

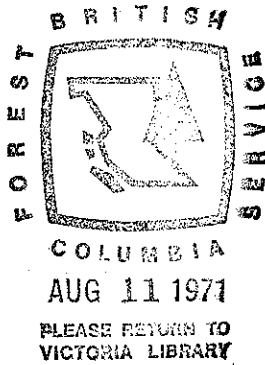
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THICKNESS AND PERCENTAGE OF  
BARK OF THE COMMERCIAL TREES OF  
BRITISH COLUMBIA



By

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Thickness and percentage of bark on the commercial  
trees of British Columbia

By J. H. G. Smith and A. Kozak<sup>1</sup>

Abstract

Thickness and percentage of bark at stump, breast height and tenths of total height above breast height were analysed in relation to tree and section characteristics for mature trees in 19 species or species groups. Dbh and bark thickness at breast height are the best indicators of tree bark thickness. Dob at that height is the best indicator of bark thickness at any particular height in a tree. Influences of age, crown class, various crown characteristics, and sapwood thickness also are statistically significant but of lesser importance.

Data on young trees which have thinner bark than mature trees were summarized for Douglas fir, western hemlock, western red cedar, silver fir, black cottonwood, and red alder. For a given dob, root thickness is less than at the root collar; but similar diameters of root collar, bole, and branch have just about the same thickness of bark.

Attention is drawn to the need to study potentially valuable chemical products in bark, and estimates are made of the volumes and weights of bark that may be recoverable. About 300 million cubic feet of bark, roughly 20 percent of the volume of wood logged in B. C., was potentially available in 1965. This bark, weighing about 4.4 million oven dry tons, represents a resource of potentially great value which should be studied intensively by chemists, economists, and foresters.

<sup>1</sup> Respectively, Professor and Assistant Professor, Faculty of Forestry, University of British Columbia, Vancouver 8, B. C. Financial support of the National Research Council and provision of data by the Inventory Division of the B. C. Forest Service, C. Joergensen of Columbia Cellulose, D. Stewart of MacMillan Bloedel, M. Gormely, and J. Walters are gratefully acknowledged.

## Introduction

Although it is conventional in British Columbia to estimate solid wood contents from measurements of tree diameter at breast height outside bark (D or dbh, ob) and total height (H), the need for data on bark thickness and percentage is increasing. Bark thickness is usually expressed as double bark thickness (dbt) and stated as a percentage of diameter outside bark (dob).

Upper bole diameters estimated outside bark for study of form, taper, or volume during timber cruising must be converted to determine inside bark diameters and volume (Bones, 1962; Dilworth and Bell, 1963; Grosenbaugh, 1964; Johnson, 1966). Growth in bark thickness is important in calculations of clear wood following pruning (Maezawa, 1956; Smith, Ker and Csizmazia, 1961).

From the point of view of total utilization it is obvious that data are needed on amounts of bark associated with various species and methods of utilization (Weldon, 1966). Increased use of weight scaling will make it necessary to learn more about volume and weight of bark. Most important of all, bark contains many potentially valuable organic compounds which should be studied thoroughly to learn their composition and to assess their economic characteristics. Ross (1966) in his introduction to a list of 41 selected references on utilization of tree bark, drew attention to the three million tons of Douglas fir bark produced annually in Oregon as a by-product of logging. He said:

"With increasing information available on the economic potential of bark and with increasing public pressure for less air pollution by burning, a careful study of the properties, chemistry, and possible uses of bark will be profitable in both money and public relations."

Srivastava (1963, 1964 and 1966) has made substantial contributions to understanding of the anatomy, chemistry, and physiology of bark.

Kokoschke (1965) used colour pictures to illustrate identification of and variation in 30 tree species native to British Columbia.

Since Chang (1954) adequately described bark structure and reported percentages of tissues and issue elements of most of the commercial tree species found in British Columbia this aspect will not be discussed herein. The literature summaries by Marian and Wissing (1956, 1957), Roth *et al.* (1960) and Ross (1966) and articles by Wissing 1955, Marian and Wissing (1959a,b) provide an adequate introduction to the literature on all aspects of utilization.

The bark thicknesses analysed herein were obtained by direct measurement on bark sections to correspond with the average difference between diameter tape measurements outside and inside bark. This avoids the problem of over-estimation with a Swedish bark measuring gauge (Von Althen, 1964) but cannot adequately compensate for volume losses associated with bark scales and fissures.

### Uses of bark thickness and bark percentage

From a statistical point of view it seems as if best results will come from estimation of dbt rather than percentage dbt. However, use of various bark percentages or bark ratios is so simple and convenient that it may be preferable for many purposes. Since all percentages have been given in Tables 1-18 using dob as the base, they must be converted if used with dib. For example the 10 per cent dbt of a 10-inch dob must be 11.1 per cent of a 9-inch dib. Similarly, a bark thickness ratio of 0.90 based on dob will give a 0.81 factor for solid wood contents expressed as a fraction of volume over-bark. A 10 per cent dbt based on dob would represent  $100^2/90^2$  or 123.7 per cent of volume based on inside bark contents as is conventional for British Columbia. Gevorkiantz and Olsen (1955) have illustrated uses of bark percentage for adjustment of estimates of volume and radial growth for the U. S. Lake States. For the Northern Rocky Mountain Region of the U. S. Finch (1948) gave formulae to estimate dbh growth from measurements of radial growth of wood. McCormack (1955) published <sup>bark</sup> growth rates for 55 tree species of Southeastern U. S. A. Spada (1960) reported bark thickness and dbh growth equations for the tree species of the Ponderosa pine subregion of Washington and Oregon. Either the bark percentages of Table 5 or the dbt's of Table 4 can be used to convert wood growth measured on increment cores to estimates of dbh growth.

Differences in solid wood contents or in bark percentage can be approximated from stem analyses by summing the measurements of dib and expressing these as a ratio or percentage of the total of dob for each tree. Smith and Walters (1964) reported that these ratios were 0.924 for 21 dominant, 0.917 for 23 codominant, 0.916 for 11 intermediate, and 0.894 for 6 suppressed Douglas fir. These ratios are the same as Meyer's k factors (1946, 1953).

Ratios of tree dib to tree dob were analysed in relation to 16 characteristics of 49, 150-year-old Douglas fir. Simple correlation coefficients for these wood ratios were -.34 for crown class, 0.55 for dbh, .59 for H, .47 for height to base of live crown, .48 for crown width, .14 for length of live crown, .30 for tree age, .54 for site index, .55 for  $dbh^2$ , .57 for  $D^2H$ , .52 for log D, .54 for log H, .11 for H/CW, -.13 for CW/D, .61 for Vcu. ft., and .60 for log V. Obviously these ratios were highly variable but well associated with factors indicative of tree volume.

In order to convert the sum of dib expressed as a ratio of the sum of dob to a ratio of solid wood contents it is necessary to use  $(\text{sum dib}/\text{sum dob})^2$ . This latter ratio usually was within one per cent of the correct solid wood volume in a check of the extremes of the Douglas fir trees studied by Smith and Walters (1964).

### Curve form for dbt on dob

Both dbt and percentage dbt have been used herein because neither is wholly adequate for description of variations in bark with tree or section dob.

