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Complete-Tree Utilization An analysis of the Literature Part III: Branches

J. L. Keays

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An Analysis of the Literature
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BY
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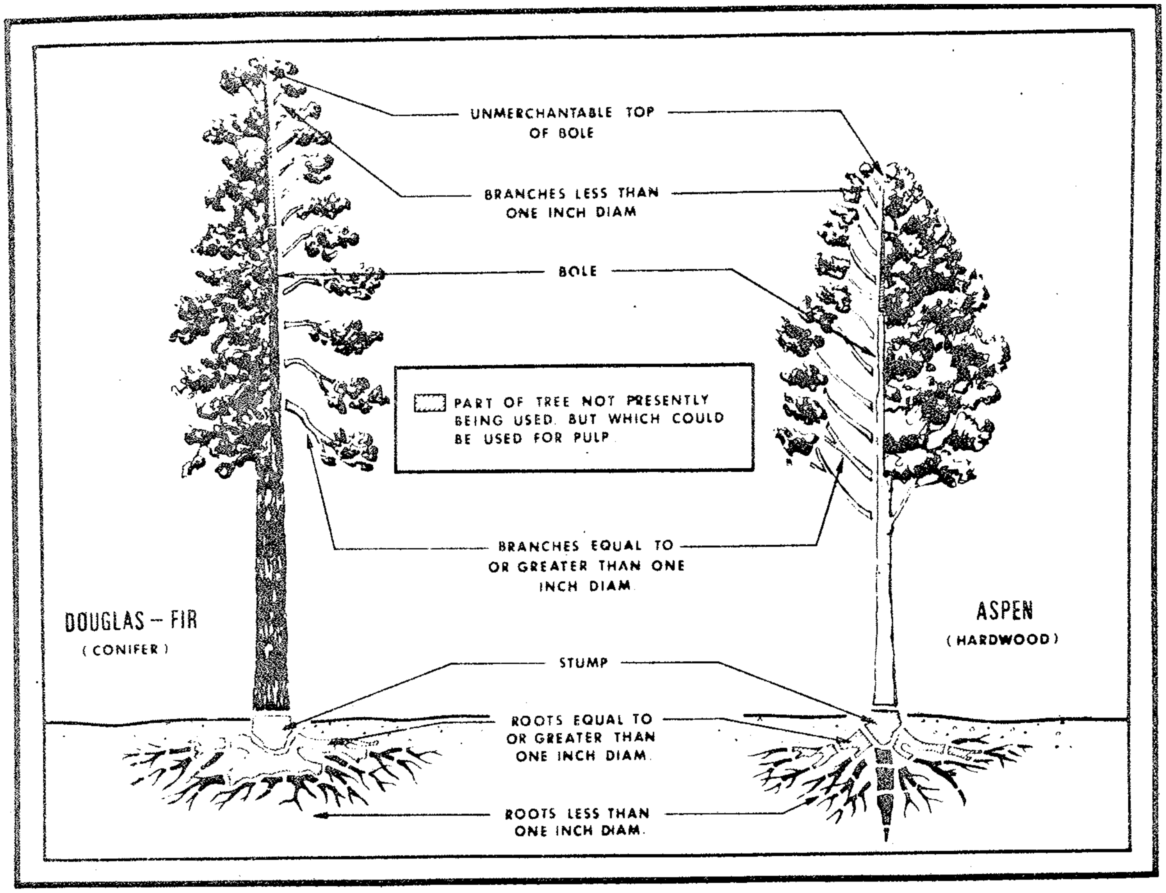

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An Analysis of the Literature

PART III: Branches

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RESUMÉ

Literature values for branch biomass on a standard basis (oven-dry and bark-free branches as a percentage by weight of oven-dry and bark-free full bole) vary from 1 to 1000%, depending upon tree species, stand density, tree size, and definition of branches. Percentage branches for most softwood pulping species would be expected to lie between 5 and 15% (standard basis). Percentage branches for high stand densities and mature trees would lie on the low side of this range; for low stand densities, good sites, young trees and hardwood species, the percentage branches would lie on the high side of this range. The amount of branches suitable for pulp would be a third to a half of the total branches for trees of approximately 8 inches dbh. It is recommended that in future studies branch biomass be determined for branches:

1. Greater than 1-inch diameter; suitable for pulping.
2. Less than 1/4-inch diameter; include with foliage for chemical extraction.
3. Branches between 1/4- and 1-inch diameter; usually not suitable for pulping or chemical extraction, but could be used for fuel, composition board, pyrolysis, etc.

In determining branch biomass for possible utilization, the following variables should be included:

Tree species...Critical

Tree height..Critical

Stand density..Critical

Site index...Unknown

Tree age and dbh.....................................Major

Time of year...Major

Stump height ....Minor

Other factors (dominance, genetics, taper, etc.) .....Unknown

Limited data are available on the specific gravity, percentage bark and moisture content of bole and branches, and it is not possible to convert green, bark on, or volume percentages to the standard basis.

Literature data on the quality of pulps from branches is contradictory; indicating that branch pulp, compared with bole pulp, is equal in quality, slightly or somewhat lower, or appreciably lower in quality. Kraft pulp at 20 permanganate number from the branches of most coniferous pulpwood species, compared with bole pulp, would be expected to be approximately 30% lower in yield, 20-30% lower in tear factor and 40-50% lower in breaking length and burst factor. Branch pulps have a short beating time and a high percentage stretch. Little work has been done on mixtures of branch pulp with other pulps, or processing combined bole-branch pulps, or on the use of branch pulp in papermaking. The lower yield and strength characteristics of branch pulp can be explained in part for coniferous species by the high content of compression wood in branches, with consequent high lignin and low cellulose contents.

Other potential uses for branch wood include conversion to cattle fodder, chemicals, power, and a variety of composition or fiber boards.

COMPLETE-TREE UTILIZATION -- An Analysis of the Literature

Part III[a]: Branches

by J. L. Keays

INTRODUCTION

Part I (41) of the present review series gives background on the concept of complete-tree utilization; that is, use of tree components other than boles -- tops, foliage, branches, stumps, roots and bark -- for conversion to fiber or other products.

With respect to branches, a problem arises concerning how they should be defined for purposes of complete-tree utilization. The data available on the processing of branches for pulp manufacture indicate that large branches give pulp inferior in yield and strength to pulp from comparable boles, but there is no reason to believe that insurmountable difficulties would be encountered in barking and chipping branches of large diameter. It can be assumed that in the utilization of branches greater than, say, 1-inch diameter, it would be technically possible, if not economical, to delimb, debark, chip and pulp. Markets might be found or developed for branch pulp -- for a secondary grade of pulp, in admixture with bole pulp, for fiber board, etc. However, several complicating factors arise in considering the utilization of branches less than 1-inch diameter as a source of raw material for pulp manufacture in the near future:

1. The quality of pulp would be lower than that of pulp from larger branches; the yield would be lower, and market acceptability of the pulp might be a serious problem at the present time.

2. The wood content of branches decreases with decreasing diameter, the percentage bark and extractives increase, and the over-all yield across the digester for branches less than 1-inch in diameter would be quite low.

(a) Part I: Unmerchantable Top of Bole -- reference 41.
Part II: Foliage -- reference 42.

3. It would be difficult to debark and to chip branches of small diameter with conventional processing equipment, and equipment specifically designed for the purpose would have to be developed. The cost of processing small-diameter material would be high, since the economics of barking, for example, are dependent upon through-put rate, which would decrease rapidly on a weight basis with decreasing branch diameter.

4. If the percentage of vitamins, sterols, etc., is generally high in smaller branches, twigs, and shoots, as has been found to be true for *Pinus sylvestris* and *Picea excelsa* (42), these tree components should be included with the foliage in any chemical extraction process.

Because of these various factors, there are reasons for a division of branches into at least two size categories. In line with the classification used by H. Young in his complete-tree utilization studies (111), it is recommended that in branch biomass studies the weight percentage of branches, percentage bark, and percentage moisture be determined for at least two size categories -- less than 1-inch diameter and 1-inch diameter or greater, as a minimum, and preferably to include three categories:

1. Branches less than 1/4-inch diameter;

2. Branches greater than 1/4-inch diameter and less than 1-inch diameter;

3. Branches 1-inch diameter or greater.

It would be most desirable to have firm data on:

- the weight of water, fiber and bark for all branches; such information would indicate the weight of material which would have to be transported and processed.

- the weight of water, fiber and bark for all branches 1-inch diameter and greater; this represents somewhat of an upper limit on the amount of material which could be barked and chipped with present equipment, and which would be expected to give a reasonable fiber yield and acceptable pulp quality.

- the weight of water, fiber and bark for all branches up to 1/4-inch diameter; this represents that part of the branches which could be used for chemical extraction or conversion, along with the foliage, twigs, etc.

