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Complete-Tree Utilization An analysis of the Literature Part IV: Crown and Slash

J. L. Keays

COMPLETE-TREE UTILIZATION
An Analysis of the Literature

PART IV: Crown and Slash

BY

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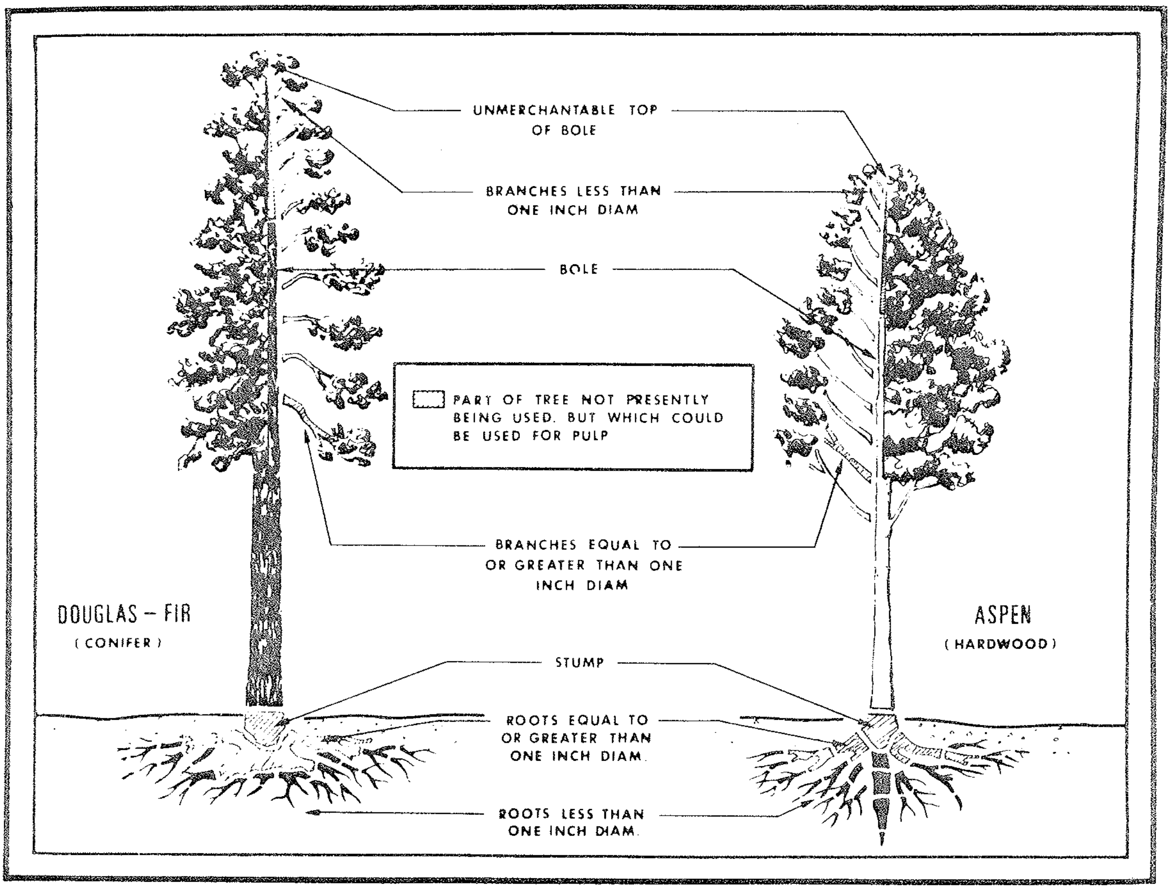

COMPLETE-TREE UTILIZATION

An Analysis of the Literature

PART IV: Crown and Slash

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RESUMÉ

Parts I, II and III of the present series have reviewed the literature on biomass and utilization of unmerchantable top of bole, foliage and branches, respectively. The present part covers the tree crown (foliage plus branches) and slash (branches plus foliage plus tops).

For most pulpwood species at 8-inch dbh and a high stand density, the crown varies from 10 to 25% by weight of the full tree bole on a standard basis (all components oven dry and bark free). For very small trees, the percentage crown can run as high as 2000. Comparable values for slash at 8-inch dbh would be 5 to 10% higher for trees at approximately 8-inch dbh because of the inclusion of the unmerchantable top.

A large number of factors affect percentage slash biomass (standard basis) including:

Wood species	Critical
Top to which merchantable bole is cut	Critical
Tree height	Critical
Stand density	Critical
Dbh	Major
Tree age	Major
Site index	Major
Crown ratio	Major
Season	Major
Dominance	Unknown, probably major
Wind throw	Unknown
Stump height	Minor
Miscellaneous (genetics, water available)	Unknown.

Data available on the biomass of crown and slash are limited, and no conversion factors are available to convert data from one basis, such as green weights, to the standard basis. It is recommended that in future studies standard basis values be obtained for:

All material less than 1/4-inch diameter -- usable for cattle fodder supplement, pharmaceuticals;

All material 1/4 to 1-inch diameter -- suitable for use as fuel, conversion to cattle food supplement, composition board;

All material greater than 1-inch diameter, which might be considered for use in pulp manufacture.

Limited data are available on the use of slash for pulping. However, from the percentage tops and branches greater than 1-inch diameter, and from their pulping characteristics, kraft pulp at 20 permanganate number from slash, compared with pulp from boles of the same species, would be expected to have lower yield, lower burst and tear factors and breaking length. The pulp would be fast beating with a high percentage stretch.

COMPLETE-TREE UTILIZATION -- An Analysis of the Literature

Part IV[a]: Crown and Slash

by J. L. Keays

CROWN

Introduction

Unless otherwise specified, in the present text crown is defined as all branches plus all foliage. Values for crown as a percentage of full bole are likely to be of increasing practical interest. The crown weight represents the amount of material which would have to be disposed of in full-bole logging, either at a felling site or intermediate landing, and the amount of material which would have to be disposed of or processed at a lower landing or at a mill site in full-tree logging. Percentage crown is included here because of this interest, and because for some wood species data are available on crown biomass, but not on branches and foliage separately. It also provides an opportunity to check some data against others, where foliage and branches may each be differently defined, but where sum of the two represents identical component combinations[b].

(a) Previous reports in the present series are:
- Part I: Unmerchantable Top of Bole (77)
- Part II: Foliage (78)
- Part III: Branches (79)

(b) In many of H.Young's studies on complete-tree utilization, for example, foliage is defined as all material 1/4 inch in diameter or less. Branches are defined as branch material down to 1/4 inch in diameter.

Appendix I gives the nomenclature and classification used throughout this complete-tree utilization series.

BIOMASS

Percentage Crown as a Function of DBH - Standard Basis

Table 1 for coniferous species and Table 2 for deciduous species give standard-basis values[c] for the percentage crown for a number of wood species as a function of dbh. There is a general trend towards a decrease in crown with decreasing dbh from 14 to 6 inches (*Pinus strobus* being an exception).

TABLE 1

Crown as a Percentage by Weight of Full Tree Bole and as a Function of DBH: Standard Basis -- Coniferous Species.

Crown: foliage plus branches
Foliage: oven-dry basis
Branches: oven-dry and bark-free basis
Full Bole: oven-dry and bark-free basis

Reference	Wood species	No. of trees sampled	Crown as a % of Full Bole — Diameter breast height (inches) 6	8	10	12	14
191	*Abies balsamea*[1]	23	5	6	7	9	9
11	*A. balsamea*[2]	89	52	-	-	-	-
12	*A. balsamea*[3]	190	49	64	79	-	-
11	*Picea glauca*[2]	2?	48	-	-	-	-
189	*P. rubens*[1]	25	5	9	12	14	13
67	*Pinus contorta* var. *latifolia*[4]	22	8	10	13	15	18
191	*P. strobus*[1]	27	7	10	10	9	7
37	*Thuja occidentalis*[1]	21-36	16	19	21	24	-
191	*Tsuga canadensis*[1]	28	13	16	17	18	21

1. Stump: 6 inches above ground level.
2. Stump: ground level.
3. Branches: oven dry and bark on.
   Stump: ground level.
4. Stump: 12 inches above ground level.

TABLE 2

Crown as a Percentage by Weight of Full Tree Bole and as a Function of DBH: Standard Basis -- Deciduous Species.

Crown: foliage plus branches
Foliage: oven-dry basis
Branches: oven-dry and bark-free basis
Full Bole: oven-dry and bark-free basis.

