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Factors and Equations to Estimate Forest Biomass in the North Central Region

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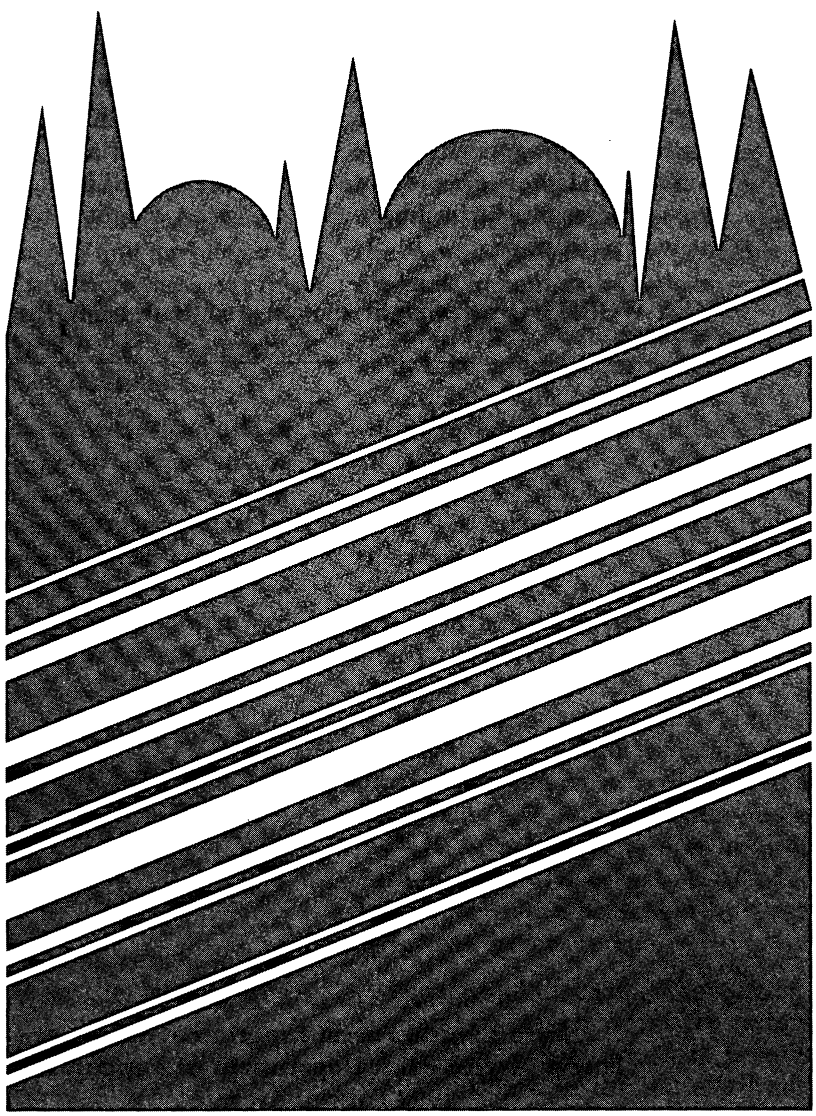

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Green weight of wood and bark can be greatly affected by moisture content. Average moisture content percentages and green weight conversion factors are presented for 42 tree species groups. Equations are also presented to compute average green weight of tops and limbs as well as stumps.

KEY WORDS: Green weight, moisture content, boles, limbs, stumps.

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FACTORS AND EQUATIONS TO ESTIMATE FOREST BIOMASS IN THE NORTH CENTRAL REGION

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As forest biomass estimates become more commonplace, there is an increasing need for organizations disseminating this information to specify the assumptions their estimates are based on. This is particularly critical in regions of the country where weight scaling of harvested wood is becoming popular and where woody biomass as an energy source is being promoted on a large scale.

The Forest Inventory and Analysis (FIA) research work unit at the North Central Forest Experiment Station has reviewed the literature and developed a set of factors for use in reporting biomass in its inventory reports. These factors and their use to estimate biomass of wood and bark of forest trees in the North Central region[1] are presented here.