BIOMASS

Percentage Branches as a Function of DBH -- Standard Values.

Table 1 gives the percentage branches (standard basis) for a number of wood species as a function of dbh. All except three species shown in the table (*Pinus strobus, Thuja plicata* and *Tsuga heterophylla*) show increasing percentage branches with an increasing dbh of more than 6 inches.

It should be noted that the data in Table 1 refer to branches greater than 1-inch diameter, with the exception of *Tsuga heterophylla* and *Thuja plicata.* This can be interpreted to mean that the percentage of branches which can be converted to pulp in many cases will increase slightly with increase in dbh from 8 to 14 inches. Typical is the 2 to 3% increase for *Abies balsamea* and 8 to 10% increase for *Acer rubrum.* The data indicate a slight decrease from 4 to 3% for *Pinus strobus.* With some species (*Picea rubens, Pinus contorta* var. *latifolia* and *Acer rubrum*) the increase in percentage branches with increasing dbh appears to be quite marked. As discussed below, the percentage branches is so highly dependent upon tree height, stand density, site index and season, that the above trends can be considered indicative only.

Percentage Branches as a Function of DBH -- Oven-dry and Bark-on Basis.

For the wood species listed in Table 2, there appears to be three trends in the relationship between percentage branches and dbh:

- Percentage branches decreases with increasing dbh -- *Picea glauca* (49), *Pinus sylvestris* (76), *P. taeda* (71).
- Percentage branches remains relatively constant over a wide range of dbh -- *Picea mariana* (102), *Pinus contorta* var. *latifolia* (49, 72).
- Percentage branches increases with increasing dbh -- *Abies balsamea* (9).

TABLE 1

Branches as a Percentage by Weight of Full Tree Bole and as a Function of DBH

Branches: oven dry and bark free
Full Bole: oven dry and bark free

Reference number	Wood species	No. of trees sampled	Branches as a % of Full Tree Bole				
			Diameter breast height, inches				
			6	8	10	12	14
115	*Abies balsamea*[1]	23	1	2	2	3	3
113	*Picea rubens*[1]	25	1	4	6	8	9
36	*Pinus contorta*[2] var. *latifolia*	22	3	5	7	9	11
115	*P. strobus*[1]	27	1	4	5	4	3
17	*Thuja occidentalis*[1]	21-36	1	3	4	6	..
19	*T. plicata*[2,3]	8	..	15	11	9	9
115	*Tsuga canadensis*[1]	28	5	7	8	10	12
19	*T. heterophylla*[2,3]	8	7	6	5	5	..
111,113,114	*Acer rubrum*[1]	20	3	8	11	11	10
115	*Betula papyrifera*[1]	17	7	9	12	14	..
115	*Populus* sp.[1]	14	5	11	14	14	..

1. Branches: equal to or greater than 1-in. diameter;
   Stump: 6 inches above ground level.

2. Stump: 12 inches above ground level;
   Branches: all branches included.

3. Branches are assumed to comprise 60% of the foliage weights for trees evaluated in this study.

TABLE 2

Branches as a Percentage by Weight of Full Tree Bole and as a Function of DBH

Branches: oven dry and bark on
Full Bole: oven dry and bark on

Reference number	Wood species	No. of trees sampled	Branches as a % of Full Tree Bole, Diameter breast height, inches: 4	6	8	10	12
9	*Abies balsamea*[1]	190	16	24	34	38	..
49	*Picea glauca*[4]	60	..	61	50	39	32
102	*P. mariana*[2]	20	12	16	..	..	..
49	*Pinus contorta* var. *latifolia*[4]	101	11	9	9	10	10
72	*P. contorta* var. *latifolia*[2]	405	14	12	14	..	..
29	*P. densiflora*[3]	...	..	9	10	12	19
69	*P. densiflora*[3]	38	26	20	21	28	..
76	*P. sylvestris*[4]	21	54	38	27	..	..
79	*P. sylvestris*[3]	20	17	23	..	..	..
71	*P. taeda*[3,5]	10	56	36	26	23	..

1. Stump: ground level.
2. Stump: 12 inches above ground level.
3. Stump: ground level.
4. Stump: not specified.
5. Bole: bark free and oven dry.

Inconsistencies between these values and the standard values might be expected to arise from the fact that, whereas the percentage bark on boles may vary only slightly with dbh, the percentage bark on branches can vary quite markedly with branch diameter (Tables 3 and 5) and by indirection, with tree dbh (Table 3, *Abies balsamea*). The percentage branches (bark-on basis) may show a marked change with decreasing dbh, but if the branch size decreases markedly with decreasing dbh, the percentage branches on a standard basis would show appreciably less change with dbh, since the correction for percentage bark on branches on a tree at, say, 4-inches dbh could be high.

Percentage Bark on Branches

The percentage bark on branches is highly variable, depending upon wood species and more particularly upon branch diameter. This is indicated indirectly in Table 3 for *Abies balsamea* (7, 8, 114). The same marked trend for increasing percentage bark with decreasing branch diameter is shown in Table 4 for *Pinus sylvestris* and *Picea abies* and in Table 5 for *Eucalyptus obliqua* (6) and for *Populus* sp. (35, 90). As discussed in previous sections (41, 42) this relationship is an important one in attempting to derive standard values from data obtained on a bark-on basis. For a given wood species, the smaller dbh of trees, the smaller the diameter of branches and the higher the percentage bark on both bole and branches, the percentage bark being as high as perhaps 60% on very small-diameter branches. This trend is also illustrated in Table 3, which shows the relationship between branch diameter and percentage bark for *Tsuga heterophylla* (45).

TABLE 3

Percentage by Weight of Bark on Branches -- Coniferous Species.

Branches -- oven dry and bark free
Bark -- oven dry

Reference number	Wood species	No. of trees sampled	Dbh, inches	% Bark on branches[1]
7,8	*Abies balsamea*	89	5.6	71.5
114	*A. balsamea*	1	8.2	28.1
39	*Picea excelsa*	..	Mature	18.4
35	*P. excelsa*	..	Mature	17.0
64	*P. excelsa*	..	Mature	39.6
7,8	*P. glauca*	2	4.4	67.5
60	*P. rubens*	6	6-11	30.0
114	*P. rubens*	1	7.6	15.0
35	*Pinus sylvestris*	..	Mature	17
39	*P. sylvestris*	..	Mature	18.4
114	*P. strobus*	1	8.9	26.7
17	*Thuja occidentalis*	1	8.4	35.6
114	*Tsuga canadensis*	1	8.1	21.7
45	*T. heterophylla*[2]	1	8.5	16.3
		1	14.0	19.1
		1	18.0	17.6

1. Percentage assumed to be on a basis of bark-free branches in all cases.
2. Average branch diameters range between 1 and 2 inches.

TABLE 4

Percentage of Bark on Branches of Various Diameters
-- *Pinus sylvestris* and *Picea abies*.

Reference: 26

Wood component	Bark % by Weight[1]	
	Pinus sylvestris	*Picea abies*
Unmerchantable top	15.0	22.9
Living branches		
Less than 1 cm diam.	55.0	57.0
1-2 cm	26.9	28.1
2-4 cm	15.7	20.9
4-6 cm	10.8	14.7
6-8 cm	7.9	....

1. Bark as a percentage of wood plus bark, oven-dry basis.

TABLE 5

Percentage by Weight of Bark on Branches -- Deciduous Species

Bark: Oven dry
Branches: Oven dry and Bark free

Reference number	Wood species	No. of trees sampled	Bole dbh, inches	% Bark on Branches[1]
114	*Acer rubrum*	1	7.6	26
7,8	*Betula papyrifera*	7	4.4	37.0
114	*B. papyrifera*	1	8.4	31
35	*B. verrucosa*	...	Mature	17
6	*Eucalyptus obliqua*	...	Branches less than 0.5" diam.	43
			More than 0.5" diam.	22-27
90	*Populus* sp.[1]	1	Branch diameter (inches)	
			0.1-0.24	50-56
			0.08-0.6	48-50
			0.6-0.8	32-45
			1.2	28-30
			2.0-2.76	16-19
			4.9-5.7	10-11
35	*Populus* sp.	...	Mature	22.0

1. Percentage bark is assumed to be on a basis of bark-free branches.

Percentage Branches for Various Tree Ages, Oven-dry and Bark-on Basis.

Data on the percentage branches for trees of various ages are given in Tables 6 (softwoods) and 7 (hardwoods). Only in the case of *Pseudotsuga menziesii* (ref. 78) is there an indication of decreasing percentage branches with increasing age. Any relationship between tree age and percentage branches for other wood species given in Tables 6 and 7 are probably obscured by other factors, or the data are too limited to show trends.

