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Complete-Tree Utilization An analysis of the Literature Part II: Foliage

J. L. Keays

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COMPLETE-TREE UTILIZATION
An Analysis of the Literature

PART II: Foliage

BY

J. L. KEAYS

INFORMATION REPORT

VP-X-70

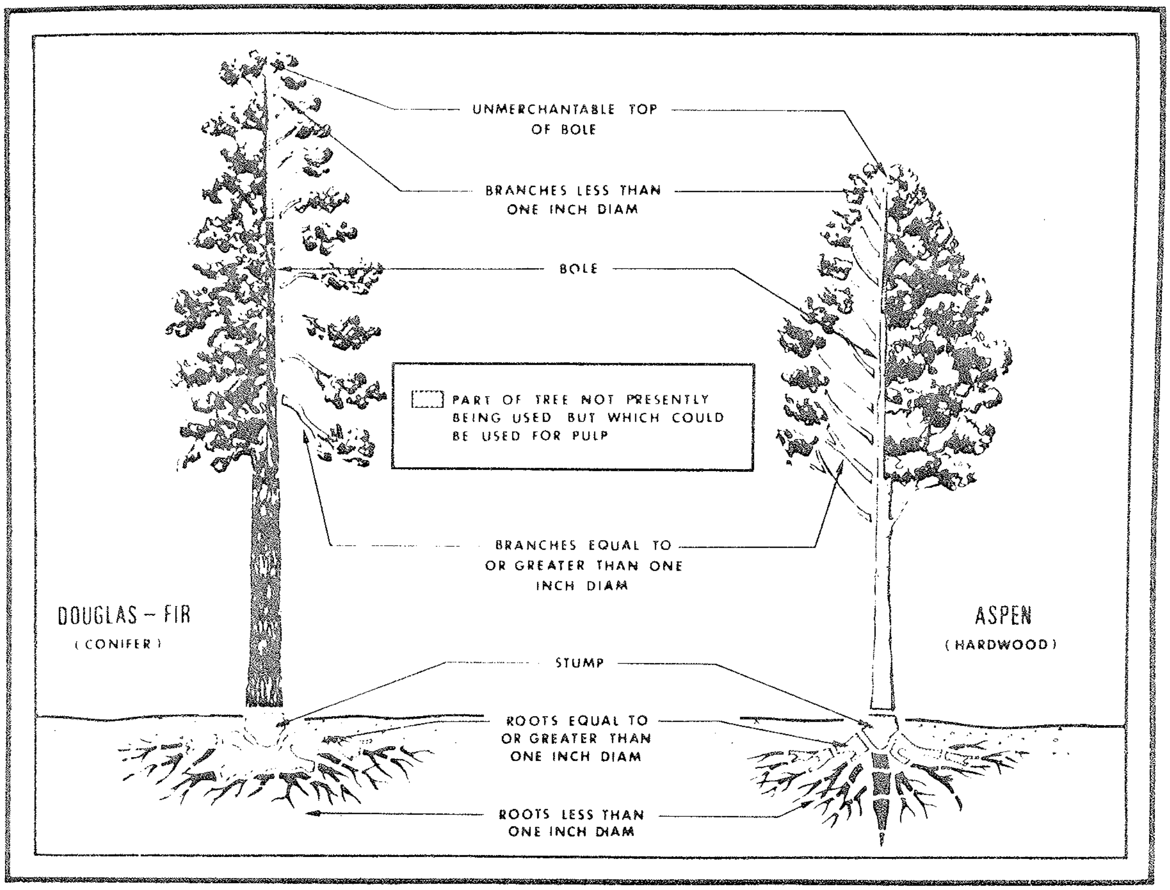
FOREST PRODUCTS LABORATORY

CANADIAN FORESTRY SERVICE

DEPARTMENT OF FISHERIES AND FORESTRY

VANCOUVER, BRITISH COLUMBIA

FEBRUARY, 1971



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RESUMÉ

The technical literature relating to foliage biomass and use has been reviewed. Literature values for foliage biomass on a standard basis (oven-dry foliage as a percentage by weight of oven-dry and bark-free full tree bole) vary from 1 to 1800 percent for all species reviewed, from 6 to 200 percent for a single species, and from 4 to 30 percent for a single species at 6-inch dbh. Foliage biomass is a function of a highly complex network of variables, including:

Tree species.........................critical
Tree height..........................critical
Stand density........................critical
Site quality.........................major
Crown ratio..........................major
Time of year.........................major
Tree taper...........................major
Stump height.........................minor
Other growth conditions..............unknown

Even for a single wood species, at a given dbh, the range of recorded values for foliage biomass is so great that average values cannot be given for individual species. For most *Picea*, *Pinus*, *Tsuga*, *Abies*, *Populus* and *Betula* species in the dbh range from 6 to 12 inches, under average growth conditions and at a high stand density, foliage biomass would probably lie between 8 and 16 percent on a standard basis. Even this wide range should be used only for preliminary feasability studies on the utilization of tree foliage. It will be necessary to determine foliage biomass by direct measurement if accurate answers are required, taking into account the various factors listed above.

Of greater interest than foliage alone is technical foliage, that is, all foliage plus shoots plus twigs plus branches less than 0.6 cm (0.24 inches) in diameter. Technical foliage would equal approximately twice

the foliage alone.

Tree foliage can be considered as a potential raw material for the recovery of essential oils, glucosides, glucose, vitamins, basic raw material for the pharmaceutical industries, fodder supplement and fuel. In the past, probably the single most serious deterrent to the development of marketable products from foliage on a large scale has been the high cost of foliage delivered to a process plant. With increasing use of whole-tree logging, serious consideration should be given by research groups, in both the public and private sectors, to research aimed at developing an industry in Canada based on foliage or technical foliage as a raw material.

A supplementary bibliography of Russian technical literature on the subject is included.

COMPLETE-TREE UTILIZATION - An Analysis of the Literature

Part II: Foliage

By J.L. Keays

INTRODUCTION

The complete-tree utilization concept was outlined in the first report (64) of the present series - Part I: Unmerchantable Top of Bole.

Although foliage is not likely to serve as a major source of fiber, this material might find application as forest compost, fuel, composition board manufacture, extractives, chemicals, animal fodder or fodder supplement, fertilizer or soil additive. It is important to the concept of complete-tree utilization that green and dry weights of all tree components be known. The weight of green foliage has a bearing on transportation costs in tree-length or complete-tree logging, and the dry weight has a bearing on fuel or chemical recovery and on the sizing of mill processing components.

A large number of studies have been carried out on the amount, composition and processing of tree foliage. The purposes of these studies have been both theoretical and applied, and include research on tree growth and synthesis, fire hazard, biomass, chemical composition, and component utilization.

Scattered and sporadic efforts have been made at foliage utilization but, with the exception of vitamin-containing fodder supplements developed in the Soviet Union, in general these efforts have met with indifferent success. This failure to achieve sustained, profitable use for foliage or derivatives or extractives from foliage has arisen in part from the high cost of raw material. This disadvantage may be eliminated or substantially reduced in whole-tree or complete-tree logging, where branches and foliage are brought to a processing plant. In this case, disposal may be a problem, and there will be increasing incentive to find profitable use for the foliage.

The most systematic and detailed studies on the amount, extraction, processing and utilization of foliage have been carried out in the Soviet Union. Many of the recent references to foliage processing and use are found in the Russian technical literature.

FOLIAGE BIOMASS

Foliage as a Function of DBH - Standard Basis

Table 1 gives the percentage foliage (standard basis) as a function of dbh for a number of wood species. It will be noted that in some cases foliage includes twigs and bark on branches less than 1-inch diameter, as well as foliage as normally defined. These data are included to indicate the trends in biomass for this type of material.

TABLE 1

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

Standard Basis - Foliage: oven-dry
Full Bole: oven-dry and bark-free

Reference number	Wood species	No. of trees sampled	Foliage as % of Full Tree Bole diameter breast height, inches 4	6	8	10	12
8	*Abies balsamea*	190	17	25	33	41	...
157	*A. balsamea*[1,5]	23	..	4	5	5	6
9,10	*A. balsamea*[2]	89	22	31	..	..	..
9,10	*Picea glauca*[2]	2	26	28	..	..	..
155	*P. rubens*[1,6]	25	..	4	5	6	6
89	*Pinus taeda*[4]	10	91	42	16	5	..
55	*P. contorta* var. *latifolia*	22	4	5	6	6	7
157	*P. strobus*[1,5]	27	..	6	7	5	5
36	*Thuja occidentalis*[1,6]	21-36	..	15	16	17	18
157	*Tsuga canadensis*[1,5]	28	..	8	9	9	8
153 155 156	*Acer rubrum*[1,6]	20	..	9	6	4	3
157	*Betula papyrifera*[1,5]	17	..	5	7	6	4
9,10	*B. papyrifera*[2]	7	7	10	..	..	..
157	*Populus* sp.[1,5]	14	..	4	4	4	3
---	*P. tremuloides*[6,7]	42	3.8	2.2	2.0	2.2	1.3
---	*P. balsamifera*[6,7]	11	4.2	2.7	2.2	2.0	..

