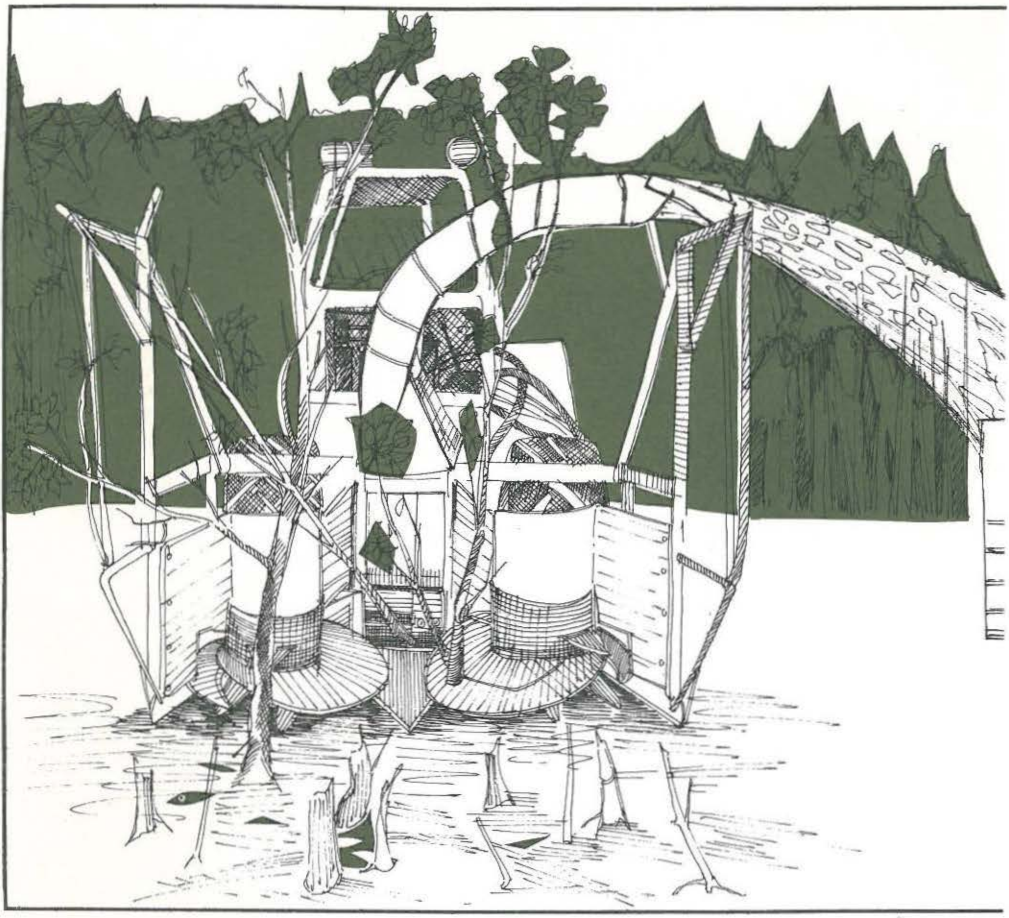
1978

B749: Pulping, Biomass, and Nutrient Studies of Woody Shrub and Shrub Sizes of Tree Species

Andrew I. Chase

Harold E. Young



PULPING, BIOMASS, AND NUTRIENT STUDIES OF WOODY SHRUB AND SHRUB SIZES OF TREE SPECIES

Andrew I. Chase
Harold E. Young

Life Sciences and Agriculture Experiment Station
BULLETIN 749 UNIVERSITY OF MAINE AT ORONO APRIL 1978

TABLE OF CONTENTS

ABSTRACT

The research described in this report was a further effort to determine the potential of woody plants and forest waste not normally used commercially as a source of wood pulp. The results of previous studies of this subject have been reported in several technical journals and as LSA Experiment Station Bulletins over a period of several years.

Nine species of woody shrubs and shrub-size trees were pulped by the sulfate process and the resulting products were evaluated for yield of useable fiber and for physical properties.

The species were striped maple, basswood, beaked hazelnut, yellow birch, hophornbeam, sugar maple, beech, sumac, and willow.

When the material was chipped as harvested, i.e., with top, branches, twigs, bark, and some foliage included and the resulting chips were pulped, a yield of acceptable fiber ranging from 35 to 45 per cent was realized. Yields of pulp varied depending on species, willow giving the highest and sumac the lowest.

Pulp strength properties, burst, tear, and tensile, were generally lower than those of pulps produced commercially from mature trees. However, several species, yellow birch, hazelnut, and hophornbeam, produced pulps comparable to commercial pulps in strength characteristics.

It was concluded that the only feasible way of harvesting this type of material for pulping would be as a whole plant. The small size and large proportions of bark and small branches would preclude any kind of bark-wood separation process.

If species of this kind and size could be grown and harvested as a crop, it might be possible to improve pulping yield and pulp characteristics by selectively pulping species, using optimum pulping conditions which might vary with the species.

The biomass and nutrient content of 15 deciduous and two coniferous species, not previously studied in Maine, in the 0.5 - 1.5" Dbh range were determined based on three specimens per species. The results were similar to the biomass and nutrient content of industrial species of similar size. Therefore, full stocked stands of these species can be expected to annually produce as much dry matter as industrial species and when they are minor components of forest stands can be expected to contain proportionately as much of the essential elements. This suggests that, when bush harvesters are commercially used on immature forest stands, reliable estimates must be made of the biomass and nutrient elements of all species harvested. This information will be essential in developing forest management practices, such as fertilization, that will maintain the available nutrient pool at the current level and, if desirable, will increase the nutrient pool level in order to increase annual dry matter production.

INTRODUCTION

Since 1959 a series of related pulping, biomass and nutrient studies has led to the Complete Tree Concept and its expansion into the Complete Forest Concept (1 through 19). The initial effort (1-9) was on merchantable size trees of industrial species including all components (leaves or needles, branches, stem and stump-root systems) except in the pulping studies which omitted the leaves and needles. These were followed by biomass and nutrient studies of the seedling and sapling sizes of the eight tree species (9,10) studied earlier.

These studies (9,10) in turn led to investigation of the puckerbrush species (9-16,18,19). These are the presently nonindustrial tree and shrub species that are generally short lived and usually grow in dense stands when young. The species studies can readily be sorted into two groups. One group that grows larger in size and is sometimes used for firewood and pulp includes gray birch, red maple and quaking aspen. The other group, usually smaller at maturity and seldom utilized includes pin cherry and willow.

Thinnings, the removal of sapling size trees that are unlikely to reach maturity, has been practiced for many years in Europe and other countries. There is now interest in such a cultural practice in Maine. Chase and Young (17) established the useful pulping potential of such material which is comparable in size to the puckerbrush hardwood species.

In the past 20 years there has been a tremendous development of mechanized harvesting equipment characterized by the mobile chip-harvesters. Initially these were very large machines but in the past three years smaller and less costly versions have been commercially built, encouraging thinning practice and the removal of entire puckerbrush stands. In Finland the Palleri Busharvester, in a prototype development stage, is being designed to harvest and reduce the seedling and sapling stages of trees and shrubs to chips that are immediately transferred to a truck moving parallel and adjacent to the busharvester. Such harvesting developments suggested the need for pulping, biomass, and nutrient studies of woody shrub species and shrub size tree species in order to determine the pulping potential of such material and any implications for forest management. Therefore, this study was confined to woody shrubs and trees ranging from 0.5-1.5" dbh in which the tree species selected represented both the industrial species group and the nonindustrial group or the puckerbrush species.

A. Experimental Procedure

1. *Chip Preparation* — The shrub and tree material was delivered to the laboratory freshly cut, in full length and with much of the foliage

attached. Diameter at Breast Height (DBH) ranged from ½ to 1.5 inches, length from 10 to 20 feet.

The material was chipped as received. A drum type chipper, manufactured by the Klockner Company of West Germany, was used. This machine has a horizontally arranged drum-shaped roll containing two knives. It is driven by a 25 horsepower motor. There are two feed rolls, each driven by a one horsepower motor, that pull the material to be chipped onto the face of the drum roll. The speed of either the drum roller or the feed rolls controls the average length of chip produced. These speeds are set at the Klockner factory but can be changed at the laboratory. In this case the speeds had been set to produce a range of chip sizes common to the commercial pulping operation.

Generally when small trees with branches and tops included are chipped, the product contains material within a wide range of sizes. The drum chipper shortens the size range significantly and results in more uniform chips than can be produced by the disk chipper.

The chips were screened on a Williams Chip Classifer, using the TAPPI Useful Method #21. There were two reasons for classifying the chips, first, to determine the composition, with respect to bark, twigs, and useful wood, of material retained on each of the classifier screens; second, to separate the material into certain size fractions for subsequent pulping.

Compositions for three species, yellow birch, sumac, and striped maple, were determined for the fractions on all screens, i.e., the 1 1/8, 7/8, 5/8, 3/8 and 3/16, and for material that passed through the 3/16 inch screen (sawdust).

For three of the species, willow, sumac, and striped maple, two combinations were prepared for pulping, one containing material retained on the 5/8 and 7/8 screens, the other containing material retained on the 3/8 and 3/16 screens.

For all nine species, a portion of the material from the chipper was pulped without being screened. This is referred to as the "whole" fraction.

2. *Pulping* — All material was dried at room temperature until moisture equilibrium was attained and it was charged to the digester in that condition.

The sulfate pulping process was used. Pulping conditions are shown in Table I. These were established by making several cooks on the willow species at different conditions of chemical concentration, and cooking time and temperature until the set of conditions that produced a pulp with a Permanganate Number of 14 was realized. Those conditions were then used for all subsequent cooks regardless of the Permanganate Number of the pulp produced.

Cooking liquor to wood ratios and liquor concentration varied slightly from cook to cook because the different wood species differed in packing density and the amount of dilution water required to assure the chips were covered by liquor also differed. However, the variation was not great.

The weight ratio of active chemical to wood is the weight of sodium hydroxide and sodium sulfide, expressed as their equivalent weight of Na_2O, per unit weight of dry chips. This was constant for all cooks at 0.2, or 20 percent.

The percent sulfidity is the weight of sodium sulfide divided by the weight of sodium hydroxide plus sodium sulfide, all expressed as equivalent Na_2O, in the cooking liquor.

The total cooking time is the time required to reach the maximum or cooking temperature plus the time the pulp is held at that temperature. The initial forty-five minutes was the minimum time to reach the 345°F cooking temperature with maximum output from the liquor heater.

Pulping equipment consisted of a vertical stainless steel digester having a capacity of approximately three pounds of chips. The time-temperature cycle for a cook was controlled automatically. Heat was supplied by continuous circulation of the cooking liquor through the digester external electric heater system.

At the end of the cook, pressure in the digester was reduced to atmospheric by relief through a valve in the cover. Then the spent (black) liquor was drained through a bottom valve, the cover was taken off, and the pulp was removed to a screen box. After washing some of the retained black liquor from the pulp it was transferred to a Morden Slushmaker and agitated vigorously for 5 minutes to complete the defibering of the cooked chips.

3. *Pulp treatment* — The defibered pulp was transferred to a vibrating slotted pulp screen where it was screened to separate "acceptable" fiber from uncooked knots and other reject material.

Pulping yields were determined by measuring the amount of acceptable fiber, the rejects, and the total material obtained from a cook. Past experience has shown that approximately 2 percent of the acceptable fiber is lost in the washing and screening operation so the measured yield was adjusted to account for that loss.

Samples of the pulp were taken for measurement of Permanganate Number and for examination with the optical microscope. The remainder was treated in the standard beater, made into hand sheets, and the sheets then tested for bursting, tearing, and tensile strength.

The tests were made in accordance with TAPPI Standard Methods and the following methods were used:

Standard Method T214 — Permanganate Number of Pulp
Standard Method T200 — Laboratory Processing of Pulp (Beater Method)

Standard Method T205 — Forming Handsheets for Physical Testing of Pulp.

Standard Method T220 — Physical Testing of Pulp Handsheets.

