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J. L. Keays

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An Analysis of the Literature

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BY
J. L. KEAYS

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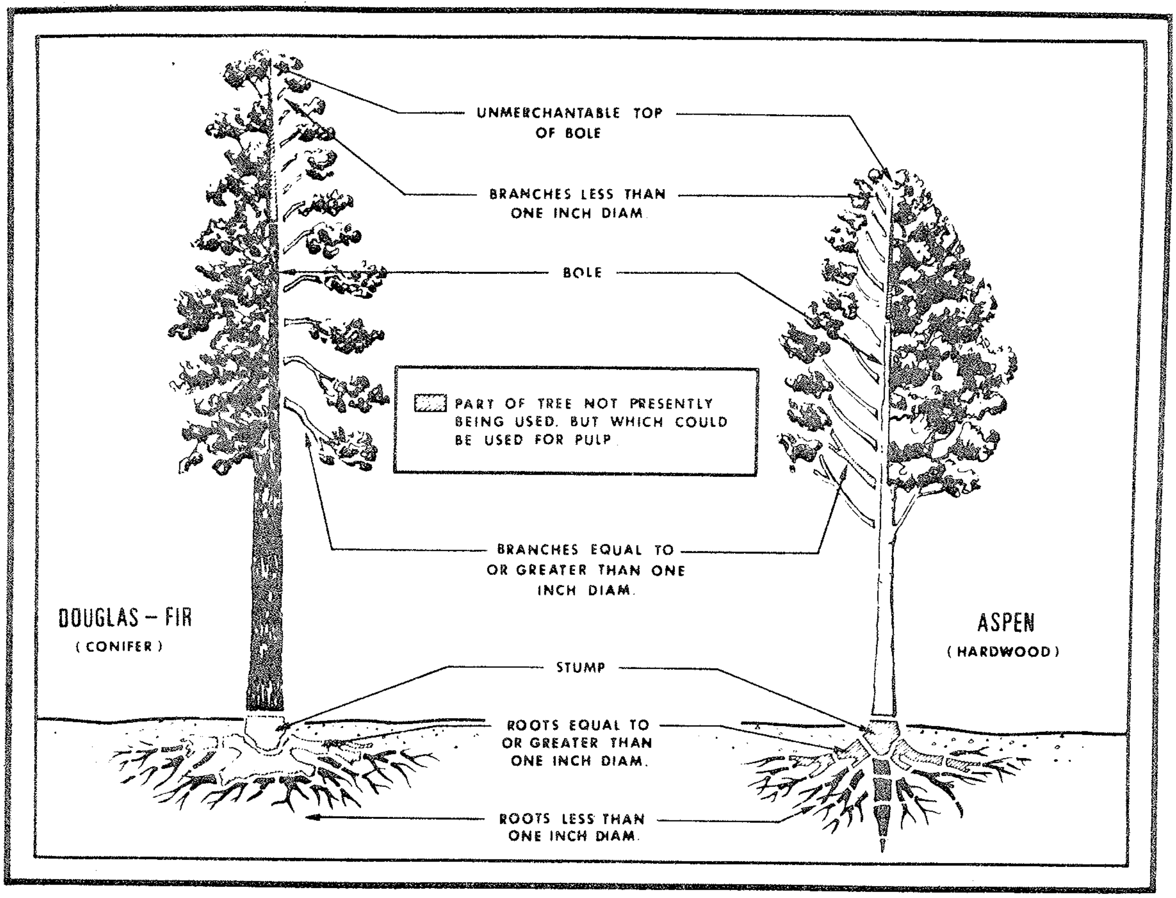

COMPLETE-TREE UTILIZATION

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PART V: Stump, Roots and Stump-Root System

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J. L. Keays

Forest Products Laboratory
Canadian Forestry Service
Department of Fisheries and Forestry
Vancouver, British Columbia

OUTLINE AND CONTENTS

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RESUMÉ

Biomass data on stump, roots and stump-root system are given. The percentage stumpwood (standard basis) is a function of stump height, species, tree taper, dbh and extent of root removal. Because of a lack of standard definition, no average values for percentage stumps can be given. Root biomass is a function of wood species, dbh and height, type and compaction of soil, and availability of water and nutrient. Root biomass may also be a function of stand density, wind throw and dominance. More consistent data are available for combined stump-root system than for either component alone. A number of standard values for a utilizable stump-root system are close to 20%; this is assumed to be fiber which can be recovered in the practical extraction of complete trees; in the case of trees 5-6 inches dbh or greater, this value probably includes few roots less than 1-inch diameter.

Compared with pulp from boles, pulp from stump-root systems is equal or slightly lower in pulp yield (2-3% based on wood), 5-10% lower in tear factor and 10-20% lower in burst factor and breaking length. For a given wood species, a marketable pulp not appreciably different in yield and quality to comparable bole pulp could be produced from stump-root systems, either pulped with boles or pulp admixed with bole pulp after the digester.

Stump-root systems are little used as a source of raw material for pulp and paper manufacture, in spite of the massive amount of such material available (say 20% of the world's wood fiber supply) and despite the high quality of pulp which can be obtained. The reasons lie in the large number of processing problems which have not yet been satisfactorily solved. The most efficient means of extracting stump-root systems is by pushing trees over and uprooting stumps, preferably with a vibratory action. Stump-root systems can be cleaned most efficiently by this method of extraction combined with cleaning by means of an impact or vibration hammer; the roots are most effectively removed with a vibration chisel. More efficient means of transporting complete trees to a mill than those presently available need to be developed. No satisfactory methods have been developed for barking and chipping the components of stump-root systems.

Few studies have been made on the micro- and macro-ecological effect of complete-tree utilization, and a number of massive problem areas remain to be explored, including: Effect on the nutrient cycle; effect on subsequent growth; soil erosion; effect on natural or artificial regeneration; reduction in fire hazard; long-range effect upon mean global temperatures.

COMPLETE TREE UTILIZATION -- An Analysis of the Literature

PART V: Stump, Roots and Stump-Root System

INTRODUCTION

The preceding sections of the present review have included:

PART I: Unmerchantable Top of Bole (32);

PART II: Foliage (33);

PART III: Branches (34);

PART IV: Crown and Slash (35).

In the present section, stumps and roots are considered as separate components and as a single stump-root system. It is important that the biomass and pulping characteristics of the roots and stumps be determined separately, since there might be cases where the stump and not the roots would be used as a raw material for pulp manufacture.[a]

STUMP BIOMASS

Data on stump biomass would be expected to be inconsistent and difficult to interpret, since the stump is the most difficult tree component to define; definition is dependent upon stump height and the extent to which the roots have been removed.

Percentage Stump as a Function of DBH -- Standard Basis

Table 1 gives data on percentage stump for various values of dbh on a standard basis[b]. The stump as a percentage of tree bole would not be expected to vary greatly with dbh and, in general, the results shown in Table 1

(a) As discussed in a later section, probably the single most serious problem barring the use of the stump-root system as a source of fiber at the present time is the presence of stones, which make chipping prohibitively costly (43). The use of a stump auger might minimize, if not eliminate, the problem of stone inclusions in the stump-root intersections. It would not reduce the problem of sand and rocks buried within the stump itself. Appendix I gives the nomenclature used in the complete-tree utilization series.

(b) In all cases, "standard basis" refers to the component (oven dry and bark free) as a percentage by weight of full tree bole (oven dry and bark free).

confirm this. This is particularly true where stump biomass for a number of wood species has been determined as a part of a single study involving the use of standard procedures, as in the extensive studies of H. Young. Although the range in stump biomass would appear to be wide - from 5% for *Abies balsamea* (80) to 34% for *Pinus caribaea* (66) at 8-inches dbh - some part of this variation may be the result of differences in how the roots were removed, or to what extent, and to variables affecting root biomass but not included as part of the biomass studies.

Percentage Stumps as a Function of DBH - Green and Bark-on Basis

The small variation in percentage stumps over a range of dbh for a given wood species is clearly shown in Table 2, which gives Young's values for percentage stumps for a number of Maine species growing under uniform conditions. In this case, the difference between species is not marked, ranging from 8 to 14% at 8 inches dbh.

TABLE 1

Stumps as a Percentage by Weight of Full Tree Boles and as a Function of DBH

Stumps: Oven dry and bark free
Full Tree Bole: Oven dry and bark free

Reference	Wood Species	No. of trees sampled	Stumps as a % of Full Tree Boles				
			Diameter breast height (inches)				
			6	8	10	12	14
80	*Abies balsamea*[1]	23	4	5	6	6	6
78	*Picea rubens*[1]	25	9	9	9	10	10
66	*Pinus caribaea*[2]	1	-	27	-	-	-
66	*Pinus caribaea*[3]	1	-	34	-	-	-
66	*Pinus palustris*[2]	1	-	22	-	-	-
80	*Pinus strobus*[1]	27	9	10	11	12	12
15	*Thuja occidentalis*[1]	21	10	13	15	18	-
17	*Thuja plicata*[4]	8	-	22	19	13	-
80	*Tsuga canadensis*[1]	28	8	9	10	11	13
17	*Tsuga heterophylla*[4]	8	11	12	13	13	-
37	*Tsuga heterophylla*[5]	2	-	2.8	-	-	6.8
75,79	*Acer rubrum*[1]	20	7	8	9	10	11
80	*Betula papyrifera*[1]	17	15	17	16	15	14
80	*Populus sp.*[1]	14	8	9	10	11	-

1. Stump height: 6 inches above ground level
2. dbh 8.25 inches; stump height 4 inches above ground level
3. dbh 8.5 inches; stump height 4 inches above ground level
4. Stump height: 12 inches above ground level
5. dbh 8.5 inches and 14.2 inches, respectively; stump height 12 inches above ground level

TABLE 2

Stumps as a Percentage by Weight of Full Tree Boles and as a Function of DBH — Green and Bark-on Basis

Reference	Wood species	No. of trees sampled	Stump as a % of Full Tree Boles				
			Diameter breast height (inches)				
			6	8	10	12	14
77	*Abies balsamea*	23	8	9	10	11	-
78	*Picea rubens*	25	8	9	9	9	9
80	*Pinus strobus*	27	10	11	12	13	14
15	*Thuja occidentalis*	21	12	14	15	17	-
80	*Tsuga canadensis*	28	8	9	10	11	12
80	*Acer rubrum*	20	8	8	9	9	9
80	*Betula papyrifera*	17	12	13	13	13	-
80	*Populus sp.*	14	7	8	9	10	-

1. Stump height: 6 inches above ground; dbh taken at a height of 4.5 feet above ground.

The amount of recoverable stumps as a volume percentage of merchantable bole is given in a Finnish study (43) as 2.9 and 4-6% for *Pinus* sp., 2.4% for *Picea* sp. and 3.3% for *Betula* sp. Since data are not available for the percentage bark or for the specific gravity of wood and bark, or the percentage moisture of wood and bark for bole and stump, volume measurements on green wood cannot be converted to the standard basis.

