SOME VARIATIONS IN SPECIFIC GRAVITY AND MOISTURE CONTENT OF 100-YEAR-OLD LODGEPOLE PINE TREES

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FOREST RESEARCH LABORATORY
CALGARY, ALBERTA
INFORMATION REPORT A-X-29

CANADIAN FORESTRY SERVICE
DEPARTMENT OF FISHERIES AND FORESTRY
FEBRUARY, 1970

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INTRODUCTION

During biomass studies of lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.), considerable data were accumulated on specific gravity and moisture content, two properties of immediate significance to utilization and weight scaling. The objective of this report is to determine the amount and nature of the variation in specific gravity and moisture content, longitudinally within trees and among trees, and to examine the possibility of predicting these characteristics.

As pointed out by Greenidge (14), and Kramer and Kozlowski (20) moisture content is dependent on a large number of internal and external factors. One of the main sources of longitudinal variations within the tree results because the moisture content in a tree increases with increasing height within the tree (9, 10, 12, 20, 24, 25). Coutts (9) found dominant Monterey pine (Pinus radiata D. Don) trees contained more moisture per unit volume than suppressed trees. This finding supported Etheridge's (10) work which found moisture content increased with increasing tree vigor in subalpine spruce (Picea glauca (Moench) Voss).

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Specific gravity is affected by a large number of internal and external characteristics, and is highly variable both within and among trees. Generally, there is an inverse relationship between specific gravity and growth rate. Keith (15) stated that, in tests on white spruce (Picea glauca (Moench) Voss), 30 to 40 per cent of the variation in specific gravity was explained by growth rate. Strong correlations between rate of growth and specific gravity have also been found by Alexander (1), Wakefield (32), Larson (21), McKimmy (22), Fielding and Brown (11), and Wellwood and Smith (33).

Because specific gravity is positively correlated with the number of rings per inch, it would seem logical that, in even-aged stands, trees having the smallest diameters would have the highest specific gravities. Stage (28), Christopher and Wahlgren (7), and Baskerville (4) found significant correlations between tree diameter and specific gravity. Some investigators (13, 26, 34) found no significant correlation between these variables. The conflicting results reported in past research may be because of this interaction of stand age and tree diameter.

Height greatly influences variations in specific gravity within a tree. Generally, specific gravity has been found to decrease from the base to the tip of the tree (5, 19, 21, 26, 30, 31, 33). Other investigators (8, 23, 29) have reported slight increases in specific gravity for a short distance up the stem from the base and then a decline in specific gravity thereafter to the tip of the tree.

The influence of the crown on specific gravity is not clear. Results reported by Spurr and Hsuing (27), and Larson (21) found no correlation between specific gravity and crown size, which conflict with more recent results reported by Knigge (19) and Stage (28).

METHODS AND MATERIALS

The data were gathered from 85 even-aged (100-year-old) lodgepole pine trees growing in two square, tenth-acre plots on the Kananaskis Forest Research Station. One of the plots was established in an undisturbed stand and the other was established in a stand that had been thinned in 1938. Because the thinning had no apparent effect on either moisture content or specific gravity, the data from the two plots were pooled. The average height of the trees was 60.4 feet and the average diameter at breast height was 7.1 inches.

Discs, about one inch thick, were sawn from the stem at 1.0 foot above the ground (stump height), at 4.5 feet, at 9.0 feet, and at 8.0-foot intervals to the top of the tree. A total of 713 discs were obtained. After measurement of diameter outside bark, the discs were sealed in polyethylene bags to minimize moisture loss during transport to the laboratory.

In the laboratory, the bark was separated from each disc and the diameter inside bark of each disc was measured. The moisture content of each disc was determined according to ASTM Standard D2016-65 Method A (2).