1. Foliage: all material less than 1/4 inch plus the bark on all branches from 1/4 to 1-inch diameter.
2. Stump: ground level.
3. Stump: 12 inches above ground level.
4. Stump at ground level: dbh is diameter at base.
5. Stump: 6 inches above ground level.
   Top: 4 inches.
6. Private communication from E. Peterson, Canadian Forestry Service, Forest Research Laboratory, Edmonton, Alta.
7. Stump cut at ground level; top diameter 2 inch o.b. Foliage: dry weight of leaves and twigs from current year.

It is evident from the data given in Table 1 that:

- The percentage of foliage does not vary greatly with dbh under similar growth conditions for many of the wood species studied: *Abies balsamea* (159), *Picea rubens*, *Pinus contorta* var. *latifolia*, *Thuja occidentalis*, *Pinus strobus*, *Tsuga canadensis*, *Betula papyrifera* and *Populus* sp. The values shown for *Abies balsamea* (8), *Acer rubrum* and *Pinus taeda* are obviously exceptions; in the first case, the percentage foliage increases markedly with increasing dbh, and in the other two cases it decreases. As shown in a subsequent section (page 30), the percentage foliage is strongly dependent upon site class, stand density and growth season. However, it has been stated in part of the studies referred to in Table 1 (153), and it has been assumed even where not implicitly stated, that for the wood species studied, the percentage foliage was determined in a limited forest area in which site index, stand density and growth rate would be expected to be relatively constant, with only a small probability that these factors would affect the results markedly. The percentage foliage for any wood species lies between 5 and 10 percent (standard basis) in the dbh range from 6 to 10 inches. *Pinus taeda* and *Thuja occidentalis* are exceptions, with an unusually high percentage of foliage.
- The total range of percentage of foliage for a given wood species can be extremely wide, as illustrated by the values recorded for *Abies balsamea* from 4 to 40 percent, even at a dbh of six inches or greater.

Foliage for Trees of Various Ages

The data shown in Table 2, which gives the percentage foliage (standard basis) for various tree ages, show extreme variability (*Abies alba, Picea excelsa, Carpinus betulus* and *Fraxinus excelsior*, for example, at 40 years of age). The values shown for *Abies alba* show the marked downward trend in percentage foliage with increasing age or dbh. This general trend is reported for a number of wood species of the Soviet Union (140). The wide range in percentage foliage shown in Table 2 is not unexpected, since the critical variables which have a major effect on percentage foliage are not known or not given in many of the studies reported.

TABLE 2

Foliage as a Percentage by Weight of Full Tree Bole for Various Tree Ages·

Standard Basis

Reference number	Wood species	Tree age in years	Foliage as % of full tree bole[1]
105	*Abies alba*	40 90 144	26 13 4
105	*Larix decidua*	40	2
105	*Pices excelsa*	40 100 120	26 7 3
150	*Pinus echinata*[2]	72	4
105	*P. strobus*	50	8
105	*P. sylvestris*	100	3-4
91	*P. radiata*[3]	29	2
105	*Acer campestre*	37	12
105	*A. platinoides*	8	15
105	*Alnus glutinosa*	70	1
136	*Betula platyphylla*	5	8
105	*Carpinus betulus*	37 40	14 5
105	*Corylus avenalla*	37	24
105	*Fagus sylvatica*	37	7
105	*Fraxinus excelsior*	40 37	10 12
150	*Liriodendron tulipifera*[2]	75	3
105	*Malus acerba*	37	14
105	*Populus tremula*	37	9
105	*Prunus avium*	37	4
149	*Quercus coccinea*[4]	38-45	12
105	*Q. robur*	37	8
105	*Robinia pseudoacacia*	30	4
105	*Sorbus terminalis*	37	6

TABLE 2 (continued)

Reference number	Wood species	Tree age in years	Foliage as % of full tree bole[1]
105	*Ulmus montana*	37	7
	Populus tremuloides[5]	10	31
		20	10
		30	5
		40	2
		50	2
		60	2
		70	2
		80	2
	P. balsamifera[5]	25	9
		35	3
		45	5
		55	2
		65	2

1. Unless otherwise specified, the full bole is defined as stemwood: all timber greater than 2.76 inches diameter.
   Stump: not specified, but assumed to be ground level.
   Number of trees: one for each age.
   Dbh: not specified.
2. Dbh for *Pinus echinata* 13.2 inches and for *Liriodendron tulipifera* 9 inches.
3. Stemwood used as defined in 1 above.
4. Trees cut at ground level.
5. Stump cut at ground level; top cut to 2 inch diameter o.b. Foliage: dry weight of leaves and twigs from current year. See footnote 6, Table 1.

Foliage as a Function of DBH - Bole Oven Dry and Bark On

Table 3 gives a number of values for oven-dry foliage as a percentage by weight of full bole, oven dry and bark on. The decrease in percentage foliage with increasing dbh is quite marked for several species: *Picea glauca*, *Pinus contorta* var. *latifolia* (67, 68), *P. densiflora* (87), *P. sylvestris*, and *P. taeda*. Where the percentage foliage appears to increase with increasing dbh (*Abies balsamea*) it is possible that the true relationship between percentage foliage and dbh is masked by other, unknown variables, or this may be a characteristic of the species in this particular study (see also Table 1).

TABLE 3

Foliage as a Percentage by Weight of Full Tree Bole and as a Function of DBH
Oven-dry Bark-on Basis

Reference number	Tree species	No. of trees sampled	Foliage[1] as % of full tree bole diameter breast height (inches) 4	6	8	10	12
7	*Abies balsamea*[2]	101	15	23	29	35	..
67,68	*Picea glauca*	60	..	13	7	6	5
147	*P. mariana*	20	7	10	..	..	..
67,68	*Pinus contorta* var. *latifolia*	101	29	17	13	13	12
90	*P. contorta* var. *latifolia*	405	6	6	6	..	..
52	*P. densiflora*[3]	..	..	3	4	4	5
87	*P. densiflora*[3]	38	18	6	4	6	..
93	*P. sylvestris*	21	52	41	36	..	..
98	*P. sylvestris*[3]	20	4	7	..	..	..
89	*P. taeda*[4]	10	64	34	14	5	3
134	*Acacia mollissima*[3]	15	19	..	..	..	..

1. Foliage only, no material from the branches.
   Stump: 12 inches above ground unless otherwise stated.
2. Stemwood assumed to mean full bole.
3. Stump: ground level.
4. Stump: ground level.
   dbh: diameter at base.

It should be emphasized that the values for percentage foliage in Tables 1, 2 and 3 should not be compared vertically. The two sets of values shown for *Pinus contorta* var. *latifolia* (67, 68 and 90) and for *P. sylyestris* (93, 98) should not be compared, since the data may have been obtained on areas with different growth conditions, stand densities, tree heights, etc., and the values would not necessarily be expected to agree. These data should be used only as an indication of potential relationships between percentage foliage and dbh for a given species, presumably at constant stand density, site index and growth class.

Foliage on Trees at Eight Inches DBH - Standard Basis

It is possible to convert the values shown in Table 3 to standard values, provided that the percentage bark on the full bole is known for the species and dbhs shown. It might be one of the few cases where data could be converted to the standard basis without danger of serious error, for some wood species and down to a dbh of perhaps six inches. When the values shown in Table 3 are corrected for various assumed values of percentage bark on the bole, the values shown in Table 4 are obtained. In many cases, and particularly for trees of small size, serious error could be introduced by using a single value for the percentage bark on the bole.

TABLE 4

Foliage as a Percentage by Weight of Full Tree Bole at Eight Inches DBH for Various Values of Percentage Bole Bark

Reference Number	Wood species	Calculated % foliage, standard basis, for various assumed values for % bark on bole (Bark-on basis)	10	12	14	16
67,68	*Picea glauca*	7	7.7	7.8	8.0	8.1
67,68	*Pinus contorta* var. *latifolia*	13	14.3	14.6	14.7	15.1
118	*P. contorta* var. *latifolia*	6	6.6	6.7	6.9	7.0
89	*P. taeda*	14	15.4	15.7	16.0	16.2
7	*Abies balsamea*	29	31.9	32.5	33.1	33.4
52	*Pinus densiflora*	4	4.4	4.5		
93	*P. sylvestris*	36	39.4	40.3		

Although a fairly large range in percentage bark on the bole (ranging from 10 to 16%[a] in the case of *Picea glauca*) will introduce a relatively small error in percentage foliage (ranging from 7.7 to 8.1 or 5.1% variation) in the case of large-diameter trees, this is not true for trees of small diameter, where the bark may be as high as 25% (*Betula papyrifera*, ref. 47) or as low as 7% (*Pinus banksiana*, ref. 47), as shown in Tables 5 and 6.

(a) It is noted (70) that the bark content of southern pines is *usually* in the range from 8 to 14 percent.