ROOT BIOMASS

Introduction

Only a limited number of studies have been made on root biomass, but many of these concern biogeocoenosis (68) or to total ground-cover biomass (41) and cannot be related directly to complete-tree utilization. The limited work in this area is understandable, since root biomass studies are difficult to carry out[(c)] and, until fairly recently, there has been little need for or interest in the use of roots, particularly as a source of fiber.

Percentage Roots as a Function of dbh - Standard Basis

Somewhat unexpectedly, the limited data available on percentage roots (Table 3, coniferous species; Table 4, deciduous species) either show a fairly consistent increase with increasing dbh or show little change with dbh. This trend is evident for *Abies balsamea*, *Picea rubens*, *Pinus strobus*, *Thuja occidentalis*, *T. plicata*, *Tsuga canadensis*, *T. heterophylla*, *Populus*, *Acer rubrum* and *Betula papyrifera*.

(c) As commented by Harper (23): "The estimate of roots is always an ecologist's nightmare." One problem which arises with respect to root biomass is the nature of the method of dividing and weighing the root system. There are three levels of complexity in root biomass studies :

- determination of all roots, including root hairs - difficult in the extreme;
- determination of all roots down to the root hairs - difficult;
- determination of those roots which remain with the stump when a tree is pushed over, pulled over, pulled up, or otherwise rooted out of the ground. This method of defining roots is neither elegant nor precise, but it does have two advantages: it is the least costly method of determining root biomass; it represents the way in which, in all probability, most roots can be recovered for use, and from a practical, use-potential point of view, would give the most meaningful data.

TABLE 3

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

Roots: Oven dry and bark free
Full tree bole: Oven dry and bark free

Reference	Wood Species	No. of trees sampled	Roots as a % of Full Tree Bole				
			Diameter breast height (inches)				
			6	8	10	12	14
80	*Abies balsamea* [1,2]	23	20	21	23	24	26
4,5	*Picea glauca* [3]	2	56	-	-	-	-
78	*P. rubens* [1]	25	22	25	30	33	37
66	*Pinus caribaea* [4]	1	-	7	-	-	-
66	*P. caribaea* [5]	1	-	8	-	-	-
66	*P. palustris* [4]	1	-	3	-	-	-
80	*P. strobus* [1]	27	16	17	18	19	21
15	*Thuja occidentalis* [1]	21	12	14	16	18	-
17	*T. plicata* [6]	8	-	20	21	19	-
80	*Tsuga canadensis* [1]	28	17	20	23	26	28
17	*T. heterophylla* [6]	8	12	16	20	24	-
37	*T. heterophylla* [6]	2	-	23.0	-	-	16.2

1. Stump height: 6 inches above ground level
2. Roots: bark on
3. Stump: ground level
   Roots: may not be bark free
4. dbh: 8.25 inches
5. dbh: 8.5 inches
6. Stump: 12 inches above ground level

TABLE 4

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

Roots: Oven dry and bark free
Full tree bole: Oven dry and bark free

Reference	Wood Species	No. of trees sampled	Roots as a % of Full Tree Bole — Diameter breast height (inches) 6	8	10	12	14
75,79	*Acer rubrum*[1]	20	12	13	14	15	17
4,5	*Betula papyrifera*[2]	7	47	-	-	-	-
80	*B. papyrifera*[1]	17	35	33	28	24	19
80	*Populus sp.*[1]	14	14	16	19	22	-

1. Stump: 6 inches above ground level
2. Stump: ground level
   Roots: may not be bark free (not specified)

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

Table 5 gives data on the percentage roots for trees of various ages (oven-dry and bark-on basis). For *Pinus sylvestris* and *Pseudotsuga menziesii* there is a marked decrease in percentage roots with increasing age; for *Pinus densiflora* there is evidence of a slight increase, and for *Picea abies* there is no marked trend. The range of root biomass as a percentage of full tree boles is quite large within species (from 7 to 110% for *Pseudotsuga menziesii*) and between species. As noted above for stumps, some part of this variation is most probably due to differences in methods of root removal; most of the difference probably results from variations in factors affecting root biomass, such as nutrient and water supply, stand density, dominance, tree height, and unknown factors.

TABLE 5

Roots as a Percentage by Weight of Full Tree Boles
and as a Function of Tree Age

Roots: Oven dry and bark on
Full Tree Bole: Oven dry and bark on

Reference	Wood Species	No. of trees	Age (years)	Roots as % of full tree bole	Notes
69	*Cryptomeria japonica*	25,000/ha	5	36	Stump ht. probably ground level
53	*Picea abies*		24	29	Stump ht. not specified
			38	34	
			60	33	
			93	26	
29	*Pinus contorta* var. *latifolia*	85	100 ave.	19	Stump ht: 12 inches Top: 4 inches diam.
24	*P. densiflora*		6" dbh	32	Stump ht. assumed to be ground level
			8" dbh	33	
		Assumed to be	10" dbh	34	
		incr. in age	12" dbh	35	
53	*P. sylvestris*	3,640/ha	23	63	Stump ht. not specified
		4,260/ha	33	30	
		760/ha	55	35	
53	*Pseudotsuga menziesii*	1,151/ha	30	110	Stump ht. not specified
		1,636/ha	32	89	
		1,151/ha	38	14	
		1,157/ha	52	7	
54	*P. menziesii*	-	-	17	Stump ht. not specifie
53	*P. menziesii*	648/ha	38	13	"
53	*Nothofagus truncata*	490/ha	110	17	"
54	*Picea* sp.		-	37	"
54	*Pinus* sp.		-	26	"
54	*Betula* sp.		-	24	"
54	*Fagus* sp.		-	32	"
54	*Quercus* sp.		-	22	"
54	Tropical mixed species		-	12	"
12	General		-	15[1]	Vol. % of merchantable bole
61	*Fagus sylvatica*	Height = 59 ft.	46	19.6)	Assumed to be wt.% of above ground tree components
		Height = 84 ft.	85	19.7)	

1. Defined as utilizable wood

The values given in Tables 5 and 6 are of interest in that they show the range of percentage roots for a number of wood species. These data, together with other values recorded for percentage roots, would indicate that the range of percentage roots is wide, although far less extreme than for other components such as foliage (33) or branches (34).

TABLE 6

Roots as a Percentage by Weight of Full Tree Bole

Roots: Oven dry and Bark on;
Bole: Oven dry and Bark free

Reference	Wood Species	Tree age (years)	Dbh (inches)	Tree height (feet)	Roots as % of Full Tree Bole[1]
59	*Abies alba*[2]	40	.....	.....	26.4
59	*Larix decidua*[2]	40	.....	.....	38.0
59	*Picea excelsa*[2]	40	.....	.....	28.6
59	*Pinus sylvestris*[2]	100	.....	.....	20.7
		100	.....	.....	31.9
59	*Fagus sylvatica*[2]	110	.....	.....	10.7
41	*Fagus* sp.	165	13	59	95
		170	15	98	73
		230	17	78	84
41	*Quercus* sp.	60	5	33	33
		160	9	43	52
41	*Quercus* sp.	220	18	69	97
41	*Quercus* and *Fraxinus* sp.	165	15	43	64

1. Stump height not specified, but trees assumed to be cut at ground level.
2. One tree for each species.

Percentage Roots for Young Trees - Oven-dry and bark-on basis

Young's data for percentage roots (oven-dry and bark-on basis) for young trees (Table 7) shows a uniform decrease in percent roots with increasing tree height for a number of species. One of the outstanding characteristics of these data is the uniformity of root percentage for the species studied, with the narrow range (for a 25-foot high tree) from 30 to 42%. Although these data are included in the root biomass section of the present report, they should probably be considered as applicable to the stump-root system, since any distinctive features of stumps and roots would disappear for small trees. The results are also characterized by a narrow range for root biomass between species at a given tree height (25 to 34%) for 30-foot trees (omitting the high value of 40% for *Acer rubrum*).

Percentage Roots - Green Basis

The data in Table 8 show the percentage roots on a green basis. Because these values were obtained under uniform conditions and by a uniform technique, and possibly because they represent biomass from a uniform forest area, they show a marked regularity in trend. An examination of percentage roots as shown in Table 7 (in relation to tree height) and Table 8 (in relation to dbh) for the same wood species would suggest that the biomass of the roots (compared to that of the bole) is not a simple, linear one. Up to a dbh of approximately 4 inches (tree height 35 feet), there is a strong inverse relationship between percent roots and dbh; in the dbh range from 4 to approximately 10 inches there is a slight inverse relationship, with the percentage roots remaining relatively constant, and for large trees, the percent roots begin to decrease with increasing dbh.

TABLE 7

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

Roots: Oven dry and bark on
Full Tree Bole: Oven dry and bark on
Reference: 74

Wood species	No. of trees sampled	Roots as a % of full tree bole									
		Tree height in feet									
		1	3	5	7	10	15	20	25	30	35
Abies balsamea	14	369	164	110	85	65	47	38	32	28	25
Picea rubens	40	235	124	93	79	64	51	43	38	34	31
Pinus strobus	10	113	73	56	49	43	36	32	29	27	25
Thuja occidentalis	34	272	124	85	68	53	41	33	29	25	23
Tsuga canadensis	9	850	240	157	114	82	56	43	35	29	25
Acer rubrum	40	125	87	73	65	58	50	46	42	40	38
Betula papyrifera	10	100	69	52	47	41	36	32	30	28	26
Populus tremuloides	6	350	108	82	68	55	43	37	32	29	27

Notes: DBH range, 1 to 4 inches
Stump height, not specified, assumed to be ground level

TABLE 8

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

Roots: Green and bark on
Full Tree Bole: Green and bark on

Reference	Wood species	No. of trees sampled	Roots as a % of Full Tree Bole[1]				
			Diameter breast height (inches)				
			6	8	10	12	14
77	*Abies balsamea*	23	24	36	53	41	-
78	*Picea rubens*	25	29	35	37.5	37	32
80	*Pinus strobus*	27	20	23	23	22	21.5
15	*Thuja occidentalis*	21	21.5	22	22.5	23	-
80	*Tsuga canadensis*	28	21.5	24	26	28	30.5
80	*Acer rubrum*	20	26	34	37.2	36.8	32.5
80	*Betula papyrifera*	17	36	37	26	24	-
80	*Populus* sp.	14	19.5	23	24	24	-

1. Includes all size roots

As noted above, the data given in Table 7 for the percentage roots (oven-dry and bark-on basis) probably refer to stump-root system, since for young trees cut at ground level and underground parts, even if called roots only, should compare closely with the stump-root system. This would be confirmed by taking the percentage stump-root system for the largest trees in the first series (Table 7) and comparing them with the small diameter trees from the second series (Table 10). The results of this comparison are shown in Table 9.