The range in dbt increases greatly and percentage dbt decreases as section dob increases. For example, dbt of 1-inch-thick western hemlock sections ranges from 0.02 to 0.31 inches; dbt of 10-inch hemlock sections ranges from 0.35 to 0.94 inches; dbt of 20-inch sections ranges from 0.7 to 1.58 inches; dbt of 40-inch sections ranges from 0.65 to 1.65 inches. Percentage dbt's representing these ranges are 2.2 to 31.0 for 1-inch sections, 3.5 to 9.4 for 10-inch, 3.5 to 7.9 for 20-inch, and 1.6 to 3.7 for 40-inch sections. Curved average bark thicknesses expressed as percentages decrease from 14.0 for 1-inch sections to 6.3 for 10-inch to 5.5 for 20-inch and to 4.1 per cent for 40-inch sections.

The appropriate curve form and variables used to estimate dbt or percentage dbt will depend largely upon the end use of the data. Johnson (1966) illustrated the influence of six independent variables and various combinations of these to estimate bark thickness of 540 young Douglas fir trees.

### Species studied

The data on mature trees are grouped by coastal and interior regions and use the terminology of the B. C. Forest Service (Brown, 1962). The scientific names and common names for each species or species group are as follows:

- Alder, Alnus rubra Bong., Red alder.  
 Aspen, Populus tremuloides Michx., Trembling aspen.  
 Balsam-coastal, Abies amabilis (Dougl.) Forbes and A. grandis (Dougl.) Lindl., Silver and Grand firs.  
 Balsam-interior, Abies lasiocarpa (Hook.) Nutt. and A. grandis (Dougl.) Lindl., Subalpine and Grand firs.  
 Cedar-coastal, Thuja plicata Donn, Western red cedar.  
 Cedar-interior, " " "  
 Cottonwood, Populus trichocarpa Torr. & Gray, Black cottonwood.  
 Douglas fir-coastal, Pseudotsuga menziesii (Mrb.) Franco.  
 Douglas fir-interior, " " "  
 Hemlock-coastal, Tsuga heterophylla (Raf.) Sarg., Western hemlock.  
 Hemlock-interior, " " "  
 Lodgepole pine, Pinus contorta Dougl.  
 Maple, Acer macrophyllum Pursh., Broadleaf maple.  
 Spruce-coastal, Picea sitchensis (Bong.) Carr., Sitka spruce.  
 Spruce-interior, Picea glauca (Moench) Voss, P. engelmanni Parry, and P. mariana (Mill.) B. S. P., White, Engelmann and Black spruces.  
 White birch, Betula papyrifera varieties.  
 White pine, Pinus monticola Dougl., Western white pine.  
 Yellow cedar, Chamaecyparis nootkatensis (D. Don) Spach.  
 Yellow pine, Pinus ponderosa Laws., Western yellow pine.

### Bark thickness of mature tree boles

The measurements supplied by the B. C. Forest Service for study of taper (Kozak and Smith, 1966) were also analysed to determine factors governing thickness and percentage of bark. Each tree had been measured at 1 foot, 4.5 feet, and tenths of tree height above breast height. The simple correlation coefficients ( $r$ ) in Table 1 indicate that dbh, age, and dbt at breast height (bh) are the most important tree variables. The best section variable is dob. Dbt at bh and section height (h) itself or as a percentage (P) of total tree height (H) also are highly correlated with section dbt. Age is not used further in these analyses because of the difficulty of measuring it in mature trees.

Table 2 contains dbt's which are summarized by number of sections sampled, mean, standard deviation, minimum, maximum, and coefficient of variation. The great variation in cottonwood and Douglas fir should be noted. The dbt's used for Table 2 have been expressed as percentages of section dob for Table 3.

Table 4 shows data on dbt at bh for all trees studied. These are expressed as percentages of dbh in Table 5. The maximum percentages in Table 5 are much less than those in Table 3, which suggests that most of the relatively extreme values in bark thickness come from small sections near the tips of trees. Comparison of the mean bark thickness for all sections (Table 3) with the mean for breast height (Table 5) shows that most species have relatively thicker bark on sections other than breast height. Only yellow pine and interior Douglas fir have relatively thicker bark at breast height.

At the bottom of Table 4, data from another study of bark thickness at breast height are given. These agree well with those of the main study when differences in average dbh and H are considered. In addition data on Western larch Larix occidentalis Nutt. are given. Dbt of larch was 14.6 per cent of the mean dbh. For all of these species no advantage was gained from use of H or H/D in addition to D to estimate dbt.

The averages and range in basic data shown in Table 6 can be used as a rough indication of the sizes of trees and sections to which the observations made herein may apply.

Equations for estimation of double bark thickness from dob at any section are given in Table 7. In most cases the quality of regression equations tabulated as expressed by standard error of estimate ( $SE_E$ ) and coefficient of determination is good. Addition of section height as a percentage of total height (Table 8) improves the regressions slightly. Use of breast height bark thickness with dob, section height, or percentage section height in Table 9 results in good equations for estimation of dbt. Table 10 contains equations for estimation of dbt of all sections from dbt at bh. Generally, the average thickness of bark of the 11 sections studied is about 70 per cent of that at breast height. Yellow cedar is similarly thick for all sections but thickness of Douglas fir sections averages only about half that at breast height.

It is much more difficult to estimate percentage dbt than dbt. Therefore, most of the equations of Table 11 using only dob will be of little value. Estimation of percentage dbt from dob at any section was improved by use of other variables. Table 12 shows the best two equations resulting from analysis of the regressions of percentage bark thickness on dbh, total height, section height, and

section height as a percentage of total height. Table 13 shows that for some species considerable improvement results from use of percentage bark thickness at breast height to estimate percentage bark thickness of all sections. The best equations are those of Table 14 which use percentage bark thickness at breast height and an additional variable which is based on tree height, except for lodgepole pine for which dbh was best.

Table 15 gives regression equations for estimation of dbt at bh from dbh, H, or H/D. Multiple regression analysis showed that almost no improvement in coefficient of determination resulted from use of more than one variable to estimate dbt at bh. With the possible exception of coast spruce none of the equations calculated adequately estimated percentage dbt from D, H, and H/D. To provide a basis for comparison data from Spada (1960) and Finch (1948) also are given in Table 15.

In Table 16 the best two regression equations for estimation of section dbt from the variables D, H, h and h/H are given. Almost no improvement resulted from the use of more than two variables to estimate dbt.

