Agriculture Canada
Service canadien des forêts

Agriculture Canada
Canadian Forestry Service

Total tree and merchantable stem biomass equations for Ontario hardwoods

I.S. Alemdag

Information Report PI-X-46
Petawawa National Forestry Institute

PNFI

ENFOR Energy from the Forest

Canada

PETAWAWA NATIONAL FORESTRY INSTITUTE

The Petawawa National Forestry Institute (PNFI) was formed on April 1, 1979, as the result of an amalgamation of the Petawawa Forest Experiment Station with the Ottawa-based Forest Management and Forest Fire Research Institutes. The Forestry Statistics and Systems Branch was established at PNFI in 1980.

In common with the rest of the Canadian Forestry Service, the Petawawa National Forestry Institute has as its objective the promotion of better management and wiser use of Canada's forest resource to the economic and social benefit of all Canadians. Because it is a national institute, particular emphasis is placed on problems that transcend regional boundaries or that require special expertise and expensive equipment that cannot be duplicated in CFS regional establishments. Such research is often performed in close cooperation with staff of the regional centres or provincial forest services.

Research at the Institute is in two main areas:

FIRE RESEARCH AND REMOTE SENSING. Every year in Canada large areas of productive forest are destroyed by fire. Research concentrates on studies of forest fire behaviour, the development of new methods of fire control, the evaluation of fire-fighting equipment and retardants, and the development of computerized fire management systems that are rapidly finding applications with fire-fighting agencies across the country. The environmental and economic impact of forest fires and the use of fire as a silvicultural tool for intensive forest management are also studied.

In remote sensing, investigations are made into the application of modern satellite and airborne remote sensing systems to forestry problems. In this respect, the ARIES digital image analysis system is proving invaluable.

INTENSIVE FOREST MANAGEMENT. As Canada moves into more intensive management of its forest to meet expected increases in demand for this vital resource, the role of this program will become increasingly important. An extensive reforestation program will require a steady supply of high-quality seed of the desired species. Improved growing stock, obtained through tree breeding and forest genetics research, is highly desirable. Increased emphasis is being placed on using the entire above-ground portion of the tree (biomass), but the effect on the environment of this and other forms of intensive management has to be carefully monitored. Biotechnological methods of improving yield while maintaining site productivity are being investigated.

In support of its research programs, the Institute has at its disposal a 98 km^2 area of forest in the western part of the Petawawa military reserve. Records of experiments and sample plots have been maintained since the 1920s. The forest also serves as a field laboratory for students from local schools, and a visitor centre is operated during the summer months.

The operations of PNFI also include THE FORESTRY STATISTICS AND SYSTEMS BRANCH (FSSB) which is responsible for the acquisition and publication of national information on the forests of Canada. Through the Canadian Forest Inventory Committee, which is comprised of provincial and federal forestry officials, the FSSB works in close cooperation with provincial forest agencies to improve and standardize the information available on Canada's forest resources.

Through the FORSTATS program, which involves all regional establishments of the Canadian Forestry Service, the FSSB coordinates the acquisition and publication within the CFS of national statistics on the forest of Canada.

Every five years, the FSSB publishes Canada's Forest Inventory; the official report on the location, extent, species, and condition of the forest resource. In addition, the FSSB is working closely with the provinces to expand the information available on changes to the forest from fire, harvesting, insects and disease, and from forest management activities. This information is essential to the development of sound policies for the improved management of this important and renewable natural resource.

TOTAL TREE AND MERCHANTABLE STEM BIOMASS EQUATIONS FOR ONTARIO HARDWOODS

Information Report PI-X-46

I.S. Alemdag

Petawawa National Forestry Institute
Canadian Forestry Service
Agriculture Canada
1984

Catalogue No. Fo46-11/46-1984E
ISSN 0706-1854
ISBN 0-662-13630-6

Additional copies of this publication can be obtained from

Technical Information and Distribution Centre
Petawawa National Forestry Institute
Canadian Forestry Service
Agriculture Canada
Chalk River, Ontario
K0J 1J0

Tel.: (613) 589-2880

Cette publication est aussi disponible en français sous le titre **Equations de biomasse d'arbre entier et de la tige marchande pour les feuillus de l'Ontario.**

Contents

Abstract

Aboveground biomass equations for single trees of 19 hardwood species of Ontario were developed. These equations are for estimating biomass, (a) in terms of ovendry mass for the main components of trees based on diameter at breast height and tree height, and (b) in terms of percent of the total stem mass for the merchantable and unmerchantable portions of the stem based on either breast height diameter and merchantable diameter, or tree height and merchantable height. In addition, several other biomass relationships were established. Computer produced tables for preparing the data for analysis are included in this report, and application of the prediction equations demonstrated.

Résumé

Des équations ont été établies pour la biomasse de la partie épigée d'arbres individuels de 19 espèces feuillus de l'Ontario. Ces équations permettent d'estimer: (a) la biomasse anhydre des principales composantes des arbres à partir du diamètre à hauteur de poitrine et de la hauteur de l'arbre; et (b) le pourcentage de la masse des parties marchandes et non marchandes de la tige par rapport à la masse totale de la tige, soit à partir du diamètre à hauteur de poitrine et du diamètre marchand, ou de la hauteur de l'arbre et de la hauteur marchande. En outre, plusieurs autres relations pour la biomasse ont été établies. On trouvera dans le rapport des tables produites par ordinateur servant à préparer les données pour l'analyse, et une démonstration de l'application des équations.

TOTAL TREE AND MERCHANTABLE STEM BIOMASS EQUATIONS FOR ONTARIO HARDWOODS

INTRODUCTION

Biomass equations are required for the direct estimation of biomass values for the main components of trees as well as of the merchantable and unmerchantable portions of stems in a forest inventory, or in any operation requiring the biomass of individual trees or stands. Such equations have been developed for some Ontario hardwoods in earlier studies (Alemdag 1981, 1982; Alemdag and Horton 1981). The present study covers the remaining major hardwood species of Ontario. Aboveground biomass estimation equations of 19 hardwoods are presented, including those of previously published species for the convenience of the reader. A species list can be found in Appendix A.

METHODS

The methods used in this study follow Alemdag (1981, 1982) and Alemdag and Horton (1971). Tree measurement and processing of wood samples for the aboveground biomass were conducted following the guidelines provided in a manual prepared for this purpose (Alemdag 1980). These field and laboratory procedures can be found in Appendix B.

Data

In addition to data on the four tree species from earlier studies, 1061 living sample trees were collected from 15 tree species from various localities in Ontario[1] and all data merged. Of these trees, 993 were from tree sizes of 5.1 cm and larger in outside-bark diameter at breast height of 1.30 m (d), and 68 from the smaller sizes. These trees were so distributed as to cover the existing tree height (h) classes of each species. Summaries of these data can be found in Table 1 (Appendix D) and in Table 6 (Appendix E). Figure 1 illustrates the various tree components for which data were collected.

I.S. Alemdag is a research scientist at the Petawawa National Forestry Institute, Canadian Forestry Service, Agriculture Canada, Chalk River, Ontario, K0J 1J0.

Manuscript approved for publication: 29 October 1984.

[1]This work was performed in 1982 and 1983 by the Dendron Resource Surveys Limited, 880 Lady Ellen Place, Ottawa, Ontario, K1Z 5L9 under a Canadian Forestry Service ENFOR contract.

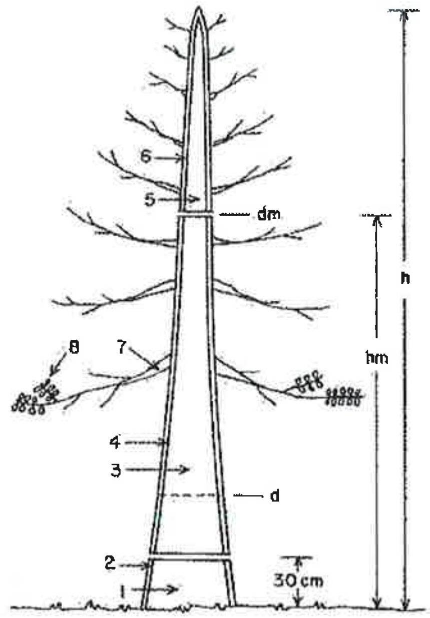

Figure 1. Diagramatic presentation of various components of trees (1) stump wood, (2) stump bark, (3) net merchantable stem wood, (4) net merchantable stem bark, (5) top wood, (6) top bark, (7) live branches, (8) twigs plus leaves.

Compilation
Following the preparation of data, basic compilations were done with regard to mass, wood density, and volume calculations. Details of these procedures can be found in Appendix B. Some computer processed tables related to these compilations are provided in Appendix C.

Analysis
After the living-tree data were assembled, analyses were conducted towards developing ovendry mass (OM) estimation equations for the main tree components (stem wood, stem bark, live branches, twigs plus leaves), and for the merchantable and unmerchantable portions of the stem (merchantable stem wood, merchantable stem bark, top wood plus bark) with stump wood and bark included in the merchantable section. These analyses were confined only to data of the most recently collected tree species. Main-component equations of largetooth aspen were taken from Alemdag and Horton (1981), and of ironwood from Alemdag (1981). Trembling aspen and white birch, for which main tree component equations had been prepared earlier for two forest regions in Ontario (Alemdag and Horton 1981), were recalculated without regional separation. Merchantability factors for trembling aspen, largetooth aspen, and white birch were adopted from Alemdag (1982). No merchantable analysis was made for ironwood because of the unavailability of merchantable-size trees of this species.

As discussed in detail in the two earlier studies (Alemdag 1981, Alemdag and Horton 1981), the following model was preferred for direct estimation of the ovendry masses of the main tree components and of the whole tree as well as of dead branches:

$$OM = b_1 \cdot d^2h \tag{1}$$

where OM, d, and h are as defined above. This model has been used by various researchers for estimating stem volume, and is referred to as the constant form-factor model by Spurr (1952) and by Clutter et al. (1983). In the present study the model was used for trees with d equal to and larger than 5.1 cm, for each species separately. This model satisfies the additivity of the OM of main components to equal the OM of the whole tree when the latter is estimated independently, and eliminates the risk of having negative estimates with small trees. After these through-the-origin equations were developed, an analysis was conducted with regard to the bias which may occur in their application, employing the whole tree equation of the combined species as an example.

For trees with d between 0.1 cm and 5.0 cm, to obtain ovendry mass of the whole tree of all species combined without separating the main tree components, the following model was employed:

$$OM = b_0 + b_1 \cdot d^2h \tag{2}$$

Ovendry mass of seedlings (woody plants under 1.30 m of height) was determined by classifying them within three height classes, and taking the averages of each for all tree species combined and for the whole tree.

