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BARK-TISSUE THICKNESS OF COASTAL WESTERN HEMLOCK IN BRITISH COLUMBIA[1]

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ABSTRACT

Bark-tissue thicknesses of coastal western hemlock are reported. Variation in these characteristics is considered between sites, trees, and height positions. Total bark thickness did not vary significantly with site, averaging 7.4 mm, 12.2 mm, and 12.6 mm for the top, middle, and butt height positions, respectively. However, the relative contribution of the individual tissues to the total thickness did vary with site. The thickness of all bark characteristics varied with height, being least at the top position, but differing very little between middle and butt positions.

Keywords: *Tsuga heterophylla*, bark, mensuration.

INTRODUCTION

Current economic demands and raw material requirements in British Columbia seem to dictate that the greatest potential use for bark is as hog fuel, either for direct combustion or for generation of producer gas. Even now many thousands of units of bark residues are surplus to the economy and are being incinerated or disposed of in land-fill projects. In the future, with inevitably increasing raw material demands, the need to utilize bark residues for higher value products may well arise. The development of these products and uses for bark will be far easier if a detailed knowledge of the raw material is available.

The physical properties of the different bark tissues vary. If separation of bark tissue types prior to utilization is necessary, it will be important to know the quantity of each available. If separation is not necessary, it could be important to recognize the variation in raw material properties with varying tissue proportions.

Considerable information has been accumulated on bark thickness and tissue content of many commercially important tree species. However, with the exception of the work by Smith and Kozak (1971) and Chang (1954), western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] bark has received little attention.

Applying the bark volume factors of Smith and Kozak (1967) to the latest information on volume production by species available from the B.C. Forest Service (1976) indicates that the volume of available western hemlock bark is second only to Douglas-fir bark in British Columbia.

Microscopically, mature bark can be separated into three distinct types of tissue —inner bark, periderm, and outer bark (Fig. 1). Terminology used with reference to tree bark is at times confusing when discussing botanical literature in a utilization context. The principal tissues in trees are grouped together as xylem and phloem, where "phloem" refers to those tissues on the outer side of the cambium that function in food conduction and "xylem" refers to those tissues located on the inner side of the cambium that function in water conduction

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and provide the mechanical strength to support the rest of the tree. "Wood" is the nontechnical term for xylem and "bark" is the term for all tissues outside the cambium, which includes living, or inner bark, and dead, or gross outer bark. Dead bark is formed when layers of periderm are laid down within the living inner bark. Periderm is composed partially of impermeable cork cells that retard moisture loss from the inner bark, resulting in death of the outermost layers of living bark. These layers have long ceased to function in food conduction so that their loss is not detrimental to a tree. Bark terminology is well summarized by Esau (1960) and by den Outer (1967).

The objective of this paper is to report on western hemlock bark tissue thicknesses at several height positions on trees from three coastal sites in British Columbia.

MATERIALS AND METHODS

Western hemlock occurs throughout the coastal and interior wet belt of British Columbia. For this study, trees typical of those currently being logged were selected from three coastal sites. These sites were near Port Renfrew on southern Vancouver Island, Maple Ridge, 40 miles to the east of Vancouver (hereafter referred to as the Lower Mainland site), and near Kitimat, representative of the North Coastal region.

Ten trees were sampled from each site. Six-inch discs were taken at three height positions: stump height, the top of the first 24-foot log, and the merchantable top of the stem (6 inch DOB). These height positions are referred to hereafter as butt, middle, and top. Three circumferential positions in each disc were to be sampled. For ease in handling, the lower two discs were broken down with an axe to yield three segments roughly 6 inches wide. These segments, plus the whole disc at merchantable top of the stem, were sealed in plastic bags to prevent drying and delivered to the laboratory and placed in freezer storage as rapidly as possible. Test samples were cut from these larger samples with a tangential length of at least 3 cm and a radial dimension sufficient to include several wood growth rings. The cross-sectional surfaces of these blocks were sanded in the green condition to obtain a smooth surface, finishing with 320A durite paper. These surfaces were photographed and prints were made at approximately 10 times magnification.