TABLE 1. Factors Governing Bark Thickness

Tree Species	Simple correlation coefficients for double bark thickness													
	Crown class	Age	Site class	Dbh	Total Height	D <sup>2</sup> H	H/D	V cu. ft.	V/BA	Section Height	Percentage Section height	Dob	Dbt, BH	Dbt, P, BH
Alder	-.09	.55	0	.51	.14	.41	-.47	.41	.09	-.66	-.45	.72	.74	.46
Aspen	-.05	.43	-.24	.53	.47	.50	-.43	.50	.46	-.43	-.61	.84	.58	.16
Balsam - Coastal	-.46	.53	-.07	.72	.71	.67	-.47	.68	.65	.03	-.35	.71	.72	-.11
Balsam - Interior	-.52	.20	-.09	.64	.56	.63	-.31	.64	.53	-.30	-.52	.82	.76	.39
Cedar - coastal	-.50	.43	-.15	.59	.55	.46	-.49	.46	.39	-.12	-.43	.56	.64	.04
Cedar - Interior	-.47	.52	-.15	.77	.66	.52	-.52	.58	.44	-.11	-.37	.65	.77	.24
Cottonwood	-.20	.70	.21	.74	.64	.69	-.61	.69	.43	-.19	-.41	.83	.77	.11
Douglas fir - coastal	-.26	.52	-.29	.62	.50	.50	-.58	.52	.39	-.35	-.58	.92	.62	.13
Douglas fir - Interior	-.31	.52	.26	.55	.36	.46	-.44	.45	.40	-.47	-.62	.88	.58	.32
Hemlock - coastal	-.60	.62	-.04	.71	.63	.63	-.53	.65	.55	-.11	-.43	.79	.78	-.05
Hemlock - Interior	-.43	.50	-.43	.71	.62	.66	-.35	.70	.57	-.30	-.57	.92	.70	.12
Lodgepole pine	-.04	.20	-.17	.33	.25	.29	-.24	.28	.22	-.40	-.63	.71	.42	.08
Maple	-.33	.45	.25	.63	.52	.64	-.40	.65	.46	-.36	-.47	.78	.60	.11
Spruce - coastal	-.55	.50	.45	.54	.57	.42	-.55	.41	.41	-.17	-.39	.77	.63	.21
Spruce - Interior	-.44	.32	-.20	.53	.51	.49	-.28	.49	.43	-.34	-.55	.79	.64	.19
White birch				.52	.39									
White pine	-.22	.51	.40	.57	.42	.52	-.55	.51	.35	-.48	-.60	.81	.63	.23
Yellow cedar	-.43	.73	0	.75	.75	.75	-.43	.75	.64	-.41	-.55	.84	.70	.32
Yellow pine	-.20	.32	-.13	.43	.35	.36	-.28	.29	.30	-.47	-.70	.80	.56	-.02

TABLE 2. Double Bark Thickness for all Sections

Species group	No. of Sections	Mean In.	Standard Deviation In.	Minimum In.	Maximum In.	Coefficient of variation %
Alder	946	0.50	0.22	0.01	1.3	44.3
Aspen	1309	0.58	0.34	0.01	2.2	57.9
Balsam - coastal	946	0.65	0.35	0.01	2.0	54.0
Balsam - interior	1056	0.47	0.28	0.01	1.6	50.5
Cedar - coastal	924	0.75	0.45	0.01	2.6	59.7
Cedar - interior	946	0.73	0.49	0.01	3.0	67.2
Cottonwood	1397	0.70	0.72	0.01	6.0	102.9
Douglas fir - coastal	1067	1.86	1.69	0.01	9.9	90.9
Douglas fir - interior	858	1.57	1.50	0.01	9.9	95.5
Hemlock - coastal	891	0.81	0.50	0.01	3.2	62.3
Hemlock - interior	671	0.77	0.50	0.01	3.0	64.6
Lodgepole pine	4994	0.38	0.23	0.01	2.2	59.6
Maple	396	0.47	0.22	0.01	1.0	46.1
Spruce - coastal	429	0.57	0.23	0.20	1.4	40.5
Spruce - interior	1331	0.56	0.31	0.01	2.8	54.9
White birch	803	0.45	0.23	0.01	1.4	50.8
White pine	1045	0.66	0.35	0.01	2.4	53.5
Yellow cedar	748	0.53	0.30	0.01	3.0	57.1
Yellow pine	1100	1.53	1.01	0.01	6.8	65.9

TABLE 3 Double Bark Thickness as a Percentage of  
Diameter Outside Bark for all sections

Species group	No. of Sections	Mean %	Standard Deviation %	Minimum %	Maximum %	Coefficient of variation %
Alder	946	7.0	2.8	2.6	40.0	40.1
Aspen	1309	8.6	3.1	2.6	50.0	36.4
Balsam - coastal	946	6.1	2.5	0.4	18.5	41.1
Balsam - interior	1056	7.0	2.8	0.8	25.0	39.6
Cedar - coastal	924	7.2	3.0	0.6	21.4	41.9
Cedar - interior	946	7.9	3.1	0.9	23.5	39.1
Cottonwood	1397	9.6	3.9	0.6	40.0	40.5
Douglas fir - coastal	1067	11.7	3.7	3.0	36.7	31.8
Douglas fir - interior	858	12.4	5.1	4.7	68.8	40.7
Hemlock - coastal	891	8.5	3.8	1.3	40.0	44.2
Hemlock - interior	671	9.4	2.5	3.6	22.2	26.8
Lodgepole pine	4994	5.2	2.2	1.0	22.2	42.1
Maple	396	5.4	1.3	2.3	14.3	24.8
Spruce - coastal	429	4.4	2.7	0.6	25.0	63.1
Spruce - interior	1331	6.7	2.7	2.2	20.0	39.8
White birch	803	8.2	4.1	1.9	54.5	49.8
White pine	1045	6.3	2.2	2.4	16.2	35.7
Yellow cedar	748	6.8	3.4	1.1	25.0	50.7
Yellow pine	1100	12.6	4.4	2.5	37.5	34.6

TABLE 4 Double Bark Thickness at Breast Height

Species group	No. trees	Mean	Standard	Minimum	Maximum	Coefficient of variation %
		In.	Deviation In.	In.	In.	
Alder	86	0.6	0.2	0.2	1.0	33.2
Aspen	119	0.8	0.4	0.3	2.0	43.1
Balsam - coastal	86	0.3	0.4	0.01	1.7	46.5
Balsam - interior	96	0.6	0.3	0.2	1.5	46.9
Cedar - coastal	84	0.9	0.5	0.01	2.5	51.1
Cedar - interior	86	1.0	0.6	0.3	3.0	59.3
Cottonwood	127	1.1	0.8	0.3	4.9	76.7
Douglas fir - coastal	97	3.2	2.1	0.7	9.1	65.2
Douglas fir - interior	78	2.9	1.7	0.6	9.9	58.9
Hemlock - coastal	81	1.0	0.5	0.4	2.3	51.9
Hemlock - interior	61	1.1	0.5	0.4	2.8	45.4
Lodgepole pine	454	0.5	0.2	0.2	1.1	34.9
Maple	36	0.6	0.2	0.2	0.9	27.6
Spruce - coastal	39	0.7	0.2	0.3	1.5	36.0
Spruce - interior	121	0.8	0.3	0.2	1.6	40.4
White birch	73	0.6	0.2	0.2	1.1	35.8
White pine	95	0.9	0.3	0.3	1.7	39.1
Yellow cedar	68	0.5	0.2	0.2	1.6	40.8
Yellow pine	100	2.4	0.9	0.7	0.6	38.1

Supplement to Table 4

Lodgepole pine	378	0.4	0.2
Douglas fir - interior	229	2.2	1.6
Cedar - interior	330	0.8	0.4
Balsam - interior	211	0.6	0.2
Spruce - interior	302	0.6	0.3
Larch	69	2.3	1.2