Ovendry mass of merchantable and unmerchantable components of a stem were studied indirectly, that is, no direct mass-estimation equation was developed for these components. Instead, they were expressed as percent of the total stem mass of wood and bark, as factors to be used later with a known ovendry mass value of total stem. This procedure, discussed in detail in an earlier study (Alemdag 1982), provides accurate solutions to the problem. Following the same method, in the present study, the above mentioned merchantable and unmerchantable stem components were analyzed for each tree species, either for a merchantable top diameter (dm) or for a merchantable height (hm). The models used were in the following forms:

$$OM\% = b_0 + b_1 \cdot (dm/d) + b_2 \cdot (dm/d)^2 \tag{3}$$

$$OM\% = b_0 + b_1 \cdot (hm/h) + b_2 \cdot (hm/h)^2 \tag{4}$$

where OM% is ovendry mass percentage of wood or bark of merchantable section below a given diameter or height, or ovendry mass percentage of wood plus bark of tree top above the same given diameter or height. The other variables are as stated before. To determine the net merchantable percentage of the stem wood and stem bark by deduction, their percentages of the total stem mass were calculated for different stump heights up to 30 cm. This approach was necessary because mass of stump wood and stump bark had been included in the merchantable portion of the stem. Calculation of the percentage mass distribution within the stump considered the latter as the frustum of a neiloid (Alemdag 1982).

Equations of the main tree components and of merchantability factors were developed by regression analysis. The goodness of fit and the regression accuracy were expressed by the coefficient of determination (r^2) or multiple determination (R^2), and by the standard error of estimate as a percent of the mean (SEE%).

In addition to these analyses, for each species, the ovendry mass/green mass (OM/GM) ratios of each tree component and of the whole tree were calculated using the sums of the observed mass values. Also, the percentage of the ovendry mass of tree components in relation to the ovendry mass of stem wood were calculated based on the above developed mass estimation equations. Furthermore, the average basic wood density was established for each tree species by taking the arithmetic average of the basic wood densities of the sample trees.

After analysing individual tree species, all the above analyses were conducted once for all the 19 hardwood species combined.

RESULTS

The regression analysis for trees equal to or larger than 5.1 cm of d, with respect to the estimation of the ovendry mass of main tree components, whole tree, and dead branches, resulted in establishing the b_1 coefficients of Equation 1 for each species and the species combinations. These regression coefficients together with some statistical data are provided in Table 2 of Appendix D. As is noted, the sum of the component coefficients is equal to the coefficient of the whole tree, with dead branches excluded. The examination of bias conducted on the accuracy of these equations produced encouraging results (Appendix F). This test was performed with the same data used to derive these prediction equations, and only for the whole tree mass of combined species. It was found, in all d^2h classes except one, that bias ranged from -5% to +4% with zero biases in five classes. For all classes combined the bias was only -0.36%.

For the trees with a d from 0.1 cm to 5.0 cm, for all species together and for the whole tree mass only, the coefficients of Equation 2 were established as being b_0 = 0.600 and b_1 = 0.020294. For the seedlings of all species combined, the average ovendry mass of the whole tree for the three height classes were found to be as follows:

Stems from 0.01 m to 0.30 m of height = 0.009 kg

Stems from 0.31 m to 0.80 m of height = 0.060 kg

Stems from 0.81 m to 1.30 m of height = 0.298 kg

Percentage values of the component ovendry masses in the stem wood ovendry mass are presented in Table 3 for each species. Ovendry mass/green mass ratios, which were established under weather conditions at the time of data collection are given in Table 4. Average basic wood densities of each species are provided in Table 5.

For the merchantable size trees, analyses resulted in establishing the regression coefficients of Equations 3 and 4 for the estimation of percents of the merchantable and unmerchantable portions of the total stem. These coefficients, together with the necessary statistical information, are presented in Tables 7 and 8 (Appendix E). Table 7 has to be used with Equation 3 when merchantability is defined by the merchantable top diameter and Table 8 with Equation 4 when merchantability is defined by merchantable height. It should be noted that the sum of these percentages of merchantable stem wood, merchantable stem bark and top wood plus bark is 100%, the total stem wood plus bark. This procedure will yield gross merchantable stem wood and gross merchantable stem bark masses. For the net merchantable values above 30 cm stump height, the average stump percentage deductions are given in Table 9 for each species. Mass distribution within the stump, as percent of the total stump mass at 30 cm is provided in Table 10.

In developing the merchantable factors, because of the limited field data collected at the very top of the stems and because of the nature of the second degree polynomials, there is an unavoidable situation that the user of these factors should be aware of. This is that, as explained in an earlier study (Alemdag 1982), below a restricted dm/d ratio (Equation 3) or above a restricted hm/h ratio (Equation 4), calculations result in unacceptable percentage values. Therefore, it is not permissible to use these equations for the out-of-confined ratios, and for this reason, the permitted ratios of dm/d and hm/h were calculated for each species and are given in Table 12.

APPLICATION

A biomass inventory or a calculation of the ovendry mass of individual living trees or stands will involve the above estimation equations applied in the following manner:

1. Calculation of main tree components:

(a) When calculating the ovendry masses of individual trees it is necessary to have d and h of these trees, either directly measured or estimated, to be employed with Equation 1 (Table 2). If calculations are to be made on an area basis, either the sum of individual trees can be taken or the mean stand d and mean stand h can be used with this equation. The result has to be multiplied by the number of trees per area--this could be done for diameter classes as well. For example, a white birch tree with a d = 24.0 cm and h = 20.00 m contains 186.8 kg of stem wood, 33.1 kg of stem bark, 40.6 kg of live branches, and 9.9 kg of twigs plus leaves; a total of 270.4 kg for whole tree ovendry mass. In the same manner, Equation 2 has to be used for the trees under 5.1 cm of d. If required, seedlings can be calculated by the three height classes.

(b) If d and h values of the individual trees or mean values of d and h of a stand are not available but the total stem volume inside bark is known, first, the ovendry mass of stem wood can be calculated using this volume and the species' basic wood density (Table 5). Then, the ovendry masses of the other tree components have to be calculated using component percentages provided in Table 3. For example, a pure white birch stand with an inside-bark volume of 200.0 m^3/ha will have 107 200 kg/ha of stem wood, 18 974 kg/ha of stem bark, 23 262 kg/ha of live branches, 5 682 kg/ha of twigs plus leaves, and 155 118 kg/ha of whole tree ovendry mass.

(c) When an inventory is conducted using the point sampling method, the ovendry mass of tree components on a sample point will be determined by employing a modified form of Equation 1. This form is $OM/ha = (40\ 000 \cdot b_1/\pi) \cdot G \cdot h$, where G is the per hectare value of basal area in terms of m^2/ha. For instance, in a pure white birch stand of G = 25.0 m^2/ha and mean stand h = 16.00 m, the stand will contain 82 562 kg/ha of stem wood, 14 632 kg/ha of stem bark, 17 953 kg/ha of live branches, 4 375 kg/ha of twigs plus leaves, and 119 522 kg/ha of the whole tree ovendry mass.

2. Calculation of merchantable and unmerchantable components of stem:

When tree dimensions of d and h of individual trees or the mean values of these variables for stands are available, either by direct measurements or by estimations, the requirement for proceeding with the calculations is to know either the allowable merchantable top diameter or merchantable height. Thus:

(a) If merchantable top diameter is specified, first, Equation 3 (Table 7) will be used in order to calculate the percentage values of gross merchantable sections and of unmerchantable section. Secondly, these percentages will be applied to the ovendry mass of stem wood plus bark to arrive at the actual masses. For example, the same white birch tree of 1(a), with dm = 10.2 cm, will have 82.29% merchantable stem wood, 14.21% merchantable stem bark, and 3.50% top wood plus bark. In terms of ovendry mass these are 181.0 kg, 31.2 kg, and 7.7 kg, respectively.

(b) If merchantable height is given as a specification of merchantability, the same procedure as above (a) will be followed, but this time using Equation 4 (Table 8). For instance, the same white birch tree used in 1(a), when defined by its hm being equal to 12.50 m (five 2.50 m logs), will contain 77.97% or 171.5 kg merchantable stem wood, 13.02% or 28.6 kg merchantable stem bark, and 9.01% or 19.8 kg top wood plus bark.

(c) Since these merchantable stem wood and bark values contain stump wood and bark, a deduction procedure should apply in order to arrive at the net merchantable figures. Let us assume that the above given tree was cut at 20 cm stump height. Employing average stump percentages of white birch (Table 9) and ovendry mass percentage distribution of various stump heights (Table 10) it will be found that, at 20 cm stump height, stump wood is 3.53% (= 5.16% x 68.36%) and stump bark is 0.60% (= 0.88% x 68.36%) of the total stem wood plus bark (Table 11). Thus, in the example of 2(a), net merchantable stem wood is 78.76% or 173.2 kg and net merchantable stem bark is 13.61% or 29.9 kg; and in the example of 2(b) these are 74.44% or 163.7 kg and 12.42% or 27.3 kg, respectively. Another example is given in Table 13.

Table 11, which shows for white birch, the deduction percentages of stump wood and of stump bark at different stump heights up to 30 cm, can easily be prepared for the other tree species in the same way, using figures given in Tables 9 and 10.

When using Equations 3 and 4, the limitations specified in Table 12 should be given serious consideration: ratios respectively below and above these permitted values should not be employed with these equations.

3. Calculation of logging residues:

As an example, let us take the shortwood harvesting system. In a logging operation of this type it is assumed that live branches, twigs plus leaves, top wood plus bark, and stump wood plus bark are left in the forest, and wood and bark of the net merchantable portion of the stem is taken to the mill. If we assume that the ovendry mass of tree top above a given merchantable diameter, and of the stump, are calculated in connection with the total stem mass, then the formula to be used for the ovendry mass of the logging residues will be in the form of

$$OM = d^2h\cdot(a_1 + a_2\cdot(a_3 + a_4\cdot(dm/d) + a_5\cdot(dm/d)^2 + k\cdot q))$$

where the new coefficients are as follows:

a_1 = b_1 of live branches plus b_1 of twigs plus leaves of Equation 1 (Table 2),

a_2 = b_1 of stem wood plus b_1 of stem bark of Equation 1 (Table 2),

a_3, a_4, a_5 = respectively, b_0, b_1, b_2 of top wood plus bark of Equation 3 (Table 7), divided by 100.0,

k = percentage of stump wood plus bark at 30 cm stump height (Table 9), and

q = percentages of different stump heights (Table 10).