As discussed below, the percentage branches is critically dependent upon tree height, stand density and season. For this reason alone, the values shown in Tables 1, 2, 6 and 7 should not be compared vertically, since the data given may not refer to comparable conditions. Further, branches in the various studies reviewed are not always defined in the same way: Reference 115, *Abies balsamea* in Table 1, for example, refers to branches 1 inch or greater in diameter, whereas reference 9 in Table 2 for the same species, refers to all branches, live and dead.

Percentage Branches, Oven-dry and Bark-on Basis -- Miscellaneous Values.

A number of individual values for percentage branches are given in Tables 8 (conifers) and 9 (deciduous species). There is little comment that can be made with reference to these data, apart from the question as to the extent to which the values shown represent average values for branch biomass for the species reported. Considering the range of values given for the percentage branches for the various species of pine, from 8% for *Pinus echinata* (Table 8) to 34% for *P. koraiensis* (Table 8), the average value shown for *Pinus* species, 8%, is likely to have limited application. Agreement between values obtained for percentage branches on the same wood species is

TABLE 6

Branches as a Percentage by Weight of Full Tree Bole for Various Tree Ages -- Coniferous Species.

Branches: Oven dry and Bark on.
Full Bole: Oven dry and Bark on.

Reference number	Wood species	Stand density	Tree age, years	Branches as a % of Full Bole[1]
78	*Picea abies*	.....	39	4
			46	11
		1125/ha	52	15
		924/ha	58	17
			46	6
69	*Pinus densiflora*[2]	(38 trees)	5	62
			6	66
			8	70
			10	70
			12	65
78	*P. densiflora*	.....	16	30
			16	9
78	*P. nigra*	1112/ha	48	12
78	*P. strobus*	.....	41	24
			41	8
78	*P. sylvestris*	3640/ha	23	23
		4260/ha	33	12
		760/ha	55	13
		815/ha	64	17
78	*Pseudotsuga menziesii*	1151/ha	30	27.5
		1636/ha	32	19.7
		1151/ha	38	12
		648/ha	38	11
		1157/ha	52	10

1. Stump height, dbh and number of trees measured not specified.
2. Assumed bark on.

TABLE 7

Branches as a Percentage by Weight of Full Tree Bole for Various Tree Ages -- Deciduous Species.

Branches: Oven dry and Bark on.
Full Bole: Oven dry and Bark on.

Reference number	Wood species	No. of trees	Tree age in years	Branches as a % of full bole[1]
78	*Betula maximowicziana*	..	47	15
			47	14
			47	10
78	*B. verrucosa*	..	20	25
		4900/ha	24	25
		2350/ha	25	15
		..	40	7
		880/ha	55	20
			67	7
80	*B. verrucosa*	2 per age	6	100
			24	24
			27	13
			32	17
			38	19
			42	16
			46	17
			53	22
			55	20
78	*Cinnamomum camphora*	..	48	10
78	*Nothofagus truncata*	490/ha	110	19
78	*Quercus borealis*	800/ha	57	44

1. Stump height and dbh not specified.

not close (Table 9, *Fagus grandifolia*, ref. 77, 103), nor is agreement expected where separate studies may refer to trees growing under entirely different conditions, with differences in tree height, growth rate, stand density, wind stress, snowfall, dominance and other factors which might influence branch biomass.

Table 10 gives the percentage branches for various dbh levels as a function of branch diameter for *Pinus sylvestris* and *Picea abies*.

In Table 11, the percentage branches for *Pinus sylvestris* and *Picea abies* is given for various classes of tree branchiness.

In this study (26) the relationship between percentage branches and tree height was found to be:

$y = 23.9 + 1.42x_1^2 - 0.766x_2$ for *Pinus sylvestris* ($R = 0.901$; $S_{y.x} = 3.9\%$), and

$y = 14.0 + 2.31x_1^2 - 0.198x_1x_2$ for *Picea abies* ($R = 0.743$; x $S_{y.x} - 6.7\%$), where

y is defined as the percentage of oven-dry and bark-free branchwood as a percentage by weight of the bole, oven dry and bark on, to a 5-cm. top;

x_1 is the branchiness class (from I to IV as defined in Table 11);

x_2 is the height in meters.

Percentage Branches as a Function of Tree Height for Small Trees.

Table 12 gives the relationship between percentage branches (oven-dry, bark-on basis) and tree height for young trees. These results show an unusually high degree of consistency and uniform change within species. The relative percentage of foliage (Table 13) and branches (Table 12) for small-diameter trees indicate the different types of technology which will have to be developed if trees are going to be utilized as a crop.

TABLE 8

Branches as a Percentage by Weight of Full Tree Bole -- Coniferous Species.

Branches: Oven dry and Bark on.
Full Bole: Oven dry and Bark on.

Reference number	Wood species	No. of trees sampled	Branches as a % of full bole[1]
103	*Abies alba*	..	above 12%
7,8	*A. balsamea*[2]	89	21
103	*A. fraseri*	..	25-35
94	*Cryptomeria japonica*	29,500/ha	4
103	*Larix decidua*	..	13
77	*Picea* sp.	..	7
83	*Picea* sp.[3]	66	10
103	*P. abies*	..	above 12
7,8	*P. glauca*[2]	2	20
98	*P. jezoensis*[3]	68	17
103	*P. rubens*	..	25-35
77	*Pinus* sp.	..	8
83	*Pinus* sp.[3]	94	8
103	*P. cembra*	..	13
37	*P. contorta* var. *latifolia*[4]	85	8
103	*P. echinata*	..	8
98	*P. koraiensis*[3]	99	34
98	*P. koraiensis*	99	19
103	*P. mugo*	..	13
103	*P. strobus*	..	10
77	*Pseudotsuga menziesii*	..	7
103	*P. menziesii*	..	13

1. Dbh not specified; stump height not specified unless otherwise stated.
2. Branches, all live branches: stump, ground level: components bark free.
3. Calculated on a basis of 1 cubic meter of merchantable wood.
4. Stump height: 12 inches above ground level.

TABLE 9

Branches as a Percentage by Weight of Full Tree Bole -- Deciduous Species.

Branches: oven dry and bark on.
Full Bole: oven dry and bark on.

Reference number	Wood species	No. of trees sampled	Branches as a % of full bole[1]
18	*Alnus rugosa*	2195/ha	18
77	*Betula* sp.	..	9
103	*B. alleghenіensis*	..	30-50
7	*B. papyrifera*[4]	7	21
98	*B. verrucosa*[2]	..	17
77	*Fagus grandifolia*	..	13
103	*F. grandifolia*	..	30-50
103	*Liriodendron tulipifera*	..	14
103	*Quercus alba*	10	38
18	*Salix babiana*	2610/ha	17
18	*Vaccinium corymbosum*	3240/ha	33
95	*Acacia mollissima*[3]	15	10

1. Dbh and stump height not specified.
2. Calculated on a basis of 1 cubic meter of merchantable wood. Assumed to be *B. verrucosa*.
3. Stump: ground level.
4. Branches: all live branches.
   Stump: ground level -- both components are oven dry and bark free.

TABLE 10

Branches of Various Diameters as a Percentage by Weight of Bole for *Pinus sylvestris* and *Picea abies*.

Oven-dry and bark-on basis.
Reference: 26

Wood species	Branch diameter (cm.)	Living Branchwood as % by Weight of Bole[1] Tree DBH (cm.) Less than 25	26-35	Greater than 36
Pinus sylvestris	Less than 1.0	24	20	16
	1.1 - 2.0	16	15	13
	2.1 - 4.0	51	41	33
	4.1 - 6.0	9	22	25
	6.1 - 8.0	..	2	11
	Above 8.1	..	..	2
Picea abies	Less than 1.0	32	25	20
	1.1 - 2.0	37	27	17
	2.1 - 4.0	31	47	59
	4.1 - 6.0	..	1	4

1. Top = 5 cm. diameter and a minimum of 1 meter in length.

TABLE 11

Branches as a Percentage by Weight of Bole for Various Branchiness Classes -- Oven-dry and Bark-on Basis

Pinus sylvestris and *Picea abies*.
Reference: 26

Wood species	Tree component	Branches as % by Weight of Bole[1] Branchiness class[2] I	II	III	IV
Pinus sylvestris	Living branches	7.5	9.7	16.6	22.1
	Dead branches	0.9	1.1	1.5	10.7
	Unmerchantable top[3]	0.3	0.3	0.2	0.4
	Foliage	4.0	5.3	6.1	11.5
Picea abies	Living branches	...	12.0	17.4	29.0
	Dead branches	...	1.6	1.6	1.8
	Unmerchantable top[3]	...	0.4	0.3	0.4
	Foliage	...	13.2	15.7	24.9

1. Branches, assumed oven dry and bark free, as a percentage by weight of the bole to a 5-cm. top; bole oven dry and bark on.

