1971

Complete-Tree Utilization An analysis of the Literature Part I: Unmerchantable Top of Bole

J. L. Keays

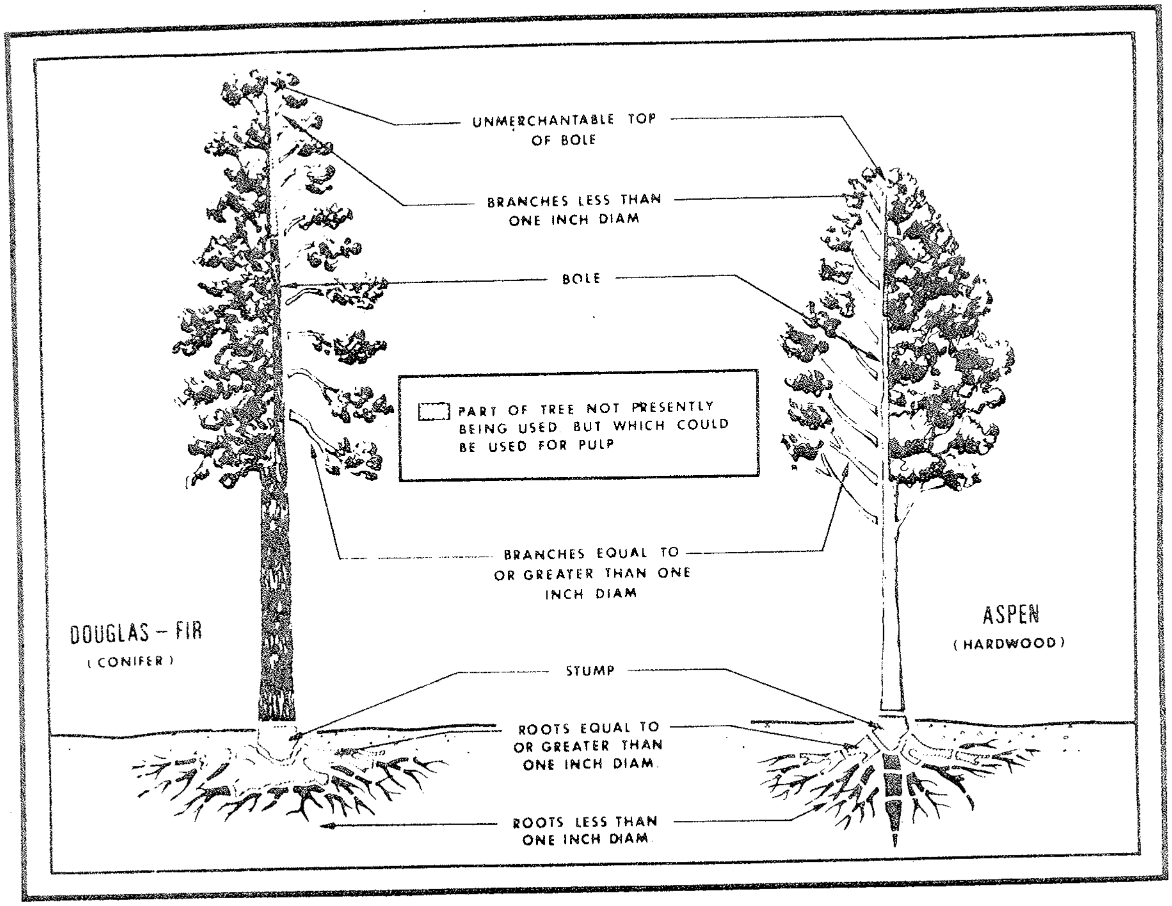
COMPLETE-TREE UTILIZATION
An Analysis of the Literature

PART I: Unmerchantable Top of Bole

BY
J. L. KEAYS

INFORMATION REPORT
VP-X-69

FOREST PRODUCTS LABORATORY
CANADIAN FORESTRY SERVICE
DEPARTMENT OF FISHERIES AND FORESTRY
VANCOUVER, BRITISH COLUMBIA
FEBRUARY, 1971.



COMPLETE-TREE UTILIZATION

An Analysis of the Literature

PART I: Unmerchantable Top of Bole

By

J. L. Keays

Information Report VP-X-69

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

OUTLINE AND CONTENTS

LIST OF TABLES

List of Tables (continued)

RESUMÉ

The present report is an analytical review of the literature dealing with the biomass and pulping characteristics of unmerchantable tops of boles. Literature values for biomass have been brought together on a comparable basis wherever possible. It is recommended that tree-component biomass be reported on what has been designated as "standard basis"; that is, the component as a percentage by weight of full tree boles on a bark-free and oven-dry basis for each component.

Because biomass data are often incomplete or unavailable, the present review should be considered as a preliminary one intending to serve only as a general guide in planning or feasibility studies and in future research studies.

The additional amount of wood, as a percentage of full boles, which might be recovered by the utilization of unmerchantable tops of boles is a function of many factors, including: wood species; dbh; tree height at a given dbh; top diameter of the merchantable bole and stump height.

For an average dbh of 8 inches and a top diameter of 4 inches, the percentage tops on a standard basis will lie between 6 and 10% for most Canadian pulpwood species of *Pinus*, *Picea*, *Abies*, *Tsuga*, *Acer*, *Betula*, and *Populus*. For an average dbh of 12 inches and a top diameter of 6 inches, the percentage tops on a standard basis will lie between 10 and 15% for the same genera. Insufficient data are available on the percentage bark, percentage moisture and specific gravity of both bole and unmerchantable top to make it possible to convert percentage tops on one basis to another basis. For most, if not all, Canadian wood species, insufficient data are available on top biomass to permit detailed engineering studies on their handling and use, and detailed field measurements would be required.

Data on the quality and yield of pulp from unmerchantable tops of boles are sparse and inconclusive or contradictory. In general, kraft pulps from the tops of coniferous species, compared with kraft pulps from the bole, would be 1 to 3% lower in yield (wood basis), 10 to 20% lower in tear, equal to or slightly lower in breaking length and burst factor, with somewhat faster beating time. For example, using the above figures, the yield and tear strength of kraft pulps from bole plus unmerchantable top, as a percentage of bole, would vary between 99.2 to 99.9% and 97.3 to 99.1%, respectively. The same general trends would be true of sulfite pulps, but the differences would be expected to be greater. In the case of pulp from deciduous trees, the differences would be somewhat less; the pulp yield, for example, might be slightly higher than from boles, provided the trees were more than say 10 years of age.

In immediate and practical terms, the analysis indicates that the utilization of what is now termed the "unmerchantable tops of boles" as a source of raw material for pulp manufacture should not be considered in terms of pulp yield, pulp quality, or mill operations, since the effect on these will be negligible, but in terms of economics -- will the use of tops give more wood at lower cost?

COMPLETE-TREE UTILIZATION - An Analysis of the Literature

Part I: Unmerchantable Top of Bole

by J.L. Keays

BACKGROUND

The present report is part of a general review of the potential use of tree components other than boles -- the unmerchantable tops, branches, roots, stumps, foliage and bark, for conversion primarily to fiber. The principal interest in complete-tree utilization is to obtain more usable fiber per unit area of forest land at a cost competitive with alternative sources of fiber[a].

The critical questions which relate to the possible use of various tree components for fiber production, for a given wood species growing in a given area of interest, are:

1. How much of each component is available?
2. What quality of pulp or other product does each component produce by whatever process is of particular interest in the area concerned?
3. How would each of the various components be extracted, transported and processed?
4. What is the effect of complete-tree utilization on the forest, on silvicultural practice, on forest regeneration, on the total ecology?

Only the first two questions above are considered in detail in the present general review. Most of the technical literature references analyzed

---

(a) As commented by Ovington (201), the use of more of each tree "....more than any other single step, would raise the level of production substantially".

relate to component biomass;[(b)] a few papers relate to the quality of products obtained from various tree components, or to chemical composition and fiber morphology, which may have a direct or indirect bearing on the quality of products which can be obtained. Only limited data are available on the processing of tree components, and technical literature concerning the short- or long-range effect of complete-tree utilization on silviculture and total environment are almost non-existent.

The whole question of complete-tree utilization today stands in much the same position as the automotive industry stood 50 years ago: the potential is high[(c)], the ramifications are many and complex, and a large number of unknown variables will affect future development. Complete-tree utilization will involve a highly complex network of variables relating to forest management, rotation cycle, soil erosion, decreasing incidence of

---

(b) A large number of studies have been made on total forest biomass (Russian *phytomass*) and nutrient balance. Only a few of these have been included, since in most cases the data given do not include component biomass. Much of this material has been reviewed by L. Rodin and N.I. Basilevich in Production and Mineral Cycling in Terrestial Vegetation, Oliver and Boyd, Edinburgh, 1967, and by V. Sukachev and N. Dylis in Fundamentals of Forest Biogeocoenology, Oliver and Boyd, Edinburgh and London, translated from Osnovy lesnoi biogeotsenologii, published in 1964 by "Nauka" Publishing Office, Moscow.

(c) By the year 2000 and beyond, the potential value of products derived from application of the complete-tree utilization concept, at a world consumption of paper and paperboard exceeding 400 million metric tons (141,223) per year, would be multiple billions of dollars. At least two sets of criteria can be used in estimating the potential:

- on a basis of 50% of potential wood recovery by complete-tree utilization, recovery would be 700 million cubic meters of wood, worth say 20 dollars per cubic meter, or 14 billion dollars;

- on a basis of the value of fiber products, and assuming 30% of 400 million metric tons of fiber recovered by complete-tree utilization, the pulp produced from this would be 120 million metric tons, worth 24 billion dollars at a selling price of 200 dollars per metric ton of pulp.

decay, method of tree harvesting, methods of reforestation and complete-tree transport, and the development of methods for barking, chipping and pulping of components. It is the primary purpose of the present study to review the technical literature relating to how much material is available from various tree components and, in general terms, the quality of pulp likely to be obtained from these components as a function of wood species for the various pulping processes.

NOMENCLATURE

General

It is important that a uniform and consistent nomenclature (28, 88, 89, 152, 224) 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 trees above the stumps) where full-bole logging is intended. In the present review the following nomenclature has, in general, been used:

Complete tree -- includes all component parts, as twigs, top, leaves, needles, cones, branches, roots, stump, bole and bark;

Tree length -- complete tree minus stump and roots, but including leaves or needles, branches, fruit or cones and top;

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

Long-length logs -- boles from stumps to bottoms of unmerchantable tops of boles, or to some length appreciably greater than has been standard practice.

Tree Components

Any classification of tree components must be to a considerable

extent arbiti

extent arbitrary[(d)], since they may be difficult or impossible to define. The unmerchantable top of a bole is that part of a tree defined by the top diameter to which a bole is cut for agiven 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 (138).

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

(d) 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 in diameter. From a practical point of view, this is a realistic classification, since the amount of chemicals extractable or derivable from twigs up to 0.6 mm in diameter is sufficiently high to warrant processing (222, 258), but it does pose a problem in comparing these data with other data in which foliage is differently defined.

problems in barking, chipping and handling.

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

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

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

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

Stump: from the bottom of a tree's merchantable bole to those sections where the roots can be removed conveniently.

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

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

Bark.

TREE COMPONENT BIOMASS

The technical literature dealing directly with complete-tree utilization as a total concept is limited, and much of it relates to the work of Professor Harold E. Young (287 to 309) of the University of Maine, who has been a pioneer in this field. Other literature relating to complete-tree utilization has been based on the need to increase resources of fiber raw material in areas which are short of fiber (Poland, France, Spain), or in areas where a shortage of fiber is anticipated in the near future (Finland and part of the United States), or as a part of a massive, long-range program

(e) 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.

to develop fully integrated forest-products industrial complexes (the U.S.S.R.). The technical literature dealing indirectly with various aspects of complete-tree utilization, that is, relating to tree components, their biomass and growth characteristics, or to wood or fiber characteristics which might have a bearing on complete-tree utilization, is vast[f] and could not be encompassed readily within a single review. Thus, the present study is a compromise between the two extremes -- the limited amount of literature dealing directly with complete-tree utilization, and the vast amount relating to the relative amounts of tree components, to their properties, composition, functions and use.

Since most of the studies under review have been carried out for a variety of purposes [g] and in many countries, there is no consistency in the type of data obtained or in the methods of reporting. The amount of wood components available for the various wood species studied has been reviewed in terms of:

Unmerchantable tops of boles;
Foliage;
Branches;
Crown and Slash;
Stumps and Roots.

(f) A number of studies have been carried out on the extraction of rosin or naval stores from stumps, on the chemical composition of extractives from thousands of trees and plant species, and on the chemical composition and possible uses for bark or other material derived from trees. This literature has not been, in general, included in the present review except insofar as it appeared to have a direct bearing on some aspect of the complete-tree utilization concept.

(g) Data have been obtained on tree or tree-component biomass in studies on complete-tree utilization, tree mechanics, nutrient uptake, logging mechanization, weight scaling, fire hazard, pulping, botany, ecology, and wood anatomy (238).

Wherever the term "standard basis" is used throughout the present text, it refers to a component (oven dry and bark free) as a percentage by weight of its full tree bole (oven dry and bark free). In a few cases, this has meant that some assumptions have had to be made, particularly with respect to bark on merchantable boles.

Literature data on the relative amounts of various tree components, with some exceptions, have been used as originally recorded; in some cases, interpolated data for specific values have been obtained from a plot of the original data in order to obtain values at comparable values of dbh. It would have been preferable to correct all data to the standard basis. However, moisture, percentage bark, and specific gravities are so highly variable within a component and between components, even for a given wood species, that only in the case of boles has it been considered reasonably safe to correct even for the percentage of bark.

The number of trees sampled is normally recorded when this information is available. The question of adequate sampling is not considered in the present review, but it is a serious and continuing problem. According to Madgewick (179), "Practically every biomass study is inadequate because of poor sampling" and "Results from inadequate sampling may be worse than no results at all."

It is basic to the development of the complete-tree utilization concept that, with but few exceptions, the bulk of complete trees or of components other than boles will be used for the manufacture of pulp, fiber-board, or composition board. For this reason, data obtained as part of biomass or tree component studies would be most logically recorded in those terms of greatest interest to the pulp and paper industry. If a given tree component is to be considered for the production of pulp, then one of the most critically important questionsis, how much pulp would it give in comparison to present operations, where only merchantable boles are used? For this reason, the keenest interest is likely to center on data for various tree components as a percentage of merchantable boles on an oven-dry, bark-free basis. In practical terms, this means that for a given mill which produces, say, 100,000 tons per year of kraft pulp, the values so derived would show directly how much additional fiber would be available from a given component. For example, if the oven-dry, bark-free unmerchantable tops of boles represents 5% of the weight of oven-dry, bark-free merchantable boles, then the use of unmerchantable tops would result in an increase in production of 5,000 tons per year at the same pulp yield from tops as from boles.

Although this may be the most practical basis to use at present, it is not considered to be the most satisfactory on a long-term basis. One reason for finally selecting full-length boles[h] as the basic unit lies in the fact that full boles are a fundamental characteristic of trees, whereas merchantable boles depend upon arbitrary and variable definition, depending as it does upon a particular choice of top diameter for merchantable boles. A second and equally important reason for choosing full boles as a basis arises from the high probability of increased full-bole, tree-length, and complete-tree logging; to the extent that this becomes established

---

(h) Standard basis values are readily converted to components as percentage by weight of the merchantable boles by prorating the standard basis value for the percentage unmerchantable tops.

practice, the present concept of merchantable bole will lose its meaning[(i)].

Ideally, complete information on the weight of tree components, regardless of the method of presenting the data, would include:

- All major tree characteristics, such as age, total height, crown height, site index, exposure, dominance, taper, etc.;
- A precise definition of each component; the bole, for example, would be defined on a basis of a stump 1 foot above ground level and a 3-inch top, inside bark;
- Something of a detailed description of growth conditions, climate, days of sunshine, rainfall, water table, soil types, etc.;
- Site and stand classification; density,
- Date on which sample was taken.

Because complete data are seldom available and because inclusion of all such data, if available, would make the present analysis too cumbersome, in most cases they are not given, except insofar as they have a direct bearing on component biomass or pulp quality. For this reason, the present review should be considered as a preliminary one intending to serve only as a general guide in planning or feasibility studies and in future research studies.

UNMERCHANTABLE TOP

BIOMASS

Introduction

Of all tree components other than the merchantable bole, that part of a tree which is most likely to be utilized first is the unmerchantable top of the bole. There are a number of reasons for this:

(i) Approximately one third of the logging in the Soviet Union, amounting to a total of approximately 400 million cubic meters per year, is presently full bole and this will double in the near future (139).

- Unmerchantable tops of boles could be brought to the mill in full-bole, full-tree, or complete-tree logging;
- Pulp produced from tops would be, in most cases, sufficiently close in yield and quality to comparable pulp from merchantable boles that it would have negligible effect on the yield and quality of mill-run pulp;
- The top of a tree, perhaps down to a 1-inch top diameter, could be processed in conventional mill equipment, such as barkers and chippers, and would not involve major changes in mill processing;
- In addition to supplying an increase of perhaps 3 to 8% of fiber to a mill, there could well be circumstances where overall costs of wood to a mill would be reduced by converting from conventional logging methods to full-bole logging, transport, and use.

The economics of transporting and processing the unmerchantable top would have to be analyzed for each species, region and local set of conditions.

Percentage Tops as a Function of DBH, Standard Basis

Table 1 gives unmerchantable tops of boles as a percentage by weight of full boles on a standard basis, i.e., both components oven dry and bark free. Where boles are cut to a fixed top diameter, the percentage of unmerchantable top decreases regularly with dbh, and becomes negligible for large-diameter trees. Conversely, as dbh decreases, the percentage of unmerchantable top below a given diameter increases rapidly, and measured values tend to be erratic for a dbh below, say, 6 inches for a 4-inch diameter top. The percentage unmerchantable top for a tree at 4 inches dbh cut to a 4-inch top would have little meaning.

The range of values for the wood species listed in Table 1 is large. At a dbh of 8 inches, for example, the percentage of unmerchantable top, leaving out the extremes, varies from 6 to 10% (standard basis).

Table 1

Unmerchantable Top of Bole as a Percentage by Weight of Full Bole and as a Function of DBH -- Standard Basis.

Reference	Wood species	No. trees sampled	Unmerchantable top as % of full bole[1]				
			Diameter breast height (inches)				
			6	8	10	12	14
309	*Abies balsamea*	23	15	10	6	4	2
305	*Picea rubens*	25	12	6	4	3	3
130	*Pinus contorta* var. *latifolia*[2]	22	17	8	4	2	1
309	*Pinus strobus*	27	13	8	5	3	2
78	*Thuja occidentalis*	21-36[3]	21	17	12	8	-
82	*Thuja plicata*	8	-	19	13	10	8
309	*Tsuga canadensis*	28	13	9	6	3	1
82	*Tsuga heterophylla*	8	15	11	6	3	-
302	*Acer rubrum*	20	18	9	5	4	4
309	*Betula papyrifera*	17	13	10	5	3	-
309	*Populus* sp.	14	12	9	6	3	-

1. Top = 4 inches diameter, unless otherwise stated.
   Stump = 6 inches above ground, unless otherwise stated.

2. Stump 12 inches above ground. Reducing the stump from 12 to 6 inches above ground would reduce the percentage of unmerchantable top (standard basis) by approximately .2%, i.e., from 10% to 9.8%.

3. Consists of two groups, 21 trees in the first group and 36 trees in the second.

Calculated values for the geometric relationship between the percentage top by volume, the dbh, and top diameter of merchantable bole are given in Table 2.

