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Estimating northern **RED OAK CROWN COMPONENT WEIGHTS** *in the northeastern United States*

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ESTIMATING NORTHERN RED OAK CROWN COMPONENT WEIGHTS IN THE NORTHEASTERN UNITED STATES

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Tree crowns, particularly those remaining as debris after logging operations, wind or ice storms, or insect epidemics, may be a significant forest fire fuel. Northern red oak, (*Quercus rubra* L.) widely distributed in the eastern United States, is found in most oak-hickory forests. To appraise potential fire behavior following disturbance in stands containing northern red oak, a method of estimating individual crown fuel weights was developed. These weight estimates are suitable for use in fuel models and also provide estimates of potentially usable fiber. While these estimates are for northeastern northern red oak, they are probably satisfactory for northern red oak and similar black oak species throughout the eastern United States.

A number of methods have been developed for estimating eastern hardwood tree crown (foliage and/or branchwood)[1] weights in addition to, independently of, or together with weights of "merchantable" or specified portions of the upper bole (Storey and Pong 1957, Young *et al.* 1964, Ralston and Prince 1965, Young and Carpenter 1967, Oak Ridge National Laboratory 1971, Zavitkovski 1971, King and Schnell 1972, Sando and Wick 1972, Ribe 1973, Schlaegel 1975, MacLean and Wein 1976, Phillips 1977, Wartluft 1977, Wiant *et al.* 1977, and Wartluft 1978). Two studies established branchwood size classes as needed for fire behavior prediction using the Rothermel (1972) model—(Loomis 1975) for northern red oak, and (Loomis and Roussopoulos 1978) for aspen.

Most investigators developing crown weight prediction methods have used d.b.h. (diameter at breast height) as an independent variable, either alone or combined with tree height, crown length, or crown ratio.[2] While bole diameter at base of crown is an excellent single estimator of crown weights, (Storey and Pong 1957, Loomis *et al.* 1966) it can be difficult to obtain. Using d.b.h. and crown ratio to estimate shortleaf pine crown weights produced more accurate estimates than using d.b.h. alone (Loomis *et al.* 1966). These results were almost as accurate as those obtainable by using the bole diameter at base of crown.

METHODS

Twenty-eight trees from Michigan and 28 from Pennsylvania were destructively sampled in 1973, 1974, and 1978. The trees were from four locations in Wexford, Manistee, and Calhoun Counties in Michigan and from one location in Huntingdon County, Pennsylvania.

The trees, from fully stocked stands on medium or better sites, ranged in size from 1.0 to 20.6 inches d.b.h., and in crown ratio from 27 to 82 percent.[3] A wide range of crown ratios was selected for each d.b.h. class. Vigorous dominant or codominant trees with relatively uniform crowns and branching were chosen. Preference was given to trees with well defined boles extending well into the crown. Sampling was done from mid-summer through early fall while trees were in full foliage, after seasonal growth was completed.

There was noticeable insect defoliation on many sample trees in both States. Selecting trees that were least affected by this minimized influence on foliage weights and resulting estimates but did not completely avoid it.

Tree measurements made included d.b.h., total height, live crown length and width, and basal diameters of all branches at 2 inches from the bole.[4] One hundred fifty-four branches were randomly selected

[1] *"Branchwood" and also "bolewood" as used in this paper refer to both wood and bark.*

[2] *Crown ratio is the ratio of live crown length to total tree height expressed as a percent.*

[3] *English-metric equivalents: 1 inch = 2.54 cm; 1 pound = 0.4536 kg; 1 acre = 0.40469 hectare.*

[4] *All bole, branch, and branchwood diameters in this paper are outside bark (d.o.b.) measurements.*

and cut from sample trees for a branch sample representing all crown parts and all trees. Bole sections measuring 1 to 3 inches in diameter were weighed.

Field weights of foliage, total live branchwood, and live branchwood in four fuel groups—with diameters of 0 to ¼ inch, ¼ to 1 inch, 1 to 3 inches, and 3 inches or more—were determined for each sample branch. Sample branches ranged from 0.5 to 10.4 inches in basal diameter.