TABLE 9

Percentage by Weight of Roots or Stump-Root System
for 35-Foot Trees 6 Inches dbh

Wood species	35-foot height[1] Reference: 74	6-inch dbh standard basis	Reference
Abies balsamea	25	23.5	80
Picea rubens	31	30	78
Pinus strobus	25	24	80
Thuja occidentalis	23	22	15
Tsuga canadensis	25	24.5	80
Acer rubrum	38	18	79,75
Betula papyrifera	26	50	80
Populus tremuloides	27	21	80

1. Roots, oven-dry and bark-on
   Full tree bole, oven-dry and bark-on.

There is a nice coincidence between the two sets of values for conifers, but no apparent connection between the two sets of values for hardwoods.

Factors Affecting Root Biomass

It is apparent from the data discussed above that percentage roots on a standard basis is a function of wood species and upon some combination of tree height, age and dbh. Of all tree components, roots are also most sensitive to soil conditions, including nutrient supply, soil density, and moisture availability (68). For example, root biomass as a percentage of bole plus branches (oven-dry and bark-on basis) was found to be 26.7% for *Quercus* sp. (48-55 years) growing on sandy loam; 11.1% for growth on a heavy, dense clay-loam soil (68).

In one study (73) on *Pinus radiata*, the following relationship was reported between the biomass of roots and branches:

$$\text{Root weight}/0.69 = \text{branch weight}$$

To the extent that this relationship is valid, all of the factors which affect percentage branches on a standard basis (34) would also affect percentage roots; these factors would include stand density, site index, wind-throw and dominance, in addition to the factors noted above, and quite possibly to factors which are presently unknown.

No systematic studies have been found which relate percentage roots on a standard basis to the various factors governing root growth. As a part of the development of the complete-tree utilization concept and its application, a great deal of research needs to be done in this area.

STUMP-ROOT SYSTEM

Introduction

Until recently (75, 80) there has been limited need for, or interest in, the use of stumps and roots as a source of fiber.[d] The use of root-stump systems as a raw material for pulp or fiberboard manufacture involves a number of critical questions relating to:

1. Extraction of trees from the ground;
2. Freeing roots and stumps of dirt and stones;
3. Transporting root-stump systems or their components;
4. The most effective method and place for separating stump-root systems from boles, and of separating roots from the stumps;
5. Debarking both stumps and roots;
6. Chipping both stumps and roots;

(d) The quantity of stumps available, or the use of stumps as a source of naval stores, has not been considered in the present review.

7. The extent to which complete-tree utilization will change the need for forest fertilization, and the effect which forest fertilization may have on component biomass ratios;

8. The amount of stumps and roots which might be available as a source of fiber in terms of various wood species, growth conditions, etc.

9. The quality of pulp obtainable by conventional pulping processes from stump-root systems, alone or in admixture with branches, unmerchantable tops and tree boles;

10. The quality of product obtainable by mixing pulps obtained separately from various tree components;

11. The effect of complete-tree utilization on land erosion, reforestation, silviculture, fire hazard, the oxygen-carbon dioxide balance, and mean global temperature.

The following review covers the biomass of stump-root systems, the quality of pulp obtained from them and problems relating to processing. From a practical point of view, most interest is likely to center on extraction and utilization of stump-root systems. In the use of components other than boles as a source of fiber, it is most likely that below-ground tree components would be treated as units, roots and stumps separated and barked and chipped separately, but probably pulped together. The question of whether stumps and roots should be pulped together with boles, or whether the pulps should be blended after pulping, would have to be resolved for each individual circumstance.

Biomass

Percentage Stump-Root System - Standard Basis

With reference to complete-tree utilization as a means of increasing fiber resources of the world, Table 10 gives data with a high level of long-range practical importance. This importance arises from several factors:

- The introduction of unmerchantable tops of boles to the mainstream of fiber use would add something of the order of 5-10% to fiber resources, depending on tree species, tree diameters, heights, ages, etc., and in practice would be expected to provide roughly 5% of additional fiber. The yield and quality of this fiber would be high.

- The use of branches would add of the order of 10-20% of fiber, with an average possibly as high as 15% in practice with increasing use of shorter rotation cycles. Because of the generally lower quality of pulp prepared from branches compared with pulp from boles, branches would not be expected to add more than possibly 10% to the effective or usable fiber supply.
- The limited data available would indicate that stump-root systems would give a quality of fiber not appreciably different from that of boles, and in an amount higher than that of branches and unmerchantable tops combined; that is, of the order of 20% [(e)].

The standard values shown in Table 10 for percentage stump-root system are appreciably higher than the 20% discussed above as potential yield of fiber from stump-root systems. However, many of the values shown in Table 10 include roots smaller than 1-inch diameter. Biomass values for stump-root systems with this material removed would be substantially lower. In addition, some allowance should be made for losses in extraction of stump-root systems in practice.

As shown by the data given in Table 7, the trend towards decreasing percentage stump-root system with decreasing dbh shown in Table 10 must reverse at a dbh somewhere between 4 and 6 inches for the species studied and under conditions of biomass determination; since below 4-inch dbh, the percentage stump-root system rises quite rapidly with decreasing tree height (and decreasing dbh), so that the percentage stump-root system for a 1-foot-high *Abies balsamea* is between 300 and 400% of the bole, this value is higher, even if allowance is made for the high percentage bark on the roots.

(e) This does not include roots less than 1-inch in diameter. As in the consideration of branches as a potential source of raw material for pulping, roots less than 1-inch in diameter are not considered suitable as a potential source of wood fiber for pulping. The exclusion of this material is based on extreme difficulty in processing with present technology and equipment available; the quality of pulp obtainable from small roots, either by the conventional pulping process or by modifications of such processes, has not been studied.

TABLE 10

Stump-Root System as a Percentage by Weight of Full Tree Bole and as a Function of DBH

Stump-root system: Oven dry and bark free
Full tree bole: Oven dry and bark free

Reference	Wood Species	No. of trees sampled	Stump-root system as a % of full tree bole Diameter breast height (inches)				
			6	8	10	12	14
80	*Abies balsamea*[1,2]	23	24	26	28	30	32
3	*A. balsamea*[3]	190	51	52	54	-	-
78	*Picea rubens*[1]	25	30	34	39	43	47
66	*Pinus caribaea*[4]	1	-	35	-	-	-
66	*P. caribaea*[5]	1	-	42	-	-	-
66	*P. palustris*[4]	1	-	24	-	-	-
80	*P. strobus*[1]	27	24	27	29	31	33
15	*Thuja occidentalis*[1]	21	22	27	31	36	-
17	*T. plicata*[6]	8	-	41	40	32	-
80	*Tsuga canadensis*[1]	28	25	29	33	37	41
17	*T. heterophylla*[6]	8	23	28	33	37	-
37	*T. heterophylla*[6]	2					
75,79	*Acer rubrum*[1]	20	18	21	23	25	28
80	*Betula papyrifera*[1]	17	50	50	44	39	33
80	*Populus* sp. [1]	14	21	25	29	33	-

1. Stump height: 6 inches above ground level
2. Stump and roots: bark on
3. Stump-root system: bark on
4. Dbh: 8.25 inches - stump: 4 inches above ground
5. Dbh: 8.5 inches - stump: 4 inches above ground
6. Stump: 12 inches above ground level

TABLE 11

Stump-Root System as a Percentage by Weight of Full Tree Bole and as a Function of Tree Age

Stump-root system: Oven dry and bark on
Full tree bole: Oven dry and bark on

Reference	Wood Species	Tree age in years	Stump-root system as % of full tree bole	Stump-root system as % of full tree bole plus canopy
52	*Pinus sylvestris*[3]	3	100	40
		7	334	82
		11	201	69
		14	123	45
		17	78.5	36
		20	52.0	27
		23	63.0	44
		31	34.0	28
		35	45.0	37
		55	35.0	29
52	*P. sylvestris*[1]	11	48	27
		14	62	45
29	*P. contorta* var. *latifolia*[1,2]	100	21.4	-
55	*Betula verrucosa*[3]	24	35.4	-
		42	44.2	-
		55	37	-

Notes: One tree for each age
1. Regenerated; canopy defined as cones, branches and foliage
2. Stump height: 12 inches above ground level
3. Stump height: not specified

Percentage Stump-Root System - Oven-dry and Bark-on Basis

The trend of increasing percentage stump-root system with decreasing age or tree height or tree diameter is shown for *Pinus sylvestris* in Table 11.

Biomass values given in Table 12 represent a general overall view of biomass of stump-root systems. The values given indicate that, in general, the percentage stump-root system lies between 20 and 30% (7) for northern forests, and is appreciably lower for equatorial forests generally, with the exception of mangrove forests which would be expected to be high because of combined aerial-underground root system.

Percentage Stump-Root System - Green and Bark-on Basis

Table 13 gives a summary of the results of extensive field trials on extraction, cleaning, separation and transport of stump-root systems of *Pinus sylvestris*. The figures shown are based on the weights of hundreds of trees. Since the percentage moisture in stump-root systems would not be expected to differ appreciably from that of comparable boles[f], the percentage stump-root system shown would be roughly the same on an oven-dry, bark-on basis as on a standard basis. Because of the method of extraction (with a bulldozer blade), there would probably be few roots less than 1-inch diameter removed from the ground. The percentage bark on stumps and on larger roots would not be expected to be appreciably greater than that on boles[g], whereas bark on small roots would be expected to be appreciably greater[h]. Conversion factors necessary to convert the data in Table 13 to a standard basis are not available.

(f) In studies (31) on *Tsuga heterophylla* (8.5 inches dbh, stump height 12 inches), percentage moisture in boles was 43, and in the stump-root system was 46.9.

(g) In the same study (37), the bark on the stump-root system was 12.9% and on the bole 11.1%.

(h) In the same study (37), the bark on roots between 1-2 inches in diameter was 26.5%, on roots 2-3 inches diameter 21.9%, and on roots greater than 3-inch diameter, 13.6%.

TABLE 12

Stump-Root System as a Percentage by Weight of Full Tree Bole

Stump-root system: Oven dry and bark on
Full tree bole: Oven dry and bark on

Reference	Wood Species	Stump-Root Systems as a % of full tree boles	
7	*Larix europaea*[1]	39	(estimate)
7	*Picea abies*[1]	25	"
		24	"
		23	"
7	*Pinus sylvestris*[1]	25	"
		26	"
7	*Pseudotsuga menziesii*[1]	24	"
16	*Alnus rugosa*	79.5	7 years old, one tree
7	*Betula verrucosa*[1]	27	(estimate)
7	*Fagus sylvatica*[1]	28	"
		20	"
		25	"
7	*Populus davidiana*[1]	30	"
7	*P. tremuloides*[1]	34	"
7	*Quercus robur*[1]	27	"
16	*Salix babiana*	91	12 years old, one tree
16	*Vaccinium corymbosum*	67.7	15 years old, one tree
7	Equatorial forest, Congo[1,2]	15	
7	Seven evergreen gymnosperms[1,2]	25	
7	Ten deciduous angiosperms[1,2]	28	
7	Eighteen cold temperate forests[1,2]	27	
7	Two equatorial forests[1,2]	16	
6	Tropical forest[2]	19–23	

Notes: No. of trees, DBH, and stump height not specified.