Fiber length and diameter were measured, using an optical microscope and calibrated eyepiece. Insofar as possible only whole fibers were measured. Diameters were measured at the midpoint of a fiber. The reported values are the arithmetic average of measurements on 50 fibers.

B. Pulping Results and Discussion.

1. *Classification of chipped material* — These results are shown in Tables II, III, and IV. An explanation of the material in each of these tables is required. Column A shows the percent by weight of total material charged to the classifier that was retained by each of the screens. For the chipping conditions used in this study it is seen that from 70 to 80 weight percent of the chips produced fall in the 3/8 to 7/8 inch range which is the size that would be acceptable for industrial pulping systems. The oversize chips, 1-1/8 inch, are rechipped and returned to the system. Generally the "pin chips" (3/16 inch) and sawdust are burned because if pulped with normal size chips they produce inferior pulp. The percent of this material obtained in this study ranges from 16 to 22 percent, higher than from chipping of mature trees because of the very small size of the original tree or shrub.

Column B shows the breakdown of the sample of material from each screen, as bark, twigs and chips (useful wood), and expressed as a weight percent. It is important to realize that the percent of "chips" is on a bark-free basis. For example, the material from yellow birch retained on the 7/8 inch screen was 8 percent bark, 2 percent twigs, and 90 percent bark-free wood. The data for these results were obtained by separation of bark and wood, by hand (a tedious operation), of representative samples from each screen. Generally the percentage of bark-free wood and twigs decreased with decreasing screen size whereas the percentage of bark increased (striped maple being an exception). Material that passed the finest screen was mostly bark and foliage dust, for all three species.

Column C shows the percent of the total of any one of the three components, bark, twigs, or chips, that was retained on a specific screen. For example, of the total bark in the yellow birch material charged to the classifier, 3.9 percent was retained on the 7/8 inch screen, 51.4 percent on the 3/8 inch, and so on. These results show that approximately 80 percent of the weight of useful wood is retained on the 7/8, 5/8, and 3/8 inch screens. Unfortunately about the same percentage of the total bark is retained on the same screens. Lower percentages of the total weight of twigs are retained on these screens, more appearing in the pin chips and to some minor degree in the sawdust.

The results of this analysis and particularly the information in column C indicate that reduction of bark in material charged to the digester cannot be effected substantially by pulping only those chip sizes that are normally pulped industrially, i.e., 3/8 through 7/8 inch. It is possible that if chips, in a dry condition, were mixed vigorously by air flotation or other mechanical means before screening much of the bark would either be removed by the operation or reduced to a size that would effect its separation in the subsequent chip screening.

Table V shows the composition of the yellow birch, sumac, and striped maple material as it was charged to the screen classifier, again expressed as bark, twigs, and bark-free chips. These data were calculated from the results shown in the preceding Tables. The values in parentheses are those obtained in a separate study by H. E. Young.

It was mentioned previously that a few species were classified to obtain size fractions that could be pulped separately. This was done with sumac and striped maple. Table VI shows the gross compositions of the "combined" fractions that were pulped. For example, the sumac material retained on the 7/8 and 5/8 inch screens was combined for pulping. The composition of the mixture was 28 percent bark, 18 percent twigs, and 54 percent bark-free wood. It represented 47 percent of the total sumac material charged to the classifier, excluding the sawdust.

The pertinent difference between the two mixtures pulped, for each of the two species, is the significantly higher percentage of bark-free wood in the larger size fractions and the higher percentages of twigs in the smaller size. It might be expected that each of these characteristics would have a material influence on the pulping yield of acceptable fiber.

Table VII shows the bark and wood content of single specimens of the nine woody shrubs and shrub size trees in the present pulping study. Any mechanical treatment, chipping, handling, conveying, etc. of this material will have an effect on the gross composition because of losses of bark, branches and some fiber.

2. *Pulping Results* — The pulping yields and pulp Permanganate Numbers are shown in Table VIII.

Yields of acceptable fiber ranged from a high of 44 percent for the willow species to a low of 36 percent for the sumac. These are yields for the "whole" tree as defined previously.

The yields for combinations of screen fractions show that the highest values were obtained from the 7/8 + 5/8 combinations for the striped maple and sumac. This can be attributed to the higher percentage of "bark-free" chips in those fractions as compared with the 3/8 + 3/16 fractions, as seen in Table VI. The pulping yields of the willow fractions cannot be included in this analysis because their gross compositions were not determined. The trend is the same, however, with the yield for the 7/8

+ 5/8" fraction being seven percentage points higher than for the smaller material. It can be assumed that the reason is the higher proportions of bark and twigs in the smaller sized material.

Compared with yield figures typical of commercial kraft pulping operations, the values obtained for the shrubs and shrub-size trees in this study were 10 to 15 percentage points lower. The main reasons are the high proportions of bark and susceptibility of the carbohydrate portion of the tree species to chemical attack.

The amount of reject material was normal and was composed mainly of oversize slivers and branch segments when the "whole" material was pulped.

There was no consistent relation between permanganate number and yield.

Based on the pulping results it is concluded that shrub-size trees and shrub material will give yields of approximately 40 percent when the whole aboveground material is pulped by the sulfate process. If the chipped material is screened and the better screen fractions, i.e., the 5/8 and 7/8 inch chips, are pulped yields of 45 percent can be attained.

Table IX shows the pulping yield for "whole" material as well as the weight percent of bark and branches (bark intact) for the whole aboveground plant. There is no relationship indicated. There is some fiber content for the bark and this undoubtedly is different for different species. This could account for the fact that willow, which has one of the highest bark contents, also has the highest pulp yield. The yield of fiber from willow bark may be significant.

3. *Fiber Analysis* — Table X contains the results of measurement of fiber length and diameter of the nine species. Each dimension as reported here is the arithmetic average of values obtained on fifty fibers. Generally, the fiber length was of the order of one millimeter which is typical for deciduous species, even for mature trees. Fiber lengths were approximately 50 times maximum fiber diameter which is typical. Exceptions to this were the basswood, hophornbeam, and beech. For these three species the length to diameter ratio was nearer to 100.

4. *Pulp Properties* — Beater tests were run and hand sheets were made of the pulp from each of the 12 cooks that were made. These included pulps from cooks on the "whole" plant for the nine species plus pulps from the six cooks made on the screen fraction combinations for the three species, willow, striped maple, and sumac.

Samples of pulp were taken from the beater at five or ten minute intervals for total times ranging from 15 to 30 minutes. The objective was to beat to a final freeness no greater than 250. The time required to do this varied with the different species. Freeness tests were made on each of the samples. Additional samples were taken at the same time intervals, handsheets were made and were tested for bulk, burst, tear, and tensile strength.

The results of the tests are shown in tabular form, Tables IA-VA, in the Appendix and in graphical form, Figs. 1-9, in the main body of this report.

(a) Freeness. Figure 1 shows the response to beating, in terms of freeness decrease, for all of the "whole" plant pulps except willow (data missing). Compared with sulfate pulps from mature trees, the initial (unbeaten) freenesses were much lower and the pulps showed higher rates of freeness decrease. In particular, the sumac started to deteriorate after fifteen minutes of beating and debris from fiber breakage passed through the freeness plate resulting in false readings.

The *rate of freeness decrease* was much the same for all species as can be seen by the slopes of the lines in Figure 1.

The basswood, beaked hazelnut, and sumac had very low initial freenesses whereas those of the yellow birch, hophornbeam, and beech were the highest, between 450 and 480.

The low freenesses and rapid decrease in freeness with beating can be attributed to the relatively fragile nature of the juvenile fiber in the small tree species and to the short chunky material and debris produced from bark and small branch and twig elements.

Figures 2, 3 and 4 show the effect of beating on the freeness of the pulps from screen fraction combinations for willow, striped maple, and sumac. It is seen that the smaller size fractions produce pulps that have lower initial freenesses and lower beating rates than the pulps from larger chips, i.e., 5/8 + 7/8 inch. This is a result of the smaller size of the fines material and the higher proportion of bark elements. The rapid deterioration of the sumac pulp with beating is evidenced by the shape of the freeness curves in Figure 4 where it appears that the freeness actually reaches a minimum and then increases with further beating. As mentioned previously, this results from extensive breakage of fibers to the point where many become small enough to pass through the freeness tester plate or screen.

(b) Bulk. Figures 5 and 6 show the development of handsheet bulk (reciprocal of density) with beating. The rate of change of bulk was similar for most species as can be seen by the slopes of the lines in Figure 5. It does appear that the rate was slightly lower for the sumac, yellow birch, and basswood pulps.

Figure 6 shows that pulps produced from the larger size chips produced the higher density (lower bulk) handsheets. This could be attributed to the better bonding characteristics of the pulp from that screen fraction which also contained the lowest proportion of bark.

(c) Bursting strength. Figure 7 shows the development of burst strength, expressed as burst factor, with beating. Generally the level of burst strength and the rate of development were low. There appear to be two distinct groups with respect to level of burst. One, containing the yellow birch, hophornbeam, beaked hazelnut, and basswood, shows burst factors (maximum) in the 85 to 100 range. These are comparable to values obtained on pulps from mature trees. The other five species form the second group in which the burst strengths are significantly lower.

Fiber length is an important characteristic affecting many paper properties. Generally, longer fibers produce stronger paper although that is not the only fiber characteristic that determines strength. It is seen from Figure 7 and Table X that, with the usual one or two exceptions, the longer fiber pulps, e.g., hophornbeam, yellow birch, and basswood, are in the higher burst factor group. Willow, sumac, and striped maple, on the other hand could be described as weak in burst strength. They are also three of the shorter fiber pulps.

(d) Tearing strength. This strength property, expressed as tear factor, is shown in Figure 8. It is seen that a maximum value was reached at a beating time of from 15 to 20 minutes. The one exception to this was the sumac which is definitely inferior in tearing strength.

The longer fiber pulps again form a group, as was the case with burst strength, having the highest tear strengths whereas the short fiber species, sugar and striped maple, willow and sumac, were very weak in tear.

(e) Tensile strength. Figure 9 shows this property, expressed as breaking length. This is defined as the length of a strip which is suspended vertically from one end that would *just* support its own weight without breaking.

Again the long fiber species produced the higher tensile strength pulp. The same trend of strength increasing with increased fiber length is evident for the three physical properties, tensile, burst, and tear. Sumac fared a little better in tensile strength than it did in the other properties being the strongest species in the short fiber group.

The level of tensile strength, in comparison with that of commercial sulfate pulps, could be described as good for the longer fiber species.

The figures of strength properties were drawn from the data contained in Tables 1A-5A of the Appendix. Smoothed curves were drawn through the data points.

Table XI contains comparison of the properties of the nine species, expressed as a numerical rating of one for the strongest pulp to nine for the weakest. The values used to determine the numerical ranking were read from the graphs of strength properties at 20 minutes beating time. In a few cases a curve had to be extrapolated to the 20 minute coordinate.

Yellow birch, hazelnut, and hophornbeam were much superior in all respects to the other six species.

Hophornbeam is somewhat unique in that it is a strong pulp yet its sheet bulk is high. This generally means a poorly bonded sheet which means low strength. The same is true, to a lesser degree, for the basswood.

The maple, beech, and willow, particularly the latter, produce very weak pulps. The beech has a low overall ranking because of its high bulk. Actually it is a stronger pulp than the sumac and, if ranked on strength properties only, would replace sumac in the number 5 spot.

C. Summary and Conclusions of Pulping Studies

Nine species of deciduous woody shrubs and shrub size trees were pulped by the sulfate process.

Screen analyses of the chips produced from a drum-type chipper showed that approximately half were in the fines or sawdust category. This was because of the small branches, twigs, and bark which constitute a significant percentage of the total weight of the shrub or small tree. The bark, when dry, tends to pulverize in the chipper producing small particle material.

Pulp yields ranged from 35 to 45 percent when the "whole" plant was pulped. When separate screen fractions were pulped, the differences in yield between the smaller and the larger chips were approximately 5 percentage points with the larger chip fraction giving the higher yield. In all cases the yields were lower than those obtained commercially. This can be attributed to the more chemically reactive components and the high bark contents of the nine species involved here as compared with mature trees.

Physical properties covered a wide range of values, generally lower than those of commercial pulps.