2. Branchiness class defined as:
   I -- Forests with few and thin branches.
   II -- Forests with normal branchiness.
   III -- Branches thick and numerous.
   IV -- Branches very thick and numerous on the merchantable bole.

3. Unmerchantable top = 5-cm. diameter and not less than 1 m. in length.

TABLE 12

Branches as a Percentage by Weight of Full Tree Bole and as a Function of Tree Height for Small Trees.

Branches: oven dry and bark on -- Full Bole: oven dry and bark on

Reference: 110

Wood species	No. of trees sampled	Branches as a Weight % of Full Bole — Tree height in feet									
		1	3	5	7	10	15	20	25	30	35
Abies balsamea	14	493	177	108	79	56	38	29	23	20	17
Picea rubens	40	365	146	94	71	52	37	29	24	20	18
Pinus strobus	10	188	84	54	42	32	24	20	16	14	13
Thuja occidentalis	34	257	144	80	63	49	37	30	26	23	20
Tsuga canadensis	9	1100	280	172	122	85	56	42	33	28	24
Acer rubrum	40	50	34	30	27	25	22	20	19	18	18
Betula papyrifera	10	100	63	49	43	36	30	26	24	22	20
Populus tremuloides	6	...	26	22	22	20	19	18	17	16	16

Notes: Dbh range, 1 to 4 inches

Stump height: not specified, but assumed to be ground level.

TABLE 13

Foliage as a Percentage by Weight of Full Tree Bole and as a Function of Tree Height for Small Trees.

Foliage: oven dry
Full tree bole: oven dry and bark on.

Reference: 110

Wood species	No. of trees sampled	Foliage as % by Weight of Full Tree Bole									
		Tree height in feet									
		1	3	5	7	10	15	20	25	30	35
Abies balsamea	14	785	287	176	128	91	62	47	38	32	28
Picea rubens	40	1060	324	190	132	90	58	43	34	28	24
Pinus strobus	10	288	84	47	34	23	15	11	9	7	6
Thuja occidentalis	34	700	228	135	97	68	45	34	27	22	19
Tsuga canadensis	9	1800	390	228	155	103	65	46	36	29	24
Acer rubrum	40	200	65	41	30	21	15	11	9	8	7
Betula papyrifera	10	125	63	45	37	29	23	19	17	15	13
Populus tremuloides	6	300	86	52	39	27	18	14	11	9	7

Notes: Dbh range 1 to 4 inches;
Stump height not specified but probably ground level.

For 20-foot high trees, for example, the branches would vary from approximately 20 to 40% of the full bole (oven-dry and bark-on basis), depending upon the wood species, and it is unlikely that the branches would be processed or pulped separately from the bole. With small trees, the bole-top-branches division would disappear, as would the division between stump and roots. For trees between, say, 1 and 3 inches in diameter, biomass determination relating to potential utilization of tree components should probably be limited to three values (43):

- foliage, including needles, leaves, twigs, shoots, small twigs, and branches up to perhaps 0.5 inches diameter;
- all other above-ground material, including full bole and branches;
- all below-ground material, i.e., the stump-root system.

For the concept of crops of silage cellulose (66), biomass determinations will probably be reduced to above-ground and below-ground components; since in reduction to practice of this concept, it is probable that complete trees and all of their components, with the possible exception of foliage, will be comminuted and pulped. A great deal of research remains to be done on wood biomass, digester yield and pulp quality relating to various types of pulp from very young trees, since so little is presently known and the ultimate potential might be quite high.

In Figure 1, Young's data for percentage branches and percentage foliage have been plotted against tree height for *Abies balsamea* and *Populus tremuloides*.

Table 14 gives miscellaneous data on the percentage branches on small trees.

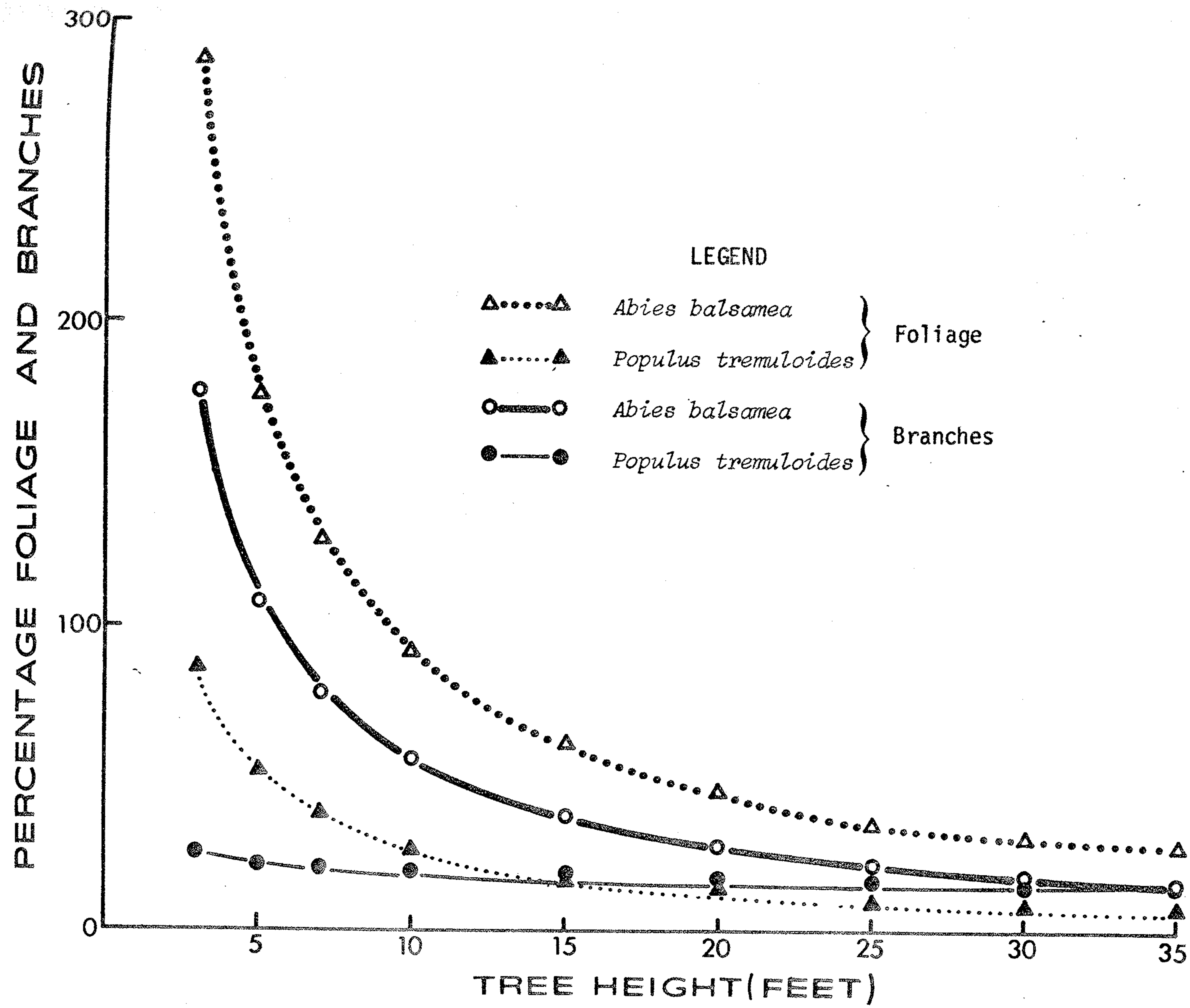

Figure 1. Percentage branches and foliage as a function of tree height for small diameter trees.

TABLE 14

Branches as a Percentage by Weight of Full Tree Bole for Small Trees.

Reference number	Tree species	No. of trees sampled	Diameter at base (inches)	Branches as % full tree bole	Notes
96	*Castanopsis cuspidata*	150,000/ha	1.0	25.9	Branches, oven dry and bark on. Full bole, oven dry and bark on.
			1.5	27.4	"
			2.0	28.9	"
96	*C. cuspidata*	40,000/ha	0.87	24.5	"
96	*Quercus glauca*	16,000/ha	0.75	26.7	"
96	*Castanopsis cuspidata*	40,000/ha	0.87	24.1	Branches, green and bark on; Full bole, green and bark on.
93	*Betula platyphylla*	9,000 to 20,000/ha	0.8	8.3	"
			1.0	9.8	
			1.2	11.2	
			1.5	12.3	
30	*Platanus occidentalis*	4	2.9-3.1	17.0	Based on weight of whole tree, bark on.
96	*Quercus glauca*	16,000/ha	0.75	29.3	Full bole, green and bark on; Branches, green and bark on.

1. Stump, assumed to be ground level.

These results confirm for additional species the trend shown in Table 12 for a high foliage biomass on young trees.

Percentage Branches as a Function of Tree Height and Stand Density.