1. Values assumed to be based on below-ground components as a percentage of full tree bole plus branches.
Montane and gallery forests – 23% Mangrove forests (aerial and underground roots) – 50% Savanna – up to 42% (estimate)
2. Roots represent 19–23% of the biomass.

TABLE 13

Stump-Root System as a Percentage by Weight of Full Tree Bole

Stump-Root System: Green and Bark on
Full Tree Bole: Green and Bark on

Reference	Wood species	Stump-Root System as a % of Full Tree Bole
44	*Pinus sylvestris*[2]	22.4%
40	*P. sylvestris*[3]	22.0 trial no.1[1]
		22.6 " " 2
		23.5 " " 3
		22.8 " " 4
		21.9 " " 5

1. Each trial involved extraction of complete trees for full working shifts, and the values shown represent averages from weighing hundreds of trees. The stump-root systems were probably removed from boles close to the roots, and the values shown are somewhat less than would be obtained for a 1-foot stump.

2. Percentage calculated as a part of bole (bole assumed to mean full tree bole).

3. Assumed to be stump-root system as a percent of the full tree bole.

In the extraction of *Tsuga heterophylla* trees by the same method (pushing over and uprooting with a bulldozer blade), the average stump-root system on a green basis was found to be 26% (Table 19). Correcting from a 1-foot stump to ground level, this value would be reduced by something of the order of 20%, which would give a value for % stump-root system in close agreement with the results obtained in the extensive field studies on *Pinus sylvestris* (40).

Table 14 gives the percentage stump-root systems for a number of Maine species studied by H. Young.

TABLE 14

Stump-Root System as a Percentage by Weight of Full Tree Bole

Roots: Green and bark on
Stump: Green and bark on
Full Tree Bole: Green and bark on
Standard basis values in brackets (oven dry and bark free)

Reference	Wood species	No. of trees sampled	Stump-Root System as a % Full Tree Bole				
			Diameter breast height (inches)				
			6	8	10	12	14
77,80	*Abies balsamea*	23	32 (24)	45 (26)	63 (28)	52 (30)	- (32)
78	*Picea rubens*	25	37 (30)	44 (34)	47 (39)	46 (43)	41 (47)
80	*Pinus strobus*	27	30 (24)	34 (27)	35 (29)	35 (31)	35 (33)
15	*Thuja occidentalis*	21	33 (22)	36 (27)	38 (31)	40 (36)	- -
80	*Tsuga canadensis*	28	30 (25)	33 (29)	36 (33)	39 (37)	43 (41)
80	*Acer rubrum*	20	34 (18)	42 (21)	46 (23)	46 (25)	42 (28)
80	*Betula papyrifera*	17	48 (50)	50 (50)	39 (44)	37 (39)	- (33)
80	*Populus* sp.	14	26 (21)	31 (25)	33 (29)	34 (33)	- -

Note: Stump height = 6 inches above ground

Percentage Bark on Stumps

Few data are available on the percentage bark on tree stumps (Table 15). The values obtained by H. Young (79) in his studies on Maine species show no consistent variation in relationship to percentage bark on boles, sometimes being lower (*Abies balsamea, Tsuga canadensis*), sometimes higher (*Tsuga heterophylla,* *Acer rubrum and Betula papyrifera)* and sometimes showing no trend with increasing dbh (*Picea rubens*, *Populus* sp.).

TABLE 15

Weight Percentage of Bark on Stumps

Stump bark: Oven dry
Stump fiber: Oven dry

Reference	Wood species	% Bark on Stump	% Bark on Full Tree Bole
79	*Abies balsamea*	10.3	7.3
79	*Picea rubens*	6.5	6.8
79	*Pinus strobus*	10.3	9.2
79	*Tsuga canadensis*	6.5	6.1
37	*T. heterophylla*[1]	11.1 11.1 10.0	12.3 13.6 20.4
79	*Acer rubrum*	7.4	8.1
79	*Betula papyrifera*	7.4	8.4
79	*Populus* sp.	10	10.2

Notes: Stump height: 6 inches above ground unless otherwise specified
Number of trees measured: one for each species

1. Stump height: 12 inches above ground level.
Respective dbh: 18.0, 14.2 and 8.5 inches

Percentage Bark on Roots

As with the stump few firm data are available on percentage bark on roots, as a function of various growth factors of trees. Table 16 gives values for percentage bark on roots for several wood species. It is noted that, as with branches, percentage of bark in general increases with decreasing root size.

TABLE 16

Weight Percentage of Bark on Roots

Roots: Oven dry and bark free
Root bark: Oven dry

Reference	Wood species	Bark as % of Roots 4"	1-4"
79	*Abies balsamea*	8.6	12.0
79	*Picea rubens*	8.0	12.5
79	*Pinus strobus*	8.5	7.6
79	*Tsuga canadensis*	8.6	10.8
37	*T. heterophylla*[1]	14.9[2]	26.5[3]
		13.6	23.4
		13.6	21.9
79	*Acer rubrum*	6.1	10.5
79	*Betula papyrifera*	7.9	11.2
79	*Populus* sp.	9.1	14.0

Notes: Stump height = 6 inches above ground level

Number of trees measured: one for each species

1. Respective dbh: 18", 14.2" and 8.5"
2. Roots greater than 3" diameter
3. Roots between 2-3" diameter

A detailed study was made in the Vancouver Forest Products Laboratory on the biomass (37) and pulping characteristics (36) of all major components for three *Tsuga heterophylla* trees, selected on a basis of high, medium and low specific gravity.

Table 17 gives the percentage stump-root system on the standard basis for a stump height of 12-inches above ground and at ground level. The difference in the two sets of values indicates the importance of specifying stump height in biomass studies.

TABLE 17

Percentage Stump-Root System by Weight for Variable Stump Heights - Standard Basis

Species: *Tsuga heterophylla*
Reference: 37

	Percentage of Stump-Root System - Standard Basis			
	dbh in inches			
Stump height	8.5	14.2	18	Average
12 inches above ground	25.8	23.3	28.1	25.7
At ground level	22.5	15.5	20.9	19.6

Percentage Stump-Root System - Miscellaneous Values

Table 18 gives various miscellaneous values for root and stump biomass.

TABLE 18

Stump-Root System Biomass - Miscellaneous Values

eference	Wood species	Percentage	Assumed basis	Comment
14	Various (Canadian)	2% of merchantable[1] bole (by volume)	Green volume, bark on	......
12	*Pinus* sp.	15% of industrial[2] wood	Green volume, bark on	......
9	U.S. forests (Maine)	Stump-root system = 25% of whole tree	Green weights, bark on	......
70	*Abies veitchii*	Roots = 30% of total biomass of stem and branches[3]	Green weights, bark on	......
43	*Picea* sp. *Pinus* sp. (Finland)	15-22%	......	Volume % of merchantable bole
31	*Picea* sp. *Pinus* sp. (U.S.S.R.)	15-22%	......	Volume % of merchantable bole
43	General (western U.S.S.R.)	20%	......	
43	General	Dbh (inches) — %	......	Volume % of merchantable bole
		0 - 1.3 — 62		
		1.3 - 2.5 — 35		
		2.5 - 5.0 — 30		
		Above 5.0 — 22		
58	*Quercus* sp. (25 yr.)	20.9[4]	Green and bark on	Roots as % of above-ground components
	Picea sp. (25 yr.)	32.0[4]	"	"
	Larix sibirica (25 yr.)	24.5[4]	"	"
10,68	*Quercus* sp.	Quality class — %[4]		
		I — 52.4	Oven-dry, bark on	Roots as % of full tree bole
		II — 30.6	"	"
		III — 30.6	"	"
		IV — 72.6	"	"
17	*Pinus contorta* var. *latifolia*	Foliage weight approx. 3 times greater than root wt.		Detailed study of root-growth relationship
	Picea glauca } *Abies lasiocarpa* }	Foliage wt. approx twice that of root weight		
17a	*Picea abies* (Scandinavian)	Stump-root system = 40% by wt. of merchantable bole Stump = 10% by wt. of merchantable bole Roots > 1" Ø = 25% by wt. of merchantable bole Roots < 1" Ø = 5% by wt. of merchantable bole	Oven-dry, bark-free	

Table 18 footnotes.

1. This percentage was calculated from the amount of sound wood contained in the stump above the point of root swelling, and does not represent the total volume of the stump from ground level.
2. Assumed to contain some roots.
3. Average of three values from three natural stands.
4. Assumed to be total root system including root hairs.

An important question arises with respect to much biomass data available in technical literature on various tree components. In biomass studies, the problem always arises as to whether the purpose of the study is best served to "....learn a lot about a little, or a little about a lot" (60). A pulp manufacturer, wishing to consider use of stump-root systems as a source of raw material for pulp, will wish to know how much material is practically available in forest areas from which the raw material for a given mill is drawn. If detailed biomass determinations (standard-basis values) are made on a few trees selected as being representative, then the answers representing a "lot about a little" may be precise, but they may also be highly inaccurate. If, on the other hand, a very large number of randomly selected trees are studied for stump-root biomass on a basis of green volumes, with bark on, simply because such data are relatively easy to obtain, then the answers may be highly accurate, in that they do represent true average values for what is being measured. Unfortunately, the wrong thing may be measured, with no means available for relating the values obtained to the values actually required. The point is illustrated in Table 19, which shows the difference between standard values and green, bark-on values for the biomass of stumps, roots and stump-root systems.

TABLE 19

Percentage Roots, Stump and Stump-Root System - Three Bases of Reporting

Species: *Tsuga heterophylla*
Reference: 37
Stump Height: 12 inches above ground.

Dbh (Inches)	Basis of reporting	Weight % of Full Tree Bole % Stump	% Roots	% Stump-Root System
18.0	Standard	5.8	20.9	26.7
	Oven dry, bark on	6.0	22.2	28.2
	Green, bark on	6.3	23.6	29.9
14.2	Standard	6.8	16.2	23.0
	Oven dry, bark on	6.7	16.6	23.3
	Green, bark on	5.8	14.7	20.5
8.5	Standard	2.8	23.0	25.8
	Oven dry, bark on	2.7	23.1	25.8
	Green, bark on	2.8	25.5	28.3

Summary

Since, of all tree components, the stump is least clearly defined, it is not possible to give an average standard value, or a reasonably narrow range of standard values, for percentage stump. Roots are perhaps more clearly defined than the stump as a tree component, but biomass data while more plentiful, are considered to be only slightly more meaningful as an index of recoverable fiber. Biomass data on stump-root systems, on the other hand, are likely to be much more reliable, since most of the difficulties arising from definition or extent of stump and root separation disappear. The various values given in the technical literature would indicate that for *Picea*, *Pinus*, *Tsuga*, and possibly *Abies* species, the percentage roots which can be recovered in practice today ranges from 15 to 25% on a standard basis,--where stump-root systems are extracted from the ground by uprooting with a tractor blade, and where stand density is high, the dbh is 4-6 inches or higher, the soil is fairly loose and uncompacted, nutrient and moisture are not abnormally low, and wind-throw is not excessively high.

