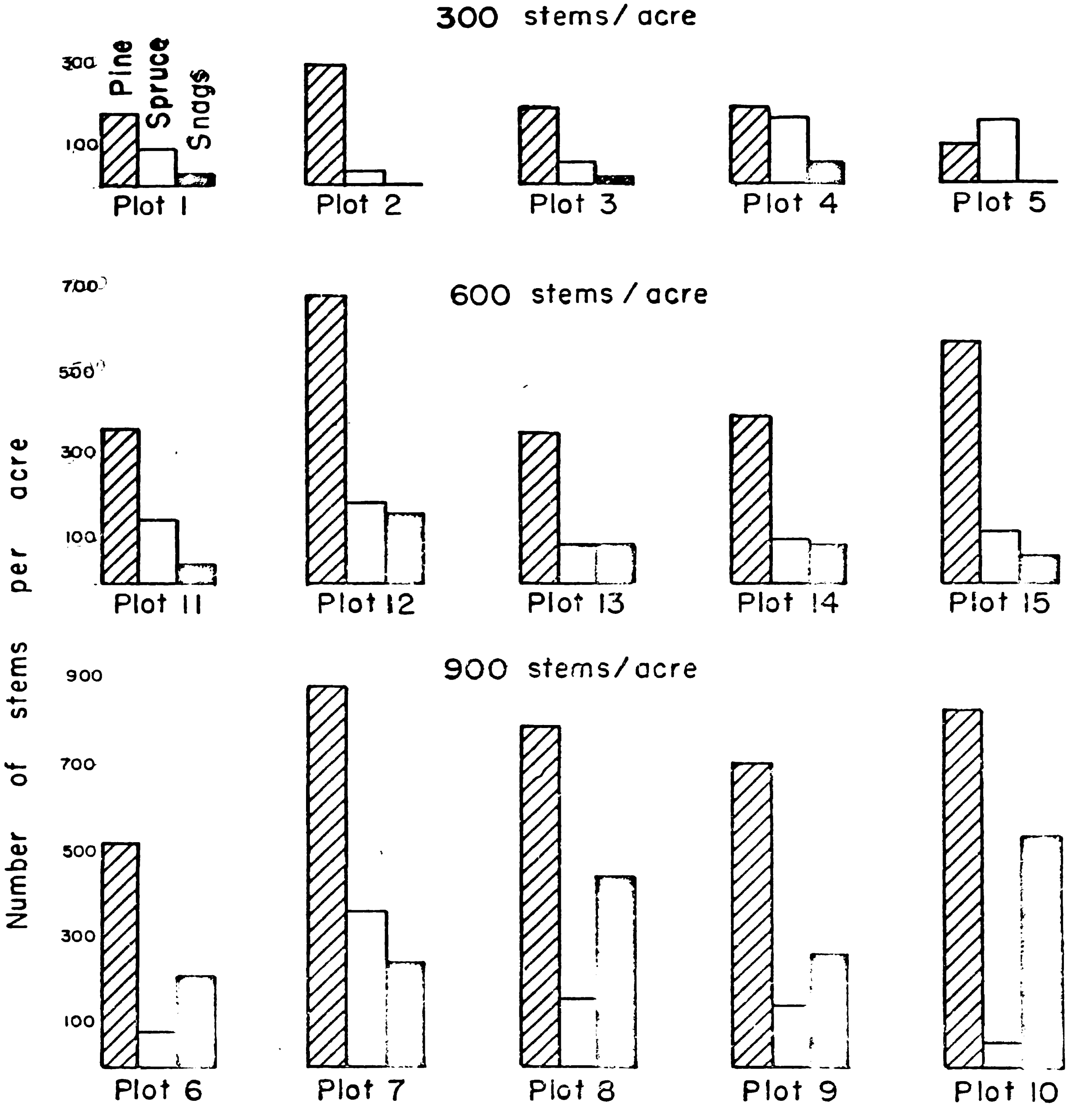


Figure 3. The distribution of live stems and standing snags by plots.

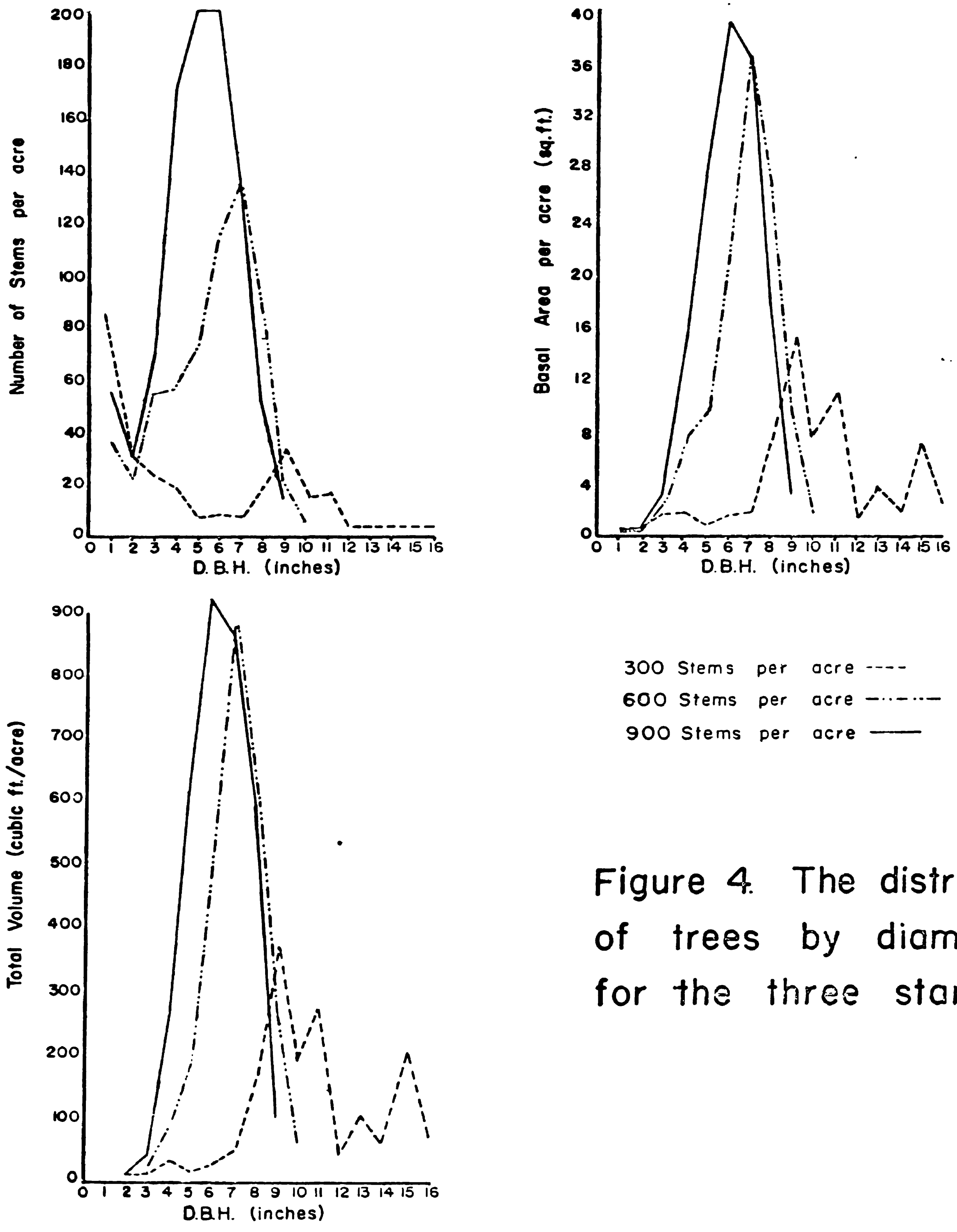


Figure 4. The distribution of trees by diameter for the three stands.