Specific gravity was measured from sectors, containing a line of mean radius, which were cut from each disc. Each sector was redried for 24 hours at 105°C, weighed to the nearest one-hundredth gram, and covered with a very thin coating of paraffin. The specific gravity of each sector was determined by Method B-II of the ASTM Designation D2395-65 T (3) procedure. The only deviations from the ASTM procedure were as follows:

1. Some of the sectors were not free from knots and other defects, and
2. No attempt was made to extract the pitch from the sectors.

The analysis was divided into two distinct parts; examination of the within- and among-tree variations in specific gravity and moisture content. A regression elimination procedure described by Kozak and Smith (18) was used for the analysis.

The within-tree variations (specific gravity and moisture content determined at various heights in the tree from the discs) were examined as functions of: height above ground, height above ground as a percentage of total tree height, diameter outside bark, diameter inside bark, age (number of rings from pith), and mean radial-growth rate at the point in the tree where the dependent variables were measured.

Average tree values of moisture content and specific gravity were used as the dependent variables in the analysis of variations among the trees. Because moisture content and specific gravity are known to change with height within a tree, an arithmetic average was not deemed representative of the whole tree. Therefore, the average value of these variables for the entire tree was determined by weighting the average moisture content or specific gravity of two consecutive discs by the volume (calculated by Smalian's formula (6)) of the section between the two discs. The sums of these weighted values for each tree were divided by the total tree volume, resulting in an average moisture content or specific gravity weighted by volume. These dependent variables were used in a multiple regression analysis on the independent variables: diameter at breast height, height, crown width, crown length, tree age, total-tree weight, total-stem weight, merchantable-stem weight, dry-needle weight, volume outside and inside bark (determined from Reineke charts (6)), height to live crown, tree basal area, mean radial growth rate at breast height, bark per cent, and the transformed variable of diameter at breast height squared times tree height.

Duncan's multiple range tests were used to determine if there were significant differences between moisture content and specific gravity measurements taken within the crown (the section measurement nearest the top of the tree), at breast height, and the average of all of the measurements within the tree.

RESULTS

Longitudinal Variations in Specific Gravity and Moisture Content Within the Tree

Table 1 presents the means, standard deviations, and maximum and minimum values obtained for the sections taken at various height-intervals in the tree.

Table 1. Statistical characteristics of specific gravity and moisture content for 713 discs of lodgepole pine.

Variable	Mean	Standard deviation	Maximum value	Minimum value
Specific Gravity	0.476	0.042	0.637	0.345
Moisture Content (%)	84.91	24.00	169.71	32.37

The range and standard deviation indicates that the variation in specific gravity is small relative to those observed for moisture content.

The correlation of specific gravity and moisture content with several variables of sections within the tree is presented in Table 2.

Table 2. The correlation of moisture content and specific gravity to several variables measured on 713 discs of lodgepole pine.

Section measurement		Simple correlation coefficients (r)	
		Moisture content	Specific gravity
Height above ground - H	(ft.)	0.676**	-0.370**
Diameter outside bark	(in.)	-0.374**	0.075*
Diameter inside bark	(in.)	-0.386**	0.084*
Section age	(yr.)	-0.663**	0.348**
Specific gravity		-0.375**	1.000**
Mean radial growth rate (mean ring width)	(in.)	0.427**	-0.358**
Height above ground as a proportion of total tree height	(%)	0.659**	-0.344**
$Height^2 - H^2$		0.699**	-0.347**
$Height^3$		0.672**	-0.323**
$Height^4$		0.630**	-0.299**
$Height^5$		0.584**	-0.276**
1/Height		-0.289**	0.327**
1/Age		0.542**	-0.200**
1/Mean radial growth		-0.415**	0.362**

** significant at the 0.01 probability level
* significant at the 0.05 probability level

As shown in Table 2, height above ground, or transformations thereof, was most closely correlated with specific gravity and moisture content. Specific gravity decreased and moisture content increased with increasing height in the tree. Moisture content decreased and specific gravity increased with increasing section age. The effect of section age is undoubtedly related to the fact that section age decreased as sampling height increased.