Measurements of tissue thickness were made on these photographs along lines perpendicular to the cambium at 30-mm intervals. Location of the measuring lines was facilitated with a transparent overlay. Radial thickness of inner bark and gross outer bark (including the periderm) was measured to the nearest 1.0 mm, while the individual periderm layers were measured to the nearest 0.1 mm with the aid of a measuring magnifier. Outer bark thickness was calculated by subtracting the sum of the thickness of the periderm layers from the gross outer bark measurements.

RESULTS

Primary bark thickness characteristics

The six primary characteristics in this study are inner bark thickness, outer bark thickness, periderm thickness, gross outer bark thickness (outer bark plus periderm thickness), total bark thickness, and the number of periderm layers. Obviously, not all of these are independent, since some are derived from others and are not measured directly. It was anticipated, *a priori*, that these primary bark characteristics would vary from tree to tree and with height position within a tree. It was of interest to determine if some greater constancy in bark characteristics might be found in the relative proportions of the different tissue types. For this reason, six more variables were derived, these being ratios of the primary variables; namely, inner bark thickness to outer bark plus periderm thickness, inner bark thickness to total bark thickness, outer bark thickness to total bark thickness, thickness of outer bark plus periderm to total bark thickness, periderm thickness to total thickness, and periderm thickness to outer bark plus periderm thickness.