The rapid decrease of freeness with beating and the low strength properties are the result of weak fibers, in some cases overcooked and containing bark components that contribute little to either yield or strength.

All nine species were pulped under the same conditions. It is reasonable to assume that those conditions were not optimum for some of the species. For example, it is possible that willow would produce a stronger pulp if a different combination of chemical concentration-time-temperature were used.

Finally, it has been shown by this study that approximately 40 percent of the solid material in these nine species is available as a marginal pulp under the pulping conditions used. A further decrease in yield would result if the pulp were bleached. If this type of material, i.e., shrubs and small trees could be managed like a crop, to be harvested systematically over short growing periods, the different species might be pulped separately. This could result in higher yields of pulp.

D. Biomass and Nutrient Studies

Each spring potential projects for the forthcoming field season go through two planning stages. In the first stage all possible projects are noted and the ideal amount of field sampling for each. This is followed by a second stage in which projects are given priority listing and the amount of sampling possible is determined within the limits of available field personnel, equipment and transportation.

A decision was reached to sample three trees or shrubs of each species, selecting samples as close as possible to 0.5", 1.0" and 1.5" Dbh. On a high priority basis, all species were to be sampled for which pulping data would be available and on a low priority basis additional species were to be sampled.

1. *Field and Laboratory Procedures* — The field crew (2) used a shovel and small garden tool to remove the tree or shrub from the ground intact, thus minimizing damage to the root system. The leaves were manually removed and the other components (branches, stem and stump-root system) were separated by shears. All components were weighed immediately on scales accurate to 0.1 gram. Samples of 50-100 grams were randomly selected from each component which would later be dried in a laboratory oven for 24 hours at 105°C to determine the moisture content. This was then applied to the total fresh weight to estimate the total dry weight of each component.

Samples of the leaves and proportionate samples of the wood and bark of the branches, stems and roots of each of the three specimens of each species were separately passed through a small Wiley mill three times. A sufficient amount was processed to provide at least a 10 gram sample for duplicate spectographic analysis for eleven elements and for duplicate kjeldahl apparatus analysis for nitrogen.

2. *Results* — Biomass and nutrient data were obtained on eight of the nine species studied in the pulping stage. The exception was willow for which some biomass and nutrient data had previously been obtained (11). In addition we obtained biomass and nutrient data on mountain maple, choke cherry, pin cherry, gray birch and red oak as puckerbrush species and black ash, white ash, red pine and larch as industrial species.

Tables XII and XIII, based on duplicate samples from three specimens of each species, list the average and range for each of eleven essential chemical elements and aluminum. Carbon, hydrogen and oxygen were not determined because those are in plentiful supply. The remaining essential element, sulphur, was not determined because of limitations of the spectrographic equipment available. Tables XII and XIII are similar in format to tables for five conifer tree species and three deciduous species presented in Tech. Bull. 28 (7). Our knowledge of the nutrient content of woody shrub and tree species in the northeast is meager so this new compilation of 17 additional species (15 deciduous and 2 conifer) adds appreciably to our small data bank.

Graphs were prepared relating fresh and dry weight separately to dbh for the leaves, branches, stem roots and complete tree or shrub for each species. Inasmuch as each graph was based on only three measurements little confidence should be placed in them. Consequently the analysis was limited to a combination of the components to obtain above ground estimates for the complete tree or shrub and in the process grams were converted to pounds. There was so much similarity between the values at each of the three diameter classes for the 15 hardwood tree and shrub species that only the average and range for the entire group are displayed in Table XII. Red pine and larch are displayed separately in Table XII because red pine is definitely heavier than the hardwood except in the 0.5" Dbh class and larch is only slightly heavier than the average of the hardwoods.

3. *Conclusions* — The biomass and nutrient content of the 15 deciduous and two coniferous species studied in the general range of 0.5 - 1.5" dbh are similar to the biomass and nutrient content of industrial species of similar size. Therefore, fully stocked stands of these species can be expected to produce annually as much dry matter as industrial species. When these 17 species are minor components of forest stands they can be expected to produce proportionately as much biomass containing proportionately as much of the essential elements. This suggests that when bush harvesters are used on immature forest stands, reliable estimates must be made of the biomass and nutrients of all species harvested. This information will be essential to develop forest management practices such as fertilization that will maintain the available nutrient pool in the forest at the present level and, if desirable, will increase the nutrient pool as a means of increasing annual dry matter production.

APPENDIXES

COMMON AND SCIENTIFIC NAMES OF THE TREE AND SHRUB SPECIES IN THIS STUDY

COMMON NAME	SCIENTIFIC NAME
Yellow Birch	*Betula alleghaniensis* Britton
Beech	*Fagus grandifolia* Ehrh.
Sugar Maple	*Acer saccharum* Marsh.
Basswood	*Tilia americana* L.
Black Ash	*Fraxinus nigra* Marsh.
White Ash	*Fraxinus americana* L.
Red Pine	*Pinus resinosa* Ait.
Larch	*Larix laricina* (Du Roi) K. Koch
Gray Birch	*Betula populifolia* Marsh.
Red Maple	*Acer rubrum* L.
Quaking Aspen	*Populus tremuloides* Michx.
Mountain Maple	*Acer spicatum* Lam.
Striped Maple	*Acer pensylvanicum* L.
Pin Cherry	*Prunus pensylvanica* L.
Choke Cherry	*Prunus virginiana* L.
Willow	*Salix babiana* Savg.
Red Oak	*Quercus rubra* L.
Hophornbeam	*Oxtrya virginiana* (Mill.) K. Koch
Beaked Hazelnut	*Corylus cornuta* Marsh.
Sumac	*Rhus typhina* Torner

REFERENCES

1. Kurrle, F. L. 1963. Nitric Acid Digestion of Logging Residues of Red Spruce. Tappi 46:267-272.
2. Young, H. E., C. B. Gammon and L. E. Hoar. 1963. Potential Fiber from Red Spruce and Red Maple Logging Residue. Tappi 46:256-259.
3. Keniston, W. W. 1964. Physical and Chemical Characteristics of Pulp from Various Parts of the Tree. M.S. Dissertation, Unpublished.
4. Michaud, C. F. and D. W. Smith. 1964. Chemical and Physical Properties of Sulfate Pulp from Various Parts of Deciduous Trees. M.S. Dissertation, Unpublished.

5. Young, H. E., C. B. Gammon and M. Ashley. 1964. Potential fiber from Balsam Fir, White Pine, Hemlock, White Birch and Aspen Logging Residue. Tappi 47:555-557.
6. Young, H. E., K. Strand and R. Altenberger. 1964. Preliminary Fresh and Dry Weight Tables for Seven Tree Species in Maine. Maine Agric. Exp. Stn. Tech. Bull. 12 76pp.
7. Young, H. E., P. N. Carpenter and R. A. Altenberger. 1965. Preliminary Tables of Some Chemical Elements in Seven Tree Species in Maine. Maine Agric. Exp. Stn. Tech. Bull. 20 88pp.
8. Young, H. E. and A. J. Chase. 1965. Fiber Weight and Pulping Characteristics of the Logging Residue of Seven Tree Species in Maine. Maine Agric. Exp. Stn. Tech. Bull. 17 44pp.
9. Dyer, R. F. 1967. Fresh and Dry Weight, Nutrient Elements and Pulping Characteristics of Northern White Cedar, *Thuja occidentalis*. Maine Agric. Exp. Stn. Tech. Bull. 27 40pp.
10. Young, H. E. and P. N. Carpenter. 1967. Weight, Nutrient Element and Productivity Studies of Seedlings and Saplings of Eight Tree Species in Natural Ecosystems. Maine Agric. Exp. Stn. Tech. Bull. 28 39pp.
11. Dyer, R. F., A. J. Chase and H. E. Young, 1968. Potential Pulp from Presently Non-Commercial Woody Perennials. Pulp and Paper Magazine of Canada, January 5, 1968.
12. Chase, A. J., F. Hyland and H. E. Young. 1971. Puckerbrush Pulping Studies. Life Sciences and Agric. Exp. Stn. Tech. Bull. 49 64pp.
13. Young, H. E. 1972. Puckerbrush Utilization for Paper Products. Tappi 55:1202-1204.
14. Chase, A. J., F. Hyland and H. E. Young 1973. The Commercial Use of Puckerbrush. Life Sciences and Agric. Tech. Bull. 65 54pp.
15. Ribe, J. H. 1973. Puckerbrush Weight Tables. Life Sciences and Agric. Exp. Stn. Misc. Report 152 92pp.
16. Hyland, F. 1974. Fiber Analysis and Distribution in the Leaves, Juvenile Stems and Roots of Ten Maine Tree and Shrub Species. Life Sciences and Agric. Exp. Stn. Tech. Bull. 71 59pp.
17. Chase, A. J. and H. E. Young. 1976. The Potential of Softwood Thinnings and Standing Dead Softwoods as a Source of Wood Pulp. Life Sciences and Agric. Exp. Stn. Tech. Bull. 82 25pp.
18. Chase, A. J. 1976. The Potential of Deciduous Weed Species and Softwood Thinnings as a Source of Wood Pulp. Applied Polymer Symposium No. 28 503-515.
19. Chase, A. J. and H. E. Young 1976. Corrugating Pulp from Puckerbrush. Research in the Life Sciences. Vol. 23, No. 10.

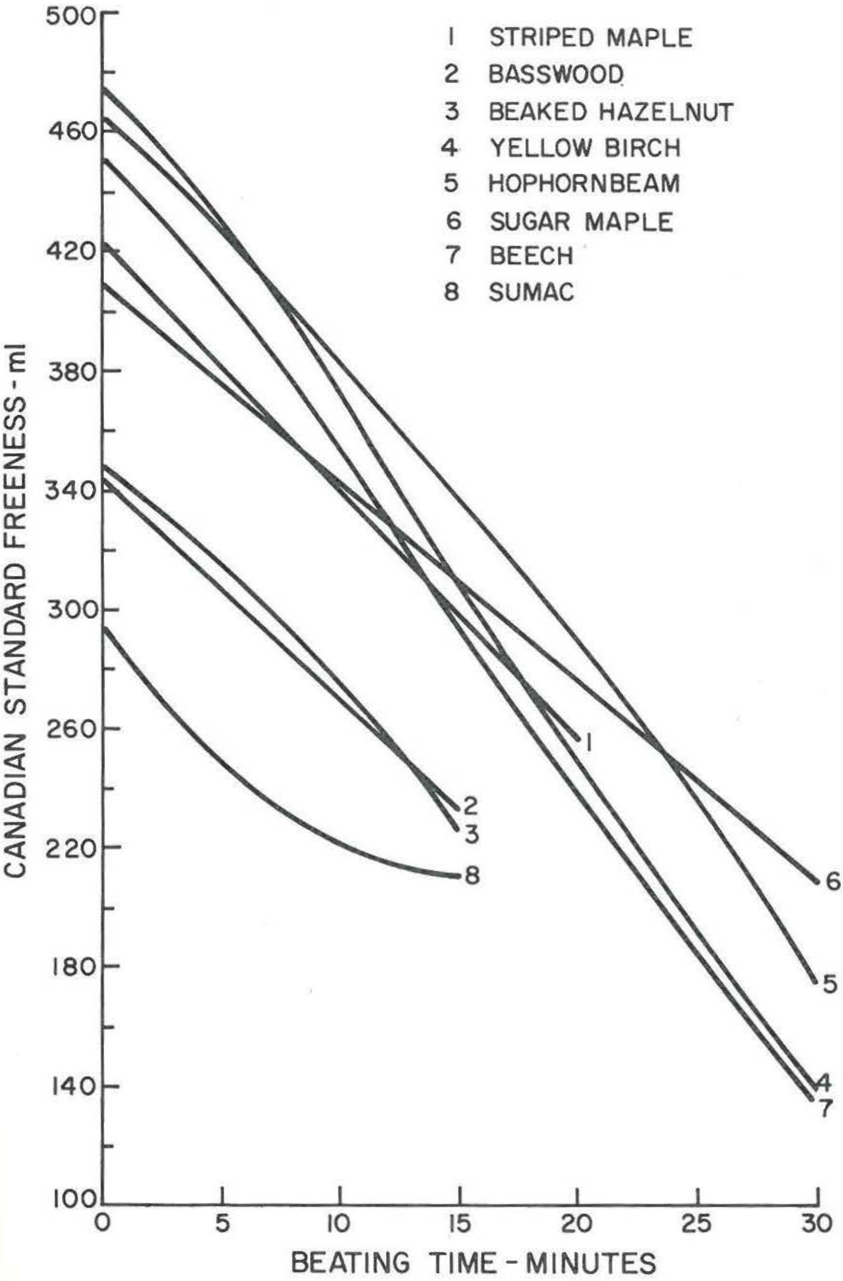


Fig. 1. Freeness vs. Beating Time ("Whole" Plant)