TABLE 5

Bark as a Percentage by Weight of Full Tree Bole and as a Function of DBH - Standard Basis

Reference number	Wood species	No. of trees sampled	Bark as a % of Full Tree Bole diameter 2	4	breast 6	height 8	(inches) 10
47	*Abies balsamea*[1]	10	23.6	17.2	14.8	14.4	15.6
8	*A. balsamea*	190	12.0	13.0	14.5	15.5	16.5
47	*Picea glauca*[1]	70	..	14.1	10.7	10.9	12.9
9,10	*P. glauca*[2]	2	.	11.5	7.0	..	..
47	*P. mariana*	70	17.1	13.6	10.9	10.7	13.6
47	*Pinus banksiana*[1]	70	6.6	6.5	7.3	8.6	9.2
56	*P. contorta* var. *latifolia*	85	..	..	13.1	..	..
47	*Betula papyrifera*[1]	70	25.0	15.8	12.5	12.0	..
47	*Populus tremuloides*[1]	70	..	17.7	13.3	12.3	11.7
	P. tremuloides[3]	46	28.6	30.2	28.7	25.8	18.3
	P. balsamifera[3]	14	28.8	25.4	22.4	25.0	23.9

Notes: Stump height not specified.
1. Stump height: ground level.
2. Stump height: 12 inches above ground level.
Dbh: not specified.
3. Stump cut at ground level, top diameter 2 cm o.b. (see Footnote 6, Table 1).

Table 6 gives the percentage bark (standard basis) for a number of species. The effect of decreasing percentage bark with increasing dbh can be quite marked, as shown in the values given for *Pinus taeda*. The limited data given emphasizes the danger inherent in assuming an average value for percentage bark in trying to extrapolate between species or even within species without a considerable background of firm data on which to base even a limited range of extrapolation.

TABLE 6

Percentage Bark by Weight on Full Tree Bole - Standard Basis

Reference number	Wood species	No. of trees sampled	Diameter at ground level (inches)	Bark as % of full bole
89	*Pinus taeda*	10	4	41
			6	28.0
			8	21.0
			10	17.0
134	*Acacia mollissima*	15	2	9.0
			4	9.0
122	*Abies* sp.[1]	..	..	14.4
122	*Picea excelsa*[1]	..	..	12.2
122	*Betula verrucosa*[1]	..	..	12.4
122	*Quercus* sp.[1]	..	..	28.2
122	*Tilia* sp.[1]	..	..	28.2
48	*Cryptomeria japonica*	53	5-12	11.1

Notes: 1. Dbh not specified.

Technical Foliage

Table 7 shows the results of detailed studies on the percentage of technical foliage [b] for a number of Siberian wood species. The regularity of the decrease in percentage technical foliage with increasing dbh results from the large number of trees measured, and the fact that all of the values shown were obtained by a standard procedure and recorded on a common basis. The amount of care taken in the study, and its magnitude, arises from the fact that the data were intended to form a basis for the industrial utilization of the foliage in the manufacture of cattle fodder supplement, vitamin extract, raw material for the pharmaceutical industry, etc. For the wood species shown, these data are the most massive and reliable values available from the technical literature for foliage as defined. It is believed that these data are the most reliable in establishing the relationship between percentage foliage and dbh at constant growth conditions and stand density. A relationship between tree height, dbh, and percentage foliage is not established in this study, and the dbh - foliage relationship shown may actually contain both a height and dbh component.

(b) Technical foliage is defined as all needles, leaves, twigs, shoots and branches up to 0.6 cm. diameter (0.24 inches). This diameter was arbitrarily chosen as representing optimum recovery in the extraction of chemicals from foliage; at increasing branch diameter, the yield of marketable extractives falls off rapidly, and the cost of chemical recovery increases rapidly.

TABLE 7

Technical Foliage(1) as a Percentage by Weight of Full Tree Bole and as a Function of DBH

Foliage: oven dry

Full Bole: assumed oven dry and bark on

Reference: 140

Wood species	No. of trees sampled	Technical Foliage(1) as % of full bole(2)				
		diameter	breast	height		(inches)
		4	6	8	10	12
Abies nephrolepis	55	62	43	30	24	20
Larix dahurica	27	6	6	5	4	4
Picea jezoensis	68	67	53	42	33	27
Pinus koraiensis	99	..	40	25	18	14
P sibirica	39	40	26	17	12	9
P sylvestris	39	33	24	18	14	11

1. Technical foliage: all needles plus needle-bearing shoots up to 0.24 inches diameter.
2. Stump height not specified.

The relationship between percentage technical foliage and dbh is shown diagramatically in Figure 1. With the exception of *Larix dahurica*, the relationship between percentage technical foliage and dbh is quite uniform between the wood species studied.

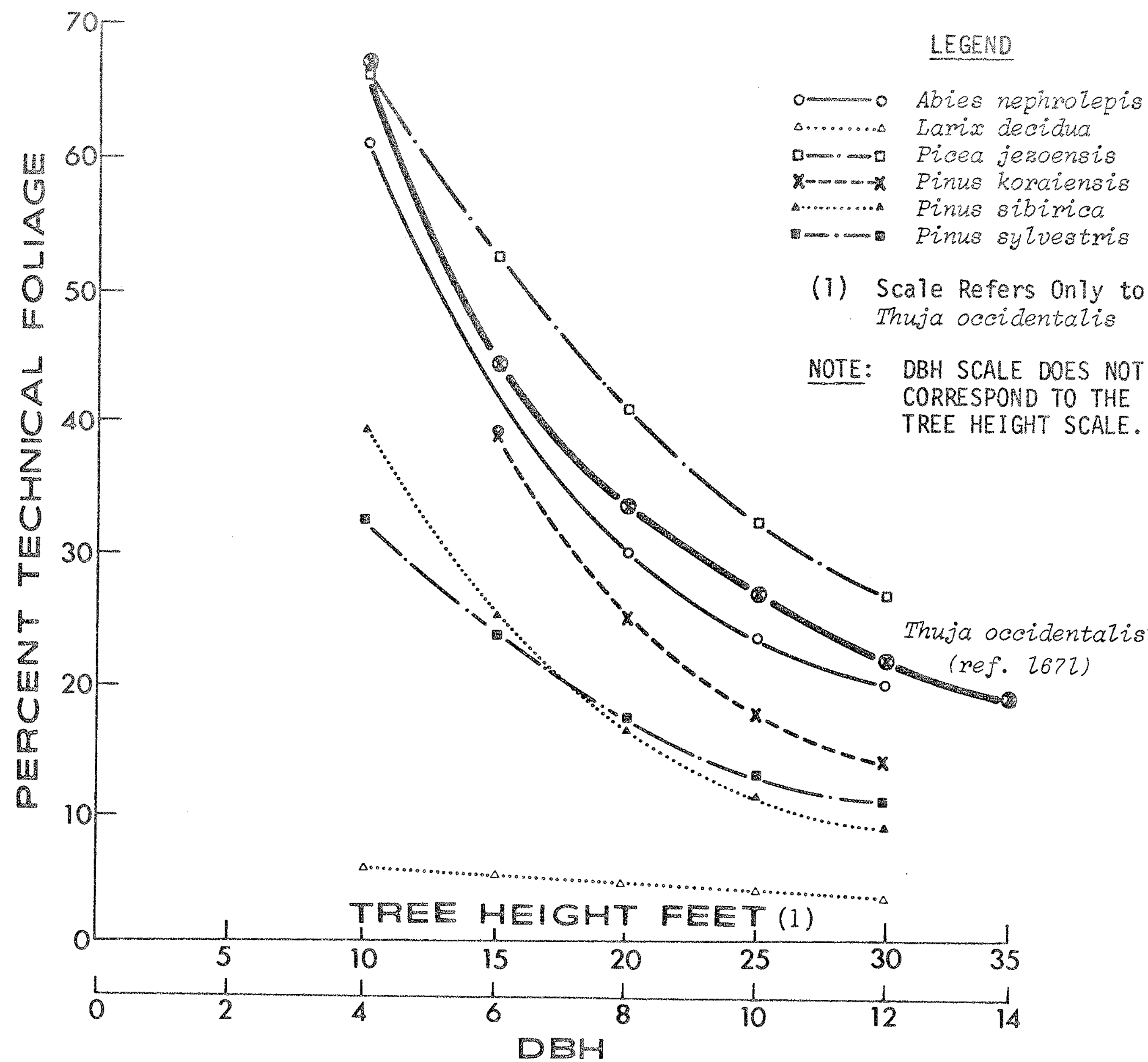

Figure 1. Relationship Between Percent Technical Foliage and DBH for Several Siberian Wood Species

Foliage as a Function of Tree Height

It is of interest to compare the relationship between percentage foliage and dbh (Figure 1) with data obtained by Young in his work on wood species from Maine. The relationship between percentage foliage and tree height from Young's studies (152) is shown in Table 8 and Figure 2.

TABLE 8

Foliage as a Percentage by Weight of Full Tree Bole and as a Function of Tree Height - Oven-dry and Bark-on Basis

Reference: 152[1]

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[2]	6	300	86	52	39	27	18	14	11	9	7

1. Dbh range up to 4 inches;
   Stump height not specified but probably ground level.
2. E. Peterson, in a biomass study on components of *Populus tremuloides* and *P. balsamifera* (footnote 6, Table I) found that the absolute amount of foliage per acre is relatively constant in fully stocked stands, ranging from sucker stands of low height to mature stands of full height. Thus it is necessary to distinguish between the percentage of a tree component and the amount of component per unit of forest area. The same point is emphasized by H. Young in a private communication.