TABLE 5 Percentage Double Bark Thickness at Breast Height

Species group	No. trees	Mean %	Standard Deviation %	Minimum %	Maximum %	Coefficient of variation %
Alder	86	5.3	1.4	2.6	9.1	26.6
Aspen	119	8.1	1.9	4.5	12.7	23.7
Balsam - coastal	86	4.8	2.3	0.4	14.0	47.3
Balsam - interior	96	6.0	1.7	2.4	10.9	29.0
Cedar - coastal	84	5.5	2.1	1.3	11.3	38.4
Cedar - interior	86	6.3	1.7	3.1	11.9	27.5
Cottonwood	127	9.4	2.8	2.4	18.4	30.0
Douglas fir - coastal	97	14.3	3.3	6.8	21.9	22.9
Douglas fir - interior	78	16.3	4.5	9.0	27.5	27.5
Hemlock - coastal	81	6.8	2.1	2.6	11.5	31.5
Hemlock - interior	61	9.1	2.0	6.3	15.4	21.5
Lodgepole pine	454	4.9	1.6	1.9	10.6	31.4
Maple	36	4.7	0.1	2.8	7.1	18.7
Spruce - coastal	39	2.9	1.5	0.7	8.3	50.5
Spruce - interior	121	5.9	1.9	2.7	13.4	32.5
White birch	73	6.4	1.6	3.5	11.3	25.4
White pine	95	5.3	1.3	3.0	8.8	24.1
Yellow cedar	68	4.3	1.3	1.7	7.8	29.8
Yellow pine	100	14.4	4.0	5.2	23.4	27.7

TABLE 6 Averages and Range of Basic Data

Species group	Min.	Ave.	Max.	H		H/D		Ave.	Max.	Min.	Ave.	Max.	Age.	Max.
				Ft.	Max.	Ft./In.	Max.							
Alder	5	11	18	53	84	8	15	8	26	29	51	122		
Aspen	5	10	21	42	78	8	11	7	30	37	95	152		
Balsam - coastal	6	18	50	32	104	5	11	13	63	66	174	372		
Balsam - interior	5	10	24	28	70	7	10	7	29	72	151	284		
Cedar - coastal	6	20	51	31	89	5	8	13	78	73	203	385		
Cedar - interior	5	16	48	27	79	6	11	11	63	83	191	489		
Cottonwood	5	12	48	45	80	8	13	8	82	20	55	279		
Douglas fir - coastal	5	22	71	52	122	7	11	15	78	67	170	409		
Douglas fir - interior	5	18	42	27	76	6	9	12	48	60	170	460		
Hemlock - coastal	5	16	42	40	100	7	12	11	67	73	206	509		
Hemlock - interior	6	12	28	42	73	7	9	8	41	74	186	331		
Lodgepole pine	5	11	23	42	75	7	12	8	28	20	57	123		
Maple	6	13	23	49	82	7	11	9	31	28	154	396		
Spruce - coastal	6	30	85	48	143	6	8	19	100	28	142	299		
Spruce - interior	5	13	26	37	89	7	12	9	41	60	142	299		
White birch	5	9	21	45	89	4	12	6	32	74	151	222		
White pine	6	16	27	45	107	7	11	11	36	74	250	999		
Yellow cedar	6	14	44	44	65	5	9	10	55	132	186	423		
Yellow pine	6	18	40	20	78	5	7	13	48	40	186	423		

TABLE 7 Regression of Double Bark Thickness on Diameter Outside Bark

Species group	Constant	Regression Coefficient	SE <sub>E</sub> <sup>1</sup>	r <sup>2</sup>
Alder	0.156	0.044	0.153	0.525
Aspen	0.103	0.065	0.182	0.705
Balsam - coastal	0.290	0.029	0.250	0.498
Balsam - interior	0.051	0.058	0.160	0.680
Cedar - coastal	0.434	0.025	0.370	0.318
Cedar - interior	0.303	0.041	0.369	0.440
Cottonwood	0.064	0.081	0.398	0.692
Douglas fir - coastal	-0.234	0.139	0.642	0.856
Douglas fir - interior	-0.403	0.170	0.715	0.774
Hemlock - coastal	0.305	0.044	0.306	0.631
Hemlock - interior	0.043	0.086	0.193	0.849
Lodgepole pine	0.073	0.039	0.159	0.509
Maple	0.107	0.039	0.109	0.743
Spruce - coastal	0.394	0.009	0.182	0.377
Spruce - interior	0.149	0.044	0.187	0.626
White birch	0.132	0.051	0.134	0.651
White pine	0.107	0.049	0.191	0.703
Yellow cedar	0.243	0.030	0.239	0.378
Yellow pine	0.208	0.103	0.599	0.647

<sup>1</sup> Standard error of estimate, SE<sub>E</sub>, and coefficient of determination, r<sup>2</sup> or R<sup>2</sup>, indicate the quality of the regression equation.

TABLE 8 Regression of Double Bark Thickness on  
Diameter Outside Bark and Section Height  
as a Percentage of Tree Height

Species group	Constant	Regr. Coeffs. for		SE <sub>E</sub>	R <sup>2</sup>
		DOB	SH/HP		
Alder	-.052	.058	.002	.148	.558
Aspen	.139	.063	-.0004	.182	.706
Balsam - coastal	.188	.032	.001	.248	.508
Balsam - interior	-.129	.070	.002	.156	.702
Cedar - coastal	.545	.022	-.002	.368	.325
Cedar - interior	.215	.044	.001	.368	.444
Cottonwood	.055	.082	.0002	.399	.692
Douglas fir - coastal	.093	.132	-.005	.631	.861
Douglas fir - interior	-.256	.165	-.002	.714	.775
Hemlock - coastal	.276	.045	.0005	.307	.632
Hemlock - interior	-.077	.091	.002	.190	.854
Lodgepole pine	.224	.030	-.002	.155	.533
Maple	.065	.041	.0005	.109	.745
Spruce - coastal	.411	.009	-.0003	.182	.378
Spruce - interior	.114	.046	.0005	.188	.628
White birch	.097	.053	.0004	.134	.652
White pine	-.084	.057	.003	.187	.719
Yellow cedar	-.052	.042	.004	.222	.467
Yellow pine	.965	.078	-.010	.561	.692

TABLE 9 Regression of Double Bark Thickness on Bark  
 Thickness at Breast Height Plus Other Variables

Species group	Constant	Regr. Coeffs. for		SE <sub>E</sub>	R <sup>2</sup>
		DOB <sup>1</sup>	BT BH		
Alder	-.124	.032	.650	.101	.792
Aspen	.001	.057	.193	.173	.736
Balsam - coastal	.018	.020	.510	.192	.705
Balsam - interior	-.118	.042	.466	.111	.848
Cedar - coastal	.468	-.006 SH/HP	.587	.293	.573
Cedar - interior	.354	-.006 SH/HP	.661	.264	.715
Cottonwood	-.126	.056	.363	.325	.796
Douglas fir - coastal	.017	-.004 SH	.136	.625	.864
Douglas fir - interior	-.193	-.004 SH	.164	.710	.778
Hemlock - coastal	.368	-.007 SH/HP	.738	.234	.784
Hemlock - interior	-.100	.073	.231	.171	.882
Lodgepole pine	.329	-.005 SH/HP	.509	.149	.569
Maple	-.039	.034	.319	.099	.789
Spruce - coastal	.131	.007	.446	.150	.577
Spruce - interior	-.056	.036	.380	.155	.746
White birch	-.056	.042	.427	.107	.777
White pine	-.126	.038	.413	.148	.824
Yellow cedar	-.047	.015	.794	.188	.620
Yellow pine	.593	-.008 SH	.009	.569	.682

<sup>1</sup> DOB or variable named

TABLE 10 Regression of all section double bark thicknesses on double bark thickness at breast height.