Field weights for dead branchwood in the four size groups were obtained for each tree. The wood was weighed for approximately half the trees. As this was considered a suitable base, ocular weight estimates were included for the other trees, particularly for material falling within the smaller diameter groups.

Factors for converting all field weights to ovendry weights for analysis were obtained by ovendrying foliage, branch, and bole sections at 105° C for 24 hours or more.

Logarithmic transformations were made to adapt to the general equation Lny = a + bLnx for predicting weights of foliage and total live wood per branch using basal diameter as the independent variable. These and all subsequent equations were adjusted for logarithmic transformation bias (Baskerville 1972).

To aid subsequent mathematical representation, measured dry weights of wood in the three mutually exclusive size classes (0 to ¼ inch, ¼ to 1 inch, 1 to 3 inches) were arithmetically combined by branch into overlapping classes: 0 to ¼ inch, 0 to 1 inch, and 0 to 3 inches. The percent of total branchwood weight per branch in each overlapping size class was then plotted against branch diameter for all sample branches. Curves were drawn defining the relations. Next, the percentage values for size groups—0 to ¼ inch, ¼ to 1 inch, 1 to 3 inches, and 3+ inches were computed using curve values. These basal branch diameter percentages were multiplied by total live branchwood weight for each applicable basal diameter to obtain class weights per branch. Foliage and branchwood weights (total and by size class) for each tree were then computed by summing the predicted weights for the tallied live branch basal diameters. Weight and dimension data for the 56 trees were then used to develop estimating equations.

RESULTS

Regression analysis yielded good relations for predicting foliage weights and total weight of live wood per branch when using basal diameter as the independent variable (table 1). Equations were developed to predict weights of foliage and branchwood per tree using various variables: bole diameter at base of crown, d.b.h., and the combination of d.b.h. and crown ratio (table 2). Resulting estimates for the pair of equations using d.b.h. and crown ratio are presented on table 3 and 4. The prediction improvement from adding crown ratio as a second independent variable was significant at the 0.01 level. Equations to compute ratios of branchwood weights within diameter size class (0 to ¼ inch, 0 to 1 inch, 0 to 3 inches) to total branchwood weight per tree were developed (table 5). These predictions are constrained at a 1.0 value as ratios cannot exceed unity. These ratios, together with available estimates of total live branchwood weight per tree, allowed computation of estimates of live branchwood weights per tree within each of the diameter size groups (table 6). Estimates of bolewood weight in the 1 to 3 inch diameter class were obtained from a curve drawn through data for the bole section weight plotted over tree d.b.h. (table 7).

Table 1.—*Equations for estimating northern red oak foliage and live branchwood[1] dry weights for individual branches*

Dependent variable	Equations	R^2	Sy·x	Percent of mean
Foliage	$Wf = 0.3925(Bd)^{1.5648}$	0.86	0.08	3.9
Total branchwood	$Wb = 1.1852(Bd)^{2.6883}$	.98	.84	2.6

[1]Branchwood includes the topmost section of the bole that is less than 1 inch in diameter. Branchwood refers to both wood and bark.

The abbreviated terms are: Wf = foliage weight (pounds)
Wb = live branchwood weight (pounds)
Bd = branch basal diameter (inches)
R^2 = coefficient of determination
Sy·x = standard deviation about the regression
Percent of mean = percent error of the mean

Table 2.—*Equations for estimating total dry weight of northern red oak foliage and live branchwood[1] using various crown and stem measurements*

Foliage	R^2	Sy·x	Percent of mean	Live branchwood	R^2	Sy·x	Percent of mean
$Wf = 0.5953Dc^{1.6428}$	0.98	0.65	3.6	$Wb = 0.4928Dc^{2.8932}$	0.99	11.42	3.7
$Wf = .4590Dbh^{1.5018}$	.96	1.18	6.5	$Wb = .3328Dbh^{2.6360}$	.97	34.07	10.9
$Wf = .0136Dbh^{1.5791} Cr^{.8612}$	.98	.69	3.8	$Wb = .0005Dbh^{2.7768} Cr^{1.5685}$	.99	16.13	5.2

[1]Branchwood includes the topmost section of the bole that is less than one inch in diameter. Branchwood refers to both wood and bark.