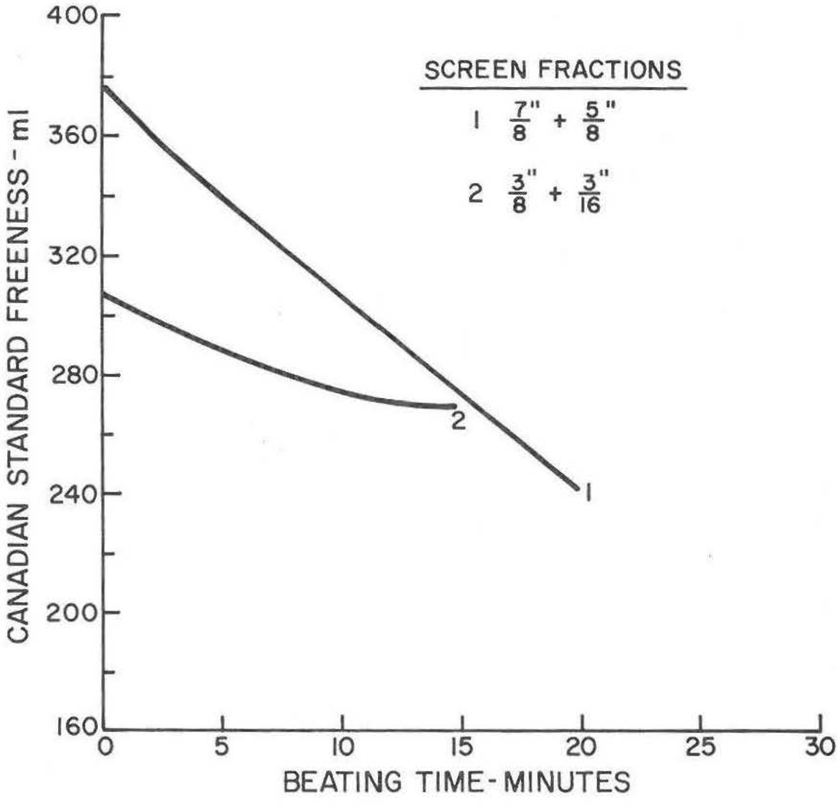


Fig. 2. Freeness vs. Beating Time (Willow)

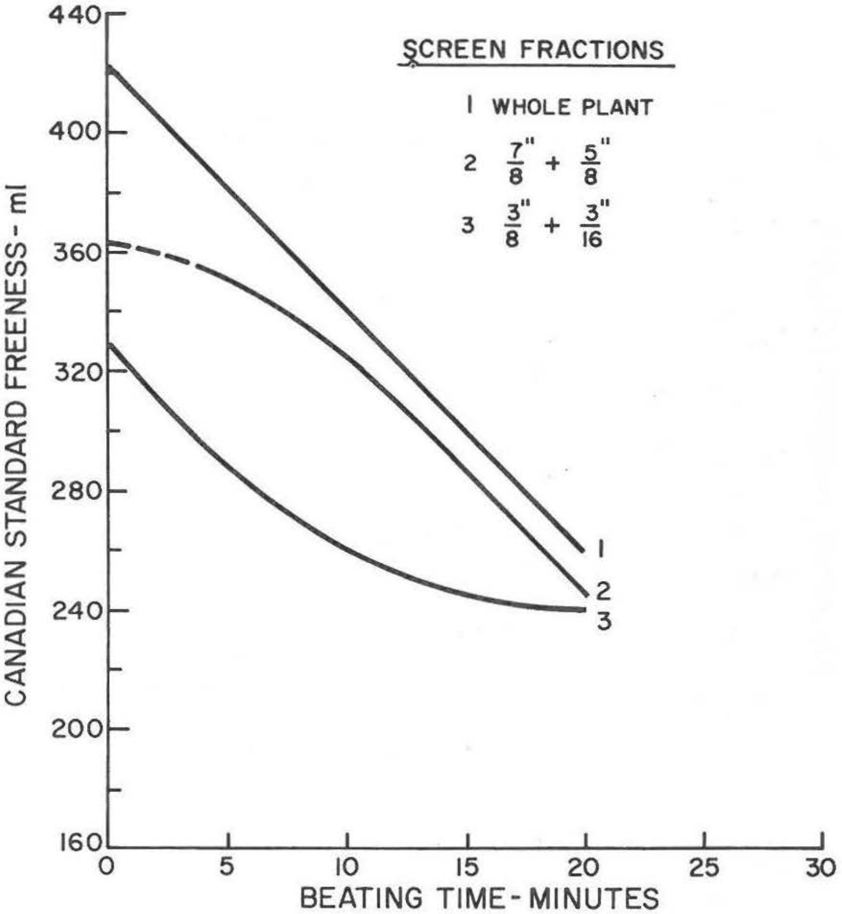


Fig. 3. Freeness vs. Beating Time (Striped Maple)

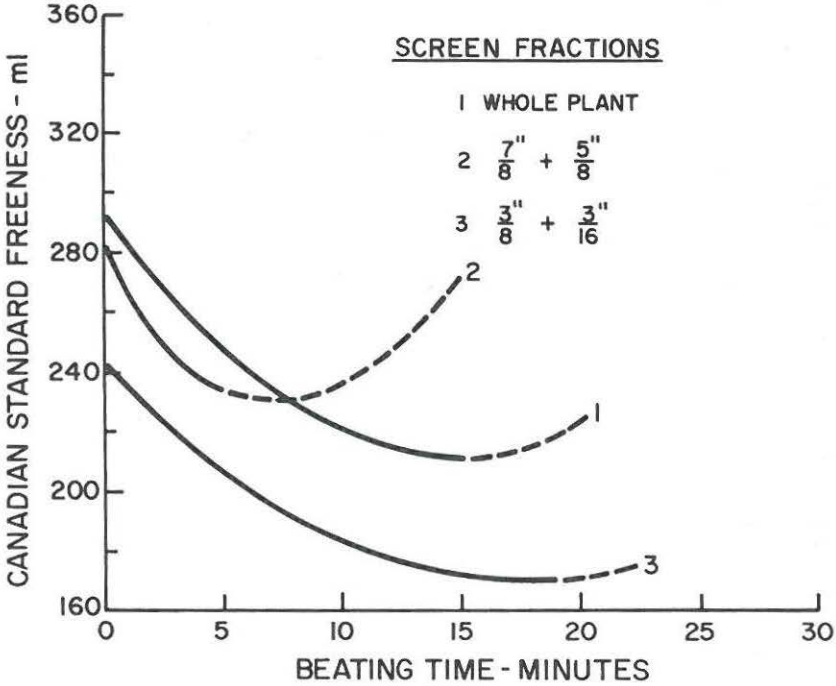


Fig. 4. Freeness vs. Beating Time (Sumac)

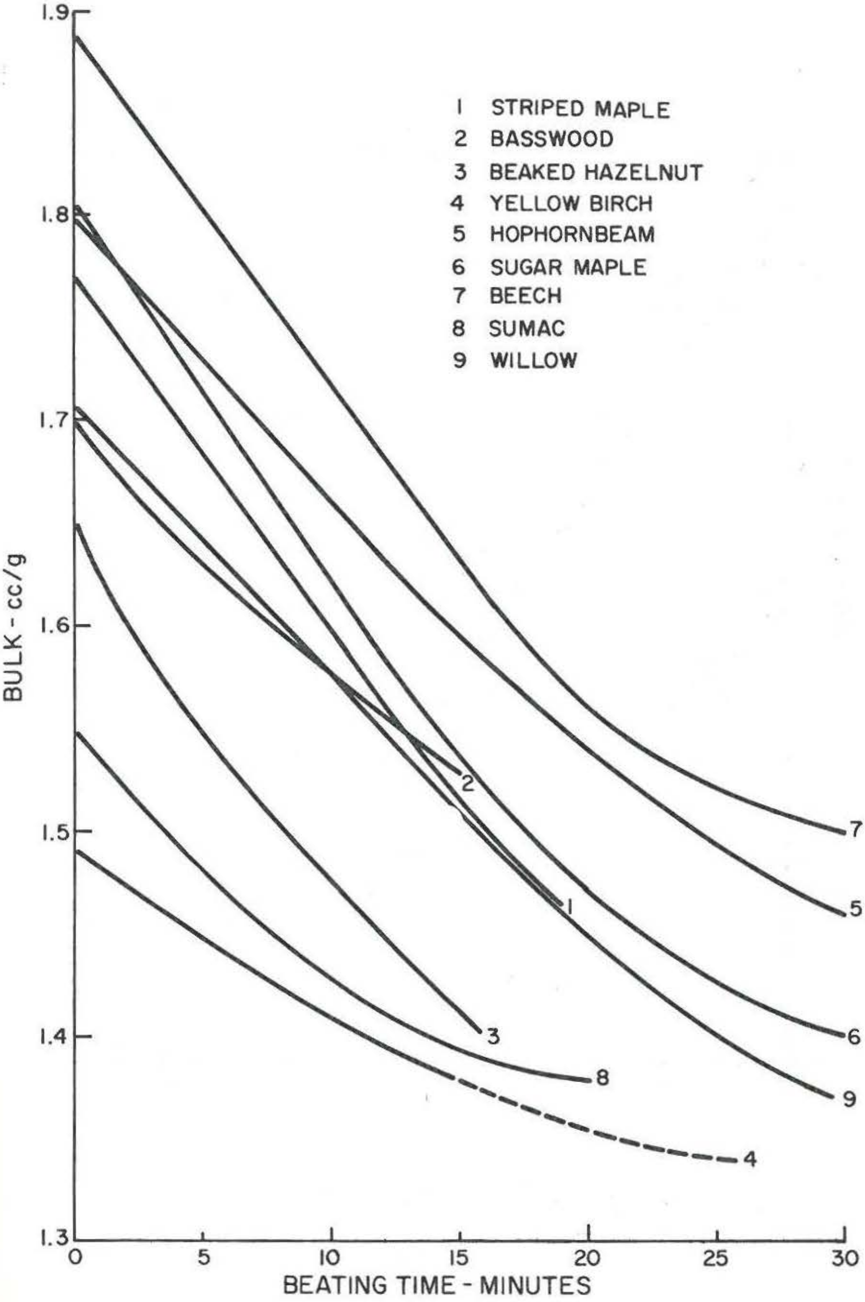


Fig. 5. Bulk vs. Beating Time ("Whole" Plant)