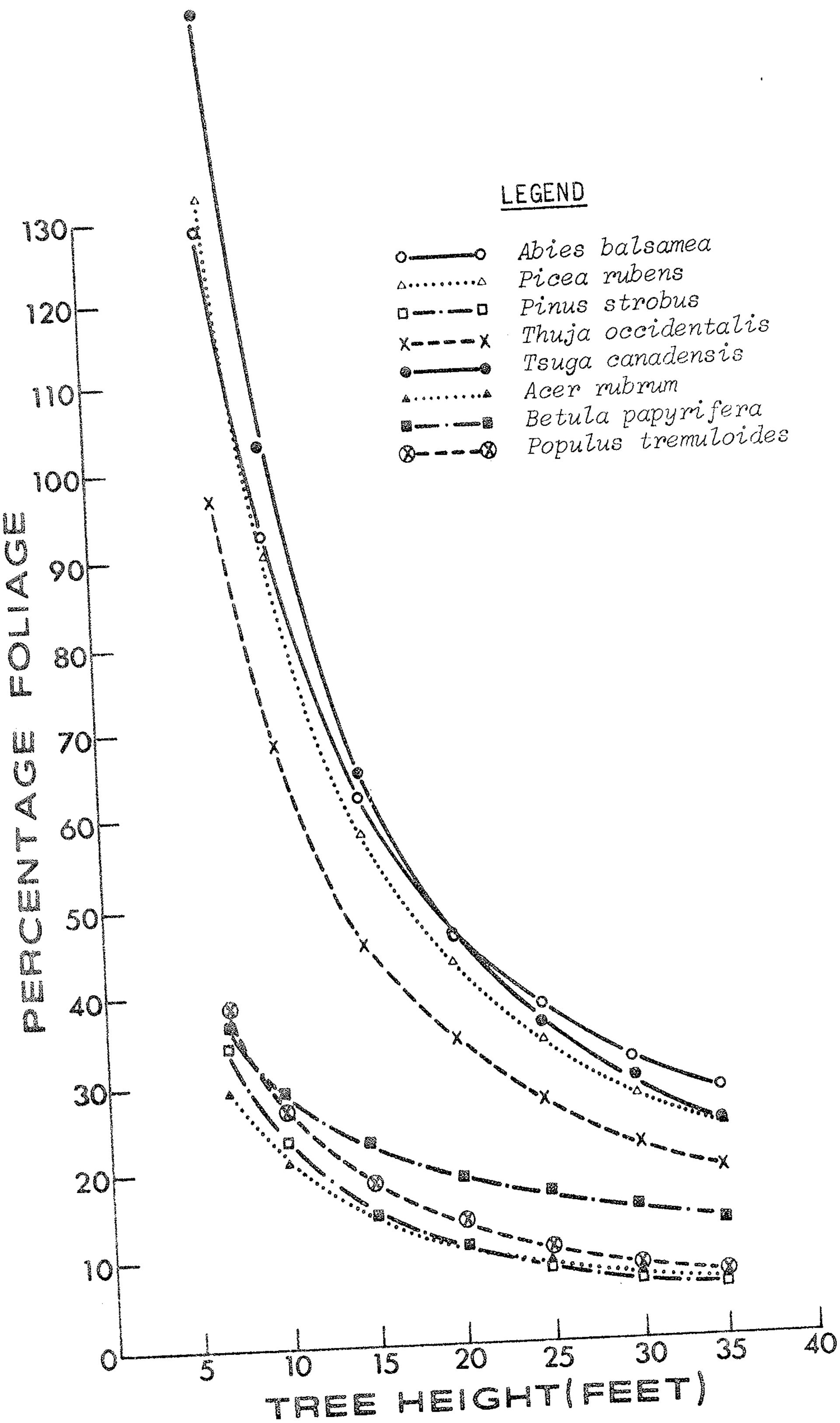

Figure 2 . Relationship for Percentage Foliage and Tree Height for Various Maine Wood Species

The regularity of the decrease in percentage foliage with tree height and dbh is quite marked for all of the species studied; again this uniformity is due in part to the uniformity of test procedures and a standard method of reporting the results; it is also probably due to small variation in growth conditions for the trees selected in the studies.

Foliage - Oven-dry and Bark-on Basis

Tables 9 and 10 summarize the data from a number of miscellaneous studies on softwoods and hardwoods. Many of the values shown cannot be used as a basis of comparison with results from other studies, since tree age, height, dbh, etc., are not specified.

TABLE 9

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

Reference number	Wood species	Foliage as % of full bole[1]
18	*Larix europaea*	90
95	*Picea* sp.	10
18	*P. abies*	22 26 41
140	*P. jezoensis*[2]	21
95	*Pinus* sp.	6
140	*P. koraiensis*[2]	9
18	*P. sylvestris*	24 65
95	*Pseudotsuga menziesii*	8
18	Seven evergreen gymnosperms	32

1. Stem is believed to be full bole, oven dry and bark on; foliage is assumed to be oven dry; dbh not specified.
2. Dbh between 4 and 12 cm.

TABLE 10

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

Foliage: oven dry

Full bole: oven dry and bark on

Reference number	Species	Foliage as % full bole[1]
37	*Alnus rugosa*	21
95	*Betula* sp.	3
140	*B.verrucosa*[2]	5
95	*Fagus grandifolia*	2
18	*F.sylvatica*	37 34
18	*Fraxinus excelsior*	40
18	*Populus tremuloides*	72
18	*Quercus robur*	38
37	*Salix babiana*	19
37	*Vaccinium corymbosum*	12
11	Tropical forests	4-5
11	Sub-tropical forests	3-5
18	Equatorial forests	49
18	Equatorial forests (Congo)	50
18	Equatorial forests (Ghana)	48
18	8 cold temperature forests	41
18	10 deciduous angiosperms	47
11	Mangrove forests	6
11	Savanna forests	8-12

1. Dbh and stump height not specified.
2. Technical foliage used - foliage plus leaf-bearing twigs less than 0.6 cm. (0.24 in.) in diameter.
   Assumed to be *Betula verrucosa*.

Foliage as a Function of Tree Age - Oven dry and Bark on

Foliage as a percentage of the bole (oven dry and bark on) is shown for a number of coniferous species of various tree ages in Table 11 and for deciduous species in Table 12. It is not considered too meaningful to convert these values to standard basis, since the conversion would depend upon the reliability of values for the percentage bark as a function of tree age for the various species shown. Some species show a regular trend of decreasing percentage foliage with increasing tree age (*Pinus densiflora, Pseudotsuga mensiesii*); a reverse trend is shown for *Picea abies* in the age range from 24 to 46 years. The low percentage foliage shown for the beech and oak forests (Table 12) may be accounted for in large part by the fact that many of these forests are mature and over-mature.

TABLE 11

Foliage as a Percentage by Weight of Full Tree Bole[1] for Various Tree Ages - Oven dry and Bark on Basis - Coniferous Species

Foliage: oven dry

Full Bole[1]: oven dry and bark on

Reference number	Species	Stand density (trees/ha.)	Tree age in years	Foliage as a % of full bole
132	*Cryptomeria japonica*[3]	29,500/ha	5	52
94	*Picea abies*	--	24	4
		--	38	9
		--	39	18
		--	46	27
		1125/ha	52	10
		924/ha	58	11
		--	60	6
94	*P. abies*	--	46	13
107	*P. excelsa* (north taiga)	--		8
	P. excelsa (central taiga)	--		6
	P. excelsa (south taiga)	--		5
56	*Pinus contorta* var. *latifolia*	(85 trees sampled)	100	5
94	*P. densiflora*	--	16	15
		--	16	6
94	*P. nigra*	1112/ha	48	6
87	*P. densiflora*	(38 trees sampled)	6	110
			8	80
			10	63
			12	55
94	*P. strobus*	--	41	9
			41	6
94	*P. sylvestris*	3640/ha	23	9
		4260/ha	33	6
		760/ha	55	7
		815/ha	64	5
94	*Pseudotsuga menziesii*	1151/ha	30	35
		1636/ha	32	23
		1151/ha	38	12
		648/ha	38	7
		1157/ha	52	7

1. Stump height and dbh not specified.
2. Assumed bark on.
3. Stump height not specified, but probably ground level.

TABLE 12

Foliage as a Percentage by Weight of Full Tree Bole
for Various Tree Ages - Oven-dry and Bark-on Basis
- Deciduous Species

Reference number	Species	Stand density (no. of trees/ha)	Tree age in years	Foliage as a % of full bole [1]
94	*Betula maximowicziana*		47	2
94	*B. verrucosa*		20	8
		4990/ha	24	5
		2350/ha	25	7
			40	2
		880/ha	55	2
			67	2
97	*B. verrucosa*[2]	(2 samples per age)	24	5
			27	2
			32	3
			38	1
			42	2
			46	2
			53	2
			55	2
94	*Cinnamomum camphora*		48	2
94	*Nothofagus truncata*	490/ha	110	1
94	*Populus davidiana*		40	2
94	*Quercus borealis*	800/ha	57	3
107	*Fagus* forests (USSR)			1
107	*Quercus* forests (USSR)			1

1. Stump height and dbh not specified.
2. Stump height not specified, but probably ground level.

As a broad generalization, the percentage foliage for many deciduous genera and species appears to be quite low (*Betula*, *Nothofagus*, *Fagus* and *Quercus* forests and *Populus davidiana*), being of the order of 2 to 5%, whereas for approximately the same tree age and diameter many of the conifers indicate values for foliage biomass of 5 to 10%. The generalization cannot have too broad an application, since *Cryptomeria japonica* shows 52% foliage (Table 11), whereas one value for *Pinus contorta* var. *latifolia* (Table 11) is only 5%. The above approximations would be expected to apply only for roughly the same stand density, season, and site index.