Although specific gravity and oven-dry weights of wood and bark reported for a given species in the literature are relatively consistent, green weight data can be variable. Major discrepencies generally occur in the value used for moisture content of the wood or bark. Factors that further confound green weight data found in the literature include weather, time of year, location, and genetic variability of the species reported.

To provide consistent biomass statistics related to forest inventory and timber drain in our reports we have made some assumptions about the characteristics of green wood and bark based upon information found in the literature. The Wood Handbook published by the U.S. Forest Products Laboratory (1974) served as the primary source of information on specific gravity and moisture content ranges for the wood of most commercial species in the region. Other data from the literature were then used to enhance this information and fill in the gaps—particularly for detailed information about bark, which is essentially lacking in the handbook.

In developing biomass factors, it is important that the specific gravity used be based upon wood or bark that is as close as possible to the moisture content for which the factor is desired (Haygreen and Bowyer 1982). Using the specific gravity and moisture content data found in the literature (table 1), we derived the average green weight per cubic foot for wood and for bark in pounds by species group.

There is far less information in the literature on bark than wood for species in the North Central region. Thus, bark characteristics for many species were synthesized from available information. Based on data presented by Manwiller (1975), Warluft (1974), and Erickson (1972), we assumed bark to have the same average moisture content as that of the wood at any given location along the stem. Bark thickness data were pooled from several timber utilization studies described by Blyth and Smith (1980) that have been conducted by the North Central FIA unit over the past 20 years. These data were analyzed by Raile (1980) and average bark percent by species was estimated using the relation of diameter-inside-bark to diameter-outside-bark. Because the bark data collection and analysis process did not address bark fissures and voids, we adjusted data for several species to account for bark fissures based upon data presented by Cassens (1976) and Krier and River (1968).

The top and limbs may represent 5 to 40 percent of the total biomass of a tree. To estimate this biomass we developed regressions to predict the weight of wood and bark in the top and limbs (excluding foliage) above the bole (4-inch top diameter outside bark) as a function of the bole biomass for trees larger than 5 inches d.b.h. Regressions based upon

[1] *The North Central Forest Experiment Station FIA research work unit is responsible for forest resource evaluation in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin.*

Table 1.--Specific gravity, green and dry weight, and moisture content for wood and bark of North Central species groups