The abbreviated terms are: Wf = foliage weight (pounds)
Wb = live branchwood weight (pounds)
Dc = bole diameter at base of crown, outside bark (inches)
Dbh = diameter at breast height, outside bark (inches) Cr = crown ratio: crown length in feet ÷ tree height in feet, expressed as percent
R^2 = coefficient of determination
Sy·x = standard deviation about regression
Percent of mean = percent error of the mean

Table 3.—*Dry weight of northern red oak foliage*
(In pounds)

D.b.h. (inches)	Crown ratio[1] (percent) 20	30	40	50	60	70	80
1	0.2	0.3	0.3*	0.4	0.5*	0.5*	0.6
2	0.5	0.8	1.0	1.2*	1.4*	1.6*	1.8
3	1.0	1.4	1.8	2.2*	2.6	3.0*	3.4
4	1.6	2.3	2.9*	3.5	4.1	4.7	5.3
5	2.3	3.2	4.1	5.0	5.9	6.7*	7.5
6	3.0	4.3	5.5	6.7	7.8	9.0	10.0
7	3.9	5.5	7.0*	8.5*	10.0	11.0	13.0
8	4.8	6.8*	8.7*	11.0	12.0	14.0	16.0
9	5.8	8.2	10.0*	13.0	15.0	17.0	19.0
10	6.8	9.7	12.0	15.0*	17.0	20.0	22.0
11	7.9	11.0*	14.0*	17.0*	20.0*	23.0	26.0
12	9.1	13.0	16.0*	20.0*	23.0	27.0	30.0
13	10.0	15.0	19.0*	23.0	26.0	30.0*	34.0
14	12.0	16.0*	21.0*	26.0	30.0*	34.0	38.0
15	13.0	18.0	23.0*	28.0*	33.0	38.0	43.0
16	14.0	20.0	26.0*	31.0	37.0	42.0	47.0
17	16.0	22.0	29.0*	35.0	40.*	46.0	52.0*
18	17.0	24.0	31.0	38.0	44.0	51.0	57.0
19	19.0	27.0	34.0	41.0	48.0*	55.0*	62.0
20	20.0	29.0	37.0*	45.0	52.0*	60.0	67.0
21	22.0	31.0	40.0	48.0	57.0*	65.0	73.0
22	24.0	34.0	43.0	52.0	61.0	70.0	78.0
23	25.0	36.0	46.0	56.0	65.0	75.0	84.0
24	27.0	38.0	49.0	60.0	70.0	80.0	90.0
25	29.0	41.0	53.0	64.0	75.0	85.0	95.0

Note: Asterisks identify observed data.
[1]Crown ratio is the ratio of live crown length to total tree height expressed as a percent.

An equation to estimate total dead branchwood weight per tree was developed:

$Wb = 0.356\ Dbh^{1.713}$

where:
Wb = dead branchwood weight per tree (pounds)
and
Dbh = diameter at breast height (inches).

The coefficient of determination (r^2) was 0.71 and the standard deviation from the regression (Sy·x) was 3.46 for this equation.

Total dead branchwood weight was subdivided into three size groups by plotting each tree's percentage of the total within size groups (0 to ¼ inch, 0 to 1 inch, and 0 to 3 inches in diameter) over d.b.h. Curves were then drawn through the data. Dead branchwood weights within size groups—0 to ¼ inch, ¼ to 1 inch, 1 to 3 inches, and 3+ inches in diameter—were computed using appropriate calculations on curve values and the equation for estimating total dead branchwood weight per tree (table 8).