Mean radial-growth rate was positively correlated with moisture content, and negatively correlated with specific gravity, which suggests that fast-growing trees generally have lower specific gravities and higher moisture contents than slow-growing trees. As expected, moisture content and specific gravity were negatively correlated, which indicates that as the wood content per unit volume increases, the moisture content decreases.

A multiple regression equation of specific gravity on a combination of all of the section variables presented in Table 2 accounted for 23.7 per cent of the variation with a standard error of estimate (SE_E) of 0.037 (7.9%)[2]. Section height, the best independent variable, accounted for 13.7 of the variation with a standard error of estimate of 0.039 (8.2%) in the relationship:

$$\text{Sp Gr} = 0.497 - 0.000854\ H \quad (\text{ft})$$

$$SE_E = 0.039\ (8.2\%) \qquad r^2 = 0.137^{**}$$

This relationship is shown in Figure 1.

A multiple regression analysis of moisture content on a combination of all of the section variables listed in Table 2 accounted for 54.8 per cent of the total variation in moisture content. The standard error of estimate of this multiple regression relationship was 16.3 per cent (19.2%). Section height squared (H^2) was the best independent variable with a coefficient of determination of 0.488 and a standard error of estimate of 17.2 per cent (20.3%). The simple curvilinear relationship between section height squared and moisture content was:

$$\text{MC}\ (\%) = 0.697 + 0.000159\ H^2 \ (\text{ft})$$

$$SE_E = 17.2\%\ (20.3\%) \qquad r^2 = 0.488^{**}$$

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2 The standard error of estimate is expressed both in absolute units and as a percentage of the mean, the latter being in parentheses.