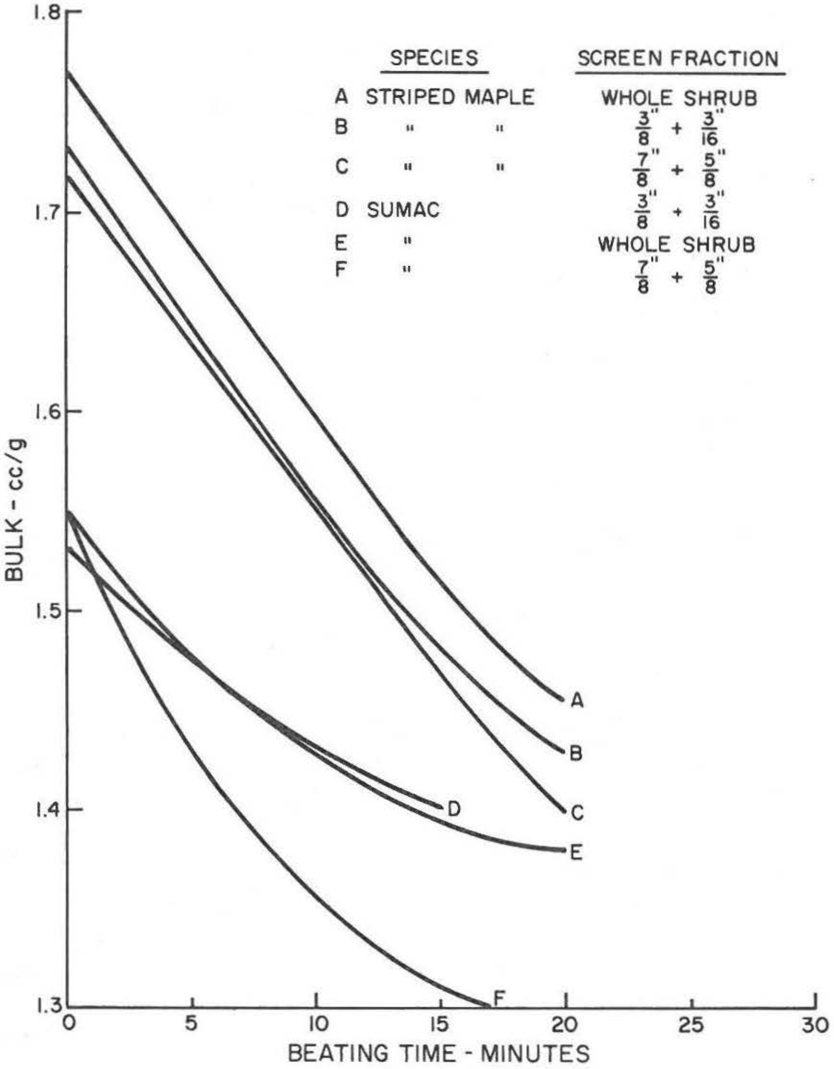


Fig. 6. Bulk vs. Beating Time

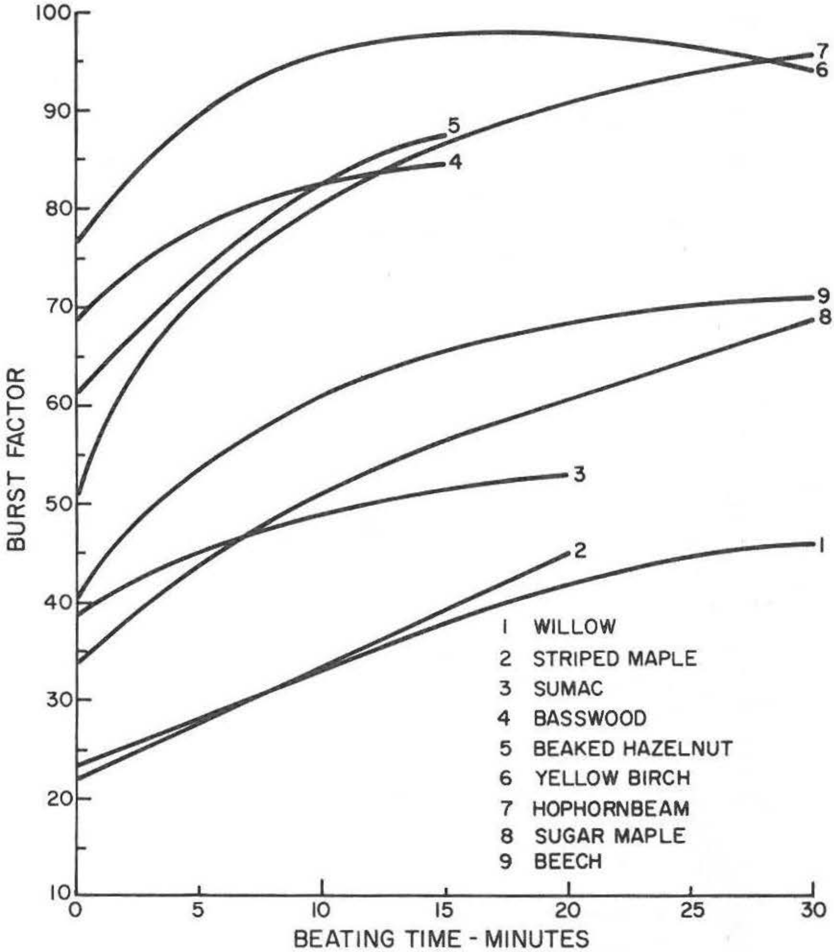


Fig. 7. Burst Factor vs. Beating Time (Whole Plant)

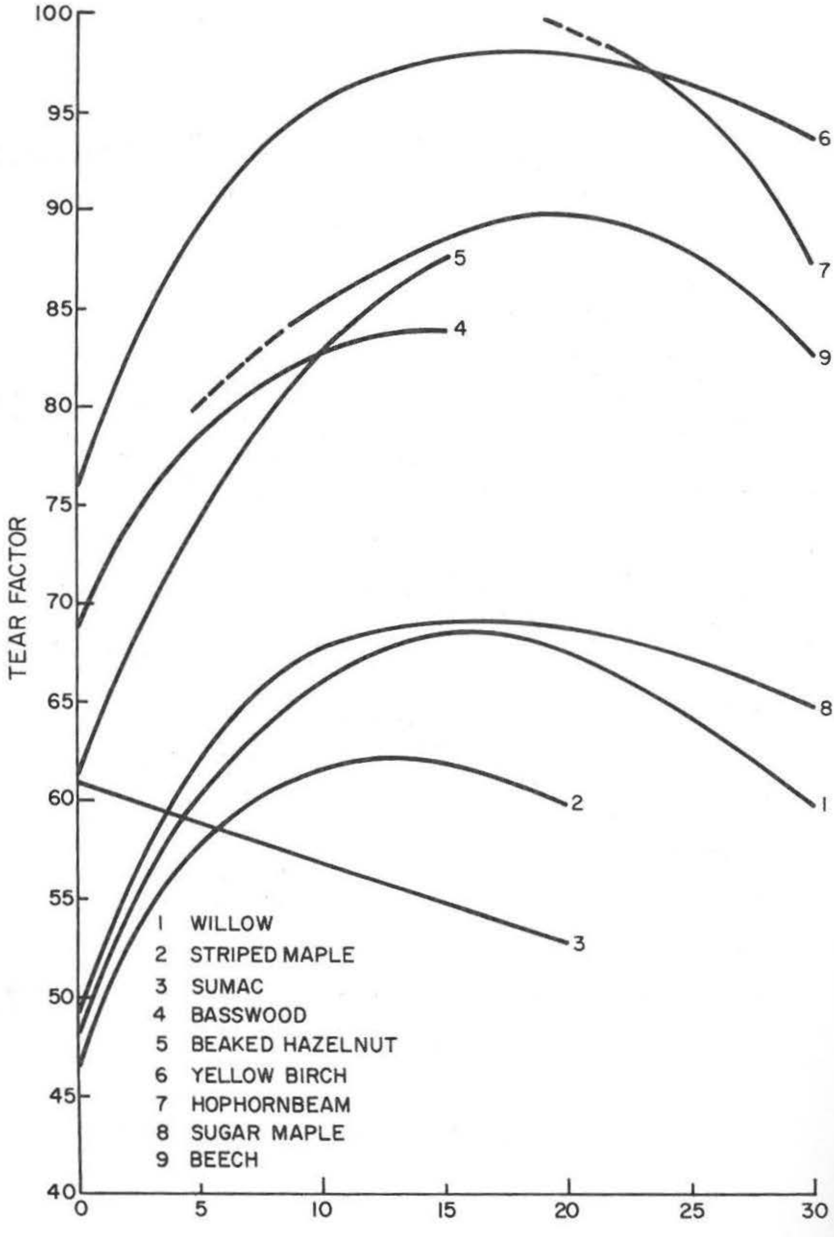


Fig. 8. Tear Factor vs. Beating Time (Whole Shrub)

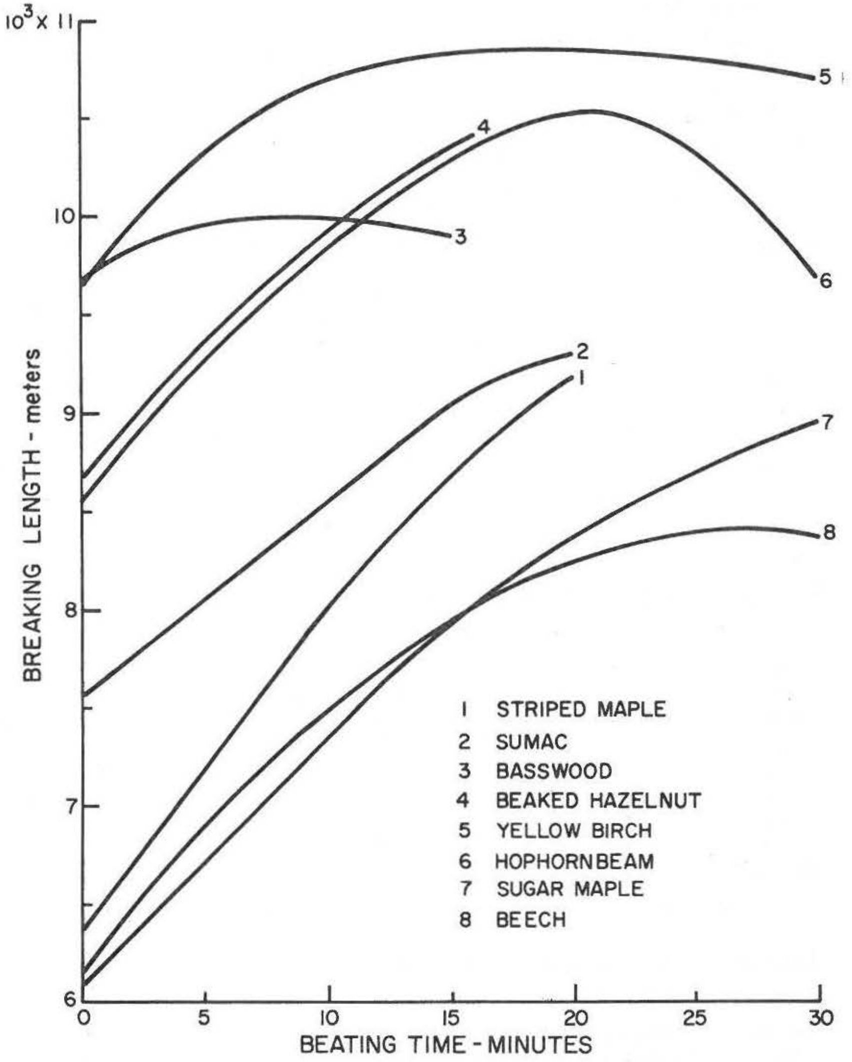


Fig. 9. Breaking Length vs. Beating Time (Whole Plant)

Table I. Pulping Conditions.