Table 4.—*Dry total weight of northern red oak live branchwood*[1]
(In pounds)

D.b.h. (inches)D.b.h.	Crown ratio[2] (percent)						
	20	30	40	50	60	70	80
1	0.1	0.1	0.2	0.2	0.3	0.4	0.5
2	0.4	0.7	1.1	1.6	2.1	2.7	3.3
3	1.2	2.2	3.4	4.9	6.5	8.3	10.0
4	2.6	4.9	7.7	11.0	14.0	18.0	23.0
5	4.8	9.1	14.0	20.0	27.0	34.0	42.0
6	8.0	15.0	24.0	33.0	45.0	57.0	70.0
7	12.0	23.0	36.0	51.0	68.0	87.0	107.0
8	18.0	33.0	52.0	74.0	99.0	126.0	155.0
9	25.0	46.0	73.0	103.0	137.0	175.0	216.0
10	33.0	62.0	97.0	138.0	184.0	234.0	289.0
11	43.0	81.0	127.0	180.0	240.0	305.0	376.0
12	54.0	103.0	162.0	229.0	305.0	389.0	479.0
13	68.0	129.0	202.0	286.0	381.0	485.0	599.0
14	84.0	158.0	248.0	352.0	468.0	596.0	735.0
15	101.0	191.0	300.0	426.0	567.0	722.0	891.0
16	121.0	229.0	359.0	510.0	679.0	864.0	1,065.0
17	143.0	271.0	425.0	603.0	803.0	1,023.0	1,261.0
18	168.0	317.0	498.0	707.0	941.0	1,198.0	1,478.0
19	195.0	369.0	579.0	822.0	1,094.0	1,393.0	1,717.0
20	225.0	425.0	668.0	947.0	1,261.0	1,606.0	1,980.0
21	258.0	487.0	765.0	1,085.0	1,444.0	1,839.0	2,267.0
22	293.0	554.0	870.0	1,234.0	1,643.0	2,092.0	2,580.0
23	332.0	627.0	984.0	1,397.0	1,859.0	2,367.0	2,919.0
24	373.0	705.0	1,108.0	1,572.0	2,092.0	2,664.0	3,285.0
25	418.0	790.0	1,241.0	1,760.0	2,343.0	2,984.0	3,679.0

[1]Branchwood includes bolewood less than 1 inch in diameter. Branchwood and bolewood include all woody parts (wood and bark).
[2]Crown ratio is the ratio of live crown length to total tree height expressed as a percent.

Table 5.—*Equations for estimating ratios of northern red oak live branchwood*[1] *within a size group, to total branchwood per tree*

Live branchwood diameter class	Equation	R^2	Sy·x	Percent of mean	n
0-¼ inch	$R_1 = 0.6262Dbh^{-1.0795}$	0.94	0.007	5.4	
	$R_1 = 0.5094Dc^{-1.1863}$	.97	.005	3.8	56
	$R_1 = 6.4735Dbh^{-1.1313} Cr^{-.5777}$	.96	.007	5.4	
0-1 inch	$R_2 = 3.1018Dbh^{-1.0114}$	.70	.016	6.4	
	$R_2 = 1.7710Dc^{-.9479}$	.82	.012	4.8	42
	$R_2 = 36.8351Dbh^{-.9345} Cr^{-.7014}$	.79	.014	5.6	
0-3 inches	$R_3 = 8.7376Dbh^{-1.0113}$	.64	.018	3.0	
	$R_3 = 4.0290Dc^{-.8443}$	.78	.015	2.5	34
	$R_3 = 28.2916Dbh^{-.8658} Cr^{-.4084}$	.72	.017	2.8	

[1]Branchwood includes the topmost section of the bole that is less than 1 inch in diameter. Branchwood refers to both wood and bark.
The abbreviated terms are: R_1,R_2,R_3 = Ratios of branchwood within a group to total branchwood weight.
Dbh = Diameter at breast height, outside bark (inches).
Dc = Bole diameter at base of crown, outside bark (inches).
Cr = Crown ratio: Crown length in feet tree height in feet, expressed as a percent.
R^2 = Coefficient of determination.
Sy·x = Standard deviation about regression.
Percent of mean = Percent error of the mean.