UTILIZATION OF STUMPS AND ROOTS

Stumps and roots have long been used for fuel and as a source of extractives (i). Although extracted stump chips have been used for pulp manufacture, the amount of stump-wood fiber recovered has been minisculely small compared with the massive amounts of such material available. Tables 20, 21 and 22 give selected literature references on the utilization of stumps, roots and stump-root systems.

(i) Neither of these uses for stumps and roots have been reviewed in the present report. An excellent specific and general bibliography of background material on naval stores is included in a review of naval stores in terms of extraction, composition and properties (65).

TABLE 20

Utilization of Stump-Root System -- Kraft Pulp

Reference	Wood species	Comment
44	*Pinus* sp.	Desirable raw material for kraft pulp
1	*Picea* sp. *Pinus* sp.	Quality of stump pulp lower than that of bole pulp
20	*P. palustris*	High burst factor and low tear compared with bole pulp
79,80	*Abies balsamea* *Picea rubens* *Acer rubrum* *Pinus strobus* *Tsuga canadensis* *Betula papyrifera* *Populus* sp.	Some pulps obtained are generally comparable to bole pulp in quality, while others have good pulping potential.
49	*Pinus* sp.	Roots and stumpwood, pulped with bole wood, gave high quality pulps
66	*P. caribaea* *P. palustris*	Good quality of pulp, lower yield
38	*Picea rubens*	Low yield of acceptable chips; pulp comparable to bole pulp
76	*Acer rubrum* *Betula papyrifera*	Low quality compared with bole pulp
15	*Thuja occidentalis*	Strength lower than bole pulp
36	*Tsuga heterophylla*	Pulp comparable in yield and quality to bole pulp
48	*Picea* sp. *Pinus* sp.	Tensile strength of pulp decreased by 10-20% as compared with bole pulp
45	*Pinus* sp.	In no case is pulp yield greater than 37%

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TABLE 21

Utilization of Stump-Root System
- Other Types of Pulp

Reference	Wood species	Pulp use	Comment
21	*Pinus sylvestris*	Sulphite	Yield and quality of pulp not affected when 20-50% of stump pulp added to mill-run pulp.
8	Kauri	Soda	Pulping of branches and stumps together gives 33-43% pulp yield; pulp is difficult to bleach, but has excellent strength and quality
79,80	*Abies balsamea* *Picea rubens* *Acer rubrum* *Pinus strobus* *Tsuga canadensis* *Betula papyrifera* *Populus* sp.	Sulphite and nitric acid	Pulps obtained are generally comparable to bole pulp in quality (*Picea rubens);* other species have the potential of good pulps
46	*Picea rubens*	Nitric acid	Pulp comparable to bole pulps

TABLE 22

Utilization of Stump-Root System
- Miscellaneous

Reference	Wood species	Use	Comment
71	General	Silverchemicals, vitamins, fodder	Review of foliage extraction and stump utilization in the Soviet Union
63	General	Production of ammonia	Roots used with other residues for the production of ammonia fertilizers
9	General	Pulp, paper, other fiber prod.	CTU - increase in fiber resources
77	*Abies balsamea*	Fiber source	CTU - increase in fiber resources
12	General	Pulp and conversion to chemicals	FAO study on the extraction of stumps and conversion to various products
57	General	Pulp fiber	Stumpwood extracted to yield turpentine and then pulped
79,80	*Abies balsamea* *Picea rubens* *Acer rubrum* *Pinus strobus* *Tsuga canadensis* *Betula papyrifera* *Populus* sp.	Pulp fiber	CTU - additional fiber source

TABLE 22 (Continued)

Reference	Wood species	Use	Comment
44	*Pinus* sp.	Tall oil, rosin, turpentine	Desirable raw material for extraction and kraft pulp
50,56	*Pinus* sp. *Picea* sp.	Pulp and paper	Stumps extracted and then pulped
78	*Acer rubrum* *Picea rubens*	Pulp fiber	CTU - additional fiber source
77	*Abies balsamea*	Pulp fiber	CTU - additional fiber source
64	General	Rosin	Utilization of stumps from logging areas
28	*Pinus* sp.	Tar-oil phenols	Study to improve the yield of tar-oil dry distillation products from roots
26	General	Fiberboard	Stumpwood used if root portion is small and mixture of species used
42	General	Pulp chips	Chief difficulty in using stumps for pulpwood has been to find a machine not readily damaged by stones and sand
72	*Pinus* sp.	Pulp chips	Review of bark and chip separation
19	General	Pulp chips	Review of bark and chip separation at the harvesting site
47	*Pinus* sp.	Rosin, turpentine, pinewood tar	Three separation systems are described for utilization
2	*Pinus* sp.	Essential oils	Review of oil extraction process
39	*Picea glauca* *P. glauca* var. *albertiana* *Pinus contorta* var. *latifolia* *Abies balsamea* *A. lasiocarpa* *Populus balsamifera*	Pulp chips	Represents a potential source of fiber
21	*Pinus* sp.	Pulp chips	Use of rosin in processing synthetic rubber
27	*Pinus* sp.	Pulp chips	Kraft pulps suitable for manufacture of wrapping paper
30	General	Pulp chips	Chipping of stumpwood with a conventional chipper produced 5% screening wastes
67	*Pinus* sp.	Rosin	Use of fresh instead of seasoned stumps indicated as best for extraction
81	General	Fiber	Uprooting of whole tree requires less power than uprooting stumps
51	General	Rosin	Use of electro-hydraulic effect for the extraction of rosin from stump-

A number of studies have reported that the strength of kraft pulps from either stumps or roots are similar to that of the comparable bole pulp[(j)]. In a study of pulping characteristics of various components of *Tsuga heterophylla* at the Vancouver Forest Products Laboratory (36), the results shown in Table 23 were found.

TABLE 23

Yield and Quality of Kraft Pulps from *Tsuga heterophylla* Tree Components[1]

Components	Relative Percentages for:			
	Unscreened pulp yield[2]	Tear factor[2]	Burst factor[2]	Breaking length[2]
Merchantable bole	100	100	100	100
Stump	96	92	86	87
Roots	98	99	82	85
Stump-root system	98	97	83	85

1. All pulps cooked to 18-22 permanganate number and all yield values corrected to 20 permanganate number (36).
2. All values compared to merchantable bole, the values for which are taken as 100.

(j) It has not been possible to reduce much of the literature pulping data on tree bole, stumps, roots and other components to a common basis from the literature data because of differences in pulping techniques, methods of pulp evaluation, and methods of reporting.

In a recent study of fibers from stump-root systems of *Picea abies* (17a), morphological characteristics (Table 24) and pulping characteristics (Table 25) were determined.

TABLE 24

Characteristics of Fibers from Stump-Root System of *Picea abies*[1]

Characteristic	Tree component			
	Merchantable bole	Stump	Roots more than 25 mm. diam.	Roots 3 - 25 mm. diam.
Specific gravity of wood (g/cm^3)	0.43	0.42	0.54	0.34
Fiber length (mm - weighted average)	3.07	2.16	2.29	3.34
Compressed fiber width (μ)	56	51	50	56
2 x Wall thickness (μ)	4.0	3.6	4.9	4.0
Wt. per unit length of fiber (mg./m.)	0.25	0.22	0.28	0.26
Zero - span tensile	22.0	18.5	19.8	12.2

1. Three trees of 7-12" dbh, 100-120 years old.

TABLE 25

Properties of Kraft Pulps from Stump-Root System of *Picea abies*[1]

(All values shown for kraft pulps at 30 Kappa number, beaten in a PFI mill to 9,000 m. breaking length)

Characteristic	Tree component			
	Merchantable bole	Stump	Roots more than 25 mm. diam.	Roots from 3-25 mm. diam.
Degrees Schopper - Riegler	20	18	32	57
CSF (approx.)	600	630	400	160
Tear factor	205	165	165	150
Burst factor	76	74	68	73
Double folds, number	6,000	4,600	5,200	5,000
Refiner revolutions (PFI mill)	5,600	4,500	7,200	14,700
Bulk (cm.^{3}/g)	1.35	1.25	1.30	1.10

1. Three trees of 7-12" dbh, 100-120 years old.

For a number of young hardwood species in Maine[k] (*Alnus, Betula, Populus tremuloides, Acer, Prunus* and *Salix* species) the yield and quality of pulp from the stump-root system compared with pulp from the comparable bole, was highly variable:

Pulp characteristic	Percentage value for pulp from the unbarked root-stump system compared with values from comparable unbarked bole = 100%
Pulp yield	70 - 110
Breaking length (m)	70 - 90
Burst factor	70 - 90
Tear factor	90 - 120
[Yield and strength of complete tree - bark on]	90 - 100

The beating characteristics of pulp from stumps and roots is sufficiently similar to that of pulp from bole that no serious difficulties would be expected in the processing of pulp from the stump or roots, or in the quality characteristics of products derived from this fiber, either in pure fiber furnishes or in blends of stump, root and bole fiber.

It is noted from Tables 20 and 21 that most of the studies on the pulping of stumps and roots have been carried out on coniferous species. The very limited data available on the pulping characteristics of stumps and roots from deciduous species (i.e. Ref. 76) would indicate that the general principles outlined above would be applicable to deciduous root or stump pulp; one exception might be pulp yield, which might be lower for pulp from deciduous roots than for pulp from coniferous roots.

(k) Private communication from H.E. Young relating to his "puckerbrush" studies.

EXTRACTION AND PROCESSING OF TREE COMPONENTS

Only a limited amount of research has been done on the extraction and processing of complete trees, *per se*. The following section outlines the results of several studies which have a direct bearing on complete-tree utilization.

Introduction

There are a number of problem areas relating to the processing of complete trees for pulp manufacture. These areas concern the extraction of complete trees, skidding, cleaning, transporting, barking and chipping the various components, for the purpose of delivering the desired component to a processing unit in the desired form:

- clean logs to a plywood plant, sawmill, or pulp mill;
- clean chips to a pulp mill;
- debris chips, barked or unbarked, to wood hydrolysis, composition board, cement board plant, etc.;
- comminuted wood to a composition board plant, chemical or extraction plant;
- delivery of foliage to a chemical extraction plant.

In the following section, complete-tree utilization is considered in terms of preparing the components for use.

Complete-Tree Extraction

Of the methods studied for complete-tree extraction, lifting, pushing, pulling or blasting, pushing the trees over with a tractor blade has proved the most efficient.

In a detailed review of stump extraction sponsored by the FAO (12), the various methods of extracting stumps have been reviewed in considerable detail, with the type of equipment used, power requirements, and production rates for various methods. Four general categories of removal are considered:

1. Vertical force only;
2. Horizontal force only;
3. Combination of vertical and horizontal forces;
4. Internal force (blasting).