Reference	Wood species	No. of trees sampled	Crown as a % of Full Bole[1] Diameter breast height (inches) 6	8	10	12	14
187, 190, 189	*Acer rubrum*	20	12	14	15	14	12
11	*Betula papyrifera*[2]	24	31				
191	*B. papyrifera*	17	12	16	18	18	-
162	*B. platyphylla*[3]	9,000-22,000/ha	40	-	-	-	-
191	*Populus* sp.	14	9	15	17	17	-

1. Stump: 6 inches above ground level unless otherwise stated.
2. Stump: ground level.
3. Stump: ground level.
Branches: assumed bark on.
DBH: 3 cm = 1.18 inches

As shown in Table 3 for a number of wood species, the percentage crown at 8 to 9 inches dbh ranges from 10 to 20% (standard basis).

TABLE 3

Crown as a Percentage by Weight of Full Tree Bole at 8 Inches DBH.

Crown: foliage plus branches
Foliage: oven-dry basis
Branches: oven-dry and bark-free basis
Full Bole: oven-dry and bark-free basis

Reference	Wood species	Crown as a % of Full Bole
67	*Pinus contorta* var. *latifolia*	10
191	*P. strobus*	10
37	*Thuja occidentalis*	19
191	*Tsuga canadensis*	16
187	*Acer rubrum*	14
191	*Betula papyrifera*	16
191	*Populus* sp.	15
81	*Tsuga heterophylla*	18

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

As shown by Table 4 for coniferous species and Table 5 for deciduous species, the crown as a percentage of full bole on an oven-dry, bark-on basis for most species shows decreasing percentage crown with increasing dbh (*Picea glauca*, *Pinus contorta* var. *latifolia* (86), *P. sylvestris*, *P. taeda*, *Arbutus menziesii*, *Lithocarpus densiflorus*, and *Quercus kelloggii*). A few species show no trend as *Pinus contorta* var. *latifolia* (110) and *P. densiflora* (104). Several species, *Picea mariana* (177), *Pinus densiflora* (53), *P. sylvestris* (123) and *Abies balsamea* (10) show an increase in percentage crown with increasing dbh.

TABLE 4

Crown as a Percentage by Weight of Full Tree Bole and as a Function of DBH -- Coniferous Species.

Crown: foliage plus branches
Foliage: oven-dry basis
Branches: oven-dry and bark-on basis
Full Bole: oven-dry and bark-on basis.

Reference	Wood species	No. of trees sampled	Crown as a % of Full Bole Diameter breast height (inches) 4	6	8	10	12	14
85, 86	*Picea glauca*[2]	60	-	74	57	45	37	30
177	*P. mariana*[4]	20	20	26	-	-	-	-
86	*Pinus contorta* var. *latifolia*[1,5]	101	35	25	19	19	19	-
110	*P. contorta* var. *latifolia*[1]	405	19	17	20	-	-	-
53	*P. densiflora*[3]	-	-	11	13	16	24	-
104	*P. densiflora*[3]	38	44	26	25	34	-	-
123	*P. sylvestris*[3]	20	21	29	-	-	-	-
119	*P. sylvestris*[2]	21	106	78	63	-	-	-
106	*P. taeda*[3]	10	147	78	42	28	-	-
10	*Abies balsamea*[2]	101	29	44	56	68	-	-

1. Stump: 12 inches above ground level.
2. Stump: not specified.
3. Stump: ground level.
4. Trees taken from Site Class 2. Values used in computation taken from graphs of Figure 3, page 83.
5. Only live branches are included.

TABLE 5

Crown as a Percentage by Weight of Full Tree Bole and as a Function of DBH -- Deciduous Species.

Crown: foliage plus branches
Foliage: oven-dry basis
Branches: oven-dry and bark-on basis
Full Bole: oven-dry and bark-on basis.

Reference	Wood species	No. of trees sampled	Crown as a % of Full Bole[1]					
			Diameter breast height (inches)					
			4	6	8	10	12	14
161	*Acacia mollissima*[2, 5]	15	39	-	-	-	-	-
157	*Arbutus menziesii*[3]	8-10		33	22	16	12	10
157	*Lithocarpus densiflorus*[3]	8-10		78	48	35	36	43
157	*Quercus kelloggii*[3]	8-10		39	35	-	21	20
179	*Liriodendron tulipifera*[3, 4]	-		-	-	-	16	-

1. Stump: 12 inches above ground level unless otherwise specified.
2. Stump: ground level.
3. Stump: height not specified.
4. Dbh: 13.4"
5. Dbh: 3.2"

Additional note: All percentages shown for reference 157 have been calculated from values taken from Figure 1, page 2.

It will be noted that the change in percentage crown with dbh is greater for values in Tables 4 and 5 (bark-on basis) than in Tables 1 and 2 (standard basis). Some part of this difference could arise from the fact that branch diameter decreases with decreasing dbh. The percentage bark increases with decreasing branch diameter, so that for small trees the percentage crown by weight would be higher on a bark-on basis. Table 6 gives selected values for percentage bark as a function of branch diameter.

TABLE 6

Percentage Bark by Weight on Branches as a Function of Branch Diameter -- Oven-dry and Bark-free Basis.

		Diameter (inches)					
Reference	Wood species	0.1-0.24	0.08-0.6	0.6-0.8	1.2	2.0-2.76	4.9-5.7
148a	*Populus* sp.	50-56	48-50	32-45	28-30	16-19	10-11

		Diameter (inches)		
		dbh	1-2"	2 -3"
81	*Tsuga heterophylla*	18.0	17.7	16.3
		14.2	19.1	-
		8.5	16.3	-

Percentage Crown as a Function of Tree Height for Young Trees.

The utilization of young trees for pulping, with the exception of a few pioneering studies (56, 63, 64, 65), is essentially an unexplored field. A great deal of work remains to be done in order to establish the general relationships outlined in Tables 1 to 5 for species of major commercial interest growing under a variety of conditions, to obtain crown biomass data on a standard basis as a function of tree height, site index, stand density, growth rate, season, dominance, etc., and to determine the yield and the quality of pulp which can be obtained by various pulping processes, both with bark on and with the bark removed. For trees ranging in diameter from 1 to 4 inches, of the type measured in H. Young's work (186) and shown in Table 7, there are four broad potential methods of utilizing tree crowns for pulping; above-ground portions of trees would be harvested like grain, stripped of foliage (or not), chipped and pulped; or complete trees would be extracted, skidded, cleaned, stripped of foliage (or not), chipped and pulped. As shown by the data in Table 7, the composition of a 15-foot *Thuja occidentalis*, as a percentage of the full bole, oven-dry, bark-on basis, would be:

Foliage.................. 45% (Table 8, ref. 78)

Branches................. 37% (Table 9, ref. 79)

Crown.................... 82% (Table 7)

Root-stump system........ 41% (Table 7 Part V)

That is, for every 100 pounds of full bole, there would be 45 pounds of foliage, 37 of branches, and 41 of stump-root system.

There is somewhat more fiber in the branches and stump-root system combined than there is in the bole, and sufficient foliage to provide material for a massive tonnage of chemicals. With decreasing tree size there is increasing motivation to utilize entire trees in stands of large-diameter trees, where merchantable boles may amount to, say, 60% of total tree weight on the average. For *Populus tremuloides*, to take one example, the percentage bole amounts to 59.5% for a 20-foot-high tree, 38.5% for a 5-foot, and 14.2% for a 1-foot tree. At sufficiently small tree size, complete-tree utilization would become a necessity, and in using trees less than five-feet in height, say, would make the silage cellulose concept (100) a reality.

As previously discussed, the percentage foliage varies inversely with tree age, diameter and tree height. At constant stand density, the percentage foliage decreases to half when tree height doubles (Part II, ref. 79) over a broad range of tree heights. The same general relationship is indicated in Table 7 for percentage crown. The effects of tree height and stand density are so marked on the percentage crown, that other factors which might have an effect on percentage crown are likely to be obscured if tree height and stand density vary widely.

TABLE 7

Crown as a Percentage by Weight of Full Tree Bole
and as a Function of Tree Height.

Crown: foliage plus branches
Foliage: oven-dry basis
Branches: oven-dry and bark-on basis
Full bole: oven-dry and bark-on basis

Reference: 186

Wood species	No. of trees sampled	Crown as a % of Full Tree Bole									
		Height, feet									
		1	3	5	7	10	15	20	25	30	35
Abies balsamea	14	1282	464	284	206	147	100	76	61	52	44
Picea rubens	40	1425	470	284	203	142	95	71	57	48	41
Pinus strobus	10	476	167	101	76	55	39	31	25	21	19
Thuja occidentalis	34	957	342	215	160	117	82	64	53	45	40
Tsuga canadensis	9	2900	670	400	277	188	121	88	69	57	48
Acer rubrum	40	250	99	71	57	46	37	32	29	26	24
Betula papyrifera	10	225	125	94	80	66	53	45	40	37	34
Populus tremuloides	6	300	112	74	60	47	37	31	28	26	23

Notes: Dbh range; 1 to 4 inches.
Stump height; not specified, assumed to be ground level.
No. of trees; one or more trees per height.
Total no. of trees for the eight species, 163.