Table 6.—*Dry weight of northern red oak live branchwood*[1] *by diameter class*
(In pounds)

D.b.h.	Crown ratio[2]																							
	20 percent diameter class (inches)				30 percent diameter class (inches)				40 percent diameter class (inches)				50 percent diameter class (inches)				60 percent diameter class (inches)				70 percent diameter class (inches)				80 percent diameter class (inches)			
(inches)	0-.25	.25-1	1-3	3+	0-.25	.25-1	1-3	3+	0-.25	.25-1	1-3	3+	0-.25	.25-1	1-3	3+	0-.25	.25-1	1-3	3+	0-.25	.25-1	1-3	3+	0-.25	.25-1	1-3	3+
1	0.1				0.1				0.1	0.1			0.1	0.1			0.2	0.1			0.2	0.2			0.2	0.2		
2	0.2	0.2			0.3	0.4			0.4	0.7			0.5	1.1			0.6	1.5			0.7	2.0	0.1		0.8	2.2	0.4	
3	0.4	0.8			0.6	1.6			0.8	2.6			1.0	3.2	0.7		1.1	3.7	1.6		1.3	4.2	2.7		1.5	4.6	3.9	
4	0.6	2.0			0.9	3.6	0.3		1.2	4.6	1.8		1.6	5.6	3.9		1.8	6.2	6.0		2.1	7.1	8.8		2.5	8.4	12.0	
5	0.9	3.9			1.3	5.5	2.3		1.7	6.9	5.3		2.2	8.4	9.4		2.7	9.8	15.0		3.1	11.0	20.0		3.5	12.0	26.0	
6	1.2	5.5	1.3		1.8	7.8	5.4		2.4	10.0	12.0		2.9	12.0	18.0		3.6	14.0	27.0		4.2	16.0	37.0		4.8	18.0	48.0	
7	1.5	7.2	3.2		2.3	10.0	10.0		3.1	13.0	20.0		3.8	16.0	32.0		4.6	19.0	44.0	0.7	5.4	21.0	55.0	6.1	6.1	24.0	64.0	13.0
8	2.0	9.7	6.3		2.8	13.0	17.0		3.8	17.0	31.0		4.7	20.0	45.0	3.7	5.7	24.0	57.0	12.0	6.7	27.0	69.0	23.0	7.6	30.0	84.0	34.0
9	2.4	12.0	11.0		3.5	16.0	26.0		4.7	22.0	42.0	4.4	5.8	25.0	57.0	15.0	7.0	30.0	71.0	29.0	8.1	34.0	88.0	46.0	9.3	38.0	106.0	63.0
10	2.8	14.0	16.0		4.2	20.0	35.0	2.5	5.5	26.0	51.0	15.0	6.9	32.0	69.0	30.0	8.3	36.0	88.0	52.0	9.6	42.0	108.0	75.0	11.0	47.0	127.0	104.0
11	3.3	17.0	22.0		4.9	24.0	42.0	9.7	6.5	30.0	64.0	27.0	8.1	37.0	85.0	50.0	9.6	43.0	108.0	79.0	11.0	50.0	131.0	113.0	13.0	55.0	154.0	154.0
12	3.7	20.0	29.0	1.6	5.7	28.0	50.0	19.0	7.5	36.0	75.0	44.0	9.4	43.0	101.0	76.0	11.0	50.0	128.0	116.0	13.0	57.0	156.0	163.0	15.0	67.0	182.0	216.0
13	4.3	24.0	33.0	6.8	6.5	34.0	59.0	30.0	8.5	42.0	87.0	65.0	11.0	52.0	114.0	109.0	13.0	60.0	149.0	160.0	15.0	67.0	179.0	223.0	17.0	79.0	210.0	294.0