TABLE 2

Unmerchantable Top of Bole as a Percentage by Volume of Full Bole -- Calculated Values.[1]

Top diameter in inches	Unmerchantable top as a Volume Percentage of Full Bole[2]						
	Diameter breast height in inches						
	4	6	8	10	12	16	20
	Tree height in feet						
	35	45	50	60	70	85	100
2	11	3.5	1.5	0.8	0.5	0.2	0.1
3	36	9.0	5.0	2.4	1.4	0.5	0.4
4	-	25.0	11.0	6.0	3.3	1.2	1.0
5	-	50.0	21.0	11.0	7.0	2.3	1.9
6	-	-	37.0	19.0	12.0	4.0	3.0
7	-	-	60.0	30.0	18.0	6.0	5.0
8	-	-	-	46.0	30.0	9.0	8.0

1. This table can be compared with values calculated by T.G. Honer (314).

2. Calculated from the geometry of a symmetrical cone.
Assumptions: Stump -- 1 foot above ground level;
Breast height -- 4.5 feet above ground level;
Top -- 4 inches at the base to 0 inches at the tip.

As would be expected, the calculated volume percentage of tops decreases quite rapidly with increasing dbh at constant top diameter, and with decreasing top diameter at constant dbh. The calculated values shown in Table 2 cannot be used to predict accurately the percentage of unmerchantable top, but the table does give a convenient method for estimating approximately the additional fiber which might be recovered by reducing the diameter of unmerchantable top. In the case of trees at 16 inches dbh, for example, 2% additional fiber (standard basis) would be recovered by reducing top diameter from 7 to 6 inches.

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

Table 3 gives values for the top as a percent of the bole on a dry basis, but including bark on both bole and top. The data shown in Table 3 could be converted to the standard basis by correcting for bark content. A different conversion factor for bark content would probably have to be used for each dbh, except for those wood species for which the bark content of the bole is known to be independent of dbh. Data for the percentage bark on the unmerchantable top are limited (Tables 4 to 7). The problem of meaningful correction for bark is further complicated by the fact that the percentage bark on unmerchantable tops is a function of the definition of unmerchantable top. For most wood species for which data are available, the percentage bark is greater on tops than on merchantable boles (Table 4), so that the values shown in Table 3 are somewhat higher than the standard values. Table 5 shows the variation in percentage bark, along the bole, for *Pinus contorta* var. *latifolia;* in at least one case (8.0 inches dbh) the percentage bark is less on the top than on the merchantable bole, and in another case (11.0 inches dbh) it is more than 100% higher on the top than on the merchantable bole.

TABLE 3

Unmerchantable Top of Bole as a Percentage by Weight of Full Bole and as a Function of DBH.
Top -- oven-dry and bark on;
Bole -- oven-dry and bark-on basis.

Reference	Wood species	No. trees sampled	Unmerchantable top as a % of full bole[1]				
			Diameter breast height (inches)				
			6	8	10	12	14
149, 150	*Picea glauca*[2]	60	23	12	6	3	2
150	*Pinus contorta*[2] var. *latifolia*	101	15	6	3	2	-
187	*Pinus contorta* var. *latifolia*	405	16	10	-	-	-
131	*Pinus contorta* var. *latifolia*[3]	85	-	9	-	-	-
143	*Tsuga heterophylla*	3	-	23[4]	-	-	3[5]

1. Top = 4-inch diameter, unless otherwise specified;
Stump = 12 inches above ground.

2. Includes needles, shoots, needle-bearing twigs plus branches less than 0.5 inches diameter.

3. Mean diameter, 7 inches.

4. Dbh 8.5 inches and top diameter 6 inches.

5. Dbh 14.2 inches and top diameter 6 inches.

Values comparable to those shown in Table 3 can be calculated for the biomass data published by H. Young, since the standard values (Table 1) and percentage bark on bole and unmerchantable top (Table 5) are given.

TABLE 4

Percentage Bark on Unmerchantable Top and on Merchantable Bole.

Reference	Wood species	DBH (inches)	Bark as % of oven-dry, bark-free component	
			Bole	Unmerchantable top
302	*Abies balsamea*	8.2	7.3	8.0
302	*Picea rubens*	7.6	6.8	10.1
302	*Pinus strobus*	8.9	9.2	6.7
302	*Tsuga canadensis*	8.1	6.1	6.2
143	*Tsuga heterophylla*	18.0	8.7	17.7
		14.2	9.9	17.7
		8.5	11.1	31.6
302	*Acer rubrum*	7.6	8.1	9.7
302	*Betula papyrifera*	8.4	8.4	11.3
302	*Populus* sp.	7.7	10.2	14.3

TABLE 5

Percentage Bark by Weight as a Function of Height above Ground -- *Pinus contorta* var. *latifolia*: reference -- 130.

DBH (inches)	Percentage bark by weight, oven-dry basis[1]										
	Distance above ground in feet										
	1	4.5	9.0	17.0	25.0	33.0	41.0	49.0	57.0	65.0	68.0
4	8.6	9.3	9.2	10.8	10.8	13.6	-	-	-	-	-
5.9	9.6	8.1	8.0	8.6	16.0	15.2	14.6	21.5	-	-	-
6.4	9.5	6.3	6.3	5.6	6.6	6.1	11.2	12.2	-	-	-
6.7	10.1	7.4	7.8	7.3	7.5	11.5	10.3	13.7	-	-	-
7.3	10.8	8.3	8.1	8.7	7.7	6.8	17.4	12.7	-	-	-
8.0	11.5	6.8	5.6	8.7	13.4	6.4	4.9	10.8	-	-	-
8.1	5.8	4.8	4.7	5.11	6.0	6.6	9.2	9.2	15.6	-	-
8.1	7.7	6.5	6.8	6.5	6.4	7.2	8.1	11.9	15.3	-	-
8.1	16.8	6.6	7.2	6.6	7.1	7.6	9.3	12.3	-	-	-
8.4	16.8	5.5	6.0	6.2	6.3	6.7	9.0	8.3	12.6	-	-
8.8	5.9	5.4	5.9	6.1	14.5	6.9	9.2	10.7	12.3	-	-
9.0	6.9	7.2	7.1	6.8	8.7	8.2	8.6	14.6	15.1	-	-
9.3	8.4	8.4	7.6	7.3	7.3	7.1	9.8	11.9	13.8	-	-
9.6	8.1	5.5	4.6	4.6	5.8	4.95	8.8	9.1	10.8	10.4	-
9.9	12.7	7.4	7.0	6.1	6.7	6.95	8.0	11.2	14.2	-	-
10.0	7.7	7.8	8.0	7.5	7.7	10.7	9.9	8.95	12.2	-	-
10.3	10.3	4.3	4.2	4.8	5.0	5.6	5.8	8.0	11.9	-	-
10.4	6.5	7.1	6.3	5.7	5.8	6.7	7.4	9.2	12.5	-	-
11.0	15.4	5.4	5.1	4.3	5.7	6.2	7.3	7.6	10.4	18.9	-
12.8	8.3	7.1	4.8	5.9	5.4	6.8	6.2	8.9	8.1	9.8	12.2
13.4	13.6	9.2	4.2	8.1	5.4	5.8	7.2	9.5	10.9	14.7	-

1. $\text{Percentage bark} = \frac{\text{Wt. of o.d. bark in g.}}{\text{Wt. of o.d. wood in g.}} \times (100)$

TABLE 6

Percentage Bark by Weight and Percentage Moisture in Bark and Bole as a Function of Distance above Ground -- *Tsuga heterophylla*: Reference -- 143.

DBH (inches)	Distance above ground in feet: 1	6	16	26	36	46	56	66	76	86	88.5	96	97.25	106.0
	Percentage bark by weight, oven-dry basis													
8.5	6.6	8.0	13.5	14.9	12.8	16.2	15.8	23.6	-	-	-	-	-	-
14.2	8.5	8.4	9.3	9.1	11.1	8.4	14.8	13.5	15.8	17.9	-	16.1	-	24.1
18.0	-	7.2	6.6	6.0	8.7	11.1	11.4	11.2	13.7	17.8	10.8	-	3.8	25.3
	Percentage moisture in bole[1]													
8.5	48	30	44	47	50	49	47	57	-	-	-	-	-	-
14.2	45	44	48	52	53	53	60	60	60	61	-	53	-	58
18.0	-	54	53	54	55	58	59	60	61	61	60	-	56	53
	Percent moisture in bark[1]													
8.5	53	50	50	51	51	49	59	63	-	-	-	-	-	-
14.2	46	43	44	45	43	45	44	47	46	48	-	49	-	58
18.0	-	48	54	50	50	48	47	47	50	53	73	-	57	62

1.

$$\text{Percentage Moisture} = \left(\frac{\text{Fresh weight} - \text{dry weight}}{\text{Dry weight}}\right) \times 100.$$

TABLE 7

Bark Content in Percentage by Volume as a Function of DBH.
Reference, 160.

	Percentage bark by volume									
	Diameter breast height in inches									
Wood Species	4.95	1.97	1.73	1.58	1.18	0.84	0.78	0.56	0.39	0.29
Populus tremula	10.6	-	22.1	-	-	32.5	-	45.7	50.9	58.1
Carpinus sp.	-	18	-	19	23	-	29	-	41	-
Fagus sp.	-	18	-	18	20	-	30	-	31	-

<u>Percentage Tops as a Function of DBH, Green and Bark-on Basis</u>.

Table 8 gives the unmerchantable top of bole as a percentage by weight of full bole, both components green and with bark on. Since the tops, compared with the bole, generally have a higher bark content (Tables 4 to 7) and a higher moisture content (Table 9 and 10), tops as a percentage of bole on a green basis would tend to be somewhat higher than the values obtained on a standard basis.

TABLE 8

Unmerchantable Top of Bole as a Percentage by Weight of Full Bole and as a Function of DBH.
Top -- green and bark on;
Bole -- green and bark on.

Reference	Wood Species	No. trees sampled	Unmerchantable top as % full bole: Diameter breast height (inches) 6	8	10	12	14
306	*Abies balsamea*[1]	23	18	8	4	3	-
-	*Picea* sp.[2, 3]	14	45	26	14	8	5
305	*Picea rubens*[1]	25	14	7	4	4	3
-	*Pinus contorta*[3, 4] var. *latifolia*	-	10	5	2	2	1
-	*Pinus contorta*[2, 3] var. *latifolia*	-	54	21	9	6	6
-	*Pinus contorta*[2, 3] var. *latifolia*	-	51	23	9	5	4
309	*Pinus strobus*[1]	27	12	9	6	3	1
78	*Thuja occidentalis*[1]	21-36[5]	25	18	13	11	-
309	*Tsuga canadensis*[1]	28	12	10	6	4	1
302	*Acer rubrum*[1]	20	18	9	6	5	6
309	*Betula papyrifera*[1]	17	14	9	6	4	-
309	*Populus* sp.[1]	14	12	8	6	5	-

1. Top -- 4-inch diameter unless otherwise specified;
Stump -- 6 inches above ground unless otherwise specified.

2. Top -- 6 inches diameter;
Stump -- 12 inches above ground.

3. Unpublished data from the Vancouver Forest Products Laboratory. Several trees in each diameter class were measured.

4. Top -- 4 inches diameter;
Stump -- 12 inches above ground.

5. Two groups of trees were measured, 21 in the first group and 36 in the second.

TABEE 9

Moisture Content of Bole and Unmerchantable Top.

Refer-ence	Wood species	Moisture as % of bark-free component[1]	
		Merchantable bole	Unmerchantable top
302	*Abies balsamea*	60	64
302	*Picea rubens*	43	46
302	*Pinus strobus*	51	60
143	*Tsuga heterophylla*[2]	57	58
		53	58
		43	50
302	*Acer rubrum*	39	41
302	*Betula papyrifera*	43	45
302	*Populus* sp.	52	48

1. Percentage moisture defined as: $\frac{\text{(Fresh weight - oven-dry weight)}}{\text{(Fresh weight)}} \times 100.$

2. Respective dbhs = 18.0, 14.2 and 8.5 inches.

Table 10 gives percent moisture in the wood as a function of distance above ground for *Pinus contorta* var. *latifolia*.

TABLE 10

Percentage Moisture in Bole Wood as a Function of Height above Ground -- *Pinus contorta* var. *latifolia:* reference -- 130.

Dbh	Percentage moisture in bole wood as a function of distance above ground[1]										
	Height above ground level in feet										
	1	4.5	9.0	17.0	25.0	33.0	41.0	49.0	57.0	65.0	68.0
4	37	37	38	39	40	52	-	-	-	-	-
5.9	43	34	39	27	29	33	29	36	-	-	-
6.4	36	37	38	38	41	41	48	48	-	-	-
6.7	43	43	41	44	46	43	51	48	-	-	-
7.3	41	46	43	48	49	53	38	56	-	-	-
8.0	39	39	39	29	35	40	48	51	-	-	-
8.1	40	37	26	39	41	32	49	49	55	-	-
8.1	47	46	47	46	47	48	52	53	57	-	-
8.1	45	46	43	47	48	51	47	54	-	-	-
8.4	45	40	41	42	43	49	52	54	55	-	-
8.8	-	49	47	45	58	51	52	53	54	-	-
9.0	41	39	39	41	39	46	46	50	53	-	-
9.3	46	39	41	42	45	46	51	54	52	-	-
9.6	44	47	45	45	47	43	51	51	57	56	-
9.9	42	44	44	44	46	49	52	53	53	-	-
10.0	41	42	42	41	44	47	49	50	49	-	-
10.3	49	47	46	53	51	50	51	53	52	-	-
10.4	43	43	43	44	46	49	50	55	56	-	-
11.0	34	45	45	45	47	49	53	54	57	59	-
12.8	37	39	38	41	39	43	44	47	45	50	52
13.4	40	39	28	35	41	41	46	49	49	46	-

1. Percentage moisture = $\frac{\text{(fresh weight - oven-dry weight)}}{\text{(fresh weight)}} \times 100$

The same data for percentage moisture in bark as given above for bole wood are shown in Table 11 for bole bark.

TABLE 11

Percentage Moisture in Bark as a Function of Height above Ground
Pinus contorta var. *latifolia:* reference -- 130.

Percentage Moisture in Bark as a Function of Distance above Ground[1]

Dbh	Distance above ground in feet										
	1	4.5	9.0	17.0	25.0	33.0	41.0	49.0	57.0	65.0	68.0
4	36	39	39	39	41	50	-	-	-	-	-
5.9	39	43	44	36	30	32	31	41	-	-	-
6.4	32	40	44	48	51	51	48	51	-	-	-
6.7	34	43	38	44	50	44	53	48	-	-	--
7.3	14	47	45	46	51	50	32	51	-	-	-
8.0	18	27	25	21	20	32	44	51	-	-	-
8.1	47	50	52	42	46	54	50	57	58	-	-
8.1	41	49	50	52	54	55	54	53	57	-	-
8.1	37	45	44	51	52	54	50	56	-	-	-
8.4	38	45	47	50	50	50	52	53	54	-	-
8.8	-	51	51	51	41	52	50	54	52	-	-
9.0	34	42	44	49	41	50	51	47	52	-	-
9.3	39	43	46	47	49	50	49	50	48	-	-
9.6	42	46	48	51	48	51	48	52	54	57	-
9.9	35	37	41	48	46	46	48	47	40	-	-
10.0	37	39	41	44	46	44	45	50	47	-	-
10.3	39	46	49	51	51	52	53	52	50	-	-
10.4	41	48	50	52	54	54	54	56	57	-	-
11.0	41	46	48	52	52	51	51	52	55	54	-
12.8	39	33	42	43	44	47	48	50	52	51	53
13.4	39	43	48	50	52	49	48	46	46	47	-

1. $$\text{Percentage moisture} = \frac{(\text{Fresh weight - oven-dry weight})}{(\text{fresh weight})} \times 100$$

A number of studies have been made on factors affecting the level and distribution of moisture in trees (22). The variation in moisture content within a bole (Tables 6 and 10) and bole bark (Tables 6 and 11) of individual trees are presented as representative of the wide variation found in most of these studies. Table 11, in particular, illustrates the need for ensuring that an adequate number of samples are measured. The wide fluctuation in moisture content of both bole and bark for one of the trees studied (7.3-inches dbh, Tables 10 and 11) also indicates a potential source of measurement error which can arise in attempting to determine the average moisture content of a tree from small samples, or from a small number of samples.

Percentage Tops for Various *Pinus* Species at Eight Inches DBH

Table 12 shows several values for the percentage of tops for *Pinus* species under comparable conditions -- 8 inches dbh, 4-inch-diameter top, and stump height 6 to 12 inches above ground.

TABLE 12

Unmerchantable Top of Bole as a Percentage by Weight of Full Tree Bole at Eight Inches DBH -- *Pinus* Species.

Reference	Wood Species	Unmerchantable top as a % by weight of full tree bole	Basis
130	*Pinus contorta* var. *latifolia*	8	Standard basis
150	*Pinus contorta* var. *latifolia*	6	Bark on, oven dry
187	*Pinus contorta* var. *latifolia*	10	Bark on, oven dry
131	*Pinus contorta* var. *latifolia*	9	Bark on, oven dry
309	*Pinus strobus*	9	Standard basis
309	*Pinus strobus*	9	Green basis, bark on

For *Pinus contorta* var. *latifolia* and *P. strobus* for which percentage tops have been measured under what are considered to be comparable conditions of tree and top size, the values for percentage unmerchantable top are in reasonably close agreement. The value of 8-10 percent tops (which would be 9-11 percent based on the merchantable bole) is also fairly close to the 13 percent of the original gross merchantable volume given in Table 21. Even where the percentage tops might be identical in two forest areas for the same wood species, reported differences could arise simply from the technique used in removing branches and difficulties arising from decisions as to where the top should be cut.

Percentage Tops, Comparison of Standard and Green Basis at Eight Inches DBH.

As indicated by the values for percentage tops shown in Table 13, the differences between green and standard basis values at a dbh of 8 inches for those species for which data are available, are not great. Close agreement would be expected where the bark and the percentage moisture do not differ appreciably for top and for full bole. Where the percentage bark and percentage moisture are higher in the top than in the bole, as is usually the case, the percentage tops on a green, bark-on basis could be substantially higher than the percentage tops on a standard basis.

TABLE 13

Unmerchantable Top as a Percentage by Weight of Full Tree Bole -- Comparison of Standard and Green, Bark-on Values.

		Top as % of Oven-dry, Bark-free Full Bole at 8 inches DBH[1]	
Reference	Wood species	Standard basis	Green, bark-on basis
302,305	*Picea rubens*	6	7
309	*Pinus strobus*	8	9
78	*Thuja occidentalis*	16	18
309	*Tsuga canadensis*	9	10
143	*Tsuga heterophylla*[2]	23	23
302	*Acer rubrum*	9	9
309	*Betula papyrifera*	10	9
309	*Populus*	9	8

1. Top = 4 inches in diameter unless otherwise stated.

2. Dbh = 8.5 inches, top diameter 6 inches.

It is considered probable that in most cases agreement between green and standard basis values for percent tops would be expected to lie within plus or minus 10%. It is perhaps one case where green weights, bark on, would give results sufficiently close to standard basis values to permit use of green weights of the unbarked wood to determine standard basis values for preliminary surveys. Even in this case, however, a few check measurements on percentage bark and moisture would be necessary to establish a relationship between standard and green-basis values for any given wood species.

The data shown in Table 13 (green values) are of specific interest in that they show the additional weight which must be transported in converting from standard bole to full-bole logging.

Percentage Tops by Volume

In practice, top volumes would be appreciably easier to determine than weights. However, volumes are likely to be of limited value in determining weight ratios with any high degree of accuracy, since the specific gravity of unmerchantable top of bole differs from that of the bole (Tables 14, 15, 16, 25 and 26), the relationship is not consistent from species to species, and firm data are not available.