<u>Percentage Crown as a Function of Tree Age.</u>

Table 8 for coniferous species and Table 9 for deciduous species give information on the percentage of crown (oven-dry and bark-on basis) for various tree ages. As would be expected, there is a trend downward for the percentage crown with increasing age, similar to the trend with dbh and increasing tree height. The trend is quite marked for some species (*Pinus densiflora*, *Pseudotsuga menziesii*) and rather weak for others (*Pinus sylvestris*, *Picea abies*).

The decrease in percentage crown with increasing tree age is shown in Table 10 for *Pinus sylvestris* and *Betula verrucosa*. The trend is somewhat irregular for *Betula verrucosa*, but again shows the high percentage crown on young trees.

<u>Percentage Crown -- Miscellaneous Values.</u>

Table 11 gives miscellaneous data on percentage crown for a number of tree species. Dbh is not specified. Again, such data are difficult to interpret, since critical factors affecting the biomass of the foliage and branches such as tree height and stand density, are not given. The range of values is quite high, from 8 percent crown for *Betula verrucosa* (168) to 45 percent for *Vaccinum corymbosum* (38).

As shown by the data in Table 12, the range in percentage crown is also highly variable, being particularly variable for *Betula platyphylla* over a narrow range of diameters. The other species show the high percentage crown normally associated with young trees. This relationship may be obscured by the fact that the data for *B. platyphylla* is on a green basis, whereas the others are on an oven-dry basis.

TABLE 8

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

Crown: foliage plus branches
Foliage: oven-dry basis
Branches: oven-dry and bark-on basis
Full Bole: oven-dry and bark-on basis.

Reference	Wood species	No. of trees	Tree age in years	Crown as a % of full tree bole[1]
120	*Larix decidua*	420/ha	46	30
120	*Picea abies*	-	20	39
		-	39	22
		-	46	37
		667/ha	47	30
		1125/ha	52	25
		924/ha	58	28
120	*P. abies*	-	46	19
		937/ha	47	44
68	*Pinus contorta* var. *latifolia*[2]	85	100	13
120	*P. densiflora*	-	16	45
104	*P. densiflora*[3]	38	6, 10	176, 133
			8, 12	150, 120
179	*P. echinata*	-	72	12
120	*P. nigra*	482/ha	46	15
		1112/ha	48	18
120	*P. strobus*	-	41	33
		-	41	13
120	*P. sylvestris*	3640/ha	23	44
		4260/ha	33	18
		445/ha	47	21
		760/ha	55	21
		815/ha	64	22
120	*Pseudotsuga menziesii*	2100/ha	22	90
		1151/ha	30	63
		1636/ha	32	43
		1151/ha	38	24
		297/ha	47	25
		1157/ha	52	17
		648/ha	38	18
160	*Cryptomeria japonica*	29500/ha	5	56

1. Stump height and dbh not specified unless otherwise stated.
2. Stump height: 12 inches above ground level.
3. Stump height: probably ground level.

TABLE 9

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

Crown: foliage plus branches
Foliage: oven-dry basis
Branches: oven-dry and bark-on basis
Full bole: oven-dry and bark-on basis.

Reference	Wood species	No. of trees	Tree age in years	Crown as a % of full bole[1]
120	*Alnus incana*	1656/ha	22	34
120	*Betula maximowicziana*	-	47	17
			47	11
			47	17
124	*B. verrucosa*	2 per age	24	30
			27	15
			32	21
			38	20
			42	18
			46	18
			53	24
			55	22
120	*B. verrucosa*	-	20	33
		4990/ha	24	30
		2350/ha	25	22
		-	40	8
		880/ha	55	22
		-	67	9
120	*Castanea sativa*	427/ha	47	8
120	*Cinnamomum camphora*	-	48	12
120	*Fagus sylvatica*	815/ha	39	36
120	*Nothofagus obliqua*	3558/ha	22	66
120	*N. truncata*	490/ha	110	20
120	*Populus davidiana*	-	40	10
120	*Quercus borealis*	800/ha	57	48
120	*Q. petraea*	10,102/ha	21	50
120	*Q. robur*	618/ha	47	20
179	*Q. alba*	-	96	41
179	*Liriodendron tulipifera*	-	75	16

1. Stump height and dbh not specified.

TABLE 10

Canopy as a Percentage by Weight of Bole and as a Function of Tree Age.

Canopy: oven-dry and bark-on basis
Bole: oven-dry and bark-on basis.

Reference	Wood species	Tree age in years	Canopy as % full bole	Canopy as % bole plus canopy
119	*Pinus sylvestris*	3	150	60
		7	300	75
		11	193	66
		14	173	63
		17	118	54
		20	89	47
		23	43	30
		31	22	18
		35	20	17
		55	21	17
119	*P. sylvestris* [1]	11	130	57
		14	38	28
124	*Betula verrucosa* [2]	6	100	
		24	30.2	
		27	14.9	
		32	20.6	
		38	19.6	
		42	17.5	
		46	18.0	
		53	23.5	
		55	21.9	

Notes: One tree for each age.
Stump height not specified.
Canopy: defined as cones plus branches plus foliage.
Assumed full bole.

1. regenerated.
2. two trees for each age.

TABLE 11

Crown as a Percentage by Weight of Full Tree Bole

Crown: foliage plus branches
Foliage: oven-dry basis
Branches: oven-dry and bark-on basis
Full Bole: oven-dry and bark-on basis

Reference	Wood species	No. of trees	Crown as a % of full bole
121	*Picea* sp.[2]		17.0
121	*Pinus* sp.[2]		14.0
168	*P. koraiensis*[1]	99	43.0
168	*P. sylvestris*[1]	39	14.0
121	*Pseudotsuga menziesii*[2]		15.0
38	*Alnus rugosa*[3]		39.0
121	*Betula* sp.[2]		12.0
168	*B. verrucosa*[1]		22.2
168	*B. verrucosa*[1]		8.0
38	*Salix babiana*[3]		35.0
38	*Vaccinium corymbosum*[3]		45.0

Notes: Dbh and stump height; not specified

1. Foliage: so-called technical foliage; i.e., all needles, leaves, twigs, shoots and branches up to 0.6 cm (0.24") diameter.
   Basis: per cubic meter of merchantable wood
   Stump height: not specified

2. No. of stands sampled: *Picea* sp. -- 16; *Pinus* sp. -- 15; *Pseudotsuga menziesii* -- 8; *Betula* sp. -- 13.

3. No. of stems per ha.: *Alnus rugosa* -- 2190 stems/ha; *Salix babiana* -- 2600 stems/ha; *Vaccinium corymbosum* -- 3240 stems/ha.

TABLE 12

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

Reference	Species	No. of trees	Diam. at base (inches)	Crown as % of bole	Notes
162	*Castanopsis cuspidata*	150,000/ha	1	57.0	Foliage: oven dry Branches: oven dry, bark on
			1.5	58.0	Bole: oven dry, bark on
			2.0	57.3	
162	*C. cuspidata*	40,000/ha	0.87	56.0	"
162	*Quercus glauca*	16,000/ha	0.75	57.8	"
162	*Castanopsis cuspidata*	40,000/ha	0.87	61.7	Foliage: green Branches: green, bark on Bole: green, bark on
159	*Betula platyphylla*	9,000 to 22,000/ha	0.8	12.5	"
			1.0	14.9	"
			1.2	17.0	"
			1.5	18.4	"
56	*Platinus occidentalis*[1]	4	2.9-3.1	33.5	"
162	*Quercus glauca*	16,000/ha	0.75	64.6	"

Notes:

Stump; ground level

1. Based on weight of whole tree.

Relationship between Percentage Crown and Site Quality

The data presented in Table 13 would suggest that for the species *Pinus thunbergii*, at least, there is no strong relationship between percentage crown and site quality. Presumably, where site index is defined as tree height at a given age, the relationship between tree height and percentage crown discussed previously should be valid, and there would be expected to be a marked and general relationship between site index and percentage crown; i.e., the lower the site index, the higher the percentage branches and foliage.

TABLE 13

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

Reference No. 6
Species: *Pinus thunbergii*
5-8 trees per site.

Plot No.	Site quality	Branches as % full bole[1]
1	Good	70
2	Good	78
3	Moderate	103
4	Poor	97
5	Good	88
6	Moderate	100

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

If the percentage branches doubles and the percentage foliage doubles when tree height is reduced to one-half, the same general relationship would be expected to hold for the sum of the two. As shown for the selected values given in Table 14, this relationship appears remarkably consistent for some conifers -- all grown on the same general forest site.

TABLE 14

Selected Values for Crown as a Percentage by Weight of Full Tree Bole

Foliage: oven-dry basis
Branches: oven-dry and bark-on basis
All values taken from reference 186.