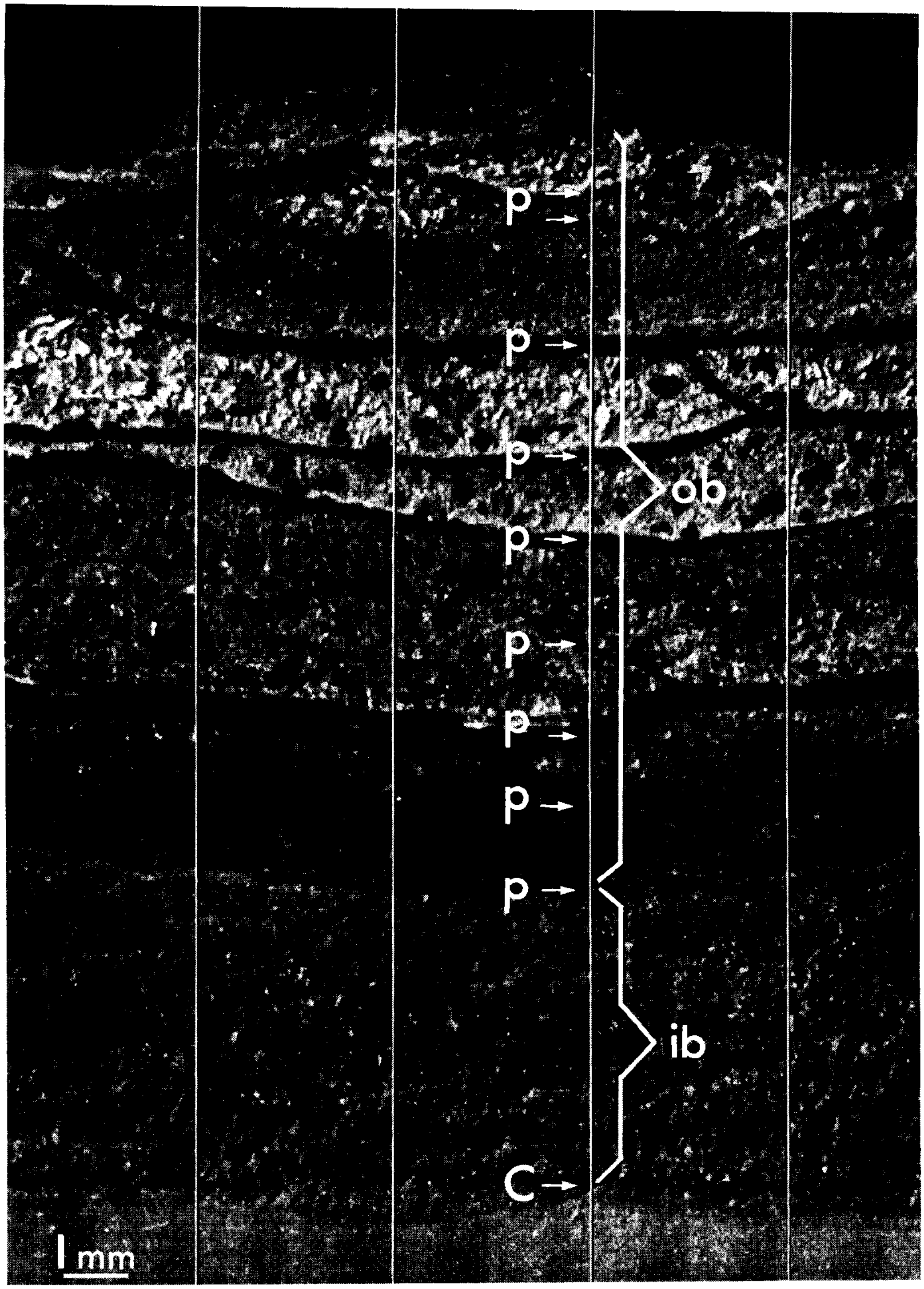

FIG. 1. Cross section of western hemlock bark showing typical measuring lines and tissue types; ob = gross outer bark, ib = inner bark, p = periderm, c = cambium.

TABLE 1. *Western hemlock bark-tissue characteristics*

	British Columbia Site								
	Vancouver Island			Lower Mainland			North Coast		
	Top[a] (mm)	Middle (mm)	Butt (mm)	Top (mm)	Middle (mm)	Butt (mm)	Top (mm)	Middle (mm)	Butt (mm)
i. Inner bark thickness	4.70	5.29	5.31	4.51	5.09	5.11	3.65	4.23	4.25
ii. Outer bark thickness	2.28	6.07	6.34	2.34	6.13	6.41	3.78	7.57	7.85
iii. Periderm thickness	0.32	0.69	0.80	0.31	0.68	0.79	0.42	0.79	0.90
iv. Outer bark and periderm	2.60	6.76	7.14	2.65	6.81	7.20	4.20	8.36	8.75
v. Total bark thickness	7.30	12.05	12.45	7.16	11.90	12.31	7.84	12.59	13.00
vi. Number of periderm	1.4	2.9	3.0	1.9	3.4	3.5	3.0	4.5	4.6
vii. Inner bark/outer and periderm	2.59	1.22	1.16	2.00	0.63	0.58	1.88	0.51	0.46
viii. Inner bark/total bark	0.64	0.46	0.44	0.61	0.42	0.41	0.54	0.36	0.34
ix. Outer bark/total bark	0.31	0.49	0.49	0.34	0.52	0.52	0.41	0.58	0.59
x. Periderm/total bark	0.04	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.07
xi. Outer and periderm/total bark	0.36	0.54	0.56	0.39	0.58	0.59	0.46	0.64	0.66
xii. Periderm/outer and periderm	0.15	0.11	0.12	0.13	0.10	0.11	0.13	0.09	0.10

[a] Top (at 6 inches DOB), middle (top of first 24-foot log), butt (at stump height).

The average values for each of these twelve variables for each of the three sites and three height positions are shown in Table 1. The averages were obtained from measurements made along each of several measuring lines on photographs from each of three segments from each of ten trees. The number of measuring lines along which satisfactory measurements could be made was variable, commonly of the order of twelve or thirteen, and at least eleven overall. Occasionally, a segment sample is missing and, in some cases, all observations from one elevation of a single tree were missing. The data set is thus unbalanced with unequal numbers in each cell.

The analysis of variance model is as follows:

$$Y_{ijkl} = g + t_i + h_j + d_{ij} + s_{k(ij)} + e_{l(k(ij))}$$

where Y_{ijkl} represents the l^{th} observation on the k^{th} segment at the j^{th} height position on the i^{th} tree. [$k = 1, \ldots 3$ for all ij, $j = 1, \ldots 3$, $i = 1, \ldots 30$, $l = 1 \ldots$ variable]. The parameters t_i, h_j, etc. measure the difference from the general mean g.

