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

by
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ABSTRACT

A study was made of the fuel complex in 70-year-old lodgepole pine stands in west-central Alberta to facilitate measurement and prediction of weight-and-size distribution of fuel components. Results showed that the weight of the entire fuel complex increased with increasing stand density in the range of 300 to 900 stems per acre (741 to 2,224 stems per hectare) but that the weight of some fuel components decreased in the same stand-density range. Correlations between basal area and expressions of fuel weight were used to construct prediction equations for minor vegetation, forest-floor litter (except humus), slash, the standing tree crop, and the entire fuel complex. The weight of aerial-fuel·components can be estimated with greater precision than the weight of ground-fuel components. The weight of ground-fuel components may also be estimated from weight per acre-inch.

EXTRAIT

Inventaire et étude des matières combustibles que
contiennent 3 peuplements de Pin de Murray (*Pinus contorta*)
dans le centre-ouest de l'Alberta, en vue de mesurer plus
facilement à l'avenir, et même d'évaluer, le rapport poids-
dimensions des différentes sortes de combustibles. Voici
quelques résultats: bien que la matière combustible globale
augmente à mesure que la densité du peuplement fait de
même, — lorsque celle-ci se tient entre 300 à 900 tiges
à l'acre (741 à 2,224 tiges à l'hectare) — le contraire
arrive à certaines catégories telles que les arbustes,
la litière des aiguilles, etc. L'auteur établit une
corrélation entre la surface terrière et le poids prévi-
sible de la végétation basse, de la litière (excepté
l'humus), des déchets d'abattage, des arbres debout et
vivants, et de l'ensemble des combustibles. Le poids
des arbres ou de leurs parties (mortes ou vivantes)
se mesurait plus précisément que les autres combusti-
bles. Ces derniers peuvent être évalués en tonnes par
acre-pouce (épaisseur ou hauteur d'un pouce dans un
acre de terrain).

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INTRODUCTION

Forest fires burn in trees, shrubs, herbs, litter, and moss, and occasionally consume part of the underlying humus. Thus, any increase in our knowledge of the behaviour of wild fires and prescribed burns is necessarily dependent on quantitative and qualitative descriptions of the fuel complex. Fuel weight, size, compactness, and moisture content are perhaps the most important factors in terms of available fuel for burning, and the first two, in particular, are of wider interest to students of forest productivity and utilization.

Fuel classification in North America has been based during the past 40 years 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 was provided by Kittredge (1944), who estimated foliage weight from tree diameter at breast height. More recently, LaMois (1958), Fahnestock (1960), Muraro (1966) and Kiil (1967) in North America and Hatch (1955) and McArthur (1962) in Australia have produced useful information on various forest fuels, but no single study has adequately described the entire fuel complex.

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The purpose of this study, therefore, was to identify and measure individual fuel components in forest stands. Lodgepole pine stands of fire origin and different densities were selected because they are typically even-aged and are of commercial importance in Alberta. The primary objective of this study was to determine the effect of stand density on weight-and-size distribution of various fuel components and to develop a simple method for predicting these values from one or more measures of stand density. All material was classified into aerial and ground fuels and sub-classified into individual fuel components. Aerial fuels make up the entire standing tree crop, while ground fuels include all other fuels within 6 feet (1.83 m.) of the forest floor. The latter group includes shrubs, herbs, conifer regeneration less than 1 inch (2.54 cm.) in diameter at breast height, forest-floor litter, moss, and humus (F and H layers combined). Slash includes all branchwood and stemwood material less than 4 inches (10.2 cm.) in diameter. Branchwood includes both live and dead material. Snags are standing dead trees.

METHODS

The study area is in the Upper Foothills Section (B.19c) of the Boreal Forest Region (Rowe, 1959). White spruce (*Picea glauca* (Moench) Voss) and lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) are the two important commercial species. The topography is typified by high rounded hills reaching 6,000 feet (1,829 m.) in elevation and deep valleys at 3,500 feet (1,067 m.). The summers are moderately warm and the winters cold, with mean July temperatures about 60°F (15.5°C) and mean January temperatures about 10°F (-12.2°C). Annual precipitation is about 20 inches (50.8 cm.), of which 60 per cent falls during the 150 days with mean daily temperatures in excess of 42°F (5.6°C).