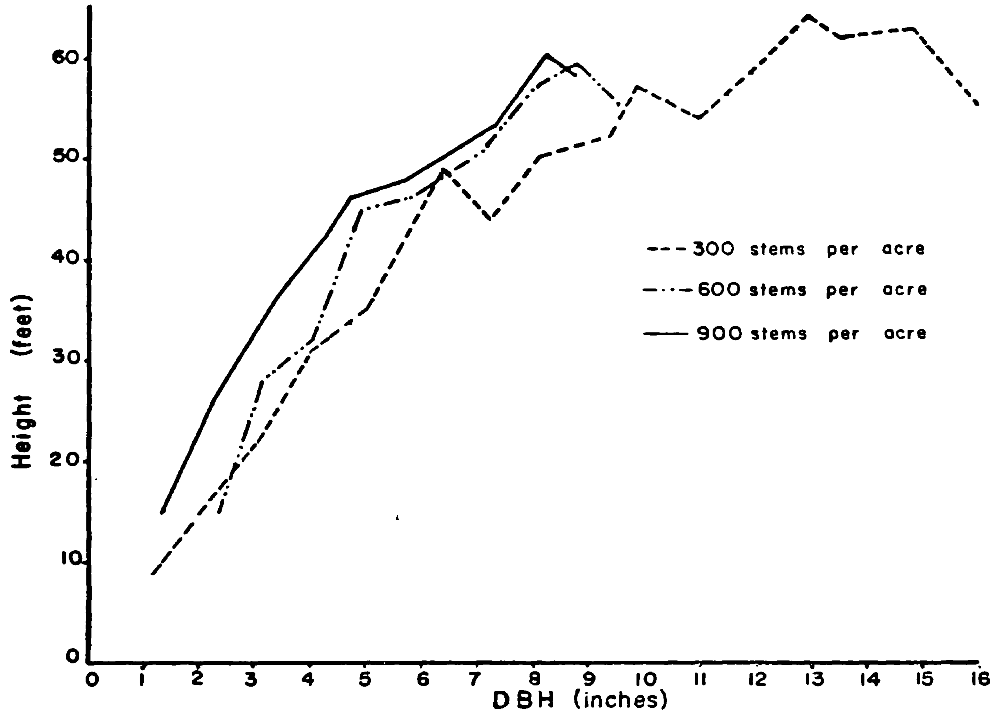


Figure 5. Total Height by diameter for the three stands.

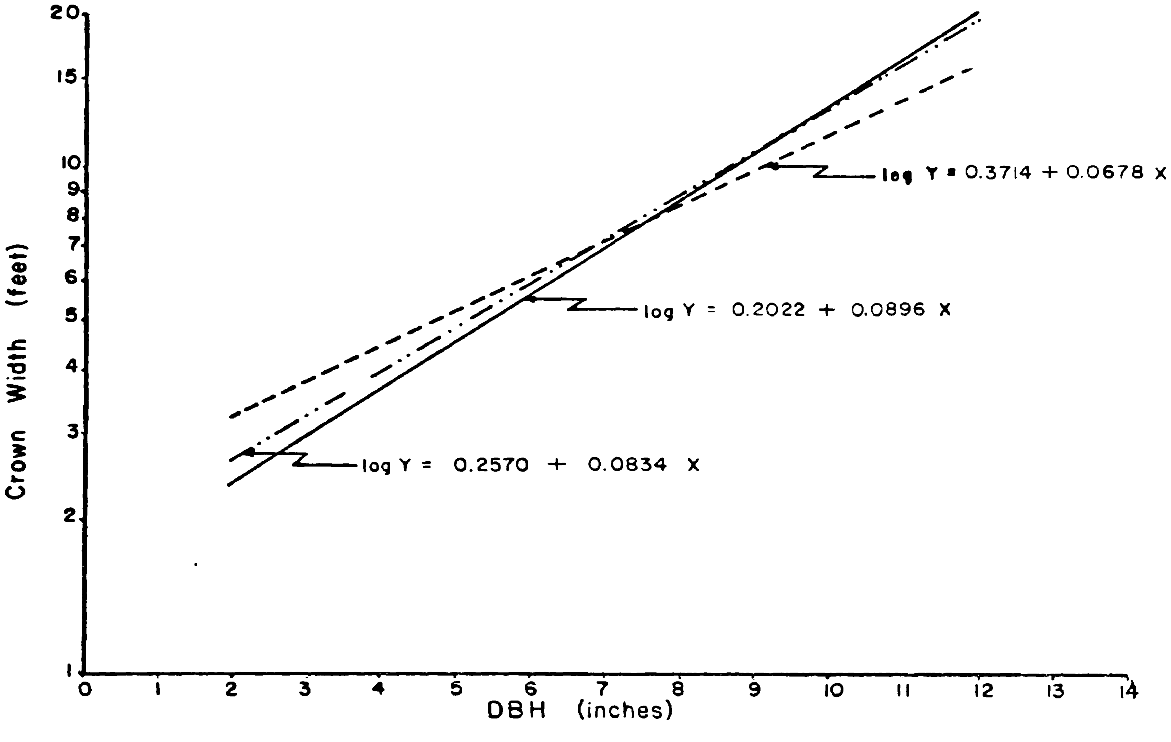


Figure 6. Relationship between the logarithm of crown width and D.B.H. for the three stands.

exponentially with tree diameter but a logarithmic transformation of crown widths equalized the variances. Additional descriptive data for all 15 plots are given in Table 1.

Aerial Fuels

The treatment means in oven-dry tons per acre for various fuel components increased with increasing stand density (Table 2). Lodgepole pine comprises about nine-tenths of the weight of branchwood and the standing tree crop in all three stands. The proportional weight of branchwood to the standing tree crop decreased from 33 to 20 per cent with increasing stand density. In addition to the standing tree crop, snags contributed 0.6, 1.9, and 4.9 tons per acre to the fuel complex in each of the sparse, medium and dense stands. A summary of aerial fuel weight data is given in Appendices III A, III B and III C.

Analysis of variance was used to test for differences in oven-dry weights of fuel components between the three stand densities. The starred F values in Table 3 show that there were significant differences in fuel weight (in terms of the unmerchantable stem, slash, and the standing tree crop) between stand densities, but not in branchwood weight. The F value for the standing tree crop was 13.19, significant at the 1% level. The significant F values indicate that all three stands do not belong to a population with a common mean but they do not indicate which differences may be considered statistically significant.

TABLE 1

STAND DATA FOR ALL 15 PLOTS

Stand Density	Number of Stems per Acre: Plot No.	Number of Stems per Acre: Live Stems	Number of Stems per Acre: Standing Snags	Number of Stems per Acre: Total Stems	Basal Area per Acre: Live Stems	Basal Area per Acre: Snags	Basal Area per Acre: Total	Volume per Acre: Total Volume	Volume per Acre: Merch. Volume	Reineke's Stand Density Index	Crown Closure
		No.	No.	No.	sq.ft.	sq.ft.	sq.ft.	cu.ft.	cords		per cent
Sparse	1	250	20	270	68	5	73	1715	23	88	34
	2	310	0	310	60	0	60	1252	13	73	33
	3	230	20	250	52	9	61	1080	13	82	40
	4	350	50	400	75	9	84	1607	20	118	43
	5	240	0	240	79	0	79	1629	21	129	54
Medium	11	490	50	540	93	6	99	2035	21	180	45
	12	870	160	1030	151	12	163	3383	38	313	58
	13	470	90	560	91	9	100	1934	23	185	42
	14	490	90	580	106	11	117	2494	31	206	43
	15	680	60	740	137	5	142	3226	36	272	56
Dense	6	750	260	1010	129	20	149	3101	34	272	51
	7	1240	240	1480	163	16	179	3225	36	357	63
	8	940	440	1380	136	30	166	3081	33	282	49
	9	790	260	1050	140	21	161	3322	42	312	65
	10	880	540	1420	143	31	174	3279	33	313	50

TABLE 2

TREATMENT MEANS FOR AERIAL FUEL COMPONENTS

Stand Density	Lodgepole Pine				Entire Stand			
	Branchwood	Unmerch. Stem	Merch. Stem	Standing Tree Crop	Branchwood	Unmerch. Stem	Merch. Stem	Standing Tree Crop
	Tons per Acre							
Sparse	8.1	1.0	17.2	26.3	9.9	1.6	18.2	29.7
Medium	9.0	4.1	28.6	41.6	10.2	4.8	28.7	43.7
Dense	9.2	6.7	33.3	49.2	11.2	7.7	33.9	52.8

TABLE 3

ANALYSIS OF VARIANCE: AERIAL FUELS ON STAND DENSITY

Source of Variation	d.f.	Branchwood (lbs)		Unmerchantable Stem (lbs)		Slash (lbs)		Table F
				Lodgepole Pine				
		MS	F	MS	F	MS	F	
Stand density	2	73,711	0.92	1,647,383	42.29##	2,384,015	17.77##	3.89 (.05)
Error	12	80,380		34,112		134,171		6.93 (.01)
Total	14							
				Entire Stand				
		MS	F	MS	F	MS	F	
Stand density	2	101,826	0.70	1,852,559	29.97##	2,777,718	9.51##	3.89 (.05)
Error	12	146,440		61,818		292,072		6.93 (.01)
Total	14							

Duncan's new multiple range test was used to discover all significant differences in weight (in terms of the unmerchantable stem, slash, and the standing tree crop) between stand densities, (Table 4). Significant differences were shown to exist for most fuel weight expressions between all stand densities but not for slash weight between sparse and medium and medium and dense stands. The differences for slash weight just missed being significant at the 5% level, indicating that an increase of 300 stems per acre is on the verge of making a real difference in slash weight.