Tree species	Crown as % of full bole for tree height in feet		
	5	10	20
Abies balsamea	284	147	76
Picea rubens	284	142	71
Pinus strobus	101	55	31
Thuja occidentalis	215	117	64
Tsuga canadensis	400	188	88

Although substantiating data are not available, the relationship between percentage crown and tree height shown for young trees with bark on would not be the same as would be obtained for standard values. Although the percentage bark would increase on both branches and boles with decreasing dbh, it would be expected to increase more rapidly on the branches, thus giving a lower percentage fiber.

Seasonal Variation in Percentage Crown.

As previously discussed under branches and foliage, there is a wide variation in percentage crown as a result of seasonal variations, certainly as shown for *Pinus densiflora* in Table 15. This point appears to have received little study, and more research should be done in this area to determine if the relationship found for *P. densiflora* has general application.

The question of annual *average* values for the amount of foliage recoverable from a given forest area would almost certainly be examined in studies relating to foliage utilization. It is less obvious, but perhaps equally critical, that the same principle apply to determination of branch biomass as part of potential utilization studies. In addition, distinction should be made concerning live and dead branches, the amount of dead branches likely to be brought to a mill, and their effect upon pulp yield and quality.

TABLE 15

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

Reference No. 52
Species: *Pinus densiflora*

Tree diameter (inches)[2]	Crown as a % of Bole[1] for Sample Collection Dates				
	April 25 1964	May 27 1964	June 1964	July 1964	March 1965
0.63	115	126	130	91	82
0.83	170	190	197	141	114
1.18	288	322	336	249	175

1. Stem assumed to be full bole -- probably cut at ground level. Branches and full bole assumed to be green and bark on.
2. Tree age: approximately seven years. Diameter at 20 cm height above ground.

All of the various difficulties discussed previously for conversion of percentage foliage or branches from green-weight basis to a standard basis are applicable to the percentage crown. In order to convert the percentage crown on a green basis to percentage crown on a standard basis, it would be necessary to know the moisture content of branches, foliage and bole, and the percentage bark on the branches and bole over a range of dbh values.

Summary

It is apparent from the data on foliage and branch biomass that the percentage of crown on a standard basis will be dependent upon a large number of biological, ecological and edaphic factors, including:

Wood species............ Critical
Tree height .... Critical
Stand density .... Critical
Dbh .... Major
Tree age .... Major
Site index .... Major
Crown ratio .... Major
Season .... Major
Dominance .... Probably major
Stump height .... Minor.

No studies have been made which would permit analysis of the relationships between even the major factors which influence crown biomass.

SLASH

Introduction

Here slash is defined as the sum of unmerchantable top of bole, branches and foliage. A number of studies have been carried out on the amount of slash generated in logging practice because of concern with forest fire hazard, nutrient return to the soil, and for theoretical reasons relating to the mechanism of tree growth. Interest in the amount, composition, characteristics and disposal of slash will increase, in part because of the growing concern over slash disposal by burning and closer forest utilization; in part, because of the implications of whole-tree or complete-tree logging.

BIOMASS

Percentage Slash as a Function of DBH -- Standard Basis.

Table 16 gives the standard-basis values for slash in relation to dbh for a number of species. It is of interest that, for some species, the percentage slash does not vary appreciably over a dbh range from 8 to 14 inches, *Pinus strobus* and *Acer rubrum* being exceptions. It is apparent from the data in Table 16 that no generalizations can be drawn concerning the relationship between percentage slash and species, ranging as it does from a low of 14% for *Picea rubens* to a high of 35% for *Thuja occidentalis* at 8 inches dbh.

TABLE 16

Slash as a Percentage by Weight of Full Tree Bole for Various Values of DBH.

Slash: tops and foliage plus branches
Foliage: oven-dry basis
Tops and branches: oven-dry and bark-free basis
Full bole: oven-dry and bark-free basis.

Reference	Wood species	No. of trees sampled	Slash as a % of Full Tree Bole				
			Diameter breast height in inches				
			6	8	10	12	14
191	*Abies balsamea*	23	19.0	16.0	13.0	12.0	11.2
189	*Picea rubens*	25	17.0	14.0	15.5	16.0	15.0
67	*Pinus contorta* var. *latifolia*[2]	22	24.2	17.5	16.5	17.5	19.0
191	*P. strobus*	27	20.0	18.0	14.0	11.0	8.5
37	*Thuja occidentalis*[1]	21-36	37.0	35.0	33.0	31.5	-
191	*Tsuga canadensis*	28	25.5	24.5	22.5	21.0	22.0
187, 189, 190	*Acer rubrum*	20	29.2	23.0	19.5	17.0	15.5
191	*Betula papyrifera*	17	24.5	25.5	23.5	20.5	-
191	*Populus tremuloides*	14	20.7	24.0	22.8	19.2	-

Notes: Stump -- 6 inches above ground

Top -- 4 inches diameter at base

1. Assumed that same top and stump parameters are used as in ref. 191
   stump = 6 inches above ground
   top = 4 inches diameter at base

2. Stump = 12 inches above ground
   Top = 4 inches diameter at base outside bark.

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

As shown by the data in Table 17 which gives percentage slash on an oven-dry, bark-on basis, the increase in percentage bark with decreasing dbh is appreciable for some species (*Picea glauca* and *Pinus contorta* var. *latifolia*) and indicates the extent to which slash utilization may become an increasingly serious disposal problem with decreasing tree size.

In general, comments made concerning the relationship between various parameters affecting percentage crown (particularly stand density and tree height) would be applicable to slash; in the case of trees greater than, say, 8 inches diameter, and for a 3- or 4-inch top, the percentage unmerchantable top would be small, and values for percentage slash would differ only slightly from values for percentage crown. Both values would be influenced by the same factors to much the same extent. For trees between 4 and 8 inches dbh, the percentage of slash would be strongly influenced by the diameter of the top. For trees much smaller than 4 inches in diameter (and all to a 3 or 4-inch top diameter), the term "unmerchantable top" would have little meaning.

TABLE 17

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

Slash: tops and foliage plus branches
Foliage: oven-dry basis
Branches and tops: oven-dry and bark-on basis
Full bole: oven-dry and bark-on basis.

Reference	Wood species	No. of trees sampled	Slash as a % of Full Tree Bole[1] Diameter breast height (inches) 4	6	8	10	12	14
122	*Abies grandis*[2]	2	-	34	-	-	-	-
86	*Picea glauca*	60	-	135	98	77	65	61
85, 86	*Pinus contorta* var. *latifolia*[5]	101	80	37	25	22	21	-
110	*P. contorta* var. *latifolia*	405	56	33	30	-	-	-
122	*Pseudotsuga menziesii*[2, 4]	6	-	-	-	-	-	-
122	*Pinus nigra*[2, 7]	6	-	13	-	-	-	-
122	*Larix decidua*[2, 6]	1	-	-	-	23	-	-
		Diameter at breast height is not specified						
120	*L. decidua*	420/ha		71				
68	*Pinus contorta* var. *latifolia*[3]	85		25				
120	*Pseudotsuga menziesii*	297/ha		83				

1. Stump 12 inches above ground and top 4 inches in diameter unless otherwise stated.
2. Stump and top not specified.
3. Stump = 12 inches above ground.
4. Dbh = 14.4 inches
5. Only live branches are included.
6. Dbh = 10.9 inches
7. Dbh = 5.6 inches

Percentage Slash for Young Trees

For small-diameter trees (Table 18) the range in percentage slash is extremely wide, from less than 20% for *Quercus* sp. (122) to over 200% for *Castanopsis cuspidata* (162).

TABLE 18

Slash as a Percentage by Weight of Full Tree Bole

Reference	Wood species	No. of trees	Diameter at base (inches)	Slash as % of full bole	Notes
162	*Castanopsis cuspidata*	150,000/ha	1	214	Foliage: oven-dry basis Tops and branches: oven-dry and bark-on basis Full Bole: oven-dry and bark-on basis
			1.5	214	
			2.0	214	
122	*Quercus* sp.[1]	1	5.75	21.6	Same as above
159	*Betula platyphylla*	9,000 to 22,000/ha	0.8	68.8	Foliage: green Tops and branches: green and bark on Full bole: green and bark on
			1.0	72.4	
			1.2	75.5	
			1.5	77.6	"
122	*Quercus* sp.[1]	1	5.75	22.5	"
82	Alberta sp.	–	–	12.5%	% of original gross merchantable volume
			–	3-11.3%	green basis, bark on in a boreal region
			–	9.9-32%	In sub-alpine stands

Notes: Slash: unmerchantable tops and foliage plus all branches
Stump: ground level unless otherwise specified
Top: assumed to be upper part of the bole containing branches

1. Stump height and top, not specified

Percentage Brush for Young Trees of Various Ages -- Oven-dry and Bark-on Basis

Table 19 gives a number of values for percentage brush, defined as the material less than 2.76 inches in diameter, from the older technical literature and compiled by Rennie (137).