The data for this study were collected in 1965 on the pulpwood lease limits of North Western Pulp and Power Limited, near Hinton (53°24' north latitude, 117°37' west longitude), Alberta. The choice of the sampling area was made on the basis of fire history, forest cover, site type and surficial-deposit maps and was limited to landforms with similar sites and growing conditions. Three 70-year-old lodgepole pine stands of fire origin, supporting an average of 300, 600, and 900 live stems per acre (741, 1,483, 2,224 stems per hectare) were chosen and are henceforth referred to as sparse, medium, and dense. The soils in the study area were classified as podzolized Grey Wooded soils on 4 to 6 feet (1.2 to 1.8 m.) of glacial till.

A completely randomized hierarchial sampling design was used. It consisted, in each stand density, of five 1/10-acre (0.04-hectare) plots for aerial fuels and fifteen 2 x 3 foot (0.56 sq. m.) subplots for ground fuels. Mensurational data recorded for each plot included diameter at breast height of all trees and snags when it was over 1 inch, crown width, height of three dominants, average height from ground to the lowest dead branches, and a tally of slope and aspect. Height or depth, and percent surface coverage of shrubs, herbs, forest-floor litter, moss, and humus,

were measured on each subplot. Each ground-fuel component was removed from place, weighed, and sampled for moisture-content determination.

Branchwood and slash weights were determined from fuel-weight tables (Kiil, 1967). Stemwood weight was estimated in conjunction with volume tables and specific gravity values for each species. Green and oven-dry weights were calculated for all ground-fuel components, but all weights given in this paper are on an oven-dry basis. Analyses of variance were applied to test for significant differences in weights of fuel components between stand densities. Prediction equations were prepared for those combinations of independent and dependent variables exhibiting a close straight-line relationship.

RESULTS AND DISCUSSION

The distribution of number of stems, basal area, and total volume showed increased proportions in the smaller-diameter classes with increasing stand density (Figure 1). The ratio of pine to spruce increased from 2 to 1 in the sparse stand to nearly 5 to 1 in the dense stand. Pine, however, constitutes more than 90 per cent of total volume in all three stands. In addition to the live trees, an average of 18, 90, and 348 standing snags per acre (44, 222, and 860 per hectare) were found in each of the sparse, medium, and dense stands. Crown closure and dominant height in these stands averaged 41, 49, and 56 per cent and 59 (18 m.), 55 (16.8 m.) and 56 (17.1 m.) feet, respectively. Only the dense stand had the outward appearance of being well stocked.

The initial stocking in these stands is pine, but a spruce under-story gradually modifies the species distribution and becomes dominant at about 120 years. The pine is gradually reduced by mortality from stagnation. The relationship between the level of stocking and the number of standing snags is attributed to stand age, the level of occupancy of the site, and physiological phenomena that regulate growth. The understory vegetation is relatively scarce and gives the stands a park-like appearance.

The weight of the standing tree crop increased with increasing stand density, but the rate of increase of individual aerial-fuel components varied (Table 1). Analyses of variance indicated that the mean weights of these fuel components, except those of branchwood, differed significantly between stand densities for pine and for the entire stand. A study of dry-matter production in balsam fir stands in New Brunswick (Baskerville, 1965) showed similar trends for stand densities ranging from 700 to 5,000 stems per acre.