TABLE 14

Specific Gravity of Bole and Unmerchantable Top.

Reference	Wood species	Specific gravity, oven-dry basis. Unmerchantable top to 1-inch diameter	Merchantable bole
302	*Betula papyrifera*	0.516	0.525
302	*Acer rubrum*	0.539	0.581
302	*Tsuga canadensis*	0.422	0.408
143	*Tsuga heterophylla*	0.439	0.360
		0.438	0.394
		0.425	0.422
302	*Picea rubens*	0.472	0.435
302	*Abies balsamea*	0.309	0.297
302	*Populus* sp.	0.381	0.342

TABLE 15

Specific Gravity as a Function of Distance Above Ground.

All values of specific gravity on a dry-volume basis.

Reference: 143.

Distance above ground in feet (*Tsuga heterophylla*)

DBH (inches)	1	6	16	26	36	46	56	66	76	86	88.8	96	97.3	106
8.5	0.46	0.45	0.41	0.39	0.40	0.41	0.47	0.46	-	-	-	-	-	-
14.2	0.46	0.39	0.39	0.39	0.39	0.40	0.37	0.37	0.37	0.39	-	0.47	-	0.45
18.0	-	0.37	0.36	0.36	0.35	0.36	0.35	0.36	0.37	0.39	0.40	-	0.47	0.47

All values of specific gravity on a green-volume basis

Reference: 313

Distance above ground in feet (*Pinus taeda*)

	1	5	10	15	20	25	30	35	40	45	50	
Not Specified	-	0.38	0.36	0.33	0.33	0.33	0.34	0.35	0.36	0.37	0.38	Core wood
	-	0.53	0.48	0.46	0.45	0.44	0.43	0.41	0.38	0.36	-	Outer wood

All values of specific gravity on a green-volume basis.

Reference: 308

Distance above ground in feet (*Pinus elliottii*)

	1	5	10	15	20	25	30	35	40	45	50	
Not specified	-	0.42	0.39	0.38	0.38	0.37	0.37	0.37	0.37	0.37	0.37	Core wood
	-	0.50	0.48	0.46	0.44	0.43	0.42	0.41	0.40	0.39	0.39	Outer wood

TABLE 16

Specific Gravity as a Function of Distance above Ground.

Reference: 30

Tree Number Species	Specific gravity green volume basis Distance above ground in feet													
Pinus palustris	0	8	17	25	33	42	50	58	67	75	92	100		
1	0.500	0.490	0.464	0.441	0.430	0.420	0.412	0.402	0.397	0.397	0.420	0.356		Rapid growth
2	0.546		0.521		0.479		0.474		0.456			0.436		Rapid growth
3	0.594	0.580	0.565	0.556	0.541	0.526	0.504	0.497	0.467	0.463	0.433	0.410		Slow growth
P. echinata	0	13	25	38	50	63	75	88	100	(Height in feet)				
4	0.550	0.484	0.442	0.414	0.393	0.405	0.395	0.391	0.376					Rapid growth
5	0.557	0.528	0.503	0.474	0.451	0.434	0.425	0.454	0.432					Slow growth
P. elliottii	0	13	25	38	50	63	75	88	100	(Height in feet)				
6	0.523	0.559	0.536	0.494	0.445	0.440	0.421	0.432	0.421					Rapid growth
P. elliottii	0	7	14	21	29	36	43	50	57	64	72	93	100	(Height in feet)
7	0.648	0.622	0.609	0.598	0.590	0.573	0.564	0.553	0.541	0.535	0.538	0.451	0.425	Slow growth
P. taeda	0	11	22	33	44	55	67	78	89	100	(Height in feet)			
8	0.494	0.564	0.429	0.423	0.406	0.412	0.411	0.414	0.409	0.416				Rapid growth
P. taeda	0	9	18	27	36	45	55	64	73	82	91	100	(Height in feet	
9	0.540	0.529	0.508	0.492	0.479	0.459	0.434	0.420	0.409	0.408	0.426	0.397		Slow growth

As H. Young comments concerning the data on Maine species given in Table 14, "This is entirely inadequate information from which to draw any major conclusions" (302).

The irregular nature of the relationship between bole and top specific gravities has been confirmed in a number of studies (30, 143, 249, 313) in which the specific gravities are reported as increasing, decreasing, or remaining constant from tree butt to apex.

Specific gravity values are normally obtained on carefully selected wood samples; tops may contain an appreciably higher percentage of knots than boles, and the values needed for converting volume to weight should be based on bulk density, which is rarely available. Considerable caution would have to be exercised in converting the volume percentage of unmerchantable tops to weight percent[j] on the standard basis, since it would be the rare case where reliable conversion factors for specific gravities, moisture contents and bark content for unmerchantable top and bole would be available.

Percent Tops for Small Trees

As shown by the data in Table 17, the term "tops" has little meaning for trees of small dbh, say up to 2 or 3 inches in diameter.

(j) For one species (*Pinus taeda*, Tables 19 and 20), data were obtained on percentage tops by weight and by volume (green and bark-on basis) for 116 trees. If the average values for percentage tops by weight for each dbh and height shown in Tables 19 and 20 are assigned a value of 100, the percentage tops by volume for the same dbh and height range from approximately 80 to 120% from 5 inches dbh up to and including 10 inches dbh.

TABLE 17

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

Reference	Wood species	Diameter at base (inches)	Top[1] As a % of full bole	Notes
252	*Castanopsis cuspidata*	1	157	Top: oven dry, bark on Bole: oven dry, bark on
		1.5	157	Bole: oven dry, bark on
		2.0	156	Bole: oven dry, bark on
254	*Ulmus parvifolia*[2]	0.2	54	Top: oven dry, bark on Bole: oven dry, bark on
		0.3	58	Bole: oven dry, bark on
		0.4	62	Bole: oven dry, bark on
253	*Betula platyphylla*	0.8	56	Top: green, bark on
		1.0	58	Bole: green, bark on
		1.2	59	
		1.5	59	

1. Top: assumed to be the upper part of the bole, including branches.
Stump: ground level.

2. Values based on total plant weight above ground.

Percentage Tops as a Function of DBH and Tree Height for *Pinus taeda*

It might be thought that the unmerchantable top of the bole would be one tree component whose volume, for many tree species, might be calculated from the theoretical geometry of a tree(k). Table 18 shows the relationship between top as a percentage by volume of tree bole as related to dbh and tree height for a "theoretical" tree. On a basis of geometry, the percentage

(k) This is obviously an over-simplification, as shown by more sophisticated calculations (191); however, the simplified volume relationship can be used to illustrate the principle of the geometrical relationship between percent tops and tree height at constant dbh, and to indicate where this relationship comes reasonably close to measured values, and where it deviates widely.

TABLE 18

Top of Bole as a Percentage by Volume of Full Tree Bole and as a Function of Tree Height -- Calculated Values[1].

Dbh in inches	Volume of top as a % of full bole — Tree height in feet: 30	40	50	60	70	80
6	24	25	26	26	27	29
8	10.0	10.5	10.9	11.1	11.2	11.4
10	5.1	5.3	5.5	5.7	5.8	5.9
12	2.9	3.1	3.2	3.3	3.3	3.4

1. Calculated from the geometry of a symmetrical "theoretical" tree
Assumptions:

Stump; 1 foot above ground, with no flare;
Breast height, 4.5 feet above ground level;
Top, 4 inches at the base to 0 inches at the top.

tops by volume shows little change with height at constant dbh. In actual fact, the change in percentage tops as a function of tree height can be quite marked, as shown in Tables 19 and 20 which give the results of a detailed study on the percentage of tops as a function of both dbh and tree height, on both a volume and weight basis.

TABLE 19

Tops as a Percentage by Volume of Full Boles and as a Function of Tree Height and DBH.

(Full bole to a top diameter of 2 inches inside bark).

Species: *Pinus taeda;* reference: 226

DBH (in inches)	Total tree height (in feet). 30	35	40	45	50	55	60	65	70
5	50	36.4	30.8	26.7	33.3	21.0	-	-	-
6	25	21.2	18.4	16.3	14.6	13.2	13.8	-	-
7	-	10.9	11.5	10.3	9.4	8.6	9.2	8.5	-
8	-	-	5.9	6.6	6.0	6.7	6.3	6.7	7.1
9	-	-	-	3.1	3.9	4.4	4.1	5.4	5.8
10	-	-	-	-	1.6	2.9	3.4	3.8	4.7
11	-	-	-	-	0.65	1.2	2.3	3.2	3.5
12	-	-	-	-	-	0.5	1.4	2.2	3.4

TABLE 20

Unmerchantable Top of Bole as a Percentage by Weight of Bole for Various Tree Heights. (Top and bole, green and bark on; Bole cut to a 2-inch top diameter.)

Species: *Pinus taeda;* reference 226.

Top[1] as a Percentage of the Full Bole

Dbh (in inches)	Tree Height in Feet								
	30	35	40	45	50	55	60	65	70
5	53	42.3	34.7	24.0	27.1	25.1	-	-	-
6	28.0	23.2	19.9	18.4	17.1	16.0	14.9	-	-
7	-	11.9	11.2	11.8	10.7	10.5	10.3	10.1	-
8	-	-	5.7	6.1	6.6	6.8	7.1	7.1	7.3
9	-	-	-	2.9	3.8	4.3	4.8	5.2	5.5
10	-	-	-	-	1.8	2.6	3.3	3.8	4.3
11	-	-	-	-	0.2	1.1	2.1	2.7	3.3
12	-	-	-	-	-	0.3	1.3	1.4	2.6

1. Tops = from 3.6 inches diameter inside bark to 2-inch diameter inside bark;
Stump = 12 inches above ground.
Number of trees measured = 116 trees in 12 plantations.

There is no obvious reason for the trends shown in Tables 19 and 20; above 7 inches dbh, the percentage tops increases with increasing height; at dbh of 7 inches or less, the top decreases with corresponding increases in tree height, and this trend becomes quite marked at 5 and 6 inches dbh. Since the percentage tops calculated from the geometry of a symmetrical cone does not take butt flare into account, the calculated values shown in Table 18 would be expected to be somewhat high. Further, there is little relationship between the actual values (percentage tops by volume) as measured on *Pinus taeda* for various tree heights and values of dbh (Table 19) and the values calculated for a geometrically symmetrical tree (Table 18); this lack of agreement illustrates the futility of attempting to calculate the percentage tops from a symmetrical or "ideal" tree over any wide range of tree height and dbh.

Some of the apparent inconsistencies in the results shown in Tables 1, 3 and 8 probably arise from the fact that for a given dbh, the percentage of unmerchantable tops was not derived for trees of the same height; as shown by the results given in Tables 19 and 20, the percentage tops by volume or weight can vary widely as a function of tree height.

The agreement between theoretical values of percentage tops by volume and the found values of percentage by weight is reasonably good for many wood species above, say, 8 inches in diameter and for a 4-inch top. As noted above, some part of the difference between the theoretical and actual values can be accounted for by tree flare, which tends to make the calculated values too high. See further in reference 315.

TABLE 21

Unmerchantable Top of Bole as a Percentage of Bole
-- Miscellaneous Values.

Reference	Wood species	Percent unmerchantable top	Assumed basis
159	*Abies* sp.	3% of merchantable bole[1]	Volume
159	*Picea* sp.	11% of merchantable bole[2]	Volume
159	*Picea* sp.	5-7% of merchantable bole[3]	Volume
159	Canadian species	2-20% of the total tree	Green weight, bark on
	Picea mariana *Pinus banksiana* *Abies balsamea*	6% of above-ground tree	Green weight, bark on
76	Canadian species	13% of original merchantable volume of stand	Green volume, bark on
146	Alberta species	7% of original gross merchant. volume of stand	Green volume, bark on
146	Alberta species	Top waste is 12% of gross merchantable volume of stand	Green volume, bark on
146	*Picea* sp.[4]	6% of original gross merchant. volume of stand	Green volume, bark on
146	*Pinus* sp.[5]	13% of original gross merchant. volume of stand	Green volume, bark on
146	*Abies balsamea*[6]	13% of original gross merchant. volume of stand	Green volume, bark on
146	*Populus balsamifera*[7]	35% of original gross merchant. volume of stand.	Green volume, bark on
4	*Picea mariana*[8]	11% of full bole	Green weight, bark on

1. Top = 3-inch diameter
2. Top = 4-inch diameter
3. Average values
4. Trees samples = 1800
5. Trees sampled = 495
6. Trees samples = 54
7. Trees sampled = 1
8. Top = from 3.5 to 1.5 inch diameter
   Stump not specified
   dbh = 7 inches.

Summary

The values for percent tops shown in Table 21 illustrate the difficulties which are likely to be encountered in planning the use of unmerchantable tops. In one case the percentage tops for *Picea* sp. is given as 11% of the merchantable bole by volume (159); in the other case, the percentage tops for *Picea* sp. is given as 6% of original gross merchantable stand volume on a green, bark-on basis (42). The question of whether the percentage tops which can be recovered from a given spruce stand is 6% or 11% may not be important in a preliminary cost-benefit analysis for the use of tops, since the analysis may indicate favourable economics for either value. For mill design, however, the actual weight, volume or length of tops for which equipment would have to be installed. should be known to within say ± 10% of the true value.

In general, the values for percentage tops indicated in the various biomass studies would indicate the following:

1. For some wood species of known dbh, tree height and top diameter, a rough guess can be made, reliable to ± 30 or 40%, for the percentage tops on a standard basis;

2. For detailed feasability studies, some measurements would have to be made in the forest in order to determine percentage tops to say ± 20%;

3. For engineering design, a detailed study would have to be made of the forest under consideration, in order to determine the potential yield of tops to the precision required for engineering design work, say ± 10%. The study should take into account:

    Wood species;
    Range of tree heights;
    Range of diameters,
    Dominance;
    Minimum top diameter which can be processed.

Tops less than 1 to 1.5 inches in diameter will not, in all probability, be used for pulping, and allowance should be made for removing them from tops to be processed. In addition to meeting the normal requirements for selecting representative samples for biomass measurements, the measurements should be taken over various periods during the year.

UTILIZATION

FACTORS RELATING TO THE PULPING CHARACTERISTICS OF UNMERCHANTABLE TOP OF BOLE

Introduction

Although unmerchantable tops of boles could be used for a variety of products, such as composition board, fiberboard (Table 22), chemical products through pyrolysis or hydrolysis, fuel, etc., it is considered that the most practical and economical use for tops down to a diameter of, say, 1 inch would be for the manufacture of pulp (Table 23, 24) and particularly of kraft pulp (Table 25).

An effort was made in the initial stages of the present review to analyze the literature data available on the yield and quality of pulp from unmerchantable tops of boles. The effort was abandoned, however, because of difficulties arising from differences in test procedures, missing essential data, and in general a lack of standard methods of wood selection, pulping, pulp testing, test units, and method of reporting. Thus, comments given in Table 25 for kraft pulps and in Table 24 for other pulps are general and subjective.

In most studies on pulping characteristics of unmerchantable tops, this tree component compared with boles gave pulps approximately equal in breaking length and burst factor, slightly lower in yield across the digester, and substantially lower in tear. Based on studies carried out in the Vancouver Forest Products Laboratory on the pulping of unmerchantable tops from *Pinus contorta* var. *latifolia*, *Tsuga heterophylla*, *Picea glauca*, *P. mariana*, and *Populus tremuloides*, the following general principles were applicable to the species studied: compared with pulp from comparable boles, pulp from unmerchantable tops (either 6- or 4-inch-diameter top, depending upon species) was:

1. Slightly lower in burst factor and breaking length;
2. Ten to 20% lower in tear factor;
3. Two percentage points lower in yield (i.e., 43 compared with 45 for boles in the case of *Tsuga heterophylla*);
4. Slightly less beating time to 500 or 300 freeness.

A high percentage of knotter and screen rejects [(1)] would lead to a further small reduction in digester capacity where the rejects are returned to the digester, and to a fiber loss where they are sewered.

---

(1) In a study of tops from *Picea glauca*, *Pinus contorta* var. *latifolia* and *Picea mariana* (140), no increase in percentage knotter rejects was found for unbleached kraft pulp at approximately 20 permanganate number. The results were somewhat unexpected, and it is not known to what extent these results might be applicable to other wood species.

TABLE 22

Utilization of Unmerchantable Top of Bole
-- General Articles.

Reference	Wood species	Use	Comment
306	*Abies balsamea*	Fiber	General - to increase fiber resource.
134	*Picea, Pinus, Betula* sp.	Building board pulp, paper, cement blocks	General - conversion of logging wastes.
305	*Acer rubrum, Picea rubens*	Fiber	General - to increase fiber resource.
49	General	Pulp, paper, new products	General - to increase fiber resource.
100	General	Wallboard, fiberboard	Use with other wood wastes.
281	General	Roofing felt, paper	Use of wood wastes.
159	General	Pulp, fiberboard, particle board agricultural use	Review of possible uses as part of wood residues from full-tree logging.
110	General	Pulp, particle board, fiberboard	FAO review on utilization of tops and other waste wood.
176	General	Pulps	Review of the literature on the pulping of tops and branches.
60	*Thuja plicata*	Essential oils	Discussion on extraction and distillation of conifers.
170	General	Fiber source (continuous)	Cellulose forestry concept.

TABLE 23

References on the Pulping of Tree Tops or Thinnings

Reference	Wood species	Pulping process
181	*Pinus sylvestris*	Kraft
86, 277	*P. elliottii*	Kraft
48, 86, 81	*P. taeda*	Kraft
48	*P. palustris*	Kraft
48	*P. echinata*	Kraft
48	*P. caribaea*	Kraft
216	*P. pinaster* (thinnings)	Kraft Neutral sulfite semichemical Groundwood
271	*P. radiata* (thinnings)	Kraft
183	*P. radiata* (thinnings)	Kraft Sodium bisulfite
	Picea glauca	Kraft
181	*P. excelsa*	Kraft
	P. mariana	Kraft
310, 311	*P. mariana*	Sulfite
302	*P. rubens*	Ammonia base sulfite
164	*P. rubens*	Nitric acid
59, 182	*Tsuga heterophylla*	Sulfite
302	*Betula papyrifera*	Kraft
302	*Acer rubrum*	Kraft
34	*Abies amabalis*	Kraft
151	*A. balsamea*	Groundwood
98	*Pseudotsuga menziesii*	Kraft
53	*P. menziesii*	Sulfite (calcium, sodium, magnesium, and ammonia base) Neutral sulfite semichemical
85	*Eucalyptus globulus* (thinnings)	Neutral sulfite semichemical Soda
17	*E. globulus* (thinnings)	Cold soda, sulfate, NSSC, groundwood
85	*E. rostrata* (thinnings)	NSSC, soda
17	*E. camaldulensis* (plantation wood)	NSSC, cold soda, groundwood
263	*E. elacophora* (thinnings)	Cold soda, kraft, NSSC, groundwood
17	*E. sideroxylon*	Cold soda, kraft, NSSC, groundwood
215	*Araucaria klinkii*	Kraft

TABLE 24

Utilization of Unmerchantable Top of Bole --
Pulps other than Kraft

Reference	Wood species	Use	Comment
145	*Picea rubens*	Pulp, sulfite	Pulp comparable to bole pulp.
284	*Chamaecyparis obtusa, C. pisifera, Pinus densiflora*	Pulp, sulfite fiberboard	Suitable for pulp manufacture.
302, 309, 307	*Picea rubens*	Pulp, sulfite, nitric acid	Pulps produced generally comparable to bole pulps.
164	*P. rubens*	Pulp, nitric acid	Strength properties comparable to bole pulp.
202	*P. sitchensis*	Pulp, sulfite	Pulp lower in strength and yield compared with pulp from butt part of boles.
55	*Pinus caribaea* *P. echinata* *P. palustris* *P. taeda*	Pulp, sulfite	Strength slightly lower than that of bole pulp.
54	*P. banksiana*	Pulp, sulfite	Pulps compare favourably with bole pulps.
151	*Picea* sp. *Abies* sp.	Pulp, mechanical	Pulp quality satisfactory; pulp slower drainage and fiber length somewhat lower.

