Single-tree Equations for Estimating Biomass of Trembling Aspen, Large Tooth Aspen and White Birch in Ontario

by
I. S. Alemdag¹ and K. W. Horton²

Abstract

Ovendry mass of single trees of trembling aspen, largetooth aspen, and white birch in the Great Lakes — St. Lawrence and Boreal forest regions in Ontario was studied in relation to stem dimensions. Mass equations for tree components based on diameter at breast height outside bark and tree height were developed. Results were found more dependable for stem wood and the whole tree than for stem bark, live branches, and twigs plus leaves. Owendry mass values were slightly higher than those reported for New York and northern Minnesota.

Résumé

On a comparé aux dimensions de leurs tiges, les poids secs absolus de peupliers faux-trembles, de peupliers à grandes dents et de bouleaux à papier de la région boréale ainsi que de la région des Grands Lacs et du Saint-Laurent. On a établi des équations de poids des éléments d'arbre selon le diamètre à hauteur d'homme, le diamètre externe et la hauteur totale. Les résultats se sont révélés plus sûrs dans les cas du bois de tige et de l'arbre entier que dans ceux de l'écorce de tige, des branches fraîches et des brindilles avec feuilles. Les poids secs absolus en questions sont légèrement supérieurs à ceux des arbres de l'État de New York et du nord du Minnesota.

Introduction

Growing concern regarding the shortage of fuel has focussed interest on renewable energy sources, prominent among which is forest biomass. In strict terms, forest biomass is the quantity of living organisms in a forest ecosystem expressed as mass³, but for practical purposes the term is generally confined to the living components of woody material—trees and shrubs. Usually, as in this report, it applies to the aboveground portions only.

If forests are to be managed for biomass production, their present and potential capacity must first be evaluated. The primary requirement is the development of functions for individual tree mass for each species. Accordingly, the purpose of this study was to formulate equations by tree components in terms of diameter at breast height outside bark (dbhob) and tree height (h) for estimating aboveground oven-dry mass of trembling aspen (*Populus tremuloides* Michx.), largetooth aspen (*Populus grandidentata* Michx.), and white birch (*Betula papyrifera* Marsh.), applicable to two forest regions (Rowe 1972) in Ontario. These species represent a large and underutilized resource, carrying a considerable biomass potential within the province.

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

²K. W. Horton is the president of Horton Forestry Services Ltd., R.R. 4, Stouffville, Ontario, L0H 1L0.

³Mass is used for weight in this paper, as suggested by the Canadian Standards Association in the *Canadian Metric Practice Guide*, 1979.

Methods

Field

The study covered three locations in the Great Lakes — St. Lawrence Forest Region, between Chalk River and Haliburton, and two broad areas near Kirkland Lake and Nipigon, representing the eastern and western portions of the Boreal Forest Region in Ontario. A total of 483 sample trees of the subject species were taken from plots of 20 m x 20 m established in natural, fully stocked, even-aged, largely pure stands sampled during this biomass yield investigation⁴ and a previous study (Alemdag 1980b). Sample trees were selected from the full range of classes of dbhob and h. Twenty-eight of these trees were between 0.1 cm and 5.0 cm dbhob and the others were larger. After felling, the sample trees were separated into the components of stem, branches, and twigs plus leaves, following Alemdag's field and laboratory instructions (1980a). From each tree, the necessary dimensional measurements were taken, the components were weighed green, and samples were collected. Statistical data on some of the measurements are shown in Table 1.

Laboratory

The samples were then processed at the laboratory to establish the oven-dry mass (OM)/green mass (GM) ratios for the stem wood, stem bark, live branches, and twigs plus leaves. These ratios, together with the field-measured green masses of the whole components, were used to calculate the oven-dry mass of the whole components. (*Stem* is defined as the main bole of the tree from ground level to tip, and *twigs* as the leaf-bearing shoots of live branches smaller than 0.5 cm in diameter.)

