TREE BIOMASS EQUATIONS FOR SEVEN SPECIES IN SOUTHWESTERN NEW BRUNSWICK

by

M.F. Ker

Maritimes Forest Research Centre
Fredericton, New Brunswick

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ABSTRACT

Logarithmic equations are given for estimating fresh and oven-dry weights of several tree components for seven common tree species of southwestern New Brunswick - white pine, hemlock, cedar, white ash, yellow birch, beech, and sugar maple. Separate equations are given for each of 12 biomass variables : 1) oven-dry weight (ODW) of stem wood, 2) ODW stem bark, 3) ODW total stem, 4) ODW branches (wood plus bark), 5) ODW foliage, 6) ODW total crown (branches plus foliage), 7) ODW total above-ground, 8) fresh weight (FW) of stem wood, 9) FW stem bark, 10) FW total stem, 11) FW total crown, and 12) FW total above-ground. For each of these components two or more equations were selected from among all possible equations which could be derived from four independent variables : 1) DBH, 2) height, 3) crown width, and 4) crown length. Stem wood comprised from 62-73% of total dry above-ground weight, stem bark 5-12%, branches 13-24% and foliage 1-7%, based on the mean oven-dry weights of each component. Average DBH of sample trees ranged from 13.1 cm for yellow birch to 15.2 cm for white pine. Mean oven-dry weight of total above-ground biomass ranged from 44.9 kg for cedar to 112.0 kg for beech. Results are based on data from 46-51 sample trees per species. Sample discs and sample branches from these trees were dried at 105°C for 24 h and provided the basis for conversion of fresh weights to oven-dry weights.

RESUME

Des équations logarithmiques sont données pour l'estimation du poids à l'état frais et du poids anhydre de plusieurs parties de l'arbre pour sept essences courantes du sud-ouest du Nouveau-Brunswick, à savoir le Pin blanc, la Pruche, le Thuya, le Frêne blanc, le Bouleau jaune, le Hêtre et l'Erable à sucre. Des équations distinctes sont données pour chacune des 12 variables de la biomasse: 1) le poids anhydre (PA) du bois de la tige, 2) le PA de l'écorce de la tige, 3) le PA de la tige entière, 4) le PA des branches, 5) le PA du feuillage, 6) le PA de la cime entière (branches plus feuilles), 7) le PA de toutes les parties aériennes, 8) le poids à l'état frais (PEF) du bois de la tige, 9) le PEF de l'écorce de la tige, 10) le PEF de la tige entière, 11) le PEF de la cime entière et 12) le PEF de toutes les parties aériennes. Pour chacune de ces parties, on a choisi deux équations ou plus parmi toutes les équations qui pourraient être dérivées des quatre variables indépendantes: 1) DHP, 2) hauteur, 3) largeur de cime et 4) longueur de cime. Le bois de la tige représentait 62 à 73% du poids anhydre total des parties aériennes, l'écorce de la tige 5 à 12%, les branches 13 à 24% et le feuillage 1 à 7%, évaluations basées sur les poids anhydres moyens de chaque partie. Le DHP moyen des arbres d'échantillonnage allait de 13.1 cm pour le Bouleau jaune à 15.2 cm pour le Pin blanc. Le poids anhydre moyen de toute la biomasse aérienne allait de 33, 9 kg pour le Thuya à 112.0 kg pour le Hêtre. Les résultats sont étayés sur les données recueillies à partir de 46 à 51 arbres d'échantillonnage par essence. Des disques et des branches d'échantillonnage prélevés sur ces arbres ont été séchés pendant 24 h à 105°C pour servir de base à la conversion des poids à l'état frais en poids anhydres.

FOREWORD

ENFOR is the bilingual acronym for the Canadian Forestry Service's ENergy from FORest (ENergie de La FORêt) program of research and development aimed at securing the knowledge and technical competence to facilitate in the medium to long term a greatly increased contribution from forest biomass to our nation's primary energy production. This program is part of a much larger federal government initiative to promote the development and use of renewable energy as a means of reducing our dependence on petroleum and other non-renewable energy sources.

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This report, based in part on ENFOR project P-38, was prepared by the Canadian Forestry Service. Field work and data analysis were done "in-house" by the Maritimes Forest Research Centre.

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INTRODUCTION

The federal government's ENFOR (energy from the forest) program was begun in 1977 as part of a large-scale effort to identify and develop alternate sources of energy, including renewable sources such as biomass (Argue 1978, Love and Overend 1978, Tillman 1978). This report contains a set of equations for estimating tree biomass of seven species in York County, New Brunswick, which were developed in support of an ENFOR biomass inventory project, the results of which will be described in a future report. Equations such as those described herein form the basis for estimation of biomass on a stand, forest, or regional basis.

The particular area sampled in this study is part of the Carleton Section (A.4) of Rowe's (1972) Acadian Forest Region (Fig. 1). This is a predominantly hardwood forest area, the major species being sugar (hard) maple (Acer saccharum Marsh.), beech (Fagus grandifolia Ehrh.), yellow birch (Betula alleghaniensis Britton), red maple (Acer rubrum L.), and white ash (Fraxinus americana L.). The most common softwood species are balsam fir (Abies balsamea (L.) Mill.), white spruce (Picea glauca (Moench) Voss), hemlock (Tsuga canadensis (L.) Carr.), red spruce (Picea rubens Sarg.), white pine (Pinus strobus L.) and cedar (Thuja occidentalis L.).

METHODS

Selection of sample trees

Seven common tree species were sampled : 1) white pine, 2) hemlock, 3) cedar, 4) white ash, 5) yellow birch, 6) beech, and 7) sugar maple. Between 45 and 50 trees of each species were selected, from across the range of tree sizes encountered in the study area. Basic data gathered for each sample tree included diameter at 1.3 m above ground (DBH), total height, crown width, and crown length as well as information on crown class, cover type, and tree location. Methods used to estimate oven-dry weights of biomass components for each sample tree are described in the following sections.

Estimation of stem biomass

1) Field and laboratory methods:

Each sample tree was felled, leaving as short a stump as possible, and then delimbed. Starting at the base of the stem, discs were cut at 1.5 m intervals and labelled by tree number and disc number. They were subsequently taken to a laboratory trailer near the field operations where the bark was separated from the wood, and the fresh weight of each obtained. The fresh weight of each stem section was measured using a 1000-lb capacity dynamometer and a 50-lb capacity field scale.

For hardwoods the single most dominant leader was considered the main stem and branches were cut as close to this main stem as possible.