TABLE 25

Utilization of Unmerchantable Top of Bole --
Kraft Pulp

Reference	Wood species	Comment
256	*Pinus* sp.	Champion Co. and Texas Leaf Lumber Co. produced pulp in 1939; selected tops only were used.
78	*Thuja occidentalis*	Pulp strength slightly lower than that of bole pulp.
241	*Pinus palustris* *P. caribaea*	High quality of pulp, high in burst and low in tear, compared with bole pulp.
54	*P. banksiana* *P. contorta* var. *latifolia*	Pulp compares favourably with bole pulp.
225	*Pinus* sp.	Approximately 10% lower in strength than bole pulp.
35	*Pseudotsuga menziesii*	Tops gave pulp with maximum burst and tensile, vs. bole pulp.
177	*P. menziesii*	Mixed with other wood wastes and branches, gave pulps with strength properties equal to those from boles for corrugating medium.
163	*Fagus, Populus* sp.	In combination with other logging wastes; pulps suitable for wrapping but not high quality paper. High knot content compared with bole.
284	*Chamaecyparis obtusa, C. pisifera, Pinus densiflora*	Suitable for pulp manufacture.
3	*Picea, Pinus* sp.	Pulp comparable to that from boles.
202	*Picea sitchensis*	Pulp lower in strength and yield compared with bole pulp.
92	*Pinus palustris*	Higher burst factor, lower tear, compared with bole pulp.
33	*P. echinata*	Yield slightly lower, burst and tensile somewhat lower than bole pulps.

(continued)

282	*Tsuga heterophylla*	Screened pulp yield somewhat lower, burst and tear factor slightly lower, tensile strength comparable to bole pulps.
142	*T. heterophylla*	Compared with pulp from the bole, kraft pulp from the tops was 5% lower in yield, 20% lower in tear factor, and equal in burst factor and breaking length.
285	*Pinus densiflora, Fagus sieboldi, Quercus crispula*	Pulp slightly inferior, yield slightly low compared to bole pulp.

Compared with pulp from boles, pulp from unmerchantable tops of boles from the same wood species are reported to be inferior to, equal to, or superior in various critical pulp quality characteristics. Because of the inconsistencies in results reported for the yield and strength characteristics of pulps derived from tops, the technical literature was reviewed with a view to understanding those factors which might be expected to have a bearing on the quality of pulps which might be expected from the various parts of tree boles. Table 26 gives a number of the more critically important factors which have been found to give, or which might affect, pulp yield and quality.

TABLE 26

Various Factors Relating to the Yield and Strength of Pulp from Unmerchantable Top of Bole

-- General

Reference	Wood species	Factors relating to pulp strength or yield.
27	28 angiosperms 8 gymnosperms	Compression wood gives shorter fibers.
65	General	Compression wood gives lower yield and strength compared with normal wood.
70	General	Compression wood gives higher lignin and lower alpha-cellulose content, compared with boles.
105	General	Compression wood of tops increases with wind blow. Boundary trees are not suitable for selection because of one-sided crowns resulting from prevailing winds.
107	General	Juvenile wood is higher in compression wood (42%) compared with mature wood (7%) and lower in pulp yield and tear. The strength increases from pith to bark.
153	General	Fiber length inc. with dec. tree taper. This should be kept in mind in the selection of trees for sampling.
197	*Picea excelsa*	The effect of knots on pulp yield and strength; fiber length inc. and fiber width dec. with inc. latewood and sp. gr.
72	General	Percentage cellulose inc. from pith to bark, reaching a constant after 6-8 years.
312	General	Tension wood gives lower lignin, higher cellulose, higher pulp yield. Compression wood gives higher lignin, lower cellulose, and presumably lower pulp yield.
103	*Picea* sp.	Tops of suppressed trees were found to have a high sp. gr.

A number of studies (Tables 27 and 28) relate directly or indirectly to the yield and strength of pulps from unmerchantable tops of boles.

TABLE 27

Factors Relating to the Yield and Quality of Pulps from Unmerchantable Tops -- Coniferous Species.

Reference	Wood species	Comment	Factors relating to pulp strength or yield
274	*Pinus radiata*	....	No relationship between fiber length and tear.
8	*P. radiata*	12 yrs.	Tear did not relate to fiber length.
272	*P. radiata*	....	Compression wood higher in lignin, lower in pulp yield. Kraft pulp somewhat weaker and sulfite pulp appreciably weaker.
107	*P. radiata*	....	Dec. in tear factor in pulp sequence: kraft, bisulfite, neutral sulfite, and neutral sulfite - bisulfite.
54	*P. banksiana*	....	Pulp yield dec. from stump to apex because of dec. in sp. gr.
63	*P. resinosa*	....	Sp. gr. did not correlate with other parameters.
184	*P. merkusii*	....	Sp. gr., cellulose content inc. from pith to bark; % cellulose and sp. gr. higher on medium than on poor sites.
31	*P. palustris*	30-35 yrs.	Top has lower cellulose content.
94	*Pinus* sp.	Scandinavia	Tops give 2% lower yield by sulfite process.
247	*Pinus* sp.	Sweden	With inc. fiber length of pulp, dry density inc. With kraft pulp, tear factor inc. as fiber length inc. Tensile strength dec. as wood sp. gr. inc.
313	*P. taeda*	670 trees	Alpha-cellulose content constant from stump to apex.

(continued)

109	*P. taeda*		Juvenile wood contains 42% compression wood, whereas mature contained only 7%.
214	*P. sibirica*	7 trees	Cellulose inc., lignin dec., from pith to bark. Hemicelluloses dec. from stump to apex.
221	*Picea abies*	....	Cellulose dec. from stump to apex.
56	*Picea* sp.	....	Induced compression wood gives lower yield, greater fiber length.
94	*Picea* sp.	Scandinavia	Tops give 2% lower yield by sulfite process.
247	*Picea* sp.	Sweden	Tear factor dec. as fiber length inc. for sulfite. Tensile strength dec. as wood sp. gr. inc.
35	*Pseudotsuga menziesii*	....	Burst inc. and tear dec. from stump to apex.
18	*Pseudotsuga menziesii*	....	The nearer the river, the higher the % latewood and the longer the fibers.
98	*Pseudotsuga menziesii*	....	Younger trees lower in alpha-cellulose, lower in tear and higher in burst.
531	*Pseudotsuga menziesii*	....	Tops give lower tear and lower percentage screenings.
190	*Cedrus* sp.	....	From pith to bark, cellulose inc. and lignin dec.
190	*Cupressus* sp.	....	From stump to apex, cellulose inc. and lignin dec.
25	*Abies* sp.	....	Compression wood lower in cellulose, higher in lignin.
239	*Araucaria cunninghamii*	7 trees, 29 years	Good pulp from tops.

TABLE 28

Factors Relating to the Yield and Quality of Pulps from Unmerchantable Tops -- Deciduous Species.

Reference	Wood species	Factors Relating to Pulp Strength and Yield
232	*Populus* sp.	Cellulose inc. from pith to bark.
193	*Quercus* sp.	Cellulose inc., lignin inc. from pith to bark. Lignin inc., uronic acids inc., from stump to apex.
25	*Quercus robur*	Strength dec. from pith to bark, from stump to apex.
25	*Carpinus betulus*	Strength inc. from pith to bark.
25	*C. betulus*	Strength dec. from stump to apex.
127	*Populus* sp.	1-year-old growth gave low pulp yield.
172	*P. robusta*	Fiber always 2-4% lower in ave. length on the south side of a tree.
198	*Betula* sp.	Tension wood gives higher yield but lower strength.
219	*Fagus sylvatica*	Reaction wood contained less lignin (15.38%) than normal wood (21.33%).

Within-tree Variationsof Specific Gravity

As mentioned in a recent review (156) on the pulping of pines in the southern United States, "The most practical and common way of characterizing wood quality is by specific gravity". In the case of *Pinus elliottii* (226), for example, it is reported that, as the specific gravity of wood decreases, the tensile strength and burst factor increase and the tear decreases. This trend towards higher burst factor with lower specific gravity is also reported for *P. taeda* and *P. palustris* (62). Tables 29 and 30 give the variation in specific gravity from pith to bark and from stump to tree apex for a number of wood species. For most woods, specific gravity decreases from bark to pith and from stump to apex, for both coniferous and deciduous species. Some exceptions to this general rule are reported: *Fraxinus angustifolia* and *F. excelsior;* one example of *Quercus* sp. (80); not all of the results are in agreement for *Pinus* sp. (196), *P. radiata, P. taeda, Pseudotsuga menziesii, Betula* sp. and *Quercus* sp.

TABLE 29

Specific Gravity Variation within Trees
-- Coniferous Species.

Reference	Wood species	Comment	Variation in specific gravity: From pith to bark	Variation in specific gravity: From stump to apex
45	*Abies* sp.	Selection forest High forest	Dec. because of slow juvenile development Incr. because of dec. ring width	......
21	*A. alba*	120 trees	......	Increase to crown, then decrease.
24	" "	80-120 yrs.	Increase	Increase
147	*A. lasiocarpa*	6 trees	Min. sp. gr. at 50-70 yrs.	......
115	*Cryptomeria japonica*	56 yrs.	Sheath of high sp. gr. at 30-40 yrs.	Dec. to min. 1/3 to 2/3 up tree.
116	" "	52 yrs.	Dec. in general	......
137	" "	Japan	......	Inc. higher in crown than in bole
283	" "	Japan	......	Inc.
57	*Larix* sp.	24 yrs.	Inc.	Inc.
213	" "	......	Inc.	Inc.
47	*Picea* sp.	15-270 yrs.	Inc. due to narrowing ring	......
102	" "	Germany	......	Dec.
103	" "	Germany	Inc. to 100 yrs., then fluctuates	......

(Table 29 continued)

112	*Picea* sp.	Germany	Inc. in thinned stands.	......
195	" "	50 yrs.	Dec. to sapwood, then inc.	Sapwood sp. gr. inc. to 10% of ht., dec. to 80 ft., then inc.
196	" "	Sweden	Dec.	Dec.
259	" "	S. Africa	......	Relatively constant.
265	" "	Germany	Inc.	Dec. to crown, then inc.
247	" "	Sweden	Dec.	......
2	*P. abies*	1 tree	No change	......
155	" "	......	......	Inc., also inc. with dec. taper.
21	*P. excelsa*	120 trees	......	Dec. to crown, then inc.
114	" "	30 yrs.	Dec. to min. at 25 -30 yrs.	Dec. to min. at 1/3 to 2/3 dist. up tree.
244	" "	75 trees	Little change	Little change.
97	*P. glauca*	100 trees	......	Tendency to inc.
118	" "	18 yrs.	43% variation in sp. gr. between provenances.	
36	*P. sitchensis*	G. Britain	Max. dec. to 20-25 yrs., then inc.	Slight dec.
43	*Pinus* sp.	80 trees	Inc.	Dec.
73	" "	21 yrs.	......	Dec.
101	" "	Germany	Inc.	Dec.
102	" "	Germany	......	Dec.
194	" "	48 yrs., 1 tree	Inc.	......
206	" "	southern pine	Inc.	......
196	" "	Sweden	Dec.	Dec.
259	" "	S. Africa	......	Dec.
260	" "	" "	Inc. (independent of ring width)	......

(Table 29 continued)

265	*Pinus* sp.	Germany	Inc.	Dec. to crown, then inc.
54	*P. banksiana*		Sp. gr. lower in suppressed trees	Decrease
280	" "	120 trees, 24 yrs.	......	Decrease
20	*P. echinata*	1 tree	Inc. to max at 100 yrs., then dec.	Dec.
32	" "	2nd growth	......	Dec.
55	" "	fast growth	......	Dec.
185	" "	south. U.S.	Highest sp. gr. at 15-80 yrs.	Dec.
207	" "	south. U.S.	Earlywood sp. gr. dec. or remains constant; latewood sp. gr. inc. to bark.	Earlywood sp. gr. dec.; latewood sp. gr. dec.
313	*P. elliottii*	south. U.S.	Inc.	Dec.
240	" "	22 yrs.	......	Dec. steadily
55	" "	fast growth	......	Dec.
173	" "	22 trees	......	Dec.
185	" "	south. U.S.	Highest sp. gr. from 15-20 yrs.	Dec.
207	" "	south U.S.	Earlywood sp. gr. dec. or remains cons.; latewood sp. gr. inc. to bark.	Earlywood sp. gr. dec. latewood sp. gr. dec.
313	" "	47 trees	Inc.	Dec. to 10 ft.
12	*P. longifolia*	27-36 yrs.	Inc. rapidly	......
184	*P. merkusii*	6 trees, var. sites	Inc.	......
261	*P. nigra*	Croatia	......	Inc.
20	*P. palustris*	2 trees	Inc. to max. at 100 yrs., then dec.	Dec.
55	" "	fast growth	......	Dec.

(Table 29 continued)

185	*P. palustris*	south U.S.	Highest sp. gr. from 15 to 120 yrs.	Dec.
205	" "	" "	Large crowns and rapid growth give low sp. gr.	
207	" "	" "	Earlywood sp. gr. dec. or levels off; latewood sp. gr. inc. to bark.	Earlywood sp. gr. dec. Latewood sp. gr. dec.
3	*P. patula*	S. Africa	Inc. same for all growth rates.	......
200	" "	37 and 160 yrs.	Inc.	Dec.
262	" "	370 yrs.	Inc.	......
65	*P. pinaster*	Australia	Inc.	......
9	*P. radiata*	36 yrs.	Inc. for 10 rings, then constant.	......
16	" "	14 yrs.	......	Range from 0.30 to 0.44.
62	" "	6 trees	Marked inc.	......
121	" "	210 trees	Inc. sharply, then slowly	Inc.
144	" "	Australia	Inc.	......
174	" "	30-40 trees	Generally inc.	......
269	" "	Australia	Inc.	......
166	" "	22-52 yrs.	Marked inc., then levels off.	......
107	" "	Australia	Inc.	Dec.
129	*P. resinosa*	35 yrs.	Inc.	Dec.
117	*P. strobus*	5-39 yrs.	Dec., then inc.	Highest sp. gr. at base and tops.
189	" "	U.S.	......	Dec. to 16 feet, then constant.
169	*P. sylvestris*	80-280 yrs.	Inc. to 160 yrs., then dec.	......

(Table 29 continued)

261	*P. sylvestris*	Croatia	Inc.	Dec.
13	*P. taeda*	South Africa	Inc., same for all growth rates.	......
20	" "	4 trees	Inc. to max. at 100 yrs.	Dec.
55	" "	fast growth	......	Dec.
185	" "	south. U.S.	Highest sp. gr. from 15-80 yrs.	Dec.
207	" "	south. U.S.	Earlywood sp. gr. dec. or levels off latewood sp. gr. inc. to bark.	Earlywood sp. gr. dec. Latewood sp. gr. dec.
313	" "	south. U.S.	Inc.	Inc.
39	*Pseudotsuga menziesii*	22 trees	Inc.	Inc.
51	" "	16 yrs.	......	Dec. to crown, then inc.
52	" "	19 yrs.	Almost constant	......
126	" "	2 trees	......	Dec. to crown, then inc.
148	" "	60 yrs.	Inc.	No variation.
208	" "	100 yrs., 33 trees	Inc. to 60 years	......
237	" "	U.S.	Inc.	......
245	" "	Canada	Inc.	Dec.
267	" "	3 trees	Inc.	Dec. rapidly, then slowly
269	" "	Australia	Inc.	......
224	" "	Several	......	Dec. only slightly on good sites.
175	*Sequoia sempervirens*	98 trees	No constant radial trend.	Dec. fairly rapidly.
276	*Tsuga hetero-phylla*	60 yrs., 39 trees	......	Dec. to the top

TABLE 30

Specific Gravity Variation within Trees
-- Deciduous Species.

Reference	Wood species	Comment	Variations in specific gravity: From pith to bark	Variations in specific gravity: From stump to apex
74	Dicotyledonous trees	......	Inc. to max., then dec.	......
192	Exotics	New Zealand	In general, dec.	In general, dec.
210	*Acer saccharum*	Vermont	Open grown, inc.	Open grown, dec.
133	*Alnus glutinosa*	Latvia	......	No significant change.
243	*Betula* sp.	Germany, 5 trees	Inc.	Dec. to min. at crown, then inc.
264	" "	Finland	Dec.	......
25	*Carpinus betulus*	......	Inc.	Dec.
255	*Diplodiscus paniculatus*	4 trees	Inc.	Dec.
67, 68	*Eucalyptus camaldulensis*	......	Inc.	Inc.
251	" "	......	Inc.	......
7	*Fagus* sp.	80 yrs.	Considerable var.	Dec. significantly.
40	" "	80 yrs.	......	Dec. to crown, then inc.
44	" "	Switzerland	Dec.	......
212	" "	......	Sp. gr. high with large crown.	......
248	" "	Bulgaria	Sp. gr. difference greater within a site than between sites.	
132	*Fraxinus* sp.	Latvia	......	Inc.
204	*F. americana*	......	Inc. (sp. gr. inc. with ring width)	......
19	*F. angustifolia*	Croatia	Dec.	Inc.
19	*F. excelsior*	Croatia	Dec.	Inc.

(Table 30 continued)

188	*Gonystylus bancana*	30 trees, 3 sites	Inc.	......
83	*Liriodendron tulipifera*	23 trees	Sp. gr.	......
211	*Lithocarpus densiflora*	U.S.	......	Little variation.
168	*Populus* sp.	12 trees	No. constant trend	Uniformly inc.
66	*Populus X euramericana*	10 yrs.	Inc.	Inc. more rapidly up tree.
69	" "	20 trees	Inc.	Inc.
93	*Populus X marylandica*	20-24 yrs.	Dec., then inc.	Inc.
93	*Populus X regenerata*	......	Inc., but only at base	Sp. gr. dec. to 6 m., constant, then dec.
42	*Quercus* sp.	13-155 yrs.	Dec.	......
80	" "	Germany	Dec.	Constant to crown, then in
104	" "	Germany	Dec.	......
119	" "	Croatia	Dec.	Dec.
158	" "	France	Dec.	......
209	" "	5 species, 82 trees	......	Dec. uniformly
248	" "	......	Sp. gr. difference greater within a site than between sites.	
189	*Q. alba*	U.S.	Dec.	Dec.
25	*Q. robur*	......	Dec.	Dec.
37	*Shorea albida*	Sarawak	Inc. rapidly to 6-8", then constant.	......
180	*S. leprosula*	old trees	......	No. diff to 50-ft.
248	*Ulmus* sp.	Bulgaria	Sp. gr. difference greater within a site than between sites.	

Within-tree Variations of Fiber Length

One of the factors which might have a bearing on the strength characteristics of pulps from unmerchantable tops of boles is fiber length[m]. Tables 31, 32 and 33 give trends in fiber length within trees as reported in a number of studies. In general, fiber length decreases from bark to pith and from stump to apex, so that, compared with merchantable boles, unmerchantable tops would be expected to have somewhat shorter fibers, possibly of the order of 20 to 30 percent (123).