For *Abies alba*, *Picea excelsa* and *Fagus sylvatica*, there is a steady decrease in percentage slash with increasing age, whereas *Quercus robur* shows little change in percentage slash from 25 to 345 years of age.

Percentage Slash as a Function of DBH -- Green Basis.

Values are shown in Table 20 for percentage slash on a green basis. The data recorded for *Abies balsamea* provide an example of the difficulty in interpreting biomass data: according to one set of data (190), percentage slash increases with decreasing dbh and, according to another set (188), it increases. As for each of the individual components making up slash, the various values recorded should not be compared between species, since it would be the exceptional case where they would be comparable. It is a commentary on the extreme complexity of tree biomass development that the relationship between dbh and the percentage of top, branches and foliage can differ not only in magnitude, which would be expected, but also in direction as witness biomass data on *Abies balsamea* (190 and 188).

TABLE 19

Brush as a Percentage by Weight of Full Tree Bole for Various Tree Ages.

Brush: all timber less than 2.76 inches in diameter
Full bole: all timber greater than 2.76 inches diameter
Brush: oven-dry and bark-on basis
Full Bole: oven-dry and bark-free basis

Reference: 137

Wood species	Tree age in years	Brush as % of bole	Notes
Abies alba	40	38.2	Number of trees: 1 tree for each age
	90	12.8	Stump: not specified, assumed to be ground level
	144	12.4	
Larix decidua	40	22.0	
Picea excelsa	40	47.7	
	100	16.6	
	120	12.8	
Pinus strobus	50	30.0	
P. sylvestris	100	28.8	
	100	15.0	
	100	9.2	
Acer campestre	37	41.4	
A. platinoides	8	20.7	
Alnus glutinosa	70	8.5	
Carpinus betulus	37	47.8	
	40	43.7	
Corylus avenalla	37	108.0	
Fagus sylvatica	37	29.6	
	50	58.3	
	90	25.2	
	110	21.4	
	220	11.2	
Fraxinus excelsior	37	34.4	
	40	61.8	
Malus acerba	37	55.0	
Populus tremula	37	41.2	
Prunus avium	37	61.0	
Quercus robur	25	32.0	
	37	29.3	
	50	33.4	
	345	38.6	
Robinia pseudoacacia	30	16.8	
Sorbus terminalis	37	38.8	
Ulmus montana	37	39.4	

TABLE 20

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

Slash: tops and foliage plus branches
Foliage: green
Tops, branches and bole: green and bark-on basis.

Reference	Wood species	No. of trees sampled	Slash as a % of Full Tree Bole — Diameter breast height (inches) 6	8	10	12	14
80	*Abies balsamea*[1]	20-30	39	34	30	27	24
188	*A. balsamea*[2]	23	19	27	35	42	-
80	*Picea glauca*[1]	20-30	41	37	34	31	29
80	*P. mariana*[1]	20-30	33	30	28	26	24
189	*P. rubens*[2]	25	37	41	45	45	40
80	*Pinus banksiana*[1]	20-30	21	18	17	15	14
191	*P. strobus*[2]	27	36	29	25	24	27
37	*Thuja occidentalis*[2]	21	70	58	54	54	-
191	*Tsuga canadensis*[2]	28	41	46	51	56	62
187, 189, 190	*Acer rubrum*[2]	20	49	32	24	21	21
191	*Betula papyrifera*[2]	17	62	57	54	57	-
191	*Populus* sp.[2]	14	28	35	39	37	-

1. Based on full-tree weight. Stump height not given.

2. Based on full bole. Stump: 6 inches above ground level. Branches: includes those branches ≥ 1" in diameter.
Foliage: includes those branches < 1" in diameter plus needles and leaves; i.e., foliage as such.

Percentage Slash on Various Bases.

Most species in Table 20 show a regular trend toward decreasing slash with increasing dbh. One set of values for *Abies balsamea* (188), values for *Tsuga canadensis* (191) and those for *Populus* sp. (191) show a reverse trend. Two species, *Picea rubens* and *Betula papyrifera*, show no marked trend in percentage slash over the dbh range from 6 to 14 inches. As with the percentage slash on a standard base, a general conclusion can be drawn for percentage slash on a green base between species, since at 8 inches dbh the range shown is threefold from 18% for *Pinus banksiana* to 58% for *Thuja occidentalis*.

It is of interest to compare percentage slash on several bases. This comparison is shown in Table 21 for *Tsuga heterophylla* (81).

TABLE 21

Slash as a Percentage of Full Tree Bole Using Various Bases and DBHs.

Species: *Tsuga heterophylla*
Reference: 81

Basis	Slash as % of Full Bole[a] Dbh in inches		
	8.5	14.2	18.0
1. Oven-dry weights, all components bark on	40.3	16.7	26.7
2. Oven-dry weights, all components bark free	40.9	17.5	27.3
3. Green weights, all components bark on	41.5	15.1	23.7

[a] All values based on full bole, top from a 6-inch to a 1-inch diameter; stump height, 12 inches.

Percentage Slash — Miscellaneous Values.

Among the miscellaneous values for percentage slash given in Table 22, it is of interest to note the wide range of slash biomass, from 3 to 32 percent (82), as a function of forest type.

TABLE 22

Percentage Slash — Miscellaneous Values.

Reference	Species	% Slash	Comment
181	U.S. sp.	45%	% of merchantable weight, green weights assumed
103	Canadian sp.	23%	% of annual harvest, basis unknown
32	Alberta sp.	13%	% of the original gross merchantable volume
	Alberta sp.	3-11	(in boreal region) % of the original merchantable stand volume
	Alberta sp.	10-32	(in sub-alpine stands) % of the original merchantable stand volume
70	*Picea excelsa*, *Pinus sylvestris*, *Betula* sp.[1]		76% = wood; 14% = bark; 10% = needles and twigs — breakdown of slash components in particle form

[1] Mixture of three species.

Calculation of Percentage Slash from Percentage Crown.

No effort has been made to convert green values for percentage slash to the standard basis, since to do so would require data on the specific gravity of foliage, top, branches and bole (where volume percentages are given) and on the moisture and bark contents of these components in all cases. That is, in the extreme case, some 10 or 11 conversion factors would have to be used and not one of these factors is known with any high degree of accuracy for most wood species.

TABLE 23

Approximate Values for Unmerchantable Top of Bole as a Percentage by Weight of Full Tree Bole.

Top as % of full bole Basis used:	Percentage Unmerchantable Top -- Estimate Dbh in inches 6	8	10	12 or over
Standard basis[1]	15	10	6	4
Oven-dry, bark-on basis[2]	15	6	3	2
Green, bark-on basis[3]	18	8	4	3

[1] *Abies balsamea* (191)
[2] *Pinus contorta* var. *latifolia* (86)
[3] *Abies balsamea* (188)

For very approximate estimates, the values in Table 23 for percentage top can be added to the appropriate crown values to give percentage slash, without introducing serious error, particularly for dbh values above, say, 10 inches. An error of 20% in tops at 10 inches dbh and 25% slash would introduce a much smaller error of plus or minus 5% in the estimate percentage of slash.

Even such a relatively straightforward correction factor would have to be used with caution for some wood species, such as *Thuja occidentalis* (Table 1), and correction would not be applicable to dbh values below 6 inches. In the case of percentage slash on a green basis, such an estimated conversion factor for percentage tops would be questionable below 8 inches dbh because of the wide variation in percentage tops at, say, 6 inches top diameter (15 to 28%, Table 20 ref. 77). In the case of *Pinus taeda* (Table 20 ref. 77), for example, a correction factor for tops of 11% for 7 inches dbh could be used for any tree height; at 5 inches dbh, however, the percentage by measurement ranges from 25 to 53% depending on tree height. Obviously no average value could be used for different wood species and over a wide dbh range.

It is again emphasized that it would be meaningless to take, even for a single wood species, the percentage branches, foliage, and tops from different tables -- i.e., from data obtained in different studies -- and add them together to obtain an estimate of percentage slash.

Summary

The previous discussion relating to variability of component biomass for tops, foliage and branches are applicable to percentage slash. The factors which are known to influence percentage slash, or which are suspected to, are summarized in Table 24.

TABLE 24

Factors Affecting Percentage Slash

Reference: 76

Slash component	Factors affecting % slash -- standard basis	General magnitude of effect
Tops	Top diameter of merchantable bole	Major
	Stump height	Minor
	Wood species	Major
	Tree height	Major
	Dbh	Major
	Dominance	Unknown, probably major
	Wind pressure	Unknown, probably major
Foliage	Wood species	Major
	Tree age	Moderate
	Stump height	Minor
	Tree height	Critical
	Dbh	Major
	Site index	Major
	Stand density	Critical
	Growth rate	Unknown
	Season	Major
Branches	Wood species	Major
	Tree age	Moderate
	Stump height	Minor
	Tree height	Critical
	Stand density	Critical
	Season	Major
	Genetics, water supply and other factors	Unknown

There may well be other factors which have an influence on the biomass of tree tops, foliage and branches (and hence on percentage crown and slash) for which data are not available. The degree of interaction between the various parameters is, in general, not known and predictability is essentially zero.