If the stump (wood plus bark) portion of the stem is also removed from the forest, then the term $k\cdot q$ will not be included in Equation 5. Also, if the merchantable section of stem is expressed in terms of merchantable height, the variable dm/d of Equation 5 will be replaced by hm/h, and the parameters a_3, a_4, and a_5 will be obtained from Table 8.

As an example, let us look at the same white birch tree used in example 2(a) with d = 24.0 cm, h = 20.00 m, stump height = 20.0 cm, and dm = 20.3 cm. If only the net merchantable portion of the stem (wood and bark) is removed from the forest, the logging residues will yield 67.9 kg of ovendry mass. Consequently, the stem section removed will amount to 270.4 - 67.9 = 202.5 kg ovendry mass.

SUMMARY AND CONCLUSIONS

Nineteen of the most important hardwood species of Ontario were studied in order to estimate aboveground biomass of standing living trees. The following conclusions were drawn, based on the analyses:

1. As in previous studies, predicting ovendry mass of the main tree components and of the whole tree from d^2h can be made more accurately for stem wood and for the whole tree than for the other components. The coefficients of determination are about 0.970 and the standard error of estimate as a percent of the mean about 20% for these better estimations. Somewhat less

accurate but still acceptable results on the foliage and live branches could be due to the social positions of the sample trees in the stand, to various densities of stands in which the sample trees were collected, and to different tree ages. Introducing these into the model as independent variables may improve estimations; however this may cause difficulties in running the biomass inventories.

The examination of bias on the results of these equations, using the whole tree mass equation of the combined species as an example indicated that they can be used with confidence.

It is interesting to observe that, for a given tree size, red oak contains the highest ovendry mass of whole tree, and basswood the lowest. When stem wood is compared, it is seen that sugar maple is the heaviest (red oak, American beech, white elm, and hickory are comparable) and basswood the lightest. For all species combined, based on the equation coefficients given in Table 2, stem wood consists of 64.8%, stem bark 8.5%, live branches 24.9%, and twigs plus leaves 1.8% of the total tree ovendry mass. In the softwoods these were 70.6%, 9.5%, 14.4%, and 5.5%, respectively (Alemdag 1983).

2. Predicting merchantable and unmerchantable portions of the stem as percents of the ovendry mass of the total stem can be done very accurately for all components as evidenced by their R^2 and SEE% values. Better results can be obtained for merchantable stem wood and for top wood plus bark than for merchantable stem bark, with the coefficient of multiple determination around 0.800 for the dm/d equations and 0.950 for the hm/h equations. For a given merchantable top diameter within a species, percents of each of these three components change with the change of the breast height diameter. A similar situation is also true when dealing with the merchantable height. After these percentages are calculated for a given tree species for a dm/d or hm/h ratio, they have to be used with the ovendry mass of stem wood plus bark of the tree. Use of these equations requires a measured or estimated ovendry mass of stem wood plus bark. Calculating the percentage values of merchantable and unmerchantable portions of the stem by Equations 3 and 4 is permissible only for the dm/d and hm/h ratios provided in Table 12.

3. If dimensional single-tree data are not available, all of the above equations can be used with stand averages (or with the averages of diameter classes) of the required independent variables.

4. All of these biomass prediction equations can be used with the same degree of reliability for the same tree species growing outside Ontario but under the same ecological conditions.

ACKNOWLEDGMENTS

The author acknowledges with thanks the computer analyses performed by Mr. T.L. Pickett and Mr. C.F. Robinson, and the drawing of the figure by Mr. D.J. McGuire, all of the Petawawa National Forestry Institute.

REFERENCES

Alemdag, I.S. 1980. Manual of data collection and processing for the development of forest biomass relationships. Can. Dep. Environ., Can. For. Serv., Petawawa Natl. For. Inst., Inf. Rep. PI-X-4. 38 p.

Alemdag, I.S. 1981. Aboveground-mass equations for six hardwood species from natural stands of the research forest at Petawawa. Can. Dep. Environ., Can. For. Serv., Petawawa Natl. For. Inst., Inf. Rep. PI-X-6. 9 p.

Alemdag, I.S. 1982. Biomass of the merchantable and unmerchantable portions of the stem. Can. Dep. Environ., Can. For. Serv., Petawawa Natl. For. Inst., Inf. Rep. PI-X-20. 20 p.

Alemdag, I.S. 1983. Mass equations and merchantability factors for Ontario softwoods. Can. Dept. Environ., Can. For. Serv., Petawawa Natl. For. Inst., Inf. Rep. PI-X-23. 24 p.

Alemdag, I.S.; Horton, K.W. 1981. Single-tree equations for estimating biomass of trembling aspen, largetooth aspen and white birch in Ontario. For. Chron. 57(4): 169-173.

Clutter, J.L.; Fortson, J.C.; Pienaar, L.V.; Brister, G.H.; Bailey, R.L. 1983. Timber management: A quantitative approach. John Wiley and Sons, New York. 333 p.

Jessome, A.P. 1977. Strength and related properties of woods grown in Canada. Environ. Can., East. For. Prod. Lab., For. Tech. Rep. No. 21, 37 p.

Spurr, S.H. 1952. Forest inventory. The Ronald Press Company, New York. 476 p.

APPENDIX A

Tree species studied

TREE SPECIES STUDIED

Trembling aspen	*Populus tremuloides* Michx.
Largetooth aspen	*Populus grandidentata* Michx.
Balsam poplar	*Populus balsamifera* L.
White birch	*Betula papyrifera* Marsh.
Yellow birch	*Betula alleghaniensis* Britton
Sugar maple	*Acer saccharum* Marsh.
Red maple	*Acer rubrum* L.
Silver maple	*Acer saccharinum* L.
White ash	*Fraxinus americana* L.
Black ash	*Fraxinus nigra* Marsh.
Red ash	*Fraxinus pennsylvanica* Marsh.
Basswood	*Tilia americana* L.
American beech	*Fagus grandifolia* Ehrh.
Black cherry	*Prunus serotina* Ehrh.
White elm	*Ulmus americana* L.
Hickory	*Carya* Nutt. spp.
Ironwood	*Ostrya virginiana* (Mill.) K. Koch
White oak	*Quercus alba* L.
Red oak	*Quercus rubra* L.

APPENDIX B

Field, laboratory, and compilation procedures

Field procedures
For the biomass and volume measurements, sample trees were randomly selected among living trees. They covered the full diameter distribution of each species, and the height range within 5 cm diameter classes. In selecting these trees, particular attention was paid to those with average vigour, unbroken tops, and sound wood. Before and after felling the trees, the following measurements and material were collected from each sample tree of each species:

(1) Outside-bark diameter at breast height of 1.30 m (d), and total tree height (h);

(2) Outside-bark merchantable diameters (dm) at three locations on the stem: 1/3, 2/3, and top of the height at which a diameter of 9.1 cm occurred; and merchantable heights (hm) from ground level to these three locations on the stem ('merchantable stem' is defined as being the part of the stem from ground level to a minimum outside-bark diameter of 9.1 cm with a minimum length of 2.80 m. This portion then is divided into three equal sections for the data collection purposes (Alemdag 1982));

(3) Outside-bark diameter at the bottom of the tree, at stump height of 0.30 m (in a few cases stump height was different), and at 0.80 m;

(4) Outside-bark diameters at 2.00 m of height and at every 2 m interval up the stem;

(5) Double-bark thickness at each place of diameter measurement except where stem disks were removed;

(6) Total tree age (number of annual rings at breast height plus the age of seedlings growing to this height);

(7) Crown length from the base of the first whorl of live branches to the tip of the tree, and the average crown diameter;

(8) Green mass (GM) of the entire aboveground portion of individual trees by weighing the following components of the trees with a d equal to or larger than 5.1 cm:

(a) each 1/3 section of the merchantable portion, and the top (the unmerchantable portion) of the stem (wood and bark together; bottom 1/3 excluding the stump's green mass),
(b) live branches (in two categories of small and large sizes, wood and bark together), twigs plus leaves, fruits, and dead branches;

(9) Green mass of whole tree where d is between 0.1 cm and 5.0 cm, and green mass of seedlings with a height up to 1.30 m (mass measured in the laboratory);

(10) Sample disks including wood and bark:

(a) from the stem, at breast height, and at the bottom of the middle and the upper merchantable sections and at the bottom of the top (on unmerchantable-size trees, from the breast height and the middle of the stem only),

(b) from the live branches (one from each size category),
(c) from the dead branches;

(11) Sample material from twigs plus leaves, and fruits.

All data were recorded on Fortran coding forms. All lengths and heights were measured and recorded in metres by 0.01 m, all diameters and bark thicknesses in centimetres by 0.1 cm (except crown diameter which is in metres), all masses in kilograms by 0.1 kg.

Laboratory procedures
In the laboratory, using samples collected in the field, the following work was performed:

(1) On stem disks, inside-bark diameter and double-bark thickness were measured;

(2) A wedge-shaped piece of wood was cut from each of the stem disks;

(3) In the remaining part of the stem disks and on branch disks, wood and bark were separated and the GM of each was measured by weighing;

(4) The disk wood and disk bark were ovendried and the ovendry mass (OM) of each was measured by weighing;

(5) After removing bark from the wedge, the wedge wood was soaked in water for some time, and its green volume determined by the immersion method; afterwards, this wedge wood was ovendried and its OM measured by weighing;

(6) Twigs and leaves together and fruits were weighed before and after ovendrying.

The samples were dried in a forced-air oven at 105° ± 3°C for 24 to 48 hours or until no change in mass was noted. Samples were weighed to the nearest 0.1 g for their GM and OM values. Wedge-wood volume was measured by 0.1 cm^3.

Compilation procedures
Mass calculations of the tree components, and wood density and stem volume calculations were conducted using the following procedures:

Mass calculations. First, bark percent in terms of wood plus bark of the stem disks were calculated using green mass obtained from the disks. Then, employing the weighted average of these percentages of the two ends of each of the bottom, middle, and upper third sections of the merchantable stem, each of these section's observed green mass of wood plus bark was separated into wood and bark. Weighting factors were the squares of the disks' outside-bark diameters. In the case of the bottom section, disk at breast height was used as the lower-end disk, and in case of the tree top, only one disk was employed. Following this, OM/GM ratios of the above mentioned sample materials were calculated. These ratios were then multiplied by the actual measured GM values of components to arrive at the OM values. When dealing with the wood mass and bark mass of the four stem sections, a weighted average of OM/GM ratios of each section was calculated similarly to the weighted bark percentages, before applying these ratios to the sections' green masses. Ovendry mass of stump wood and of stump bark were calculated by using the ratio of stump volume to the volume of the part between stump height and the top height of the lower merchantable section. After these calculations for the stem were completed, they were put together to arrive at the ovendry mass of wood and of bark of the total stem. Then, ovendry mass of live branches, twigs plus leaves, fruits, and dead branches were added to this stem total to obtain the ovendry mass of the whole tree. However, when doing estimation analyses, the mass of fruits and dead branches were not included in the whole tree mass. In addition to the ovendry mass of the various tree components, the ovendry mass of the total merchantable stem wood, total merchantable stem bark, and the harvesting residue (whole tree minus merchantable stem wood and bark) were calculated.