As applied to complete-tree extraction, no method has been developed as yet for lifting whole trees out of the ground because of severe damage to the butt end of the trees, and because of the lack of control, resulting in hang-ups and damage to other trees.

Extraction by Pulling Up the Trees

With a sufficiently powerful crawler tractor, capacity can be high by this method - 180 to 200 trees per shift (12) - but the safety hazard is high.

Studies on the Extraction of Complete Trees by Pushing or Pulling Over

In Poland, Hungary, Italy, East Germany and Russia, this method has proven itself to be unsatisfactory and inefficient.

Dynamometric measurements on the extraction of whole trees were carried out in the Warsaw Forest Research Institute (10, 11). The torque required for uprooting *Pinus sylvestris* and *Betula verrucosa* on sandy soil under summer conditions is shown in Table 26.

TABLE 26

Torque Required for Uprooting Pine and Birch
Trees - References 10 and 11

Dbh (cm.)	Torque in 1,000 Kg.	
	Pine	Birch
Less than 25	7	7
26-30	10	11
31-40	16	17
41-50	20	--

In a detailed study of the extraction of stump-root systems and of complete trees in Finland (43), it was found that efficiency was low in pulling out trees compared with pushing them over. In the extraction of 43 *Picea* sp. in rocky ground, the time required was:

For cable transfer........... 6.2 minutes

For rigging .... 4.2 minutes

For pulling the tree down.... 3.7 minutes

For disengaging the choker... 2.8 minutes

For *Pinus* sp. on rocky ground, the average time required to remove the choker from the extracted tree was 10 minutes. The time required for pushing trees down with a HD-6 tractor was 2.4 minutes for trees less than 14 inches dbh and 3.1 minutes for trees greater than 14 inches dbh[ℓ].

In general, removal of complete trees was found to have considerable advantages over felling trees and extracting stump-root systems, in part because of reduced power extraction because of lever action of the trees themselves and, in part, because of greater ease in skidding and hauling.

Another possibility in complete-tree utilization would be tree felling followed by extraction of the stump and some part of the root system by means of an auger, such as the Capacetti (18) or Levaceppi (25).

The choker height at which a tree of given dbh can be overthrown by a winch with a drawbar pull of 3,000 kg. is shown in Table 27.

[ℓ]The tractor blade force against the bole at three feet above ground level was sufficient to damage trees at the contact point to a depth of one inch.

TABLE 27

Choker Height for Overthrowing Pine and Birch Trees

References 10 and 11

Choker ht. from ground (m)	Diameter Class at 1.3 m. ht. (diam. in cm.) Pine	Birch
2	Less than 23	Less than 24
3	24-28	24-27
4	29-33	28-32
5	34-39	33-37
6	40-45	38-43

At a fixed choker height of 3 m., the drawbar pull required to uproot pine and birch trees is shown in Table 28.

TABLE 28

Drawbar Force Required to Uproot Pine and Birch Trees
(choker height 3.0 m. above ground)

References 10 and 11

Dbh (cm.)	Force in 1000 kg. required for : Pine		Birch	
	Overthrowing	Extraction	Overthrowing	Extraction
Less than 26	2.5	1	2.5	2.0
26-30	3.5	2	3.5	3.3
31-40	5.3	3	5.5	5.3
41-50	6.5	3.5		

Table 29 shows the force required to extract complete pine trees under summer conditions by pushing them over and pulling them out, as a function of dbh (40).

TABLE 29

Force Required to Extract Pine Trees by Pushing Over and Pulling Out[1]

Dbh (cm.)	Max. Moment of Force in extraction of pine trees by pushing them over (Metric tons)	Force Necessary to Extract pine trees by pulling them out (Metric tons)[2]
20	2.8	0.7
24	5.4	1.4
28	7.4	1.9
32	9.4	2.4
36	10.8	2.7
40	19.4	4.8
44	26.0	-
48	23.2	-
52	25.6	-
56	27.5	-
60	32.9	-

1. Trees extracted with a C-80 tractor (Russian manufacture) with bulldozer blade attachment.

2. Choker set at 1.5-3.0 meters above ground along the tree bole.

The values shown in Table 29 are for pine in the over-mature forests of Karelia. Compared with the values shown in Table 29, the maximum forces required under various conditions are:

Complete spruce trees, summer conditions.........40% less

Complete birch trees, summer conditions ....33% less

Large pine trees, winter conditions.....1.5 times more

Small pine trees, winter conditions.....2.5 times more

In Table 30 a comparison is given (40) of the productivity resulting from the use of five different methods of extracting and preliminary processing of complete pine trees[(m)]:

I. Tractor TD-40 with cable winch, choker set at 1.5-3.0 meters above ground on the bole, complete-tree skidded to working platform where crown is removed;

II. The same, but roots are removed with a chain saw at the working platform;

III. The same, but roots are removed with a chain saw at the felling site, and roots and the remainder of trees are skidded separately to the working platform;

IV. Trees extracted by cable and winch with a loader-skidder and whole trees carried from the felling site;

V. Trees extracted by being pushed over with a bulldozer blade attached to a TD-80 crawler tractor, and stump-root systems removed from the ground with a bulldozer blade.

TABLE 30

Productivity of Extraction and Preliminary Processing of Complete Pine Trees

Characteristic	Process method studied				
	I	II	III	IV	V
Time spent in tree extraction (minutes per cubic meter)	2.5	2.5	3.5	4.2	0.9
Time required for skidding a distance of 100 meters (minutes per cubic meter)	6.7	9.6	18.5	6.6	5.0
Total time spent in extraction and skidding (minutes per cubic meter)	9.2	12.2	22.0	10.8	5.9
Average load per trip (cubic meters)	1.37	1.37	1.95	2.02	3.07
Estimate of productivity per machine-shift (cubic meters of clean wood):	50.0	38.0	21.0	43.0	78.0
Bole	41.0	31.0	17.0	35.0	64.0
Roots	9.0	7.0	4.0	8.0	14.0

Notes: Two-man crew operating in all cases

The average volume of the full bole is given as 0.6 to 0.8 cubic meters.

As shown in Table 30, the most efficient method of whole tree extraction was found to be the use of a bulldozer blade on a crawler tractor, pushing trees over with the blade and use of the blade or special prongs to tease out the stump-root systems.

Cleaning Stump-Root Systems

Cleaning roots will be one of the more serious problems in practical complete-tree logging and utilization, particularly for pulp use. In a Finnish study (43), stump-root system in the extraction of *Pinus* sp.

from stony ground contained approximately 50% of the total weight in earth, sand and stones. In a study of five methods of cleaning stump-root systems of *Pinus* sp., the times in Table 31 were found.

TABLE 31

Cleaning Stump-Root Systems in Complete-Tree Utilization

Reference: 40

Method	Time required to clean one root-stump system
By Hard Impact:	
with or without bole attached; component raised to 2-4 meters and dropped 3-8 times on to a hard surface	1.1-1.6 minutes, bole removed
Hydraulic:	
roots (bole separated) subjected to a water jet at 6 atmospheres pressure	2-7.6 minutes
Air Jet:	
roots (separated from bole) blasted with air at 7 atmospheres pressure	20-60 minutes
Vibration Shock:	
vibration hammer CM-3010, force of 3 tons. Full trees[a], in both frozen and unfrozen conditions, used on trees up to 40 cm. diameter.	0.05-0.28 minutes

[a] This method is used successfully under both summer and winter conditions and on trees up to 40 cm. diameter.

It is apparent from the data in Table 31 that the vibration-hammer method is many times more efficient than any of the other methods tried in cleaning stump-root systems. The problem of cleaning stump-root systems can be reduced appreciably by the use of vibration during extraction (3); in addition to removal of debris around the roots, the power requirements in extraction are reduced by approximately one third.

Skidding and Loading

Only limited studies have been made on skidding complete trees, compared with studies on tree-length skidding and loading but, in general, it was found in one study that conventional skidding equipment could be used, with some increase in hazard (40). No particular difficulty was encountered with the unloading and loading of complete trees, compared with tree-length logs, although with some equipment the productivity was reduced.

This is an area in which further study and research and development and field trials are required.

Transportation

Because of the bulk factor of the complete tree roots (which cannot be left to hang over the back of a logging truck), as is the case in tree-length logging, the capacity of a haul will be substantially reduced (to 1/2 or 1/3 of normal load) where conventional logging trucks are used. The problem is mainly one of properly designing logging trucks for complete-tree transport, and considerable research and development work is needed in this area. A number of problems will have to be solved in this area before complete-tree extraction, cleaning and transport can be reduced in cost to be competitive with conventional logging production, on a basis of unit weight of usable fiber delivered to the point of use. Where fiber is in short supply substantially increased costs could be borne, since the additional cost of added fiber would be equated in part against the profit on products produced and not on wood costs alone.

A number of problems will have to be solved. These problems include:

- The type of truck design best suited to complete-tree hauling;
- Cleaning stump-root systems at or close to felling sites, so that the dirt, stones and debris do not have to be hauled;
- Road design and construction which will permit complete-tree (or tree-length) hauling.

In a study of the economics of complete-tree utilization, it was found that, with the use of conventional equipment, the cost of logging complete trees was less than the cost of tree-length logging (40). However, the delivered cost of usable fiber to the point of use (in this case, a railroad siding), was approximately 25% higher for complete-tree logging than for tree-length logging, the higher cost in the former case being due to the substantially higher hauling costs.

Removal of Roots from Stumps

In one study (40), the most efficient method of removing roots from stump cores was found to be by means of a pneumatic drill equipped with a chisel. Production rate was 4.5 cubic meters per man shift. Presumably this cost could be very substantially reduced by the development of in-line equipment for removing roots. Considerable research and development is required in this area.

Barking

Documentation of problems encountered in attempting to debark roots and stumps has not been included in the present review; most of the reports on tree-component pulping studied make some reference (43) to the difficulty of removing bark, particularly from stumps. Bark inclusion is likely to be high in roots and, to the extent that this is true, it may be necessary in pulping chips from stumps to develop more efficient methods for separating bark and chips. Because of the wide variation in stump geometry, particularly of the below-ground part, it may be necessary to develop several methods of barking, chipping and bark-chip separation, or to use the stump-root system in the manufacture of types of products where contamination is least damaging to quality, as in the manufacture of corrugating medium.

Chipping

Most reports of studies on attempted processing and utilization of stump-root systems refer to difficulty in chipping (43) or to the poor quality of chips obtained by the use of conventional chippers (42)[n]. Where chips for pulping are prepared from stumps, the problem is two fold. Because of the geometry of tree stumps, they tend to bounce around in a conventional chipper spout and, like short blocks, give a low percentage of acceptable chips compared with the percentage of acceptable chips from comparable boles. The percentage of over-sized chips is high and, if these are sent to a re-chipper, the percentage of fine material becomes excessively high. In addition, conventional chippers are designed to remove chips at a specific angle to the wood grain and, where the wood grain is approximately parallel to the walls of a chipper spout, acceptable chips are obtained with a maximum retention of fiber length. In the case of stumps, however, and particularly in below-ground components, fiber orientation can be at every possible angle with respect to the original bole direction.. Consequently, many of the chips are cut at right angles to the grain, and chip length is, say, 1/8 inch rather than the desired 3/4 inch. The strength of pulp from these chips will be 30-40% lower than the strength from a chip 3/4 inch in grain length.