Lodgepole pine accounts for about nine tenths of the weight of the various fuel components in all stands. Slash weight (the sum of branch-wood and the unmerchantable part of the stem) increased from 11.5 tons per acre in the sparse stand to 18.9 tons per acre in the dense stand, most of the increase being accounted for by the greater number of live stems. The ratio of slash weight to the weight of the standing tree crop decreased with increasing tree diameter.
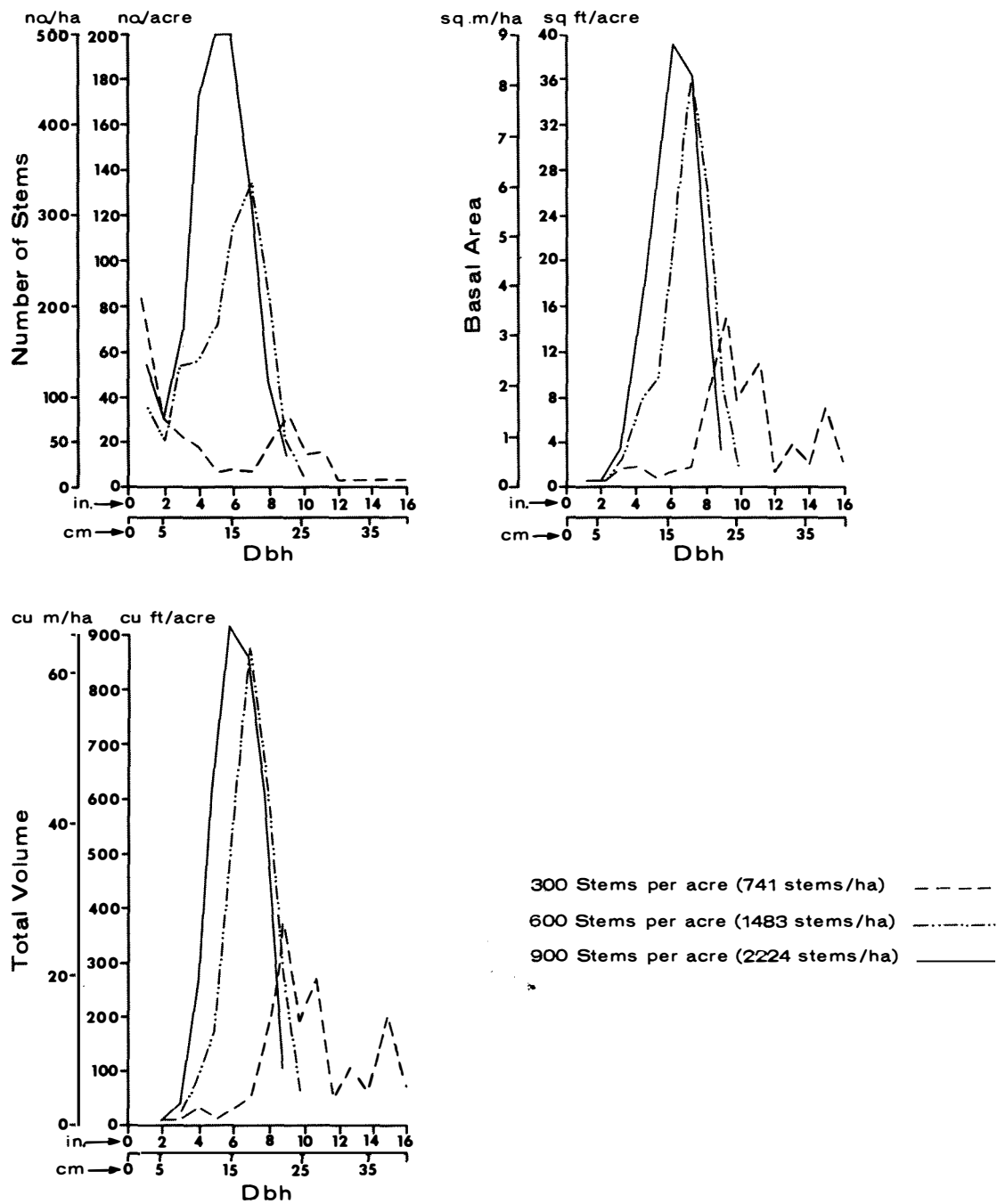
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Figure 1. The distribution of number, basal area, and volume by diameter for the three stands.

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TABLE 1. MEAN WEIGHTS FOR AERIAL-FUEL COMPONENTS IN ALL THREE STANDS.

tons per acre

Stand Density	Branchwood	Unmerchantable stem	Merchantable stem	Standing tree crop	Snags
Lodgepole pine					
Sparse	8.1	1.0	17.2	26.3	0.6
Medium	9.0	4.1	28.6	41.7	1.9
Dense	9.2	6.7	33.3	49.2	4.9
Entire stand					
Sparse	9.9	1.6	18.2	29.7	0.6
Medium	10.2	4.8	28.7	43.7	1.9
Dense	11.2	7.7	33.9	52.8	4.9

Graphical and regression analyses indicated that weights of aerial-fuel components were more closely correlated with basal area than with any other single expression of stand density. Regression equations, coefficients of correlation (r), and standard errors of estimate (SEe) were determined where correlations were judged to be potentially useful for fuel weight prediction. An unknown amount of error exists in all equations for predicting weights of aerial-fuel components because weights were calculated from fuel weight and volume tables instead of being representative of actual weights.

The weights of several aerial-fuel components related to basal area as follows:

Slash: $W = 4.02 + 0.103$ B.A.

$r = 0.94$ SEe = 1.43 tons

Standing tree crop: $W = 7.93 + 0.315$ B.A.

$r = 0.98$ SEe = 2.60 tons

Entire fuel complex: $W = 31.82 + 0.334$ B.A.

$r = 0.87$ SEe = 7.14 tons

where W is the weight in tons per acre and B.A. is basal area in square feet per acre. The prediction equation for the entire fuel complex includes ground fuels.