TABLE 4

CRITICAL DIFFERENCES BETWEEN TREATMENT MEANS FOR AERIAL FUELS

Stand Density	Unmerch. Stem		Slash		Standing Tree Crop
	Pine	Entire Stand	Pine	Entire Stand	
Sparse vs medium	##	##	##	NS	##
Sparse vs dense	##	##	##	##	##
Medium vs dense	##	##	#	NS	##

NS not significant

significant at .05 level

significant at .01 level

One of the assumptions underlying the analysis of variance is that the experimental error must have a common variance. To test the hypothesis that all variances are from the same population, Bartlett's test of homogeneity of variances was applied and in all cases the calculated Chi-square value was less than the tabular value at the 5% level. Thus, the hypothesis of homogeneous variances was accepted.

The distribution of slash weight and weight of the standing tree crop by diameter classes is shown in Figure 7. This relationship showed increasing proportions in larger diameter classes with decreasing stand density. The slash weight-standing tree crop ratio decreases with increasing tree diameter. For example, a 3 inch tree is left as slash following a clearcutting operation whereas only about 25 per cent of a 9 inch tree becomes slash.

The demonstration of significant differences in fuel weight between stand densities prompted a further analysis of data to facilitate selection of fuel weight and stand factors suitable for the construction of prediction equations. Data were first examined graphically for straightline relationships between fuel weight expressions (in terms of slash fuel components, the standing tree crop and the entire fuel complex) and stand factors (in terms of number of stems per acre, basal area, cubic foot volume and Reinike's stand density index). Combinations of independent and dependent variables exhibiting straightline relationships and a high degree of correlation were subjected to regression analysis.

Results of the graphical examination and regression analysis showed that basal area gave the most precise estimate of fuel weight. Straightline relationships were also evident between some fuel weight

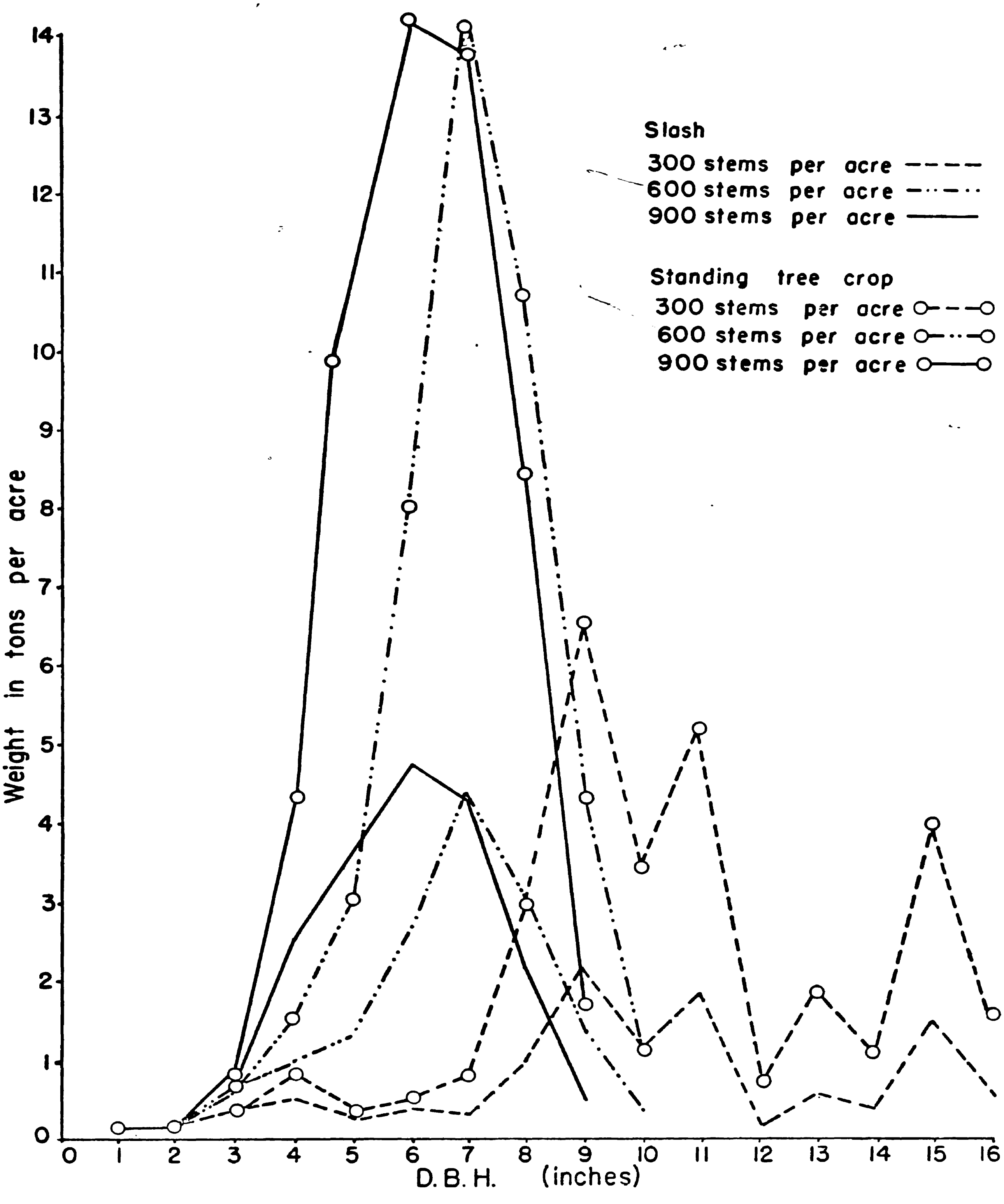


Figure 7. The distribution of slash weight and weight of the standing tree crop by diameter classes for the three stands.

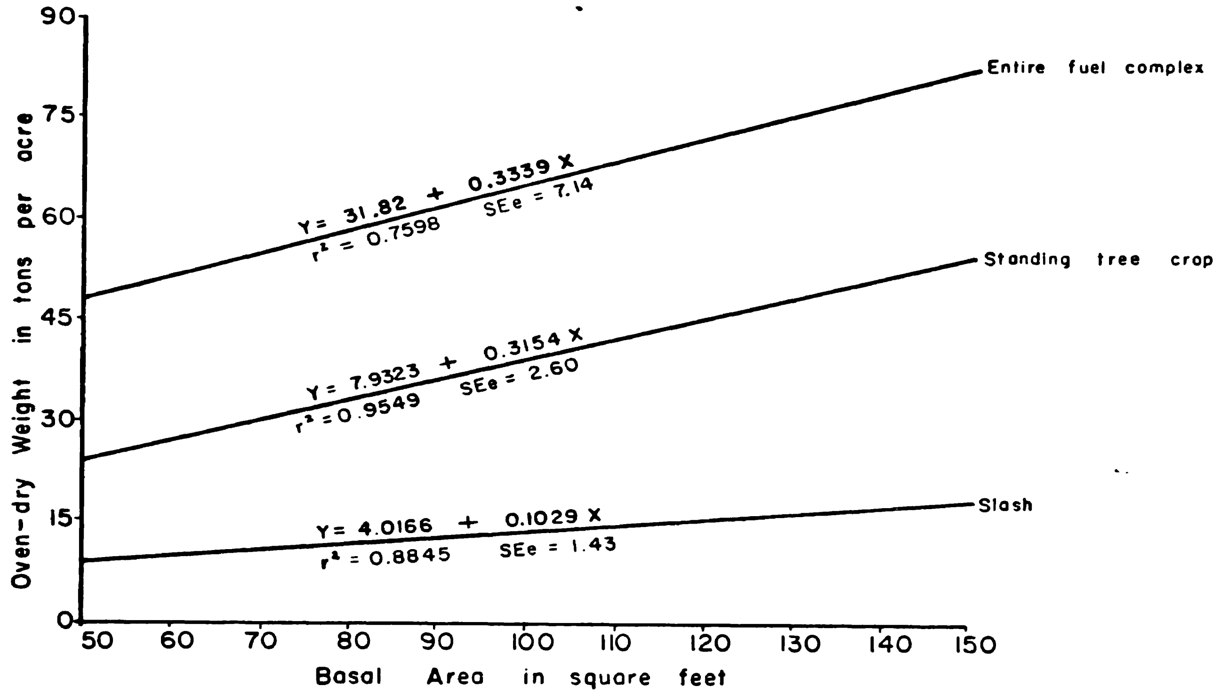
expressions and either number of stems per acre, cubic foot volume or Reinike's stand density index. However, basal area was judged to be a more convenient measure for fuel weight prediction purposes because it was easier to measure in the field and can be estimated from aerial photographs. The general equation used for predicting weight of fuel components is:

$$Y = a + b\,X,$$

where Y = predicted value of the dependent variable,
X = observed value of basal area in square feet per acre,
a and b = constants.

The relationships between selected fuel weight expressions and basal area are shown in Figure 8. All correlations were significant at the 5% level for fuel weight prediction purposes. A linear equation adequately describes the relationship between the fuel weight expressions and stand factors over the stand density range sampled, but it is recognized that the relationship may well become curvilinear beyond the range of data. Also, an unknown amount of error exists in all aerial fuel weight equations because these weights were calculated from fuel weight tables and are therefore not actual weights.

Crown closure correlated sufficiently well with basal area ($r = 0.83$) to be useful for basal area prediction purposes (Figure 9). While the standard error of estimate is relatively high (21.1 sq. ft.) the precision of the estimate can probably be increased with additional



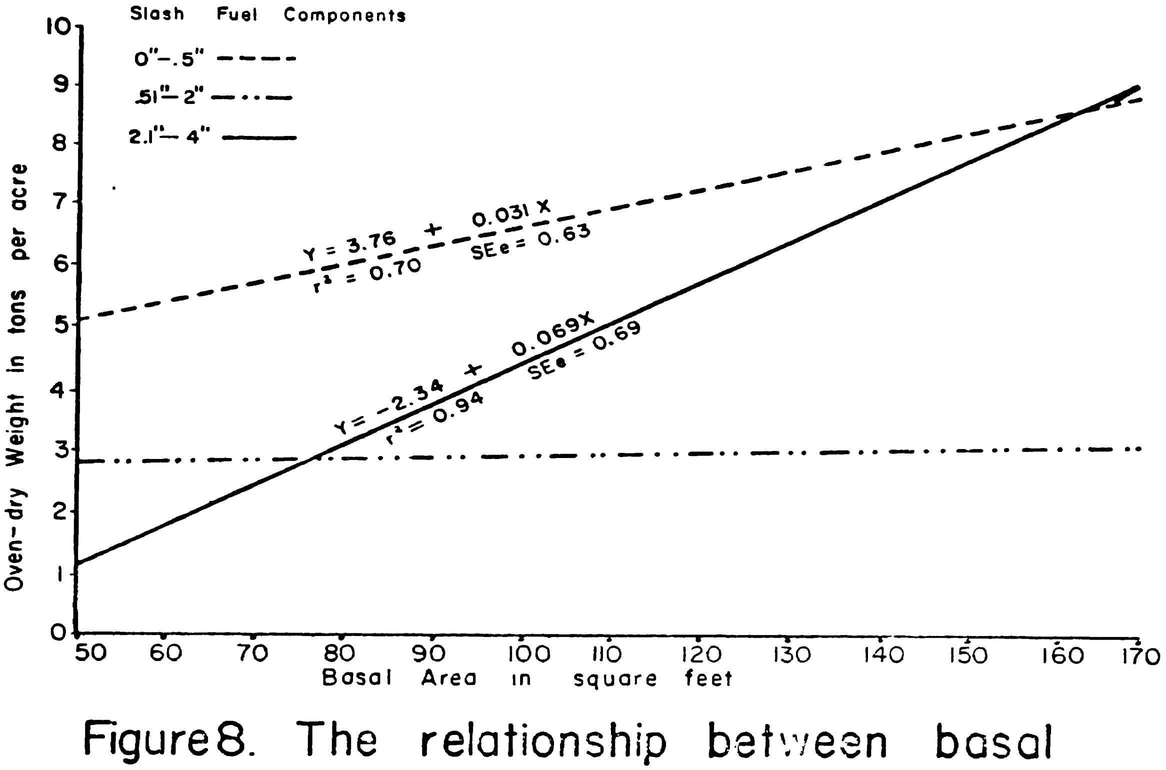


Figure 8. The relationship between basal area and weight of fuel components.

sampling. Since crown closure is based on crown width measurements of individual tree crowns one source of error is the possibility of overlap within the crown canopy.

Ground Surface Fuels

Treatment means in oven-dry tons per acre are given in Table 5 and plot summaries are listed in Appendices III A, III B and III C. Weight of all ground surface fuel components, less humus, averages 3.94, 5.13 and 7.19 tons per acre, or 16, 21 and 27 per cent of the weight of all ground surface fuels in the sparse, medium, and dense stands. Weight of minor vegetation (in terms of herbs and shrubs) decreased with increasing stand density whereas weight of moss increased with increasing stand density.

TABLE 5

TREATMENT MEANS FOR GROUND SURFACE FUELS

Stand Density	Shrubs	Herbs	Needle Litter	Other Forest Floor Litter		Moss	Humus (F&H)	All Ground Surface Fuels
				less than ½ inch	over ½ inch			
				Tons per Acre				
Sparse	1.63	0.63	1.18	0.09	0.08	0.33	21.05	24.99
Medium	0.07	0.82	1.44	0.19	0.51	2.10	20.08	25.21
Dense	0.07	0.45	1.07	0.46	2.99	2.15	20.25	27.44

Analysis of variance was used to test for significant differences in oven-dry weights of selected ground surface fuel components (Table 6). Four fuel groups were analyzed, viz. (1) minor vegetation (in terms of herbs and shrubs), (2) moss, (3) forest floor litter, and (4) forest floor litter, including moss. Starred F values show significant differences for minor vegetation, moss and forest floor litter, including moss, between stand densities, but not for forest floor litter. The variation between plots within densities was significant for forest floor litter and forest floor litter, including moss.

Duncan's new multiple range test was applied to test for significant differences in weights between stand densities and the results are presented in Table 7. Significant differences were found to exist for minor vegetation and moss between sparse and medium and sparse and dense stands and for forest floor litter, including moss, between all stand densities.

The demonstration of significant differences in weights of some ground surface fuels between stand densities led to a further analysis of data to facilitate selection of stand factors for prediction purposes. The data were first examined graphically for straightline relationships between ground surface fuel weights and stand factors (in terms of basal area per acre and crown closure). Combinations of independent and dependent variables exhibiting straightline relationships and a high degree of correlation were subjected to regression analysis.

TABLE 6

ANALYSIS OF VARIANCE: GROUND FUEL WEIGHTS ON STAND DENSITY

Source of Variation	d.f.	Minor Vegetation		Moss		Forest Floor Litter		Forest Floor Litter, incl. Moss	
		MS	F	MS	F	MS	F	MS	F
Stand density	2	198,860	8.89 ##	251,286	7.11 ##	637,759	2.97	1,455,228	11.59 ##
Plots within densities	12	26,674	1.19	35,433	1.00	564,238	2.63 #	792,456	6.31 ##
Subplots within plots within densities	30	22,345		35,335		214,532		125,543	
Total	44								

significant at .05 level.
significant at .01 level.