Table 15 gives data obtained in a detailed study[b] of percentage branches in terms of tree height and stand density, considered by the authors of the study (2) to be the two most critical parameters relating branch biomass to bole biomass. The relationship between branch and bole biomass was found to be:

Percentage branches = 3,000/H D; where H is tree height in meters and D is stand density.

Studies of this type are of particular importance, not because of the absolute values obtained, but because they represent systematic studies in depth and, in particular, because they establish general relationships between critical factors affecting branch biomass.

The question arises here, as it does with all component biomass studies, of the relationship between volume and weight measurements. Some values have been reported for the relationship between volume percentage and weight percentage of branch bark (Table 16). These data show that in order to convert from a green, volumetric, bark-on basis to standard basis, the specific gravity and moisture content of the full bole, the branches and the bark on the bole and the bark on the branches would have to be known.

Table 17 gives values for the distribution of moisture in bark and wood of branches of *Pinus sylvestris* and *Picea abies*. Table 18 gives some values for the specific gravity of various components for the same species.

(b) The same type of relationship between branch biomass and stand density was also found in low-density plots in a 40-year-old *Pinus strobus* plantation (89). A number of other studies have concerned the relationship between branch biomass and stand density (62, 74, 87, 99).

TABLE 15

Branches as a Percentage by Volume of Merchantable Bole and as a Function of DBH, Tree Height, and Stand Density.

Branches assumed to be green and bark on;
Merchantable bole assumed to be green and bark free.

Reference: 2

Wood species	Dbh (in.)	Tree height (feet)	Stand density	Branches as % of merchantable bole	
				Measured	Calculated[1]
Abies sp.[2]		67	0.9	16	-
		125	0.8	10	-
		135	0.7	10	-
		138	0.7	10	-
Fagus sp.[2]		69	0.9	16	-
		105	0.8	12	-
		118	0.8	11	-
		125	0.8	10	-
		128	0.7	11	-
Picea sp.	3.9	39	0.9	28	28
	6.3	59	0.9	20	19
	7.1	62	0.9	19	18
	7.8	69	0.9	18	16
	8.7	76	0.9	17	15
Pinus sp.	4.7	39	1.0	23	25
	7.9	56	1.0	16	18
	9.4	62	1.0	15	16
	11.0	66	1.0	15	15
	12.6	69	1.0	15	14
	15.7	72	1.0	14	14

1. Calculated from the formula: $3000 = BHD$;
   where B = percentage branches by volume (based on bole volume);
   H = average stand height or tree height in meters;
   D = stand density.

   Branches consist of all branches plus twigs plus top from 1.18 inches diameter, but does not include foliage.

   The ratio between brushwood (diameter less than approximately 1 inch) and fuelwood (diameter greater than approximately 1 inch) is 30 to 70.

   Dbh is taken at a height 1.3 meters above ground level.
2. *Abies* sp. = 12 trees sampled;
   Fagus sp. = 15 trees sampled.

TABLE 16

Percentage Bark on Branches by Weight and by Volume.

Branches, oven dry and bark free; bark, oven dry.

Reference: 14

Species	% Bark by Weight	% Bark by Volume[1]
Pinus halepensis	12.6	16.7
P. laricio	17.8	28.7
P. pinaster	20.6	31.6
P. radiata	17.8	23.6
P. sylvestris	11.4	14.5
Eucalyptus camaldulensis	25.0	38.9
E. globulus	15.0	20.5
Fagus sylvatica	7.5	12.4

1. Assumed to be green volumes.

TABLE 17

Distribution of Moisture in Wood and Bark of Branches.

Reference: 27

Wood species	Tree component	Percentage moisture	
		In wood	In bark
Pinus sylvestris	Tops[1]	156	167
	Living branches		
	Less than 1 cm	...	...
	1-2 cm	126	143
	2-4 cm	121	147
	4-6 cm	109	151
	6-8 cm	93	152
Picea abies	Tops[1]	148	131
	Living branches		
	Less than 1 cm	...	...
	1-2 cm	78	111
	2-4 cm	71	111
	4-6 cm	58	123

1. Top = 5 cm. diameter and not less than 1 m. in length.

TABLE 18

Density of Branchwood of *Pinus sylvestris* and *Picea abies*.

Reference: 27

Wood component	Density in kg. per cu. meter. *Pinus sylvestris*	*Picea abies*
Av. for bole of species (Finland)	398	383
Unmerchantable Top[1]	365	399
Living branches		
1-2 cm diam.	402	531
2-4 cm diam.	410	579
4-6 cm diam.	423	621
6-8 cm diam.	455	...

1. Top = 5 cm. diameter and not less than 1 m. in length.

Table 19 gives miscellaneous values for the percentage bark (green basis) on branches; agreement between the miscellaneous values shown is rather closer than might have been expected on a basis of other data discussed above. Neither the dbh of the bole nor the diameter of the branches are given, but it is assumed that these are average values representing average mature trees.

Table 20 gives the percentage branches, oven dry and bark on, for selected tree heights obtained by Young in studies on Maine wood species.

Since the table values were obtained on trees selected from stands with even stand density, the percentage branches-tree height relationship should be affected by a limited number of other variables. The relationship between percentage branches by weight and tree height is close to that derived from the data given in Table 20. For *Tsuga canadensis*, for example, the relationship between tree height and percentage branches is precisely the same as that derived for *Pinus* sp. and *Picea* sp. (Table 15).

Percentage Branches as a Function of Site Quality.

The limited data shown in Table 21 indicate that for *Pinus thunbergii*, at least, there is no marked relationship between site quality and percentage branches. In a study of 93-year-old *Picea abies* (49 trees) at 38.9 cm. dbh, no relationship was found between the volume of branchwood greater than 3 cm. diameter and either site class or tree height (94).

Percentage Branches as a Function of Seasonal Variation.

The relationship between percentage branches and time of year at which measurements are made is quite marked (Table 22). Since branch fall occurs mainly during the period from June to March, and growth is most extensive from May to June, it would be expected that the highest branch biomass would

TABLE 19

Bark as a Percentage by Weight of Branches -- Miscellaneous Values.

Bark, green (assumed); branches, green (assumed).

Reference	Wood species	No. of trees	% Bark on branches[1]
35	*Picea* sp.	...	17
35	*Pinus* sp.	...	17
35	*Betula* sp.	...	17
35	*Populus* sp.	...	22
30	*Platanus occidentalis*	4	16

1. Dbh of bole and branch diameter not specified.

   Bark on branches is given as a percentage of the wood weight in the branches; bark and branches assumed to be green.

TABLE 20

Selected Values for Branches as a Percentage by Weight of Full Tree Bole and as a Function of Tree Height for Small Trees.

Bole and branches, oven dry and bark on.

Reference: 110

Wood species	Branches as a % of Full Bole Tree height in feet 5	 10	 20
Abies balsamea	108	56	29
Picea rubens	94	52	29
Pinus strobus	54	32	20
Thuja occidentalis	80	49	30
Tsuga canadensis	172	85	42

TABLE 21

Branches as a Percentage by Weight of Full Tree Bole and as a Function of Site Quality.

Species: *Pinus thunbergii*; 5-8 trees tested for each site.

Reference: 4

Plot	Site Quality	As a % of full bole[1] Branches	Foliage	Ratio of foliage to branches.
1	Good	34	36	1.1
2	Good	42	36	0.9
3	Moderate	46	57	1.2
4	Poor	39	58	1.5
5	Good	45	43	1.0
6	Moderate	50	51	1.0

1. Trees probably cut at ground level; branches and full bole assumed to be oven dry and bark on.

be found in the May-June period. The fact that the maximum values for small-diameter *Pinus densiflora* are 30-35% higher than the minimum values shows that for meaningful or accurate branch biomass determination, particularly where these determinations may be related to potential use, the time of year when the measurements are made may be critically important.

The question of the ratio between foliage and branches[c] biomass was considered in Part II (42) of the present series. Of particular interest is the variation in this ratio as a function of season, as shown in Table 23.

Ratio of Living to Dead Branches.

In many of the biomass studies discussed in the present review, no distinction is made between living and dead branches. An indication of the ratio of dead to living branches is shown in Table 24.

Volume and increment tables have been prepared for branch biomass of *Pinus sylvestris*, *Picea abies* and *Populus* (84*), *Salix alba* (119), *Juglans regia* (51), and a number of Siberian wood species (25).

Percentage Branches -- Miscellaneous Values.

The two outstanding characteristics of the miscellaneous values for percentage branches shown in Table 25 are the wide range of values and the lack of uniformity in reporting. Because of the relationship between branch biomass and stand density, season, tree height, and other unknown factors, it is not reasonable to expect agreement between branch biomass values where these parameters have not been taken into account.

(c) For *Pinus radiata* it was found that the branch weight = root weight /0.69, all weights oven dry and assumed to be bark on (105).