Ratio of active chemical to wood	0.20
Percent Sulfidity	25
Maximum Temperature	345°F
Time to Temperature Time at Temperature	45 min. 60 min.
Liquor to wood ratio	8 to 9
Liquor Concentration, Initial. Pounds of active chemical per Ft^3 of liquor	1.5 to 1.7

Table II. Chip Classification and Analysis (Yellow Birch)

Screen Size (inches)	A Percent of Total Retained on Screen	B Composition of Material on Screen (wgt. %)			C Percent of Total of Component on Screen		
		Bark	Twigs	Chips	Bark	Twigs	Chips
1 1/8	7	2	0	98	<1.0	0	14.3
7/8	10	8	2	90	3.9	1.0	18.8
5/8	30	20	15	65	29.4	19.0	40.7
3/8	35	30	40	30	51.4	59.1	21.9
3/16	10	30	50	20	14.7	21.1	4.3
Through 3/16	8	Primarily Bark & Foliage Dust					

Table III. Chip Classification and Analysis (Sumac)

Screen Size (inches)	A Percent of Total Retained on Screen	B Composition of Material on Screen (wgt. %)			C Percent of Total of Component on Screen		
		Bark	Twigs	Chips	Bark	Twigs	Chips
1 1/8	4	2	0	98	<1.0	0	4.0
7/8	5	10	0	90	2.0	0	9.1
5/8	40	30	20	50	48.1	40.6	40.5
3/8	35	25	30	45	35.1	53.3	31.8
3/16	12	30	10	60	14.4	6.1	14.6
Through 3/16	4	Bark & Foliage Dust					

Table IV. Chip Classification and Analysis (Striped Maple)

Screen Size (inches)	A Percent of Total Retained on Screen	B Composition of Material on Screen (wgt. %)			C Percent of Total of Component on Screen		
		Bark	Twigs	Chips	Bark	Twigs	Chips
1 1/8	8	40	0	60	11.0	0	10.3
7/8	15	35	5	60	17.8	4.3	19.3
5/8	30	40	10	50	41.2	17.4	32.2
3/8	25	20	30	50	17.2	43.5	26.9
3/16	15	25	40	35	12.8	34.8	11.3
Through 3/16	7	Bark & Foliage Dust					

Table V. Composition of Screened Species (Charged to Classifier)

Species	Weight Percent Bark	Twigs	Chips	Dust
Yellow Birch	20.4 (20.8)	23.7	47.9	8.0
Sumac	24.9 (35.3)	19.7	49.4	6.0
Striped Maple	29.2 (26.6)	17.2	46.6	7.0

Table VI. Gross Composition of Screen Fractions that were Pulped.

Species	Screen Fraction	Composition (wgt. %) Bark	Twigs	Chips	Percent of Total Sample (Excluding Dust)
Sumac	7/8" + 5/8"	28	18	54	47
Sumac	3/8" + 3/16"	26	25	49	49
Striped Maple	7/8" + 5/8"	38	8	54	48
Striped Maple	3/8" + 3/16"	22	34	44	43

Table VII. Bark and Wood Content of Shrub and Shrub-Size Trees

Species	Size Dbh (Inches)	Branches %Wood	Branches %Bark	Stem %Wood	Stem %Bark	Above Ground Total %Wood	Above Ground Total %Bark
Sumac	1.0	45.3	54.7	64.7	35.3	64.7	35.3
Beech	0.5	82.9	17.1	88.6	11.4	86.6	13.4
Basswood	1.0	47.1	52.9	44.6	55.4	45.3	54.7
Beaked Hazelnut	0.3	64.0	36.0	81.5	18.5	75.9	24.1
Hophornbeam	0.3	66.6	33.4	85.1	14.9	81.2	18.8
Yellow Birch	0.4	75.4	24.6	82.1	17.9	79.2	20.8
Sugar Maple	0.3	57.8	43.2	92.2	7.8	82.8	17.2
Striped Maple	0.6	61.2	38.8	76.3	23.7	73.4	26.6
Willow	1.0	51.8	48.2	71.3	28.7	64.8	35.2

Table VIII. Pulping Results.

Species	Fraction Pulped	Permanganate Number	Yield of Acceptable Pulp (%)	Reject Pulp %
Yellowbirch	Whole	12.9	39	0.9
Hophornbeam	Whole	17.6	39	2.2
Sugar Maple	Whole	14.6	41	2.3
Beech	Whole	13.3	37	1.9
Beaked Hazelnut	Whole	15.8	39	0.9
Basswood	Whole	12.1	38	0.6
Willow	3/8" + 3/16"	14.3	36	Neg.
Willow	7/8" + 5/8"	14.3	43	0.5
Willow	Whole	16.5	44	0.8
Striped Maple	3/8" + 3/16"	15.6	44	0.3
Striped Maple	7/8" + 5/8"	14.8	45	1.2
Striped Maple	Whole	17.4	41	0.6
Sumac	3/8" + 3/16"	16.0	36	0.9
Sumac	7/8" + 5/8"	19.3	40	3.5
Sumac	Whole	18.1	36	2.4

Table IX. Pulping Yield, Percent Bark and Branches.

Species	% Yield	% Bark	% Branches
Sumac	36	35.3	40.9
Beech	37	13.4	35.9
Basswood	38	54.7	27.9
Beaked Hazelnut	39	24.1	32.2
Hophornbeam	39	18.8	21.3
Yellow Birch	39	20.8	42.3
Sugar Maple	41	17.2	27.7
Striped Maple	41	26.6	19.1
Willow	44	35.2	33.3

Table X. Fiber Dimensions.

Species	Fiber Length (mm.)	Fiber Diameter (maximum) (mm.)	(microns)
Striped Maple	0.62	.0155	15.5
Basswood	1.52	.0146	14.6
Beaked Hazelnut	0.67	.0140	14.0
Yellow Birch	1.15	.0247	24.7
Hophornbeam	1.16	.0140	14.0
Sugar Maple	0.65	.0142	14.2
Beech	1.07	.0133	13.3
Sumac	0.52	.0129	12.9
Willow	0.81	.0191	19.1

Table XI. Comparative Strength Characteristics (Whole Shrub)

	Rank				
Species	Density	Burst	Tear	Tensile	Overall
Yellow Birch	1	1	2	1	1
Hazelnut	2	2	3	2	2
Hophornbeam	8	3	1	3	3
Basswood	7	4	5	4	4
Sumac	3	7	9	5	5
Sugar Maple	6	6	6	7	6
Beech	9	5	4	8	7
Striped Maple	5	8	8	6	8
Willow	4	9	7	9	9

Table IA. Canadian Standard Freeness (ml.)

Species	Screen Fraction	Beating Time (minutes) 0	5	10	15	20	30
Willow	Whole						
Willow	7/8" + 5/8"	377	341	307	275	242	
Willow	3/8" + 3/16"	307	289	273	270		
Striped Maple	Whole	424	384	347	295	257	
Striped Maple	7/8" + 5/8"	362	354	327	281	244	
Striped Maple	3/8" + 3/16"	330	310	260	246	239	
Sumac	Whole	242	2.0	2.0	136	170*	
Sumac	7/8" + 5/8"	296	248	221	210	230*	
Sumac	3/8" + 3/16"	287	233	237*	272*		
Basswood	Whole	346	306	271	234		
Beaked Hazelnut	Whole	350	315	274	227		
Yellow Birch	Whole	478		373		250	139
Hophornbeam	Whole	467		383		289	176
Sugar Maple	Whole	411		350		272	210
Beech	Whole	453		353		240	136

*Increase in final readings registered from passage of fiber fines through the freeness tester screen.

Table IIA. Bulk (cc/G)

Species	Screen Fraction	Beating Time (minutes) 0	5	10	15	20	30
Willow	Whole	1.71			1.51		1.37
Willow	7/8" + 5/8"	1.72	1.63	1.53	1.44	1.39	
Willow	3/8" + 3/16"	1.76	1.69	1.67	1.50		
Striped Maple	Whole	1.77		1.60	1.51	1.45	
Striped Maple	7/8" + 5/8"	1.72	1.68	1.57	1.47	1.40	
Striped Maple	3/8" + 3/16"	1.73	1.60	1.57	1.53	1.43	
Sumac	Whole	1.55	1.50	1.42	1.42	1.38	
Sumac	7/8" + 5/8"	1.55	1.44	1.35	1.34	1.29	
Sumac	3/8" + 3/16"	1.53	1.48	1.44	1.40		
Basswood	Whole	1.70	1.63	1.64	1.53		
Beaked Hazelnut	Whole	1.65	1.55	1.48	1.41		
Yellow Birch	Whole	1.49		1.41		1.40	1.24
Hophornbeam	Whole	1.80		1.66		1.54	1.46
Sugar Maple	Whole	1.81		1.66		1.47	1.40
Beech	Whole	1.89		1.72		1.56	1.50

Table IIIA. Burst Factor

Species	Screen Fraction	Beating Time (minutes)					
		0	5	10	15	20	30
Willow	Whole	23			38		46
Willow	7/8" + 5/8"	24	30	33	39	47	
Willow	3/8" + 3/16"	25	26	32	36		
Striped Maple	Whole	22		32	39	46	
Striped Maple	7/8" + 5/8"	26	30	34	42	48	
Striped Maple	3/8" + 3/16"	30	35	38	41	45	
Sumac	Whole	38	46	48	50	53	
Sumac	7/8" + 5/8"	33	40	49	51	55	
Sumac	3/8" + 3/16"	35	38	46	47		
Basswood	Whole	69	78	83	84		
Beaked Hazelnut	Whole	61	72	83	88		
Yellow Birch	Whole	76		96		98	94
Hophornbeam	Whole	50		81		88	96
Sugar Maple	Whole	33		51		61	69
Beech	Whole	40		61		68	71

Table IVA. Tear Factor

Species	Screen Fraction	Beating Time (minutes)					
		0	5	10	15	20	30
Willow	Whole	48			69		60
Willow	7/8" + 5/8"	39	38	55	52	63	
Willow	3/8" + 3/16"	52	56	50	54		
Striped Maple	Whole	46		62	56	60	
Striped Maple	7/8" + 5/8"	58	57	62	66	53	
Striped Maple	3/8"+3/16"	49	58	62	66	57	
Sumac	Whole	61	58	57	57	53	
Sumac	7/8" + 5/8"	52	58	60	55	53	
Sumac	3/8" + 3/16"	51	55	58	54		
Basswood	Whole	69	78	83	84		
Beaked Hazelnut	Whole	61	72	83	88		
Yellow Birch	Whole	76		96		98	94
Hophornbeam	Whole	104		111		98	87
Sugar Maple	Whole	48		68		69	65
Beech	Whole	85		85		90	83

Table VA. Breaking Length (meters).

Species	Screen Fraction	Beating Time (minutes)					
		0	5	10	15	20	30
Willow	Whole	5450			8270		9080
Willow	7/8" + 5/8"	6130	6590		7350	8140	8460
Willow	3/8" + 3/16"	5760	6230	6870	7220		
Striped Maple	Whole	5590		7840	8760	9180	
Striped Maple	7/8" + 5/8"	6310	6620	7390	8270	7380	
Striped Maple	3/8" + 3/16"	6590	7320	7600	8130	8820	
Sumac	Whole	7690	8000	8510	9040	9110	
Sumac	7/8" + 5/8"	7110	7740	8900	9140	9620	
Sumac	3/8" + 3/16"	7540	8000	8430	9160		
Basswood	Whole	9650	9970	10870	9890		
Beaked Hazelnut	Whole	8790	8960	9620	10520		
Yellow Birch	Whole	9640		10700		10830	10710
Hophornbeam	Whole	8550		9830		10550	9670
Sugar Maple	Whole	6080		8200		8380	8960
Beech	Whole	6110		8610		8280	8280

Table XII

Average And Actual Range Of Five Essential Elements As A Percent For Components Of Seedlings And Saplings Of Seventeen Tree And Shrub Species In Maine