UTILIZATION OF CROWN AND SLASH

Introduction

Under utilization the crown and slash are not considered separately. Tables 25 to 31 give literature references relating to the utilization of wood wastes generally. The use categories reviewed include:

Table 25 -- General

Table 26 -- Construction Materials

Table 27 -- Pulp and Paper Manufacture

Table 28 -- Power and Fuel

Table 29 -- Agricultural Uses

Table 30 -- Bulk Chemicals

Table 31 -- Pharmaceutical Products, Essential Oils and Fodder Supplement

TABLE 25

Utilization of Crown and Slash -- General

Reference	Wood species	Use	Comment
99	*Platanus occidentalis*	Fiber source	Sycamore silage
2	General	Polishing and finishing agent	Wood meal prepared by grinding sawdust and planer shavings
128	*Platanus* sp. *Fagus* sp.	Food	Use of leaves, wood and growth on forest floor for food manufacture
26	General	....	General review, wood waste utilization
174	*Pinus sylvestris*	Vitamin meals, by-products	Utilization of logging residues and small-sized wood
71	General	....	General review, logging slash utilization
19	General	Silvichemicals	Discussion of production of silvichemicals in the United States
75	General	Vitamin meal	Production methods
193	General	Silvichemicals	Utilization of logging slash
5	General	Silvichemicals	Logging waste is about equal to the amount of residues from processing
94	General	Silvichemicals	Review of wood waste utilization and future prospects
165	General	Silvichemicals	Review of complete-tree utilization
146	General	Silvichemicals	Review of slash utilization
27	General	Road binder, other by-products	Review on slash utilization
31	*Fagus* sp. *Picea* sp. *Pinus* sp.	Chips	Utilization of thinnings, branchwood
41a	Hardwoods	Pyrolysis, power, chemicals, hydrolysis, tanning agents, wood/plastic combinations	Review of the chemical utilization of hardwoods (other than in pulping).

TABLE 26

Utilization of Crown and Slash -- Construction Materials

Reference	Wood species	Use	Comments
70	General	Building boards, floor tiles, hardboards	Review of waste wood utilization
50	General	Wallboard and fiberboard	Tops, thinnings and wood wastes generally have been used.
147	General	Fiberboard and particleboard	Utilization of wood and wood residues
22	*Pinus* sp.	Particle board	Discussion of the economics involved in the use of small trees, tops and branches
176	General	Insulation boards	Bark does not affect the insulating effect, but does increase hydroscopicity.
59	General	Wood blocks	Use of blocks in buildings is technically and economically feasible.
1, 69	General	Branchwood blocks	Used in the building industry -- excellent structural characteristics
57	General	Branchwood blocks	Use of a ram baler for block preparation
136	General	Wood particle board	Utilization of wood wastes and low quality wood
43	General	"Arbolit"	Mixture of wood particles and cement to give construction blocks and panels.
116	General	Pressed board	Utilization of logging slash; boards are prepared at the logging site
144	General	Hardboard Particle board Pressed wood laminates Composite boards	General review of raw materials used in the production of these end products

TABLE 26 (continued)

Utilization of Crown and Slash — Construction Materials

Reference	Wood species	Use	Comments
113	General	Concrete-containing building material	Utilization of bark and wood chips: product has high strength excellent heat and sound insulation
55	General	Fiberboard, particle board	Use of small coniferous trees
185	*Pinus densiflora* *Fagus sieboldi* *Quercus crispula*	Fiberboard	Use of tops of trees as a raw material
95	General	Particle board	Made from mill wastes, properties similar to those of conventional boards
62	*Tectona grandis*	Plastic boards, fiberboards, particle boards	Utilization of complete-tree components in manufacture
174	*Pinus sylvestris*	Particle board, fiberboard	Utilization of logging residues and small-sized wood because of abundance
88	General	Building material	Utilization of logging slash
118	General	Particle board	Production from organic raw material
87	*Pinus sylvestris* *Picea abies* *Betula* sp. *Populus* sp. *Alnus* sp.	Chipboard without binder	Manufactured from logging waste — thermal insulation materials
163	General	Branchwood building blocks	Speed of building increased, easier handling of construction materials
184	*Chamaecyparis obtusa* *C. pisifera*	Fiberboards	Fiber quite suitable for fiberboard manufacture
89	General	Fiberboard	Review of possible utilization of wood residues from full-tree logging

TABLE 26 (continued)

Utilization of Crown and Slash -- Construction Materials

Reference	Wood species	Use	Comments
16	*Abies amabilis*	Particle board, fiberboard	Raw material potential is high
61	General	Binderless hardboard	Review on use of logging wastes
34	General	Chipboards	Review on utilization of logging slash

TABLE 27

Utilization of Crown and Slash -- Pulp and Paper Manufacture

Reference	Wood species	Use	Comment
70	General	Semichemical pulps, boxboards	Sulfite and soda pulps
131	General	Corrugating medium	Possible use of brushwood
4	*Picea* sp. *Pinus* sp.	Sulfate pulps	Review of sulfate pulping of tops, branches, foliage
60	*Betula* sp. *Picea* sp. *Pinus* sp. *Populus* sp.	Sulfate pulps	Best suited to manufacture of boxboard and fiberboards
22	*Pinus* sp.	Pulp and paper	Discussion of economics in use of tops, branches and small trees
29	General	Pulp chips	Use of young coppice growth
46	*Populus* sp.	Semichemical pulps	From veneer waste and poplar branches
107	General	Pulps	Utilization of wood wastes
108	*Tsuga heterophylla* *Abies concolor*	Pulps	Mill operation on waste wood
111	General	Pulps	Problems involved in the use of small-dimensioned wood and sawmill wastes
109	General	Pulps	Utilization of sawdust for pulp
142	General	Paper making fibers	Utilization of sawdust and shavings and wood wastes generally
55	General	Pulp	Use of coniferous thinwood
126	General	Pulp chips	From hardwood coppice produced at felling site
152	General	Pulp	New method of crushing small-dimensioned hardwood prior to pulping

TABLE 27 (continued)

Utilization of Crown and Slash -- Pulp and Paper Manufacture

Reference	Wood species	Use	Comment
44	*Pinus taeda* *P. elliottii*	Pulp, paper, linerboard	Use of slash for the production of pulp chips
185	*Pinus densiflora* *Fagus sieboldi* *Quercus crispula*	Pulps	Utilization of small-dimensioned wood for chemical and semi-chemical pulps
83, 84	*Salix alba*	Pulp	Utilization of waste wood in monosulfite process
158	General	Pulp chips	Review and description of new portable chipper for use in forest
34	General	Hardboard, particle boards, pulp, paper	Review on slash utilization
165	General	Pulp and paper	Review on complete-tree utilization concept
146	General	Fiberboards	Review on slash utilization
66	General	Pulps	Review on slash utilization
35	General	Wallboards, pulps	Review on slash utilization
48	General	Paper, board, cellulose derivatives	Review on problems of waste disposal and utilization
27	General	Pulps	Review on slash utilization
183	General	Pulps and paper	Review on slash utilization
140	*Picea* sp.	Soda pulp	Pulp yield 75%, cellulose content 70 to 77 %
182	General	Pulps for papers, roofing felt	Utilization of wood wastes generally
24	General	Pulps	Review of possible use for wood residues in Alberta
170	*Populus* sp.	Pulp chips	Use of fast-growth stock in pulping
28	*Populus* sp.	Pulp chips	Utilization of fast-growth wood in manufacture of high-yield sulfite pulp

TABLE 27 (continued)

Utilization of Crown and Slash -- Pulp and Paper Manufacture

Reference	Wood species	Use	Comment
101	*Platanus occidentalis*	Pulp	Use of 1-year-old sycamore sprouts shows promise
129	*Abies* sp. *Fagus* sp. *Picea* sp. *Populus* sp. *Quercus* sp. *Salix* sp.	Pulps	Various dimensions of logging residues result in non-uniform chips, heterogeneous pulping, and non-homogeneous pulps
105	*Pinus* sp. *Picea* sp. *Populus* sp.	Sulfate and sulfite pulps	Kraft pulps from all materials tested have higher strengths than corresponding sulfite pulps.
20	General	Sulfite pulp	Logging wastes a potential source of fiber
25	*Pinus sylvestris* *P. pinaster* *P. laricio* *P. halopensis* *P. radiata* *Eucalyptus camaldulensis* *E. globulus*	Sulfate pulp, NSSC pulps	Barking problems are serious
34	General	Papers	Review of slash utilization