TABLE 7

CRITICAL DIFFERENCES BETWEEN TREATMENT MEANS FOR GROUND SURFACE FUELS

Stand Density	Minor Vegetation	Moss	Forest Floor Litter, incl. Moss
Sparse vs medium	##	##	##
Sparse vs dense	##	##	##
Medium vs dense	NS	NS	##

NS not significant
significant at .01 level

In general, correlations between ground surface fuels and stand factors were too weak for prediction purposes, with two exceptions. Weight of minor vegetation and weight of forest floor litter, including moss, are significantly correlated with basal area per acre (Figure 10). Basal area per acre was also sufficiently well correlated with moss weight per acre (r = 0.53) and weight of all ground fuels, less humus per acre (r = 0.35) to be potentially useful in weight prediction.

The density of ground surface fuels was computed from volume and weight of each fuel component and expressed in terms of weight per acre - inch (Table 8). The volume of each component was determined from average height and depth and contains both solid material and void space. As expected, needle litter was the most compacted ground surface fuel, followed by moss, herbs, and shrubs in order of decreasing compactness. The humus layer (F and H layers combined) is more than twice as dense as any other ground surface fuel component but it is of little importance in terms of fire spread. Weight per acre - inch values for

for other ground surface fuels, such as dead logs, were not computed because no known method was available whereby their volume could be conveniently estimated. A summary of height or depth and percentage surface coverage for ground surface fuels by plots is presented in Appendices IV A and IV B.

TABLE 8

OVEN-DRY FUEL WEIGHTS PER ACRE-INCH FOR SELECTED GROUND SURFACE FUELS

Stand Density	Shrubs	Herbs	Needle Litter	Moss
		Tons per Acre - inch		
Sparse	0.08	0.18	2.07	no data
Medium	0.11	0.25	2.81	1.60
Dense	0.12	0.25	2.91	1.90
Average	0.10	0.23	2.60	1.75

APPLICATION OF RESULTS

The findings of this study provide a breakdown of the fuel complex in 70-year old even-aged lodgepole pine stands of fire origin on one site, slope, and exposure. Weight-and-size distribution and density of several fuel components can be estimated in such stands growing on similar sites and under similar growing conditions. Additional work is required to assess the effect of different sites, stand densities and ages on fuel variables.

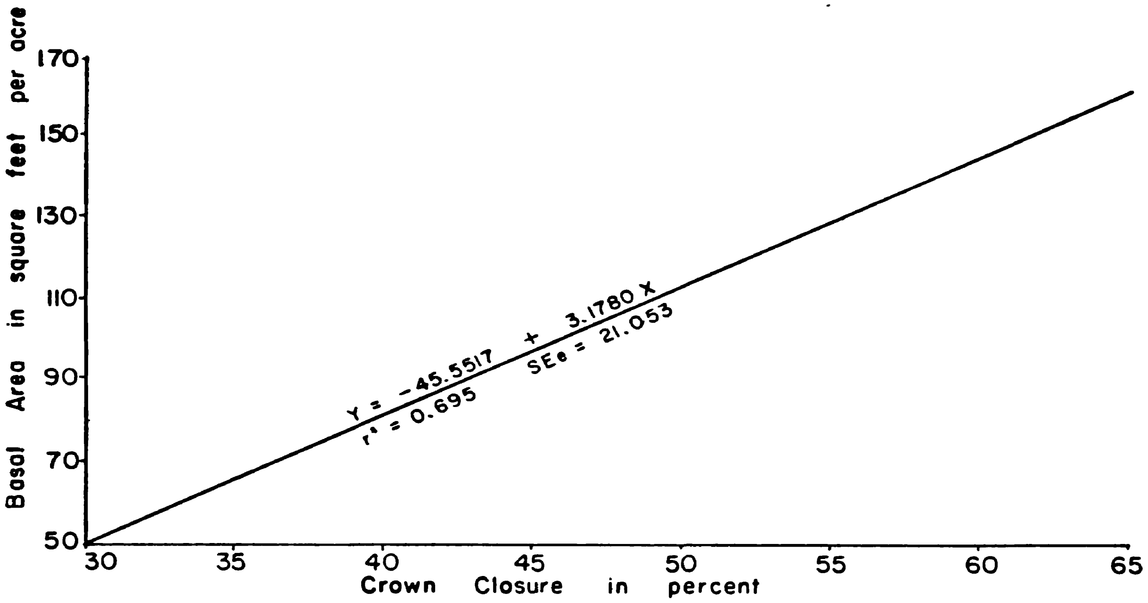


Figure 9. The relationship between crown closure and basal area.

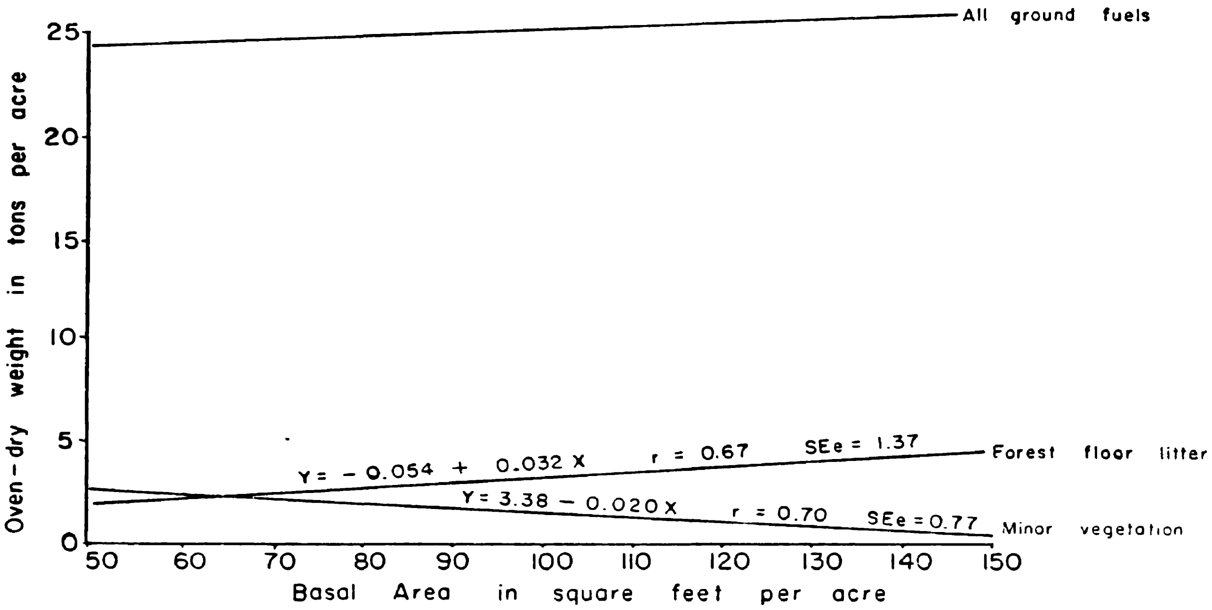


Figure 10. The relationship between basal area and weight of ground fuel components.

In the light of this study, basal area appears to be the only field measurement required for estimating weight-and-size distribution of most fuel components. This can be determined from either a plotless cruise or from temporary sample plots. When a prism tally is used only the number of trees included in the sweep need be recorded but a cruise utilizing temporary sample plots would necessitate the tally of all trees by diameter classes. If weight of some ground surface fuel components is to be estimated from weight per acre-inch values in Table 8, fuel depth or height in inches and percentage surface coverage need be known.

Results of field tests conducted in lodgepole pine stands growing on sites and under growing conditions similar to those in this study suggest that the prediction equations in Figures 8 and 10 give reliable estimates of fuel weight-and-size distribution. Basal area per acre values from three of fifteen randomly located one-tenth acre plots were entered in the equations in Figures 8 and 10 and the predicted fuel weights in Table 9 were obtained. The measured and predicted weight values compare favourably for most fuel components. It should be noted that the three plots represent a basal area range from 134.4 square feet per acre to 147.5 square feet per acre; hence additional sampling is required to test the usefulness of the prediction equations beyond this range of basal area values.