Analysis

Ovendry mass plotted over tree size (expressed as dbhob²•h) suggested a strong linear correlation. An example of this, using components of trembling aspen from the Great Lakes — St. Lawrence Forest Region, can be seen in Figure 1. Because of the close relationships between oven-dry mass and tree size, the following regression models were tested for oven-dry mass estimates of the tree components and of the whole tree for trees 5.1 cm and larger in dbhob:

$$OM = b_0 + b_1 \cdot (dbhob)^2 + b_2 \cdot h + b_3 \cdot (dbhob)^2 \cdot h \quad (1)$$

$$OM = b_1 \cdot (dbhob)^2 + b_2 \cdot h + b_3 \cdot (dbhob)^2 \cdot h \quad (2)$$

$$OM = b_0 + b_1 \cdot (dbhob)^2 \cdot h \quad (3)$$

$$OM = b_1 \cdot (dbhob)^2 \cdot h \quad (4)$$

where OM is expressed in kilograms, dbhob in centimetres, and h in metres. The tree components are those listed above.

⁴Funded by the Energy from the Forest Program (ENFOR) of the Canadian Forestry Service.

Table 1. Statistical data on dbhob, h, and green mass of the whole tree for sample trees 5.1 cm dbhob and larger

	Great Lakes — St. Lawrence Forest Region			Boreal Forest Region	
	Trembling Aspen	Largetooth Aspen	White Birch	Trembling Aspen	White Birch
Number	128	96	68	96	67
dbhob (cm)					
Mean	16.1	16.3	17.7	17.2	16.3
SD ¹	8.0	7.1	6.0	7.4	6.2
Range	5.2–43.5	5.4–39.2	7.1–32.7	5.2–35.4	5.4–28.6
Height (m)					
Mean	17.3	17.5	17.3	17.5	15.8
SD	5.4	5.0	3.8	4.0	4.0
Range	6.7–26.8	7.5–28.9	8.8–22.3	8.1–27.3	7.3–21.7
GM² (kg)					
Mean	257.8	216.6	279.8	257.1	212.7
SD	332.1	222.7	213.4	247.9	161.9
Range	9.8–1490.5	8.9–1195.0	16.9–1162.4	8.7–1181.1	12.8–664.0

¹Standard deviation.²Green mass.**Table 2. Regression data on the prediction of oven-dry mass for trees of 5.1 cm dbhob and larger, using the model $OM = b_1 \cdot (dbhob)^2 \cdot h$**

	b_1	r^2	SEE%	Mean (kg)	Range (kg)
(a) Great Lakes — St. Lawrence Forest Region					
Trembling Aspen (n = 128)					
Stem wood	$1.4483 \cdot 10^{-2}$	0.979	18.1	101.9	3.2–671.6
Stem bark	$3.4560 \cdot 10^{-3}$	0.936	34.6	23.3	0.8–160.3
Live branches	$2.6715 \cdot 10^{-3}$	0.811	77.2	15.8	0.3–174.8
Twigs and leaves	$4.7615 \cdot 10^{-4}$	0.585	62.3	4.3	0.3– 18.5
Whole tree	$2.1087 \cdot 10^{-2}$	0.976	20.1	145.3	5.1–964.4
Largetooth Aspen (n = 96)					
Stem wood	$1.3427 \cdot 10^{-2}$	0.981	13.9	86.7	2.9–403.4
Stem bark	$2.9314 \cdot 10^{-3}$	0.917	28.7	19.4	1.0–112.4
Live branches	$1.8398 \cdot 10^{-3}$	0.714	76.9	10.7	0.3–116.9
Twigs and leaves	$3.7936 \cdot 10^{-4}$	0.736	54.0	2.6	0.2– 20.7
Whole tree	$1.8577 \cdot 10^{-2}$	0.982	13.7	119.4	4.6–641.2
White Birch (n = 68)					
Stem wood	$1.6351 \cdot 10^{-2}$	0.977	10.7	111.2	4.5–350.8
Stem bark	$2.9578 \cdot 10^{-3}$	0.949	15.8	20.2	0.7– 48.6
Live branches	$4.1696 \cdot 10^{-3}$	0.615	82.7	23.9	0.8–222.9
Twigs and leaves	$9.7522 \cdot 10^{-4}$	0.820	33.8	6.6	0.5– 25.6
Whole tree	$2.4454 \cdot 10^{-2}$	0.975	12.2	162.0	8.0–657.1
(b) Boreal Forest Region					
Trembling Aspen (n = 96)					
Stem wood	$1.4748 \cdot 10^{-2}$	0.963	18.7	104.3	3.4–449.0
Stem bark	$2.7476 \cdot 10^{-3}$	0.931	27.8	18.8	0.6–107.7
Live branches	$2.1939 \cdot 10^{-3}$	0.774	59.8	14.4	0.3– 81.6
Twigs and leaves	$5.7001 \cdot 10^{-4}$	0.683	62.2	4.1	0.2– 23.2
Whole tree	$2.0259 \cdot 10^{-2}$	0.964	18.8	141.5	4.6–650.7
White Birch (n = 67)					
Stem wood	$1.6001 \cdot 10^{-2}$	0.973	12.1	88.1	3.4–273.9
Stem bark	$2.7467 \cdot 10^{-3}$	0.609	58.6	15.1	0.7– 90.0
Live branches	$2.5581 \cdot 10^{-3}$	0.726	50.3	13.5	0.7– 59.5
Twigs and leaves	$6.8510 \cdot 10^{-4}$	0.678	44.3	3.9	0.4– 15.4
Whole tree	$2.1991 \cdot 10^{-2}$	0.970	13.0	120.6	6.2–355.8