* The use of these tables has been criticized by Ledvik (61).

TABLE 22

Branches as a Percentage by Weight of Full Tree Bole and as a Function of Seasonal Variation.

Species: *Pinus densiflora*

Reference: 28

Tree diameter (inches)	Foliage as a Percentage of Bole[1] Period of sample selection				
	April 25 1964	May 27 1964	June 26 1964	July 30 1964	March 30 1965
0.63	38	49	51	39	36
0.83	64	77	79	63	56
1.18	127	135	142	118	89

1. Stem, assumed to be full bole, probably cut at ground level; branches, green and probably bark on; stem, same as branches. Tree age: approximately 7 years.

TABLE 23

Ratio of Foliage to Branch Biomass as a Function of Seasonal Variation.

Species: *Pinus densiflora*

Reference: 28

Tree diameter (inches)	Foliage to Branchwood Ratio Period of sample selection April 25 1964	May 27 1964	June 26 1964	July 30 1964	March 3 1965
0.63	2.0	1.6	1.6	1.3	1.3
0.83	1.7	1.5	1.5	1.2	1.0
1.18	1.3	1.4	1.4	1.1	0.96

TABLE 24

Percentage of Dead and Living Branches by Weight for *Pinus sylvestris* and *Picea abies*.

Oven-dry and bark-on basis.

Reference: 26

Tree component	Percentage Branches by Weight[1] *Pinus sylvestris*	*Picea abies*
Living branches	91.3	95.1
Dead branches	7.4	3.9
Unmerchantable top (to 5 cm. diameter)	1.3	1.0

1. Branches, oven dry and bark on, as a % by weight of bole to 5-cm top, oven dry and bark on.

TABLE 25

Branch Biomass -- Miscellaneous Values.

Reference number	Wood species	Percentage branches	Assumed basis	Comments
83	*Pinus sylvestris*	8% of bole wood	Green volume, bark on.	.....
83	*Picea excelsa*	10% of bole wood	Green volume, bark on.	.....
55	Canadian sp. *Picea mariana* *Pinus banksiana* *Abies balsamea*	Large branches = 5-30% of total tree	Green weights, bark on.	.....
	"	7% of above-ground tree	Green weights, bark on.	.....
3	*Pinus* sp.	4-5% of slash	Volume, green, bark on.	.....
3	*Picea* sp.	6-12% of slash	Volume, green, bark on.	.....
15	U.S. forests	Branches + tops, 10% of the tree.	Green weights, bark on.	
91	*Pinus palustris*	9% of full-tree bole	Standard basis	Stump 4" from ground; dbh 8.75"-- 1 tree measured.
96	*Betula platyphylla*	27% of full-tree bole	Standard basis (branches with bark on)	Cut at ground level; dbh = 3".
7,8	*Abies balsamea*	21% of full bole	Standard basis	Stump 6" dbh = 6"
7,8	*Picea glauca*	20% of full bole	Standard basis	"
7	*Betula papyrifera*	21% of full bole	Standard basis	"

TABLE 25, cont'd.

Reference number	Wood species	Percentage branches	Assumed basis	Comments
104	*Liriodendron tulipifera*	14.3% of full bole	Branches, bark on; bole, bark on; both o.d.	Stump not specif. dbh 13.35"
104	*Quercus alba*	38% of full bole	"	dbh 17.6"
104	*Pinus echinata*	10.1% of full bole	"	dbh 13.2"
75	*Pinus radiata*	6.0% of full bole	Branches, bark on; bole, bark free; both comp. oven-dry.	dbh 16.3"
84	*Pinus sylvestris*	Volume and increment tables	See criticism by Ledvik (61)	
	Picea abies	"		
	Populus sp.	"		
119	*Salix alba*	"		
51	*Juglans regia*	"		
25	Siberian sp.	"		

Summary.

The various values presented in Tables 1 to 25 on branch biomass indicate the following general conclusions:

1. The most important variables relating to the percentage branches on a volume or weight basis, oven dry or green, with bark on or bark free, are:

   - Tree species: the percentage branches can probably vary at least 10 fold under otherwise similar conditions, depending upon wood species only.
   - Tree height: for many coniferous species, at constant stand density, the percentage branches will roughly double when tree height is reduced to one half. This relationship holds true over a broad range of tree heights.
   - Stand density: over a stand density from, say, 1.0 to 0.5, and at constant tree height, the percentage branches will roughly double if the stand density is reduced to one half.
   - Time of year when biomass is measured: for one species (*Pinus densiflora*), the difference in minimum and maximum percentage branches was 50 to 35%, depending upon the time of year when the biomass measurements were made.

2. The relationship between percentage branches and dbh or tree age shows no marked trend, the relationship being sometimes positive, sometimes negative, and sometimes neither. The effect of stand density and tree height on percentage branches appears to be the dominating one for a given wood species, so that other factors, such as tree age

or dbh, are likely to be obscured. The interaction of stand density, dbh, tree height and age, season, growth rate, site index, etc., for various wood species remains an unexplored research field.

3. With decreasing branch diameter and tree-bole diameter, there is generally an increase in percentage bark, particularly at small diameters; consequently it is not possible to use an average percentage bark for either branches or boles to convert bark-on data to bark-free data.
4. Other factors known to affect branch biomass, or expected to influence branch biomass by analogy with factors influencing foliage, include tree taper (26), dominance, moisture availability, fertilization, wind exposure and genetic structure (39).
5. Reliable data are not available for the percentage moisture in wood and bark, nor for the specific gravity of branches, bole or bark for any wood species, and it is not possible to convert green volume data to standard values.

Literature data on branch biomass are sparse, inconsistent and incomplete[d], and standard techniques for determining and reporting branch biomass have not been developed. Data relating to the standard value biomass of branches are, with but very few exceptions, insufficient to permit even a rough feasability study on branchwood use. As a first approximation, the percentage branches for most major pulpwood species would be expected to lie between 5 and 15% on a standard basis. For high stand densities and mature trees, the percentage branches will tend to be on the low side of this range. For low stand densities, good sites and young trees, the percentage branches will tend to be on the high side of the range between 5 and 15%, standard basis.

(d) As noted by Leif Holt (55): "It would appear that no figures can be presented which would express regional averages for the proportion of material in different parts of the tree.

UTILIZATION

General

Based on present knowledge, technology and markets, application of the complete-tree utilization concept to the various tree components is likely to develop as follows:

Unmerchantable top of bole: high use potential; tops down to 1-2 inches diameter, can and should be used for pulping.

Foliage: high use potential; it can be used for extraction of vitamins, sterols, pharmaceutical chemicals, carotene, cattle fodder supplement, and essential oils.

Stump and roots: high use potential; they can be used to produce pulps comparable in yield and quality to pulps from comparable boles.

Branches and bark: use potential unknown.

Branches greater than 1-inch diameter might be barked and chipped, and the quality of the pulp might be sufficiently high to blend with bole pulp, or to find special end uses. Branches less than 1-inch diameter have a high percentage of bark, would be extremely difficult if not impossible to bark with equipment presently available, and would give a pulp too poor in quality to be marketable with the present quality demands of markets.

A number of studies have been reported on potential branch utilization, and these have been divided into the following potential use categories:

General .... Table 26
Raw material for pulp manufacture
  Pulps other than kraft .... Table 27
  Kraft process .... Table 28
Composition boards and building materials .... Table 29
Power and fuel .... Table 30
In agriculture .... Table 31
As a source of chemicals .... Table 32

TABLE 26

Utilization of Branches -- General

Reference number	Wood species	Use	Comments
88	General	Charcoal, acetic acid, methanol, turpentine, pine oil, pine tar	Generally use of branches greater than 3-4 inches diameter: products of wood distillation.
34	General	Fiber source	Variable techniques involved in the derivation of fiber from branches.
1	General	Hydrolysis	Logging slash utilization.
57	General	Charcoal, methanol, acetic acid	Pyrolysis products
112	*Abies balsamea*	Fiber preparation	General
39	*Picea* sp. *Pinus* sp. *Betula* sp.	Pulp and paper products	General; review of use of logging wastes for various products.
15	General	Pulp and paper	General; complete-tree utilization for additional fiber.
16	*Betula* sp. *Populus* sp. *Tsuga* sp. *Abies* sp. *Picea* sp.	Various types of pulp	Mixed species, combined with fruit tree prunings, gave a good quality of bleachable-grade pulp.
55	General	Various types of fiber products	Review of utilization in connection with wood wastes from full-tree logging.
65	General	Pulping	

TABLE 26 (cont'd)

Reference number	Wood species	Use	Comments
81	*Pinus* sp.	Pulp chips	Chips produced by portable equipment at harvesting site.
53	General	Pulp chips	Review on chips produced from logging waste.
92	*Pinus* sp.	Pulp chips	Potential source of chips from branchwood.
111	*Picea rubens*	Pulp chips	Branch pulps inferior to bole pulp in all cases.
113	*Acer rubrum* *Picea rubens*	Pulp chips	General: complete-tree utilization for additional fiber source.
115	*Acer rubrum*	Pulp chips	Additional fiber source.
114	*Abies balsamea* *Pinus strobus* *Tsuga canadensis* *Betula papyrifera* *Populus* sp.	Pulp chips	Additional fiber source.
49	*Picea glauca* *Pinus contorta* var. *latifolia*	Pulp and paper	General: complete-tree utilization for additional fiber.
22	*Salix alba*	Fiberboard	A high quality of fiberboard obtained from the branches.