Percentage Foliage for Young Trees

Table 13 shows the percentage foliage for very young trees. Data of this type are not of immediate interest to an industry which uses trees with a minimum diameter of 3-4 inches and practices short-length, long-length, or full-bole logging. However, it is the type of data which will become of increasing importance as part of the development of full-tree or complete-tree logging, shorter rotation cycles and, ultimately, the concept of silage cellulose (88).

TABLE 13

Foliage as a Percentage by Weight of Full Tree Bole for Small Trees - Oven-dry and Bark-on Basis

Reference number	Species	Stand density (trees/ha)	Diameter at base (inches)	Foliage as % of full bole
136	*Castanopsis cuspidata*	150,000/ha	1	31.1
			1.5	29.8
			2.0	28.4
136	*C. cuspidata*	40,000/ha	0.87	31.5
136	*Quercus glauca*	16,000/ha	0.75	31.1
133	*Ulmus parvifolia*[1]	500-2500/ha	0.2	5.5
			0.3	10.0
			0.4	14.0

Notes: stump, ground level
1. Values are given as percentage of total plant weight.

Foliage - Green Basis

Table 14 for large-diameter trees and Table 15 for small-diameter trees gives selected values for percentage foliage on a green basis.

TABLE 14

Foliage as a Percentage by Weight of Full Tree Bole - Green and Bark-on Basis

Reference number	Wood species	No. of trees sampled	Foliage[1] as a % by weight of full tree bole				
			Diameter breast height (inches)				
			6	8	10	12	14
154	*Abies balsamea*	23	11.5	19	26	33	..
155	*Picea rubens*	25	21.0	30.0	35.0	34.0	28.0
157	*Pinus strobus*	27	20.0	15.0	13.0	13.0	14.0
36	*Thuja occidentalis*	21	43.0	37.0	36.5	38.0	..
157	*Tsuga canadensis*	28	26	28	30.5	33.0	35.0
153,155	*Acer rubrum*	20	30.0	20.0	13.0	8.0	6.0
157	*Betula papyrifera*	17	34	27	21.5	19.0	..
157	*Populus* sp.	14	13	17	17	13	..

1. Foliage: twigs and bark on the branches less than 1-inch diameter, as well as foliage as such.

TABLE 15

Foliage as a Percentage by Weight of Full Tree Bole for Small Trees – Green and Bark-on Basis

Reference number	Wood species	No. of trees/ha	Diameter at base (inches)	Foliage as % of full bole[1]
136	*Castanopsis cuspidata*	40,000/ha	0.87	38
131	*Betula platyphylla*	9,000/ha to 26,000/ha	0.8	4
			1.0	5
			1.2	6
			1.5	6
53	*Platanus occidentalis*[2]	4 sampled	2.9-3.1	17
136	*Quercus glauca*	16,000/ha	0.75	35

1. Stump: ground level.
2. Values based on weight of whole tree. Diameter taken at breast height.

Table 16 gives values for the percentage moisture in the foliage and in the comparable merchantable bole. There is no consistent relationship between the two moisture contents, indicating that reliable values for percentage foliage on a standard basis cannot be derived from green weight and the assumption that the foliage and the bole will have the same moisture contents.

TABLE 16

Percentage Moisture in Foliage and in Merchantable Bole

Reference number	Wood species	Percentage moisture in: Foliage	Merchantable bole
153	*Abies balsamea*	61.7	59.5
153	*Picea rubens*	52.1	43.4
55	*Pinus contorta* var. *latifolia*	49.0	43.6
153	*Tsuga canadensis*	54.0	56.2
65	*T. heterophylla*	53.0	56.6
		51.5	52.6
		51.0	43.0
153	*Pinus strobus*	53.2	50.9
153	*Acer rubrum*	44.1	39.0
153	*Betula papyrifera*	42.3	43.3
153	*Populus* sp.	47.8	52.2

The distribution of moisture in the components of technical foliage (foliage, twigs, shoots, and branches up to 6-8 mm. in diameter) is shown in Table 17.

TABLE 17

Distribution of Moisture in Coniferous Technical Foliage

Reference: 140

Wood species	No. of tests	Distribution of moisture in %: in needles	- in bark	- in wood
Pinus koraiensis	12	37	31	32
Picea jezoensis	13	46	20	34
Abies nephrolepis	10	53	25	22

Foliage as a Function of Site Index, Stand Density and Growth Class

Table 18 gives a summary of one of the most detailed and comprehensive studies made to date on the biomass of tree foliage. It is apparent from the results shown in this table that the percentage foliage is strongly dependent upon a number of growth variables[c]. As indicated for *Pinus sylvestris* and *Picea excelsa* (Table 18) growing under identical macro-ecological conditions, the percentage foliage:

- Can vary twofold between approximately 4 and 12 inches dbh;
- Can vary twofold between site class I (excellent site) and site class V (poor site);

(c) This is in general agreement with the relationship which has been established for some species between stand density, etc., and percentage branches (Table 18).

- Increases with decreasing site quality index;
- Can vary twofold between a stand density[d] of 0.9 and 0.6;
- Increases with decreasing stand density;
- Can vary twofold between growth class I and growth class IV;
- Increases with increasing growth class.

Since the study on which the data are given in Table 18 were obtained from carefully designed experiments, and the measurements were made on trees from uniform natural stands within a narrow range of geographical conditions and climate, the ranges shown can be considered as minimal for the parameters studied. Based on these data, it can be assumed that two measurements of percentage foliage, made without reference to tree height, dbh, tree age, site index, stand density, or growth vigor, could vary appreciably more than 4 to 1. This would account for the extreme variation in percentage foliage as recorded by different authors for a given wood species (*Pinus contorta* var. *latifolia*, Table 3; *Abies balsamea*, Table 1).

The variation shown indicates that in future studies on the amount of foliage biomass, not only should standard values be determined (oven-dry, bark-free basis), but it would be highly desirable to specify such critical factors as tree diameter, age, height, crown class, site index, stand density, time of year, etc., in order to obtain more data on the relationship between these factors and percentage foliage for various wood species.

(d) The effect of stand density on percentage foliage is not an independent variable, and is undoubtedly related to growth conditions and other factors (compare with the data given in Table 20).

Table 19 gives the raw data for technical foliage from which the values shown in Table 18 were derived and, as expected, the values for percentage technical foliage follow the same trends as discussed above.

TABLE 18

Foliage as a Percentage by Weight of Full Tree Bole
and as a Function of Age, Site, Growth Class and Stand Density
Foliage: green (assumed) - Bole: oven dry and bark on - Reference: 103

Classification		Foliage as a percentage of full bole *Picea excelsa*	*Pinus sylvestris*
Age class	III	32.0	-
	IV	-	11.0
	VI	15.0	-
	VII	-	5.0
Site class	I	9.0	-
	III	-	6.7
	IV	-	7.2
	V	21.0	-
Stand density	0.6	15.0	8.0
	0.7	-	7.0
	0.9	8.0	-
Growth class	I	13.0	6.0
	II	16.0	7.0
	III	21.0	9.0
	IV	31.0	13.0

Notes - Foliage: green needles, assumed to be 60% of technical foliage, values for which are given. This ratio is quite variable for different wood species, being reported as 80% for some *Picea* sp., 60% for *Populus* sp. and 53% for *Betula* sp. (54).

Basis: green foliage weight per cubic meter of wood; bole assumed to be full bole with bark on.

Number of trees measured: *Picea excelsa*, 66; *Pinus sylvestris*, 94.

TABLE 19

Technical Foliage as a Percentage by Weight of Full Tree Bole and as a Function of Age, Site, Growth Class and Stand Density

Foliage: green - Bole: oven dry, bark on - Reference: 103

Classification		Technical foliage[1] as a percentage of full bole	
		Picea excelsa	*Pinus sylvestris*
Age class	III	53.8	...
	IV	...	17.7
	VI	24.4	...
	VII	...	7.7
Site class	I	16.8	...
	III	...	11.2
	IV	...	12.0
	V	34.2	...
Stand density	0.6	24.8	12.8
	0.7	...	11.4
	0.9	13.2	...
Growth class	I	22.0	10.8
	II	26.1	12.0
	III	34.2	14.2
	IV	51.7	21.1

1. Technical foliage defined as foliage plus needle-bearing twigs less than 0.6 cm in diameter.
Basis: green technical foliage weight given per cubic meter of wood, assumed bark on and full bole.
No. of trees measured: *Picea excelsa* = 66; *Pinus sylvestris* = 94.

Table 20 gives similar, but limited and more subjective, data for the percentage foliage on *Pinus thunbergii*. The range of variation is not high, but the values shown may indicate a trend towards higher percent foliage on poor growth sites.

TABLE 20

Foliage as a Percentage by Weight of Full Tree Bole

and as a Function of Site Quality - *Pinus thunbergii*

Reference: 3

Plot	Site quality	Foliage as a percentage of full tree bole[1]
1	Good	36
2	Good	36
3	Moderate	57
4	Poor	58
5	Good	43
6	Moderate	51

1. Number of trees sampled per site, 5--8; trees assumed to be cut at ground level; foliage assumed to be oven dry, full bole oven dry and bark on.