Fig. 1 Distribution of ovendry mass of components and of whole tree over $\text{dbhob}^2 \cdot h$: trembling aspen for the Great Lakes — St. Lawrence Forest Region.

The regression analyses of ovendry mass of tree components revealed negligible differences among the multiple correlation coefficient (R^2) and the standard error of estimate (SEE) figures for the four models. The coefficient of variation in all tree-size classes was essentially the same for any given tree component. For its practical simplicity, therefore, Equation 4 was adopted for trees of dbhob 5.1 cm and larger. This is a *Standard mass-equation* as opposed to a *local mass-equation*, which is based on dbhob alone.

Separate analyses were performed with this model for each species, samples being drawn from the two forest regions and the two boreal subregions, and for pooled data (except for largetooth aspen in the Boreal Forest Region, where the species rarely occurs). An F-test was then used to examine the significance of differences between categories.

Besides its simplicity and other properties, Equation 4 has the advantage that the ratio between the masses of any two components estimated from it is constant for all diameters and heights. For this reason, the relative percentages of mass for the components were determined by dividing the b_1 coefficients of the equations for the components by those of the stem wood and the whole tree. These percentages were also calculated directly, employing the raw data of the sample trees of each species, with the formula

$$\text{Ratio} = (\Sigma \text{OM of component}) / (\Sigma \text{OM of stem wood, or, } \Sigma \text{OM of the whole tree}) \quad (5)$$

The distribution of ovendry mass of wood within four stem sections was studied independently in order to approximate the contents of merchantable trees, using those with a 9.1-cm top diameter outside bark. The four sections were the lower, middle, and upper third of the bole from ground level to the top diameter of 9.1 cm (merchantable part of the stem), and the top.

A comparison of whole-tree ovendry mass of the three species was made, and, based on the same variables of dbhob and h , the results of trembling aspen from the Great Lakes — St. Lawrence Forest Region were compared with the results from New York and northern Minnesota.

Trees smaller than 5.1 cm in dbhob and woody plants less than 1.31 m high were studied separately.

Results

Statistical analyses revealed that, for the form of the equation adopted (Equation 4), there is no significant difference between the two boreal subregions. However, the difference between the Great Lakes — St. Lawrence Forest Region and the Boreal Forest Region is significant (though marginally so), and for this reason the two regions were not combined. Similar significant differences prevented the combining of the two aspens. The statistical data and the regression coefficients of this equation for all species studied in the two regions can be seen in Table 2. This combined-variable equation has the following properties:

- (1) the component mass estimates add up to the independent estimate for the whole tree;
- (2) is easy to apply;
- (3) fits into a compatible system of equations for taper and stem volume; and
- (4) is suitable for point sampling.

For trees 0.1 cm to 5.0 cm dbhob, the whole-tree ovendry mass was derived from the following equation, which combines all species in both regions:

$$\text{OM} = 0.030 + 0.021107 \cdot (\text{dbhob})^2 \cdot h \quad (6)$$

For woody plants 1.30 m or less high, the following average ovendry mass figures, which were established for the Petawawa area (Alemdag 1980b), were thought to be applicable also for the area covered by the present study: height from 0.31 m to 0.80 m, 8 g/stem; height from 0.81 m to 1.30 m, 22 g/stem.