Species group	Constant	Regression Coefficient	SE <sub>E</sub>	r <sup>2</sup>
Alder	.003	.870	.150	.547
Aspen	.127	.543	.275	.334
Balsam - coastal	.105	.724	.246	.515
Balsam - interior	.007	.755	.185	.578
Cedar - coastal	.186	.595	.345	.408
Cedar - interior	.089	.667	.314	.595
Cottonwood	-.030	.677	.455	.600
Douglas fir - coastal	.244	.504	.133	.384
Douglas fir - interior	.077	.509	.122	.338
Hemlock - coastal	.045	.747	.315	.610
Hemlock - interior	-.003	.709	.356	.491
Lodgepole pine	.106	.521	.206	.179
Maple	-.005	.779	.173	.358
Spruce - coastal	.163	.589	.180	.391
Spruce - interior	.075	.640	.237	.404
White birch	.045	.702	.177	.395
White pine	.026	.737	.252	.489
Yellow cedar	-.022	1.019	.204	.548
Yellow pine	.192	.548	.872	.253

TABLE 11 Regression of Average Percentage  
Double Bark Thickness on Diameter  
Outside Bark

Species group	Constant	Regression Coefficient	SE <sub>E</sub>	r <sup>2</sup>
Alder	9.45	-0.319	2.53	0.174
Aspen	10.66	-0.281	2.87	0.154
Balsam - coastal	7.96	-0.150	2.13	0.268
Balsam - interior	8.63	-0.223	2.63	0.104
Cedar - coastal	9.08	-0.151	2.61	0.252
Cedar - interior	9.61	-0.159	2.82	0.168
Cottonwood	10.23	-0.853	3.82	0.026
Douglas fir - coastal	10.46	0.082	3.59	0.061
Douglas fir - interior	10.09	0.204	4.81	0.097
Hemlock - coastal	10.71	-0.194	3.31	0.220
Hemlock - interior	10.27	-0.102	2.46	0.046
Lodgepole pine	6.79	-0.197	2.04	0.138
Maple	6.35	-0.108	1.23	0.148
Spruce - coastal	6.40	-0.109	2.19	0.362
Spruce - interior	8.78	-0.220	2.39	0.203
White birch	11.09	-0.469	3.71	0.172
White pine	7.96	-0.147	2.05	0.159
Yellow cedar	9.66	-0.301	2.90	0.289
Yellow pine	14.68	-0.158	4.19	0.081

TABLE 12 Regression Equations for Estimation of  
Double Bark Thickness as a Percentage  
of Diameter Outside Bark

Species group	Constant %	Regression coefficients & variables	SE <sub>E</sub> %	r <sup>2</sup> or R <sup>2</sup>
Alder	8.4	-0.043 H +0.049 h/HP	2.35	0.290
	4.8	+0.049 h/H	2.40	0.259
Aspen	8.9	-0.029 H +0.043 h/HP	2.81	0.192
	6.7	0.044 h/H	2.86	0.163
Balsam - coastal	6.8	-0.026 H +0.045 h	2.00	0.363
	4.6	0.033 h	2.19	0.231
Balsam - interior	4.4	0.063 D +0.044 h/HP	2.47	0.215
	5.1	0.044 h/HP	2.48	0.209
Cedar - coastal	8.0	-0.035 H +0.060 h	2.49	0.322
	5.5	0.044 h	2.69	0.205
Cedar - interior	4.4	0.010 h +0.063 h/HP	2.52	0.342
	5.2	0.062 h/HP	2.53	0.335
Cottonwood	8.6	-0.011 H +0.042	3.66	0.106
	7.7	+0.043 h/HP	3.67	0.101
Douglas fir - coastal	12.6	0.035 D -0.040 h/HP	3.50	0.116
	13.4	-0.040 h/HP	3.53	0.099
Douglas fir - interior	12.4	0.114 D -0.044 h/H	4.82	0.100
	14.3	-0.045 h/HP	4.90	0.065
Hemlock - coastal	8.1	-0.024 H +0.065 h/HP	3.10	0.322
	5.6	+0.066 h/HP	3.23	0.264
Hemlock - interior	6.1	-0.014 H +0.038 h/HP	1.91	0.274
	4.6	0.039 h/HP	1.94	0.254
Lodgepole pine	6.9	-0.033 H +0.019 h/HP	2.03	0.155
	7.8	-0.034 H	2.10	0.099
Maple	4.7	-0.012 D +0.019 h/HP	1.21	0.181
	4.5	+0.019 h/HP	1.21	0.180
Spruce - coastal	5.5	-0.026 H +0.060 h/HP	1.82	0.566
	1.8	0.061 h/HP	2.09	0.422
Spruce - interior	6.8	-0.151 D +0.050 h	2.29	0.274
	5.1	0.043 h	2.39	0.208
White birch	6.9	-0.022 H +0.064 h/HP	3.63	0.209
	5.4	0.064 h/HP	3.64	0.205
White pine	6.1	-0.014 H +0.038 h/HP	1.91	0.274
	4.6	0.039 h/HP	1.94	0.254
Yellow cedar	3.3	-0.032 D +0.088 h/HP	2.33	0.542
	2.9	+0.089 h/HP	2.34	0.538
Yellow pine	18.1	-0.069 H -0.002 h/HP	3.98	0.171
	18.0	-0.069 H	3.98	0.171

TABLE 13 Regression of Average Percentage Double  
Bark Thickness on Percentage Bark  
Thickness at Breast Height

Species group	Constant	Regression Coefficient		r <sup>2</sup>
		BT BHP	SE <sub>E</sub>	
Alder	.851	1.143	2.28	.334
Aspen	5.56	0.375	3.05	.052
Balsam - coastal	3.70	8.496	2.24	.201
Balsam - interior	2.27	.797	2.42	.244
Cedar - coastal	4.00	.583	2.77	.162
Cedar - interior	2.88	.798	2.78	.200
Cottonwood	3.54	.638	3.43	.216
Douglas fir - coastal	6.51	.362	3.52	.101
Douglas fir - interior	4.27	.501	4.55	.196
Hemlock - coastal	2.79	.840	3.31	.226
Hemlock - interior	6.05	.370	2.42	.081
Lodgepole pine	2.59	.536	2.05	.142
Maple	3.85	.322	1.30	.044
Spruce - coastal	1.65	.940	2.40	.241
Spruce - interior	2.91	.647	2.38	.213
White birch	2.66	.865	3.83	.117
White pine	1.06	.978	1.86	.311
Yellow cedar	3.52	.767	3.30	.079
Yellow pine	3.69	.621	3.61	.318

TABLE 14 Regression of Average Percentage Double Bark Thickness on Percentage Section Height and Percentage Bark Thickness at Breast Height

Species group	Constant	Regression coeffs. for		SE <sub>E</sub>	R <sup>2</sup>
		SH/HP <sup>1</sup>	BTBHP		
Alder	-1.25	.049	1.134	1.78	.591
Aspen	3.66	.044	.373	2.77	.214
Balsam - coastal	1.18	.041 SH	.634	1.69	.544
Balsam - interior	.31	.044	.796	2.06	.453
Cedar - coastal	1.09	.054 H	.736	2.23	.454
Cedar - interior	.47	.066 H	.819	2.18	.508
Cottonwood	1.77	.042	.632	3.21	.313
Douglas fir - coastal	8.21	-.040	.364	3.32	.201
Douglas fir - interior	6.25	-.044	.497	4.37	.258
Hemlock - coastal	.06	.065	.826	2.71	.481
Hemlock - interior	4.73	.041 SH	.370	2.22	.228
Lodgepole pine	4.37	-.153 DOB	.420	1.95	.220
Maple	2.91	.023 SH	.347	1.18	.220
Spruce - coastal	-.83	.060	.918	1.63	.652
Spruce - interior	.91	.046	.643	1.96	.467
White birch	-.45	.087	.936	3.38	.314
White pine	-.55	.038	.971	1.49	.561
Yellow cedar	-.31	.088	.749	2.14	.613
Yellow pine	4.67	-.040	.589	3.59	.323

<sup>1</sup> SH/HP or variable named.