		N %		Ca %		K %		Mg %		P %	
Species	Component	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
Larch	Foliage	1.500	1.255-1.651	0.246	0.188-0.311	1.155	0.924-1.360	0.114	0.010-0.124	0.180	0.112-0.239
	Branches	0.279	0.199-0.367	0.246	0.118-0.315	0.289	0.224-0.394	0.040	0.027-0.051	0.037	0.025-0.046
	Stem	0.192	0.151-0.240	0.151	0.108-0.191	0.233	0.106-0.297	0.032	0.020-0.039	0.031	0.024-0.041
	Roots	0.267	0.187-0.383	0.168	0.098-0.273	0.447	0.237-0.694	0.053	0.032-0.074	0.048	0.027-0.093
Red Pine	Foliage	0.929	0.892-1.013	0.237	0.104-0.339	0.784	0.537-0.926	0.079	0.051-0.102	0.107	0.087-0.121
	Branches	0.216	0.161-0.309	0.263	0.118-0.370	0.161	0.104-0.250	0.041	0.034-0.049	0.026	0.021-0.029
	Stem	0.176	0.083-0.230	0.185	0.111-0.328	0.153	0.022-0.257	0.032	0.020-0.040	0.020	0.009-0.029
	Roots	0.194	0.188-0.197	0.136	0.106-0.153	0.253	0.232-0.304	0.046	0.040-0.054	0.032	0.028-0.037
Black Ash	Foliage	2.106	1.364-2.573	2.006	1.310-2.842	2.698	1.549-3.389	0.469	0.262-0.710	0.167	0.105-0.207
	Branches	0.536	0.239-0.842	0.642	0.463-0.897	1.063	0.296-1.968	0.067	0.036-0.098	0.060	0.019-0.107
	Stem	0.262	0.152-0.416	0.452	0.269-0.778	0.416	0.229-0.743	0.034	0.025-0.053	0.025	0.015-0.042
	Roots	0.570	0.250-0.956	0.634	0.465-0.951	0.813	0.576-1.071	0.123	0.077-0.162	0.064	0.028-0.107
White Ash	Foliage	1.730	1.600-1.919	0.983	0.770-1.368	2.013	1.739-2.240	0.262	0.199-0.351	0.161	0.143-0.178
	Branches	0.285	0.216-0.361	0.421	0.256-0.541	0.372	0.319-0.459	0.065	0.052-0.079	0.040	0.023-0.069
	Stem	0.216	0.157-0.250	0.434	0.347-0.509	0.256	0.175-0.353	0.054	0.038-0.069	0.025	0.020-0.031
	Roots	0.294	0.259-0.342	0.361	0.251-0.476	0.448	0.315-0.644	0.120	0.078-0.199	0.041	0.031-0.056
American Basswood	Foliage	2.840	2.602-3.080	1.543	1.426-1.658	3.560	2.830-4.282	0.411	0.344-0.478	0.302	0.260-0.346
	Branches	0.494	0.453-0.531	1.189	1.027-1.363	0.711	0.424-1.000	0.095	0.075-0.116	0.081	0.075-0.088
	Stem	0.365	0.328-0.398	0.621	0.606-0.638	0.558	0.468-0.657	0.080	0.071-0.089	0.056	0.050-0.063
	Roots	0.420	0.331-0.511	0.983	0.880-1.086	0.568	0.462-0.678	0.125	0.101-0.149	0.062	0.048-0.077

Table XII
Average And Actual Range Of Five Essential Elements As A Percent For Components Of Seedlings And Saplings Of Seventeen Tree And Shrub Species In Maine

		N %		Ca %		K %		Mg %		P %	
Species	Component	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
Beech	Foliage	1.724	1.376-2.055	0.617	0.510-0.809	1.553	1.282-1.876	0.174	0.148-0.191	0.146	0.121-0.177
	Branches	0.278	0.223-0.371	0.501	0.383-0.623	0.278	0.210-0.337	0.035	0.028-0.048	0.028	0.014-0.043
	Stem	0.215	0.192-0.231	0.586	0.453-0.727	0.213	0.180-0.254	0.027	0.024-0.033	0.018	0.013-0.023
	Roots	0.214	0.167-0.247	0.378	0.336-0.436	0.401	0.288-0.591	0.041	0.035-0.052	0.066	0.039-0.085
Gray Birch	Foliage	2.441	1.735-2.912	0.607	0.384-0.791	1.366	1.196-1.700	0.217	0.187-0.269	0.223	0.202-0.249
	Branches	0.329	0.215-0.392	0.353	0.146-0.618	0.192	0.162-0.221	0.038	0.034-0.045	0.034	0.030-0.044
	Stem	0.270	0.181-0.339	0.355	0.206-0.519	0.144	0.122-0.170	0.031	0.027-0.039	0.030	0.021-0.039
	Roots	0.642	0.238-1.247	0.529	0.260-1.048	0.338	0.285-0.410	0.072	0.063-0.082	0.097	0.058-0.163
Yellow Birch	Foliage	1.825	1.163-2.198	1.366	1.099-1.599	1.877	0.962-2.456	0.356	0.297-0.399	0.157	0.121-0.179
	Branches	0.272	0.173-0.334	0.416	0.342-0.471	0.184	0.111-0.256	0.030	0.027-0.033	0.028	0.025-0.033
	Stem	0.217	0.154-0.265	0.478	0.336-0.701	0.178	0.091-0.253	0.024	0.022-0.027	0.023	0.020-0.026
	Roots	0.252	0.204-0.287	0.710	0.600-0.825	0.246	0.208-0.281	0.046	0.033-0.062	0.038	0.028-0.044
Hophornbeam	Foliage	1.887	1.698-2.233	2.340	2.194-2.433	1.301	1.124-1.605	0.306	0.275-0.325	0.160	0.140-0.180
	Branches	0.350	0.301-0.392	1.150	0.582-1.511	0.307	0.230-0.396	0.048	0.037-0.054	0.044	0.035-0.056
	Stem	0.276	0.245-0.309	0.995	0.915-1.170	0.214	0.156-0.300	0.035	0.032-0.041	0.029	0.024-0.036
	Roots	0.280	0.245-0.351	0.723	0.559-1.026	0.414	0.285-0.555	0.123	0.054-0.203	0.163	0.056-0.322
Sugar Maple	Foliage	1.369	1.042-1.556	1.086	0.941-1.212	1.423	1.201-1.803	0.168	0.145-0.187	0.120	0.094-0.158
	Branches	0.254	0.199-0.321	0.625	0.500-0.778	0.337	0.204-0.486	0.030	0.021-0.042	0.026	0.017-0.038
	Stem	0.239	0.222-0.250	0.743	0.389-1.022	0.478	0.174-0.902	0.032	0.027-0.041	0.027	0.020-0.032
	Roots	0.294	0.250-0.364	0.835	0.538-1.284	0.656	0.450-0.851	0.061	0.046-0.082	0.054	0.041-0.075
Red Oak	Foliage	1.957	1.779-2.216	0.777	0.680-0.962	1.724	1.503-1.936	0.204	0.176-0.229	0.157	0.123-0.197
	Branches	0.321	0.302-0.349	0.654	0.616-0.729	0.317	0.248-0.426	0.040	0.038-0.042	0.045	0.039-0.053
	Stem	0.200	0.147-0.275	0.456	0.417-0.515	0.193	0.151-0.240	0.025	0.020-0.031	0.021	0.013-0.029
	Roots	0.286	0.165-0.472	0.618	0.389-0.764	0.438	0.376-0.483	0.056	0.044-0.064	0.108	0.044-0.144

Table XII

Average And Actual Range Of Five Essential Elements As A Percent For Components Of Seedlings And Saplings Of Seventeen Tree And Shrub Species In Maine

		N %		Ca %		K %		Mg %		P %	
Species	Component	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
Choke Cherry	Foliage	1.781	1.492-2.281	2.322	1.866-3.196	1.960	0.880-3.106	0.389	0.367-0.421	0.160	0.150-0.173
	Branches	0.484	0.420-0.546	0.616	0.487-0.748	0.253	0.228-0.274	0.054	0.046-0.063	0.051	0.046-0.056
	Stem	0.276	0.204-0.361	0.414	0.270-0.640	0.183	0.139-0.220	0.036	0.032-0.039	0.034	0.032-0.038
	Roots	0.336	0.285-0.373	0.861	0.301-1.363	0.393	0.322-0.498	0.109	0.042-0.192	0.105	0.052-0.176
Pin Cherry	Foliage	1.724	0.295-2.598	1.046	0.879-1.177	1.583	0.286-2.353	0.235	0.042-0.391	0.224	0.036-0.327
	Branches	0.250	0.136-0.318	0.430	0.302-0.507	0.211	0.127-0.390	0.032	0.020-0.039	0.031	0.013-0.049
	Stem	0.767	0.200-1.892	0.884	0.466-1.719	1.013	0.132-2.610	0.141	0.032-0.358	0.082	0.028-0.178
	Roots	0.276	0.187-0.435	0.637	0.353-0.797	0.369	0.186-0.531	0.049	0.033-0.061	0.070	0.042-0.115
Beaked Hazelnut	Foliage	2.010	1.871-2.104	1.442	1.082-1.883	1.577	1.331-1.951	0.301	0.269-0.327	0.197	0.180-0.225
	Branches	0.389	0.324-0.447	0.721	0.571-0.962	0.412	0.247-0.583	0.046	0.040-0.058	0.052	0.039-0.072
	Stem	0.261	0.223-0.284	0.810	0.400-1.338	0.204	0.158-0.257	0.027	0.023-0.032	0.037	0.026-0.051
	Roots	0.445	0.391-0.497	0.511	0.252-0.907	0.346	0.259-0.489	0.072	0.051-0.093	0.118	0.059-0.189
Mountain Maple	Foliage	1.965	1.353-2.371	1.625	1.455-1.930	2.270	1.070-3.376	0.284	0.251-0.340	0.237	0.140-0.320
	Branches	0.351	0.181-0.466	0.674	0.470-0.845	0.360	0.134-0.505	0.046	0.023-0.066	0.048	0.024-0.064
	Stem	0.192	0.150-0.250	0.424	0.345-0.524	0.217	0.150-0.262	0.027	0.019-0.031	0.024	0.019-0.028
	Roots	0.495	0.154-0.892	0.868	0.661-1.205	0.400	0.183-0.604	0.090	0.028-0.152	0.126	0.025-0.227
Striped Maple	Foliage	1.760	1.436-1.956	0.919	0.635-1.351	2.211	2.135-2.368	0.244	0.182-0.310	0.227	0.130-0.302
	Branches	0.224	0.180-0.272	0.594	0.464-0.667	0.266	0.159-0.343	0.036	0.028-0.044	0.028	0.025-0.033
	Stem	0.180	0.161-0.215	0.710	0.533-0.972	0.184	0.125-0.262	0.030	0.024-0.032	0.023	0.019-0.030
	Roots	0.257	0.198-0.361	0.781	0.386-1.118	0.326	0.200-0.455	0.080	0.042-0.112	0.049	0.034-0.075
Sumac	Foliage	2.828	2.574-3.260	0.680	0.579-0.792	3.172	2.944-3.484	0.158	0.141-0.183	0.424	0.380-0.471
	Branches	0.420	0.325-0.577	0.891	0.851-0.934	1.040	0.628-1.807	0.078	0.046-0.125	0.110	0.055-0.219
	Stem	0.224	0.169-0.260	0.514	0.499-0.537	0.355	0.246-0.520	0.038	0.033-0.049	0.043	0.033-0.062
	Roots	0.485	0.400-0.539	0.758	0.631-0.972	0.788	0.604-1.013	0.090	0.072-0.100	0.174	0.112-0.210

Table XIII

Average And Actual Range Of Six Essential Elements And Aluminum As Parts Per Million For Components Of Seedlings And Saplings Of Seventeen Tree And Shrub Species