Species group	Wood: Specific[1/] gravity	Wood: Green weight (lbs/cu.ft.)	Wood: Oven dry[2/] weight (lbs/cu.ft.)	Bark: Specific[1/] gravity	Bark: Green weight (lbs/cu.ft.)	Bark: Oven dry[2/] weight (lbs/cu.ft.)	Percent[3/] of bark	Average[4/] percent moisture content	Stump regression coefficient
Jack pine	0.40	47	25	0.34 (8,14,18,22,33)	40	21	17	90 (8,9,21)	0.007017
Red pine	.41	49	26	.24 (8,18)	29	15	16	90 (8,9)	.007176
White pine	.37 (9)[5/]	43	23	.49 (22,30)	59	31	16	90 (36)	.008269
Ponderosa pine	.38	45	24	.34 (30)	40	21	15	90 (36)	.007176
Southern pine	.47	58	29	.32 (29,33)	40	20	15	100 (36)	.007176
Other pines	.40	45	25	.40	45	25	15	80 (36)	.007176
White spruce	.37	46	23	.29 (14,18,33)	36	18	10	100 (8,9)	.010699
Black spruce	.38	45	24	.38 (14,23,33)	46	24	14	90 (36)	.008877
Balsam fir	.34	46	21	.38 (8,14,18,33)	53	24	15	120 (8,9,21)	.009967
Hemlock	.38	50	24	.40 (23,33)	53	25	21	110 (9)	.008579
Tamarack	.49	55	31	.30 (23,33)	34	19	13	80 (3)	.008877
Baldcypress	.42	57	26	.40	55	25	13	120 (36)	.008269
Eastern redcedar	.44	43	27	.40	40	25	12	60 (36)	.008877
Northern white-cedar	.29	36	18	.30	38	19	12	100 (9)	.011946
Other softwoods	.38	43	24	.45	50	28	13	80 (36)	.008877
White oak	.60	59	37	.53 (7,22)	53	33	18	60 (5,20,26,38)	.009727
Red oak	.56	63	35	.65 (7,22)	74	41	14	80 (5,37,38)	.008908
True hickory	.64	64	40	.60 (26)	59	37	13	60 (5,26,38)	.008980
Pecan hickory	.60	59	37	.60 (26)	59	37	13	60 (5,26,38)	.008980
Basswood	.32	40	20	.45	56	28	16	100 (36,37)	.009639
Beech	.56	59	35	.56 (23,33)	60	35	7	70 (15,37,38)	.010202
Yellow birch	.55	61	34	.56	63	35	12	80 (15)	.009968
Hard maple	.56	63	35	.54 (7,18)	61	34	12	80 (7)	.008894
Soft maple	.49	55	31	.52	58	32	12	80 (5,26)	.008476
Elm	.46	58	29	.28 (22,23,33)	34	17	14	100 (15)	.010422
Black ash	.45	50	28	.45	50	28	14	80 (36)	.011016
White and green ash	.54	54	34	.34	34	21	16	60 (5,20)	.008728
Sycamore	.46	58	29	.45	56	28	8	100 (36)	.008980
Cottonwood	.37	50	23	.43 (22,30)	59	27	15	120 (36)	.011145
Willow	.34	46	21	.43	59	27	16	120 (36)	.011145
Hackberry	.49	52	31	.49	53	31	15	70 (19)	.010422
Balsam poplar	.37 (9)	50	23	.50 (9)	68	31	18	120 (8,9,21)	.006594
Aspen	.39 (2)	48	24	.50 (14,18,33)	62	31	18	100 (2,8,9)	.007369
Paper birch	.48	54	30	.51 (7,14,33)	58	32	16	80 (9,15)	.008380
Sweetgum	.46	60	29	.46 (26)	61	29	15	110 (5,20,26)	.008980
Black tupelo	.46	58	29	.46 (26)	58	29	15	100 (5,26,38)	.008980
Black cherry	.47	49	29	.48 (30)	51	30	10	70 (36)	.008980
Black walnut	.51	57	32	.28 (25)	31	17	15	80 (36)	.008980
Butternut	.36	44	22	.40	50	25	15	100 (36)	.008980
Yellow-poplar	.40	52	25	.40 (22,26)	53	25	15	110 (5,20,26,37,38)	.008980
Other hardwoods	.42	46	26	.42	47	26	15	80 (36)	.008980
Noncommercial species	.45	50	28	.45	50	28	15	80 (36)	.008980

1/ Based on weight oven-dry and volume when green.

2/ Computed from specific gravity presented (based on green volume).

3/ Expressed as percent of green wood volume. To express as percent of total green volume including bark, multiply decimal value of percent shown by (1.0 - (1.0/(1.0 + decimal value of percent shown))).

4/ Expressed as percent of oven-dry weight. To express as a percent of green weight, divide green weight minus dry weight by the green weight.

5/ Numbers in parentheses indicate literature source used to establish value estimate.

biomass data for whole trees presented by Myers *et al.* (1980), Steinhilb *et al.* (1984), and Carpenter (1983) were used to describe this relation. The basic data included foliage, so factors presented by Young *et al.* (1976) were used to deduct average foliage values before regression analysis. For all equations presented, d.b.h. is in inches, volume is in cubic feet, and biomass is in pounds.