Percentage Foliage -- Seasonal Variation

Table 21 shows, for small-diameter *Pinus densiflora*, the variation in percentage foliage as a function of seasonal variation[(e)]. The same type of seasonal variation has been found in studies on biomass yield of foliage from *Pinus sylvestris* and *Picea excelsa* (140). More studies of this type will be required for wood species of commercial interest in order to accumulate firm data required for potential foliage utilization. In a detailed study of the distribution of moisture in foliage and technical foliage (140), the percentage moisture was found to vary with rainfall, necessitating changes in processing the technical foliage. Thus, not only the amount, but also the processing characteristics of foliage are not constant throughout a year, and this has to be taken into account in considering foliage utilization.

(e). According to Ovington (94) ".....the annual production of inflorescences in stands of aspen, *Populus tremuloides*, and of male cones in stands of white pine, *Pinus strobus*, amounts to about 230 and 656 kg. per hectare, equal to 5 and 25% respectively of the annual production of leaves; if sampling is restricted to summer and autumn, these would not be included in primary production estimates."

TABLE 21

Foliage as a Percentage by Weight of Full Tree Bole

and as a Function of Seasonal Variation -- *Pinus densiflora*

Reference: 51

Tree diameter (inches)	Foliage as a Percentage of Full Bole[1] Period of sample selection				
	April 25, 1964	May 27, 1964	June 26, 1964	July 30, 1964	March 3, 1965
0.63	77	77	79	52	46
0.83	106	113	118	78	58
1.18	161	187	194	131	86

Notes: Tree age -- 7 years;
Stem -- assumed to be full bole, probably cut at ground level;
Branches and bole -- oven dry and probably bark on.

Foliage Biomass -- Dry Weights

The studies thus far analyzed have given data on biomass percentages. In addition, a number of papers and review articles (Table 22) give foliage in terms of green or dry weights per unit forest area, or as a function of dbh or other variables.

TABLE 22

Literature References on Foliage Weight

Reference number	Tree species	Foliage weights	Basis

69	*Pinus ponderosa*
	P. strobus
	P. resinosa
		Log W = b.log D - a,
		where: W = foliage weight;
		b = correlation coefficient;
		D = dbh in inches;
		a = correlation coefficient.	

	Quercus chrysolepis		
	Pinus banksiana		
	Picea abies		
	Pinus sylvestris		
	Abies amabilis		
	Pseudotsuga menziesii		
	Fagus sylvatica		
111	General *Pinus densiflora* *Zelkova serrata*	Discussion of methods of estimating leaf biomass weights.	
108	*Pinus taeda*	Foliage weights as a function of dbh.	Oven dry
29	*P. ponderosa*	Dbh from 12 to 60 inches. Weight of needles and branches given as a function of dbh and tree volume.	
66	*Picea abies* *Abies* sp.	Regression analysis of the relationship between dry needle weight and bole increment.	
112,132	*Cryptomeria japonica*	Relationship between leaf biomass and dbh.	

TABLE 22(cont'd)

Reference number	Tree species	Foliage weights	Basis
124	*Betula* sp.	Fresh and dry leaf and branch weights for four age classes -- 22, 44, 50 and 88 years.	Oven dry
90	*Pinus contorta* var. *latifolia*	8.0" dbh, 10,700 lbs. per acre; 4.8" dbh, 6,200 lbs. per acre.	Oven dry
86	*Fagus* sp.	Annual increment = 11 tons	Dry matter per ha.
	Quercus sp.	Annual increment = 7 tons	Dry matter per ha.
	Fraxinus sp.	Annual increment = 8 tons	Dry matter per ha.
	Betula sp.	Annual increment = 6 (ave.) tons	Dry matter per ha.
	Picea abies	Annual increment = 17 tons	Dry matter per ha.
	Pinus sylvestris	Annual increment = 11 (ave.) tons	Dry matter per ha.
	Larix sp.	Annual increment = 11 tons	Dry matter per ha.

Madgwick (84) discusses the weakness of using an equation of the form

Log weight = b log dbh + c

for determining the biomass of tree components. The constants b and c are assumed to be invariant with change in tree height, age and spacing, etc.; whereas the foliage biomass-diameter or biomass-dbh relationship is affected by stand structure, season genotypic variation, site quality, dominance, etc. The equations are, of course, invalid for small diameter or low trees. Madgwick suggests that it would be better to use the base of the crown rather than dbh as the independent variable, and to introduce the logarithm of the tree height as a third variable (84, 98, 127, 128) or to use branch diameter rather than bole diameter.

A comprehensive review of leaf biomass has been prepared by Tadaki (130). Table 23 gives values selected from this review to show both green and dry values for foliage biomass.

TABLE 23

Green and Dry Foliage Weights per Hectare

Reference: 130

Reference number	Wood species	Leaf Biomass in Forests Green wts. (tons/ha.)	Oven-dry wts. (tons/ha.)	% moisture (fresh wt. basis)
21,25	*Fagus sylvatica*	7.9	3.2	59
24	*Quercus robur*	14.3	5.3	62
133	*Q. mongolica* var. *grosseserrata*	7.3	2.5	65
133	*Fraxinus mandshurica*	9.9	2.2	77
131	*Betula platyphylla* var. *japonica*	4.0	1.2	70
114	*Populus davidiana*	5	2	60
17	*P. grandidentata*	3.52	1.55	55
116	*Zelkova serrata*	7	3	57
89	*Ulmus parvifolia*	11	3	72
133	*Alnus sieboldiana*	7.5	4.3	42
133	*A. hirsuta*	9.0	2.6	71
133	*Salix vulpina*	5.6	2.3	58
133	*Ligustrum tschonoskii*	10.2	2.5	75
136	*Castanopsis cuspidata*	27.3	11.4	58
134	*Acacia mollissima*	20–23	6.9–8.1	
23	*Larix decidua*	5–7	1.8–2.6	
22	*Pinus sylvestris*	12–13	5	
115	*P. densiflora*	12–13	5.3–5.4	
57	*P. thunbergii*	20	8	60
121	*P. strobus*	18–20	7.4–10.1	

TABLE 23(cont'd)

Reference number	Wood species	Leaf biomass in forests Green wts. (tons/ha.)	Oven-dry wts. (tons/ha.)	% moisture (fresh wt. basis)
22	*Picea abies*	33-34	15-20	
123	*P. glehnii*	35	7.35	80
123	*Abies sachalinensis*	55	19.1	65
113	*Chamaecyparis obtusa*	23-24	9.5-10.0	
137,135	*Cryptomeria japonica*	43.3-54.5	16.7-21.8	

It is apparent from the data given in Table 23 that:

- It is impossible to consider or discuss average moisture contents of foliage, since the figure ranges from 40 to 80%.
- The oven-dry leaf biomass covers a wide range, varying 20 fold from 1 to 20 tons per hectare, depending upon a wide range of variables.

Foliage as a Percentage of Branches

Table 24 gives the foliage as a percentage of branchwood for various crown ratios and various values of dbh. These data do not relate directly to the standard values for percentage foliage, but they do indicate the critical relationship between tree crown and the ratio of foliage to branches showing a twofold variation at a given dbh. The data in Table 21 also illustrate the uncertainty involved in extrapolating from one set of data to another, even for a given wood species[(f)]. Depending on dbh and crown ratio, the foliage as a percentage of the branches can vary over fivefold (from 19 to 107 percent) in the case of *Pinus echinata*. It is probably safe to assume that the same variation occurs with many other wood species.

(f) In the present study, two temptations have been resisted:

- to extrapolate from one set of data to another, or to use correction factors to bring raw data to a standard form, except in a limited number of cases where there appears little possibility of introducing serious error in so doing.

- to give average values for tree component biomass values. There are two compelling reasons for not averaging data of this type:

  - data obtained by different authors and under different conditions may not be even remotely comparable;

  - measurements made on, say, 1000 trees by careful selection and all pertinent data recorded, should not be averaged with values from a single tree of unknown history or setting.

TABLE 24

Foliage as a Percentage of Branchwood and as a Function of DBH

Reference number	Wood species	No. of trees sampled	Foliage as a Percentage of Branchwood[2] Crown ratio[1]	Dbh in inches 4	6	8	10	12	14
81	*Pinus echinata*	182	20	107	77	60	49	42	35
			40	81	56	44	36	30	26
			60	65	46	35	29	26	22
			80	58	39	32	25	21	19
148	*P. serotina*[3]	20	...	100	61	46	36	31	..
4	*Eucalyptus obliqua*[3]	75	...	..	60	48	52	35	..
	Populus tremuloides[4]	42	...	26	19	17	14	9	..
	P. balsamifera[4]	11	...	70[5]	22	28	12	..	..

1. Crown ratio = ratio of crown length to total tree height, expressed as a percentage.
2. Assumed basis - by weight, foliage oven dry, branchwood oven dry and bark on.
3. These percentages are calculated from the regression equation given in the reference.
4. See footnote 6, Table 1.
5. Five values averaged were 154.0, 52.7, 40.3, 57.6 and 46.2%.

In Tables 25 and 26, selected values are given for the ratio of foliage to branchwood (oven-dry and bark-free basis) for several wood species.