Weight of several ground surface fuel components can be estimated from per acre-inch values in Table 8. For example, the average depth and surface coverage of moss in a 70-year old lodgepole pine

TABLE 9

COMPARISON OF MEASURED AND PREDICTED FUEL WEIGHTS PER ACRE

Fuel	Basal Area in Square Feet per Acre					
	134.4		137.9		147.5	
	Measured	Predicted	Measured	Predicted	Measured	Predicted
	Tons per Acre					
Slash						
less than ½"	7.4	7.9	7.9	8.0	7.6	8.3
½ to 2"	3.2	2.9	2.7	2.9	2.8	3.0
2 to 4"	3.4	6.9	8.0	7.2	7.8	7.9
Total Slash	14.0	17.8	18.6	18.2	18.2	19.2
Standing Tree Crop	50.0	50.3	48.6	51.4	52.1	54.4
Minor Vegetation	1.1	0.7	0.5	0.6	0.6	0.5
Forest Floor Litter, incl. Moss	5.9	4.2	6.8	4.4	8.5	4.7
All Ground Surface Fuels	25.1	26.2	25.8	26.2	29.7	26.3
Entire Fuel Complex	75.1	76.7	74.4	77.8	81.8	81.1

stand of fire origin was 2.7 inches and 80 percent, respectively. From Table 8, an acre-inch of moss in a dense stand weighs 1.90 tons. The estimated weight of moss is 1.90 x 2.7 x 0.80 = 4.1 tons per acre. This figure compares favourably with the measured value of 3.9 tons per acre, using the sampling technique established in this study. The values in Table 8 are presented for interim use until additional field testing to determine the effects of different sites and stand densities on fuel weight is completed.

The relationship between crown closure and basal area appears useful for fuel weight prediction in conjunction with aerial photographs (Figure 9). Field data is not available to test the precision of the prediction equation, but it is possible that the relationship may break down beyond the range of stand densities sampled. Crown closure should therefore not be used as a predictor of basal area per acre for stands outside the study area.

Reliable estimates of fuel weight-and-size distribution are important in a number of applications. For example, the methods used in this study may be used to develop a preliminary fuel classification for similar lodgepole pine stands in terms of weight-and-size distribution. It could be based on available heat energy for different combinations of fuel and weather conditions. Byram (1957) has listed the four basic fuel factors related to energy as (1) combustion period, (2) critical burn out time, (3) available fuel energy, and (4) total fuel energy. If the combustion period of a fuel is less than the critical burn out time the fuels will have an available fuel energy equal to their total fuel energy. While considerable work will be needed to determine the relationship between these factors and fire behaviour, the principle appears feasible and warrants further study.

The development of an objective fuel classification would clear the way for a new approach to forest fire danger rating. To make the system workable it would be necessary to establish the available fuel energy levels for each major fuel complex over a range of weather conditions and to convert these values into a meaningful fire danger rating scale. The system would be based on fuel energy and the same fire danger index in two widely separated areas, but with the same available fuel, would represent a similar burning potential.

A knowledge of the amount of slash expected following logging is valuable to the forest manager interested in the application of fire for hazard reduction and seedbed preparation. In Alberta, the slash left from pulpwood operations is usually comprised of branchwood and the unmerchantable portion of the stem less than four inches in diameter. Branchwood weight was found to increase slightly with increasing stand density (Table 2), whereas the weight of the unmerchantable portion of the stem increased nearly five-fold over the same density range; hence, the increase in slash weight with increasing stand density is primarily a function of the number of stems per unit area. As expected, the slash weight-standing tree crop weight ratio decreases with increasing stand density (Figure 7). A breakdown of slash into size-classes shows that the weight of fine and heavy fuels increases with stand density whereas medium fuels do not vary importantly in the same density range (Figure 8).

In a wider sense, fuel weight-and-size distribution data would also be useful in determining productivity levels of forest stands. With the advent of full tree utilization it would appear that weight, rather than volume, has a wider application for measuring yield. Designers of pulpwood processing and handling equipment utilize factual information on weights of trees and their components (Keen, 1963).

DISCUSSION

The results of the study demonstrated that weight-and-size distribution of the fuel complex in lodgepole pine stands varies with stand density but the relative magnitude of that effect is not the same for individual fuel components. The preliminary stratification of stands was made on the basis of number of stems per acre but differences are also described in terms of basal area, cubic foot volume, and Reinike's stand density index.

To fulfill the assumptions underlying the analysis of variance, namely that (1) treatment and environmental effects are additive, and (2) experimental errors are random, independently and normally distributed about zero mean and with a common variance, all plots and subplots were assigned to stand densities at random. The need for randomization is summarized by Cochran and Cox (1957) in the following statement:

> Randomization is somewhat analegous to insurance, in that it is a precaution against disturbances that may or may not occur and that may or may not be serious if they do occur. It is generally advisable to take the trouble to randomize even when it is not

expected that there will be any serious bias from failure to randomize. The experimenter is thus protected against unusual events that upset his expectations.

Experience suggests that if the above procedure is adhered to, the failures in the assumptions are not sufficiently great to invalidate the technique. At the same time it should be pointed out that significance levels must be considered approximate rather than exact. One of the most serious effects on the validity of significance levels arises when the error variance is not common over all observations. The probability of Type I error was assessed by Bartlett's test of homogeneity of variances and the error variances were shown to be constant at the 5% level. Type II error could not be determined but decreases with an increase in sample size.

Scatter diagrams of fuel weight expressions against stand density indicators led to the assumption of linear regression. Even when the relationship exhibited a curvilinear tendency within the range of stand density indicators involved, the straightline was chosen as an approximation because of computational ease. No transformation of data was carried out because the variances had already been shown to be homogeneous. Further study is needed to demonstrate the true relationship over a wider range of stand densities and to make the testing of hypotheses more exact.

Another source of error may have been introduced by using fuel weight tables, rather than actual weight measurements, to determine weight of aerial fuel components (Kiil, 1967). The tables are based on actual fuel weights taken within a 20-mile radius of the study area, but represent a range of site and stand density conditions. An indication of the accuracy of these tables is provided by results of two field tests. The first test was conducted on a one-tenth acre plot supporting a 90-year old lodgepole pine stand growing on a dry site. Basal area was 145 square feet per acre and height of dominants was 55 feet. All 75 trees on the plot were felled and weighed and actual oven-dry weight of slash and the entire standing crop was 18.7 and 57.7 tons per acre, respectively. These figures compare favourably with predicted values of 17.1 and 53.8 tons per acre for the same fuel components and support the comparisons in Table 9. The results of the second test are based on actual slash weight from the thirteen largest trees on Plot 5. The actual oven-dry weight was 2678 pounds whereas application of the fuel weight tables gave 2552 pounds. These findings support the theory that weight of slash fuel components of individual trees of a given diameter and crown width class is independent of stand density. Baskerville (1965) noted that five-inch dominants in a 5,000-stem per acre stand appear to be identical to five-inch intermediate or suppressed trees in a 700-stem per acre stand and suggested that this is logical since the present size of a tree represents the integrated effects of all competition to this point in its life.

Basal area is strongly correlated with age and physiographic site quality (Smithers, 1956), but there is no correlation between number of trees per acre and basal area in fully stocked stands (Duffy, 1964). According to Vezina (1964), basal area is a more useful expression of stand density than the single variable of number of trees for crown closure and growth prediction. In understocked stands, basal area appears to be a useful expression of density. The inference drawn from the relationship between basal area and fuel weight is that basal area may be used in a range of site and stand age conditions, particularly if the number of trees constituting full stocking is known. While it is expected that basal area-fuel weight ratios will not vary significantly between sites, further work will be required to establish the actual relationships.

The finding that the weight of the standing tree crop increases with increasing stand density (Figure 8) is in agreement with Baskerville's (1965) findings from a study of dry matter production in balsam fir stands over a range of 700 to 5,000 stems per acre. He suggested that the relationship of production to stand density might be explained by (1) a variation in site and production merely indicating site differences, (2) the stand not yet fully occupying the site in which case production is greatest in the stands which come closest to full occupancy, and (3) the stands have in fact reached full occupancy and there are physiological phenomena which operate to increase efficiency even while the stands get tighter. With reference to the present study, the latter two explanations appear useful in assessing the relationship between fuel weight and stand density. The considerations are relevant to the present study because a better understanding of the relationship between production and stand density would undoubtedly facilitate assessment of the fuel complex in terms of weight-and-size distribution and spatial arrangement of fuel components.

The number of standing snags was found to increase with increasing stand density (Table 1) and this tendency appears to reflect the level of occupancy of the site. They are an important source of cured fuel, particularly in terms of spotting and crowning. For example, residence time of prescribed burns in slash may be related to the number or quantity of felled snags in the fuelbed. Or a combination of number of snags and a decrease in the distance between ground surface fuels and the lowest dead branchwood may be directly related to crowning potential in forest stands.