Species	Component	Al ppm Ave.	Al ppm Range	B ppm Ave.	B ppm Range	Cu ppm Ave.	Cu ppm Range	Fe ppm Ave.	Fe ppm Range	Mn ppm Ave.	Mn ppm Range	Mo ppm Ave.	Mo ppm Range	Zn ppm Ave.	Zn ppm Range
Larch	Foliage	232	140-396	19	14.6-22.1	7	5.6-9.8	183	114-288	340	224-472	1.8	0.7-3.9	40	16-91
	Branches	173	78-403	7	2.8-10.1	5	4.4-5.2	112	27-284	247	95-402	1.2	0 -2.3	21	16-27
	Stem	107	51-166	5	3.7-6.6	4	2.6-4.4	60	24-94	215	121-332	1.0	0.1-2.4	16	15-18
	Roots	270	96-432	6	3.4-9.4	4	2.1-5.9	157	44-243	180	84-389	2.4	0.7-5.9	19	12-26
Red Pine	Foliage	343	296-439	10	8.1-12.6	5	3.8-6.2	107	44-201	201	100-342	1.9	1.0-2.8	24	12-37
	Branches	214	93-396	4	2.0-6.0	4	2.0-7.4	122	27-266	122	87-153	1.3	0.2-2.2	39	31-57
	Stem	163	75-310	3	1.0-4.1	4	2.6-10.2	107	53-206	97	53-141	1.6	0.9-2.2	23	16-30
	Roots	186	152-212	3	2.7-3.3	4	2.4-5.2	88	51-133	82	54-114	1.6	1.1-2.0	32	16-45
Black Ash	Foliage	216	22-332	29	24.8-34.4	20	5.9-46.0	288	90-404	96	43-137	2.7	1.0-3.8	25	15-38
	Branches	41	17-57	12	6.9-15.7	10	6.1-18.1	60	46-72	38	22-51	1.1	0 -1.8	23	14-40
	Stem	28	14-44	7	4.4-11.3	5	3.3-6.8	33	23-51	26	7-45	1.0	0 -1.6	10	2-19
	Roots	89	44-134	9	5.3-12.6	12	7.1-18.8	138	119-159	61	20-105	1.4	0.2-2.4	25	10-44
White Ash	Foliage	65	44-100	23	15.3-34.6	11	10.1-12.2	91	79-110	28	22-35	1.7	0.2-3.5	21	15-30
	Branches	25	21-30	10	7.3-12.1	11	6.3-15.1	32	27-39	9	5-15	1.2	0 -2.7	42	22-58
	Stem	27	15-39	7	5.1-10.4	9	7.2-11.8	33	26-39	7	4-11	1.1	0 -2.3	57	12-187
	Roots	132	47-182	8	6.1-10.6	34	21.8-62.2	100	42-167	5	3-8	1.7	0.5-3.9	89	23-237
American Basswood	Foliage	76	53-100	28	27.0-29.8	12	9.0-14.7	108	81-136	180	135-226	1.6	0.5-2.6	41	34-47
	Branches	25	15-35	15	13.1-17.2	7	6.0-7.1	26	19-33	49	48-49	0.9	0 -1.7	80	72-89
	Stem	19	11-28	11	8.7-12.9	6	5.8-6.2	22	16-28	42	35-48	0.1	0 -0.2	32	26-38
	Roots	199	71-332	14	10.3-16.7	9	8.2-10.6	156	60-257	59	39-82	0.8	0.2-1.2	55	40-71

Table XIII

Average And Actual Range Of Six Essential Elements And Aluminum As Parts Per Million For Components Of Seedlings And Saplings Of Seventeen Tree And Shrub Species

Species	Component	Al ppm		B ppm		Cu ppm		Fe ppm		Mn ppm		Mo ppm		Zn ppm	
		Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
Beech	Foliage	69	54-90	20	18.1-22.5	10	6.4-15.7	84	80-90	435	217-654	1.5	0.8-1.9	25	24-26
	Branches	32	14-57	7	5.4-8.8	4	2.4-5.9	35	19-50	143	52-203	1.6	0.6-3.0	22	7-42
	Stem	30	21-43	6	5.1-6.3	20	3.4-52.2	32	24-42	139	50-255	1.2	0.5-1.9	97	10-268
	Roots	345	231-582	6	3.5-9.4	4	1.3-6.3	182	128-276	100	29-171	1.8	1.4-2.6	33	15-62
Gray Birch	Foliage	51	35-74	14	11.8-16.2	9	8.2-9.9	71	67-74	287	147-369	2.1	1.4-2.7	131	119-152
	Branches	37	32-43	6	2.9-8.4	7	5.1-9.3	52	41-66	81	48-136	1.4	0.2-2.1	113	62-154
	Stem	30	27-35	5	2.5-7.2	11	3.3-25.7	39	27-56	61	39-93	1.4	0.4-2.1	117	52-184
	Roots	464	416-534	6	3.7-9.9	9	3.7-15.4	277	135-377	59	57-63	2.5	1.8-2.8	87	52-139
Yellow Birch	Foliage	91	49-145	31	29.3-32.8	7	4.1-8.9	101	39-158	173	147-201	3.2	2.8-3.6	228	168-292
	Branches	23	19-30	4	3.1-5.1	4	3.1-6.3	33	25-39	29	18-43	2.2	1.6-2.6	72	65-77
	Stem	20	13-34	4	3.2-4.2	3	2.7-3.5	26	18-35	26	18-41	2.1	1.4-2.4	58	53-66
	Roots	94	63-116	4	3.5-5.0	5	4.5-8.0	205	52-559	29	15-60	2.3	1.6-3.0	61	54-66
Hophornbeam	Foliage	209	130-343	25	22.0-28.3	9	7.5-10.8	103	46-162	320	205-544	3.2	2.0-5.0	23	22-24
	Branches	45	31-54	10	8.3-12.0	6	4.9-7.0	54	42-60	86	26-138	2.0	1.2-3.1	31	21.37
	Stem	34	26-46	8	6.8-10.0	4	3.5-5.2	50	38-62	73	23-108	2.3	1.4-4.1	18	12-30
	Roots	176	106-299	9	7.5-11.6	5	4.5-5.4	117	79-187	55	28-87	2.7	2.1-3.3	33	23-42
Sugar Maple	Foliage	56	38-80	29	22.2-37.0	8	4.3-9.9	81	49-119	404	168-792	1.7	0.5-2.5	27	16-36
	Branches	21	15-30	7	5.9-9.0	4	3.7-5.2	30	19-41	116	31-240	1.0	0 -1.5	12	10-17
	Stem	67	13-161	7	5.6-7.8	4	2.8-5.7	63	14-134	106	40-237	1.3	0.4-2.4	13	6-22
	Roots	247	30-652	10	7.0-14.8	5	4.2-7.7	136	40-317	93	54-158	1.4	0 -2.8	25	15-37
Red Oak	Foliage	81	65-101	36	35.0-36.8	9	7.1-10.0	63	56-73	464	165-994	1.5	0.6-2.2	27	21-31
	Branches	30	21-36	12	9.4-14.8	5	4.0-6.0	29	18-38	203	54-489	1.0	0.4-1.7	16	12-22
	Stem	29	22-36	8	4.0-12.0	12	4.9-25.1	36	19-54	135	34-327	1.2	0.7-1.7	17	8-27
	Roots	341	221-589	11	3.0-21.2	19	4.7-46.6	127	83-204	44	21-76	1.9	1.0-2.9	56	8-109

Table XIII
Average And Actual Range Of Six Essential Elements And Aluminum As Parts Per Million For Components Of Seedlings And Saplings Of Seventeen Tree And Shrub Species

Species	Component	Al ppm Ave.	Al ppm Range	B ppm Ave.	B ppm Range	Cu ppm Ave.	Cu ppm Range	Fe ppm Ave.	Fe ppm Range	Mn ppm Ave.	Mn ppm Range	Mo ppm Ave.	Mo ppm Range	Zn ppm Ave.	Zn ppm Range
Choke Cherry	Foliage	127	91-160	43	29.7-58.4	7	5.6-7.9	157	111-201	301	260-325	2.8	2.4-3.7	17	15-20
	Branches	53	45-62	11	9.6-14.3	10	6.2-11.9	73	63-83	78	45-109	1.8	1.3-2.3	33	28-37
	Stem	35	29-40	7	5.6-8.9	5	2.6-7.5	51	40-65	53	31-80	1.6	1.3-2.3	18	15-22
	Roots	265	184-436	6	4.2-8.8	5	3.5-6.8	172	111-289	56	32-87	2.4	1.2-3.1	25	20-30
Pin Cherry	Foliage	54	47-67	19	10.8-24.2	8	5.5-10.3	83	66-98	126	19-204	1.4	0 -3.1	31	23-39
	Branches	36	22-46	8	5.4-10.8	4	2.5-5.3	55	35-75	28	14-40	0.9	0 -2.7	23	18-31
	Stem	31	26-39	13	7.6-24.0	6	3.9-7.8	47	27-73	49	30-85	1.2	0 -2.3	25	10-39
	Roots	135	69-255	10	7.2-13.6	4	3.0-5.1	83	34-173	20	12-37	1.9	1.4-2.6	23	19-26
Beaked Hazelnut	Foliage	292	280-311	36	30.7-45.2	10	7.6-16.0	130	73-163	437	208-756	2.7	1.8-3.3	25	23-27
	Branches	54	33-70	11	7.3-14.0	7	5.5-10.1	53	29-73	179	94-281	1.1	0.0-1.9	38	24-48
	Stem	43	27-62	7	5.2-9.3	5	3.5-7.4	46	27-58	144	91-212	1.3	0 -2.1	15	8-26
	Roots	566	275-781	11	9.1-13.4	7	4.0-11.3	137	121-149	83	55-107	2.4	0.9-3.5	32	11-73
Mountain Maple	Foliage	90	58-136	26	19.6-33.2	8	5.8-11.6	105	52-149	196	105-342	3.3	2.3-4.2	32	24-45
	Branches	30	20-37	10	7.8-11.2	7	5.4-9.5	33	21-43	78	43-140	2.0	1.2-3.2	28	22-35
	Stem	21	10-33	5	4.4-6.0	5	2.7-7.4	22	11-39	38	26-53	1.6	1.0-2.0	18	14-22
	Roots	77	25-124	9	6.4-10.3	4	3.0-4.9	62	31-87	66	39-109	2.5	1.3-4.0	37	26-55
Striped Maple	Foliage	58	45-69	25	20.1-28.1	7	6.2-9.5	76	54-102	641	195-971	1.7	0.3-3.1	27	14-34
	Branches	16	9-21	9	6.0-10.8	4	2.3-6.6	21	12-27	302	53-463	1.1	0 -2.1	19	13-23
	Stem	19	11-29	8	6.2-8.9	3	2.9-4.5	28	13-36	280	63-422	1.2	0 -2.3	16	13-22
	Roots	82	62-112	8	5.7-10.7	5	3.1-6.6	78	34-148	283	96-477	1.6	0.3-2.9	28	19-44
Sumac	Foliage	165	123-229	16	14.3-18.7	8	6.6-9.6	188	172-212	35	26-40	1.5	1.2-1.8	36	31-43
	Branches	100	40-206	14	13.9-15.9	6	4.8-7.5	83	36-141	20	16-27	1.1	0 -1.8	41	30-48
	Stem	67	31-119	9	8.7-9.2	3	2.1-4.3	60	37-109	12	11-13	0.7	0.4-0.9	26	10-46
	Roots	397	155-646	10	9.7-10.9	8	3.4-15.0	241	54-509	32	28-39	2.0	1.5-2.7	52	29-98

Table XIV.

Fresh and Dry Weight Estimates for the Above Ground Portion and Complete Trees/Shrubs for Seven Species in Central Maine.

	In Pounds Fresh Weight - Above Ground Portion						In Pounds Fresh Weight - Complete Tree/Shrub					
	0.5" Dbh		1.0" Dbh		1.5" Dbh		0.5" Dbh		1.0" Dbh		1.5" Dbh	
	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range
15 Hardwood Shrub and Tree species	2.0	1.0-3.5	5.7	3.4-9.3	11.1	4.8-16.9	2.6	1.3-4.2	7.8	5.1-13.5	15.1	8.5-25.9
Larch	2.8	—	6.5	—	15.1	—	3.5	—	9.2	—	18.9	—
Red Pine	1.9	—	26.0	—	66.7	—	2.2	—	33.5	—	81.9	—

	In Pounds Fresh Weight - Above Ground Portion						In Pounds Fresh Weight - Above Ground Portion					
	0.5" Dbh		1.0" Dbh		1.5" Dbh		0.5" Dbh		1.0" Dbh		1.5" Dbh	
	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range
15 Hardwood Shrub and Tree species	1.0	0.4-1.4	3.3	1.4-5.7	6.3	3.9-16.1	1.3	0.7-2.5	4.4	2.0-8.1	8.4	3.4-15.9
Larch	1.0	—	2.5	—	5.7	—	1.4	—	3.5	—	7.3	—
Red Pine	0.9	—	9.8	—	18.9	—	1.0	—	12.4	—	24.0	—

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the Maine Transportation Department, The Cooperative Forest Research Unit, and the Life Sciences and Agriculture Experiment Station (McIntire-Stennis funds). This made it possible for Richard Walker and Russell Dingle to harvest and prepare the tree and shrub material for analysis, for the analytical laboratory of the Plant and Soils Sciences Department to determine the nutrient content there of, and for A. Krishnagopalan to conduct the pulping studies.

The contribution by the Chemical Engineering Department of the University of Maine at Orono is gratefully acknowledged for the use of its facilities and equipment.