The relationships between the ovendry mass and the tree size are better for the whole tree and for stem wood than for the other tree components, the relationships of the former having r^2 values over 0.97 and SEE% values as low as 11%. A similar situation was found for six hardwood species (including trembling aspen and white birch) by Alemdag (1980b) and for trembling aspen Zavitskovski (1971).

The proportions of the ovendry mass of tree components in relation to stem wood and the whole tree are provided in Table 3. These figures show that stem wood constitutes 67-73% of the total mass, stem bark 12-16%, live branches 10-17%, and twigs and leaves 2-4%. Thus the stem with bark represents the major part (79-88%).

When the percentages in Table 3 are compared with a second set of percentages calculated using Equation 5⁵, they show a very close resemblance, which in turn is an indication of the accuracy of the model chosen for the estimation of component masses.

The component percentages are useful tools when used with the ovendry mass of stem wood, particularly when the latter is estimated using inside-bark volume of single trees or of an entire stand, together with stem-wood density.

The average distribution of ovendry mass of the stem, excluding bark, is given in Table 4. The proportional values of the mass drop from the lower third of the merchantable bole to the top section of the stem in almost the same percentage values for all species and forest regions. On the average, these are 46.4%, 30.8%, 17.5%, and 5.3%. The merchantable bole makes up around 95% of the stem wood.

A comparison of the three species is presented in Figure 2. It shows the relationship mass and dbhob in Great Lakes — St. Lawrence Forest Region using specific mass-equations of the whole tree with an average h/dbhob curve for all species. Though the patterns are similar because of the same form of an equation, it is evident that the increase

⁵Although not given in Table 3, these ratios can be established by employing the mean values of components and of whole tree in Table 2.

Table 3. Component oven-dry masses in relation to stem wood and whole-tree oven-dry masses

		Trembling Aspen	Large-tooth Aspen	White Birch
Percent of Stem Wood Oven-dry Mass				
Stem bark	(1)	23.9	21.8	18.1
	(2)	18.6		17.1
Live branches	(1)	18.4	13.7	25.5
	(2)	14.9		16.0
Twigs and leaves	(1)	3.3	2.8	6.0
	(2)	3.9		4.3
Whole tree	(1)	145.6	138.3	149.6
	(2)	137.4		137.4
Percent of Whole-Tree Oven-dry Mass				
Stem wood	(1)	68.7	72.3	66.9
	(2)	72.8		72.8
Stem bark	(1)	16.4	15.8	12.1
	(2)	13.6		12.5
Live branches	(1)	12.7	9.9	17.0
	(2)	10.8		11.6
Twigs and leaves	(1)	2.2	2.0	4.0
	(2)	2.8		3.1

(1) Great Lakes — St. Lawrence Forest Region;

(2) Boreal Forest Region.

Table 4. Percentage distribution of oven-dry mass of wood within stem¹

	Trembling Aspen		Large-tooth Aspen		White Birch	Birch
	(a)	(b)	(a)	(b)	(a)	(b)
	n = 86	n = 79	n = 71	n = 53	n = 53	n = 50
Lower third of merch. bole	46.4	44.4	47.1	48.2	45.9	
Middle third of merch. bole	31.4	32.2	30.1	30.6	29.9	
Upper third of merch. bole	17.6	17.5	17.5	16.6	18.0	
Tree Top	4.6	5.9	5.3	4.6	6.2	
Total	100.0	100.0	100.0	100.0	100.0	

¹ Includes stump, excludes bark.

(a) Great Lakes — St. Lawrence Forest Region;

(b) Boreal Forest Region.

Table 5. Whole-tree mass estimates for trembling aspen using three different equations reported by (1) the present study for the Great Lakes — St. Lawrence Forest Region, (2) Monteith (1979) for New York, and (3) Schlaegel (1975) for northern Minnesota

		Whole-tree mass (kg)				
dbhob (cm)	Height (m)	(1)	(2)	(3)	(1)/(2)	(1)/(3)
5	7	3.7	—	3.4	—	1.09
10	12	25.3	22.6	23.2	1.12	1.09
15	16	75.9	72.4	68.7	1.03	1.10
20	19	160.3	156.0	143.9	1.03	1.11
25	21	276.8	272.8	247.2	1.01	1.12
30	22	417.5	415.8	371.4	1.00	1.12

in mass with dbhob is greatest in white birch and least in largetooth aspen. The oven-dry mass of the whole tree of trembling aspen is 1.14 times, and of white birch 1.32 times, that of largetooth aspen of the same size. The ratio of the total mass of white birch to that of trembling aspen is 1.16.