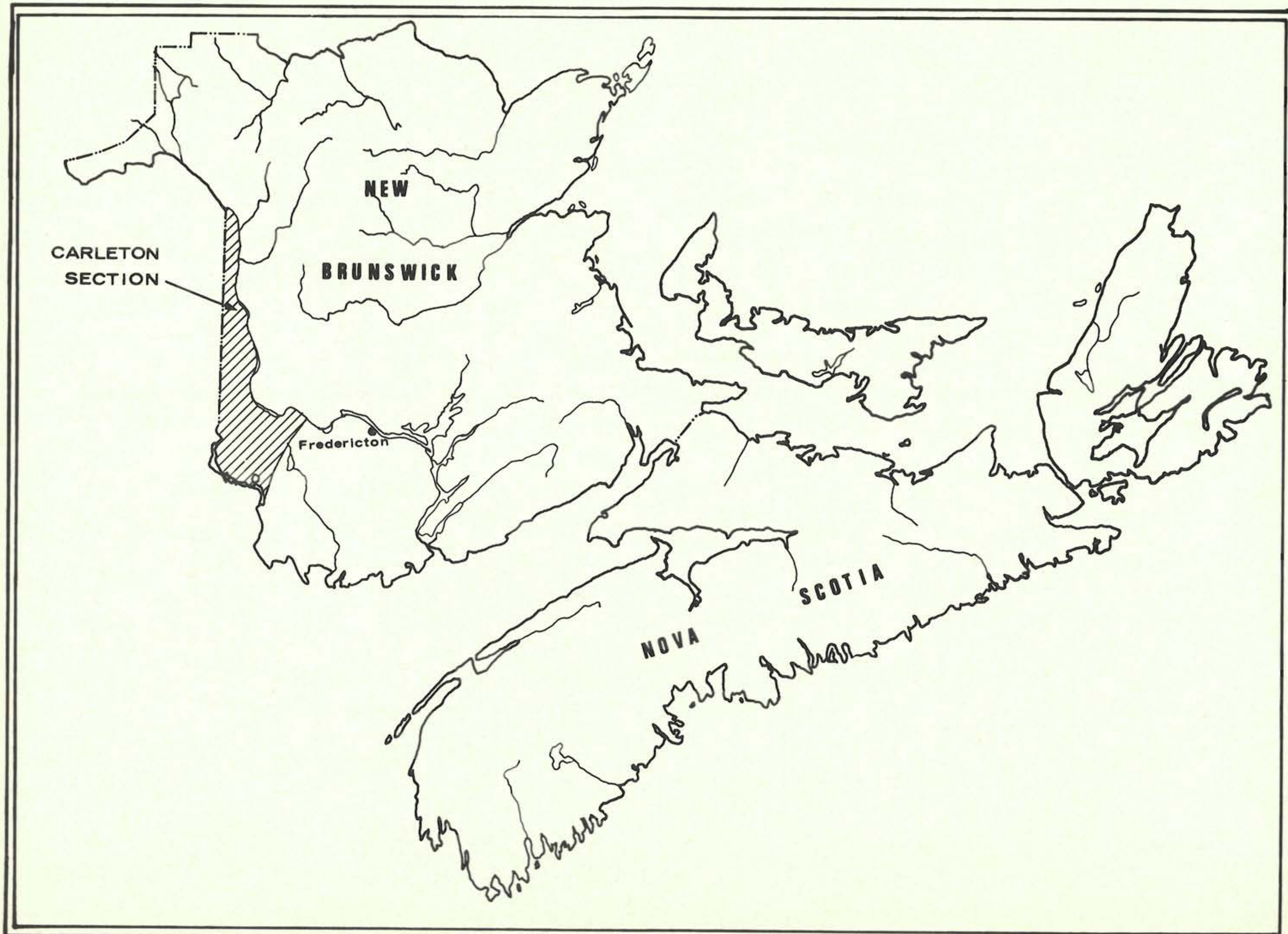
The disc samples were taken to the Maritimes Forest Research Centre laboratory, Fredericton, where they were dried at 105°C for at least 24 h. Dry weights of disc wood and bark were then measured to the nearest 0.1 g.

2) Analysis of data:

The notation used for stem disc and stem section weights is:

	Fresh Weight	Dry Weight
Disc		
Wood	w	w'
Bark	b	b'
Total	t	t'
Section		
Wood	W	W'
Bark	B	B'
Total	T	T'

Figure 1. Area sampled is part of the Carleton Section (A.4) of Rowe's 1972 Acadian Forest Region.



The fresh and dry weights of the i^{th} stem section were calculated as:

$$W_i = [(w_i + w_{i+1})/(t_i + t_{i+1})]\ T_i$$
$$B_i = T_i - W_i$$
$$W'_i = [(w'_i + w'_{i+1})/(t_i + t_{i+1})]\ T_i$$
$$T'_i = [(t'_i + t'_{i+1})/(t_i + t_{i+1})]\ T_i$$
$$B'_i = T'_i - W'_i$$

For top sections the weight ratios observed in the last (top) disc were used, e.g.,

$$W_i = (w_i/t_i)\ T_i$$

Total stem component weights are then simply:

	Fresh	Dry
Wood	$\Sigma w + \Sigma W$	$\Sigma w' + \Sigma W'$
Bark	$\Sigma b + \Sigma B$	$\Sigma b' + \Sigma B'$
Total	$\Sigma t + \Sigma T$	$\Sigma t' + \Sigma T'$

Estimation of crown biomass

1) Field and laboratory methods:
Oven-dry weights of branches and foliage for each sample tree were estimated using a stratified sampling system. Live softwood branches were sorted into 2-cm size classes (0-2, 2-4, 4-6 cm etc.) according to the diameter of the branch as measured 3 cm from the base. The fresh weight of each stratum (size class) was measured. One sample branch was selected at random from each stratum and its fresh weight was measured, either in the woods or at the field laboratory.

Hardwood crowns were cut into sections not longer than 2 m and then sorted into 2 cm size classes (strata) according to the estimated mid-diameter of the section. All foliage is in the 0-2 cm stratum using this approach. The fresh weight of each stratum was obtained, as for softwoods. Two sample branches were selected at random from the 0-2 cm stratum and their total fresh weight was determined. Five sample discs were cut at random from each of the remaining hardwood crown strata and the fresh weight of each 5-disc group was determined.