This gives rise to an ANOVA table of the form shown in Table 2. The sum of squares for observations [SS(O)] can be obtained by subtraction or by direct calculation as a check. Note that, because of the unbalanced structure, although strictly speaking the sum of squares for sites (adjusted for height) plus the sum of squares for trees within sites (adjusted for height) is not equal to the sum of squares for trees (adjusted for height), we have obtained the sum of squares for trees within sites (adjusted for height) by subtraction. The error, in so doing, should be inconsequential with the present structure.

Accordingly, the mean square for site should be judged against the mean square for trees within sites. The mean square for height position (adjusted for trees) should be judged against the interaction mean square which, in turn, should be judged against the mean square for segments within discs.

The analysis of variance tables for all twelve variables will not be presented, but an example for inner bark thickness is shown in Table 2. An appreciation of the variance in the observations can be obtained from Table 3, which presents estimates of the several variance components for each property. For example, the variance of an inner bark thickness measured as the average of twelve observations on three segments at each of two height positions for a single tree would be estimated as:

$$\frac{0.80}{12} + \frac{0.55}{3} + \frac{0.26}{2} + 0.48 = 0.86 .$$

TABLE 2. *Analysis of variance. General form and specific values for thickness of inner bark*

Source	Degrees of freedom	Sum of squares		Mean square
Trees (adjusted for height)	29	SS(TH)	2,290.80	
Sites	2		565.97	282.98
Trees within sites	27		1,724.83	63.88
Height position (unadjusted)	2	SS(H)	116.50	
	31	SS(TH) + SS(H)	2,457.30	
Trees (unadjusted)	29	SS(T)	2,232.57	
Height position (adjusted for trees)	2	SS(HT)	224.75	112.38
	31	SS(T) + SS(HT)	2,457.32	
Interaction	52	by subtraction	864.21	16.62
Discs	83	SS(D)	3,321.52	
Segments within discs	165	SS(S)	1,219.28	7.39
Observations within segments	2,723	SS(O)	2,167.97	0.80
Total	2,971	SS(G)	6,708.77	

Consideration will now be given to the results of the analysis of variance for each of the bark variables. For inner bark thickness, the variable used for illustration in Table 2, the interaction term is formally significant, but it is clear that its magnitude is of little consequence in relation to the main effect. There are significant differences between height positions. This effect is a result of the lower value of the inner bark at the top position as there are clearly no differences between the butt and middle positions. This same pattern of change with height position has been reported by Smith and Kozak (1971). However, the comparable average value determined from their data for inner bark thickness of thirteen western hemlock trees is approximately 2.9 mm, considerably less than values reported here. The significant

TABLE 3. *Estimates of variance components for random effect*

Variables	σ_e^2	σ_s^2	σ_d^2	σ_t^2
i. Inner bark thickness	0.80	0.55	0.26	0.48
ii. Outer bark thickness	5.50	1.45	1.84	1.13
iii. Periderm thickness	0.099	0.039	0.028	0.008
iv. Outer bark and periderm	6.35	1.77	2.29	1.27
v. Total bark thickness	4.98	1.78	2.60	2.50
vi. Number of periderm	1.90	0.49	0.69	0.09
vii. Inner bark/outer and periderm	n.a.	1.52	0.98	0.10
viii. Inner bark/total bark	n.a.	0.00736	0.00347	0.00222
ix. Outer bark/total bark	n.a.	0.00660	0.00267	0.00248
x. Periderm/total bark	n.a.	0.000228	0.000078	0.000013
xi. Outer and periderm/total bark	n.a.	0.00736	0.00347	0.00222
xii. Periderm/outer and periderm	n.a.	0.00222	0.00012	0.00050

σ_e^2 = variance of observations within segments.
σ_s^2 = variance of segments within discs.
σ_d^2 = variance of height position by tree interaction.
σ_t^2 = variance of trees within sites.

effect of site reported here must result from the consistently lower values at all height positions for the North Coast site.