TABLE 28

Utilization of Crown and Slash -- Power and Fuel

Reference	Wood species	Use	Comments
164	General	Power	General review of waste conversion
192	General	Power	Discussion of increased utilization of logging residues
170a	General	Fuel	Special machines could be developed to chip branches at felling sites.
193	General	Power	Slash, combined with other wood wastes
86	*Picea glauca* *Pinus contorta* var. *latifolia*	Fuel	Determination of fuel value of crown
34	General	Steam and power generation	Review on slash utilization

TABLE 29

Utilization of Crown and Slash -- Agricultural Uses

Reference	Wood species	Use	Comments
138	General	Ammonia fertilizers	Conversion of 66 tons/day of wood wastes
169	General	Compost	Use of microbiological agents to compost sawdust to increase mineral value
36	General	Compost	Utilization of sawdust and shavings for composting
18	*Fagus* sp.	Compost	Three procedures for composting air-dried beechwood sawdust
33	*Abies* sp. *Pinus* sp. *Sequoia* sp.	Cattle bedding, soil improvement, mulching	Agricultural and horticultural uses of wood wastes reviewed
73	General	Cattle feed	Utilization of logging and lumber waste
180	General	Compost	Sawdust composts proved beneficial to field and forest crops
148	General	Animal feed	Review on possibilities of using wood wastes as roughage or energy source
178	General	Animal and poultry bedding	Use of residues from primary wood conversion
21	Conifers	Vitamin-rich food for animals	Utilization of foliage
13	*Prosopis spicigera* *Adina cordifolia* *Bauhinia purpurea* *Morus alba*	Animal fodder	Discussion of potential of species cited as animal food
91	*Acacia mellifera* var. *detinens* *A. erubescens* *A. hebeclada* *Phaeoptilon spinosum* *Rhigozum trichotomum* *Acacia haematoxylon* *Terminala sericea* *Colophospermum mopane*	Fodder	Used successfully as a source of nourishment, no loss of animal weight

TABLE 29 (continued)

Utilization of Crown and Slash -- Agricultural Uses

Reference	Wood species	Use	Comments
89	General	Agricultural uses	Review of possible utilization of wood residues from full-tree logging
1	General	Cattle fodder production	Wide variation in logging slash utilization
168	General	Cattle feed supplement, etc.	Review in depth of the utilization of foliage and small branches
14	General	Soil conditioner, mulch	Porous wood structure improves the water-holding capacity of soil and improves soil aeration -- a review.
17, 153	General	Cattle feed, soil conditioner	Review of slash utilization
32	General	Fertilizer	Review of literature on utilization of wood wastes for fertilizer
34	General	Agricultural uses	Review on slash utilization
139	*Picea* sp. *Populus* sp.	Organic fertilizers	Fertilizers by the fermentation of wood waste and manure.
112	*Alnus rubra* *Pseudotsuga menziesii*	Soil conditioners	Utilization of sawdust

TABLE 30

Utilization of Crown and Slash -- Bulk Chemicals

Reference	Wood species	Use	Comments
164	General	Chemicals	General review of conversion of wastes from whole-tree logging
97	General	Chemicals	Wood gasification products
114	General	Chemicals	Pyrolysis products
45	Hardwoods	Chemicals	Pyrolysis products from logging and wood wastes
93	General	Chemicals	Pyrolysis products from logging wastes
96	General	Ammonia	From logging wastes
142	General	Chemicals	Utilization of sawdust and shavings
98	General	Chemicals	Use of unsaponifiable fraction from resinous extracts
154	*Betula* sp.	Furfural	Use of branches
174	*Pinus sylvestris*	Cellulose	Utilization of logging residues
192	General	Chemicals	Increased utilization of logging residues
171	*Picea* sp.	Polyphenols	Biological activity of polyphenols in spruce foliage
54	General	Chemicals	Review of chemicals presently being extracted from whole trees
141	General	Chemicals	Review of utilization of wood residues
133	*Pinus* sp. *Picea* sp.	Chemicals	Review on possible conversion to chemicals of wood components
125	*Pinus* sp.	Chemicals	Production from logging refuse by portable equipment
7	General	Chemicals	Gasification products from logging slash
92	General	Chemicals	Gasification of logging wastes
27	General	Chemicals	Review on slash utilization
48	General	Organic chemicals	Review of the problem of waste disposal and utilization

TABLE 30 (continued)

Utilization of Crown and Slash -- Bulk Chemicals

Reference	Wood species	Use	Comments
149	General	Levulinic acid	From wood wastes and residues generally
173	General	Chemicals	New species of wood used in the chemical industry
117, 132, 134	General	Oxalic acid and other chemicals	Produced by fusion of wood wastes with NaOH
102	General	Chemicals	Obtained from wood wastes by steam and solvent extraction
139	*Picea* sp. *Populus* sp.	Methane	Wood-waste fermentation
23	General	Chemicals	Discussion of chemicals derived from logging waste
155	Hardwoods	Furfural	Utilization of wood wastes such as sawdust

TABLE 31

Utilization of Crown and Slash -- Pharmaceutical Products, Essential Oils and Fodder Supplement

Reference	Wood species	Use	Comments
115	*Pinus sylvestris*	Chemicals	Harvesting and utilization of conifer foliage during thinnings seems of doubtful value
151	*P. clausa* *P. echinata* *P. elliottii* var. *elliottii* *P. elliottii* var. *densa* *P. glabra* *P. palustris* *P. pungens* *P. rigida* *P. serotina* *P. taeda* *P. virginiana*	Chemicals	General review of extractives from wood, bark and foliage of the southern pines
175	General	Fir oil	Utilization of logging slash
150	General	Vitamins	Review on utilization of forest slash
58	*Pinus* sp. *Picea* sp. *Betula* sp.	Essential oils	Utilization of logging slash
9	Conifers	Water-soluble chlorophyll derivatives	Preparation from foliage
8	Conifers	Conifer leaf oils	Experimental distillation
15	*Thuja* sp.	Cedar leaf oils	Distillation of cedar foliage
42	Conifers	Terpenes	General review of terpene extraction
51	*Pinus* sp.	Pine oil	Review of utilization of pine oil
74	*P. roxburgii*	Pine oil	Extraction of pine oil from foliage

TABLE 31 (continued)

Utilization of Crown and Slash — Pharmaceutical Products, Essential Oils and Fodder Supplement

Reference	Wood species	Use	Comments
143	*Picea* sp. *Pinus* sp.	Vitamin C	Variation in vitamin C content as a function of foliage age and season
156	*Pinus* sp.	Pinene	Review of perfume chemicals from pinene
30	*Populus tremula*	Glucose	Chemical extraction from leaves
39	*Pinus* sp.	Vitamins	From pine foliage
40	*Pinus* sp.	Vitamins C and E, carotene	Review of extraction methods
72	*Pinus* sp.	Vitamin extracts	Preparation of extracts from foliage
75	General	Chlorophyll-carotene pastes	Production methods reviewed
90	*Pinus* sp.	Vitamin C	Accumulation during storage of foliage
127	General	Vitamin C	Concentration in needles reviewed
135	*Picea morinda*	Soap, cosmetics, perfumery	Utilization reviewed
166	*Abies* sp.	Essential oils	Review of yield and production of essential oils from white and Sakhalin fir
172	Conifers	Chlorophyll-carotene paste	Review of extraction and yields
130	General	Pharmaceutical chemicals	Review on wood waste utilization
181	General	Carbohydrates	Review of wood wastes and spent pulping liquors for possible conversion to carbohydrates
49	General	Essential oil	Discussion of essential oils and related products

TABLE 31 (continued)

Utilization of Crown and Slash -- Pharmaceutical Products, Essential Oils and Fodder Supplement

Reference	Wood species	Use	Comments
41	*Pinus* sp.	Chemicals and pharmaceuticals	Possible uses of foliage
3	Conifers	Chemicals, chlorophyll/carotene pastes	Extracts from foliage
167	*Abies* sp. *Picea* sp.	Carotene	Production of carotene paste

CONSTRUCTION MATERIALS

The long-term potential for construction materials manufactured from wood wastes is probably quite high, and will become increasingly attractive as wood fiber resources or substitute materials diminish or become increasingly costly. As shown in Table 26, the various components of slash -- tops, thinnings and branches with or without foliage and bark -- have been converted to a wide range of construction materials in laboratories and on a commercial or pilot plant scale. These construction materials include a number of categories:

- Low-density insulating or sheathing boards from pulp fiber;
- Medium-density fiberboard from pulp fiber;
- Medium-density composition board from chips, shavings, sawdust, shingle hay and foliage;
- High-density fiberboard or composition board from wood particles;
- Structural blocks or panels from mixtures of cement and comminuted wood;
- Solid blocks reconstructed from solid wood in smaller form.