All sample branches and sample discs were identified, bagged, labelled, and brought to the laboratory in Fredericton, where they were dried at 105°C for at least 24 h. After drying, the foliage was separated from the branches, either by hand (for hardwoods and cedar) or with a winnowing machine. Oven-dry weights of foliage, branches, or discs were obtained for the sample material from each stratum.

2) Analysis of data:
The oven-dry weights of foliage (ODF) and branches (ODBR) for a given sample tree were estimated as

$$ODF = \sum_{i=1}^{7} RF_i \cdot FW_i$$

and

$$ODBR = \sum_{i=1}^{7} RWB_i \cdot FW_i$$

where

RF_i = mean ratio of oven-dry weight of foliage to total fresh weight for i^{th} crown stratum.

RWB_i = mean ratio of oven-dry weight of wood and bark to total fresh weight for i^{th} crown stratum

FW_i = total fresh weight of i^{th} crown stratum.

The values of RF and RWB for each species and stratum were calculated from the fresh and dry weights of the crown sample material.

DERIVATION OF TREE BIOMASS EQUATIONS

The general model

Given the estimated oven-dry weights of each component for each sample tree it was possible to develop tree biomass equations relating fresh and oven-dry weights of each component to stem and crown dimensions, such as DBH, height, crown width and crown volume, which can be measured with relative ease. The general model used for this analysis was

$$\ln W = b_0 + b_1 \ln D + b_2 \ln H + b_3 \ln CW + b_4 \ln CV$$

where

W = fresh or dry weight of biomass component (kg)
D = diameter at 1.3 m above ground (cm)
H = total tree height (m)
CW = crown width (m)
CV = conical crown volume $= \frac{\pi}{12} CW^2 CL$ (m^3)
CL = live crown length (m)
$\ln$ = natural logarithm (base e)
$b_0 \ldots b_4$ = regression coefficients

Selection of equations

The coefficients of this model were calculated using a computer program (Dixon 1977, Furnival and Wilson 1974) which examines all possible subsets of the independent variables and reports the regression coefficients for the "best" regressions for each subset size using one of three criteria. In this report, we include the best one-and two-variable regressions (using the R^2 criterion) for each of 12 biomass variables: fresh and oven-dry weights of stem wood, stem bark, total stem, total crown, and total above-ground; and oven-dry weight only of foliage and of branches.

The exceptions to this selection strategy were as follows:

1) In most cases the best one-variable equation was that using DBH. For some components, however, the crown volume (CV) equation was superior to the diameter equation, in which case both equations are included.
2) For two-variable equations, the diameter-height equation was included, if the coefficients were statistically significant, even though this equation was not always "best" in terms of R^2 values.
3) For some components there was no two-variable equation with significant coefficients. In these situations the "best" three-variable equation was included if significant.

RESULTS AND DISCUSSION

Mean values of DBH, height, total volume and biomass are summarized in Table 1 by species and component. Total volume of each tree was calculated using Honer's (1967) coefficients. Also given in Table 1 are the ranges of DBH and height for the sample trees of each species.

The biomass equations for the seven species are listed in Tables 2-8, along with sample sizes (n), R^2 values, and a correction factor (c) which is associated with the use of the logarithmic transformation in regression analysis (Beauchamp and Olson 1973, Baskerville 1972). The adjusted weight estimate W* is given by

$$W^* = c \cdot e^{\ln W}$$

where ln W is the mean logarithm of weight as given by the logarithmic equations.

Various aspects of these final results, and some intermediate results, are discussed in the following sections.

Stem biomass

Equations for predicting fresh and oven-dry weights of the three stem components (wood, bark, and total) are given in Tables 2-8. The addition of a height term to the model usually resulted in a small but statistically significant increase in R^2 values. The complete two-variable model (DBH and height) should account for most of the variation in stem biomass caused by such factors as age, site quality and stand density, since these factors influence both diameter and height.

Mean values of the stem biomass components are given in Table 1. Moisture content of the total stem component, as calculated from the mean fresh and dry weights of Table 1, ranges from 46% of dry weight for white ash to 119% for hemlock. Bark comprises from 7-16% of total stem weight, based on the mean dry weights of Table 1.

Crown biomass

The fresh and oven-dry weight data obtained from the crown sample branches and discs were used to derive the mean ratios of Table 9. These ratios were multiplied by the total fresh weights of each crown stratum to estimate the oven-dry weights of foliage and branches for each sample tree.

The softwood foliage ratios (RF) decrease with increasing branch diameter (d) and vice-versa for the branch (wood plus bark) ratios (RWB). The RWB ratios for hardwoods show little variation among the larger branches ($d > 2$), suggesting that for hardwoods two sampling strata may be sufficient.

Mean fresh and oven-dry weights of the crown biomass components are given in Table 1. Foliage comprises 26-34% of the total crown among softwood species, and 7-10% among hardwoods, on a dry weight basis. For branches the corresponding percentages are 66-74% for softwoods and 90-93% for hardwoods. Dry foliage weight ranged from 13-17% of total fresh crown weight for softwoods and from 4-6% for hardwoods. For branches the corresponding percentages are 34-38% for softwoods and 50-53% for hardwoods.

Equations for predicting biomass of crown components are listed in Tables 2-8. Four crown variables are distinguished: 1) oven-dry weight of branches (wood plus bark), 2) oven-dry weight of foliage, 3) oven-dry weight of total crown (branches plus foliage), and 4) fresh weight of total crown. Crown volume ($\frac{\pi}{12} CW^2 CL$) gave a higher R^2 value than DBH for some crown components, as noted earlier. For example, the crown volume equation for oven-dry weight of white pine foliage has an R^2 value of 0.909 versus 0.781 for the DBH equation.

Total above-ground biomass

Mean fresh and oven-dry weights of total above-ground biomass for each species are given in Table 1. Mean oven-dry above-ground weight was 46-52% of fresh above-ground weight for softwoods and 58-67% of same for hardwoods.