Basic wood density calculations. The basic wood density by definition is the ratio of ovendry mass of wood to its green volume, expressed in terms of mass per unit of volume. For each disk location on the stem it was calculated by dividing the wedge wood's ovendry mass in grams to its green volume in cubic centimetres. The average wood density of the bole was computed by taking the weighted averages of these wood densities, the weighting factors being the square of the inside-bark diameter of the disks.

Volume calculations. Stem volume, from ground level to the top of the tree, was calculated for inside bark and outside bark, in cubic metres. In these calculations the formula for a neiloid frustum was used for the stump volume, the cone formula for the tree top, and Smalian's formula for the part of the stem in between these two sections. The calculated values were presented for the lower third (excluding stump), middle third, and upper third of the merchantable stem, for the top, and for the stump.

The results of these calculations and most of the sample tree information were then entered into computer-produced tables called single-tree summaries. A copy of such a table for a sample tree is given in Appendix C. Subsequently, these processed data were visually checked to see if there were any anomalies among the calculated values, by tabulating them in an ascending order of d and h. The obvious errors were then either corrected by referring to the field data, or the trees with these errors were rejected. The examples of these computer checking tables are also provided in Appendix C. Computer programs to produce these tables and to store the data for further analyses were written in FORTRAN-77/RSX and made operational on the DEC PDP 11/44 with the RSX-11M+ operating system. They were named as ISA42 (Single-Tree Summaries), ISA43 (Checking Table No. 1) and ISA44 (Checking Table No. 2). Copies of these programs can be obtained by writing to the Director, Petawawa National Forestry Institute, Canadian Forestry Service, Agriculture Canada, Chalk River, Ontario, K0J 1J0, Canada.

APPENDIX C

Computer printouts of single-tree summary and checking tables

TABLE OF SINGLE-TREE SUMMARIES

PROJECT NO.: PI-12-067 STUDY NO.: ENFOR-234

PLOT NO. 1	TREE NO. 12	SPECIES CODE	720	DBHOB (CM)	35.0	HEIGHT (M)	22.06
	AGE (YR) 94	CR DIAM (M)	8.5	HT BLCR (M)	8.17	MERCH HT (M)	15.60
	TREE STATUS 1	DBT AT BH (CM)	2.0				

ROW NO.	DESCRIPTION	SEC NO.	GREEN MASS (KG)	OVENDRY MASS (KG)	OM/GM RATIO	VOLUME (M * * 3) OUTSIDE BK	VOLUME (M * * 3) INSIDE BK
1	STEM WOOD	1*	342.468	186.529	0.545		0.436
2		2	236.462	127.487	0.539		0.227
3		3	90.256	48.342	0.536		0.089
4		4	11.650	6.147	0.528		0.013
5	ROWS 1-4	TOTAL	680.836	368.506	0.541		
6	STEM BARK	1*	38.232	21.638	0.566		
7		2	27.338	15.659	0.573		
8		3	13.044	7.305	0.560		
9		4	2.450	1.344	0.549		
10	ROWS 6-9	TOTAL	81.064	45.946	0.567		
11	STEM WOOD PLUS BARK	1*	380.700	208.168	0.547	0.483	
12		2	263.800	143.146	0.543	0.257	
13		3	103.300	55.647	0.539	0.104	
14		4	14.100	7.491	0.531	0.016	
15	ROWS 11-14	TOTAL	761.900	414.452	0.544		
16	BARK % OF WOOD PLUS BARK **	1	10.0	10.4			
17		2	10.4	10.9			
18		3	12.6	13.1			
19		4	17.4	17.9			
20		AVG.	10.6	11.1			
21	BRANCHES, DEAD		10.100	7.070	0.700		
38	WOOD, LIVE BRANCHES > 9.0 CM		106.049	58.962	0.556		
39	BARK, LIVE BRANCHES > 9.0 CM		20.751	11.081	0.534		
22	BRANCHES, LIVE > 9.0 CM		126.800	70.043	0.552		
40	WOOD, LIVE BRANCHES < 9.1 CM		150.632	78.704	0.522		
41	BARK, LIVE BRANCHES < 9.1 CM		31.768	16.661	0.524		
23	BRANCHES, LIVE < 9.1 CM		182.400	95.365	0.523		
42	TWIGS		16.619	8.837	0.532		
43	LEAVES		20.181	7.266	0.360		
24	TWIGS AND LEAVES		36.800	16.103	0.438		
44	NEW CONES		1.700	0.551	0.324		
45	OLD CONES		0.400	0.181	0.453		
46	CONES		2.100	0.732	0.349		
25	STUMP WOOD		91.078	49.892	0.548		0.116
26	STUMP BARK		7.165	3.999	0.558		
27	STUMP WOOD PLUS BARK		98.242	53.892	0.549	0.125	
28	TOTAL (ROWS 15,21,22,23,24,27,46)		1218.343	657.657	0.540	0.984	0.881
29	MERCHANTABLE-STEM WOOD		669.186	362.359	0.541		0.752
30	MERCHANTABLE-STEM BARK		78.614	44.602	0.567		
31	MERCHANTABLE-STEM WOOD PLUS BARK		747.800	406.961	0.544	0.843	
32	HARVESTING RESIDUE (28 MINUS 31)		468.443	249.964	0.534		
33	WOOD DENSITY (GRAM/CM**3)	1			0.633		
34		2			0.620		
35		3			0.608		
36		4			0.601		
37		AVG.***			0.624		

* EXCLUDING STUMP
** WEIGHTED AVERAGE BY DOB**2 OF DISKS
*** WEIGHTED AVERAGE BY DIB**2 OF DISKS

PROJECT: PI-12-067 STUDY: ENFOR-234

CHECKING TABLE NO. 1
NUMBER OF TREES: 5
SPECIES CODE : 720
TREE STATUS : 1

* TOTAL OF THE COLUMN / N
** INCLUDING STUMP
*** DISREGARDING COMPONENTS WITH ZERO VALUES
**** WHOLE TREE CONTAINS DEAD BRANCHES AND CONES

				OM OF COMPONENTS						OM OF COMPONENT/ OM OF STEM WOOD***									S W'S
DBHOB	TOTAL HEIGHT	PLT NO.	TR NO.	STEM WOOD**	STEM BARK**	DEAD BRCH	LIVE BRCH	TWG,LVS & CONES	WHOLE TREE	MERCH WOOD	MERCH BARK	STUMP W & BK	DEAD BRCH	LIVE BRCH	TWG,LV &CONES	STEM BARK**	WHOLE TREE	OM** /GM**
1.7	3.21	8	3	0.19	0.02	0.00	0.23	0.12	0.56	0.00	0.00	0.28	0.00	1.21	0.66	0.10	2.98	0.63
6.2	5.00	1	39	6.46	1.34	0.00	1.42	1.42	10.64	0.00	0.00	0.12	0.00	0.22	0.22	0.21	1.65	0.59
16.1	16.30	2	6	60.22	9.03	1.93	14.72	2.97	88.86	0.75	0.11	0.06	0.03	0.24	0.05	0.15	1.48	0.56
35.0	22.06	1	12	418.40	49.94	7.07	165.41	16.84	657.66	0.87	0.11	0.13	0.02	0.40	0.04	0.12	1.57	0.54
59.6	23.87	8	28	1085.32	201.48	3.69	649.89	13.75	1954.13	0.93	0.18	0.07	0.00	0.60	0.01	0.19	1.80	0.60
AVG*				314.12	52.36	2.54	166.33	7.02	542.37	0.51	0.08	0.13	0.01	0.53	0.20	0.15	1.89	0.58

PROJECT: PI-12-067 STUDY: ENFOR-234

CHECKING TABLE NO. 2
NUMBER OF TREES: 5
SPECIES CODE : 720
TREE STATUS : 1

* TOTAL OF THE COLUMN / N
** INCLUDING STUMP
*** DISREGARDING COMPONENTS WITH ZERO VALUES
**** WHOLE TREE CONTAINS DEAD BRANCHES AND CONES

				INSIDE VOL. OF 4 SECT'S				INSIDE VOLUME	OM OF WOOD OF 4 SECTIONS				INSIDE OM	WOOD DENSITY OF 4 SECTIONS					SW OM**/
DBHOB	TOTAL HEIGHT	PLT NO.	TR NO.	1ST**	2 ND	3 RD	4 TH	STEM WOOD	1 ST**	2 ND	3 RD	4 TH	STEM WOOD	1 ST	2 ND	3 RD	4 TH	AVG.	S INSIDE VOLUME**
1.7	3.21	8	3	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.188	0.649	0.687	0.000	0.000	0.664	188.0
6.2	5.00	1	39	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	6.457	0.602	0.517	0.000	0.000	0.574	807.1
16.1	16.30	2	6	0.041	0.026	0.019	0.018	0.104	20.678	15.414	12.309	11.816	60.217	0.602	0.527	0.583	0.536	0.569	579.0
35.0	22.06	1	12	0.552	0.227	0.089	0.013	0.881	236.421	127.487	48.342	6.147	418.398	0.633	0.620	0.608	0.601	0.624	474.9
59.6	23.87	8	28	1.543	0.506	0.134	0.005	2.189	656.491	321.168	103.205	4.455	1085.320	0.676	0.720	0.628	0.596	0.683	495.8
AVG*				0.427	0.152	0.048	0.007	0.637	182.718	92.814	32.771	4.484	314.116	0.632	0.614	0.364	0.347	0.623	509.0