14	4.9	27.0	39.0	13.0	7.3	39.0	68.0	44.0	9.7	50.0	99.0	89.0	12.0	58.0	134.0	148.0	15.0	70.0	168.0	215.0	17.0	79.0	209.0	292.0	19.0	84.0	250.0	382.0
15	5.5	31.0	44.0	20.0	8.0	44.0	78.0	61.0	11.0	55.0	114.0	120.0	14.0	67.0	153.0	192.0	16.0	81.0	193.0	278.0	19.0	90.0	238.0	375.0	21.0	103.0	276.0	490.0
16	6.1	35.0	50.0	30.0	8.9	48.0	89.0	82.0	12.0	64.0	129.0	154.0	15.0	77.0	173.0	245.0	18.0	91.0	217.0	353.0	21.0	100.0	268.0	475.0	23.0	115.0	320.0	607.0
17	6.7	39.0	57.0	40.0	10.0	55.0	100.0	106.0	13.0	72.0	145.0	196.0	16.0	86.0	193.0	308.0	20.0	100.0	249.0	434.0	24.0	109.0	307.0	583.0	26.0	125.0	366.0	744.0
18	7.4	43.0	64.0	54.0	11.0	62.0	111.0	133.0	14.0	80.0	159.0	244.0	18.0	95.0	219.0	375.0	22.0	110.0	282.0	527.0	25.0	131.0	335.0	707.0	30.0	133.0	414.0	902.0
19	8.0	49.0	70.0	68.0	12.0	69.0	122.0	166.0	16.0	89.0	179.0	295.0	20.0	104.0	247.0	452.0	24.0	118.0	317.0	635.0	28.0	139.0	376.0	850.0	31.0	158.0	446.0	1,082.0
20	8.8	52.0	79.0	86.0	13.0	76.0	136.0	200.0	17.0	96.0	200.0	354.0	22.0	111.0	275.0	540.0	26.0	137.0	340.0	757.0	31.0	146.0	418.0	1,012.0	34.0	164.0	495.0	1,287.0
21	9.6	58.0	88.0	103.0	14.0	83.0	151.0	239.0	19.0	103.0	222.0	421.0	24.0	128.0	293.0	640.0	27.0	146.0	375.0	895.0	33.0	169.0	460.0	1,177.0	36.0	190.0	544.0	1,496.0
22	10.0	63.0	94.0	126.0	15.0	90.0	166.0	283.0	20.0	110.0	244.0	496.0	25.0	136.0	321.0	753.0	30.0	168.0	411.0	1,035.0	36.0	174.0	502.0	1,381.0	41.0	191.0	619.0	1,729.0
23	11.0	69.0	103.0	149.0	16.0	97.0	182.0	332.0	22.0	126.0	266.0	571.0	27.0	155.0	349.0	866.0	33.0	171.0	446.0	1,208.0	38.0	199.0	544.0	1,586.0	44.0	219.0	642.0	2,014.0
24	12.0	74.0	112.0	175.0	18.0	102.0	197.0	388.0	23.0	132.0	288.0	665.0	30.0	159.0	393.0	990.0	36.0	195.0	481.0	1,381.0	40.0	226.0	586.0	1,812.0	46.0	246.0	690.0	2,300.0
25	13.0	79.0	121.0	205.0	19.0	115.0	205.0	450.0	25.0	149.0	310.0	757.0	32.0	180.0	405.0	1,144.0	37.0	197.0	539.0	1,570.0	45.0	224.0	656.0	2,059.0	48.0	250.0	773.0	2,612.0