TABLE 27

Utilization of Branches for Pulp Other than Kraft

Reference number	Wood species	Type of pulp	Comment
46	*Picea rubens*	Sulfite	Low yield of acceptable chips. Pulp low in quality compared with bole pulp.
107	*Chamaecyparis obtusa* *C. pisifera*	Sulfite Sulfate	Sulfate more suitable than sulfite; both pulps inferior to comparable bole pulps.
60	*Picea rubens*	Nitric acid	Yield lower, but strength values comparable to bole pulp.
16	*Betula* sp. *Populus* sp. *Tsuga* sp. *Abies* sp. *Picea* sp.	Sulfate, soda, sulfite	Mixed species, combined with fruit-tree prunings, gave a good quality, bleachable-grade pulp.
118	*Picea mariana*	Mechanical	Satisfactory yield and quality of pulp.
50	*Picea abies*	Sulfite	Thinnings gave satisfactory yield and good quality of pulp.
12	Kauri	Soda	Mixed with stumpwood for manufacture of pulp; yields 33 to 43%, pulp difficult to bleach but high quality and strength.
23	*Populus* sp.	Semichemical	Part of raw material supply to semichemical pulp mill.
5	General	Cold soda	25% of the pulp used for furnish in newsprint manufacture.
47	*Salix alba*	Sulfite	Pulps of good mechanical props. obtained from Mg-base liquor. NH_4-based pulp yielded pulps of higher breaking length and tearing strength, while Mg-based pulps had improved folding endurance.
48	*S. alba*	NSSC	Unbarked, yields of pulp ranged from 69 to 78%. Use for manufacture of paper and board indicated.

TABLE 28

Utilization of Branches for Pulp -- Kraft Process

Reference number	Wood species	Comment
109	*Acer rubrum* *Betula papyrifera*	High quality pulps were produced from both species.
30	*Platanus occidentalis*	Pulping of mixture (bole, branches, leaves) gave pulps comparable with bole pulps.
58	*Fagus* sp. *Populus* sp.	Pulped with other wastes (slash). Pulp unsuitable for high-strength papers, but suitable for wrapping. Logging wastes have a high knot content compared with bole.
59	Coniferous and deciduous sp. of *Picea* *Pinus*, *Fagus*, hornbeam	Pulp comparable to that from the bole in all cases.
107	*Chamaecyparis obtusa* *C. pisifera*	Sulfate more suitable than sulfite; chemical pulps inferior in strength to bole pulps.
3	*Picea* sp. *Pinus* sp.	Lower pulp quality compared with bole pulp; pulps have extremely high stretch.
17	*Thuja occidentalis*	Pulps strength inferior to those of bole pulp, with exception of stretch.
91	*Pinus caribaea* *P. palustris*	Pulp quality acceptable, but yield low.
35	*Betula* sp. *Picea* sp. *Pinus* sp.	Slightly lower in strength than bole pulp.
67	*Pinus elliottii*	Higher chemical consumption, slightly inferior strength properties.
68	*Pseudotsuga menziesii*	High-yield kraft; mixed with other wastes, including stumps. Strength properties equal to those obtained from bole pulps for corrugating medium.
24	*Pinus palustris*	Slightly higher burst factor, but lower tear factor compared with bole pulp.
106	*Tsuga heterophylla*	Lower screened yield, lower burst, tear and tensile strength compared with bole pulp.

TABLE 28 (cont'd.)

Reference number	Wood species	Comment
108	*Pinus densiflora* *Fagus sieboldi* *Quercus crispula*	Pulp yield lower, strength properties inferior to bole pulp.
73	*Picea* sp. *Pinus* sp.	More alkali required (3-5%), lower strength. Should pulp to a high yield; at high yield, 10% branches added had no effect on pulp quality.
44	*Tsuga heterophylla*	Compared with pulp from the merchantable bole, pulp from branches had 30% lower yield, 20-25% lower tear, 40-45% lower breaking length and burst factor.
70	*Pinus* sp. *Picea* sp.	Pulp produced by kraft process can be used for low-grade wrapping paper.
85	*Betula* sp. *Picea* sp. *Populus* sp. *Alnus* sp.	Unbarked birch yield gave 83% pulp. Barked birch yield gave 65% pulp. Unbarked aspen yield gave 82% pulp. Unbarked alder yield 78% pulp. Spruce cellulose yields of 70-77% based on hemicellulose used or 53-60% based on weight of barked wood used.
(a)	Maine "puckerbrush" (*Alnus*, *Betula*, *Populus*, *Acer*, *Prunus*, *Salix*)	Kraft pulp from young trees. Approximate values for branch pulp compared with bole pulp (assigned a value of 100): Pulp yield .... 80% (*Salix*=90%) Breaking length .. 80-90% Burst factor ..... 70-80% (*Alnus*=90%) Tear factor ...... from 60% (*Populus*) to 90% *Alnus*.
26	*Picea* sp. *Pinus* sp.	The chief disadvantage of kraft pulp from branches in small trees is the low brightness.

(a) Private communication from H. Young.

Comment

The low yield and strength of branch pulp can be accounted for in large part by the high percentage of compression wood in coniferous species (21, 30), the high lignin content (31, 78), high water extractives and pentosan content, and low cellulose content (31, 82, 90).

The compression wood content of branches from coniferous wood species has been found to be high (82). Branchwood differs from bole wood in its lower cellulose content and higher lignin, mannan, pentosan, and ash content (82). Studies in the Vancouver Forest Products Laboratory (31) have confirmed these general trends in branchwood.

Before branches can be used to any great extent in pulping in Canada, research and development work will have to be done on developing economical and satisfactory means of debarking and chipping, or of incorporating bark into the end product. Considerable research remains to be done on the conversion of branches to pulp, by both chemical and mechanical processes. The high percentage stretch and rapid beating characteristics of branchwood pulp should be further investigated, both for branchwood pulp alone and for mixtures of bole and branchwood pulp. The conversion of branches to mechanical or chemical-mechanical pulps remains an unexplored field.

A further area requiring research relates to synergistic effects. In studies on *Tsuga heterophylla* (44) pulped by the kraft process, no synergistic effect was found for pulp yield; that is, a 50:50 mixture of branchwood and bole wood gave the same yield of kraft pulp at 20 permanganate number as would have been expected from the yield of each component pulped separately. However, synergistic effects in pulp quality characteristics have been reported in several studies (3, 14, 30, 68, 73).

TABLE 29

Utilization of Branches -- Composition Board and Building Materials.

Reference number	Wood species	Use	Comment
52	*Pinus sylvestris* *Picea abies* *Betula* sp. *Populus* sp. *Alnus* sp.	Binderless chipboards	Manufactured from logging wastes; large branches, tops, bark and rotten wood. For use as thermal insulation.
54	General	Building materials	Manufactured from logging wastes.
11	*Pinus* sp.	Composition board	
97	General	Branchwood building blocks	Facilitates materials handling and speeds up building.
33	General	Branchwood building blocks	Thermal insulation and strength properties satisfactory.
1,38	General	Building blocks	Compression strength in branch direction, 12-21 kg/sq.cm. at a density of 650 kg. per cu. m.
32	General	Building blocks	Modified hay baler used for production of blocks from logging slash.
20	General	Arbolit or "Wood Stone"	Use of milled wood particles from logging slash as an additive to portland cement.
39	*Picea* sp. *Pinus* sp. *Betula* sp.	Building and insulating boards, cement blocks	General review of use of logging slash for a variety of products.
107	*Chamaecyparis obtusa*	Fiberboards	Fiber quite suitable for fiberboard manufacture.
27	General	Wallboard, fiberboard	Branches used with other wood wastes.
55	General	Fiberboard, agricultural uses	Review of possible uses of wood residues from full-tree logging.
108	*Quercus crispula* *Pinus densiflora* *Fagus sieboldi*	Fiberboard	Pulp essentially same in quality as bole pulp for fiberboard.
10	*Abies amabilis*	Particleboard, fiberboard and paper	Potential raw material for these products include branches.

TABLE 30

Utilization of Branches -- Power and Fuel.