TABLE 15. Equations for Estimation of Double Bark Thickness at Breast Height

Species group	Constant	Regression coefficient and variable	SE <sub>E</sub>	R <sup>2</sup>
Alder	1.18	-0.075 H/D,	0.13	0.51
Aspen	0.06	0.074 D <sub>L</sub>	0.21	0.67
Balsam - coastal	0.34	0.023 D	0.28	0.38
Balsam - interior	-0.03	0.062 D	0.18	0.61
Cedar - coastal	1.92	-0.190 H/D	0.43	0.23
Cedar - interior	0.09	0.057 D	0.30	0.74
Cottonwood	0.16	0.078 D	0.45	0.71
Douglas fir - coastal	0.15	0.137 D	0.89	0.82
Douglas fir - interior	-0.39	0.191 D	0.86	0.76
Hemlock - coastal	0.33	0.042 D	0.32	0.64
Hemlock - interior	0.04	0.087	0.24	0.77
Lodgepole pine	0.23	0.027 D	0.15	0.31
Maple	1.17	-0.085 H/D	0.11	0.58
Spruce - coastal	1.22	-0.094 H/D	0.21	0.33
Spruce - interior	0.03	0.008 H	0.23	0.42
White birch	0.13	0.048 D	0.15	0.48
White pine	0.01	0.052 D	0.18	0.65
Yellow cedar	0.21	0.024 D	0.15	0.55
Yellow pine	0.89	0.086 D	0.66	0.50

Supplement to Table 15

			No. trees	Dg/Wg <sup>1</sup>	Dg/wg <sup>2</sup>
Douglas fir	0.0704	+0.1176 D	2,259	1.133	1.154
Ponderosa pine	0.5661	+0.0976 D	1,845	1.108	1.089
Lodgepole pine	0.3147	+0.0274 D	743	1.028	1.033
White fir	-0.0122	+0.1047 D	764	1.117	
Subalpine fir	0.0539	+0.0633 D	400	1.068	1.031
Engelmann spruce	0.2113	+0.0445 D	585	1.047	1.014
Western larch	0.1231	+0.1306 D	1,058	1.150	1.175
Western white pine					1.037
Western red cedar					1.052
Western hemlock					1.070
Grand fir					1.093
Black cottonwood					1.133
Aspen					1.096

<sup>1</sup> Diameter growth as a ratio of wood growth from Spada (1960)

<sup>2</sup> Diameter growth as a ratio of wood growth from Finch (1948)

TABLE 16 Regression Equations for Estimation of  
Section Double Bark Thickness

Species group	Constant	Regression coefficients & variables	SE <sub>E</sub>	r <sup>2</sup> or R <sup>2</sup>
Alder	0.21	0.041 D -0.00348 h/HP	0.153	0.465
	0.56	0.041 D	0.192	0.259
Aspen	0.25	0.059 D -0.00845 h	0.204	0.632
	0.11	0.045 D	0.285	0.284
Balsam - coastal	0.35	0.027 D -0.00407 h/HP	0.215	0.630
	0.17	0.027 D	0.245	0.518
Balsam - interior	0.03	0.063 D -0.0068 h	0.165	0.664
	-0.05	0.051 D	0.219	0.410
Cedar - coastal	0.58	0.023 D -0.00622 h/HP	0.315	0.506
	0.30	0.023 D	0.363	0.344
Cedar - interior	0.24	0.047 D -0.00688 h	0.309	0.609
	0.12	0.040 D	0.352	0.493
Cottonwood	0.29	0.072 D -0.026 h	0.831	0.759
	-0.01	0.060 D	0.485	0.545
Douglas fir - coastal	0.88	0.105 D -0.04 h	0.842	0.688
	-0.15	0.076 D	1.326	0.386
Douglas fir - interior	0.55	0.135 D -0.04 h	0.842	0.688
	-0.26	0.105 D	1.259	0.299
Hemlock - coastal	0.35	0.045 D -0.00665 h	0.285	0.681
	0.22	0.036 D	0.356	0.504
Hemlock - interior	0.08	0.088 D -0.0117 h	0.231	0.785
	-0.09	0.071 D	0.350	0.506
Lodgepole pine	0.39	0.019 D -0.0049 h/HP	0.161	0.496
	0.59	0.00497 h/HP	0.176	0.398
Maple	0.16	0.038 D -0.00519 h	0.111	0.735
	0.02	0.034 D	0.168	0.399
Spruce - coastal	0.11	0.0041 H -0.002 h	0.168	0.474
	0.11	0.0032 H	0.190	0.321
Spruce - interior	-0.01	0.009 H -0.006 h	0.203	0.564
	-0.03	0.007 H	0.264	0.265
White birch	0.29	0.040 D -0.00465 h/HP	0.1412	0.614
	0.65	-0.00471 h/HP	0.182	0.355
White pine	0.15	0.049 D -0.006 h	0.204	0.667
	0.03	0.039 D	0.289	0.326
Yellow cedar	0.138	0.034 D -0.00153 h/HP	.195	0.589
	0.06	0.034 D	0.200	0.569
Yellow pine	1.62	0.053 D -0.024	0.599	0.649
	2.61	-0.0244 h/HP	0.723	0.487

### Crown class

Although most of the simple correlation coefficients in Table 1 show only minor influences of crown class on bark thickness there are great differences among species. The tolerant species groups -- balsam, western red and yellow cedars, hemlock, and spruce show significant influences of crown class on bark thickness. In Douglas fir there is a moderate influence of crown class on bark thickness.

The influence of crown class on bark thickness of young Douglas fir, hemlock, and cedar was illustrated by Smith and Walters (1964). On all sites studied by them, Douglas fir bark was relatively thickest on suppressed and thinnest on dominant tree sections of the same size, probably because the dominant trees were fastest growing. The opposite was true for western hemlock and western red cedar which had thicker bark on dominant trees and thinner bark on suppressed trees at the same dob. The difficulty of generalizing about crown class also is shown by the data of Smith and Walters (1964).

### Region

Meyers and Van Duesen (1958) concluded that bark thicknesses of ponderosa pine in the Black Hills of Dakota were similar to that in eastern Oregon and Washington. McCormack (1955) also found no significant geographic differences for the regression of dbt on dbh. On the other hand Honer (1964) concluded that because of significant regional differences in bark thickness local expressions of bark thickness should be developed to avoid consistent errors and biased volume estimates.