APPENDIX D

Tables for the main tree components: 1-5

Table 1. Statistical data for trees of component-mass analysis

Species	Number of sample trees n	d(cm) Mean	d(cm) SD†	d(cm) Range	h(m) Mean	h(m) SD†	h(m) Range	GM of whole tree (kg) Mean	GM* SD†	GM* Range
Trembling aspen	224	16.6	7.7	5.2 - 43.5	17.4	4.8	7.0 - 27.3	257.5	298.3	8.7 - 1854.9
Largetooth aspen	96	16.3	7.1	5.4 - 39.2	17.5	5.0	7.5 - 28.9	216.6	222.7	8.9 - 1195.0
Balsam poplar	90	24.9	9.9	6.6 - 53.2	18.5	4.9	6.2 - 27.0	603.6	613.7	19.9 - 3091.9
White birch	135	17.0	6.1	5.4 - 32.7	16.5	4.0	7.3 - 22.3	246.5	191.9	12.8 - 1162.4
Yellow birch	95	35.4	16.7	6.2 - 70.3	19.7	4.8	5.0 - 25.6	1495.6	1276.5	19.4 - 4971.7
Sugar maple	112	27.1	14.9	5.1 - 57.8	18.1	4.9	7.3 - 26.4	925.5	957.1	9.5 - 3928.4
Red maple	63	21.4	10.7	5.7 - 45.2	16.7	5.0	8.0 - 25.4	437.6	467.3	17.1 - 1690.0
Silver maple	37	24.3	12.1	5.3 - 45.3	20.4	5.1	9.5 - 26.4	620.7	605.2	19.6 - 1953.7
White ash	74	23.8	11.4	5.9 - 53.7	18.0	3.6	9.1 - 26.9	502.7	464.0	15.8 - 2738.1
Black ash	26	15.0	7.6	5.7 - 33.1	13.7	3.2	7.2 - 20.3	175.6	177.9	14.0 - 597.9
Red ash§	28	21.2	8.8	6.9 - 40.2	18.3	5.1	7.2 - 26.7	377.3	303.0	18.3 - 1001.8
Basswood	76	27.7	13.7	5.3 - 54.8	18.1	5.5	3.8 - 26.1	665.6	631.8	4.5 - 2201.7
American beech	76	26.5	10.9	6.1 - 46.3	19.1	5.0	5.6 - 26.5	782.9	657.5	14.6 - 2478.7
Black cherry	72	24.1	10.7	6.4 - 49.6	17.8	4.1	8.4 - 25.9	514.9	433.4	20.2 - 1989.4
White elm	77	21.2	9.3	5.4 - 55.2	14.0	3.5	6.6 - 23.2	378.3	455.9	8.3 - 3080.6
Hickory	73	22.0	9.7	5.5 - 46.6	20.3	6.0	7.9 - 29.4	659.3	629.6	9.6 - 2390.8
Ironwood	14	7.7	3.5	5.2 - 18.5	8.6	1.7	6.3 - 11.9	30.1	34.3	9.7 - 131.9
White oak	61	24.6	15.9	5.5 - 74.3	11.9	4.5	5.0 - 21.5	573.1	858.8	10.4 - 3988.6
Red oak	114	23.8	10.0	5.5 - 55.3	16.0	3.7	6.5 - 23.0	575.1	551.9	11.6 - 3421.6
All hardwoods	1543	22.4	12.0	5.1 - 74.3	17.3	5.0	3.8 - 29.4	544.4	684.9	4.5 - 4971.7

*GM of whole tree is green mass of tree above ground including stem, live branches, twigs and leaves.
†SD is standard deviation.
§Red ash includes some sample trees from green ash (*Fraxinus pennsylvanica* var. *subintegerrima* [Vahl] Fern.).

Table 2. Regression coefficients and statistics of Equation 1: $OM = b_1 \cdot d^2h$

Component	b_1	r^2	SEE%	Mean (kg)	Range (kg)
		Trembling aspen (n = 224)			
Stem wood	0.014579	0.974	18.4	102.9	3.2 - 671.6
Stem bark	0.003198	0.918	36.7	21.4	0.6 - 133.1
Live branches	0.002498	0.792	72.7	15.2	0.3 - 174.8
Twigs plus leaves	0.000510	0.619	63.2	4.2	0.2 - 23.2
Whole tree	0.020785	0.972	19.7	143.7	5.1 - 964.4
Dead branches*	-	-	-	-	-
		Largetooth aspen (n = 96)			
Stem wood	0.013427	0.981	13.9	86.7	2.9 - 403.4
Stem bark	0.002931	0.917	28.7	19.4	1.0 - 112.4
Live branches	0.001840	0.714	76.9	10.7	0.3 - 116.9
Twigs plus leaves	0.000379	0.736	54.0	2.6	0.2 - 20.7
Whole tree	0.018577	0.982	13.7	119.4	4.6 - 641.2
Dead branches*	-	-	-	-	-
		Balsam poplar (n = 90)			
Stem wood	0.013164	0.978	15.3	202.1	4.5 - 996.3
Stem bark	0.001888	0.908	30.7	29.9	1.3 - 164.2
Live branches	0.003150	0.781	58.2	46.7	2.0 - 352.6
Twigs plus leaves	0.000303	0.491	51.8	5.9	0.5 - 20.2
Whole tree	0.018505	0.974	16.9	284.6	9.6 - 1516.3
Dead branches*	0.000677	0.491	143.8	8.6	0.0 - 124.7
		White birch (n = 135)			
Stem wood	0.016211	0.976	11.3	99.7	3.4 - 350.8
Stem bark	0.002873	0.785	37.7	17.7	0.7 - 89.9
Live branches	0.003525	0.588	85.1	18.8	0.7 - 222.9
Twigs plus leaves	0.000859	0.745	43.1	5.2	0.4 - 25.6
Whole tree	0.023468	0.967	14.1	141.4	6.2 - 657.1
Dead branches*	-	-	-	-	-

*Ovendry mass of dead branches is not included in the whole tree ovendry mass.

Table 2. (cont'd)

Component	b_1	r^2	SEE%	Mean (kg)	Range (kg)
		Yellow birch (n = 95)			
Stem wood	0.015339	0.932	21.2	546.5	6.5 - 1623.9
Stem bark	0.002193	0.773	43.0	77.7	1.3 279.0
Live branches	0.006947	0.774	52.0	226.5	1.3 - 1110.0
Twigs plus leaves	0.000343	0.430	68.1	13.3	1.0 - 68.3
Whole tree	0.024822	0.927	23.3	864.1	10.6 - 2951.4
Dead branches*	0.000001	0.424	138.3	15.4	0.0 - 164.8
		Sugar maple (n = 112)			
Stem wood	0.017806	0.983	13.5	371.1	3.8 - 1536.4
Stem bark	0.001675	0.714	48.7	39.6	0.5 - 233.7
Live branches	0.006717	0.890	37.7	136.8	0.2 - 684.5
Twigs plus leaves	0.000526	0.655	52.8	12.7	0.2 - 49.6
Whole tree	0.026724	0.978	15.2	560.1	6.2 - 2421.1
Dead branches*	0.000297	0.381	120.6	6.4	0.0 - 46.3
		Red maple (n = 63)			
Stem wood	0.014497	0.962	20.7	173.2	5.6 - 691.1
Stem bark	0.001562	0.857	34.6	20.6	0.8 - 59.8
Live branches	0.005162	0.814	55.6	58.1	1.6 - 347.6
Twigs plus leaves	0.000499	0.713	45.7	7.0	0.4 - 26.3
Whole tree	0.021720	0.970	18.6	258.9	10.2 - 972.8
Dead branches*	0.000506	0.311	140.3	6.4	0.0 - 52.0
		Silver maple (n = 37)			
Stem wood	0.013607	0.973	14.4	245.5	6.4 - 722.2
Stem bark	0.001326	0.956	18.7	23.9	0.8 - 73.2
Live branches	0.006684	0.803	59.0	102.6	0.7 - 492.1
Twigs plus leaves	0.000394	0.707	45.5	7.7	0.7 - 26.8
Whole tree	0.022011	0.968	17.2	379.7	11.6 - 1163.7
Dead branches*	0.000169	0.206	164.6	3.1	0.0 - 26.5

*Ovendry mass of dead branches is not included in the whole tree ovendry mass.

Table 2. (cont'd)

Component	b_1	r^2	SEE%	Mean (kg)	Range (kg)
		White ash (n = 74)			
Stem wood	0.015349	0.940	21.8	215.4	8.2 - 1077.8
Stem bark	0.001810	0.814	32.5	27.8	1.1 - 103.7
Live branches	0.006197	0.739	69.3	75.1	0.6 - 653.4
Twigs plus leaves	0.000328	0.186	64.0	5.8	0.1 - 15.8
Whole tree	0.023684	0.931	24.9	324.2	0.7 - 1850.1
Dead branches*	0.000855	0.264	192.7	10.4	0.0 - 93.6
		Black ash (n = 26)			
Stem wood	0.015574	0.980	15.6	71.3	5.3 - 286.8
Stem bark	0.001914	0.720	43.4	10.5	1.0 - 32.0
Live branches	0.001808	0.405	98.3	9.4	0.6 - 50.2
Twigs plus leaves	0.000315	0.307	76.3	1.9	0.2 - 6.7
Whole tree	0.019611	0.957	21.3	93.2	7.9 - 326.2
Dead branches*	0.001724	0.780	87.7	6.0	0.0 - 43.2
		Red ash (n = 28)			
Stem wood	0.012970	0.932	21.8	149.1	5.9 - 418.2
Stem bark	0.002161	0.880	27.0	25.7	1.4 - 73.6
Live branches	0.002593	0.836	38.3	29.0	0.8 - 97.2
Twigs plus leaves	0.000326	0.268	51.9	4.6	0.1 - 9.1
Whole tree	0.018050	0.942	19.8	208.4	9.9 - 587.8
Dead branches*	0.000190	0.179	199.4	2.1	0.0 - 20.4
		Basswood (n = 76)			
Stem wood	0.011626	0.972	16.4	240.1	1.4 - 822.2
Stem bark	0.001877	0.826	39.3	40.9	0.2 - 144.6
Live branches	0.002677	0.844	42.6	54.5	0.4 - 202.5
Twigs plus leaves	0.000329	0.445	68.1	8.0	0.1 - 32.3
Whole tree	0.016509	0.973	15.8	343.6	2.2 - 1118.9
Dead branches*	0.000131	0.420	108.7	2.8	0.0 - 17.0

*Ovendry mass of dead branches is not included in the whole tree ovendry mass.