The weights of selected slash-fuel components on each plot were calculated from unpublished data and related to basal area per acre (Figure 2). The weight of fuels in the less-than-½-inch (less-than-12.7-mm.) and 2- to 4-inch (50.8- to 101.6-mm.) size classes increased with increasing basal area,
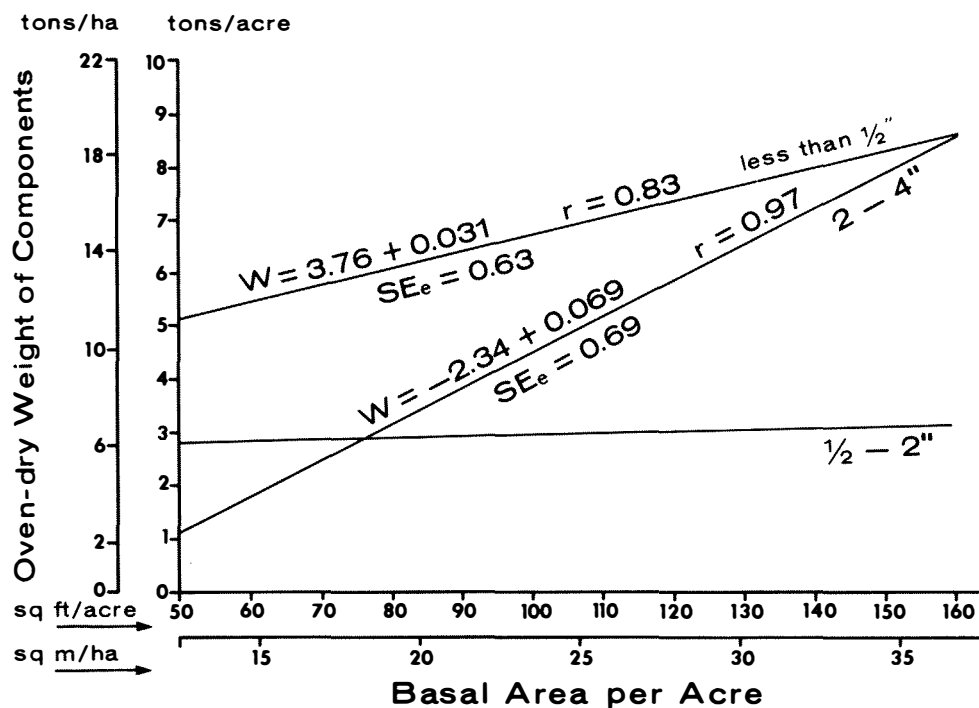
Figure 2. Size distribution of slash-fuel components by basal area.

but the weight of material in the ½- to 2-inch (12.7- to 50.8-mm.) size class was not affected by basal area. About 60 per cent of the material less than ½ inch (12.7 mm.) consisted of foliage.

The mean weights of individual ground-fuel components also varied with stand density, but the total weight of these, less that of humus, averaged only 16, 20 and 26 per cent of total ground-fuel weight in the sparse, medium and dense stands (Table 2). The weight of minor vegetation decreased with increasing stand density, whereas the total weight of all other forest-floor litter components, less humus, increased with increasing stand density. The differences are significant at the 1 per cent level.

In general, correlations between ground fuels and stand factors were too weak for prediction purposes, with two exceptions. Weight of minor vegetation and weight of forest-floor litter, less humus, were significantly correlated with basal area as follows:

Green vegetation: W = 3.38 - 0.020 B.A.

r = -0.70   SEe = 0.77 tons

Forest-floor litter: W = -0.054 + 0.032 B.A.

r = 0.67   SEe = 1.37 tons

Basal area per acre, a stand factor, was sufficiently well correlated with moss weight per acre (r = 0.53) and weight of all ground fuels, less humus (r = 0.35), to be potentially useful in fuel-weight prediction. The high

TABLE 2. MEAN WEIGHTS OF GROUND-FUEL COMPONENTS IN ALL THREE STANDS

tons per acre

Stand density	Shrubs	Herbs	Needle litter	Other litter		Moss	Humus	Total
				Twigs <½"	Twigs ½"+			
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

variation in the weights of ground-fuel components is attributed to the inherent variability in these fuels and to the subsamples not being sufficiently large to indicate a true relationship within stand densities.

The density of ground fuels was computed from the volume and weight of each fuel component and expressed in terms of weight per acre-inch (Table 3). As expected, shrubs and herbs are least compacted and are followed by moss and needle litter in order of increasing compactness. The humus layer is more than twice as dense as any other ground-fuel component, but it is of little importance in terms of fire spread. Weight per acre-inch values for other ground fuels, such as dead logs, were not computed because no known method was available whereby their volume could be conveniently estimated.