The evidence from this study suggests that weight of some ground surface fuels can be estimated from basal area per acre (Figure 10) or from measurements of fuel depth or height and percentage surface coverage (Table 8). It is logical to conclude that the accumulation of dead ground surface fuels, including litter and humus, is a function of stand production and rate of decay to this point in its life. However, the amount of minor vegetation and to some extent, moss, probably reflects the current occupancy of the site rather than the cumulated effects of competition over the full life-span of the stand. The problem of numbers of organisms utilizing space and the relationship between species which utilize the same food and space is discussed by Zimmerman (1960) for aquatic beetles but the principle may be applicable in studies of minor vegetation under forest canopies.

SUMMARY AND CONCLUSIONS

A field study was carried out in west-central Alberta to investigate the fuel complex in 70-year old, even-aged lodgepole pine stands of fire origin on one site, slope, and exposure. The stands on the study area were stratified on the basis of 300, 600, and 900 stems per acre and referred to as sparse, medium, and dense stands. A completely randomized hierarchial sampling design was used in each stand density class and consisted of five one-tenth acre plots for aerial fuels and three 2 x 3-foot subplots in each plot for ground surface fuels.

The purpose of the sampling was to determine which stand factors were related to differences in weight-and-size distribution and density of fuel components. Stand and fuel data were collected for each plot and subplot and summarized for stand description and fuel weight-and-size prediction purposes. Analysis of variance was used to determine whether stand density affected the fuel complex in terms of weight-and-size distribution. Scatter diagrams were used to assess the relationship between stand factors and expressions of fuel weight-and-size distribution. The relationships exhibiting straightline tendencies were subjected to regression analysis. Some applications of study results are discussed.

The main findings of this study are:

1. Weight of most aerial fuel components increases with increasing stand density (Tables 3 and 4, Figure 8) for lodgepole pine stands sampled in this study.

2. No correlation between stand density and weight of all ground surface fuels was found, but the weight of individual ground surface fuel

components increases or decreases with stand density (Tables 6 and 7, Figure 10).

3. Weight-and-size distribution of many aerial and ground surface fuel components may be conveniently predicted from basal area per acre (Figures 8 and 10). The linear regression equations are based on a small number of samples in a relatively small range of stand densities (300 to 900 stems per acre) but the results of a limited number of field tests suggest that the predicted values are fairly indicative of actual fuel conditions (Table 9).

4. Basal area per acre can be predicted from crown closure. This relationship, substantiated by additional sampling, could be used in conjunction with aerial photographs to estimate weight of fuel components.

5. Weight of some ground surface fuel components may be conveniently determined using weight per acre-inch values in Table 8. Fuel depth or height and percentage surface coverage need to be measured or estimated in the field but this can be done in conjunction with basal area determination. The weight per acre-inch values in Table 8 should prove of value in assessing the relative compactness of ground fuel components.

6. The relationship between diameter at breast height and crown width does not vary importantly between stand densities in the range of 300 to 900 stems per acre (Figure 6).

7. No correlation between basal area and humus weight was found in this study probably because the rate of accumulation of dead ground surface fuels is similar in all three stands. It is suggested that although needle fall increases with increasing stand density, production of litter

from minor vegetation decreases with increasing stand density. Furthermore, it is speculated that more humus was left on the ground by the fire in the sparse than in the denser stands.

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APPENDIX I

Soil Profile Description for all Three Stands.

Moisture Regime 1, dry.

Horizon	Item	Stand Density		
		Sparse	Medium	Dense
Organic material	L Depth	½"	¾"	1"
	Humus Depth (F & H layers)	3"	3½"	4"
Ae horizon	Depth	2"	3"	3"
	Texture	sandy loam	sandy loam	sandy loam
	Colour	dark grey to reddish brown	dark grey to reddish brown	dark grey to reddish brown
Weathered fill to bedrock	Depth	35"	46"	42"
	Texture	sandy loam, pebbles	sandy loam, pebbles	sandy loam, pebbles
	Colour	Yellow brown	yellow brown	yellow brown

APPENDIX II A

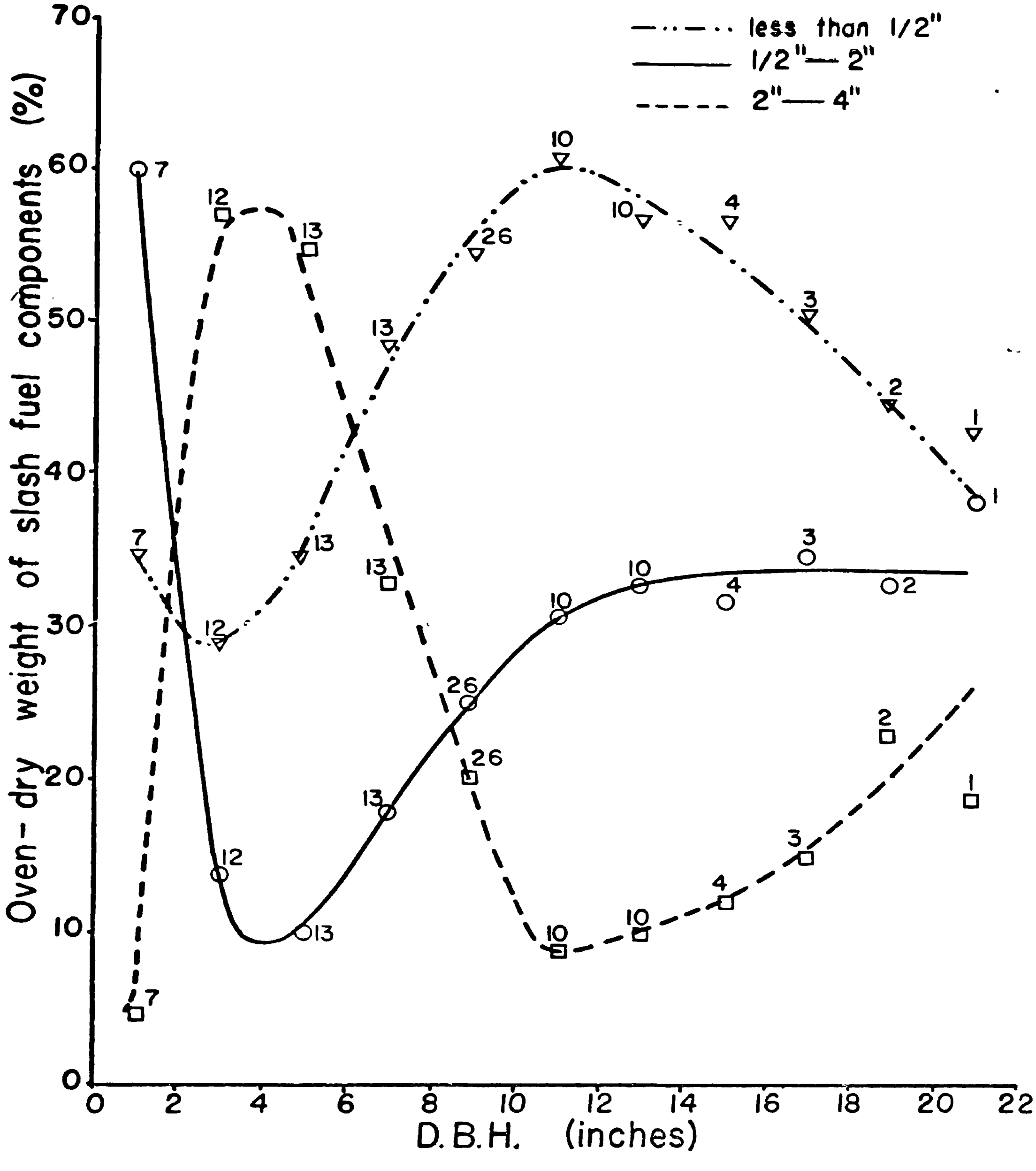

Figure 11. Size distribution of slash fuel components by diameter breast height for lodgepole pine.