Table 2. (cont'd)

Component	b_1	r^2	SEE%	Mean (kg)	Range (kg)
		American beech (n = 76)			
Stem wood	0.017437	0.897	25.3	317.7	5.5 - 1013.8
Stem bark	0.001230	0.754	36.5	23.5	0.9 - 74.5
Live branches	0.005880	0.647	64.7	100.6	0.7 - 444.1
Twigs plus leaves	0.000356	0.315	80.9	7.1	0.4 - 31.2
Whole tree	0.024903	0.878	28.6	449.0	8.3 - 1372.5
Dead branches*	0.000545	0.326	124.4	9.4	0.0 - 55.4
		Black cherry (n = 72)			
Stem wood	0.014529	0.826	31.7	212.0	8.7 - 689.6
Stem bark	0.001741	0.666	43.2	26.4	1.3 - 82.8
Live branches	0.005579	0.719	71.4	65.3	0.4 - 403.7
Twigs plus leaves	0.000275	0.269	68.2	4.5	0.2 - 15.0
Whole tree	0.022124	0.901	26.1	308.2	12.1 - 1183.5
Dead branches*	0.001129	0.322	105.7	16.2	0.0 - 95.4
		White elm (n = 77)			
Stem wood	0.017416	0.970	23.0	146.7	2.8 - 1328.9
Stem bark	0.002443	0.803	68.9	19.7	0.5 - 246.7
Live branches	0.003957	0.647	58.7	42.7	0.7 - 234.8
Twigs plus leaves	0.000404	0.517	53.4	4.9	0.3 - 22.0
Whole tree	0.024220	0.962	23.7	213.9	4.3 - 1832.2
Dead branches*	0.000067	0.029	175.3	0.9	0.0 - 7.0
		Hickory (n = 73)			
Stem wood	0.017007	0.940	21.4	241.1	3.7 - 857.6
Stem bark	0.002114	0.899	26.2	30.8	0.8 - 121.2
Live branches	0.008546	0.769	61.1	106.0	0.9 - 621.4
Twigs plus leaves	0.000667	0.813	41.8	9.3	0.3 - 37.0
Whole tree	0.028334	0.949	21.1	387.3	5.7 - 1335.1
Dead branches*	0.000106	0.026	256.6	1.8	0.0 - 31.0

*Ovendry mass of dead branches is not included in the whole tree ovendry mass.

Table 2. (cont'd)

Component	b_1	r^2	SEE%	Mean (kg)	Range (kg)
		Ironwood (n = 14)			
Stem wood	0.015409	0.947	23.8	12.1	3.0 - 48.1
Stem bark	0.001432	0.593	45.2	1.4	0.6 - 3.9
Live branches	0.004147	0.953	29.8	2.8	0.3 - 13.7
Twigs plus leaves	0.002432	0.906	35.6	1.8	0.7 - 8.9
Whole tree	0.023420	0.963	20.4	18.1	6.3 - 74.5
Dead branches*	-	-	-	-	-
		White oak (n = 61)			
Stem wood	0.012846	0.959	27.9	200.5	2.8 - 1362.8
Stem bark	0.001608	0.866	47.9	26.9	0.7 - 162.5
Live branches	0.007350	0.979	26.1	95.4	0.0 - 843.0
Twigs plus leaves	0.000460	0.898	45.2	7.2	0.0 - 58.8
Whole tree	0.022264	0.978	22.1	329.9	4.7 - 2385.5
Dead branches*	0.002018	0.521	220.4	2.1	0.0 - 406.9
		Red oak (n = 114)			
Stem wood	0.017601	0.936	21.6	207.5	5.2 - 887.4
Stem bark	0.003002	0.817	34.8	37.0	0.7 - 156.6
Live branches	0.008438	0.718	79.2	80.2	0.2 - 896.2
Twigs plus leaves	0.000669	0.624	51.7	8.5	0.3 - 37.3
Whole tree	0.029710	0.950	21.4	333.2	6.5 - 1977.5
Dead branches*	0.001242	0.430	103.8	14.1	0.0 - 158.9
		All hardwoods (n = 1543)			
Stem wood	0.015220	0.936	30.5	208.1	1.4 - 1623.9
Stem bark	0.001992	0.769	55.8	29.3	0.2 - 279.0
Live branches	0.005859	0.737	90.5	67.8	0.0 - 1110.0
Twigs plus leaves	0.000415	0.555	73.1	6.7	0.0 - 68.3
Whole tree	0.023486	0.928	34.0	311.9	2.2 - 2951.4
Dead branches*	0.000566	0.245	243.3	7.0	0.0 - 406.9

*Ovendry mass of dead branches is not included in the whole tree ovendry mass.

Table 3. Component, whole tree, and dead-branches ovendry mass as percent of stem wood ovendry mass

Species	Number of sample trees n	Stem bark	Live branches	Twigs plus leaves	Whole tree	Dead branches*
Trembling aspen	224	21.9	17.1	3.5	142.5	-
Largetooth aspen	96	21.8	13.7	2.8	138.3	-
Balsam poplar	90	14.4	23.9	2.3	140.6	5.1
White birch	135	17.7	21.7	5.3	144.7	-
Yellow birch	95	14.3	45.3	2.2	161.8	0.0
Sugar maple	112	9.4	37.7	3.0	150.1	1.7
Red maple	63	10.8	35.6	3.4	149.8	3.5
Silver maple	37	9.8	49.1	2.9	161.8	1.2
White ash	74	11.8	40.4	2.1	154.3	5.6
Black ash	26	12.3	11.6	2.0	125.9	11.1
Red ash	28	16.7	20.0	2.5	139.2	1.5
Basswood	76	16.2	23.0	2.8	142.0	1.1
American beech	76	7.1	33.7	2.0	142.8	3.1
Black cherry	72	12.0	38.4	1.9	152.3	7.8
White elm	77	14.0	22.7	2.3	139.0	0.4
Hickory	73	12.4	50.3	3.9	166.6	0.5
Ironwood	14	9.3	26.9	15.8	152.0	-
White oak	61	12.5	57.2	3.6	173.3	15.7
Red oak	114	17.1	47.9	3.8	168.8	7.1
All hardwoods	1543	13.1	38.5	2.7	154.3	3.7

*Ovendry mass of dead branches is not included in the whole tree ovendry mass.

Table 4. Ovendry mass/green mass ratios

Species	Number of sample trees n	Stem wood	Stem bark	Live branches	Twigs plus leaves	Whole tree
Trembling aspen	224	0.573	0.580	0.510	0.372	0.558
Largetooth aspen	96	0.560	0.576	0.530	0.333	0.551
Balsam poplar	90	0.472	0.474	0.484	0.375	0.472
White birch	135	0.573	0.663	0.575	0.400	0.574
Yellow birch	95	0.580	0.585	0.584	0.411	0.578
Sugar maple	112	0.620	0.596	0.591	0.429	0.605
Red maple	63	0.612	0.558	0.570	0.444	0.592
Silver maple	37	0.630	0.568	0.597	0.441	0.612
White ash	74	0.664	0.583	0.652	0.373	0.645
Black ash	26	0.544	0.513	0.510	0.354	0.531
Red ash	28	0.568	0.542	0.523	0.377	0.552
Basswood	76	0.528	0.506	0.499	0.397	0.516
American beech	76	0.585	0.558	0.553	0.442	0.573
Black cherry	72	0.616	0.556	0.584	0.388	0.599
White elm	77	0.574	0.565	0.565	0.390	0.566
Hickory	73	0.609	0.512	0.593	0.380	0.587
Ironwood	14	0.632	0.569	0.603	0.465	0.601
White oak	61	0.584	0.588	0.570	0.420	0.576
Red oak	114	0.568	0.655	0.597	0.442	0.579
All hardwoods	1543	0.581	0.571	0.573	0.404	0.573

Table 5. Average basic wood densities

Species	Basic wood density (kg/m³)		Number of sample trees		Number of specimens*
Trembling aspen	390	(374)+	54	(20)+	164
Largetooth aspen	363	(390)	19	(10)	60
Balsam poplar	354	(372)	87	(10)	348
White birch	536	(506)	56	(16)	200
Yellow birch	596	(559)	95	(25)	368
Sugar maple	623	(597)	112	(19)	402
Red maple	583	(516)	63	(6)	198
Silver maple	477	(461)	37	(5)	136
White ash	594	(570)	64	(13)	256
Black ash	545	(468)	18	(5)	72
Red ash	555	(373)	24	(6)	96
Basswood	426	(360)	76	(4)	288
American beech	610	(590)	76	(17)	292
Black cherry	569	(510)	64	(5)	256
White elm	580	(524)	68	(23)	272
Hickory	616	(628)	67	(5)	268
Ironwood	652	(652)	14	(6)	28
White oak	646	(654)	49	(5)	196
Red oak	590	-	100	-	400
All hardwoods	548	-	1143	-	4300

*Number of wedges taken from the disks (one from each) in order to determine basic wood density.

+Figures in parentheses are from Jessome (1977).

APPENDIX E

Tables for the merchantable and
unmerchantable components of
the stem: 6-13

Table 6. Statistical data for trees of merchantable-mass analysis

Species	Number of sample trees n	Number of observations	d(cm) Mean	d(cm) Range	h(m) Mean	h(m) Range	dm/d* Mean	dm/d* Range	hm/h* Mean	hm/h* Range
Trembling aspen	164	492	19.5	10.1 - 43.5	19.53	9.58 - 27.25	0.731	0.209 - 0.995	0.422	0.083 - 0.852
Largetooth aspen	71	213	19.2	9.6 - 39.2	19.71	11.60 - 28.90	0.716	0.232 - 0.990	0.429	0.066 - 0.849
Balsam poplar	87	261	25.5	10.0 - 53.2	18.81	8.70 - 27.00	0.637	0.174 - 0.990	0.458	0.121 - 0.884
White birch	103	309	19.4	10.0 - 32.7	18.21	11.70 - 22.25	0.716	0.278 - 0.992	0.426	0.071 - 0.797
Yellow birch	89	267	37.3	10.4 - 70.3	20.47	10.00 - 25.60	0.598	0.136 - 0.991	0.468	0.088 - 0.874
Sugar maple	89	267	31.6	10.0 - 57.8	19.82	9.86 - 26.41	0.639	0.157 - 1.000	0.445	0.076 - 0.838
Red maple	36	108	28.1	13.5 - 45.2	20.04	10.76 - 25.35	0.620	0.201 - 0.993	0.449	0.152 - 0.804
Silver maple	31	93	27.4	13.3 - 45.3	21.99	14.15 - 26.38	0.606	0.205 - 0.933	0.441	0.106 - 0.812
White ash	64	192	26.3	10.7 - 53.7	18.83	11.75 - 26.93	0.626	0.169 - 0.975	0.451	0.138 - 0.837
Black ash	17	51	18.8	10.7 - 33.1	15.48	12.60 - 20.30	0.728	0.248 - 0.991	0.401	0.107 - 0.775
Red ash	24	72	23.3	12.0 - 40.2	19.66	13.50 - 26.70	0.669	0.226 - 0.950	0.433	0.129 - 0.828
Basswood	68	204	30.0	11.5 - 54.8	19.31	9.41 - 26.10	0.647	0.166 - 0.993	0.473	0.121 - 0.866
American beech	70	210	28.0	10.5 - 46.3	19.98	9.72 - 26.50	0.635	0.197 - 0.989	0.468	0.106 - 0.858
Black cherry	63	189	26.4	10.1 - 49.6	18.64	8.35 - 25.92	0.614	0.183 - 0.991	0.468	0.138 - 0.866
White elm	67	201	23.2	11.3 - 55.2	14.74	8.11 - 23.24	0.643	0.165 - 0.992	0.400	0.083 - 0.824
Hickory	67	201	23.5	10.0 - 46.6	21.25	11.60 - 29.40	0.643	0.204 - 0.990	0.426	0.076 - 0.821
White oak	45	135	29.9	12.2 - 74.3	13.48	5.00 - 21.50	0.609	0.125 - 0.994	0.434	0.149 - 0.834
Red oak	100	300	25.6	10.1 - 55.3	16.64	9.92 - 23.00	0.629	0.180 - 0.998	0.452	0.106 - 0.889
All hardwoods	1255	3765	25.6	9.6 - 74.3	18.81	5.00 - 29.40	0.660	0.125 - 1.000	0.445	0.066 - 0.889

*dm is merchantable top diameter and hm is merchantable height.