The distribution of total above-ground biomass among the different components depends on tree size, species, site quality, age, stand density, and other factors. We can, however, get a general idea of how biomass is distributed from the mean values of the weights of the different components which are referred to in previous sections of this report. This approach was used in deriving Fig. 2, which shows the distribution of above-ground biomass for each

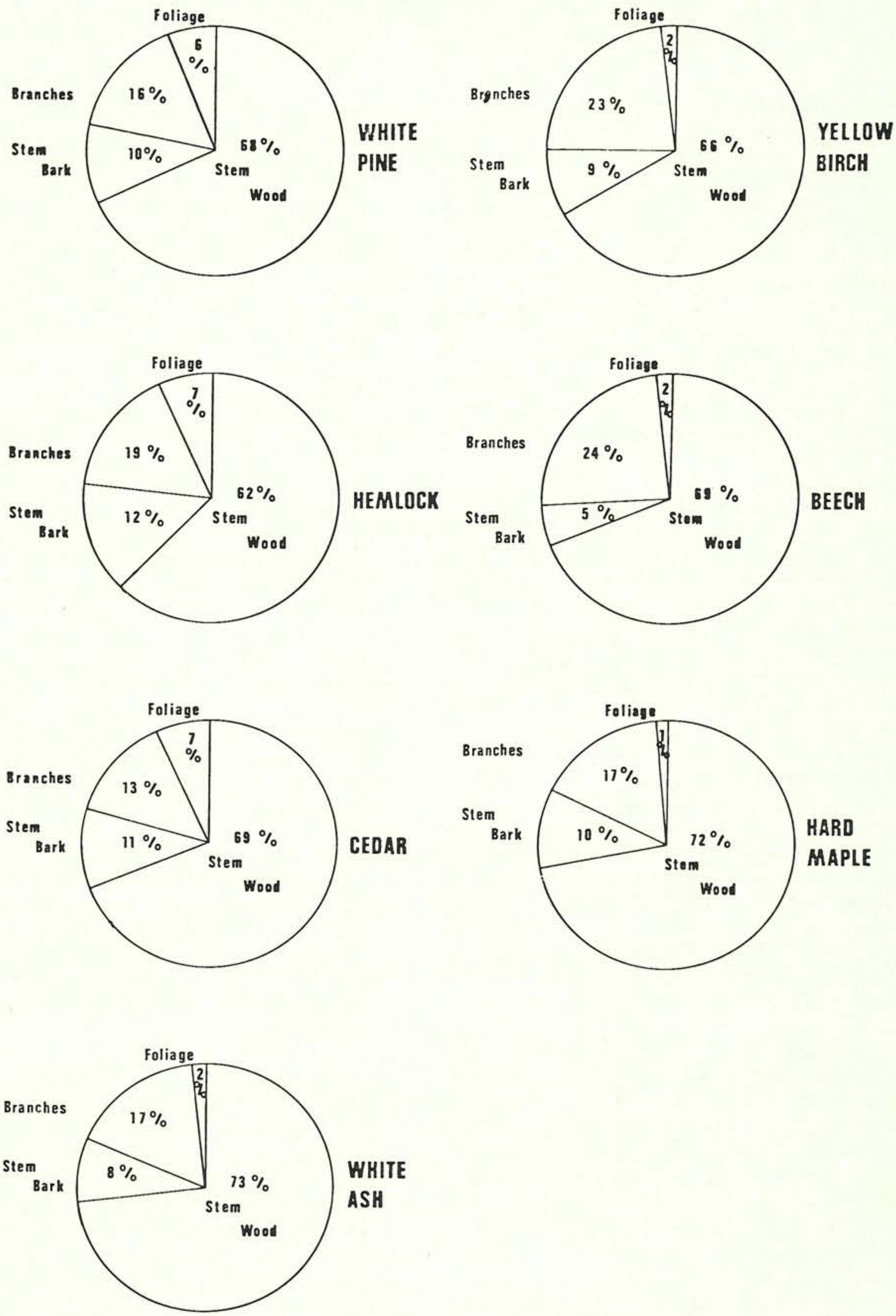


Figure 2. Distribution of above - ground biomass for seven species in Southwestern New Brunswick, based on mean oven - dry weights of each component.

species, based on the mean oven-dry weights of each component.

Equations for predicting fresh and oven-dry weights of total aboveground biomass are listed in Tables 2-8.

Comparisons with other studies

We compared the equations developed in this study with those of some other biomass studies (Stanek and State 1978, Young et al. 1964, Ribe 1973, Young and Carpenter 1967) by computing the weights of two components for each sample tree for each of six species using equations from these other studies, and then comparing the mean of the predicted component weights to the means obtained using the equations in Tables 2-8, using a paired t-test of the mean differences.

The results of these comparisons are summarized in Table 10, which lists the mean component weights as estimated from the equations of other studies ($\overline{W}_1$) and from the equations of this report ($\overline{W}_2$), along with the difference ($\overline{d}$) between means and the probability (P) of observing such differences under the null hypothesis $H_0 : \overline{d} = 0$.

Eleven of the 12 pairs of means were significantly different ($P < 0.05$). The single non-significant differences occurred for dry stem biomass of cedar ($P = 0.071$). Some of these differences probably simply reflect differences in definitions of components. For example, the large difference in mean branch weights for yellow birch and sugar maple probably means that some material which was classified as branches or crown in one study was classified as stem material in the other and vice versa. This hypothesis is supported by the observation that the total weights of stem and branch material are very close, at least for yellow birch (99.9 kg vs. 100.8 kg). For maple the same totals are 131.2 kg vs. 109.6 kg.

There are a large number of additional factors which could account for such differences and which make it difficult to interpret these differences in biological or ecological terms. Such factors would include: 1) methods of selecting sample trees, 2) sample size, 3) location of DBH measurement (4.5 ft vs. 1.3 m), 4) subsampling methods used to estimate dry component weights, 5) accuracy and precision of field and laboratory instruments, 6) training and experience of personnel, 7) nature of statistical models used, and 8) biological and ecological factors such as site, climate, stand history, levels of defoliation, etc.

To make valid inferences about the existence and magnitude of real biological differences in biomass relationships between species and/or regions it is necessary to have models based on data which have been collected using a statistically rigorous sampling system such as that described by Cunia (1979). The logistical problems and high costs of such sampling systems pose formidable obstacles and there are few if any biomass studies which fully satisfy the requirements of such systems, especially for random selection of sample trees and sample size.

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REFERENCES

1) Argue, R. 1978. Renewable Energy Resources: a guide to the literature. Can. Dep. Energy, Mines, Resources. Rep. EI77-5.

2) Baskerville, G.L. 1972. Use of logarithmic regression in the estimation of plant biomass. Can. J. For. Res. 2, 49-53.

3) Beauchamp, J.J. and J.S. Olson. 1973. Corrections for bias in regression estimates after logarithmic transformation. Ecology 54: 1403-1407.

4) Cunia, T. 1979. On sampling trees for biomass tables construction: some statistical comments. pp 643-664 In Proc. 1979 Workshop on Forest Resource Inventories, Colorado State University, Fort Collins, Colorado.

5) Dixon, W.J. 1977. Biomedical Computer Programs. (P-series). University of California Press.