Because of the differences shown in Tables 1 - 16 and influences of species and genetic characteristics on bark growth, which differ between the Coast and Interior of British Columbia, it seems desirable to continue to treat bark data separately for these regions.

Data secured by C. Joergensen on 149 black cottonwoods near Terrace B. C. agreed within about one per cent of our bark volume estimates (21 vs our 22 per cent).

### Tree to tree variation

Although much of the general pattern of variation in bark thickness can be accounted for by differences in species, region, tree size, age and crown class there are many individual tree differences. As shown in Tables 10, 13, and 14 these can be expressed well by a bark correction factor based on bark thickness at breast height. It is likely that this tendency toward growth of thin or thick bark on trees is genetically controlled.

### Bark thickness of young trees

Because of the significant influence of age on bark thickness it may be necessary to develop special regression equations for young trees. In any case the data from Tables 1 - 16 do not apply to trees less than 5 inches dbh, and mature tree equations with large values for zero dbh may not fit young trees adequately.

Data from the U. B. C. Research Forest suggest that average bark thickness of many young trees is about three per cent less than the averages given in Table 3. Smith and Walters (1964) reported that bark percentage of 61 Douglas fir trees averaged 8.3 and ranged from 5.6 to 15.8. Bark percentage of 91 hemlocks averaged 5.6 and ranged from 2.8 to 8.9. Bark percentage of 62 cedars averaged 3.8 and ranged from 2.3 to 6.8. Douglas fir bark percentage decreased from dominant to suppressed classes and with dbh, total height, age, and site index. Almost all of the variation in hemlock bark percentages was independent of these factors and likely to be genetic. Bark percentage of cedar trees increased with dbh, total height, and total age.

Our limited data on silver fir from the U. B. C. Research Forest suggest similar bark percentages for old and young trees.

For some purposes, use of a constant percentage of over-bark volume has been assumed to be adequate. Hummel, Irvine, and Jeffers (1951) assumed that bark percentage was 12.5 for all height, and girth classes of Douglas fir in Britain. Hummel, Locke, and Verel (1962) suggested, however, that bark of Sitka spruce varied from 7 to 11 per cent of over-bark volume. Bark of Douglas fir varied from 12 to 13 per cent of over-bark volume. They observed: "Bark percentages will generally be near the lower limit on large trees and near the upper limit on small trees. The rate of growth and locality may, however, affect the issue. Fast growth on sheltered sites generally makes for thinner bark than slow growth on poor sites."

Smith, Ker, and Csizmazia (1961) gave several estimates of bark thickness of young Douglas fir, hemlock, and cedar.

Stanek (1966) found that bark expressed as a percentage of volume of wood and bark of young lodgepole pine trees decreased with dbh as  $16.6 - 0.59$  dbh. He found that bark volume percentage of young Engelmann spruce decreased with dbh as  $17.8 - 0.40$  dbh.

### Sapwood thickness and distance from live crown

The 58 young Douglas fir trees and their 437 sections studied by Smith, Walters, and Wellwood (1966) to define variation in sapwood thickness were also analysed to determine factors influencing bark thickness. There was a relatively minor influence of dbh ( $r.23$ ), crown class ( $r.19$ ), and years to base of live crown ( $r.09$ ) on dbt of all sections. Dbt decreased with height of section above ground ( $r-.73$ ), with section height as a percentage of total height ( $r-.80$ ) and with distance of section from base of live crown ( $r-.83$ ). Dbt increased with: decadal radial growth of wood ( $r.23$ ), number of years in sapwood

(r.34), width of sapwood (r.63), number of years above or below the base of the live crown (r.72), number of rings from pith (r.79), section dob<sup>2</sup> (r.86), and section dob (r.88).

### Stand density

With the exception of alder, the data in Table 17 suggest that trees grown rapidly in the open have thicker bark at breast height than those of the same dbh grown much more slowly. The difficulty of interpreting these data is great and the whole question deserves further study. For example, dbt of Douglas fir and hemlock increased significantly with number of sides free from competition and with the ratio of crown width to dbh as might be expected. However, dbt also increased with basal area per acre, possibly because of the association of increased basal area with age and dbh.

Hale (1955) observed that some very fast growing young white spruce (perhaps open grown) had unusually thick bark.

TABLE 17 Influence of Stand Density on Bark Thickness

Species	Source	No.	Forest Grown			No.	Open Grown		Age Yr.
			Dbh In.	Dbt %	Age Yr.		Dbh In.	Dbt %	
Alder	Apsey (1961)	50	10.3	3.3	30	72	11.4	3.5	24
Cottonwood	Pearson (1962)	40	14.1	5.9	37	47	16.2	3.5	28
Douglas fir	Johnson (1962)	39	11.0	8.6	70	35	11.0	17.4	44
Engelmann spruce	Johnson (1962)	21	11.0	7.0	81	33	10.0	7.8	40
Lodgepole pine	Bailey (1964)	63	9.2	6.9	42	111	8.2	10.3	35

### Bark thickness of roots and branches

Table 18 contains data secured from the trees studied by Smith (1964). Although the form of each relationship varies and differs slightly from species to species, data are summarized by dbt as a percentage of median dob for each class. Root bark is relatively thick and root collar bark relatively thin for alder, cedar, Douglas fir, and hemlock. Root bark thickness of cedar was relatively and absolutely much thinner than that of the other three species.

The last line of Table 18 provides a comparison with data collected earlier by Smith, Ker, and Csizmazia (1961) which agree well with these with the exception of hemlock. Branch bark thickness was highly variable but significantly correlated with dob which accounted for 10 to 20 per cent of the variation in cedar, 25 to 36 per cent in hemlock, and 50 to 50 per cent in Douglas fir (Smith, Ker, and Csizmazia, 1961).

TABLE 18 Bark Thickness of Roots and Branches

Source of data	Dob In.	<u>Species, number of samples and percentage dbt</u>							
		Alder		Cedar		Douglas fir		Hemlock	
		No.	%	No.	%	No.	%	No.	%
Roots	3.5	28	11.5	32	4.6	53	15.5	49	13.5
Root collar	16.0	33	4.7	61	4.3	89	11.9	81	4.6
Branch butt	1.5	33	10.7	54	12.7	80	12.7	56	13.3
Branch middle	1.3	33	9.2	54	13.9	80	11.6	56	13.1
Butt and middle branches	-	-	-	60	12.7	76	13.1	36	9.6

Specific gravity of bark

Hale (1955) reported the following ranges in basic density of bark, green volume: Balsam fir 0.35-0.43; Black spruce 0.35-0.44; White spruce 0.32-0.37; Jack pine 0.30-0.41; White birch 0.48-0.56; Trembling aspen 0.46-0.54. With the exception of aspen in which it increased, bark specific gravity decreased from stump to top of the bole.

Dobie (1965) summarized all available data on weights and moisture contents of the bark some North American conifers. His limited data for old growth on the B. C. Coast showed that oven-dry hemlock bark weighed 34 pounds per cubic foot, Douglas fir 31, and western red cedar 21. Eastern balsam fir bark weighed 31, Black spruce 24, White spruce 28, and Jack pine 33 pounds per cubic foot.