TABLE 25

Foliage as a Percentage of Branchwood at Eight Inches DBH

- Coniferous Species

Foliage - oven dry; branches - oven dry and bark free

Reference number	Wood species	% Foliage standard basis
157	*Abies balsamea*	300
9,10	*A. balsamea*[1]	148
9,10	*Picea glauca*[1]	143
155	*P. rubens*	143
55	*Pinus contorta* var. *latifolia*	120
157	*P. strobus*	185
157	*Tsuga canadensis*	140
75	*T. heterophylla*[2]	414
36	*Thuja occidentalis*	640
42	*T. plicata*	126

1. Dbh = 6 inches;
2. Dbh = 8.5 inches.

TABLE 26

Foliage as a Percentage of Branchwood at Eight Inches DBH

- Deciduous Species

Foliage - oven dry; branches - oven dry and bark free

Reference number	Wood species	% Foliage standard basis
153,155 156	*Acer rubrum*	75
157	*Betula papyrifera*	72
9	*B. papyrifera*[1]	45
157	*Populus* sp.	40

1. Dbh = 6 inches.

The results of a number of miscellaneous studies from which values for the foliage-branchwood ratio can be obtained are shown in Table 27. In general, the foliage as a percentage of the branches increases rapidly with decreasing dbh.

TABLE 27

Foliage as a Percentage of Branches - Miscellaneous Values

Reference number	Wood species	Dbh (inches)	Foliage as % branches	Basis
148	*Pinus serotina*	4	100	Oven-dry, bark-on branches
		6	56	
		8	49	
		10	36	
4	*Eucalyptus obliqua*	6	36	Assume oven dry, bark on
		8	28	
		10	18	
71	*Picea mariana* (slash)[1]		Twigs, needles 12%, Branches...5%	Green, bark on
117	*Picea* sp.		49-82	Green and bark on

Percentage Foliage - Miscellaneous Values

Miscellaneous data on foliage are given in Table 28. The wide range of variation in foliage biomass between species is indicated by the values shown for foliage as a percentage of crown,[2] ranging from 21% for *Pinus banksiana* to 43% for *P. resinosa* (Table 28). The range for a single wood species within a given stand can be almost as great, as indicated by the values shown for *P. sylvestris*.

1. Defined as the sum of all branches, needles and unmerchantable top.
2. Defined as the sum of all branches and foliage (needles and leaves).

TABLE 28

Foliage as a Percentage by Weight -- Miscellaneous Values.

Reference number	Wood species	Percentage foliage	Assumed basis	Comments
96	Conifers (England)	50% of canopy[1] weight	Green weights, bark on	Canopy = cones + branches + foliage
20	*Pinus resinosa*	43% of total crown weight	Oven-dry weights, bark on	....
20	*P. banksiana*	21% of total crown weight	Oven-dry weights, bark on	....
117	*P. sylvestris*	50-80% of branches	Green weights, bark on	Ranges within a given stand
71	Canadian sp. *Picea mariana* *Pinus banksiana* *Abies balsamea*	3-30% of total tree	Green weights, bark on	....
71	Canadian sp.	Twigs = 3-15% of total tree	Green weights, bark on	....
71	Canadian sp.	Twigs = 5% of above-ground trees	Green weights, bark on	Working average
71	Canadian sp.	Foliage = 12% of above-ground trees	Green weights, bark on	Working average
58	Various softwoods and hardwoods of the U.S.S.R.	Foliage + twigs = 10% of slash	Green weights, bark on	....
59		Branches + fol.	Green weights, bark free	Percentage of merchantable bole
	Pinus sp.	14%		
	Picea sp.	18%		
	Betula sp.	6%		
	Abies sp.	8%		

TABLE 28(cont'd)

Reference number	Wood species	Percentage foliage	Assumed basis	Comments
54	*Pinus* sp.	(36 kg.)	By weight, assumed green and bark free	Per cu. m. of solid wood
	Picea sp.	(32 kg.)		Per cu. m. of solid wood
	Betula sp.	(74 kg.)		Per cu. m. of solid wood

1. Defined as the sum of all cones inflorescences, needles or leaves and branches in the tree crown.

Summary

An examination of data available in the technical literature on foliage biomass would suggest that average values for percentage foliage, even for a single wood species growing within a narrow ecological range, in pure, even-aged stands, would be difficult to obtain, with need for massive sampling sufficient to give a Gaussian distribution of size over the dbh range, because of interaction between the variables affecting foliage biomass. Averages based on limited sampling or involving more than one species, or covering a range of stand densities and site indices, would be of limited value at best, and could be meaningless as a measure of potential raw material.

In the light of the above, it is not surprising that measured values for percentage foliage range from 2% (*Larix decidua*, Table 2) to 1800% (*Tsuga canadensis*, Table 8) for coniferous species; from 1% (*Alnus glutinosa*, Table 2) to more than 300% (*Populus tremuloides*, Table 8). In view of this wide variation and of the above discussion, it would be hazardous to attempt extrapolation from one set of growth conditions to another, even for a single wood species. The foliage as a percentage by weight of tree bole[g]

(g) The amount of foliage per unit of forest area may be appreciably less variable than the standard-basis percentages shown in the present text. In the case of fully stocked stands of *Populus tremuloides* and *P. balsamifera* in Alberta, for example, the amount of foliage available from a given forest area is considered to be relatively predictable (footnote 6, Table 1).

is dependent upon a complex network of variables, including:

Tree species
Dbh
Tree height
Crown ratio
Growth class
Site quality
Stand density
Tree taper
Dominance
Time of year
Moisture availability.

There may well be other factors influencing foliage biomass, such as fertilization, wind, exposure, genetic structure, etc. Because of this highly complex interdependent network of variables, it can be assumed that with but few exceptions[h] there are no data available on the amount of foliage, or technical foliage (Table 19), which might be recovered from a practical point of view.

Should interest develop in the possible utilization of tree foliage in Canada, it will be necessary to determine by direct measurement the amount of foliage available from the species and forest sites of specific interest.

(h) Exceptions are the foliage biomass available from forests of *Picea excelsa* and *Pinus sylvestris* in the taiga and, perhaps, from *Abies nephrolepis*, *Larix dahurica*, *Picea jezoensis*, *Pinus koraiensis* and *Pinus sibirica* grown in some regions of the Soviet Union.

UTILIZATION

The potential areas for foliage utilization include pyrolysis, power generation and extraction of chemicals, including vitamins, carotene, chlorophyll, and as a vitamin supplement for animal fodder. With some wood species, the fiber component of foliage might be used for board, paperboard, or pulp manufacture. Greatest use of foliage has been attained in the Soviet Union, and of the 144 literature references given in Tomchuk and Tomchuk[i] (140), all but four refer to Russian technical literature. A selected bibliography relating to the use of tree foliage[i] is given in Tables 29 to 32.

(i) References have been selected because they are reviews, or because they have a fairly direct bearing on the complete-tree utilization concept. The literature on foliage composition and conversion is quite voluminous, and its analysis has not been attempted in the present review. For those interested in the practical utilization of foliage, particularly from coniferous wood, the book by Tomchuk and Tomchuk (140) is recommended. It includes chapters on:

- Tree Foliage Raw Material Reserves
- Chemical Composition of Technical Foliage
- Production of Conifer Needle Vitamin Flour
- Ester Oils and Their Production
- Chlorophyll-Carotene Paste
- Utilization of Technical Foliage in the Pharmaceutical and Food Industries
- Utilization of Slash After Separation of Technical Foliage.

TABLE 29

Utilization of Tree Foliage - General[(a)]

Reference number	Wood species	Use	Comment
146	*Thuja occidentalis*	Essential oils, waxes, pharmaceutical chemicals	A new industry in Ontario.
44	General	Chemical conversion	Review on use of wood wastes for conversion to chemicals.
100	*Populus tremuloides* *P. grandidentata*	Chemical conversion	Review on possible conversion of foliage to various chemicals.
39	*Pinus* sp.	Chemical conversion source of protein	Extracts give various vitamins.
71	General	Agricultural uses, essential oils	Review on possible uses of foliage in connection with other residues from full-tree logging.
158	General	Silvichemicals, electrical generation	Foliage used in conjunction with other wood wastes.
140	General	Essential oils, vitamins, pharmaceutical chemicals, cattle fodder supplements	A detailed review of foliage biomass, extraction, conversion and utilization in the U.S.S.R.
140	*Picea, Pinus, Abies* sp.	1,700 m. tons of paperboard, 2600 m. tons of vitamin C, 5.3 million m. tons vitamin flour, 0.9 million m. tons chlorphyll-carotene paste. Other vitamins and essential oils	Estimated yield from approx. 18 million m. tons of technical foliage, from 350 million cu. m. wood logged.
73	*Acacia mellifera* var. *detinens*	Cattle fodder	Discussion use of blackthorn leaves, and effect on cattle.