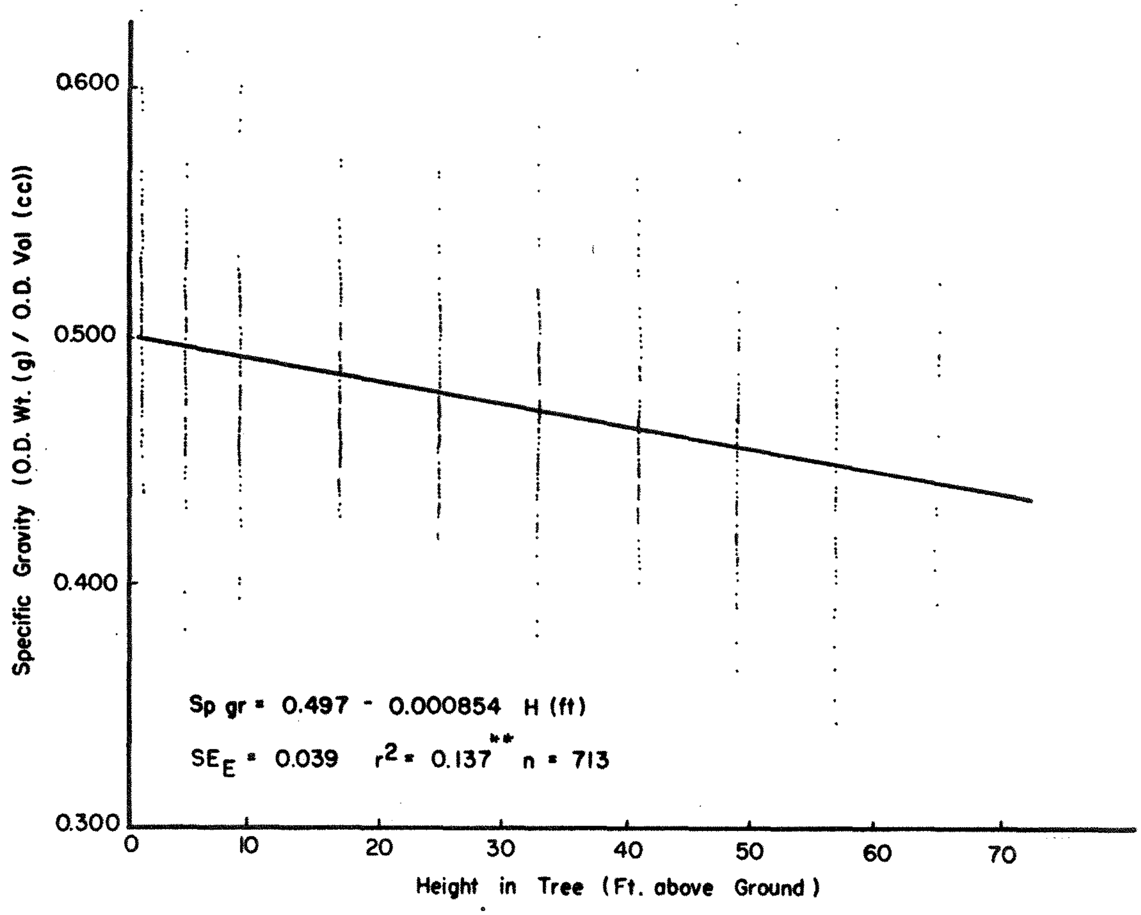

Figure I. The Relationship Between Specific Gravity and Height in the Tree.