Reference number	Wood species	Use	Comment
100	General	Fiberwood, wood chips for fuel	To be used for domestic heating. Special machines could be developed to be used at the harvesting site to chip branches.
116	General	Power production	Use of logging wastes.
117	General	Generation of electrical power	Branches combined with other wood wastes.
49	*Picea glauca* *Pinus contorta* var. *latifolia*	Fuel	Fuel value of crown.

TABLE 31

Utilization of Branches -- Agricultural Use.

Reference number	Wood species	Use	Comment
56	*Acacia mellifera*	Fodder	Used successfully as a source of nourishment; no loss in animal weight.
55	General	Agricultural uses	Review of possible utilization of wood residues from full-tree logging.
1	General	Cattle fodder	Utilization of a wide variety of logging slash.
40	General	Cattle forage	No processing required.
98	General	Cattle feed supplement	Review in depth of the utilization of foliage.

TABLE 32

Utilization of Branches as a Source of Chemicals

Reference number	Wood species	Use	Comment
86	General	Conversion to chemicals	Review of utilization of wood residues.
83	*Pinus* sp. *Picea* sp.	Chemicals	Review on possible conversion to chemicals.
81	*Pinus* sp.	Turpentine, pine oil, rosin, pyroligneous acid, tars	Produced from logging refuse by portable apparatus.
13	*Pinus* sp. *Picea* sp. *Larix* sp. *Betula* sp. *Populus* sp. *Salix* sp. *Alnus* sp.	Chemicals	Logging wastes regarded as a raw material suitable for the manufacture of a number of products through chemical or mechanical processing.
118	General	Chemicals	From logging wastes.
101	*Thuja occidentalis*	Essential oils	Cedar oil and wax extracted
117	General	Silvichemicals	Branches in combination with other wood wastes.

APPENDIX I

NOMENCLATURE

General

It is important that a uniform and consistent nomenclature be used in reporting biomass or component biomass studies and that a standard nomenclature be adopted for reporting logging practice. Reference may be made, for example, to tree-length logging--that is, logging all of a tree above the stump--where full-bole logging is intended. In the present review the following nomenclature has, in general, been used:

Complete tree: includes all component parts -- twigs, top, leaves, needles, fruits or cones, branches, roots, stumps, bole and bark.

Tree length: a complete tree minus the stump and roots, but including leaves, needles, branches, fruits or cones and top.

Full-tree bole: the trunk or bole of a tree, from the stump to the tip minus all leaves, needles, branches, fruits or cones and twigs.

Long-length logs: bole from the stump to the bottom of the unmerchantable top of bole, or to some length appreciably greater than has been standard practice.

Tree Components

Any classification of tree components must be, to a considerable extent, arbitrary[a], since it may be difficult or impossible to define. The unmerchantable top of bole is that part of a tree defined by the top diameter to

(a) One extreme difficulty in analyzing data on biomass or tree-component studies arises from the fact that components cannot be rigidly defined, and from the fact that a common nomenclature and a common procedure for selecting and measuring components are not used. For example, much of the Russian literature on the biomass of foliage available from various wood species presents data in terms of foliage plus all twigs or branches less than 0.6 mm. diameter. From a practical point of view this is a realistic classification, since the amount of chemicals extractible or derivable from twigs up to 0.6 mm. in diameter is sufficiently high to warrant processing, but it does pose a problem in comparing these data with other data in which foliage is differently defined.

which a bole is cut for a given wood species by local logging practices. Similarly, merchantable bole may be defined as that part of a tree from a distance normally varying from 0 to 1 foot above ground level to a top diameter varying from 2 to 8 inches.

TREE COMPONENT CLASSIFICATION

In the complete-tree utilization studies of the Department of Fisheries and Forestry, the following classification of tree components has been used.

Unmerchantable top of bole: bottom diameter of the unmerchantable top of bole is defined by local logging practice, and may vary from as high as 6 to 8 inches (in British Columbia) to 2 inches or less (in Finland). It is a relatively minor point, since the percentage involved would normally be quite small, but in pulping studies, the unmerchantable top of bole less than 1 inch in diameter should be included with the branches less than 1 inch in diameter; not only because this part of a tree would be expected to give a similar type of pulp, but also because tops less than 1 inch in diameter would have the same problems in barking, chipping and handling.

Branches 1 inch in diameter or greater: normally free of leaves or needles, shoots, fruits or cones, and leaf-bearing twigs. These branches can be considered as a potential source of raw material for pulp fiber.

Branches less than 1 inch in diameter: not suitable for pulping.[b]

Foliage: all needles, leaves, shoots, cones, flowers and twigs.

Bole: that part of the tree extending from the stump to the bottom of the unmerchantable top.

Stumps: from the bottom of the merchantable bole to those sections where the roots can be removed conveniently.

Roots less than 1 inch in diameter: cannot be used for pulping.[b]

Roots 1 inch in diameter or greater: can be considered as a source of raw material for pulp fiber.

Bark.

(b) This should be considered as a tentative assumption. In a recent communication, Harold E. Young notes that he has recently pulped alder, grey birch, aspen and pin cherry ranging in age from 6 to 20 years, and has found that the yield of pulp from the unbarked branches, bole and roots has averaged 41%. Professor Young points out that the long bast fibers in young bark may be an asset in pulping this material.

APPENDIX II

CHECKLIST OF SPECIES CITED BY TABLES AND PAGES

Species	Table No.	Page No.
Abies sp.	15, 26, 27	23, 40, 42
A. alba	8	14
A. amabilis	29	46
A. balsamea	1, 2, 3, 8, 12, 13 20, 25, 26	3, 4, 5, 6, 7, 10, 14, 18, 19, 20, 29, 35, 40 Fig. 1 pg. 20
A. fraseri	8	14
Acacia mellifera	31	47
A. mollissima	9	15
Acer sp.	28	43
A. rubrum	1, 5, 12, 13, 26, 28	3, 4, 9, 18, 19, 40, 43
Alnus sp.	28, 29, 32	43, 46, 48
A. rugosa	9	15
Betula sp.	9, 19, 26, 27, 28, 29, 32	15, 28, 40, 42, 43 46, 48
B. allegheniensis	9	15
B. maximowicziana	7	12

Appendix II, cont'd.

Appendix II, cont'd.

Species	Table No.	Page No.
F. grandifolia	9	13, 15
F. sieboldi	28, 29	43, 46
F. sylvatica	16	24
Hornbeam	28	43
Juglans regia	25	35
Kauri	27	42
Larix sp.	32	48
L. decidua	8	14
Liriodendron tulipifera	9, 25	15, 35
Nothofagus truncata	7	12
Picea sp.	8, 15, 19, 25, 26, 27, 28	14, 23, 27, 28, 35, 40, 42, 43
P. abies	4, 6, 8, 10, 11, 17, 18, 24, 25, 27, 29, 32	6, 8, 11, 13, 14, 16, 17, 22, 25, 26, 27, 34 35, 42, 46, 48
P. excelsa	3, 25	2, 7, 35

Appendix II, cont'd.

Species	Table No.	Page No.
P. glauca	2, 3, 8, 25, 26, 30	3,5, 7, 14, 35, 40, 47
P. jezoensis	8	14
P. mariana	2, 25, 27	3, 5, 35, 42
P. rubens	1, 3, 8, 12, 13, 20, 26, 27	3, 4, 7, 14, 18, 19, 29, 40, 42
Pinus sp.	8, 15, 19, 25, 26, 28, 29, 32	10, 14, 23, 27, 28, 35, 40, 43, 46, 48
P. banksiana	25	35
P. caribaea	28	43
P. cembra	8	14
P. contorta var. *latifolia*	1, 2, 8, 26, 30	3, 4, 5, 14, 40, 47
P. densiflora	2, 6, 22, 23, 28, 29	5, 11, 31, 32, 33, 37, 43, 46
P. echinata	8, 25	10, 14, 35

Appendix II, cont'd.

Appendix II, cont'd.

Species	Table No.	Page No.
Populus sp.	1, 5, 19, 25, 26, 27, 28, 29, 32	4, 9, 28, 35, 40, 42, 43, 46, 48
P. tremuloides	12, 13	18, 19, Fig. 1, pg. 20
Prunus sp.	28	20, 43
Pseudotsuga menziesii	6, 8, 28	10, 11, 14, 43
Quercus alba	9, 25	15, 35
Q. borealis	7	12
Q. crispula	28, 29	43, 46
Q. glauca	14	21
Salix sp.	28, 32	43, 48
S. alba	25, 26, 27	35, 40, 42
S. babiana	9	15
Siberian sp.	25	35
Thuja occidentalis	1, 3, 12, 13, 20, 28, 32	4, 7, 18, 19, 29, 43, 48
T. plicata	1	3, 4
Tsuga sp.	26, 27	40, 42

Appendix II, cont'd.

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