The results with the trembling aspen whole-tree equation developed in this study for the Great Lakes — St. Lawrence Forest Region compare favourably with results reported in New York (Monteith 1979) and in northern Minnesota (Schlaegel 1975), although ranging up to 12% higher (Table 5). In general, however, this indicates that the tree mass of these species is reasonably constant over a large part of their range.

Fig. 2 Trends of whole-tree oven-dry mass of the three species in the Great Lakes — St. Lawrence Forest Region.

Applications

The equations given here for estimating aboveground oven-dry mass of the whole tree and of its components for trembling aspen, largetooth aspen, and white birch are obviously best applied to single trees in the Ontario portions of the Great Lakes — St. Lawrence and Boreal forest regions, where the data were collected. However, based as they are on dbhob and h, they may be used reliably in ecologically similar areas. Because the estimates of mass of the components, using their own equations, add up to the whole-tree mass, that mass can be determined either by its own equation or by summing the values from the component equations. If, however, the dimensions are lacking but the inside-bark stem volume of a tree or of a stand is known, then the oven-dry mass of stem wood can be calculated by using this volume and the species' wood density. Whole-tree and component masses can then be found by employing the percentages given in Table 3. By employing those in Table 4, the distribution of mass in a stem can be determined for utilization purposes.

For stand estimates of aboveground oven-dry mass by the use of stand data and these equations, calculations could be based on any of the following variables:

- (1) single-tree dbhob and h data of full inventory;
- (2) single-tree dbhob and corresponding h values from the stand h/dbhob curve;
- (3) mean dbhob (quadratic mean) and mean h of each diameter class together with the number of trees per

class (h can be either Lorey's height or from the stand h/dbhob curve);

- (4) mean dbhob (quadratic mean) and mean h of the stand together with total number of trees in the stand (h can be either Lorey's height or taken from the stand h/dbhob curve); and
- (5) in point sampling, basal area per hectare (G, m^2) and mean h of the stand, using the modified oven-dry mass formula $OM/ha = (40\ 000 \cdot b_i / \pi) \cdot G \cdot h$.

Woody plants less than 1.31 m high should be evaluated from their mass/stem figures, provided herein.

Tables of oven-dry mass by dbhob and h class, tree component, species, and forest region, derived from the equations presented in this paper, are available on request from the Petawawa National Forestry Institute, Chalk River, Ontario K0J 1J0.

Acknowledgement

The authors wish to extend their appreciation to Mr. T. L. Pickett, Scientific Programmer/Analyst, Petawawa National Forestry Institute for his assistance in doing the computer analyses.

Lost Members

Last known address as shown. Can you help?