The analyses of variance for outer bark thickness and gross outer bark thickness (outer bark thickness plus periderm) were very similar. Specifically, both revealed relatively stronger interaction effects than those found for the inner bark, but again their magnitude in relation to the main effect of site and height position is small. As in the inner bark thickness, the height position effect is greatest between the top and the two lower positions. As with the inner bark, the North Coast sample stands apart from the samples of the two southerly sites, but in the case of the outer bark thickness the values are consistently higher rather than lower.

As in the case of the inner bark thickness, the pattern of gross outer bark thickness change with height position is similar in degree of change to that reported by Smith and Kozak (1971). However, the absolute level of average gross outer bark thickness determined from their figures is approximately 3.5 mm, compared to an average value of 5.5 mm for the Lower Mainland material.

It appears questionable whether there are systematic differences in periderm thickness between sites, although there are clearly differences between height positions. The mean values for the three sites, nevertheless, follow much the same pattern as with the other variables. That is, the characteristics of bark from the Lower Mainland and Vancouver Island sites are similar, but quite distinct from bark of the North Coast site. The analysis of the number of periderms follows a similar pattern.

The top-to-butt ratio of periderm thicknesses for all sites is consistently less than the top-to-butt ratio of periderm numbers. Even though the variability in periderm thickness would appear to be related primarily to the number of periderm layers present, there must be some additional variability in the thickness of the individual periderm layers.

The analysis of the total bark thickness data shows no evidence of a systematic difference with site. The results from the relatively low inner bark thickness for the North Coast material were more or less compensated for by its relatively high outer bark thickness. The effect of height position is still highly significant, the great difference being between the top material and that of the middle and butt positions which differ only slightly.

Derived bark thickness ratios

The purpose of examining the variance in the derived bark thickness ratios was to determine if any of these ratios might exhibit greater constancy between sites and height position.

Consideration must be given to the question of the most appropriate measure of the bark thickness ratios. Within any radius for any disc there are several sample lines. The ratios could be either on the basis of the measurements made along each sample line, or on the basis of the average values for each radius. The former estimates the expected value of the thickness ratio at a point on the circumference; the latter estimates, more or less, the expected value of the ratio of the individual bark samples. Whichever is the most meaningful of these depends on how the measures are to be used. For the purpose of this paper, consideration of the bark thickness ratios will be confined to the analyses based on the ratio of the means for each radius. The average values for these ratios for the three height positions at three sites are shown in Table 1.

It was found that all bark thickness ratios were a function of height position. As in the case of the primary variables, the values for the top, in general, differ from those for the butt and middle positions, which differ very little. As for site differences, it would appear that the ratio of inner bark thickness to gross outer bark thickness is independent of site, as is the ratio of periderm thickness to total bark thickness. However, the ratio of inner bark to total bark thickness does vary with site, being smaller for the North Coast site than for the other two sites. Conversely, the proportion of outer bark or gross outer bark thickness to total bark thickness is greater for the North Coast site than for the Lower Mainland or Vancouver Island sites.

CONCLUSIONS

The thickness of all primary bark characteristics for the western hemlock samples studied is less at the top position (6 inch DOB) than at the middle (top of first 24-foot log) or butt positions (stump height) which, in turn, differ very little from each other. Total bark thickness did not vary significantly with site, averaging 7.4 mm, 12.2 mm, and 12.6 mm for the top, middle, and butt height positions, respectively. However, the relative contribution of the individual tissues to the total thickness did vary with site. For the North Coast site, the inner bark thickness was less and the outer bark thickness or gross outer bark thickness greater at all height positions than material from either the Vancouver Island or Lower Mainland sites.

The use of bark thickness ratios generally did not help to reveal a greater constancy in the measurements. All bark thickness ratios were found to vary with height position. As with the primary variables, the values for the top positions generally differ significantly from those for the butt and middle positions, which differ very little from each other. However, the ratio of inner bark thickness to gross outer bark thickness was independent of site; whereas, both the primary variables varied significantly with site. The average values for this ratio for top, middle, and butt positions are 2.16, 0.79, and 0.73, respectively. The only other ratio that was independent of site, periderm thickness to total bark thickness, was one in which both of the primary variables were also independent of site.

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