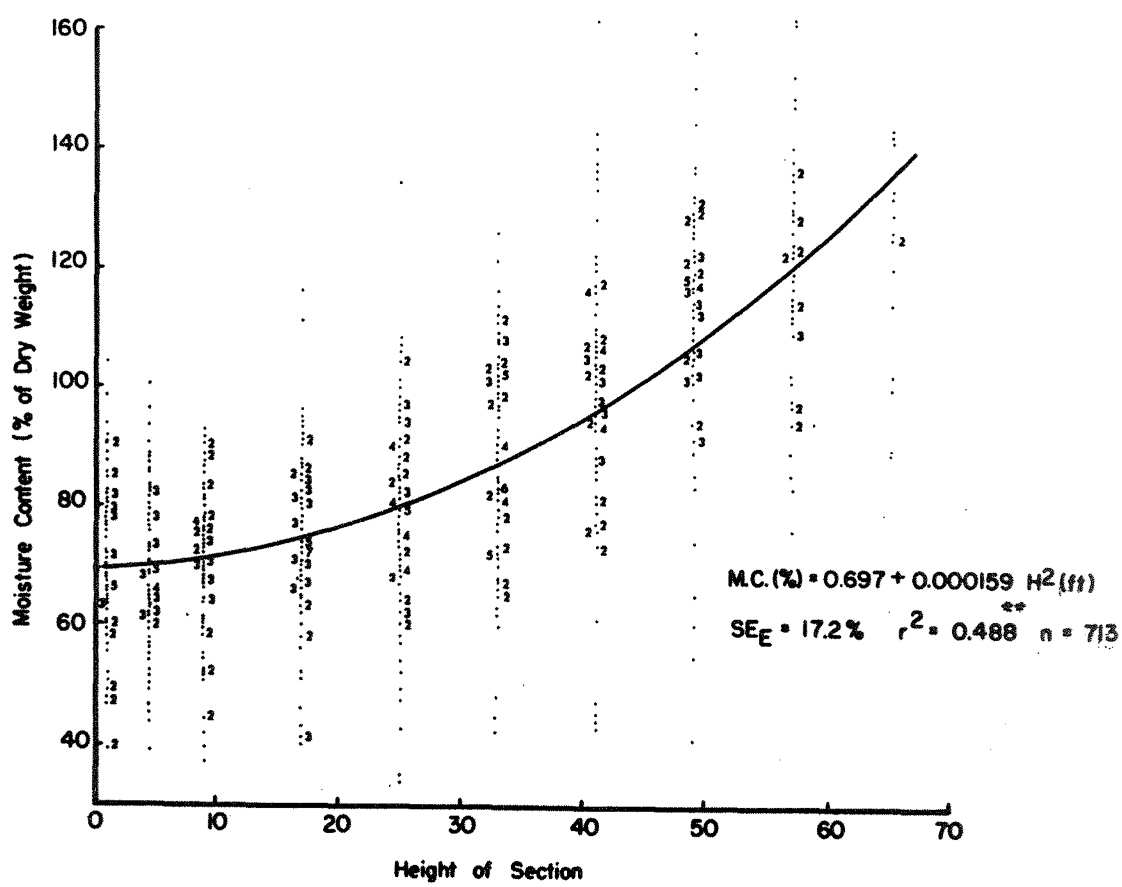

Figure 2. The Relationship Between Moisture Content and Height in the Tree.

This relationship is presented in Figure 2.

The means, standard deviations, and maximum and minimum values of specific gravity and moisture content measurements from within the crown, at breast height, and a weighted average of each tree are presented in Table 3.

Table 3. Statistical characteristics of specific gravity and moisture content at three different positions in 85 lodgepole pine trees.

Variable	Position	Mean	Standard deviation	Maximum	Minimum
Specific gravity	Crown	0.468	0.047	0.636	0.385
	Breast height	0.488	0.391	0.617	0.382
	Ave. tree	0.479	0.033	0.635	0.416
Moisture content (%)	Crown	99.24	22.65	169.70	42.50
	Breast height	69.82	12.38	100.30	39.40
	Ave. tree	79.07	13.55	108.50	44.60

Average tree specific gravity was significantly higher than that in the crown, and significantly lower than at breast height. Average tree moisture content was significantly higher than that at breast height, and significantly lower than that at the crown.

Variations in Specific Gravity and Moisture Content Among Trees

Weighted-average tree values for specific gravity and moisture content were used to analyse variations in specific gravity and moisture content among trees. The weighted-average tree-specific-gravity had a mean of 0.479, and the mean for the weighted-average tree-moisture-content was 79.07 per cent. Table 4 presents the simple correlations between weighted average specific gravity and moisture content, and several tree variables.

Table 4. Correlation coefficients between specific gravity and moisture content and several tree characteristics for 85 lodgepole pine trees.

Tree characteristics	Correlation coefficients (r)	
	Moisture content	Specific gravity
Diameter at breast - dbh (in.)	0.302**	-0.370**
Height - H (ft)	0.315**	-0.295**
Crown length (ft.)	0.258*	-0.323**
Crown width (ft)	0.269*	-0.308**
Total stem weight (lb)	0.323**	-0.343**
Dry needle weight (lb)	0.373**	-0.298**
Tree volume (cu ft)	0.263*	-0.346**
Ave. Specific gravity	-0.155 ns	-
Height to live crown (ft)	-0.043 ns	0.167 ns
Tree basal area (sq ft)	0.267*	-0.354**
Diameter squared ($in.^2$)	0.267*	-0.354**
Mean radial growth (in.)	0.256*	-0.363**
Bark per cent (%)	0.063 ns	-0.147 ns
Diameter squared times height($in.^2 \cdot ft$)	0.251*	-0.334**

** significant at the 0.01 probability level
* significant at the 0.05 probability level
ns not significant at the 0.05 probability level

Differences in moisture content among trees are most closely related to dry-needle weight, and this in turn is probably due to the influence of the crown characteristics on evapo-transpiration and photosynthesis. Dry-needle weight, stem weight, and tree height were the three variables most closely associated with differences in moisture content.

Measures of tree size were found to be most closely associated with weighted average tree specific gravity. The negative correlation coefficients suggest that as tree size increased, specific gravity decreased. The results suggested, as did the analysis of variations within the tree, that specific gravity and moisture content are inversely related and that tree vigor has a marked influence on these properties.