- A. Aiking, 199 Academy Dr., Apt. 301, Thunder Bay, Ont. P7B 5W2
- Carolynn J. Anderson, 5336 Elm St., Vancouver, B.C. V6N 1A1
- P. C. Anderson, 9916 — 77 St., Edmonton, Alta. T6A 3B7
- M. Ardenne, 257 Riverside Dr., Oakville, Ont. L6K 3N1
- D. N. Bacala, 429 Allard, Winnipeg, Man. R3K 1T1
- V. P. Bender, c/o Burn, Great Lakes Products, Box 160, Ignace, Ont. P0T 1T0
- W. Bientjes, 5474 Monarch St., Burnaby, B.C. V5G 2A1
- V. E. Bradford, Box 895, Ignace, Ont. P0T 1T0
- D. G. Brand, 740 Gilford St., Vancouver, B.C. V6G 2N4
- B. E. Burghardt, #2-12918 — 118 Ave. Edmonton, Alta. T5L 2L4
- P. J. G. Collins, Selkirk College, Box 1200, Castlegar, B.C. V1N 3J1
- G. N. Dalrymple, 4-424 — 10th St. E., Saskatoon, Sask. S7N 0C9
- G. A. Dick, 9818 — 78 Ave., Grande Prairie, Alta. T8V 4V6
- H. A. Erickson, General Delivery, Macdowall, Sask. S0K 2S0
- R. W. Evered, Apt. 118 — 100 Seagram Dr., Waterloo, Ont. N2L 3B8
- R. Greet, 176 Windemere St., Thunder Bay, Ont. P7B 3R4
- John Hugues, 70 N. Ranelagh Ave., Burnaby, B.C. V5B 1H6
- H. B. Jensen, Box 152, Gold River, B.C. T6J 0L7
- A. M. S. Jones, 406-237 Bath Rd., Kingston, Ont. K7M 2X8
- B. Juneau, 2976 Place Dompierre, Ste. Foy, P.Q. G1X 1E1
- J. K. Kelly, 48-455 SW Marine Dr., Vancouver, B.C. V5X 2R9
- A. D. J. Ker, #502-1686 W. 12th Ave., Vancouver, B.C. V6J 2E4
- T. K. Killins, 102 Seagram Dr., Apt. 203, Waterloo, Ont. N2L 3B8
- D. J. McCrea, Riverview Dr., R.R. 3, Fredericton, N.B. E3B 4X4
- B. J. Murphy, 216-5951 Balsam St., Vancouver, B.C. V6M 4C3
- K. K. Nielson, 19 Marshall St., Thunder Bay, Ont. P7A 6Z9
- J. A. Osborne, 107 Colborne St., Apt. 505, Lindsay, Ont. K9V 3T4
- R. W. Parker, #308-916 Memorial Dr., Calgary, Alta.
- J. R. Patch, 488 Charlotte St., Apt. 2, Fredericton, N.B. E3B 5V7
- M. C. Pedersen, 202 Parkside Dr., Apt. 14, Fredericton, N.B. E3B 5V7
- R. W. Reid, CFS, 5320 — 122 St., Edmonton, Alta. T6H 3S5
- C. R. Rogers, 5 Devonshire Place, Toronto, Ont. N5S 2C3
- E. A. Sauder, 101-2174 York St., Vancouver, B.C. V6K 1C3
- M. A. SAYERS, 2B — 9113-112 St., Edmonton, Alta. T6G 2L5
- S. D. Somers, 66A North St., Perth, Ont. K7H 2T2
- Diane L. Stuart, Apt. 104-418 N. Ave., Williams Lake, B.C. V2G 2E4
- M. G. Taylor, Faculty of Forestry, University of Toronto, Toronto, Ont. M5S 1A1

References

- Alemdag, I. S. 1980a.** Manual of data collection and processing for the development of forest biomass relationships. Can. For. Serv., Pet. Nat. For. Inst., Inf. Rep. PI-X-4, 38 pp.
- Alemdag, I. S. 1980b.** Aboveground-mass equations for six hardwood species from natural stands of the research forest at Petawawa. Can. For. Serv., Pet. Nat. For. Inst., Inf. rep. PI-X-6, 9 pp. *In press.*
- Monteith, D. B. 1979.** Whole tree weight tables for New York. State Univ. NY, Appl. For. Res. Inst., Res. Rep. No. 40, 64 pp.
- Rowe, J. S. 1972.** Forest regions of Canada. Can. Dept. Environ., Can. For. Serv. Publ. 1300, 172 pp.
- Schlaegel, B. E. 1975.** Estimating aspen volume and weight for individual trees, diameter classes, or entire stands. USDA For. Serv., NCFES, Gen. Tech. Rep. NC-20, 16 pp.
- Zavitkovski, J. 1971.** Dry weight and leaf area of aspen trees in northern Wisconsin. *In* Forest biomass studies. IUFRO. International Union of Forest Research Organizations. Life Sciences and Agriculture Experiment Station, U. of Maine at Orono. pp. 193-205.

- A. C. Treadway, Apt. 7A, Park W., 2366 Portage Ave., Winnipeg, Man. R3J 0M8
- B. Voldock, Box 548, Barry's Bay, Ont. K0J 1B0
- D. G. Walsh, Box 499, Port Alice, B.C. V0N 2N0

**Alan Moss &
Associates Ltd.**

Consultants in Forestry and
Forest Industries

Domestic and International

1334 St. Paul Street
Kelowna, British Columbia V1Y 2E1
Telephone: (604) 763-4811
Cable: Sylva