(m) Recent reviews have been published by Nordman (77) and by Dinwoodie (75) on the relationship between various anatomical and chemical characteristics of wood fibers and their principal paper-making properties. It is apparent from this review that the relationship between fiber geometry, wood specific gravity, and the quality characteristics of a pulp are anything but unequivocal. The comment is made (75) that, "Relationships ascribed to fiber length variation may in fact be related, in large part, to some other variable".

TABLE 31

Variation of Fiber Length within Boles

-- General

Reference	Comment	Variation in fiber length
11	General	Discussion of Sanio's laws. Fiber length inc. to a constant value from pith to bark, and inc. to a max, then dec., from stump to apex.
38	*Populus tremuloides*	No consistent relationships found for fiber-length variation.
74	Some dicotyledons	Fiber length inc. to a max., then dec. to the top.
79	*Pinus sylvestris*	Fiber length in general inc. from stump to apex, reaching a max. and then dec.
46	General	Fiber length inc. to 50 yrs.,then remains constant from pith to bark, reaching a max. at 10 to 20 feet from stump.
94	General	Fiber length dec. from stump to top.
165	General (20-30 year old trees)	Fiber length inc. from pith to bark.
186	General	Fiber length inc. from pith to bark.
203	General	With a high stand density, fiber length inc. from pith to bark. With a low stand density, fiber length is uniform from pith to bark.
228	General	Fiber length inc. to a constant from pith to bark; inc. to a max., then dec., from stump to apex.
236	Conifers	Max. fiber length occurs higher from the ground in rings close to the bark.
250	*Pseudotsuga menziesii* (35 yrs.)	Fiber length inc. from pith to bark; dec. from stump to apex.
87	General	Longest elements usually occur in trunks rather than roots.

(Table 31 continued)

242	General	Investigators must consider the overall picture of wood growth and not only the single factor of fiber length.
270	*Pseudotsuga menziesii*	Micellar angle is governed by cell length.
268	General	General review on fiber variation in a conifer stem.

TABLE 32

Variation of Fiber Length within Boles
-- Coniferous Species.

Reference	Wood species	Variation in fiber length: From pith to bark	Variation in fiber length: From stump to apex
1	*Pinus banksiana*	......	Inc. to crown, then dec.
162	" "	Inc.	Inc. to 41 feet, then dec. to top.
184	*P. merkusii*	Inc.	Higher 25% up tree than at base.
9	*P. radiata* (36 years)	Inc., then levels off	......
269	*P. radiata*	Inc.	......
274	*P. radiata* (12 years)	Inc.	......
20	*P. taeda*	Inc. rapidly to 10 yrs., then slowly	Inc.
23	" "	Inc. at all heights.	......
123	" "	......	Ft. from stump / Fiber length mm.: 1 — 1.39 1.38 27 (max) — 1.77 1.84 top — 1.35 1.43
123	" "	Inc.	Inc. to mid-stem, then dec.
161	" " (65-69 yrs.)	Inc. to 10 yrs. rap., then slowly	......

(Table 32 continued)

273	*P. taeda*	Inc.	......
20	*P. palustris*	Inc. rapidly to 10 yrs., then slowly	Inc.
91	" "	Inc. rapidly to 20 yrs., more slowly to 45-55 yrs.	
108	*P. densiflora*	Inc. to 8 yrs., then constant	Inc. to a max., then dec.
249	" "	......	Inc.
24	*P. sylvestris*	Sharply inc.	Dec.
199	" "	Inc. to 35-45 yrs., then dec.	....
246	*P. caribaea*	Inc.	......
269	*P. pinaster*	Inc.	......
90	*P. strobus*	Inc. irregularly, no relationship to pulp strength.	......
124	*P. elliottii*	Inc. to 15-25 yrs., then slowly inc.	......
247	*Pinus* sp.	Inc.	......
21	*Picea* sp.	Inc. to 30 yrs., then variable	......
103	" "	Inc. to 70 yrs., then var.	......
106	" "	Inc. to 20-30 yrs., then var.	Inc. to midstem, then dec.
247	" "	Inc.	......
178	*P. rubens*	Inc.	......
234	*Picea* sp. (85 yrs.)	Inc. at all levels	......
244	*P. excelsa* (75 trees)	Little variation.	Little variation.
50	*P. sitchensis* (40 yrs.)	Inc. at all levels.	Inc. to max., then dec.
6	*Abies concolor* (1 tree)	Inc. rapidly, then slowly. Inc.	

(Table 32 continued)

6	*A. procera* (1 tree)	Inc. rapidly, then slowly,	Inc.
24	*A. alba* (80-100 yrs.)	Inc.	......
6	*Pseudotsuga menziesii* (2 trees)	Inc. rapidly, then slowly.	Inc.
91	" "	Inc. rapidly to 20 yrs., then slowly	......
167	" "	Inc. rapidly to 50 yrs., then varied irregularly	Inc. to 1/3 stem ht., then dec.
245	" "	Inc.	Inc. to a ht. of 42 ft., then dec. to top.
14	*Thuja occidentalis*	Inc.	......
99	" "	Inc.	......
171	*Larix* sp.	Inc. sev. years, then fluctuates.	Inc. from upper stem down to a max. at 20% of tree ht., then dec.
276	*Tsuga heterophylla*	Inc. to 60 yrs.	......
10	*Araucaria cunninghamii*	Inc.	......
15	*Juniperus virginiana*	Inc.	......

TABLE 33

Variation of Fiber Length within Boles -- Deciduous Species.

Reference	Wood species	Variation in fiber length: From pith to bark	From stump to apex
5	*Eucalyptus gigantia* (12-inch dbh)	Inc.	......
26	*E. regnans*	Inc. rapidly	......
220	*Carya* sp.	Inc. to 20-25 yrs., then variable.	......

(Table 33 continued)

80	*Quercus* sp.	Inc. to 50-60 yrs., then max.	Inc. to 5 m. ht., then dec.
29	*Fraxinus* sp.	Inc. to 30, then dec. slightly.	Varied with age of cambium.
264	*Betula* sp. (20 trees)	Inc.	......
227	*B. pubescens*	Inc. to 40 yrs., then constant	......
	B. verrucosa	Inc.	....
230 231	*Populus X euramericana* (10 years)	Inc. to 6-8 yrs., then constant	......
229	*P. nigra* (39 trees)	Inc. rapidly for 15 yrs.	......
111	*P. tremula*	Inc. at all levels.	Variable with tree ht.
122	*P. japano-gigans*	Inc. to a constant.	Inc. to a max., then dec.
135	*P. deltoides*	Inc.	......
136	*P. deltoides*	Inc.	......
172	*P. robusta*	Inc. rapidly to 10 yrs., more slowly to 25 yrs., then variable.	......

Effect of Dominance on the Quality of Pulps from Tops

Whether a species or tree is dominant, sub-dominant or suppressed may have an effect upon the yield and quality of pulp obtained from the tops. Dominance has been reported to favor greater fiber length (178, 235), reaching a maximum in co-dominants (276). For slow-growth *Araucaria* (157), fiber length was greatest in suppressed trees. Dominants of *Picea abies*, *Larix* sp., and *Pinus mugo* were found to have a large fiber diameter and cell-wall thickness (233).

A high specific gravity has been reported for suppressed trees of *Picea* sp. (46), *Pinus*, *Picea*, *Betula* and *Populus* sp. (125), *Larix leptolepis*

(118), *Pinus banksiana* (54) and *Pseudotsuga menziesii* (208). Similarly, low specific gravity has been reported for dominant trees of *Larix leptolepis* (113), *Picea* sp. (58), *Picea excelsa* (41),*Cryptomeria japonica* (115), *Pinus sylvestris* (41, 43), *Abies* sp. (21), *Pseudotsuga menziesii* (275), for *Picea* sp. generally (84, 106), and for *Betula* sp. (40).

Tops of suppressed *Picea* sp. were found to have a high specific gravity (103) and, in general, suppressed trees are reported to give high-strength pulps (95).

There are insufficient data to draw firm conclusions concerning the effect of dominance on the yield and quality of pulp from tops. It is clear from the effects of dominance generally on fiber characteristics and specific gravity, however, that pulp yield and quality may be affected by dominance, and this should be kept in mind in selecting trees for complete-tree utilization studies. Dominant trees with a high wind-throw on the tops, for example, would be expected to give tops high in compression wood, with low tear strength and low pulp yield. Stand density would be expected to affect pulp quality, a low stand density giving more branches, with tops containing a higher percentage of knots, compression wood and pulps with lower yield and strength (154, 157).

Reaction Wood

Chemical Composition

A number of papers have been published which report the chemical analysis of reaction wood for a wide variety of tree species. The results of tests on 15 gymnosperms are summarized below for *Abies*, *Larix*, *Picea* and *Pinus* sp. (64):

Lignin,	normal wood	26.2-31.7%
	compression wood	37.0-40.8%
Cellulose,	normal wood	39.6-43.9%
	compression wood	29.0-32.8%
Galactose,	normal wood	1-2%
	compression wood	8-10%

The mannose content of compression wood is only 30-60% of that present in normal wood. The xylose content is higher in compression wood than in normal wood in some cases; lower in others, the difference being small.

Anatomical

A comprehensive review by Westing (278, 279) covers existing knowledge on the subject of compression wood formation and function. Compression wood appears to be a geotropic response of a cambial layer, which expands *in situ*, righting an inclined stem and maintaining the inherent angle of the branches. Compression tissue is heavily lignified and possesses thick cell walls. Compression wood is weaker than normal wood, apparently because of the more horizontal or transverse orientation of the microfibrils of the secondary cell wall. Specific gravity of compression wood is higher than that of normal wood. The sharp transition between springwood and summerwood is not found in the compression area, where the transition is gradual (217). The tracheids of compression wood are shorter and the tips often distorted.

Compression wood in stand-boundary spruce trees was found to be related to one-sided crowns as a result of the pressure of prevailing winds (105). It is reported (217) that trees with moderate lean do not always show compression wood, but where the angle of lean is 5.5° or greater, compression wood is almost always present (217).

Mechanical Pulp

Conventional stone groundwood prepared from two *Picea mariana* trees containing 60 and 80% compression wood was of poor quality because of the large proportion of broken tracheids and small fragments (218).

Chemical Pulps

Kraft pulping studies of *Abies balsamea* containing varying amounts of compression wood indicated a decreasing yield of pulp with increasing amounts of compression wood. The pulps were poorly delignified and, consequently, required longer cooking times to lower yields compared with normal wood (286).

Compression wood from *Pinus radiata* gave sulfate pulps somewhat inferior to comparable pulps from sound wood, whereas the sulfite pulps were markedly inferior to those derived from normal wood (272). The chemical composition of normal and compression wood and pulps derived from them are shown in Table 34.

The quality of kraft and sulfite pulps obtained from normal and compression wood of *Pinus radiata* is shown in Table 35.

TABLE 34

Chemical Composition of Normal and Compression Wood and Pulps from *Pinus radiata*. Reference: 272

	Wood		Sulfate Pulp				Sulfite Pulp			
Wood sample	Klason Lignin (%)	Pento-sans (%)	Yield on o.d. wood (%)	Klason lignin (%)	Pentosan (%)	Perman-ganate No.	Yield on o.d. wood (%)	Halse lignin (%)	Pento-san (%)	Perman-ganate No.
Compression	34.4	7.2	40	11.6	8.3	54.2	35	10.6	0.5	52
Normal	24.2	10.0	48	2.8	8.7	15.5	45	0.7	0.7	11.8
Average fiber length (mm)										
Compression wood					2.76			0.08		
Normal wood					3.85			3.73		

TABLE 35

Characteristics of Kraft and Sulfite Pulps from Compression Wood and Normal Wood for *Pinus radiata* -- Reference: 272

Wood	Type of pulp	Quality Characteristics						
		Freeness (Csf)	Bulk	Breaking length in km.	Burst	Tear	No. of double folds	Revs. Beating
Compression	Kraft	505	1.47	7.8	67	110	946	18,000
Normal		336	1.40	10.9	91	117	2306	18,000
Compression	Kraft	683	1.53	7.6	59	113	902	9,000
Normal		631	1.46	11.0	85	126	3089	9,000
Compression	Sulfite	438	1.61	3.2	13	34	2	......
Normal		611	1.47	4.9	38	67	150	......

It is apparent from the results shown in Table 35 that the quality of sulfite pulp is much less affected by the presence of compression wood than is the quality of sulfate pulp. The results shown in Table 29 would help account for the lower yield obtained from unmerchantable tops of boles compared with the same type of pulp from boles. The results given for normal and compression wood in Table 35 are not strictly comparable, since strength values are not given at the same freeness. Even allowing for this, however, there is less difference in the tear factor for pulps from normal and compression wood than might be expected on a basis of the difference in strength characteristics of pulp from tops and from comparable boles. It is probable that the strength data found for pulp from tree tops are the result of some interacting combination of compression wood, lower specific gravity, shorter fiber length, and a higher percentage of thin-walled fibers, tending to give pulps with high breaking length and burst factor, but with low tear factor.

Tension Wood

Hardwoods possess a righting mechanism more or less comparable to that of conifers, resulting in an asymmetric distribution of growth, usually but not always, on the upper side of inclined growth. Tension wood is low in lignin content and the fibers are characterized in cross section by a gelatinous, cellulosic inner zone within the secondary cell wall. Tension wood is difficult to detect in many hardwoods except by specialized means (278).

Chemical Composition of Tension Wood

Results of analytical studies show that the composition of tension wood from different species may vary widely, this variation being indicated in Table 36.

TABLE 36

Composition of Tension Wood (257).

Wood species	Lignin Content		Cellulose Content		Pentosan Content	
	Normal	Tension	Normal	Tension	Normal	Tension
Populus tremuloides	17.6	16.5	51.0	56.3	19.9	18.5
Eucalyptus goniocalyx	23.2	13.8	42.9	62.1	19.3	11.0
Populus canadensis	23.2	21.6	40.9	49.2	16.1	12.8

Pulping Characteristics of Tension Wood (120)

Jayme *et al.* (128) found that the yield of kraft pulp from *Populus* sp. increased with increasing percentage tension wood. Clermont and Bender (59), using the NSSC process, obtained slightly higher yields from the tension wood than from normal wood of *Populus tremuloides*.

Compared with pulp from normal wood, chemical pulps from material high in tension wood are inferior in strength characteristics, particularly breaking length and burst factor, which are closely related to fiber bonding; the fiber walls in tension wood pulp are thicker and more resistant to beating, and the content of non-resistant polysaccharides is lower (71).

Tension wood of *Populus tremuloides* required a longer beating time to reach a given freeness compared with pulp from normal wood; the tear factor was higher, but the breaking length and folding endurance lower in NSSC pulps. Tension wood pulp from *Ulmus americana,* however, showed little difference in beating time or strength characteristics (59). Lower values for breaking length, folding endurance, bursting strength, and percentage stretch were reported by Jayme, *et al.* (128) for pulps from tension wood of *Populus* sp.

SUMMARY AND DISCUSSION

Based on the data presently available, it is not possible to present a single unified picture for the yield and quality of pulps from unmerchantable tops of boles. However, it is possible to draw a few generalizations. For many wood species the tops, compared with boles, will show the following differences:

Unmerchantable Tops Compared with Merchantable Boles

Characteristics	Coniferous sp.	Deciduous sp.
Known General Wood or Fiber Characteristics		
Specific gravity	Lower	Lower
Fiber length	Shorter	Shorter
Cell wall thickness	Thinner	Thinner
Wind throw	Higher	Higher
Percentage knots	Higher	Higher
Percentage reaction wood	Higher	Higher
Percentage lignin	Higher	Lower
Percentage alpha-cellulose	Lower	Higher
Pulp Characteristics		
Anticipated Quality Based on Known Wood and Fiber Characteristics		
Weight yield	Lower	Higher
Tear factor	Lower	Lower
Burst factor	Higher	Higher
Tensile strength	Higher	Higher
Beating time	Faster	Faster
Percent knotter and screen rejects	Higher	Higher

Some of the characteristics of the fiber in unmerchantable tops of boles are likely to be cancelling in their effects on pulp yield and quality. A high percentage of compression wood will tend to give pulps with a low breaking length, whereas low specific gravity and thin cell-wall fibers will tend to give pulps with a high breaking length. The actual breaking length of a pulp from a given sample of unmerchantable tops may then depend upon the relative effects of compression wood and specific gravity, and these differences, in turn, relate back to more basic factors which affect percentage compression wood and specific gravity, such as taper, dominance, growth conditions and rate, wind throw, etc.

The above broad generalization would be expected to be generally applicable to most *Pinus*, *Picea*, *Abies*, and *Tsuga* species. *Pseudotsuga menziesii* might be an exception. For both hardwoods and softwoods, these trends would be accented where the species is dominant or where wind throw is high and, for both softwoods and hardwoods, these effects would be least with kraft pulp and greatest with calcium-base sulfite pulp.

APPENDIX 1

Check List of Species by Tables and Pages

Species	Table No.	Page
Abies sp.	21, 24, 27 29 - - -	35, 41, 45 48, 61, 61 69
A. alba	29, 32	48, 57
A. amabilis	23	40
A. balsamea	1, 4, 8 9, 14, 21, 22, 23 -	11, 15, 19 20, 26, 35 39, 40, 63
A. concolor	32	57
A. lasiocarpa	29	48
A. procera	32	57
Acer rubrum	1, 4, 8 9, 13, 14 22, 23	11, 15, 19 20, 25, 26 39, 40
A. saccharum	30	53
Alberta species	21	35
Alnus glutinosa	30	53
Angiosperms	26	44
Araucaria sp.	-	60
A. cunninghamii	27, 32	46, 59
A. klinkii	23	40
Betula sp.	22, 28, 30 33, - -	39, 47, 53 59, 48, 60
B. papyrifera	1, 4, 8 9, 13, 14, 23	11, 15, 19 20, 25, 26 40
B. platyphylla	17	30
B. pubescens	33	59

Species	Table No.	Page
Betula verrucosa	33	59
Canadian species	21	35
Carpinus sp.	7	18
C. betulus	28, 30	47, 53
Carya sp.	33	59
Castanopsis cuspidata	17	30
Cedrus sp.	27	45
Chamaecyparis obtusa	24, 25	41, 42
C. pisifera	24, 25	41, 42
Conifers	31	
Cupressus sp.	27	45
Cryptomeria japonica	29, -	48, 61
Dicotyledonous trees	30, 31	53, 56
Diplodiscus paniculatus	30	53
Eucalyptus camaldulensis	23, 30	40, 53
E. elacophora	23	40
E. gigantea	33	59
E. globulus	23	40
E. goniocalyx	36	67
E. regnans	33	59
E. rostrata	23	40
E. sideroxylon	23	40
Exotics	30	53
Fagus sp.	7, 25, 30	18, 42, 53
F. sieboldi	25	42
F. sylvatica	28	47
Fraxinus sp.	30, 33	53, 59

Species	Table No.	Page
T. canadensis	1, 4, 8 13, 14	11, 15, 19 25, 26
T. heterophylla	1, 3 4 9, 13, 14 15, 23, 25 29, 32, -	11, 14, 15 20, 25, 26 27, 40, 42 48, 57, 37
Ulmus sp.	30	53
U. americana	-	67
U. parvifolia	17	30

BIBLIOGRAPHY

1. Adams, W. R., Jr. 1928. Studies in tolerance of New England forest trees. VIII. Effect of spacing in a jack pine plantation. Vermont Univ., Agr. Exp. Sta. Bull. No. 282. 51 p.

2. Aldridge, F., and R. H. Hudson. 1958. Growing quality softwoods: variation in strength and density of *Picea abies* -- specimens taken from a commercial consignment. *Quart. J. Forest.* 52:107-114.