Table 7. Regression coefficients and statistics of Equation 3: $OM\% = b_0 + b_1 \cdot (dm/d) + b_2 \cdot (dm/d)^2$

Component	Regression coefficients b_0	b_1	b_2	R^2	SEE%	Mean (%)	Range (%)
		Trembling aspen (n = 164)					
Merchantable stem wood	63.449	102.391	-144.963	0.894	11.18	55.4	13.7 - 88.0
Merchantable stem bark	16.920	5.385	-18.227	0.660	25.24	10.5	2.6 - 24.7
Top wood plus bark	19.631	-107.776	163.190	0.911	19.86	34.1	0.2 - 83.5
		Largetooth aspen (n = 71)					
Merchantable stem wood	67.474	82.794	-131.142	0.902	10.31	55.0	15.1 - 86.7
Merchantable stem bark	14.522	20.714	-31.798	0.730	20.65	12.0	3.4 - 22.4
Top wood plus bark	18.004	-103.508	162.940	0.925	18.35	33.0	0.5 - 81.1
		Balsam poplar (n = 87)					
Merchantable stem wood	91.781	4.388	-69.670	0.788	13.3	63.4	23.0 - 90.1
Merchantable stem bark	13.225	1.641	-11.409	0.483	27.9	91.7	2.5 - 24.2
Top wood plus bark	-5.006	-6.029	81.079	0.801	34.1	27.4	0.4 - 71.9
		White birch (n = 103)					
Merchantable stem wood	59.476	121.358	-159.218	0.901	9.94	59.2	14.4 - 87.2
Merchantable stem bark	13.736	9.510	-19.791	0.551	29.91	9.7	2.4 - 39.8
Top wood plus bark	26.788	-130.868	179.009	0.912	20.88	31.1	1.2 - 83.2
		Yellow birch (n = 89)					
Merchantable stem wood	84.625	31.697	-89.097	0.805	12.6	66.2	19.6 - 93.0
Merchantable stem bark	11.620	4.975	-12.759	0.313	37.3	9.3	2.0 - 25.3
Top wood plus bark	3.755	-36.672	101.856	0.839	34.6	24.5	0.2 - 74.8
		Sugar maple (n = 89)					
Merchantable stem wood	81.135	62.534	-117.722	0.869	11.2	65.7	15.6 - 94.9
Merchantable stem bark	6.479	17.474	-20.842	0.376	31.4	7.9	1.8 - 18.2
Top wood plus bark	12.386	-80.008	138.564	0.882	28.9	26.4	0.3 - 81.8

Table 7. (cont'd)

Component	Regression coefficients b_0	b_1	b_2	R^2	SEE%	Mean (%)	Range (%)
			Red maple (n = 36)				
Merchantable stem wood	83.812	42.894	-98.309	0.870	9.6	67.7	31.1 - 92.2
Merchantable stem bark	7.023	15.746	-19.931	0.431	26.9	8.1	3.3 - 15.4
Top wood plus bark	9.165	-58.640	118.240	0.875	29.1	24.2	0.6 - 63.0
			Silver maple (n = 31)				
Merchantable stem wood	84.812	49.197	-113.081	0.892	8.8	68.2	28.9 - 91.2
Merchantable stem bark	9.137	0.488	-7.394	0.738	15.8	6.4	2.7 - 9.8
Top wood plus bark	6.051	-49.685	120.475	0.894	25.7	25.4	0.7 - 66.8
			White ash (n = 64)				
Merchantable stem wood	93.678	-6.814	-56.461	0.769	13.8	64.6	27.0 - 90.7
Merchantable stem bark	11.275	2.051	-8.816	0.327	30.9	86.9	2.7 - 19.0
Top wood plus bark	-4.953	4.763	65.277	0.753	39.0	26.7	0.6 - 68.5
			Black ash (n = 17)				
Merchantable stem wood	75.421	62.257	-109.466	0.741	17.5	58.2	21.9 - 90.2
Merchantable stem bark	2.200	34.020	-31.739	0.295	34.3	88.2	2.5 - 17.3
Top wood plus bark	22.379	-96.277	141.205	0.713	36.4	33.0	1.4 - 74.8
			Red ash (n = 24)				
Merchantable stem wood	83.398	35.204	-95.131	0.809	13.3	60.8	27.4 - 87.0
Merchantable stem bark	14.609	3.859	-14.861	0.581	24.9	99.8	3.5 - 17.1
Top wood plus bark	1.993	-39.063	109.992	0.798	33.7	29.2	0.1 - 66.1
			Basswood (n = 68)				
Merchantable stem wood	77.644	56.210	-108.042	0.875	10.4	62.6	19.2 - 91.2
Merchantable stem bark	10.807	21.497	-27.680	0.440	27.7	11.6	3.6 - 22.8
Top wood plus bark	11.549	-77.707	135.722	0.886	27.9	25.8	0.2 - 75.4

Table 7. (cont'd)

Component	Regression coefficients b_0	b_1	b_2	R^2	SEE%	Mean (%)	Range (%)
			American beech (n = 70)				
Merchantable stem wood	88.296	39.002	-96.680	0.831	11.8	68.9	21.0 - 94.5
Merchantable stem bark	5.838	6.056	-9.870	0.455	29.1	5.2	1.5 - 15.5
Top wood plus bark	5.866	-45.058	106.550	0.836	33.2	25.9	0.5 - 77.6
			Black cherry (n = 63)				
Merchantable stem wood	94.449	-9.283	-53.612	0.724	14.7	66.1	23.4 - 93.2
Merchantable stem bark	11.359	0.527	-7.697	0.237	39.9	84.4	2.7 - 23.9
Top wood plus bark	-5.808	8.756	61.309	0.743	40.9	25.4	0.6 - 73.4
			White elm (n = 67)				
Merchantable stem wood	92.939	1.385	-66.592	0.813	12.1	63.7	22.5 - 91.7
Merchantable stem bark	11.291	2.651	-10.233	0.292	37.2	83.7	1.3 - 20.1
Top wood plus bark	-4.230	-4.036	76.825	0.822	30.1	27.9	0.9 - 72.4
			Hickory (n = 67)				
Merchantable stem wood	88.439	24.672	-90.829	0.791	13.8	63.2	18.3 - 91.9
Merchantable stem bark	10.927	5.022	-13.047	0.489	26.7	82.5	1.6 - 18.1
Top wood plus bark	0.634	-29.694	103.876	0.791	34.5	28.6	0.9 - 79.1
			White oak (n = 45)				
Merchantable stem wood	90.538	-2.508	-54.275	0.776	12.9	66.0	30.8 - 91.4
Merchantable stem bark	13.653	-2.516	-6.611	0.331	37.2	93.1	3.0 - 24.2
Top wood plus bark	-4.191	5.024	60.886	0.799	37.0	24.7	0.4 - 66.2
			Red oak (n = 100)				
Merchantable stem wood	92.925	-22.559	-37.195	0.615	17.8	62.4	21.4 - 90.6
Merchantable stem bark	15.729	1.312	-12.847	0.437	30.7	10.9	2.9 - 26.0
Top wood plus bark	-8.654	21.247	50.042	0.650	46.7	26.7	0.1 - 74.1
			All hardwoods (n = 1255)				
Merchantable stem wood	84.472	33.065	-91.403	0.811	13.3	62.5	13.7 - 94.9
Merchantable stem bark	10.087	12.415	-18.786	0.320	37.2	9.3	1.3 - 39.8
Top wood plus bark	5.441	-45.480	110.189	0.825	31.9	28.2	0.1 - 83.5

Table 8. Regression coefficients and statistics of Equation 4: $OM\% = b_0 + b_1 \cdot (hm/h) + b_2 \cdot (hm/h)^2$

Component*	Regression coefficients b_0	b_1	b_2	R^2	SEE%
		Trembling aspen (n = 164)			
Merchantable stem wood	0.943	182.017	-101.509	0.948	7.82
Merchantable stem bark	0.978	27.838	-10.393	0.692	24.02
Top wood plus bark	98.079	-209.855	111.902	0.964	12.51
		Largetooth aspen (n = 71)			
Merchantable stem wood	2.470	170.247	-91.041	0.969	5.79
Merchantable stem bark	0.525	34.983	-15.863	0.771	19.03
Top wood plus bark	97.005	-205.230	106.904	0.990	6.64
		Balsam poplar (n = 87)			
Merchantable stem wood	5.821	182.087	-102.280	0.925	7.9
Merchantable stem bark	0.757	25.443	-12.849	0.588	24.9
Top wood plus bark	93.422	-207.530	115.129	0.945	17.9
		White birch (n = 103)			
Merchantable stem wood	4.707	178.755	-98.470	0.956	6.58
Merchantable stem bark	0.935	26.566	-11.562	0.558	29.70
Top wood plus bark	94.358	-205.321	110.032	0.962	13.73
		Yellow birch (n = 89)			
Merchantable stem wood	2.749	209.118	-129.872	0.924	7.9
Merchantable stem bark	2.022	20.851	-9.560	0.357	36.0
Top wood plus bark	95.229	-229.969	139.432	0.960	17.2
		Sugar maple (n = 89)			
Merchantable stem wood	0.923	218.456	-134.802	0.931	8.1
Merchantable stem bark	-0.162	29.482	-21.276	0.464	29.1
Top wood plus bark	99.239	-247.938	156.078	0.963	16.3

*Mean values and ranges of these components are the same as those provided in Table 7.