The regression equations to estimate biomass in top and limbs (excluding foliage) for trees larger than 5 inches d.b.h. as a function of bole biomass (from a 1 foot stump to a 4-inch top diameter outside bark) by species group follow:

Pines and tamarack

$$\text{Total top biomass} = (0.092 + (1.0/\text{d.b.h.}^{1.628})) \times (\text{total bole biomass}) \quad (1)$$

Other softwoods

$$\text{Total top biomass} = (0.061 + (1.0/\text{d.b.h.}^{0.659})) \times (\text{total bole biomass}) \quad (2)$$

Aspen

$$\text{Total top biomass} = (0.106 + (1.0/\text{d.b.h.}^{0.832})) \times (\text{total bole biomass}) \quad (3)$$

Other hardwoods

$$\text{Total top biomass} = (1.0/\text{d.b.h.}^{0.471}) \times (\text{total bole biomass}) \quad (4)$$

The following regression equation is used to predict the average total above-ground biomass (excluding foliage) for all trees less than 5 inches d.b.h.:[2]

$$\text{Total biomass (pounds)} = 3.912 + \text{d.b.h.}^{2.4324} \quad (5)$$

Equations to determine bole volume of trees in the North Central region have been presented by Hahn (1975, 1976, 1984) and Smith and Weist (1982). Stump volume equations have been developed by Raile (1982) and shrub and herbaceous vegetation biomass equations are presented by Smith and Brand (1983). A simplified version of Raile's stump regressions is presented here for the wood volume of 1-foot stumps (excluding bark). Coefficients for the following equation are presented in the last column of table 1:

$$\text{Stumpwood volume} = b_0 \times \text{d.b.h.}^2 \quad (6)$$

where b_0 is the species specific regression coefficient.

To demonstrate the use of the information described here, the total above-ground cubic-foot volume and biomass (excluding foliage) of a 15-inch basswood tree on site index 60 forest land in Indiana is calculated as follows:

1. Using the volume equation and species specific coefficients from Smith and Weist (1982) for basswood and factors from table 1, the bole and bark volume and biomass from a 1-foot stump to a 4-inch top diameter outside bark for this tree are:

$$\begin{aligned}
\text{Bole wood volume} &= 16.882 \times \text{SI}^{.572} \times [1.0 - e^{-.0001\text{dbh}^{2.707}}] \\
&= 16.882 \times 60^{.572} \times [1.0 - e^{-.0001(15)^{2.707}}] \\
&= 24.85 \text{ cubic feet} \\
\text{Bole bark volume} &= (\text{bark percent}) \times (\text{bole volume}) \\
&= 0.16 \times 24.85 \\
&= 3.98 \text{ cubic feet} \\
\text{Total bole volume} &= 24.85 + 3.98 \\
&= 28.83 \text{ cubic feet} \\
\text{Bole wood biomass} &= (\text{bole wood volume}) \times \\
&\quad (\text{species wood height per cubic foot}) \\
&= 24.85 \times 40 \\
&= 994.00 \text{ pounds} \\
\text{Bole bark biomass} &= (\text{bole bark volume}) \times \\
&\quad (\text{species bark weight per cubic foot}) \\
&= 3.98 \times 56 \\
&= 222.88 \text{ pounds} \\
\text{Total bole biomass} &= 994.00 + 222.88 \\
&= 1216.88 \text{ pounds}
\end{aligned}$$

2. Using regression equation 4 presented above, the biomass and volume of the top are:

$$\begin{aligned}
\text{Top biomass} &= (1.0/\text{d.b.h.}^{0.471}) \times (\text{total bole biomass}) \\
&= (1.0/15^{0.471}) \times 1{,}216.88 \\
&= 339.87 \text{ pounds (green weight)}
\end{aligned}$$

   If we assume bark to be the same proportion of the top as of the bole:

$$\begin{aligned}
\text{Total top volume} &= 339.87/(.84 \times 40 + .16 \times 56) \\
&= 7.99 \text{ cubic feet}
\end{aligned}$$