3. Alestalo, Aaro and Yrjö Hentola. 1966. Sulfate pulp from unbarked softwood tops, branches and stumps. Translated from the Finnish by E. Jarvlepp. *Paperi Puu* 48(12):737-42. (Dep. Forest. & R.D. Transl. No. 136).

4. Amidon, George B., and LeBarron, Russell K. 1944. To what top diameter can spruce pulpwood be cut profitably? *Pulp Pap. Mag. Can.* 45 (10):756-758.

5. Amos, G. L., I. J. W. Bisset and H. E. Dadswell. 1950. Wood structure in relation to growth in *Eucalytus gigantea* Hook F. *Australian J. Sci. Res.*, Ser. B. 3:393-413.

6. Anderson, E. A. 1951. Tracheid length variation in conifers as related to distance from pith. *J. Forest.* 49:38-42.

7. Anderson, K. F., and P. Moltesen. 1955. [Technological research on beech: density and its variation; in Danish, English summary]. *Dansk SkogForen. Tidsskr.* 40:592-611.

8. Australia, Commonwealth Sci. Ind. Res. Organ. 1952. Div. Forest Prod., Annu. Rep. 1951/52. 41 p.

9. Australia, Commonwealth Sci. Ind. Res. Organ. 1953. Div. Forest Prod., Annu. Rep. 1952/53. 42 p.

10. Australia, Queensland Dep. Forest. 1958. Annu. Rep. 1957/58. 59 p.

11. Bailey, I. W., and H. B. Shepard. 1915. Sanio's laws for the variation in size of coniferous tracheids. *Bot. Gaz.* 60:66-71.

12. Banks, C. H. 1955. The mechanical properties of the mature wood of *Pinus longifolia*, Roxb. grown in the Union of South Africa. *J. S. African Forest. Ass.* 26:18-31.

13. ____________ and L. M. Schwegmann. 1957. The physical properties of fast- and slow-grown *Pinus patula* and *P. taeda* from South African sources. *J. S. African Forest. Ass.* 30:44-59.

14. Bannan, M. W. 1941. Wood structure of *Thuja occidentalis*. *Bot. Gaz.* 103:295-309.

15. ________________ 1942. Wood structure of the native Ontario species of *Juniperus*. *Amer. J. Bot.* 29:245-252.

16. Bannister, M. H. 1959. Artificial selection and *Pinus radiata*. *New Zealand J. Forest.* 8:69-90.

17. Barbadillo, P. 1967. Summary of Spanish experiments on the pulping of eucalypts. *Appita* 21(2):27-40.

18. Barrow, G. P. 1951. Loss of weight of three Douglas-fir poles. *Quart. J. Forest.* 45:235-236.

19. Benić, R. 1957. [Investigations on the distribution of some physical properties of wood in the stem of narrow-leaved and common ash, *Fraxinus angustifolia* Vahl. and *F. excelsior* L.; in Croatian, English summary]. *Glasnik sumske pokuse* 13:509-536.

20. Barkley, E. F. 1934. Certain physical and structural properties of three species of southern yellow pine correlated with the compression strength of their wood. *Ann. Missouri Bot. Garden* 21:241-338.

21. Bertog, H. 1895. *Untersuchungen uber den Wuchs and das Holz der Weisstanne und Fichte* [Investigation concerning the growth and the wood of white fir and spruce; in German]. *Forstl.-naturw.* Z. 4:97-112; 177-216.

22. Besley, Lowell. 1967. Importance, variation and measurement of density and moisture. Proc. wood measurement conf. Faculty of Forestry, Univ. Toronto, Ontario. Tech. Rep. No. 7:112-142.

23. Bethel, J. S. 1941. The effect of position within the bole upon fiber length of loblolly pine (*Pinus taeda* L.). *J. Forest.* 39:30-33.

24. Bielczyk, S. 1956. [Investigations of the physical and mechanical properties of wood of *Abies alba* and *Pinus sylvestris* originating from a forest community resembling a natural community; in Polish English summary]. *Prâce Inst. Tech.*, Drewna 3(1):86-106.

25. ________________ 1956. [Investigation of the physical and mechanical properties of wood of *Quercus robur* S.l. and *Carpinus betulus* originating from a forest community resembling a natural community; in Polish, English summary]. *Prâce Inst. Tech.*, Drewna 3(3):92-110.

26. Bisset, I.J.W., and H.E. Dadswell. 1949. The variation of fiber-length within one tree of *Eucalyptus regnans*, F.v.M. *Australian Forest.* 13:86-96.

27. ________________________________. 1950. The variation in cell length within one growth ring of certain angiosperms and gymnosperms. *Australian Forest.* 14:17-29.

28. Bjerkelund, T.C. 1967. The primary [wood] transport function [in stump-to-roadside logging] and its major problems. *Pulp Pap. Mag. Can.* (Woodlands Rev.) 68(7):WR314.

29. Bosshard, H.H. 1951. *Variabilität der Elemente des Eschenholz Funktion von der Kambiumtätigkeit* [Variation in the elements of ash wood as a function of cambial activity; in German]. *Schw. Z. Forstw.* 102:648-665.

30. _______________ and C. E. Curran. 1937. Sulfate pulping of southern yellow pines: effect of growth variables on yield and pulp quality. *Pap. Trade J.* 105(20):39-46.

31. Bray, Mark W. and Benson H. Paul. 1930. The evaluation of second growth longleaf pine pulpwood from trees of varying rate of growth. *Southern Lumberman* 141(1793):163-168, 170.

32. _______________ and B. H. Paul. 1934. Evaluation of southern pines for pulp production. III. Shortleaf pine (*Pinus echinata*). *Pap. Trade J.* 99:38-41.

33. _______________ J.S. Martin and S.L. Schwartz. 1939. Sulfate pulping of southern yellow pines. II. Effect of growth variables on yield and pulp quality. *Southern Pulp Pap. J.* 2(6):35-41.

34. _______________________________ 1939. Sulfate pulping of silver fir: effect of chemical concentration and of wood selection on yield and pulp quality. *Pap. Trade J.* 109(18):29-36.

35. _______________________________ 1940. Sulfate Pulping of Douglas-fir: Effect of Growth Variables on Yield and Pulp Quality, III. Tappi Papers Series 23:232-138.

36. Bryan, J. and F.G.O. Pearson. The Quality of Sitka Spruce Grown in Great Britain. *Empire Forest. Rev.* 34:144-59. 1955.

37. Brazier, J.D. 1956. Density variation in the timber of *Shorea albida*. *Empire Forest. Rev.* 35:404-419.

38. Buijtenen, von, J.P., D.W. Einspahr, and P.N. Joranson. 1959. Natural variation in *Populus tremuloides* Michx. *Tappi* 42:819-823.

39. Burger, H. 1935. *Holz, Blattmenge und Zuwachs. II. Die Douglasie* [Wood, foliage yield and growth. II. Douglas-fir; in German]. *Mitt. Schweiz. Anstalt forstl. Versuchsw.* 19:21-72.

40. _______________ 1940. *Holz, Blattmenge und Zuwachs. IV. Ein 80-jähriger Buchenbestand* [Wood, foliage yield and growth. IV. An 80-year old beech stand; in German]. *Mitt. Schweiz. Centralanstalt forstl. Versuchsw.* 21:307-348.

41. ______________ 1941. *Holz, Blattmenge und Zuwachs. V. Fichten und Föhren verschiedener Herkunft auf verschiedenen Kulturorten* [Wood, foliage yield and growth. V. Spruce and pine of different origins planted on different sites; in German]. *Mitt. Schweiz. Centralanstalt forstl. Versuchsw.* 22:10-62.

42. ______________ 1947. *Holz, Blattmenge und Zuwachs. VIII. Die Eiche* [Wood, foliage yield and growth. VIII. Oak; in German]. *Mitt. Schweiz. Centralanstalt forstl. Versuchsw.* 25:211-279.

43. ______________ 1948. *Holz, Blattmenge und Zuwachs. IX. Die Föhre* [Wood, quantity of foliage and increment. IX. Scots pine; in German, French summary]. *Mitt. Schweiz. Anst. forstl. Versuchsw.* 25:435-493.

44. ______________ 1950. *Holz, Blattmenge und Zuwachs. X. Die Buche* [Wood, foliage yield and growth. X. Beech; in German]. *Mitt. Schweiz. Centralanstalt forstl. Versuchsw.* 26:419-468.

45. ______________ 1951. *Holz, Blattmenge und Zuwachs. XI. Die Tanne* [Wood foliage yield and growth. XI. Fir; in German]. *Mitt. Schweiz Centralanstalt forstl. Versuchsw.* 27:247-286.

46. ______________ 1952. *Holz, Blattmenge und Zuwachs. XII. Fichten im Plenterwald* [Wood, foliage yield and growth. XII. Spruce in the selection forest; in German]. *Mitt. Schweiz. Centralanstalt forstl. Versuchsw.* 28:109-156.

47. ______________ 1953. *Holz, Blattmenge und Zuwachs. XIII. Fichten im gleichalterigen Hochwald* [Wood, foliage yield and growth; in German]. *Mitt Schweiz Centralanstalt forstl. Versuchsw.* 29:38-130.

48. Byrd, Von, L. and others. 1965. Wood characteristics and kraft paper properties of four selected loblolly pines. Part II: wood chemical constituents and their relationship to fiber morphology. *Forest Prod. J.* 15(8):313-320.

49. *Can. Pulp Pap. Ind.* Think of forest as a system like farm crops. 20(9):42-4. 1967.

50. Chalk, L. 1930. Tracheid length, with special reference to Sitka spruce. *Forest.* 4:7-14.

51. ______________ 1930. The formation of spring and summer wood in ash and Douglas-fir. Oxford Univ., Forest. Mem. No. 10. 48 p.

52. ______________ 1953. Variation of density in stems of Douglas-fir. Forest. 26:33-36.

53. Chidester, G.H. and J.N. McGovern. 1941. Sulfite pulp from Douglas-fir. *Pap. Trade J.* 113(9):34-38.

54. ________________ M. W. Bray, and C. E. Curran. 1939. Growth rate and position of wood in tree as factors influencing kraft and sulfite pulps from jack pines. *J. Forest.* 37:680-683.

55. ________________ J.N. McGovern and G.C. McNaughton. 1938. Comparison of sulfite pulps from fast-growth loblolly, shortleaf, longleaf and slash pines. *Pap. Trade J.* 107(4):36-39.

56. Cieslar, A. 1896. *Das Rotholz der Fichte* [The "redwood" of spruce; in German]. *Centr. ges. Forstw.* 22:149-165.

57. ________________ 1914. *Studien über die Alpen- und Sudetenlärche* [Studies of Alpen and Sudeten larch; in German]. *Centr. ges. Forstw.* 40:171-184.

58. ________________ and G. Janka. 1902. *Studien über die Qualität rasch erwachsenen Fichtenholzes* [Studies of the wood quality of rapid-growth spruce; in German]. *Centr. ges. Forstw.* 28:337-403.

59. Cleremont, L.P. and F. Bender. 1958. The chemical composition and pulping characteristics of normal and tension wood of aspen, poplar and white elm. *Pulp Pap. Mag. Can.* 59(7):139-143.

60. Cochrane, James A. 1951. Cedar leaf oil extraction. *J. Forest. Prod. Res. Soc.* 1(1):120.

61. Cockrell, R.A. 1959. Mechanical properties of California-grown Monterey pine. *Hilgardia* 28:227-238.

62. Cole, D. E., B. J. Zobel, and J. H. Roberds. 1966. Slash, loblolly, and longleaf pine in a mixed neutral stand -- A comparison of their wood properties, pulp yields, and paper properties. *Tappi* 49(4):161.

63. Cooper, G.A. 1960. Specific gravity of red pine as related to stem and crown-formed wood. *Iowa State Coll. J. Sci.* 34:693-707.

64. Côté, W. A., Jr., B. W. Simson, and T. E. Timell. 1966. Studies in compression wood. Part 2. The chemical composition of wood and bark from normal and compression regions of fifteen species of gymnosperms. *Svensk Papperstidn.* 69:547-558.

65. Curran, C.E. 1936. Some relations between growth conditions, wood structure and pulping quality. *Pap. Trade J.* 106:36-40.

66. Curró, P. 1955. Variations in moisture content, basic density and oven-dry density in *Populus X euramericana* (Dode) Guinier cv. 'I 214'. Int. Poplar Comm. 8th session, Madrid.

67. ________________ 1957. [Seasonal variations in moisture content and variations in basic density in 4 trees of *Eucalyptus camaldulensis* Dehn; in Italian, English summary]. *Pubbl. centro sper. agr. e forestale* 1:215-226.

68. _______________ 1957. [Variations in moisture content and basic density of 15 trees of *Eucalyptus camaldulensis* Dehn; in Italian, English summary]. *Pubbl. centro sper. agr. e forestale* 1:227-238.

69. _______________ 1960. [Technological investigations on the wood of some Euramerican poplar hybrids. I. Physical and mechanical properties; in Italian. English summary]. *Pubbl. centro sper. agr. e forestale* 3:3-61.

70. Dadswell, H. E., and L. F. Hawley. 1929. Chemical composition of wood in relation to physical characteristics. A preliminary study. *Ind. Eng. Chem.* 21:973-975.

71. Dadswell, H. E., A.B. Wardrop and A. J. Watson. 1958. Fundamentals of papermaking fibers. Brit. Pap. Board Makers Ass., London. p. 187-219.

72. Dadswell, H. E., A. J. Watson and J.W.P. Nicholls. 1959. What are the wood properties required by the paper industry in trees of the future? *Tappi* 42:521-526.

73. Dengler, A. 1908. *Das Wachstum von Kiefern aus einheimischem und nordischem Saatgut in der Oberförsterei Eberswalde* [Growth of indigenous and northern pine seed sources in the Eberswalde; in German]. *Z. Forst-u. Jagdw.* 40:137-152; 206-219.

74. Desch, H. E. 1932. Anatomical variations in the wood of some dicotyledonous trees. *New Phytol.* 31:73-118.

75. Dinwoodie, J. M. 1965. The relationship between fiber morphology and paper properties: a review of literature. *Tappi* 48(8):440-447.

76. Doyle, J.A. 1954. Logging waste in eastern Canada. *Ottawa*. Dept. of N. Affairs and Nat. Resources, Forest. Br. Bull. No. 115. 824 p.

77. Duncker, B., and L. Nordman. 1968. *Den enskilda fiberns mekaniska egenskaper.* [Mechanical properties of single fibers; in Swedish]. *Svensk Papperstidn.* 71:165-177.

78. 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.

79. Echols, R.M. 1958. Variation in tracheid length and wood density in geographic races of Scotch pine. Yale Univ., School Forest. Bull. No. 64, New Haven, Conn. 52 p.

80. Eichhorn, E. 1895. *Untersuchungen über das Holz der Roteiche* [Investigation of the wood of red oak; in German]. *Forstl.-naturw. Z.* 4:233-264; 281-296.

81. Einspahr, D.W., J.P. Buijtenen, and J.R. Peckham. 1969. Pulping char-

82. Eis, S. 1968. Letter to author re. dbh measures and data on cedar and hemlock. Forest Research Laboratory, Dep. Forest. Rural Develop., Victoria, B.C. 1 p.

83. Erickson, H. D. 1949. Relation of specific gravity to shrinkage and these factors to growth in yellow poplar. *J. Agr. Res.* 78:103-127.

84. Etheridge, D.E. 1958. The effect on variations in decay of moisture content and rate of growth in subalpine spruce. *Can. J. Bot.* 36:187-206.

85. Ezpeleta, L. Bustamante, and A. Caperos Sierra. 1966. The use of small wood of *Eucalyptus globulus* and *E. rostrata* as raw material for pulping. Transl. from Spanish; Inst. Forest. Invest. Exper. Madrid, Bol. 35(87):89-92. Ontario Res. Foundation, Dep. Organic Chem. Transl. 66-1. 4 p.

86. Fahey, D. J., and J. F. Laundrie. 1968. Kraft pulps, papers, and linerboard from southern pine thinnings. U. S. Dep. Agr., Forest Serv. Res. Note FPL-0182. 8 p.

87. Fegel, Arthur C. 1941. Comparative Anatomy and Varying Physical Properties of Trunk, Branch, and Root Wood in Certain Northeastern Trees. Bull. N.Y. State Coll. Forest., Syracuse Univ. Syracuse, Tech. Pub. No. 55, 20 p.

88. Fogh, I.F., D.C. Horncastle and Rose, L.B. 1963. The development of mechanical logging methods for eastern Canada. *Pulp Pap. Mag. Can.* 64(9):WR340-342, WR344-346.

89. Fogh, I.F. and others. 1965. Fundamentals of mechanized logging. *Pulp Pap. Mag. Can.* 66(5):WR234, WR236-237, WR239-241, WR244-245, WR248-249, WR252-253.

90. Gerry, E. 1915. Fiber measurement studies; Length variations: Where they occur and their relation to the strength and uses of wood. *Sci.* 41:179.

91. ________________ 1916. Fiber measurement studies: A comparison of tracheid dimensions in longleaf pine and Douglas-fir, with data on the strength and length, mean diameter and thickness of wall of the tracheids. *Sci.* 43:360.

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

93. Göhre, K. 1960. *Die Verteilung von Rohwichte im Pappelstamm* [The distribution of density in poplar stems; in German, English summary]. Wiss. Abhandl. deut. Akad. LandwWiss. (Berlin) No. 44:51-79.

94. Hägglund, Erik. 1942. *Vedbeskaffenhetens inflytande pa utbyte och kvalitet av sulfitmassa* [The influence of wood quality upon yield and quality

95. ______________ 1944. [The relationship between stand management and the quality of wood for pulp; in German]. *Silvae Orbis* 15:237-241.

96. Hale, J. D. 1928. Timber physics research in Canada. Third Brit. Empire Forest. Conf., Australia and New Zealand. 13 p.

97. ______________ and K. G. Fensom. 1931. The rate of growth and density of the wood of white spruce. Can. Dep. Interior, Forest Serv. Circ. 30. 19 p.

98. Hammond, R. N. and P. S. Billington. 1949. The relation of kraft pulp qualities to the wood properties of Douglas-fir. *Tappi* 32(12):563-568.

99. Harlow, W. M. 1927. The effect of the site on the structure and growth of white cedar (*Thuja occidentalis* L.). *Ecol.* 8:453-470.

100. Harstad, F. Lier. 1956. [Consumption and use of raw material by the wallboard industry and quality of fiberboards required by consumers; in Norwegian]. *Norsk. Skogind.* 10(6):204-213. (Ottawa Forest Prod. Lab., Transl. No. 110. 17 p.)

101. Hartig, R. 1874. *Das Specifisch Frisch und Trockengewicht, Wassegehalt und das Schwinden des Kiefernholzes* [Fresh and air-dry specific gravity, moisture content and shrinkage of pine wood; in German]. *Z. Forst- u. Jagdw.* 6:194-219.

102. ______________ 1888. *Das Fichten- und Tannenholz des bayerischen Waldes* [Spruce and fir from Bavarian forests; in German]. *Cenges. Forstw.* 14:357-364.

103. ______________ 1892. *Die Verschiedenheiten in der Qualität und im anatomischen Bau des Fichtenholzes* [Differences in the quality and anatomical structure of spruce wood; in German]. *Forestl.-naturw. Z.* 1:209-233.

104. ______________ 1894. *Untersuchungen über die Entstehung und die Eigenschaften des Eichenholzes* [Investigations of the formation and the characteristics of oak wood; in German]. *Forstl.-naturw. Z.* 3:1-13; 49-68; 172-191; 193-203.

105. ______________ 1896. *Das Rotholz der Fichte* [Compression wood of spruce; in German]. *Forstl.-naturw. Z.* 5:96-109; 157-169.