The best means of comminuting stumps for pulping found to date has been use of a hog or crusher (42) which simply breaks stumps into variable-sized chunks. This method of wood subdivision is far from satisfactory, since it means an appreciable loss of the strength inherent in stump fibers.

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[n] Some of the apparently inconsistent results reported in the literature for the quality of pulp from stump wood may be due to poor chip quality rather than to the inherent pulping potential of the raw material. Consequently, it is considered desirable to use hand-cut chips in all pulping studies on tree components, particularly stump-root systems.

Considerable research and development will have to be done in both barking and chipping of stumps and roots in order to realize the yeild and strength inherent in the raw material for pulp production. An entirely new principle of removing bark and of subdividing stumps is required[o].

Summary

An assessment of studies made on the extraction and processing of complete trees for pulping would indicate that the following procedures offer the greatest promise in terms of low cost and high efficiency:

Extraction of Trees from the Ground

The trees are pushed over with a protected bulldozer blade or pusher bar, the pressure being applied approximately three feet above ground level. A felled tree is then removed from the ground by means of vibrating root prongs on bulldozer blade or pusher bar.

Cleaning Stump-Root Systems

Stump-root systems are freed of rocks, sand and earth with an impact or vibration hammer, either at the felling site or after skidding complete trees to an upper landing.

Complete-Tree Transport

No satisfactory equipment has been developed for transport of complete trees. In the use of conventional logging trucks to transport complete trees, the load was decreased by approximately 50% (40) compared with transport of tree-length logs.

Separation of Tree Components

Separation of complete trees will ultimately involve a series of processing steps, which would include:

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[o] One possibility for comminuting stumps might be to soak stumps in cooking liquor until they are sufficiently soft to separate readily into pieces small enough to feed to a digester. Another possibility would be to develop a process for cooking stumps without subdivision.

- Separation of stump-root systems from boles by means of saws;
- Delimbing above-ground parts of trees, as with an iris-type, in-line delimber;
- Separation of foliage from branches;
- Removal of roots from stump-root systems. Thus far the most effective means of doing this has been found to be with a vibration chisel (40).

Debarking

Processing equipment will have to be developed for removal of bark from stumps. Roots can be debarked in a Cambio-type barker, but there is no operating experience for so doing. Use of roots in conventional pulping processes will require considerable research and development work.

Chipping

There is no satisfactory method for chipping stumps other than present use of a hog. New principles and processing equipment will have to be developed before the full potential of stumps as a raw material for pulp manufacture can be realized. Large roots can probably be chipped in a conventional chipper, but new types of chippers will have to be developed for small-diameter material.

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

Full tree bole - the trunk or bole or 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[p], 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

[p] 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 the 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.

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.

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). This 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 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.

Branches less than 1 inch in diameter - not suitable for pulping[q].

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[q].

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

Bark.

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

CHECK LIST OF SPECIES CITED BY TABLE AND PAGE

BIBLIOGRAPHY

1. Alestalo, Aaro and Yrjo Hentola. 1966. [Sulphate pulp from unbarked softwood tops, branches and stumps; in Finnish] *Paperi ja Puu* 48(12):737-742. Can. Dep. Forest. Rural Develop. Transl. ODF TR 136.

2. Arend, A.G. 1964. Initial recovery of essential oils from pine wood chips. *Perfum. Essent. Oil Rec.* 55(3):180-183.

3. Baskerville, G.L. 1965. Estimation of dry weight of tree components and total standing crop in conifer stands. *Ecol.* 46(6):867-869.

4. ________________ 1965. Dry-matter production in immature balsam fir stands. Forest Sci. Monogr. No. 9. 42 p.

5. ________________ 1966. Dry-matter production in immature balsam fir stands: roots, lesser vegetation, and total stand. *Forest Sci.* 12:49-53.

6. Bazilevic, N.I. and L.E. Rodin. 1966. The biological cycle of nitrogen ash elements in plant communities of the tropical and subtropical zones. *Forest. Abstr.* 27(3):368.

7. Bray, J.R. and E. Gorham. 1963. Litter production in forests of the world. *Adv. Ecol. Res.* 2:101-57.

8. *Bull. Imp. Inst.* 1926. Waste kauri wood as a source of paper pulp and resin. 24(4):654.

9. *Can. Pulp Pap. Ind.* 1967. Think of forest as a system like farm crops. 20(9):42-44.

10. Czereyski, K. 1962. [Report on the test on determining factors affecting the selection of the stump wood splitting site in view of using transportation facilities; in Polish] Res. Inst., Warsaw. Mineo.

11. _____________ 1963. Report on rationalization of stump extraction tests carried out in Poland on harvesting stump wood with the Kreutzinger-Matusz method of tree uprooting. FAO LOG/WP.2/Conf. Room Doc. 4-1963, Geneva.

12. _____________ Galinska, I., and Robel, H. 1965. Rationalization of stump extraction. Joint Committee on Forest Working Techniques and Training of Forest Workers. FAO/ECE/LOG/158.

13. Demin, K.A., Vasjukov, V.A. and Kuznetsova, A.I. 1968. Mehanizirovannaja zagotovka pnevogo osmola; [The mechanized processing of stump rosin-forestry; in Russian] *Lesnaya Prom.* 5:5-6.

14. Doyle, J.A. 1954. Logging waste in eastern Canada. Can. Dep. Northern Affairs Nat. Resources, Forest Br. Bull. No. 715 Ottawa, 24 p.

15. Dyer, Richard F. 1967. Fresh and dry weight, nutrient elements and pulping characteristics of northern white cedar *Thuja occidentalis*. Maine Agr. Exp. Sta. Tech. Bull. 27, Orono. 40 p.

16. _______________, Andrew J. Chase and Harold E. Young. 1968. Pulp from presently non-commercial woody perennials. *Pulp pap. Mag. Can.* 69(1):57-62.

17. Eis, S. 1970. Root growth relationships of juvenile white spruce, alpine fir and lodgepole pine on three soils in the interior of British Columbia, Dep. Fish. Forest., Can. Forest. Serv., Pub. No. 1276.

Also April 11, 1968. Communication to author on dbh measures and data on western red cedar and western hemlock.

17a. Eskilsson, Staffan. 1969. Fiber properties in the spruce root system. *Cellulose Chem. Tech.* 3(4):409-416.

18. F.A.O. 1968. Mechanical stump extractor. *Forest. Equip. Notes* B. 33.62.

19. Forman, William O. Apparatus for producing and debarking wood chips. U.S. pat. 2,825,371; March 4, 1958: Can. pat. 567,708; Dec. 23, 1958.

20. Gleaton, E.N. and L. Saydah. 1956. Fiber dimensions and papermaking properties of the various portions of a tree. *Tappi* 39(2):157A-158A.

21. Gurich, N.A. *et al.* 1961. [Pine stumpwood as a valuable raw material; Transl. from Russian] Can. Dep. Fish. Forest. Transl. OOFF TR 80, Ottawa. From *Bumazhn. Prom.* 1961(10):16.

23. Harper, J.L. 1967. A Darwinian Approach to Plant Ecology. *J. Ecol.* 55(2):247-270.

24. Hatiya, Kinji, Kyooji Doi and Reiji Kobayashi. 1965. Analysis of the growth in Japanese red pine (*Pinus densiflora*) stands -- A report on the matured plantation in Iwate Prefecture. Bull. Gov. Forest. Exp. Sta., Tokyo. 176:75-88.

25. Hippoliti, G. 1963. New implements for uprooting stumps in poplar stands. *Silviculture.*

26. Homann, J. 1953. Verarbeitung von Stockholz in der Faserplattenindustrie. [Stumpwood as raw material for fiberboard manufacture; in German] *Holz-Zbl.* 79(118):1265.

27. Jamer, Bruno and Hanna Komorowska. 1963. [The utilization of fresh pine stumpwood in the pulp and paper industry; in Polish, Eng. abstr.] *Przeglad Papier.* 19(8):241-245. (Pol.;eng.)

28. Jodai, Susumu. 1968. [Dry distillation of the roots of pine with nickel carbonate; in Japanese]. *Kogyo Kagaku Zasshi* 71(7):1111-1112.

29. Johnstone, W.D. 1968. Some observations of the biomass of lodgepole pine trees. Dep. Forest. R.D., Calgary, Alberta. 11 p. 8 fig. (Paper presented Mensuration Session, C.I.F. Annual Meeting, Sept. 26, 1968, St. John's, Newfoundland.)

30. Kaminskaya, R.M., Parshevnikova, E.N. and Filippov, B.S. 1965. Utilization of stumpwood in the manufacture of kraft pulp; in Russian. Khim. Pererabotka Drevesiny, Ref. Inform. no. 4:5-7.

31. Kaminski, E. 1961. Pine green stumpwood - a new raw material for pulp and rosin production. *Sylvan* 105:41-49.

32. Keays, J.L. 1971. Complete-Tree Utilization -- An Analysis of the Literature. Part I: Unmerchantable Top of Bole. Can. Dep. Fish. Forest., Forest Prod. Lab., Inform. Rep. VP-X-69, Vancouver, B.C. 98 p.

33. __________ 1971. Complete-Tree Utilization -- An Analysis of the Literature. Part II: Foliage. Can. Dep. Fish. Forest., Forest Prod. Lab., Inform. Rep. VP-X-70, Vancouver, B.C. 94 p.

34. __________ 1971. Complete-Tree Utilization -- An Analysis of the Literature. Part III: Branches. Can. Dep. Fish. Forest., Forest Prod. Lab., Inform. Rep. VP-X-71, Vancouver, B.C. 67 p.

35. __________ 1971. Complete-Tree Utilization -- An Analysis of the Literature. Part IV: Crown and Slash. Can. Dep. Fish. Forest., Forest Prod. Lab., Inform. Rep. VP-X-77, Vancouver, B.C. 75 p.

36. __________ and J.V. Hatton. 1970. Complete-tree utilization studies: the yield and quality of kraft pulp from the components of *Tsuga heterophylla*. *Tappi* 54(1):99-104.

37. Kellogg, R.M. and J.L. Keays. 1968. Weight distriubtions in western hemlock trees. *Bi-Mo. Res. Notes*, Can. Dep. Fish. Forest. 24(4):32-33.

38. Keniston, William W. 1964. Physical and chemical characteristics of pulp from various parts of the tree. Univ. Maine, M. Sc. thesis, Orono. 59 p.