[1]Branchwood includes bolewood less than 1 inch in diameter. Branchwood and bolewood include all woody parts (wood and bark).
[2]Crown ratio is the ratio of live crown length to total tree height expressed as a percent.

Table 7.—*Dry weight of bole section from 1 to 3 inches in diameter for northern red oak per tree by d.b.h.*

D.b.h. (inches)	Bole section (lbs.)	D.b.h. (inches)	Bole section (lbs.)
1	2	16	10
2	11	17	10
3	12	18	9
4	13	19	9
5	13	20	8
6	13	21	8
7	13	22	8
8	13	23	7
9	13	24	7
10	12	25	7
11	12		
12	12		
13	11		
14	11		
15	10		

Table 8.—*Dry weight of northern red oak dead branchwood[1] by four diameter classes and total per tree by d.b.h.*

D.b.h.	Diameter				Total dead
(inches)	0-.25	.25-1	1-3	3+	branchwood
1	0.1	0.3			0.4
2	0.2	1.0			1.2
3	0.3	2.0			2.3
4	0.5	3.3			3.8
5	0.6	5.0			5.6
6	0.7	6.9	0.1		7.7
7	0.8	6.1	3.1		10.0
8	0.9	5.6	6.0		13.0
9	0.9	5.2	9.1	0.2	15.0
10	0.9	4.8	12.0	0.9	18.0
11	1.0	4.4	15.0	1.7	22.0
12	1.0	4.0	17.0	2.8	25.0
13	1.0	3.6	21.0	3.7	29.0
14	1.0	3.4	23.0	4.9	33.0
15	1.0	3.4	27.0	5.9	37.0
16	1.0	3.1	30.0	7.4	41.0
17	1.0	2.7	33.0	8.6	46.0
18	1.0	2.7	37.0	10.0	50.0
19	1.1	2.5	40.0	12.0	55.0
20	1.2	2.4	43.0	13.0	60.0
21	1.3	2.3	48.0	14.0	66.0
22	1.4	2.3	51.0	16.0	71.0
23	1.5	2.3	55.0	18.0	77.0
24	1.7	2.5	59.0	20.0	82.0
25	1.8	2.6	63.0	21.0	88.0

[1]Branchwood refers to both wood and bark.

DISCUSSION

The northern red oak equations with two independent variables (d.b.h. and crown ratio) were used to estimate foliage and branchwood weight for two independent sets of data. The first set used six species of hardwood trees (silver maple, *Acer saccharinum* L.; sweet birch, Betula *lenta* L.; pignut hickory, *Carya glabra* Sweet; American beech, *Fagus grandifolia* Ehrh.; yellow-poplar, *Liriodendron tulipifera* L.; and scarlet oak, *Quercus coccinea* Muenchh.) from the Pisgah National Forest in North Carolina (Storey and Pong 1957). A second data set was for quaking aspen, (*Populus tremuloides* Michx.) from northeastern Minnesota (Loomis and Roussopoulos 1978). Results of analysis with this independent data were inconclusive.

The actual and estimated weights were compared by a paired t-test (table 9). No significant difference between actual and estimated foliage weights was indicated for sweet birch, pignut hickory, and aspen. Foliage weight differences for all other species tested were significant. No significant difference between actual and estimated branchwood weights was indicated for pignut hickory, American beech, scarlet oak, and aspen while differences for sweet birch, silver maple, and yellow-poplar were significant.

Specific gravity for wood varies by species, and, to a lesser extent, by location (Phillips 1977). Thus, the effect of specific gravity adjustment on branchwood estimates was examined. Specific gravity values, based on volumes at 12 percent moisture content, were taken from Wood Handbook (USDA 1974). The ratio of specific gravity of each species to specific gravity of northern red oak was computed. This ratio was used as a multiplier to obtain adjusted branchwood weight estimates. The specific gravity adjustment yielded a significant improvement in the gap

Table 9.—*Comparison of actual dry weights of foliage and branchwood[1] per tree with estimated weights using the equations developed for northern red oak[2]*

Species[3]	Crown component	Number of trees	Specific[4] gravity adjustment	D.b.h. range (inches)	Crown ratio range (percent)	Means		Standard error of the difference	Paired[5] t
						Actual (pounds)	Estimated (pounds)		
Aspen, quaking	Foliage		—			12	11	0.8	1.00 NS
(*Populus tremuloides* Michx.)	Branchwood	15	—	1.2-15.0	31-79	88	115	14.9	1.80 NS
			0.60			88	53	10.0	3.53**
Beech, American	Foliage		—			24	15	3.4	2.61*
(*Fagus grandifolia* Ehrh.)	Branchwood	14	—	4.1-15.8	42-79	262	199	34.5	1.82 NS
			1.02			262	203	33.3	1.77 NS
Birch, sweet	Foliage		—			17	14	1.5	2.14*
(*Betula lenta* L.)	Branchwood	17	—	1.9-13.8	31-68	107	140	12.5	2.61*
			1.03			107	144	13.2	2.78*
Hickory, pignut	Foliage		—			31	18	6.7	2.02 NS
(*Carya glabra* Sweet)	Branchwood	16	—	1.9-23.4	25-65	260	327	55.7	1.21 NS
			1.19			260	390	69.8	1.86 NS
Maple, silver	Foliage		—			21	15	2.2	2.64*
(*Acer saccharinum* L.)	Branchwood	16	—	2.2-14.0	27-77	108	163	14.6	3.77**
			.75			108	122	8.8	1.60 NS
Oak, scarlet	Foliage		—			28	16	4.7	2.60*
(*Quercus coccinea* Muenchh.)	Branchwood	14	—	4.1-20.2	30-58	197	199	15.2	0.13 NS
			1.06			197	211	14.1	0.99 NS
Yellow-poplar	Foliage		—			11	14	.9	4.09**
(*Liriodendron tulipifera* L.)	Branchwood	18	—	2.1-21.6	21-63	48	180	51.2	2.58*
			.67			48	121	30.0	2.42*