Specific gravity of bark of 20 Douglas firs from the U.B.C. Campus Forest aged 10 to 75 years was studied recently. Bark specific gravity of roots was 0.41, at breast height 0.38, at half total height 0.31, and of branches was 0.33. Specific gravity of bark at half the total height of the six 10-year-old trees was very low, only 0.21. Bole bark specific gravity of the 14 Douglas fir trees, 20 to 75 years old, averaged about 0.35 or 22 pounds per cubic foot. When compared with Dobie's (1965) data on specific gravity of old growth Douglas fir these data confirm Hale's (1955) observation that bark specific gravity increases with tree and section age.

Besley (1966) summarized available data on density and moisture. He observed that bark weights expressed as a percentage of rough tree weight were 12-15 for balsam fir, 16 for jack pine, 10-12 for eastern spruces, and 12 for paper birch.

Obviously, further studies of bark specific gravity are needed. Even the U. S. Forest Products Laboratory has data on bark specific gravity for only one tree from each of the tree species of the U. S. A.

Volume and weight of bark logged in B. C.

Kokoschke (1965) suggested that for every hundred cords of wood processed in a pulp mill 6 to 8 tons of bark (oven-dry) are obtained. He also said that for every M fbm of lumber cut in a sawmill roughly 500 pounds of bark is available.

The report of the B. C. Forest Service for 1965 included the data shown in Table 19 on cubic foot volumes logged that year. These can be combined with data from our Tables 4 and 5 and various estimates of bark density to give information about volumes and weights of bark potentially available for improved utilization.

The estimates in Table 19 must be reduced by a correction for fissures and scales which decrease the actual volume of bark available. In addition bark will be lost in every phase of logging and storage up to the point at which bark is removed to facilitate further processing of the logs. No data are available for estimation of these losses. Loose piling of bark will roughly double the volumes calculated here. In addition machine peeling of bark from poles and piling may remove as much outer wood as bark (Weldon, 1966).

TABLE 19 Production of wood and bark in British Columbia, 1965

		Bark					
		Solid wood	Dob	volume	volume	Wt.	Wt.
		M cu. ft.	%	%	M cu. ft.	per	M tons
						cu. ft	
Douglas fir	Coast	204,381	13	32	65,500	31 <sup>1</sup>	1,011.0
	Interior	175,348	14	35	61,400	31 <sup>1</sup>	950.0
Cedar	Coast	169,735	6	14	23,800	21 <sup>1</sup>	249.0
	Interior	35,014	7	16	5,600	21 <sup>3</sup>	59.0
Spruce	Coast	39,782	3	6	2,400	28 <sup>1</sup> , 29 <sup>2</sup>	33.9
	Interior	278,529	6	14	39,000	28 <sup>3</sup>	546.0
Lodgepole pine	Coast	152	5	11	17	33 <sup>1</sup>	.3
	Interior	81,104	5	11	8,900	33 <sup>3</sup>	147.0
Hemlock	Coast	300,365	8	18	54,100	34 <sup>1</sup> , 29 <sup>2</sup>	851.0
	Interior	42,351	9	21	8,900	30 <sup>3</sup>	133.5
Balsam	Coast	125,740	5	11	13,700	32 <sup>2</sup>	221.8
	Interior	30,660	6	14	4,300	31 <sup>1</sup>	67.5
White pine	Coast	3,963	6	14	555	33 <sup>3</sup>	9.1
	Interior	6,149	6	14	861	32 <sup>3</sup>	13.8
Yellow pine	Coast	1	13	32	0	31 <sup>3</sup>	0
	Interior	8,436	13	32	2,700	31 <sup>3</sup>	44.7
Cypress	Coast	10,171	5	11	1,120	21 <sup>3</sup>	11.8
Larch	Interior	16,007	14	35	5,600	31 <sup>3</sup>	92.5
Hardwoods	Coast	974	6	14	136	31 <sup>3</sup>	2.3
	Interior	93	7	16	15	31 <sup>3</sup>	.2
Cottonwood	Coast	3,054	9.5	22	671	31 <sup>3</sup>	10.4
	Interior	1,105	9.5	22	243	31 <sup>3</sup>	3.8
Total	Coast	853,318			161,999		2,400.6
	Interior	674,796			137,519		2,058.0
	B. C.	1,528,114			299,518		4,458.6

<sup>1</sup> From Dobie (1965).

<sup>2</sup> Provided by Don Stewart, MacMillan Bloedel.

<sup>3</sup> Estimated for this study; all estimates of bark weight per cubic foot must be confirmed by further study.

### Current values of bark

Boyd (1965) reported prices per 200 cubic foot unit of hog fuel made of bark, sawdust and other sawmill residues. Douglas fir was worth 50 cents, hemlock/balsam 20 cents, and cedar nothing. During milling of one M fbm of logs 0.5 units of Douglas fir bark, 0.3 units of hemlock/balsam or 0.2 units of cedar can be expected on the coast of B. C. These would be the rough equivalent of 1200 pounds dry weight of Douglas fir bark 720 pounds of hemlock/balsam bark, and 300 pounds of cedar bark. Assuming that bark has the same value as wood, 8,600 BTU per pound, the energy available is considerable even after allowance for removal of bark moisture, which amounts to about 1,100 BTU at 50 and 1,600 BTU at 100 per cent moisture content on an oven dry basis.

Kokoschke (1965) tabulated fuel values of various barks, expressed as heat of combustion at air dry conditions (4 to 6 per cent moisture). Expressed as BTU per pound these were 8861 for Balsam fir, 8204 for Larch, 8246 for Black spruce, 8761 for Jack pine, 8302 for Eastern hemlock, 7301 for Sugar maple, 7947 for Yellow birch, 8433 for Aspen, and 5995 for White oak.

Mr. Puppin of H. A. Simons Ltd. estimated that generation of steam from bark will cost roughly half as much as steam from bunker "C" grade fuel oil. Costs per million BTU of steam average 20 to 25 cents from bark and about 55 cents from fuel oil. Assuming that combustion of bark is quite incomplete and moisture content extreme it might take four pounds of bark to equal the heating content of a pound of bunker "C" fuel oil (13.2 M BTU). Then the cost of replacing a pound of fuel oil with a pound of bark will be about 0.27 cents. If burning efficiency could be improved to near optimum the fuel oil replacement cost of a pound of bark would be about 0.4 cents.

Since number three sawlogs which are often used for manufacture of pulp sell for roughly one cent per pound in the Vancouver Log Market there would appear to be considerable incentive for research into finding ways in which bark could supplement or replace wood in various kinds of pulp and fiber boards. These data also can estimate the replacement cost for bark as a raw material in processes for extraction of organic chemicals from bark.

Literature on bark removal was summarized by Perem (1958).

### Conclusions

Our equations describing distribution of bark on the commercial trees of B. C. can be used as required to convert outside bark measurements of form and taper to inside bark values.

Further work is needed to find better values for estimation of specific gravity of bark. However, those presently available are adequate to roughly indicate a maximum yield of about 4.4 million oven dry tons of bark from the 1.5 billion cubic feet of wood logged in 1965 in B. C. The volume of bark involved is about 300 million cubic feet, roughly 20 per cent of the current annual cut of wood.

Bark is either not used or rather poorly used, today in B. C. Therefore, fundamental research should be directed toward securing the information needed to utilize commercially much more of this vast storehouse of fibers and organic chemicals.

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