A multiple regression analysis of tree specific gravity on a combination of all of the characteristics listed in Table 4 accounted for only 34.4 per cent of the variation in specific gravity with a standard error of estimate of 0.030 (6.3%). The best simple linear regression was:

$$\text{Tree Sp Gr} = 0.522 - 0.00594 \text{ dbh}$$

$$SE_E = 0.031\ (6.3\%) \quad r^2 = 0.137^{**}$$

This relationship accounted for 13.7 per cent of the variation and had a standard error of estimate of 0.031 (6.3%).

A multiple regression of weighted-average tree-moisture-content on a combination of all of the variables listed in Table 4 accounted for 42.7 per cent of the total variation in moisture content. The regression of weighted-average tree-moisture-content on tree height removed 9.9 per cent of the variation and had a standard error of estimate of 12.9 per cent (16.3%).

$$\text{Tree MC } (\%) = 0.449 + 0.0057 \text{ H (ft)}$$

$$SE_E = 12.9\%\ (16.3\%) \quad r^2 = 0.099^{**}$$

The equation of the simple linear regression of weighted-average tree-specific-gravity on breast height specific gravity was:

$$\text{Sp Gr (ave. tree)} = 0.1660 + 0.642 \text{ Sp Gr (bh)}$$

$$SE_E = 0.022\ (4.6\%) \quad r^2 = 0.576^{**}$$

This relationship, which is presented in Figure 3, accounted for 57.6 per cent of the total variation with a standard error of estimate of 0.022 (4.6%).

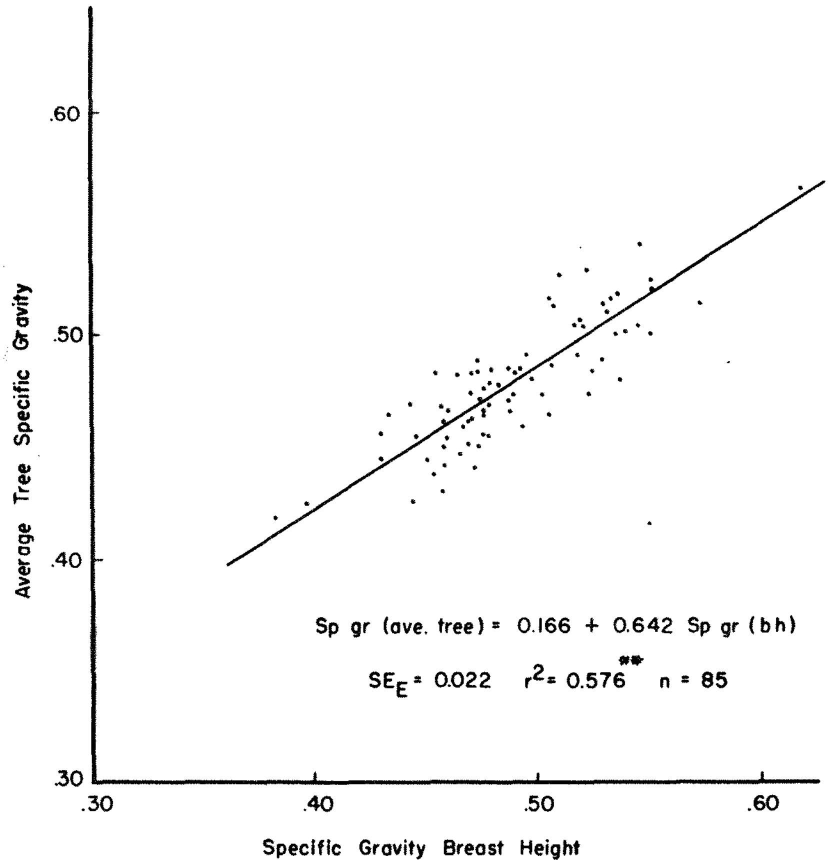

Figure 3. The Relationship Between Average Tree Specific Gravity and Specific Gravity at Breast Height.