[1]Branchwood refers to both wood and bark.

[2]Dry weight estimates for foliage and live branchwood per tree obtained using (northern red oak) equations: $Wf = 0.0136\ Dbh^{1.5791}$ and $Wb = 0.005\ Dbh^{2.7768}\ Cr^{1.5685}$ where Wf and Wb = weight of foliage and branchwood respectively in pounds; Dbh = diameter breast height, outside bark in inches; Cr = crown ratio (live crown length ÷ total tree height expressed as a percent).

[3]All species groups except aspen are from Storey and Pong (1957); aspen is the sample tree group used for Loomis and Roussopoulos (1978) publication—data on file at North Central Forest Experiment Station, East Lansing field office.

[4]Specific gravity adjustment is a multiplier for the computed branchwood weight estimates; it is the ratio of the specific gravity of the concerned species to the specific gravity of northern red oak. Specific gravity values obtained from Wood Handbook (USDA 1974).

[5]Levels of significance: 0.01 (**), 0.05 (*), and not significant (NS).

between estimated and actual weights for silver maple, and an insignificant improvement for American beech and yellow-poplar. In contrast, sweet birch, pignut hickory, and scarlet oak had greater differences between estimated and actual values. Quaking aspen results were significantly poorer. In general, using specific gravity adjustment to increase the accuracy of applying the red oak equations to other species has variable results.

The results support use of the northern red oak equations for foliage and for total live branchwood weight for those species where tests indicated no significant difference between actual and estimated values. Under most circumstances, however, better results would probably be obtained by using estimating equations based on data for each species.

Scarlet oak estimated foliage weights averaged only 73 percent of actual weights. Although species and/or site related differences are possible, estimates for northern red oak may be lower due to insect defoliation on sample trees. Foliage, not as constant as branchwood, represents an annual crop, and its quantity may be altered by many things—not only insects, but also unusually strong wind and drought.

The equation, using two independent variables, was also tested on an additional data base for estimating branchwood weight. These data concerned 71 northern red oak trees ranging from 6 to 24 inches d.b.h. from uneven-aged stands on better than average sites on the Pisgah National Forest in North Carolina. The estimates from the equations developed here compared favorably with those using equations that had been developed from the independent data base.[5] This further supports the application of this method throughout the Eastern deciduous forest.

The use of the combination of d.b.h. and crown ratio as independent variables is believed to minimize effects of differences in stand density and site.

The equations presented here for estimating northern red oak crown component weights are applicable to the range of northern red oak in the eastern United States. The branchwood estimates for northern red oak are considered usable for other black oak species, and for approximations for other hard hardwoods with similar crown form such as hickory. (For practical application, see Loomis and Blank 1981.) However, it is suggested foliage estimates be used for other black oak species and other hard hardwoods only when no other estimating procedure is available.

[5]*Personal communication with Alexander Clark III, Forestry Sciences Laboratory, Athens, Georgia, February 11, 1980.*

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Equations are described for estimating crown weights for northern red oak trees. These estimates are for foliage and branchwood weights. Branchwood (wood plus bark) amounts are subdivided by living and dead material into four size groups. Applicability of the equations to other species is examined.

KEY WORDS: forest fuels, fuel modeling, biomass.