106. ______________ 1898. *Bau und Gewicht des Fichtenholzes auf bestem Standorte* [Structure and weight of spruce wood on the best sites; in German]. *Forstl.-naturw. Z.* 7:1-19.

107. Harwood, V. D., and J. M. Uprichard. 1969. Pulp quality and chemical composition of *Pinus radiata* pulps. *Appita* (Melbourne) 22(6):153-162.

108. Hata, K. 1949. Studies on the pulp of Akamatsu (*Pinus densiflora* Sieb. et Zucc.). (I) On the length, diameter, and length-diameter ratio

109. Haught, E. 1957. Distribution and extent of compression wood in loblolly pine. N. C. State Coll., School Forest., 1st Forest Tree Impr. Progr. Rept., Raleigh. 14 p.

110. Heiskanen, V. 1968. Experience obtained in Finland on the utilization of small-sized timber. Geneva, Switz., FAO/ECE/ILO Joint Comm. Tech. Traini Forest Workers, 7th session, Warsaw. Symposium on the mechanization of harvesting of small-sized wood and logging residues. 4 p. 3 fig. (FAO/ECE/LOG/213).

111. Hejnowicz, A., and Z. Hejnowicz. 1958. Variation of length of vessel members and fibers in the trunk of *Populus tremula* L. *Acta Soc. Bot. Polon.* 27:131-159.

112. Hildebrandt, G. 1954. *Untersuchungen an Fichtenbeständen über Zuwachs und Ertrag reiner Holzsubstanz* [Investigation of growth and yield of pure wood substance in a spruce stand; in German]. Deut. Verlag Wissenschaften, Berlin. 133 p.

113. Hirai, S. 1949. [Studies on the variation in density of woods in the green stem of Japanese larch; in Japanese, English summary] Hokkaido Univ. Exp. Forest. Res. Bull. 14:124-154.

114. ________________ 1950. [Studies on the weight-growth of forest trees. II *Picea excelsa* Link of the "Chichibu" Univ. Forest.; in Japanese, English summary]. Tokyo Univ. Forests Bull. No. 38:139-152.

115. ________________ 1951. [Studies on the wood density of forest trees. III. *Cryptomeria japonica* D. Don of Daigo district, Ibaragi prefecture; in Japanese, English summary]. Tokyo Univ. Forests Bull. No. 39:219-234.

116. ________________ 1951. [Study on the distribution of moisture, "Dichtezahl" shrinkage and moisture-air space, and wood-substance-volume percentage in the green stem of Japanese larch; in Japanese, English summary]. Hokkaido Univ. Exp. Forest Res. Bull. 15:97-150.

117. ________________ 1955. [Studies on weight-growth of forest trees. V. *Pinus strobus* L. of the Tokyo University Forest in Hokkaido; in Japanese, English summary]. Tokyo Univ. Forests Bull. No. 48:221-235.

118. Holst, M. J. 1958. Thoughts on wood density. Can. Comm. Forest Tree Breeding Proc., Part II:S31-S32.

119. Horvat, I. 1942. [Investigation of the specific gravity and shrinkage of Slovakian oak wood; in Croatian, German summary]. *Glasnik sumske pokuse* 8:61-135.

120. Hughes, F.E. 1965. Tension wood: A review of literature. Part II. The properties and use characteristics of tension wood. *Forest. Abstracts* 26(2):179-186.

121. Hughes, R. V., and A. W. Mackney. 1949. Density and moisture content of New Zealand *Pinus radiata* D. Don. *Appita Proc.* 3:387-407.

122. Inokuma, T., K. Shimaji, and T. Hamaya. 1956. [*Studies on poplars. (l) Measurement on fiber-length and specific gravity of Japanese giant poplar* (*Populus Japono-gigas*); in Japanese, English summary]. Tokyo Univ. Forests, Misc. Inform. No. 11:77-86.

123. Jackson, L.W.R. 1959. Loblolly pine tracheid length in relation to position in tree. *J. Forest.* 57:366-367.

124. Jacobs, M. R. 1945. The growth stresses of woody stems. Australian Commonwealth Forest. Bur., Bull. No. 28. 67 p.

125. Jalava, M. 1945. [Strength properties of Finnish pine, spruce, birch and aspen; in Finnish, English summary]. *Communs. Inst. Forest. Fenniae* 33:1-66.

126. Janka, G. 1921. *Ueber die technische Qualität des Douglastannenholzes* [The technical quality of Douglas-fir wood; in German]. *Centr. ges. Forstw.* 47:185-198.

127. Jayme, G., K. G. Hindenburg, M. Harders-Steinhäuser, and F. Branscheid. 1943. *Über die Eignung ein-und zehnjährigen Pappelholzes zur Zellstoffgewinnung* [The suitability of wood from one and ten-year-old poplars for the production of pulp; in German]. *Holz Roh-u. Werkstoff* 6:1-16.

128. Jayme, G., M. Harders-Steinhäuser, and W. Mohrberg. 1951. Papier Darmstadt 5:411-417, 445-447.

129. Jayne, B. A. 1958. Effect of site and spacing on the specific gravity of wood of plantation-grown red pine. *Tappi* 41:162-166.

130. Johnstone, W. D. 1968. Weight data *Pinus contorta* var. *latifolia*. Kananaskis. Forest Exp. Sta., Alberta. Private communcation.

131. ________________ 1968. Some observations of the biomass of lodgepole pine trees. Dept. Forestry and R.D., Calgary, Alberta. 11 p. 8 fig. (Paper presented Mensuration Session, C.I.F. Annual Meeting, Sept. 26, 1968, St. John's Newfoundland.)

132. Jukna, A. D., and K. K. Tiltinsch. 1955 [Physical and mechanical properties of ash wood grown on first-quality sites in the Latvian SSR; in Latvian]. *Izvest. Akad. Nauk Latv. S.S.R.* 6:35-48.

133. ________________________________ 1956. [Physical and mechanical properties of the wood of *Alnus glutinosa* growing in the Latvian S.S.R.; in Latvian]. *Latvijas PSR Zinatnu Akad. Vestis*, Riga 3:69-74.

134. Kachelkin, L. I., V.M. Cherezova and V. I. Bukharkin. 1962. [Logging wastes as an industrial raw material; in Russian]. *Lesnaya Prom.*

135. Kaeiser, M., and M. Y. Pillow. 1955. Tension wood in eastern cottonwood. U. S. Dep. Agr. Cent. States Forest Exp. Sta., Tech. Pap. No. 149. 9 p.

136. Kaeiser, M., and K. D. Stewart. 1955. Fiber size in *Populus deltoides* Marsh. in relation to lean of trunk and position in trunk. *Bull. Torrey Bot. Club* 82:57-61.

137. Kano, T. 1959. [On the breadth of annual rings, the percentage of summerwood and the bulk-density of sugi (*Cryptomeria japonica* D. Don) grown at Kamabuchi District; in Japanese, English summary]. Hokkaido Univ. Expt. Sta. Res. Bull. 20:139-151.

138. Keays, J. L. 1968. Whole-tree utilization studies: selection of tree components for pulping research. Can. Dep. Forest. Rural Develop., Forest Prod. Lab., Inform. Rep. VP-X-35, Vancouver, B.C. 31 p.

139. ________________ 1968. The forests and forest industries of the U.S.S.R Proc. Forest Eng. Conf., Amer. Soc. Agr. Eng., East Lansing, Mich.

140. ________________ 1969. Preliminary report on the pulping of spruce and pine tops. Can. Dep. Fish. Forest., Vancouver Forest Prod. Lab., Project V-145-4-3. Vancouver, B. C. 8 p.

141. ________________ 1970. Wood supply and wood-products demand to the year 2000. Can. Dep. Fish. Forest., Forest Prod. Lab., Internal Rep. VP-52, Vancouver, B. C.

.42. ________________ and J. V. Hatton. 1971. Complete-tree utilization studies. I. The yield and quality of kraft pulp from the components of *Tsuga heterophylla*. *Tappi* 54(1):99-104.

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

.44. Kelsey, J. E., and R. L. Steele. 1956. Shrinkage and density of plantation grown *Pinus radiata*. Australia, CSIRO, Div. Forest Prod., Proj. T. P. 22, Progr. Rep. No. 2. 12 p.

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

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

47. Kennedy, R. W., and J. W. Wilson. 1954. Studies on smooth and cork-bark *Abies lasiocarpa*. II. Specific gravity comparison. *Pulp Pap. Mag. Can.* 55:119-121.

148. Keylwerth, R. 1954. *Ein Beitrag zur qualitativen Zuwachsanalyse,* A contribution to qualitative growth analysis; in German. *Holz Roh-u. Werkstoff* 12:77-83.

149. Kiil, A. D. 1965. Weight and size distribution of slash of white spruce and lodgepole pine. *Forest. Chron.* 41(4):432-37.

150. Kiil, A. D. 1967. Fuel weight tables for white spruce and lodgepole pine crowns in Alberta. Can. Dep. Forest. Rural Develop., Dep. Pub. No. 1196, Ottawa.

151. Kincaid, D. H. 1945. Groundwood from spruce and balsam tree tops. *Pulp Pap. Mag. Can.* 46(2):155-156.

152. Klass, Charles P. 1967. What are the latest developments in Canadian logging techniques? *Pap. Trade J.* 151(33):50-52.

153. Klem, G. G. 1933. *Untersuchungen über die Qualität des Fichtenholzes* [Studies of the quality of spruce wood; in Norwegian, German summary]. *Medd. Norske Skogforsksv.* 5:197-348.

154. ________________ 1942. [Effect of planting space on the quality of spruce wood and sulfite pulp; in Norwegian, English summary]. *Medd. Norske Skogforsksv.* 8:257-293.

155. ________________ Fritujof Loschbrandt, and Otto Bade. 1945. [Investigation of spruce wood in connection with mechanical wood pulp and sulfite pulp experiments; in Norwegian, Eng. sum.]. Papirindustriens Forsk., Meddeleln No. 20. 127 p. (Also Meddelelser fra Det Norske Skogforsöksvesen, No. 31).

156. Kleppe, Peder J. 1970. The process of, and products from, kraft pulping of southern pine. *Forest Prod. J.* 20(5):50-59.

157. Koeppen, A. von and Luise Sitzman. 1954. A Laboratory investigation of the pulping properties of two Araucaria species from New Guinea. *Appita Proc.* 8:264-289.

158. Konig-Vrolijk, G. M. C. 1958. [Relationship of structure and mechanical properties of oak; in Dutch]. Houtwereld, Ned. Aug. 30. 4 p.

159. Koroleff, A. 1954. Full-tree logging -- a challenge to research. Pulp and Pap. Res. Inst. Can. Montreal, 101 p. Woodlands Research Index No. 93 (B-1).

160. Kossoj, A. S. 1967. [Utilization of hardwood in the pulp and paper industry; In Russian]. Lesnaja Promyshlennost, Moscow. 316 p.

161. Kramer, P. J. 1957. Tracheid length variation in loblolly pine. Texas Forest Serv., Tech. Rep. 10. 22 p.

162. Kribs, D. A. 1928. Length of tracheids in jack pine in relation to their position in the vertical and horizontal axes of the tree. Univ. Minn., Agr. Exp. Sta., Tech. Bull. No. 54. 14 p.

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

65. Kuziel, S. 1953. *Recherches sur la longueur de fibres du bois* [Research on the length of wood fibers; in French]. Bull. Soc. Sci. Lettres Lodz, Classe III de Sciences mathématiques et naturelles 4(13). 2 p.

66. Langlands, I. 1938. The mechanical properties of South Australian plantation-grown *Pinus radiata* D. Don. Australia Dep. Forest., Div. Forest Prod., Tech Pap. No. 30. 53 p.

67. Lee, H. N., and E. M. Smith. 1916. Douglas-fir fibers, with special reference to length. *Forest. Quart.* 14:671-695.

68. Lenz, O. 1954. *Le bois quelques peupliers de culture en Suisse* [The wood of a few poplars cultivated in Switzerland; in French] *Mitt. Schweiz. Centralanstalt forstl. Versuchsw.* 30:9-61.

69. Leont'ev, N. L. 1948. [Influence of age on the quality of Scots pine timbers; in Russian]. Priroda (Moskva) 37:53-55.

70. Leslie, A. J. 1956. Cellulose, forestry. *Appita Proc.* 10:12-29.

71. Liang, S. C. 1948. Variation in tracheid length from the pith outwards in the wood of the genus *Larix*, with a note on variation of other anatomical features. *Forest.* 22:222-237.

72. Liese, W., and U. Ammer. 1958. *Untersuchungen über die Länge der Holzfaser bei der Pappel* [Investigation of the length of the wood fibers in poplar; in German]. *Holzforschung* 11:169-174.

73. Lindgren, R. M. 1949. Density and moisture relations in slash pine wood. U. S. Dep. Agr., Southern Forest Exp. Sta., Forest. Notes No. 63.

74. Loe, J. A., and A. W. Mackney. 1953. Effect of age on density and moisture content of New Zealand *Pinus radiata*. *Appita Proc.* 7:183-194.

75. Luxford, R. F., and L. J. Markwardt. 1932. The strength and related properties of redwood. U. S. Dep. Agr., Forest Serv., Tech. Bull. No. 305. 48 p.

76. MacArthur, J. D. 1968. North Western [Pulp & Power Ltd.] pioneer and pace-setter in forest management. *Pulp Pap. Mag. Can.* 69(16):36-43.

77. MacLaurin, D. J. and J. F. Whalen. 1954. Continuous high-yield kraft pulping of Douglas-fir lumber waste. *Tappi* 37(4):143-147.

78. MacMillan, W. B. 1925. A study in comparative lengths of tracheids of red spruce grown under free and suppressed conditions. *J. Forest.* 23:34-42.

179. Madgwick, H.A.I. 1963. Nutrient research: Some problems of the total tree approach. *Proc. Soil Sci. Soc. Amer.* 27(5):598-600.

180. *Malayan Forest.* 1948. Quality of meranti tembaga from different areas. 11:128.

181. Maširević, Borde. 1960. [Logging and sawmill wastes as raw material for the manufacture of pulp]. *Tehnika* 15(4). Hem. ind. 14(4): 56-63. (Croatian; Ger.; abstr. only avail.).

182. McGovern, J. N., and G. H. Chidester. 1938. Sulfite pulps from the top, middle and butt logs of western hemlock of four growth types. *Pap. Trade J.* 106(23):37-39.

183. Melo, Roberto S. and Ernesto P. Madsen. 1966. Pulps from sawmill waste and thinnings. *Tappi* 49(9):54A-55A.

184. Meulenhoff, L.W.M., and W. Sukotjo. 1965. [Variations in specific gravity, fiber length and cellulose content in *Pinus merkusii;* in Indonesian, English summary]. *Rimba Indonesia* 10(2/3):120-141.

185. Mohr, C., and F. Roth. 1896. The timber pines of the southern United States together with a discussion of the structure of their wood.

186. Mottet, A., and J. Quoilin. 1957. *Variation de la longueur des trachéides et de l'épaisseur de leurs parois chez quelques résineux* [Variation in the length of tracheids and the thickness of their walls in several coniferous species; in French]. Inst. agron. sta. recherches Gembloux, Bull. 25:116-138.

187. Muraro, S. J. 1966. Lodgepole pine logging slash. Can. Dep. Forest., Dep. Publ. No. 1153. 14 p.

188. Murthy, L.S.V. 1959. Density variation in the timber of ramin, *Gonystylus bancana.* Oxford Univ., Imp. Forest Res. Inst. Rep. 1958/59:19.

189. Myer, J.E. 1930. The structure and strength of four North American woods as influenced by range, habitat, and position in the trees. N.Y. State Coll. Forest., Syracuse Univ. Tech. Publ. 31, Syracuse. 39 p.

190. Narayanamurti, D., and N. R. Das. 1955. *Die Abhängigkeit der chemischen Zusammensetzung des Holzes einiger indischer Holzarte von seiner Lage innerhalb des Stammes* [The dependence of the chemical composition of the wood on its location within the stem in several species of Indian trees; in German]. *Holz Roh-u. Werkstoff* 13:52-56.

191. Nesterov, V. G., and S. A. Korotkova. 1968. [Calculation technique of parabolic curves to describe the forms of tree trunks; in Russian]. *Timiryazevskaya Sel'skokhoz. Akad. Dokl. Tskha,* Moscow 144:227-233.

192. New Zealand Forest Service. 1948. New Zealand Forest Serv. Annu. Rep. 1947/48. 70 p.

193. Nikitin, N.I., T.I. Rudneva, A.F. Zaitseva, and M.M. Chochieva. 1949. [Study of the chemical composition of oak wood as influenced by the type of forest; in Russian]. *Zhur. Priklad, Khim.* 22:67-78.

194. Nördlinger, H. 1879. *Grössere Tragkraft im Lichstande erwachsenen Föhrenholzes* [Greater strength of pine wood from an open-grown stand; in German]. *Centr. ges. Forstw.* 5:1-2.

195. Nylinder, P. 1953. [Variations in density of planted spruce; in Swedish, English summary]. *Medd. Statens Skogsforskningsinst.* 43:1-44.

196. ________________ 1959. [A study on quality production; in Swedish, English summary]. *Kungl. Skogshögskolan Nr U* 2:1-19.

197. ________________ and E. Hägglund. 1954. [The influence of stand and tree properties on yield and quality of sulfite pulp of Swedish spruce (*Picea excelsa*); in Swedish, English summary]. *Medd. Statens Skogsforskingsinst.* 44(11):1-184.

198. Ollinmaa, P. J. 1956. [On the anatomic structure and properties of the tension wood in birch; in Finnish, English summary]. *Acta Forest Fennica* 64:1-263.

199. Omeis, E. 1895. *Untersuchungen des Wachsthumsganges und der Holzbeschaffent Unes 110 jakrigon Kiefernbestandes.* [Investigation of the growth processes and wood quality of a 110-year-old pine stand; in German]. *Forstl.-naturw. Z.* 4:137-170.

200. Orman, H. R. 1952. Physical properties of *Pinus patula* from Whakarewarewa Kaingaroa State Forests. New Zealand Forest Prod. Res. Notes. 1:1-24.

201. Ovington, J. D. 1962. Quantitative ecology and the woodland ecosystem concept. *Advance. Ecol. Res.* 1:103-192.

202. Packman, D. F., and R. A. Laidlaw. 1967. Pulping of British-grown softwoods. Part IV. A study of juvenile, mature and top wood in a large Sitka spruce tree. *Holzforsch.* 21(2):38-45.

203. Paul, B. H. 1927. Producing dense southern pine timber in second-growth forests. *Southern Lumberman* 128(1668):46-47.

204. ________________ 1929. The relation of growth factors to wood quality -- white ash. *Southern Lumberman* 136(1762):57.

205. ________________ 1929. Relation of growth factors to wood quality growing space -- longleaf pine. *Southern Lumberman* 136(1768):53-54.

206. ________________ 1930. The application of silviculture in controlling the specific gravity of wood. U. S. Dep. Agr., Tech. Bull. No. 168. 20 p.

207. ________________ 1939. Variation in specific gravity of the springwood and summerwood of four species of southern pines. *J. Forest.* 37:478-482.

208. ________________ 1950. Wood quality in relation to site quality of second-growth Douglas-fir. *J. Forest.* 48:175-179.

209. ________________ 1959. Second-growth oak. Part I. Southern Lumber J. Bldg. Material Dealer, Jan. 1959. 4 p; Part II. Feb. 1959. 3 p.

210. ________________ and M. E. Baudendistel. 1945. Open-grown sugar maple for textile shuttles. *Southern Lumberman* 161(2153):173-175.