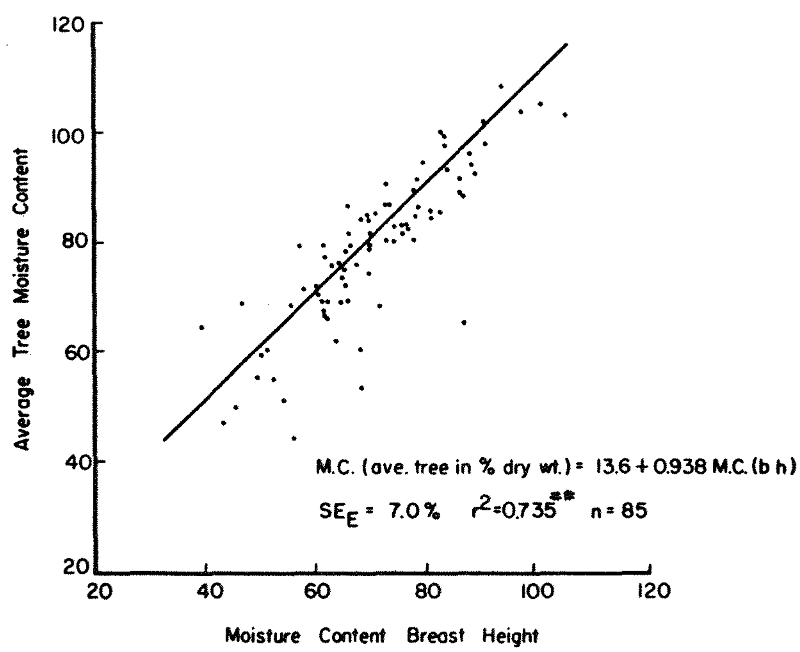

Figure 4. The Relationship Between Average Tree Moisture Content (%) and Moisture Content (%) at Breast Height.

The relationship between weighted-average tree-moisture-content and moisture content at breast height was:

$$MC\ (\text{ave. tree}) = 13.6 + 0.938\ MC\ (\text{bh})$$

$$SE_E = 7.0\%\ (8.8\%) \quad r^2 = 0.735^{**}$$

This relationship, which accounted for 73.5 per cent of the variation with a standard error of estimate of 7.0 per cent (8.8%), is shown in Figure 4.

SUMMARY

Variations in moisture content and specific gravity (longitudinally within, and among trees), were examined for 85 100-year-old, forest-grown lodgepole pine trees in southwestern Alberta. Longitudinal variations in specific gravity and moisture content within the tree were found to be most closely related to height within the tree (Table 2). Specific gravity decreased linearly from the base to the top of the tree (Figure 1) and moisture content increased curvilinearly with increasing height in the tree (Figure 2). Specific gravity and moisture content cannot be predicted with a high degree of certainty within the tree.

Much variation in moisture content and specific gravity exists among trees. The dry weight of needles was most closely associated with weighted-average tree-moisture-content. Weighted-average tree-specific-gravity was mostly correlated with tree size (Table 4). The results indicate that low specific gravity and high moisture content are characteristic of fast-growing trees.

By regression analysis, average tree specific gravity and moisture content can be predicted fairly accurately from moisture content and specific gravity measurements taken at breast height (Figures 3 and 4). This suggests that possibly a single sample (such as an increment core) taken at breast height may be sufficient to estimate average tree values for specific gravity and moisture content.

The average tree specific gravity of the 85 trees analysed in this study had a mean of 0.479, which is higher than the national average of 0.460 reported by Kennedy (17). This higher value is attributable to two reasons. First, some of the samples contained excess oil and pitch,

which, as Keith (16) has demonstrated, results in an overestimation of specific gravity. Second, the weighting process, by which the averages were determined, weights those samples from the base of the tree (which have a higher density) more than those samples from the top of the tree.

Although these data and results are not suited for direct application to weight scaling they do show the degree of variability in two of the most important factors affecting the weight of trees and logs. It is advisable, therefore, that careful study be given to how log moisture content, thus log weight, changes as a result of changes in season, weather, location, species, and time after harvesting.

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