TABLE 29 (cont'd)

Reference number	Wood species	Use	Comment
144	General	Various chemicals	Use of wood as a raw material for chemical manufacture.
16,15	General	Silvichemicals	Utilization of wood wastes.
82	*Picea* sp.	Fuels	From gasification of logging wastes.
1	General	Cattle fodder production, building materials	Products of hydrolysis of wood wastes.
26	General		Contains many references on wood waste utilization.
101	Baobab and drumstick	Food	Leaves contain 20-30% protein.
120	General	Animal feed	Use of wood wastes as roughage or energy source: cellulose or sugar.
12	General	Fodder production	From leaves of *Prosopis spicigera*, *Adina cordinfolia*, *Bauhima purpurea*, *Morus alba*.
79	General	Ammonia	Discussion of ammonia production

(a) Literature on the composition and chemical conversion of foliage and its components is quite extensive and would be impossible to review in brief compass. The literature cited above relates primarily to industrial application or to reviews on use potential.

TABLE 30

Utilization of Tree Foliage

for Fiber and Pulp

Reference number	Wood species	Use	Comment
53	*Platanus occidentalis*	Kraft pulp	16.5% foliage, combined with bole and branches: pulp produced was comparable to commercial, unbleached sulphate pulp.
154	*Abies balsamea*	Fiber	Increasing fiber resources, CTU concept.
155	*Acer rubrum* *Picea rubens*	Fiber	Increasing fiber resources, CTU concept.
156	*Abies balsamea*	Fiber	Increasing fiber resources, CTU concept.
28	General	Pulp-paper	Increasing fiber resources, CTU concept.
68	*Pinus contorta* var. *latifolia* *Picea glauca*	Fiber, fuel	Possible use for pulp and paper; study of forest fuels in relationship to fire behavior.
39	*Pinus* sp.	Board	Fibrous material gives cellulose for board.
71	General	Pulp, fiber-board, composition bd.	Review on possible uses of wood residues from full-tree logging.
45	*Pinus* sp.	Fiber for yarn and insulating material	Used as a substitute for asbestos for insulation: 40-50% could be used with wood or cotton for yarn.
119	Canadian wood sp.	Fiberboard and particleboard	Wood and wood residues.

Table 31

Utilization of Foliage in Pharmaceutical Preparations

Reference number	Wood species	Utilization	Comment
41	....	Carotene preparation	For addition to food.
83	General	Phytol, sterols	Unsaponifiable fractions separated by fractional distillation.
139	*Picea* sp. *Abies* sp.	Carotene	....
92	*Pinus sylvestris*	Protein, sugars, essential oils and beta-carotene	Needles from young trees contained smaller amounts of these chemicals than needles from older trees.
126	*P. clausa* *P. echinata* *P. elliottii* *P. glabra* *P. palustris* *P. pungens* *P. rigida* *P. serotina* *P. taeda* *P. virginiana*	Quercetin, kaempferol, a- and b-pinene, myrcene and limonene, oleoresins and flavonoids	Extractives from pine needles.
102	General	Phytosterols	Derived from chlorophyll-carotene pastes.
78	*Abies* sp. *Pinus* sp.	Vitamin E	Concentration of vitamin varies with age, being highest in older trees. Highest content in *Abies* and *Pinus* sp.
77	*Pinus* sp.	Vitamin C	From crushed pine needles.
106	15 conifers	Ascorbic acid	Highest in *Juniperus communis*, *Pinus montana*, *Abies alba*, and *Picea excelsa*.

TABLE 31(cont'd)

Reference number	Wood species	Utilization	Comment
6	Conifers	Water soluble chlorophylls	Prepared from coniferous needles.
19	General	Vitamins	Prepared as food for animals.
33	*Populus tremula*	Glucosides	Prepared from leaf extracts.
38	*Pinus* sp.	Vitamins	Prepared from foliage extracts.
40	*Pinus* sp.	Vitamins C and E, and carotene	Extracted from needles.
60	*Pinus* sp.	Vitamin extracts	From tree leaves and grassy plants.
62	Softwoods	Chlorophyll-carotene paste, vitamin meal	....
72	*Pinus* sp.	Vitamin C	....
99	General	Vitamin C	From natural products.
110	*Pinus*, *Picea* sp.	Vitamin C	Wide seasonal variation.
142	*Picea* sp.	Polyphenols	....
143	Softwoods	Chlorophyll-carotene	....
125	General	Vitamins	From forest raw materials.

TABLE 32

Utilization of Foliage for Essential Oils

Reference number	Tree species	Use	Comment
2	General	"Pinabin"	One of the essential oils obtained by steam distillation of chlorophyll/carotene paste
5	Conifers	Conifer leaf oil	By steam distillation
13	*Thuja* sp.	Cedar leaf oil	
27	Ontario conifers	Oils	New type of pilot plant to cut distillation costs
43	General	Terpenes	....
50	*Pinus* sp.	Pine oil	Preparation of rubber softner from turpentine oil and coal tar
61	*Pinus roxburghii*	Pine needle oil	Extraction
104	*Picea morinda*	Pine needle oil	For soaps, perfumery, cosmetics
129	General	Pinenes	For perfumery chemicals
138	*Abies* sp.	Essential oils	From needles of white and sakhalin firs
46	General	Essential oils	Oils and associated products
14	*Pinus attenuata* *Pinus radiata* plantation	Pine oil	Yield variation
32	General	Flavor oils - spearmint and peppermint oils	Manufactured from alpha or beta-pinene

TABLE 32(cont'd)

Reference number	Tree species	Use	Comment
31	*Thuja plicata*	Cedar leaf oil	For possible use in perfumes, soaps, drugs, etc.

TABLE 33

Utilization of Foliage -- Miscellaneous

Reference number	Wood species	Use	Comments
141	General	Fertilizer	Compost product
74	General	Neoabietin	Pyrolysis product of wood wastes
75	General	Charcoal, methyl alcohol, acetone	Pyrolysis products of wood wastes
76	*Pinus* sp.	Composition board binder	Pyrolysis products of wood wastes
19	General	Ammonia	From logging wastes
34,35	General	Fertilizer	Composts from wood wastes
85	*Pinus* sp.	Quinic and shikimic acids	Extracted from pine needles and *Ginkgo biloba* leaves
151	General	Vanillin, fatty acids, rosin, turpentine, antioxidants, ethanol	Review
30	General	Rubber, adhesives, perfume additives	Synthesized from b-pinene
109	General	Hemicellulose	From evergreen and tree leaf waste
49	General	Hemicellulose	From hydrotropic pulping and pre-hydrolysis of foliage
80	General	Flotation of ores	Various oils obtained from foliage

Discussion

From the viewpoint of foliage utilization, the chief interest would concern the amount of foliage recoverable at a process plant rather than the amount of foliage available *in situ*. It was estimated that in 1961 the total amount of technical foliage available in the Soviet Union was approximately 18 million tons, based on a total cut of 350 million cubic meters (140). Based on the operation of a number of processing plants in widely distributed regions of the Soviet Union, the actual amount of technical foliage delivered to a processing plant, averaged for all wood species, would be not more than 110 pounds of wood per cubic meter of wood logged. On the assumption that the average specific gravity is 30 pounds per cubic foot, this would represent 110 pounds of technical foliage recoverable for each 35.5x30 or 1065 pounds of merchantable bole. That is, the technical foliage, as a percentage of merchantable bole, would be approximately 10% on a bark-free basis. This is close to the value given by Kachelkin (59) of 11%, made up of 65% foliage and 35% needle-bearing twigs.

The yield of leaf foliage from *Abies* sp. is reported to be approximately 20% (145), but this may refer to total technical foliage rather than to the recoverable technical foliage. The yield is given as 8-10 tons per hectare in winter and 12-15 tons per hectare for technical foliage (140). Based on several assumptions for density and forest yield, this would be of the order of 8-10% of the merchantable bole in summer and 12-15% in winter.

It has been noted that the amount of foliage recovered is critically dependent upon the method of felling, skidding, transporting, storing and processing of trees or tree components (140). If trees are skidded butt forward, for example, the loss of foliage and branches has been reported as 47% for *Pinus* sp., 45% for *Picea* sp., 37% for *Abies* sp., 17% for *Betula* sp. and 59% for *Populus* sp.

In spite of the extreme variation in percentage foliage shown in the present analysis, a few broad generalizations applicable to preliminary feasability studies might be suggested:

- For most mature stands of *Picea* sp. with a high stand density, the total technical foliage would be 9-10%, and the recoverable foliage alone 6-8% of the full bole........all values standard basis. Comparable figures for most *Pinus* sp. would be approximately half of these values.

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 of a tree; twigs, top, leaves, needles, cones, branches, roots, stump, bole and bark.

Tree length -- complete tree minus the stump and roots, but including leaves, needles, branches, cones and top.

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

Long-length logs -- tree 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[j], since it may be difficult or impossible to define. Unmerchantable top of a 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, a 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.

(j) 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 biomass of foliage available from various wood species presents data in terms of foliage plus all twigs or branches less than 0.6 cm. 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 cm. 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.

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 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). This is a relatively minor point, since the percentage involved would normally be quite small, but in pulping studies the unmerchantable top of the 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 trees 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 needles, shoots, cones, and needle-bearing twigs. These branches can be considered as a potential source of raw material for pulp fiber, since conventional equipment could be used in processing.

Branches less than 1 inch in diameter: not suitable for pulping with present processing equipment[k].

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

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

Stump: 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[k].

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

Bark.

(k) This should be considered as a tentative assumption. In a recent communication, Harold 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.

CHECK LIST OF SPECIES CITED BY TABLE AND PAGE

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