APPENDIX II B

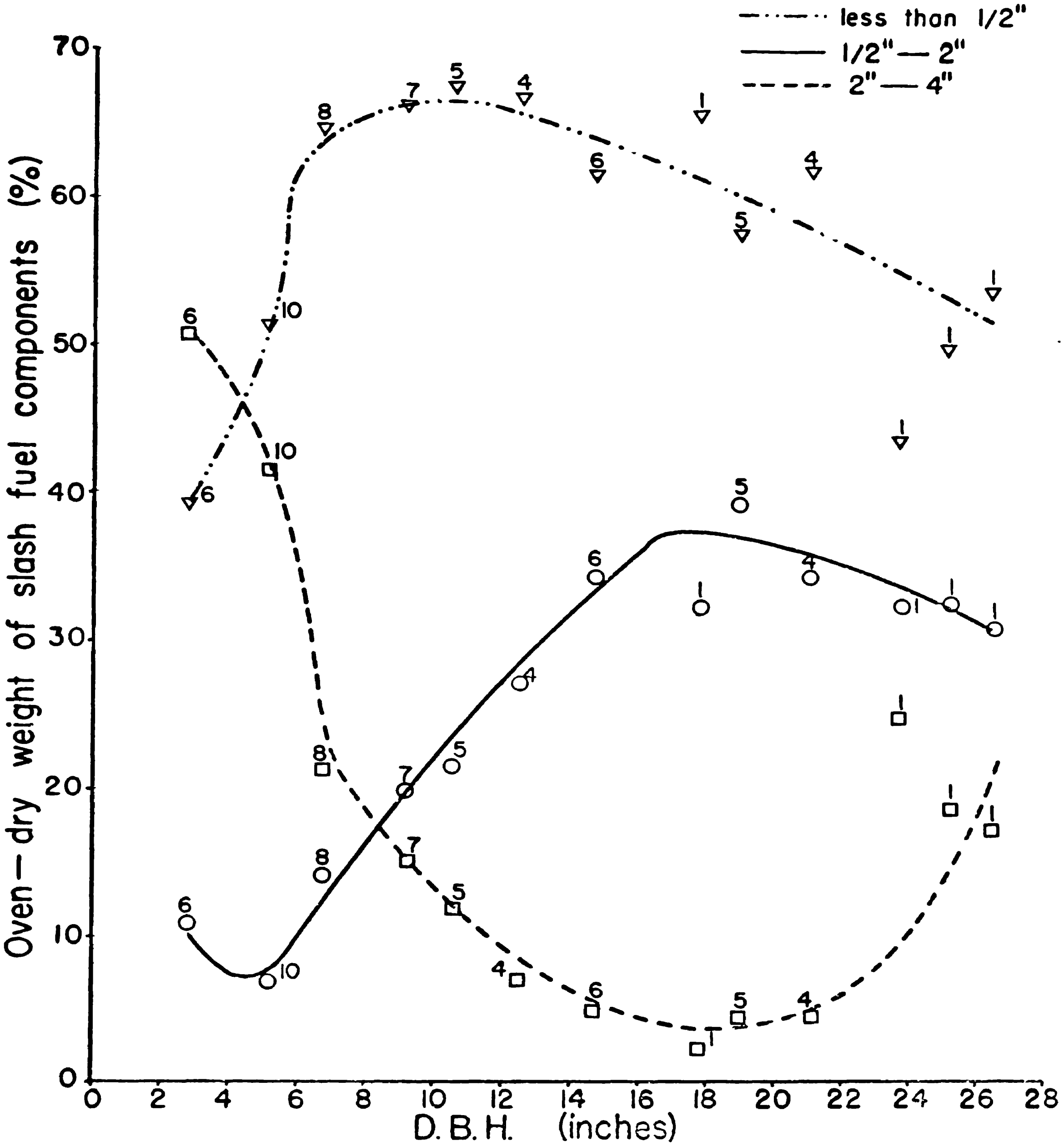

Figure 12. Size distribution of slash fuel components by diameter breast height for white spruce.

APPENDIX III A

Fuel Weight Data

Sparse Density (300 trees per acre)

Fuel	Plot No.				
	1	2	3	4	5
	Tons per Acre				
Aerial					
Branchwood	9,50	7.85	8.33	9.65	13.95
Unmerch. stem less than 4"	1.30	1.50	1.32	2.20	1.90
Slash (all material less than 4")	10.80	9.37	9.65	11.85	15.80
Live stemwood	22.00	18.65	13.70	22.37	24.42
Standing snags	1.14	0	2.71	5.34	0
Ground Surface					
Shrubs	0.04	0.70	4.10	1.35	1.63
Herbs	0.98	0.55	0.34	0.81	0.48
Dead branchwood less than ½"	0	0.10	0.17	0.10	0.09
over ½"	0	0	0	0	0.41
Needle litter	0.90	1.66	1.50	0.43	1.30
Moss	1.46	2.60	0.92	2.10	3.46
Humus	27.03	12.62	18.84	25.48	25.99

APPENDIX III B

Fuel Weight Data

Medium Density (600 stems per acre)

Fuel	Plot No.				
	11	12	13	14	15
	Tons per Acre				
Aerial					
Branchwood	8.93	11.98	8.91	9.34	11.74
Unmerch. stem less than 4"	3.92	7.01	3.63	3.85	5.49
Slash (all material less than 4")	12.85	18.99	12.54	13.21	17.23
Live stemwood	26.11	43.35	25.05	31.75	40.68
Standing snags	1.43	2.31	1.95	2.76	0.92
Ground Surface					
Shrubs	0.31	0	0	0	0.01
Herbs	0.77	0.87	0.88	0.55	0.96
Dead branchwood less than ½"	0	0.32	0.17	0.27	0.20
over ½"	2.55	0	0	0.02	0
Needle litter	1.35	0.69	2.79	1.65	0.69
Moss	0	1.67	0	0	0
Humus	27.24	24.28	19.06	14.85	14.98

APPENDIX III C

Fuel Weight Data

Dense Stand (900 stems per acre)

Fuel	Plot No.				
	6	7	8	9	10
	Tons per Acre				
Aerial					
Branchwood	10.11	12.34	9.67	13.56	10.41
Unmerch. stem less than 4"	6.25	10.28	7.58	6.81	7.76
Slash (all material less than 4")	16.36	22.62	17.25	20.37	18.17
Live stemwood	39.03	43.79	39.46	43.69	41.95
Standing snags	4.07	3.76	7.00	3.92	5.23
Ground Surface					
Shrubs	0.10	0.01	0.10	0.03	0.23
Herbs	0.69	0.37	0.38	0.49	0.33
Dead branchwood less than ½"	0.03	0.52	0.55	0.45	0.78
over ½"	0	0	6.12	0	0.66
Needle litter	0.14	1.00	0.69	1.62	1.38
Moss	1.88	1.50	2.37	3.55	1.46
Humus	30.42	18.99	24.88	14.50	12.40

APPENDIX IV A

Fuel Depth and Height Data

(averages of 3 sub-plots per plot)

Plot No.	Herbs	Shrubs	Needle Litter	Other Forest Floor Litter less than ½"	Moss
			Inches		
1	7.0	22.7	1.0	-	-
2	4.8	32.0	1.0	-	2.0
3	4.7	68.0	1.3	-	-
4	3.7	29.0	0.8	-	-
5	4.3	30.0	0.7	-	-
6	7.7	6.3	0.3	-	-
7	4.3	1.7	0.5	-	2.0
8	4.0	8.3	2.3	1.0	2.3
9	2.7	4.0	0.7	0.5	2.4
10	2.5	21.2	1.2	1.8	1.5
11	7.0	8.0	0.8	-	2.3
12	5.0	-	1.0	0.3	2.3
13	5.3	-	1.3	0.2	1.3
14	3.5	1.3	0.8	0.2	2.5
15	5.7	2.0	0.5	0.7	3.2

APPENDIX IV B

Surface Coverage Data

(averages of 3 sub-plots per plot)

Plot No.	Herbs	Shrubs	Needle Litter	Other Forest Floor Fuels less than ½"	Moss
			per cent		
1	80	14	58	-	-
2	65	35	62	-	-
3	53	87	77	-	-
4	66	39	33	-	-
5	63	39	57	-	-
6	78	9	23	-	83
7	72	1	47	-	63
8	62	6	30	8	75
9	58	6	40	10	65
10	61	23	62	17	35
11	58	12	52	-	43
12	73	-	35	7	67
13	67	-	60	8	43
14	62	-	35	10	65
15	82	2	27	10	77