6) Furnival, G.M. and R.W. Wilson. 1974. Regression by leaps and bounds. Technometrics 16: 499-511.

7) Honer, T.G. 1967. Standard volume tables and merchantable conversion factors for the commercial tree species of central and eastern Canada. Can. Dep. For. Rural Dev., For. Br. Inf. Rep. FMR-X-5.

8) Love, P. and Overend, R. 1978. Tree Power: an assessment of the energy potential of forest biomass in Canada. Can. Dep. Energy, Mines, Resources. Rep. ER78-1.

9) Ribe, J.H. 1973. Puckerbrush weight tables. Life Sci. and Agri. Exp. Sta., Univ. Maine, Orono. Misc. Rep. 152.

10) Rowe, J.S. 1972. Forest Regions of Canada. Dep. Env., Can. For. Serv. Publ. No. 1300.

11) Stanek, W. and D. State. 1978. Equations predicting primary productivity (biomass) of trees, shrubs and lesser vegetation based on current literature. Can. For. Serv. Pac. For. Res. Cent. Inf. Rep. BC-X-183.

12) Tillman, D.A. 1978. Wood as an energy resource. Academic Press, New York, N.Y.

13) Young, H.E., L. Strand, and R. Altenberger. 1964. Preliminary fresh and dry weight tables for seven tree species in Maine. Maine Agr. Exp. Sta., Orono, Maine. Tech. Bull. 12.

14) Young, H.S. and P.M. Carpenter. 1967. Weight, nutrient element and productivity studies of seedlings and saplings of eight tree species in natural ecosystems. Maine Agr. Exp. Sta., Univ. Maine, Orono. Tech. Bull. 28.

Table 1. Mean diameters, heights and component weights of sample trees

Variable	White Pine	Hemlock	Cedar	White Ash	Yellow Birch	Beech	Sugar Maple
	Species						
n	48	50	48	48	51	48	46
DBH (cm)	15.2	14.4	13.9	13.7	13.1	14.2	13.8
(range)	2.1-36.9	1.5-33.8	2.2-30.2	0.9-27.9	1.4-26.5	1.7-29.1	1.1-40.5
Height (m)	10.9	9.8	9.2	14.4	13.1	12.5	13.7
(range)	2.4-20.0	2.1-17.3	2.5-16.9	2.2-20.3	3.4-19.7	3.4-18.7	2.7-20.4
Total volume (m^3)	0.181	0.142	0.106	0.134	0.126	0.147	0.136
Oven-dry weight (kg)							
Stem wood	59.4	50.1	31.0	69.6	70.2	77.2	78.4
Stem bark	8.7	9.6	4.8	8.0	9.2	6.0	11.3
Total stem	68.0	59.7	35.8	77.7	79.5	83.2	89.7
Branches	13.7	15.5	6.0	16.1	24.3	26.6	18.4
Foliage	5.2	5.5	3.1	1.7	1.8	2.2	1.6
Total crown	18.9	21.0	9.1	17.8	26.1	28.8	20.0
Total above-ground	87.0	80.7	44.9	95.5	105.6	112.0	109.7
Fresh weight (kg)							
Stem wood	132.8	113.9	59.2	99.0	118.0	128.6	124.9
Stem bark	15.6	17.1	8.7	14.4	15.7	10.7	18.0
Total stem	148.4	131.0	67.9	113.4	133.6	139.2	142.9
Total crown	40.3	40.5	17.8	30.2	48.6	53.5	36.1
Total above-ground	188.7	171.5	85.7	143.6	182.2	192.8	179.0
Moisture content (%, based on mean fresh and dry weights)							
Total stem	118	119	90	46	68	67	59
Total crown	113	93	96	70	86	86	81
Total above-ground	117	112	91	50	72	72	63

Table 2. Tree biomass equations for white pine in southwestern New Brunswick

Component	Equation	n	R^2	c
	Oven-dry weight in kg			
Stem wood	$\ln W = -3.5128 + 2.5979 \ln D$	47	.976	1.03
	$\ln W = -3.5301 + 1.9360 \ln D + 0.7523 \ln H$	47	.984	
Stem bark	$\ln W = -4.1854 + 2.1781 \ln D$	47	.949	1.05
	$\ln W = -4.2142 + 1.4141 \ln D + 0.8783 \ln H$	47	.963	
Stem	$\ln W = -3.1855 + 2.5360 \ln D$	47	.973	1.03
	$\ln W = -3.2020 + 1.8990 \ln D + 0.7240 \ln H$	47	.982	
Branches	$\ln W = -0.4690 + 0.9568 \ln CV$	47	.900	1.08
	$\ln W = -2.6466 + 1.7086 \ln D$	47	.783	
	$\ln W = -1.3612 + 0.5805 \ln D + 0.7027 \ln CV$	47	.927	
Foliage	$\ln W = -0.8355 + 0.8254 \ln CV$	47	.909	1.05
	$\ln W = -2.6925 + 1.4653 \ln D$	47	.781	
	$\ln W = -1.5600 + 0.4715 \ln D + 0.6190 \ln CV$	47	.933	
Crown	$\ln W = 0.04932 + 0.9142 \ln CV$	47	.904	1.07
	$\ln W = -2.0241 + 1.6296 \ln D$	47	.783	
	$\ln W = -0.7881 + 0.5449 \ln D + 0.6757 \ln CV$	47	.930	
Total above-ground	$\ln W = -1.8221 + 2.1420 \ln D$	47	.968	1.03
	$\ln W = -1.5555 + 1.9057 \ln D + 0.1472 \ln CV$	47	.973	
	Fresh weight in kg			
Stem wood	$\ln W = -2.4267 + 2.5004 \ln D$	47	.980	1.03
	$\ln W = -2.4371 + 2.1037 \ln D + 0.4509 \ln H$	47	.984	
Stem bark	$\ln W = -3.3103 + 2.1002 \ln D$	47	.956	1.05
	$\ln W = -3.2351 + 1.3661 \ln D + 0.6162 \ln H + 0.3818 \ln CW$	47	.962	
Stem	$\ln W = -2.1249 + 2.4390 \ln D$	47	.978	1.03
	$\ln W = -2.1348 + 2.0590 \ln D + 0.4319 \ln H$	47	.981	
Crown	$\ln W = 0.8202 + 0.9120 \ln CV$	47	.904	1.06
	$\ln W = -1.2483 + 1.6258 \ln D$	47	.783	
	$\ln W = -0.01507 + 0.5435 \ln D + 0.6741 \ln CV$	47	.930	
Total above-ground	$\ln W = -0.9696 + 2.1135 \ln D$	47	.965	1.03
	$\ln W = -0.5640 + 1.7572 \ln D + 0.2227 \ln CV$	47	.977	