TABLE 3. MEAN WEIGHTS PER ACRE-INCH OF SELECTED GROUND-FUEL COMPONENTS

tons per acre-inch

Stand density	Shrubs	Herbs	Needle litter	Moss
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. Where estimates of fuel weight are required, it is only necessary to determine the basal area of the stand. If a plotless cruise with an angle prism or a relascope is used, only the number of stems included in the tally is needed to give basal area per acre. An alternate method for estimating the weight of some ground-fuel components consists in determining their depth or height and percent surface coverage. The product of depth or height and percent surface coverage is multiplied by the appropriate value in Table 3 to give weight in tons per acre. For example, the average depth of moss in a lodgepole pine stand with 900 stems per acre is 2 inches (5.08 cm.) and covers 75 percent of the ground surface. According to Table 3, moss weighs 1.9 tons per acre-inch; hence the estimated weight of moss in the stand is $2 \times \frac{75}{100} \times 1.9 = 2.85$ tons per acre (6.39 metric tons per hectare). The fuel-prediction equations and weight per acre-inch values in this paper are presented for interim use until additional field testing to determine the effects of different sites and stand densities on fuel weight and compactness is completed.

The limitations of predicting the weight of any fuel component from basal area alone are recognized. An indication of the accuracy of the method is provided by results of a field test on a single 1/10th-acre plot supporting a 90-year-old lodgepole stand of fire origin. The basal area was 145 square feet per acre (33.3 sq. m. per hectare) and the height of dominants was 55 feet (16.8 m.). All 75 trees on the plot were measured, felled, weighed, and sampled for moisture-content determination. The actual weight of the slash and the entire standing crop was 18.7 and 57.7 tons per acre (41.9 and 129.3 metric tons per hectare), respectively. These figures compare favourably with the predicted values of 17.1 and 53.8 tons per acre (38.3 and 120.6 metric tons per hectare) for the same fuel components. While it is expected that basal area-fuel weight ratios will not vary importantly between sites, further work will be required to establish the actual relationships.

Reliable estimates of fuel weight are important in a number of applications. For example, fire spread in slash is related to fuel weight (Fahnestock, 1960). Calculation of fire intensity requires that available fuel weight be known (Davis *et al.*, 1959). A fuel-classification system based on potential heat energy for different combinations of fuel and weather conditions appears feasible. While the determination of available fuel energy for each major fuel type in the range of weather conditions is difficult and time-consuming, the heat-energy concept would provide a basis for an objective fuel-classification system and warrants further study.

In a wider sense, fuel-weight data would also be useful in assessing 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). A knowledge of ground and aerial fuels available for prescribed burning may be useful in assessing nutrient release in a range of burning conditions.

REFERENCES

Baskerville, G.L. 1965. Dry matter production in immature balsam fir stands. Amer. Soc. Foresters, For. Sci. Monograph No. 9.

Davis, K.P., *et al*. 1959. Forest fire: control and use. McGraw-Hill Book Company, Inc., New York, Toronto, London.

Fahnestock, G.R. 1960. Logging slash flammability. U.S.D.A. Intermountain For. and Range Expt. Sta., Res. Paper No. 58.

Hatch, A.B. 1955. The influence of plant litter on the Jarah Forest soils of the Dwelling-cup Region - Western Australia. Commonwealth of Australia, Forestry and Timber Bureau Leaflet No. 70.

Hornby, L.G. 1935. Fuel type mapping in Region One. J. For. 33:67-72.

Keen, R.E. 1963. Weights and centres of gravity involved in handling pulpwood trees. Pulp and Paper Research Inst. of Canada, Tech. Rept. No. 340.

Kiil, A.D. 1967. Fuel weight tables for white spruce and lodgepole pine crowns in Alberta. Canada Dept. Forestry and Rural Development, For. Br., Departmental Publ. 1196.

Kittredge, J. 1944. Estimation of the amount of foliage of trees and stands. J. For. 43:905-912.

LaMois, L. 1958. Fire fuels in red pine plantations. U.S.D.A., Lake States For. Expt. Sta. Paper No. 68.

McArthur, A.G. 1962. Control burning in eucalypt forests. Commonwealth of Australia, Forestry and Timber Bureau Leaflet No. 80.

Muraro, S.J. 1966. Lodgepole pine logging slash. Canada Dept. Forestry Publ. 1153.

Rowe, J.S. 1959. Forest Regions of Canada. Canada Dept. Northern Affairs and National Resources, For. Br. Bull. 123.