Table 8. (cont'd)

Component*	Regression coefficients b_0	b_1	b_2	R^2	SEE%
		Red maple (n = 36)			
Merchantable stem wood	5.701	205.037	-126.416	0.952	5.9
Merchantable stem bark	-0.801	32.981	-24.698	0.530	24.5
Top wood plus bark	95.100	-238.018	151.114	0.971	14.0
		Silver maple (n = 31)			
Merchantable stem wood	7.404	205.391	-127.666	0.964	5.1
Merchantable stem bark	0.796	18.541	-11.047	0.749	15.4
Top wood plus bark	91.800	-223.932	138.713	0.962	15.5
		White ash (n = 64)			
Merchantable stem wood	4.518	191.649	-109.340	0.921	8.1
Merchantable stem bark	-0.105	29.444	-18.622	0.550	25.3
Top wood plus bark	95.587	-221.093	127.962	0.937	19.7
		Black ash (n = 17)			
Merchantable stem wood	5.790	173.468	-87.042	0.952	7.5
Merchantable stem bark	0.433	31.809	-22.160	0.513	28.5
Top wood plus bark	93.777	-205.277	109.202	0.965	12.7
		Red ash (n = 24)			
Merchantable stem wood	8.626	166.532	-88.121	0.893	10.0
Merchantable stem bark	-0.002	32.111	-17.312	0.749	19.3
Top wood plus bark	91.376	-198.643	105.433	0.902	23.5
		Basswood (n = 68)			
Merchantable stem wood	2.628	186.156	-104.876	0.934	7.5
Merchantable stem bark	-0.419	40.536	-26.925	0.520	25.7
Top wood plus bark	97.791	-226.692	131.801	0.963	16.0

*Mean values and ranges of these components are the same as those provided in Table 7.

Table 8. (cont'd)

Component*	Regression coefficients b_0	b_1	b_2	R^2	SEE%
		American beech (n = 70)			
Merchantable stem wood	3.519	209.415	-123.829	0.952	6.2
Merchantable stem bark	0.142	16.151	-9.579	0.528	27.0
Top wood plus bark	96.339	-225.566	133.408	0.959	16.5
		Black cherry (n = 63)			
Merchantable stem wood	3.914	197.353	-115.569	0.938	7.0
Merchantable stem bark	0.285	27.027	-17.249	0.326	37.5
Top wood plus bark	95.801	-224.380	132.818	0.968	14.4
		White elm (n = 67)			
Merchantable stem wood	9.608	195.956	-125.377	0.891	9.3
Merchantable stem bark	1.641	22.800	-12.361	0.384	34.7
Top wood plus bark	88.751	-218.756	137.738	0.919	20.3
		Hickory (n = 67)			
Merchantable stem wood	8.519	182.844	-104.420	0.927	8.1
Merchantable stem bark	0.449	26.946	-16.531	0.665	21.6
Top wood plus bark	91.032	-209.790	120.951	0.943	18.1
		White oak (n = 45)			
Merchantable stem wood	6.179	205.137	-130.539	0.897	8.7
Merchantable stem bark	-0.400	35.019	-24.484	0.364	36.2
Top wood plus bark	94.221	-240.156	155.023	0.917	23.7
		Red oak (n = 100)			
Merchantable stem wood	5.216	185.909	-109.777	0.900	9.1
Merchantable stem bark	0.276	32.881	-17.274	0.572	26.8
Top wood plus bark	94.508	-218.790	127.051	0.933	20.5
		All hardwoods (n = 1255)			
Merchantable stem wood	4.148	191.629	-111.474	0.903	9.5
Merchantable stem bark	0.560	28.197	-15.933	0.433	34.0
Top wood plus bark	95.292	-219.826	127.407	0.943	18.2

*Mean values and ranges of these components are the same as those provided in Table 7.

Table 9. Average stump values at 30 cm stump height, as percent of the total stem mass

Species	Number of sample trees n	Mean value			Stump wood plus bark	
		Stump wood	Stump bark	Stump wood plus bark	SD*	SE*
Trembling aspen	164	3.53	0.80	4.33	1.078	0.049
Largetooth aspen	71	3.34	0.88	4.22	0.862	0.059
Balsam poplar	87	4.57	0.63	5.20	1.99	0.123
White birch	103	5.16	0.88	6.04	1.573	0.089
Yellow birch	89	6.51	0.72	7.23	2.521	0.154
Sugar maple	89	4.95	0.52	5.47	1.710	0.105
Red maple	36	5.92	0.60	6.52	2.613	0.251
Silver maple	31	7.00	0.55	7.55	2.472	0.256
White ash	64	5.23	0.67	5.90	2.570	0.184
Black ash	17	5.88	0.77	6.65	1.844	0.258
Red ash	24	5.08	0.66	5.74	2.029	0.239
Basswood	68	4.35	0.74	5.09	0.226	0.159
American beech	70	5.56	0.37	5.93	2.938	0.203
Black cherry	63	4.71	0.65	5.36	2.172	0.158
White elm	67	7.30	0.89	8.19	3.145	0.222
Hickory	67	5.25	0.64	5.89	2.768	0.195
White oak	45	8.03	1.11	9.14	2.860	0.246
Red oak	100	6.47	1.02	7.49	2.849	0.165
All hardwoods	1255	5.25	0.74	5.99	2.575	0.042

*SD = standard deviation; SE = standard error of the mean.

Table 10. Volume (and mass) percentages at different stump heights in relation to stump volume (and mass) at 30 cm

Stump height (cm)	%
5	17.95
10	35.28
15	52.07
20	68.36
25	84.45
30	100.00

Table 11. Deduction percentages of stump wood and stump bark mass at different stump heights in relation to total stem mass (wood plus bark): an example using white birch

Stump height (cm)	Stump wood (%)	Stump bark (%)	Stump wood plus bark (%)
5	0.93*	0.15	1.08
10	1.82	0.31	2.13
15	2.69	0.46	3.15
20	3.53	0.60	4.13
25	4.36	0.74	5.10
30	5.16	0.88	6.04

*0.93% = (5.16% from Table 9) x (17.95% from Table 10).

Table 12. Permissible ratios for Equations 3 and 4

Species	Equation 3 Smallest permitted dm/d	Equation 4 Largest permitted hm/h
Trembling aspen	0.330*	0.885
Largetooth aspen	0.318	0.842
Balsam poplar	0.288	0.872
White birch	0.366	0.819
Yellow birch	0.180	0.825
Sugar maple	0.289	0.794
Red maple	0.248	0.788
Silver maple	0.206	0.807
White ash	0.241	0.864
Black ash	0.341	0.783
Red ash	0.293	0.798
Basswood	0.286	0.860
American beech	0.211	0.845
Black cherry	0.245	0.845
White elm	0.262	0.794
Hickory	0.263	0.867
White oak	0.224	0.775
Red oak	0.255	0.861
All hardwoods	0.206	0.863

*A dm/d ratio of 0.330 means, for example, 7/21.2, 8/24.2, 9/27.3 and 10/30.3, and a value such as 0.100 is not realistic for the species studied.

Table 13. Percentage distribution of stump, merchantable part and top of the stem by various stump heights for white birch using Equation 3

dm/d	Stump height (cm)	Stump wood	Stump bark	Net merchant-able stem wood	Net merchant-able stem bark	Top wood plus bark	Total
		% of total stem ovendry mass					
0.40	10	1.82	0.31	80.73	14.06	3.08	100.00
	20	3.53	0.60	79.02	13.77	3.08	100.00
	30	5.16	0.88	77.39	13.49	3.08	100.00
0.65	10	1.82	0.31	69.27	11.25	17.35	100.00
	20	3.53	0.60	67.56	10.96	17.35	100.00
	30	5.16	0.88	65.93	10.68	17.35	100.00
0.90	10	1.82	0.31	37.91	5.96	54.00	100.00
	20	3.53	0.60	36.20	5.67	54.00	100.00
	30	5.16	0.88	34.57	5.39	54.00	100.00

APPENDIX F

An examination of the bias
of the whole tree equation

AN EXAMINATION OF THE BIAS OF THE WHOLE-TREE EQUATION

Because the biomass equations given in this report are only approximations to the true relationships, there will be situations in which they will give biased estimates. This is true irrespective of the form of equation employed, whether a standard linear formation of d^2h, a straight line through the origin as in this report, a polynomial, etc.

There are two principal reasons to expect bias when these equations are used to estimate the biomass of a given stand of trees. Firstly, the equations were developed from one specific data set, and may tend to generally overestimate or underestimate biomass when applied to a stand whose characteristics are different. Secondly, even if there is no general tendency for the equations to underestimate or overestimate, they may overestimate for some tree sizes and underestimate for others. This can produce an overall bias, particularly if the stand consists mainly of small trees or mainly of large ones.

Investigation of the first source of bias was deemed irrelevant because of different inherent degrees of bias in each independent data set owing to differences in compositions of the number of trees and of the tree sizes in each set. But the second source could be studied using the original data set, by examining how well the equations fit for all tree sizes. This was done here only for the whole tree equation for all hardwoods combined, to provide a general idea of the fit of the equations. The trees in the data set were divided into size classes, and the average bias was obtained for each class as a percent of the mean biomass for that class as shown in the following table (Note that minus sign indicates underestimates and plus sign overestimates):

d^2h class	Number of trees	Average bias as a percent of mean OM
1 - 1 000	195	-16
1 001 - 2 000	127	-3
2 001 - 3 000	117	-1
3 001 - 4 000	91	+2
4 001 - 5 000	74	+2
5 001 - 6 000	73	+3
6 001 - 7 000	79	-2
7 001 - 8 000	50	+3
8 001 - 9 000	55	+2
9 001 - 10 000	52	0
10 001 - 12 000	81	0
12 001 - 14 000	60	0
14 001 - 16 000	67	+4
16 001 - 18 000	57	-5
18 001 - 20 000	53	0
20 001 - 30 000	124	-5
30 001 - 40 000	75	+2
40 001 - 50 000	47	+4
50 001 - 60 000	24	-3
60 000 +	42	0
All combined	1 543	-0.36

The fit of this equation appears to be fairly good except for the underestimate of 16 percent for the smallest d^2h class. This probably occurs because, for small trees, the 1.30 m measurement height for the diameter is relatively high on the stem instead of being near the base as it is for the other size classes.

A more detailed analysis could be performed for this equation by dividing the trees into diameter classes and also into height classes for each diameter class. This was not done, as it was considered necessary to keep a reasonably large number of trees in each class.

In conducting this analysis the assistance received from Mr. D.A. MacLeod, Statistician, Applied Statistics Division, Applications Software and Quantitative Methods Branch, Department of the Environment is gratefully acknowledged.