Table 3. Tree biomass equations for eastern hemlock in southwestern New Brunswick

Component	Equation	n	R^2	c
	Oven-dry weight in kg			
Stem wood	$\ln W = -2.9095 + 2.3570 \ln D$	49	.990	1.01
	$\ln W = -3.2971 + 1.8047 \ln D + 0.7980 \ln H$	49	.993	
Stem bark	$\ln W = -4.2813 + 2.2660 \ln D$	49	.985	1.03
	$\ln W = -4.5589 + 1.8705 \ln D + 0.5714 \ln H$	49	.986	
Stem	$\ln W = -2.6855 + 2.3418 \ln D$	49	.990	1.01
	$\ln W = -3.0535 + 1.8174 \ln D + 0.7576 \ln H$	49	.993	
Branches	$\ln W = -2.8376 + 1.9157 \ln D$	49	.927	1.05
	$\ln W = -2.3240 + 1.1670 \ln D + 0.4433 \ln CV$	49	.948	
	$\ln W = -2.1353 + 2.9165 \ln D - 1.4459 \ln H$	49	.940	
Foliage	$\ln W = -3.0924 + 1.6829 \ln D$	49	.928	1.04
	$\ln W = -2.6619 + 1.0553 \ln D + 0.3716 \ln CV$	49	.948	
	$\ln W = -2.5014 + 2.5251 \ln D - 1.2168 \ln H$	49	.940	
Crown	$\ln W = -2.2934 + 1.8442 \ln D$	49	.928	1.04
	$\ln W = -1.8029 + 1.1292 \ln D + 0.4233 \ln CV$	49	.949	
	$\ln W = -1.6215 + 2.8016 \ln D - 1.3833 \ln H$	49	.941	
Total above-ground	$\ln W = -1.8223 + 2.1536 \ln D$	49	.987	1.02
	$\ln W = -1.7006 + 1.9762 \ln D + 0.1050 \ln CV$	49	.988	
	Fresh weight in kg			
Stem wood	$\ln W = -2.2532 + 2.4057 \ln D$	49	.990	1.02
	$\ln W = -2.5109 + 2.0385 \ln D + 0.5306 \ln H$	49	.991	
Stem bark	$\ln W = -3.4390 + 2.1794 \ln D$	49	.985	1.02
	$\ln W = -3.7136 + 1.7881 \ln D + 0.5653 \ln H$	49	.987	
Stem	$\ln W = -1.9993 + 2.3693 \ln D$	49	.990	1.02
	$\ln W = -2.2570 + 2.0022 \ln D + 0.5305 \ln H$	49	.991	
Crown	$\ln W = -1.5973 + 1.8322 \ln D$	49	.928	1.04
	$\ln W = -1.1107 + 1.1227 \ln D + 0.4200 \ln CV$	49	.949	
	$\ln W = -0.9299 + 2.7832 \ln D - 1.3741 \ln H$	49	.941	
Total above-ground	$\ln W = -1.1567 + 2.1783 \ln D$	49	.984	1.02
	$\ln W = -0.9903 + 1.9358 \ln D + 0.1436 \ln CV$	49	.986	

Table 4. Tree biomass equations for eastern white cedar in southwestern New Brunswick

Component	Equation	n	R^2	c
	Oven-dry weight in kg			
Stem wood	$\ln W = -2.9565 + 2.2804 \ln D$	47	.989	1.01
	$\ln W = -3.2164 + 1.9219 \ln D + 0.5349 \ln H$	47	.991	
Stem bark	$\ln W = -4.6633 + 2.2228 \ln D$	47	.987	1.02
Stem	$\ln W = -2.7842 + 2.2706 \ln D$	47	.990	1.01
	$\ln W = -3.0179 + 1.9483 \ln D + 0.4811 \ln H$	47	.992	
Branches	$\ln W = -1.0525 + 1.0295 \ln CV$	46	.898	1.05
	$\ln W = -3.0529 + 1.7434 \ln D$	46	.863	
	$\ln W = -2.1162 + 0.8016 \ln D + 0.6243 \ln CV$	46	.941	
Foliage	$\ln W = -1.5063 + 0.9629 \ln CV$	46	.902	1.04
	$\ln W = -3.3534 + 1.6206 \ln D$	46	.856	
	$\ln W = -2.4454 + 0.7077 \ln D + 0.6052 \ln CV$	46	.941	
Crown	$\ln W = -0.5616 + 1.0059 \ln CV$	46	.900	1.05
	$\ln W = -2.5075 + 1.6998 \ln D$	46	.861	
	$\ln W = -1.5809 + 0.7681 \ln D + 0.6176 \ln CV$	46	.941	
Total above-ground	$\ln W = -2.1643 + 2.1439 \ln D$	46	.991	1.01
	$\ln W = -2.0000 + 1.9882 \ln D + 0.09948 \ln CV$	46	.993	
	$\ln W = -2.3939 + 1.8187 \ln D + 0.4796 \ln H$	46	.992	
	Fresh weight in kg			
Stem wood	$\ln W = -2.4662 + 2.3376 \ln D$	46	.989	1.01
	$\ln W = -2.8917 + 1.7348 \ln D + 0.8889 \ln H$	46	.993	
Stem bark	$\ln W = -4.1827 + 2.2692 \ln D$	46	.985	1.02
	$\ln W = -3.7709 + 2.1201 \ln D - 0.6098 \ln CW + 0.2646 \ln CV$	46	.988	
Stem	$\ln W = -2.2976 + 2.3271 \ln D$	46	.990	1.01
	$\ln W = -2.6909 + 1.7699 \ln D + 0.8217 \ln H$	46	.993	
Crown	$\ln W = 0.1339 + 0.9977 \ln CV$	46	.900	1.04
	$\ln W = -1.7931 + 1.6847 \ln D$	46	.860	
	$\ln W = -0.8698 + 0.7564 \ln D + 0.6154 \ln CV$	46	.941	
Total above-ground	$\ln W = -1.6163 + 2.1799 \ln D$	46	.984	1.01
	$\ln W = -1.3157 + 1.8950 \ln D + 0.1820 \ln CV$	46	.990	