The field of converting slash or slash components to construction materials is complex, since there is a wide range of starting materials, probably variable in composition and properties, a large number of processing possibilities, and numerous end uses for various types of products. The near-future potential is probably not high in Canada, primarily because categories of construction materials which might be manufactured from wood wastes generally are not competitive with materials of equal or superior quality which are presently manufactured, or could be manufactured, from bole wood or mill wastes from log processing.

The primary need in this field is a review in depth of the material supply, processing, economics and potential markets for the types of constructions materials which could be produced from slash or from selected slash components.

PULP AND PAPER MANUFACTURE

The use of tops and branches as raw material for pulp manufacture has been discussed in previous sections of the present review. Progressively poorer pulp is obtained from large branches, small branches, shoots and twigs, bark and foliage. The best of branch pulp would be expected to have in the order of 60 to 70% of the yield and strength of pulp from comparable boles. Pulp appreciably lower in quality than this, such as would result from admixtures of large branches with small branches, bark, etc., would not appear a promising development with the present Canadian economy.

Again the subject is a complex one, since raw material is highly variable, and only limited information is available on the properties and possible end uses of pulps which might be obtained. The question as to whether foliage should be separated, or whether the material should be debarked prior to pulping, is dependent upon amount and type of slash components.

It is probable that only kraft or neutral sulfite semichemical pulping processes would be applicable to pulping slash, and that the pulp would be best suited for corrugating medium or fiberboard. Slash is most likely to serve as a supplementary source of fiber rather than as a primary source.

What is most needed is a comprehensive review of all aspects of slash utilization for pulp manufacture; raw material supply and transport, processing, product quality, economics, end uses, markets and integration with other aspects of forest use.

POWER AND FUEL

Wood wastes of all types, including bark, slash, chipper fines, sander dust and other wood materials not presently converted to forest products, can be converted to steam, electricity and chemical by-products. It is technically feasible to do so[d], but whether or not it is economically or politically expedient is dependent upon alternative sources of power available in the present or near future, upon long-range availability of fossil fuels, upon sources of atomic energy and pollution loads, upon the total need for power in a given location, together with legal restrictions upon the expansion of certain types of power generation because of a number of potential pollution effects, and upon the marketability of the by-products.

Insufficient data are available to make any judgement concerning the economic potential in this case, and the economics and total implications would have to be studied for each potential application.

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[d] One full-scale plant for the recovery of chemicals and electricity from logging slash has been in operation for several years in the Soviet Union. Information on this mill includes:

Capacity:	50,000 solid cubic meters of logging slash per year, made up of tops, branches, twigs, foliage and bark.
Annual output:	2,500 tons of tar for phenol extraction; 1,000 tons of calcium acetate; 5 to 5.5 million kilowatt hours of electricity.
Capital costs:	Pyrolysis and chemical recovery plant = $530,000 electrical station = $240,000
Cost of electricity:	0.7 cents per kilowatt hour.
Manning:	pyrolysis and chemical recovery plant = 35; electrical station, including operation and maintenance = 13.

AGRICULTURAL USES

There is an abundance of literature on the use of wood wastes in agriculture for a variety of broad purposes:

- as a source of fertilizer;
- as compost;
- for mulching and soil improvement;
- as animal and poultry bedding;
- as cattle feed, used directly;
- as cattle feed, after hydrolysis;
- as a vitamin enrichment for cattle food by chemical processing (included in section on Pharmaceuticals).

Much of the research in this field in the past has involved the use of shavings, sawdust and comminuted mill residues, prior to the time that these materials had found widespread acceptance in pulp manufacture. Many of these studies are highly relevant to slash utilization, however, since slash is either as suitable, or in some cases more suitable, as a raw material for agricultural use than the wood wastes originally studied.

The use potential of slash or of slash components in agriculture may well be quite high, but considerable research and economic studies on specific components, processing and markets remain to be done; again the single most serious need in Canada is for a review in depth of materials, processing, products, and economics.

BULK CHEMICALS

A number of chemicals can be derived from wood. When Glesinger (47) in 1949 reviewed the possibility of using wood as a major source of chemicals, a promising future was predicted for the conversion of wood to a number of bulk chemicals, including methyl and ethyl alcohol, acetic acids, sugars and producer gas, as well as lubricants, plastics, lignin derivatives, cattle fodder and yeast. This high promise has not been realized because:

- Product quality has not been satisfactory in many cases;
- Complex mixtures have been difficult and costly to separate into pure components;
- The chemicals which could be obtained in satisfactorily pure form have not been competitive with the same chemicals from other raw materials, particularly petroleum.

The problem is far too complex to be considered in any depth in the present brief overview. If coal, petroleum and natural gas were in short supply, then the forests of the world might serve as an inexhaustible, renewable source of chemicals. The year 1971 may be 22 years closer to the actual use of forests for chemicals than was 1949, but it may still be too far away to have realistic meaning today. The author is inclined to give this possibility of slash utilization as a massive source of raw material for chemicals a low potential in the near future.

PHARMACEUTICAL PRODUCTS, ESSENTIAL OILS, FODDER SUPPLEMENT

Table 32 gives an outline of the main products which can be derived from technical foliage.

TABLE 32

Products from Technical Foliage

Product	General use	Processing of technical foliage by:	Yield as % of technical foliage.
Essential oils	Perfumes, cosmetics, etc.	Steam distillation	0.5
Vitamin C	Pharmaceutical industry	Extraction with hot water	0.2
Carotene paste[1]	Pharmaceutical industry	Extraction with petroleum ether	5
Vitamin flour[2]	Supplement to animal feed	Heating to 350°C	25

1. The Soviet Union has some 15 plants operating, producing approximately 150 tons per year of product.
2. The Soviet Union has some 50 small plants in operation, producing approximately 100,000 tons per year of vitamin flour.

According to Tomchuk and Tomchuk, approximately 20 million tons of technical foliage is generated annually in the Soviet Union.

UTILIZATION - SUMMARY

Table 33 summarizes the major use categories for slash. The various categories are listed in what is considered to be roughly descending order of promise for massive slash utilization, but the order of promise may not be valid for specific regions or circumstances. Utilization of slash for conversion to bulk chemicals, for example, may be considered to have limited promise *in toto*, whereas analysis would indicate that in a given location this is the most promising of the utilization possibilities.

TABLE 33

Summary of Crown and Slash Utilization

Product category	Main Products	Potential in Canadian economy Short term < 10 yrs.	Long term > 10 yrs.	Research needs
Pharmaceuticals, vitamins, essential oils	Vitamin C Chlorophyll Carotene Vitamin flour Chemicals for perfumes, cosmet. Fodder supplement	High	High	Review in depth of known technology and possible application in Canada
Electrical power and chemicals	Electricity Phenols Acetic acid	Unknown, possibly moderate	Unknown, possibly high	Detailed study of economics and potential application
Agricultural use	Fertilizer Compost Mulch Soil conditioner Animal bedding Cattle feed Fodder supplement	Unknown, may be high	Unknown, may be high	Review in depth of markets, processing, material supply, overall economics
Pulp manufacture	Kraft and semi-chemical pulps Secondary fiber Supplementary fiber	Low	Moderate	Review in depth of, raw material supply, transport processing product quality end uses product quality integration in wood-processing complex
Construction materials	Low, medium and high density fiber-boards, composition boards Cement-wood blocks Reconstructed solid blocks	Low	May be high	Review in depth of, markets processing material supply
Bulk chemicals	Methyl alcohol Ethyl alcohol Acetic acid Sugars Lignin derivatives Oxalic acid Levulinic acid Furfural	Unknown but probably low	Unknown but probably low	Continuing review of developments and possibilities

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 the component parts -- twigs, top, leaves, needles, cones, branches, roots, stump, 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: boles 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.

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[a] One extreme difficulty in analyzing data on biomass or tree component studies arises from the fact that the 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.

The unmerchantable top of bole is that part of a tree defined by the top diameter to 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.

APPENDIX II

Check List of Species by Tables and Pages

Species	Table	Page
Alnus sp.	26	34
A. glutinosa	19	26
A. incana	9	13
A. rubra	29	41
A. rugosa	11	15
Bauhinia purpurea	29	41
Betula sp.	11	15
	22	29
	26	34
	27	37
	30	43
	31	45
B. maximowicziana	9	13
B. papyrifera	2	4
	3	5
	7	10
	16	21
	20	27
B. platyphylla	2	4
	18	24
B. verrucosa	9	13
	10	14
	11	15
Canadian sp.	22	29
Carpinus betulus	19	26
Castanea sativa	9	13
Castanopsis cuspidata	12	16
	18	24
Chamaecyparis obtusa	26	34

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