39. Kennedy, R.W. and G.R.W. Nixon. 1955. Logging waste survey in Alberta, 1954 - final report. Can. Dep. Northern Aff. Nat. Resources, Forest Br., Forest Prod. Lab., Vancouver, B.C. 15 p.

40. Kishchenko, T.I. and others. 1962. [Whole tree logging; in Russian] *Lesnaya Prom.* 40(10):13-16.

41. Kochkin, M.A. 1955. Soils, forests and climates of the Crimean mountain district and their rational utilization; authors abstract of thesis, Univ. of Sinferopol. See bibliography of reference 6.

42. Kiovulehto, Pentti. 1966. [Crushed stumps as raw material for the pulp industry; transl. from Finnish] Metsat. Aikak. 83:163-165. 1966. Can. Dep. Fish. Forest. Transl. OOFF TR 39, Ottawa.

43. _____________ 1969. [The extraction of stumps and roots; in Finnish, English summary]. *Folia for.* Inst. For. Fenn. No.73. 12 p.

44. Komshilov, N.F., T.I. Kishchenko and L.V. Kyalina. 1963. Fresh pine stumpwood -- a promising raw material; translated from Russian by J.L. Keays. *Bumazh. Prom.* No.7:11-12.

45. Kress, Otto, and Robert H. Mosher. 1943. The pulping of extracted yellow pine chips. *Pap. Trade J.* 117(15):29-34.

46. Kurrle, Frederick L. 1963. Nitric acid digestion of logging residues of red spruce; pulp yield and physical properties. *Tappi* 46(4):267-272.

47. Lyamin, V.A. 1962. [The combined production of extraction rosin, turpentine and pinewood tar; in Russian] *Gidroliz. Lesokhim. Prom.* 15(3):15-17.

48. Matyuskina, A.P., *et al.* 1965. [Use of green resinous stumpwood in sulfate pulping; in Russian]. *In* G.D. Atamanchukov, Osmolozagotovki, Mater, Soveshch. Kompleks. Mekh. Osmolozagotovok, Petrozavodsk, USSR. p.91-100.

49. _______________ , Ageeva, M.I., and Skvortsova, L.B. 1966. [Sulphate pulp from the stump and roots of pine; in Russian] *Bumazh. Prom.* 41(12):10-11. (Transl. by J.L. Keays).

50. Mednikov, F.A. and R.A. Akomova. 1961. [Technical and economic data on processing of fresh stumpwood in the rosin extraction industry; in Russian] *Lesnoi Zhur.* 4(5):160-164.

51. _____________ and V.I. Zhernakova. 1964. [The application of the electro-hydraulic effect to the extraction of resinous substances from stumpwood and the production of wood flour; in Russian]. *Lesnoi Zh.* 7(4):143-146.

52. Ovington, J.D. 1957. Dry-matter production by *Pinus sylvestris L. Ann. Bot. Lond. N.S.* 21(82):287-314.

53. _____________ 1962. Quantitative ecology and the woodland ecosystem concept. *Advances Ecol. Res.* 1:103-192.

54. _____________ 1965. Organic production; turnover and mineral cycling in woodlands. *Biol. Rev.* 40(3):295-336.

55. _____________ and H.A.I. Madgwick. 1959. The growth and composition of natural stands of birch. 1. Dry-matter production. *Plant Soil* 10(3):271-283.

56. *Paper* 1921 Making pulp from pine stumps and logging refuse. 29:11-13.

57. *Paper Trade J.* 1924. Making paper from stumpwood. 8(15):299, 303.

58. Remezov, N.P. 1961. [Summary of studies of interactions of oak forest and soil; in Russian]. Trudy voronezh. gos. Zapov.

59. Rennie, Peter J. 1955. The uptake of nutrients by mature forest growth. *Plant Soil* 7(1):49-95.

60. ________________ 1966. A forest-sampling procedure for nutrient-uptake studies. *Commonw. Forest. Rev.* 45(2) No. 124:119-128.

61. Rodin, L.E., and Bazilevich (Bazilevic), N.I. 1967. Production and mineral cycling in terrestial vegetation. Oliver and Boyd, Edinburgh. 288 p.

62. Rozanova, I.M. 1960. [Circulation of mineral elements and variation in physiochemical features of leached chernozems under coniferous and broad-leaved plantations; in Russian]. Trudy vost.-sib. Fil. Akad. Nauk SSSR, 35.

63. Rutherford, R.W. and K. Ruschin. 1949. The production of ammonia synthesis gas from wood fuel in India. *Trans. Inst. Chem. Eng.* (Brit.) 27:169-181.

64. Setsko, L.S. 1960. [The supply of resinous stumpwood; in Russian]. *Gidroliz Lesokhim. Prom.* 13(3):16-17.

65. Skolnik, Herman, Enos, H.I., and Gardiner, Frank, H. Jr. 1968. The Literature of Wood Naval Stores, p. 349 to 361. *In* Literature of Chemical Technology. (Advances in chemistry series no. 78). Washington, D.C., American Chemical Society.

66. Sproull, R.C., R.B. Parker and W.L. Belvin. 1957. Whole tree harvesting. *Forest Prod. J.* 7(4):131-134.

67. Strizhak, L.N. 1961. [The preparation and processing of fresh stumpwood; in Russian]. Perspektivy Uvelichaniya Ob'ema Dobychi Zhivitsy v Ukr. S.S.R., Sbornik, Kiev, 1960. p. 117-119.

68. Sukachev, V., and N. Dylis. [Undated]. [Fundamentals of forest biogeocoenology; Transl. from Russian; Osnovy lesnoi biogeotsenoligii, "Nauka" Publishing Office, Moscow, 1964]. Oliver & Boyd Ltd., Edinburgh and London. 672 p.

69. Tadaki, Yoshiya and Yoshinori Kawasaki. 1966. Studies on the production structure of forest. IX. Primary Productivity of a Young *Cryptomeria* Plantation with Excessively High Stand Density. *J. Jap. For. Soc.* 48(2):55-61.

70. Tadaki, Yoshiya, Kinji Hatiya, and Hiroshi Miyauchi. 1967. Studies on the production structure of forest XII. Primary productivity of *Abies veitchii* in the natural forests at Mt. Fuji. *J. Jap. Forest Soc.* 49(12):421-428.

71. Tomcuk, R.I. and G.N. Tomcuk. 1966. [Tree foliage and its utilization; in Russian]. Izdatel stvo "Lesnaya Promyslennost", 241 p.

72. Wesner, Adam L. 1962. Method of separating wood chips from bark chips. U.S. Pat. 3,032,188 May 1, 1962.

73. Will, G.M. 1966. Root growth and dry-matter production in a high-producing stand of *Pinus radiata*. *New Zeal. Forest. Res. Notes No.* 44. 15 p.

74. Young, Harold E. and Paul M. Carpenter. 1967. Weight, nutrient element and productivity studies of seedlings and saplings of eight tree species in natural ecosystems. Orono, Maine Agr. Exp. Sta., Tech. Bull. 28, Orono 39 p.

75. ______________ and Andrew J. Chase. 1965. Fiber weight and pulping characteristics of the logging residue of seven tree species in Maine Univ. Maine, Maine Agr. Exp. Sta. Tech. Bull. 17. 44 p.

76. ______________ and others. 1966. Pulping hardwoods? Try sulfate process on branches, roots. *Pulp Pap.* 40(27):29-31.

77. ______________, Gammon, Calvin B., and Ashley, Marshall. 1964. Potential fiber from balsam fir, white pine, hemlock, white birch, and aspen logging residues. *Tappi* 47(9):555-557.

78. ______________ ,______________, and Hoar, Leigh E. 1963. Potential fiber from red spruce and red maple logging residues. *Tappi* 46(4):256-259.

79. ______________, Leigh Hoar, and Marshall Ashley. 1965. Weight of wood substance for components of seven tree species. *Tappi* 48(8):466-469.

80. ______________, Lars Strand and Russell Altenberger. 1964. Preliminary fresh and dry weight tables for seven tree species in Maine. Maine Agr. Ex. Sta., Tech. Bull. 12, 76 p. Orono.

81. Zima, I.M. and V.S. Kurilo. 1962. [Felling of trees with the roots at the Boyar experimental forest range; in Russian]. *Lesnoe Khoz.* 15(1):26-28.

SUPPLEMENTARY BIBLIOGRAPHY

Papers prepared for the XVth IUFRO Congress, held March 15 to 20, 1971, at the University of Florida at Gainesville, have been published in Forest Biomass Studies[h], Life Science and Agriculture Experiment Station, University of Maine at Orono as University Press Miscellaneous Publication 132, January, 1971, in 205 pages. This publication appeared after the last of the present series was in press; that is, too late to incorporate into the present analysis. However, the following supplementary bibliography lists the papers given in Forest Biomass Studies. A number of these are highly germane to the complete-tree utilization concept.

Art, H.W., and P.L. Marks. A summary Table of Biomass and Net Annual Primary Production in Forest Ecosystems of the World. Williamstown, Massachusetts, and Ithaca, New York.

Crow, T.R. Estimation of Biomass in an Even-Aged Stand -- Regression and "Mean Tree" Techniques. St. Paul, Minnesota.

Hakkila, P. Branches, Stumps and Roots as a Future Raw Material Source in Finland. Helsinki, Finland.

Honer, T.G. Weight Relationships in Open- and Forest-Grown Balsam Fir Trees. Ottawa, Ontario.

Johnstone, W.D. Total Standing Crop and Tree Component Distributions in Three Stands of 100-Year-Old Lodgepole Pine. Edmonton, Alberta.

Madgwick, H.A.I. The Accuracy and Precision of Estimates of the Dry Matter in Stems, Branches and Foliage in an Old-Field *Pinus virginiana* Stand. Blacksburg, Virginia.

Olson, D.F. Jr. Sampling Leaf Biomass in Even-Aged Stands of Yellow-Poplar (*Liriodendron tulipifera* L.). Asheville, North Carolina.

Schreuder, H.T. and W.T. Swank. A comparison of Several Statistical Models in Forest Biomass and Surface Area Estimation. Research Triangle Park, North Carolina and Franklin, North Carolina.

Smith, J.H.G. Bases for Sampling and Simulation in Studies of Tree and Stand Weights. Vancouver, British Columbia.

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[h] The publication resulted from the efforts of Harold E. Young, Chairman, Working Group on Forest Biomass, International Union of Forest Research Organizations.

Steinbeck, K. and J.T. May. Productivity of Very Young *Platanus occidentalis* L. Plantings Grown at Various Spacings. Athens, Georgia.

White, E.H., W.L. Pritchett and W.K. Robertson. Slash Pine Root Biomass and Nutrient Concentrations. Stoneville, Mississippi, Gainesville, Florida and Gainesville, Florida.

Young, H.E. Biomass Sampling Methods for Puckerbrush Stands. Orono, Maine.

Zavitkovski, J. Dry Weight and Leaf Area of Aspen Trees in Northern Wisconsin. Rhinelander, Wisconsin.