Table 5. Tree biomass equations for white ash in southwestern New Brunswick

Component	Equation	n	R^2	c
	Oven-dry weight in kg			
Stem wood	$\ln W = -2.3689 + 2.3903 \ln D$	47	.992	1.01
	$\ln W = -2.9309 + 2.0466 \ln D + 0.5391 \ln H$	47	.994	
Stem bark	$\ln W = -3.9236 + 2.1762 \ln D$	47	.971	1.03
	$\ln W = -4.5223 + 1.8100 \ln D + 0.5744 \ln H$	47	.973	
Stem	$\ln W = -2.1858 + 2.3649 \ln D$	47	.991	1.01
	$\ln W = -2.7500 + 2.0199 \ln D + 0.5412 \ln H$	47	.993	
Branches	$\ln W = -3.4591 + 2.1935 \ln D$	46	.927	1.05
	$\ln W = -1.3458 + 3.4031 \ln D - 1.9487 \ln H$	46	.954	
Foliage	$\ln W = -4.1177 + 1.6932 \ln D$	46	.935	1.04
	$\ln W = -3.0430 + 2.3071 \ln D - 0.9888 \ln H$	46	.947	
Crown	$\ln W = -3.1300 + 2.1207 \ln D$	46	.927	1.05
	$\ln W = -1.1481 + 3.2550 \ln D - 1.8275 \ln H$	46	.953	
Total above-ground	$\ln W = -1.8740 + 2.3213 \ln D$	46	.992	1.01
	$\ln W = -1.8603 + 2.4488 \ln D - 0.2344 \ln CW$	46	.993	
	Fresh weight in kg			
Stem wood	$\ln W = -1.9761 + 2.3755 \ln D$	46	.991	1.01
	$\ln W = -2.6103 + 2.0266 \ln D + 0.5703 \ln H$	46	.993	
Stem bark	$\ln W = -3.2359 + 2.1452 \ln D$	46	.970	1.02
	$\ln W = -4.0504 + 1.7383 \ln D + 0.6928 \ln H$	46	.975	
Stem	$\ln W = -1.7168 + 2.3322 \ln D$	46	.990	1.01
	$\ln W = -2.3314 + 1.9940 \ln D + 0.5527 \ln H$	46	.992	
Crown	$\ln W = -2.2985 + 2.0294 \ln D$	46	.944	1.04
	$\ln W = -0.5469 + 3.1243 \ln D - 1.7055 \ln H$	46	.968	
Total above-ground	$\ln W = -1.2498 + 2.2430 \ln D$	47	.993	1.01
	$\ln W = -1.2648 + 2.3699 \ln D - 0.2145 \ln CW$	47	.994	

Table 6. Tree biomass equations for yellow birch in southwestern New Brunswick

Component	Equation	n	R^2	c
	Oven-dry weight in kg			
Stem wood	$\ln W = -2.4467 + 2.4369 \ln D$	50	.992	1.01
	$\ln W = -3.2174 + 1.8934 \ln D + 0.8283 \ln H$	50	.995	
Stem bark	$\ln W = -4.0633 + 2.3086 \ln D$	50	.980	1.02
	$\ln W = -5.1395 + 1.5495 \ln D + 1.1568 \ln H$	50	.986	
Stem	$\ln W = -2.2673 + 2.4200 \ln D$	50	.992	1.01
	$\ln W = -3.0782 + 1.8482 \ln D + 0.8715 \ln H$	50	.995	
Branches	$\ln W = -3.5521 + 2.3585 \ln D$	50	.908	1.14
	$\ln W = -3.7872 + 1.8731 \ln D + 0.9945 \ln CW$	50	.926	
	$\ln W = -2.0235 + 3.4366 \ln D - 1.6430 \ln H$	50	.919	
Foliage	$\ln W = -4.1049 + 1.7241 \ln D$	49	.914	1.07
	$\ln W = -4.0759 + 1.1443 \ln D + 0.3944 \ln CV$	49	.937	
Crown	$\ln W = -3.1709 + 2.2683 \ln D$	49	.923	1.11
	$\ln W = -3.3970 + 1.8103 \ln D + 0.9401 \ln CW$	49	.941	
	$\ln W = -2.0298 + 3.0821 \ln D - 1.2370 \ln H$	49	.929	
Total above-ground	$\ln W = -1.8701 + 2.3666 \ln D$	50	.992	1.01
	Fresh weight in kg			
Stem wood	$\ln W = -1.7835 + 2.3880 \ln D$	50	.993	1.01
	$\ln W = -2.4818 + 1.8955 \ln D + 0.7506 \ln H$	50	.995	
Stem bark	$\ln W = -3.3798 + 2.2522 \ln D$	50	.984	1.02
	$\ln W = -4.2873 + 1.6121 \ln D + 0.9755 \ln H$	50	.988	
Stem	$\ln W = -1.6008 + 2.3699 \ln D$	50	.993	1.01
	$\ln W = -2.3255 + 1.8588 \ln D + 0.7789 \ln H$	50	.996	
Crown	$\ln W = -2.3111 + 2.1951 \ln D$	49	.923	1.10
	$\ln W = -2.5349 + 1.7419 \ln D + 0.9302 \ln CW$	49	.941	
	$\ln W = -1.1985 + 2.9886 \ln D - 1.2061 \ln H$	49	.929	
Total above-ground	$\ln W = -1.1509 + 2.3072 \ln D$	50	.991	1.01
	$\ln W = -1.1437 + 2.1733 \ln D + 0.09099 \ln CV$	50	.992	