211. ________________ A. W. Dohr, and J. T. Drow. 1955. Specific gravity, shrinkage, and strength of tanoak. U. S. Dep. Agr., Forest Serv., Forest Prod. Lab. Rep. No. 2041. 8 p.

212. Pechmann, H. von. 1958. *Über den Zusammenhang zwischen der Struk tur und der Festigkeit bei einigen Laubhölzern* [The relationship between the structure and strength of a few hardwoods; in German]. Int. Union Forest Res. Organ., 12th Congr., Oxford, 1956. 41/3:229-236.

213. ________________ and O. Schaile. 1955. *Untersuchungen über die Holzeigenschaften japanischer Lärchen von bayerischen Anbaugebieten* [Investigation of the wood characteristics of Japanese larch from different sites in Bavaria; in German]. *Forstwiss. Centr.* 74: 87-112.

214. Pentegova, V. A. 1950 [Chemical composition of the wood of *Pinus sibirica*; in Russian]. *Zhur. Priklad. Khim.* 23:998-1000.

215. Phillips, F.H. and A. J. Watson. 1959. Pulping studies on New Guinea woods; pulping properties of *Araucaria* veneer waste and plantation thinnings. *Appita* 12(5):156-166.

216. ________________________________ 1963. Pulping of *Pinus pinaster*. Melbourne, Proc. 19th Pulp and Pap. Res. Conf., 1963. p. 50-51.

217. Pillow, M. Y., and R. F. Luxford. 1937. Structure, occurrence and properties of compression wood. U. S. Dep. Agr., Tech. Bull. No. 546. 32 p.

218. ________________ E. R. Schafer, and J. C. Pew. 1936. Occurrence of compression wood in black spruce and its effect on properties of groundwood pulp. U. S. Dep. Agr., Forest Serv., Forest Prod. Lab. Rep. No. R1288. 3 p.

219. Pjević, V. 1970. Studies on the chemical composition of reaction wood of *Fagus sylvatica*. Sumaretvo 23(1/2):62-65.

220. Prichard, R. P., and I. W. Bailey. 1916. The significance of certain variations in the anatomical structure of wood. *Forest. Quart.* 14:662-670.

221. Prosinki, S., W. Kontek, and R. Babicki. 1954. [Dependence of the chemical composition of Norway spruce wood on the age of the trees and their geographical location; in Polish, English summary]. *Prace Inst. Tech.* Drewna 1:5-22.

222. Puchkov, M. V. 1963. [Study of the yield of usable pine and spruce twigs and needles in logging; translated from the Russian by J. L. Keays]. *Lesnoi Zh.* 6(3):149-52.

223. *Pulp Pap. Mag. Can.* 1968. Man-made forests: wood supply for the future. 69(6):91-93.

224. Quaile, George. 1966. The case for long length logging (condensation). Tech. Rel., Amer. Pulpwood Ass., New York, N. Y.

225. Reid, H. A. 1962. Some factors affecting the kraft pulping of pine woods. *Appita* 15:102-110.

226. Romancier, Robert M. 1961. Weight and volume of plantation-grown loblolly pine. U. S. Dep. Agr., Forest. Serv., S.E.F.E.S. Res. Notes 161. 2 p.

227. Runquist, E., and B. Thunell. 1945. [Research on some wood properties in birch; in Swedish, English summary]. Medd. Svenska Träforskn-Inst. (Trätekn. Avd.) No. 7. 11 p.

228. Sanio, K. 1872. *Ueber die Grösse der Holzzellen bei der gemeinen Kiefer (Pinus sylvestris)* [The size of the wood cells in the common pine, *Pinus sylvestris;* in German]. *Jahrb. wiss. Bot.* 8:401-420.

229. Sårkány, S., J. Stieber, and Z. Filló. 1957. Investigations on the wood of Hungarian *Populus* species by means of quantitative xylotomy. Ann. Univ. Sci. Budapest., Sect. Biol. No. 1:219-229.

230. Scaramuzzi, G. 1955. Dimensional data about wood fibers in *Populus X euramericana* (Dode) Guinier cv. "I 214". Int. Poplar Comm., 8th Session, Madrid, 1955.

231. ________________ 1958. Variation of the volume proportions of wood elements within the stem in *Populus X euramericana* (Dode) Guinier CV. "I 214". Int. Union Forest Res. Organ., 12th Congr., Oxford, 1956. 41/5:242-251.

232. Schonbach, H. 1954. *Cellulose untersuchungen an Einzelstämmen und Klonen der Pappal* [Cellulose contents of individual stems and clones of poplar; in German]. *Z. Forstgenet.* 3:139-140.

233. Schultze-Dewitz, G. 1958. *Einflusa der soziologischen Stellung auf den Jahrringbau sowie auf die Holzelemente bei Kiefern, Spirken und Lärchen eines Naturwaldes* [Influence of position in the stand on the annual ring structure and on the wood elements in Scotch pine, Mugo pine and larch; in German]. *Holz-Zentr.* 84:849-851.

234. ________________ 1959. *Variation und Häufigkeit der Faserlänge der Fichte* [Variation and frequency distribution of tracheid length in spruce; in German]. *Holz Roh-u. Werkstoff* 17:319-326.

235. ________________ 1959. *Einfluss der Kronenhöhe auf den Jahrringbau sowie auf die Faserlänge und den Markstrahlenanteil bei der Fichte verschiedener Altersklassen* [Influence of crown height on annual ring structure, tracheid length, and the proportion of medullary rays in spruce of different age classes; in German, English summary]. *Holzforsch. u. Holzverwert.* 11:67-74.

236. Shepard, H. B., and I. W. Bailey, 1914. Some observations on the variation in length of coniferous fibers. *Proc. Soc. Am. Forest.* 9:522-527.

237. Smith, D. M. 1956. Effect of growth zone on specific gravity and percentage of summerwood in wide-ringed Douglas-fir. U. S. Dep. Agr., Forest Serv., Forest Prod. Lab. Rep. No. 2057 15 p.

238. Smith, J. H. G. 1968. Simulation of forest fuels. Forest. Sect., Northwest Sci. Ass., Cent. Wash. State Coll., Ellensburg. 7 p.

239. Smith, W. J. 1959. Tracheid length and micellar angle in hoop pine (*Araucaria cunninghamii* Ait). Their variation, relationship and use as indicators in parent tree selection. Res. Note Qd. For. Serv. Australia, No. 8. 61 p. 44 refs.

240. *Southern Lumberman.* 1949. Density and moisture relations in slash pine wood. 179:160.

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

242. Spurr, Stephen H. and Matti J. Hyvärinen. 1954. Wood fiber length as related to position in tree and growth. *Bot. Rev.* 20(9):561-75.

243. Stauffer, O. 1892. *Untersuchungen über spezifisches Trockengewich sowie anatomischen Bau des Holzes der Birke* [Study of the specific dry weight and the anatomical structure of birch wood; in German]. *Forstl.-naturw. Z.* 1:145-163.

244. Strekalovskii, N. I. 1946. [The technical properties of northern spruce wood; in Russian]. Sbornik Nauch. Isaledovatel. Rabot Arkhangel. lesotekh. Inst. 1946(8):17-36.

245. Sterns, R. W. 1918. Canadian Douglas-fir. Can. Dep. Interior, Forest. Br. Bull. 60. 84 p.

246. Stevens, S.H.I. 1959. Tracheid length in *Pinus caribaea* Morelet. Oxford Univ., Imp. Forest Res. Inst., Rep. 1958/59:18-19.

247. Stockman, Lennart. 1962. Influence of some morphological factors on the quality of spruce sulfite and pine sulfate pulp. *Svensk Papperstidn.* 65:978-982.

248. Stojanoff, V., and E. Entcheff. 1958. *Über die Verteilung der Rohwichte im Stamm und ihre Beeinflussung durch Wuchsgebiet und Standort* [On the distribution of specific weight within the stems, and how far it may be influenced by growth locality and site; in German, English summary]. *Arch. Forstw.* 7:953-958.

249. Sudo, S. 1968. [Variation in tracheid length in akamatsu (*Pinus densiflora* Sieb. et Zucc.). I. Variation in tracheid length within a young tree stem. II. Variation in tracheid length in one-year-old branches of a tree; in Japanese, English summary]. *J. Jap. Wood Res. Soc.* 14(1):1-10.

250. Susmel, L. 1952. [Correlations between annual rings, proportion of latewood, tracheids, and density of Douglas-fir wood; in Italian, French summary]. *Ital. forest. e mont.* 7:30-45.

251. Susmel, L. 1954. *Le poids specifique du bois d'eucalyptus camaldulensis par rapport á quelques facteurs relatifs á l'individu et au milieu* [The specific weight of the wood of *Eucalyptus camaldulensis* with regard to a few factors pertaining to the individuals and the environment; in French]. Int. Union Forest Res. Organ., 11th Congr. (Rome) 1953:1065-1075.

252. Tadaki, Yoshiya, Nobuo Ogata and Tetsuo Takagi. 1962. Studies on production structure of forest (III) Estimation of standing crop and some analyses on productivity of young stands of *Castanopsis cuspidata*. *J. Jap. Forest. Soc.* 44(12):350-360.

253. ________________ and others. 1961. Studies on productive structure of forest (II) Estimation of standing crop and some analyses on productivity of young birch stand (*Betula platyphylla*). *J. Jap. Forest. Soc.* 43(1):19-26.

254. ________________ and Tsunahide Shidei. 1960. Studies on productive structure of Forest (I) The seasonal variation of leaf amount and the dry matter production of deciduous sapling stand (*Ulmus parvifolia*). *J. Jap. Forest. Soc.* 42(12):427-434.

255. Tamolang, F. N., and B. B. Balcita. 1957. The specific gravity of balobo (*Diplodiscus paniculatus* Turcz.) from Makiling National Park. *Forest Leaves* (Philippines) 10:21-28.

256. Texas Forest Service, A. and M. College. 1939. Pine pulpwood from logging tops. *Pap. Trade J.* 109(26):28-29.

257. Timell, T.E. 1969. The chemical composition of tension wood. *Svensk Papperstidn.* 72:173-181.

258. Tomćuk, R. I. and G. N. Tomćuk. 1966. [Tree foliage and its utilization; in Russian]. Moscow, Izdatel stvo 'Lesnaja Promyślennost´' 241 p.

259. Turnbull, J. M. 1937. Variations in strength of pine timbers. *S. African J. Sci.* 33:653-682.

260. ________________ 1947. Some factors affecting wood density in pine stems. Union S. Africa, Dep. Forest., Publ. No. 82. 22 p.

261. Ugrenović, A., and B. Solaja. 1931. [Investigation of the specific weight of the wood and the oleoresin content of the pine species *Pinus nigra* Arn. and *Pinus sylvestris* L.; in Croatian, German and French summary]. *Glasnik umske pokuse* 3:27-90.

262. Union of S. Africa, Dep. Forest. 1947. Timber mechanics. Ann. Rep. 1946:9.

263. Vries, J. de. 1969. Utilisation and harvesting of small-sized wood. *Australian Timb. J.* 35(8):59-73.

264. Wallden, P. 1935. [Investigation of the relationship between the technical characteristics and anatomical structure of birch wood according to cell measurements; in Finnish, German summary]. *Acta Forest. Fennica* 40:329-366.

265. Wandt, R. 1937. *Die Eigenschaften "Stamm- und Kronenburtigen" Holzes. Eine Untersuchungen über den Einfluss von Alter und Stammhöhe auf Holzeigenschaften der Fichte und Kiefer* [The characteristics of stem and crown-formed wood. An investigation of the influence of age and stem height upon the wood characteristics of spruce and pine; in German]. *Mitt. a Forstwirtsch. u. Forstwiss.* 8:343-369.

266. Wangaard, F. F., R. M. Kellogg, and A. W. Brinkley. 1966. Variation in wood and fiber characteristics and pulp sheet properties of slash pine. *Tappi* 49(6):263-277.

267. Wangaard, F. F., and E. V. Zumwalt. 1949. Some strength properties of second-growth Douglas-fir. *J. Forest.* 47:18-24.

268. Wardrop, A. B. 1948. Fiber studies. E. The growth of conifer stem in relation to the physical and chemical properties of the secondary xylem. Melbourne, Australia, C.S.I.R.O. Pulp and Pap. Res. Conf. Proc., 1948. p. 62-83.

269. ________________ 1951. Cell wall organization and the properties of the xylem. I. Cell wall organization and the variation of breaking load in tension of the xylem in conifer stems. *Australian J. Sci. Res., Ser. B.,* 4:391-414.

270. ________________ and R. D. Preston. 1950. The fine structure of the wall of the conifer tracheid. V. The organization of the secondary wall in relation to the growth rate of the cambium. *Biochem. Biophys. Acta* 6:36-47.

271. Watson, A. J. 1963. Pulping of *Pinus radiata* thinnings. Melbourne, Australia, C.S.I.R.O. Proc. 19th Pulp and Pap. Res. Conf. p. 47-50.

272. ________________ and H. E. Dadswell. 1957. Paper making properties of compression wood from *Pinus radiata*. *Appita Proc.* 11:56-70.

273. _______________ and I. G. Hodder. 1954. Relationship between fiber structure and handsheet properties in *Pinus taeda*. *Appita Proc.* 8:290-310.

274. Watson, A. J., A. B. Wardrop, H. E. Dadswell, and W. E. Cohen. 1952. Influence of fiber structure on pulp and paper properties. *Appita Proc.* 6:243-269.

275. Wellwood, R. W. 1952. The effect of several variables on the specific gravity of second-growth Douglas-fir. *Forest. Chron.* 28:34-42.

276. _______________ 1960. Specific gravity and tracheid length variations in second-growth western hemlock. *J. Forest.* 58:361-368.

277. Wendel, G. W. 1960. Fuel weights of pond pine crowns. U.S.D.A., Forest Serv., SEFES., Paper 149. 2 p.

278. Westing, A. H. 1965. Formation and function of compression wood in gymnosperms. Part I. *Bot. Rev.* 31:381-480.

279. _______________ 1965. Formation and function of compression wood in gymnosperms. Part II. *Bot. Rev.* 34(1):51-78.

280. Wilde, S. A., B. H. Paul and P. Mikola. 1951. Yield and quality of jack pine pulpwood produced on different types of sandy soils in Wisconsin. *J. Forest.* 49:878-881.

281. Winters, Donald W. 1947. Feltwood in forest management. *J. Forest.* 45(6):447-448.

282. Worster, H. E., and M. G. Vinje. 1968. Kraft pulping of western hemlock tree tops and branches. *Pulp Pap. Mag. Can.* 69(14):57-60. *Also* Can. Pulp Pap. Ass. Tech. Pap. T308.

283. Yazawa, K., and K. Fukazawa. 1959. [Studies on the relation between physical properties and growth conditions for planted sugi (*Cryptomeria japonica* D. Don) in Central District of Japan. V. On the specific gravity, fiber saturation point and volumetric shrinkage of the spring and summerwood; in Japanese, English summary]. Hokkaido Univ. Exp. Forest Res. Bull. 20:93-117.

284. Yonezawa, Yasumasa and others. 1959. On the branches and tops of trees as raw material for pulp and fiberboard. *In* Government Forest Experimental Station Bulletin No. 113. Meguro, Tokyo, Govt. F.E.S., March 1959. p. 145-152. Ontario Res. Found., Dep. Orga. Chem., Transl. 65-1.

285. _______________ *et al.* 1965. [On the branches and tops of trees as raw material for pulp and fiberboard (2); transl. from Japanese]. Ontario Res. Found., Dep. Org. Chem., Transl. 65-2. 15 p.

286. Yorston, F. H. 1940. The sulfate pulping of balsam fir containing compression wood. Pulp Pap. Res. Inst. Can., Montreal.

287. Young, Harold E. World forestry based on the complete tree concept. Sch. Forest., Univ. Maine, Orono mimeo. 9 p. undated.

288. ________________ 1964. The complete tree concept -- A challenge and an opportunity. Proc. Soc. Amer. Forest. Denver, Colo. p. 231-233.

289. ________________ 1965. Pound wise and penny foolish. Amer. Pulpwood Ass. Annu. meeting, New York, N. Y.

290. ________________ 1965. Is tree growth of ten cords per acre per year attainable? *Pulp Pap.* 39(35):28-30.

291. ________________ 1967. Weight and nutrient elements of seedlings and saplings of eight tree species in Maine. Maine Agr. Exp. Sta., Tech. Bull. 28, Orono.

292. ________________ 1967. The lost cord. Area IV Sect., Southern Pulpwood Conserv. Ass., Nag's Head, N. C. 11 p. mimeo.

293. ________________ 1967. Complete tree mensuration. Forest Biometry Working Group, Freiburg, Ger. 5 p. mimeo.

294. ________________ 1968. Challenge of complete tree utilization. *Forest Prod. J.* 18(4):83-86.

295. ________________ 1968. A research approach to increased forest productivity. Sch. Forest Resources, Univ. Maine, Orono. 4 p. mimeo.

296. ________________. 1968. Quantum increases in fiber production. Sch. Forest. Resources, Univ. Maine, Orono. 13 p. Pap. No. FE-3568, 1968 Forest Eng. Conf., Amer. Soc. Agr. Eng., East Lansing, Mich.

297. ________________ 1968. Memorandum: to working group on mensuration forest biomass, sec. 25, IUFRO. Dep. Forest., Australian National Univ. Canberra. 2 p.

298. ________________ 1969. Five hundred million potentially useful forest acres in Australia. *Australian Forest.* 33(2):129-134.

299. ________________ 1969. Preliminary results for a pilot study of "puckerbrush". Univ. Maine, Orono, private communication.

300. ________________ 1969. A ten year progress report. Sch. Forest Resources, Univ. Maine, Orono. mimeo.

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

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

303. Young, H. E. and V. P. Guinn. 1966. Chemical elements in complete mature trees of seven species in Maine. *Tappi* 49(5):190-197.

304. Young, H. E., P. Carpenter and R. Altenberger. 1965. Preliminary tables of some chemical elements for seven tree species in Maine. Maine Agr. Exp. Sta., Tech. Bull. 20.

305. Young, Harold E., Gammon, Calvin B., and Hoar, Leigh E. 1963. Potential fiber from red spruce and red maple logging residues. *Tappi* 46 (4):256-259.

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

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

308. Young, Harold E. and others. 1966. Pulping hardwoods. Try sulfate process on branches, roots. *Pulp Pap.* 40(27):29-31.

309. Young, Harold E., Lars Strand and Russell Altenberger. 1964. Preliminary fresh and dry weight tables for seven tree species in Maine. Maine Agr. Exp. Sta., Tech. Bull. 12, Orono. 76 p.

310. Zasada, Z.A. and F.T. Frederickson. 1948. Limits of closer utilization of black spruce pulpwood. *Pulp Pap. Mag. Can.* 49(11):128, 130, 132, 134.

311. Zasada, Z.A. and C.A. Richardson. 1949. Logging and pulping black spruce thinnings. *Tappi* 32(9):393-396.

312. Zherebov, L. P. 1946. [Mechanical functions of the chemical constituents of wood; in Russian]. *Bumazhn. Prom.* 21(3/4):14-26.

313. Zobel, Bruce, Charles Webb and Fay Henson. 1959. Core or juvenile wood of loblolly and slash pine trees. *Tappi* 42(5):345-356.

314. Honer, T. G. 1967. Standard volume tables and merchantable conversion factors for the commercial tree species of central and eastern Canada. Can. Dep. Forest. Rural Develop., Forest Manage. Res. Serv. Inst., Inform. Rep. FMR-X-5, Ottawa, Ont.

315. ________________ 1965. Volume distribution in individual trees. *Pulp Pap. Mag. Can.* 66 (11): WR-499, WR-500, WR-502, WR-506-508.