Table 7. Tree biomass equations for beech in southwestern New Brunswick

Component	Equation	n	R^2	c
	Oven-dry weight in kg			
Stem wood	ln W = -2.0961 + 2.2956 ln D	47	.987	1.01
	ln W = -3.1855 + 1.8396 ln D + 0.8957 ln H	47	.993	
Stem bark	ln W = -4.1698 + 2.1154 ln D	47	.979	1.03
Stem	ln W = -1.9797 + 2.2809 ln D	47	.988	1.01
	ln W = -2.9936 + 1.8565 ln D + 0.8336 ln H	47	.994	
Branches	ln W = -3.5982 + 2.3708 ln D	47	.892	1.13
	ln W = -4.2190 + 1.6225 ln D + 1.6126 ln CW	47	.934	
Foliage	ln W = -3.7607 + 1.6303 ln D	47	.869	1.06
	ln W = -3.9991 + 0.9004 ln D + 0.5536 ln CV	46	.937	
Crown	ln W = -3.0908 + 2.2377 ln D	46	.904	1.09
	ln W = -3.6856 + 1.5623 ln D + 1.4734 ln CW	46	.944	
	ln W = -1.6216 + 2.8545 ln D - 1.2100 ln H	46	.916	
Total above-ground	ln W = -1.6309 + 2.2538 ln D	46	.988	1.01
	ln W = -2.0464 + 2.0799 ln D + 0.3416 ln H	46	.989	
	Fresh weight in kg			
Stem wood	ln W = -1.5497 + 2.2837 ln D	47	.986	1.01
	ln W = -2.6754 + 1.8124 ln D + 0.9256 ln H	47	.994	
Stem bark	ln W = -3.4909 + 2.0834 ln D	47	.981	1.02
Stem	ln W = -1.4166 + 2.2650 ln D	47	.988	1.01
	ln W = -2.4588 + 1.8287 ln D + 0.8569 ln H	47	.994	
Crown	ln W = -2.2837 + 2.1786 ln D	46	.903	1.09
	ln W = -2.8731 + 1.5094 ln D + 1.4599 ln CW	46	.944	
	ln W = -0.8800 + 2.7680 ln D - 1.1562 ln H	46	.915	
Total above-ground	ln W = -1.0007 + 2.2240 ln D	47	.986	1.02
	ln W = -1.0405 + 2.0989 ln D + 0.09465 ln CV	47	.987	

Table 8. Tree biomass equations for sugar maple in southwestern New Brunswick

Component	Equation	n	R^2	c
	Oven-dry weight in kg			
Stem wood	ln W = -2.2792 + 2.3869 ln D	45	.990	1.01
	ln W = -3.5437 + 1.8322 ln D + 1.0213 ln H	45	.996	
Stem bark	ln W = -3.8804 + 2.2684 ln D	45	.976	1.03
	ln W = -4.6586 + 1.9131 ln D + 0.6425 ln H	45	.979	
Stem	ln W = -2.0675 + 2.3603 ln D	45	.991	1.01
	ln W = -3.2158 + 1.8566 ln D + 0.9274 ln H	45	.996	
Branches	ln W = -4.0484 + 2.3841 ln D	45	.908	1.11
	ln W = -4.3679 + 1.6786 ln D + 1.4864 ln CW	45	.941	
Foliage	ln W = -4.1703 + 1.6990 ln D	45	.928	1.04
	ln W = -4.0202 + 1.0973 ln D + 0.4031 ln CV	45	.952	
Crown	ln W = -3.6321 + 2.2839 ln D	45	.911	1.09
	ln W = -3.9409 + 1.6019 ln D + 1.4370 ln CW	45	.944	
Total above-ground	ln W = -1.8329 + 2.3376 ln D	45	.993	1.01
	ln W = -2.5129 + 2.0393 ln D + 0.5492 ln H	45	.995	
	Fresh weight in kg			
Stem wood	ln W = -1.8371 + 2.3928 ln D	45	.991	1.00
	ln W = -3.0407 + 1.8648 ln D + 0.9721 ln H	45	.997	
Stem bark	ln W = -3.0833 + 2.1559 ln D	45	.986	1.02
	ln W = -3.6339 + 1.8795 ln D + 0.4794 ln H	45	.987	
Stem	ln W = -1.5886 + 2.3541 ln D	45	.992	1.00
	ln W = -2.6878 + 1.8719 ln D + 0.8878 ln H	45	.997	
Crown	ln W = -2.7578 + 2.1979 ln D	45	.914	1.08
	ln W = -3.0545 + 1.5428 ln D + 1.3803 ln CW	45	.947	
	ln W = -1.0645 + 2.9407 ln D - 1.3677 ln H	45	.925	
Total above-ground	ln W = -1.2670 + 2.3094 ln D	45	.994	1.01
	ln W = -1.8422 + 2.0571 ln D + 0.4645 ln H	45	.995	

Table 9. Mean ratios of oven-dry weight of wood and bark to total fresh weight (RWB) and oven-dry weight of foliage to total fresh weight (RF), by species and crown stratum. Based on 802 crown samples

Crown Stratum[1]	Species						
	White Pine	Hemlock	Cedar	White Ash	Yellow Birch	Beech	Sugar Maple
				- RWB -			
1	.282	.321	.308	.408	.367	.378	.346
3	.315	.396	.377	.646	.580	.570	.609
5	.370	.427	.360	.665	.588	.578	.611
7	.375	.349	*	.665	.589	.570	.612
9	.420	*	*	.651	.594	.582	.615
11	*	*	*	*	.602	.604	.614
13	*	*	*	*	.586	*	.638
				- RF -			
1	.183	.185	.192	.114	.093	.105	.119
3	.141	.127	.151	0	0	0	0
5	.107	.100	.154	0	0	0	0
7	.103	.098	*	0	0	0	0
9	.070	*	*	0	0	0	0
11	*	*	*	0	0	0	0
13	*	*	*	0	0	0	0

1. Midpoint of crown size class in centimetres.
* No data available.

Table 10. Mean weights ($\bar{W}_1$ and $\bar{W}_2$) of various biomass components of six species as estimated from two different equations, mean difference between weights ($\bar{d}$), and probability (P) of observed differences under null hypothesis H_0: $\bar{d} = 0$

Species	Component	Equation Source (W_1)	$\bar{W}_1$ (kg)	$\bar{W}_2$ (kg)	$\bar{d}$	P	df
White pine	Fresh total above-ground	Young et al. 1964	223.4	193.0	30.4	.002	47
	Fresh total stem	Young et al. 1964	167.2	155.3	12.0	.004	47
Hemlock	Fresh total above-ground	Young et al. 1964	180.3	162.9	17.4	.001	49
	Fresh total stem	Young et al. 1964	121.3	124.8	-3.6	.000	49
Cedar	Oven-dry branches	Young and Carpenter 1967	7.4	6.1	1.4	.037	47
	Oven-dry total stem	Young and Carpenter 1967	40.1	35.8	4.3	.071	47
Yellow birch	Oven-dry branches	Ribe 1973	5.6	22.7	-17.1	.000	50
	Oven-dry total stem	Ribe 1973	94.3	78.1	16.2	.000	50
Beech	Oven-dry foliage	Ribe 1973	3.2	2.3	0.9	.000	47
	Oven-dry total stem	Ribe 1973	132.9	82.7	50.1	.003	47
Sugar maple	Oven-dry branches	Ribe 1973	4.0	18.9	-14.9	.003	45
	Oven-dry total stem	Ribe 1973	127.2	90.7	36.5	.004	45