3. Using the simplified stump regression for 1-foot stumps shown in equation 6 above and coefficient from table 1 for basswood, the volume and biomass of the 1-foot stump is:

$$\begin{aligned}
\text{Stump wood volume} &= .009639 \times \text{d.b.h.}^2 \\
&= .009639 \times 15^2 \\
&= 2.17 \text{ cubic feet} \\
\text{Stump bark volume} &= (\text{bark percent}) \times (\text{stump volume}) \\
&= 0.16 \times 2.17 \\
&= 0.35 \text{ cubic feet} \\
\text{Total stump volume} &= 2.17 + 0.35 \\
&= 2.52 \text{ cubic feet} \\
\text{Stump wood biomass} &= (\text{stump wood volume}) \times \\
&\quad (\text{species wood weight per cubic foot}) \\
&= 2.17 \times 40 \\
&= 86.80 \text{ pounds (green weight)} \\
\text{Stump bark biomass} &= (\text{stump bark volume}) \times \\
&\quad (\text{species bark weight per cubic foot}) \\
&= 0.35 \times 56 \\
&= 19.60 \text{ pounds} \\
\text{Total stump biomass} &= 86.80 + 19.60 \\
&= 106.40 \text{ pounds (green weight)}
\end{aligned}$$

4. Total tree weight and volume (above-ground including bark) are:

$$\begin{aligned}
\text{Total above-ground green weight} &= \text{bole} + \text{top} + \text{stump} \\
&= 1{,}216.88 + 339.87 + 106.40 \\
&= 1{,}663.15 \text{ pounds (excluding foliage)} \\
\text{Total above-ground tree volume} &= 28.83 + 7.99 + 2.52 \\
&= 39.34 \text{ cubic feet}
\end{aligned}$$

[2]*Equation developed by Gerhard K. Raile (personal communication, 1982) using data from Young* et al *(1976).*

FIA reports provide basic information on the timber inventory and drain. Biomass estimates for standing inventory rely upon development of methods to convert volume of inventory to weight of green wood and bark. Drain data, on the other hand, are often derived by determining the volume of solid wood represented by a given weight of rough green wood delivered to a primary user. Both of these situations are consistently addressed by the factors and equations presented in this report. The weight-per-unit-of-volume factors were validated by comparison with data from weight scale studies such as those by Lothner *et al.* (1974), Hardy and Weiland (1964), Upper Great Lakes Timber Inc. (1973), and Bowyer (1983). Biomass reported by FIA is an estimate of the green weight of standing timber and shrubs in the average moisture content condition.

Information in table 2 should be of particular interest to individuals or companies using weight scaling to buy wood. These columns provide values for average total weight of wood and bark for both 100-inch and standard cords, and conversion factors for estimating cord equivalents from rough green tons of wood and bark. These figures assume an average of 79 cubic feet of solid wood per standard cord and 82.3 cubic feet of solid wood per 100-inch cord (all USDA Forest Service FIA reports use standard cords). Stacking and average diameter of material may affect these solid wood relations in actual practice. Large diameter wood may increase the number of solid cubic feet per cord while poor stacking and rough or crooked bolts can reduce it. Specific knowledge of solid wood contents, therefore, would allow the user to adjust the factors presented as necessary.

Table 2.--Green weight conversion factors and moisture content for wood with bark for North Central species groups

Species group	Green weight Wood and bark/ cu.ft. of wood	Weight of 100" cords (lbs/cord)	Number of 100" cords per ton	Weight of standard cords (lbs/cord)	Number of standard cords per ton
Jack pine	54	4,428	0.4517	4,266	0.4688
Red pine	54	4,428	.4517	4,266	.4688
White pine	53	4,346	.4602	4,187	.4777
Ponderosa pine	51	4,182	.4782	4,029	.4964
Southern pine	64 (6)[1/]	5,248	.3811	5,056	.3956
Other pines	52	4,264	.4690	4,108	.4869
White spruce	50 (15)	4,100	.4878	3,950	.5063
Black spruce	51 (15,19)	4,182	.4782	4,029	.4964
Balsam fir	54 (15,35)	4,428	.4517	4,266	.4688
Hemlock	61 (35)	5,002	.3998	4,819	.4150
Tamarack	59 (35)	4,838	.4134	4,661	.4291
Baldcypress	64 (6)	5,248	.3811	5,056	.3956
Eastern redcedar	48	3,936	.5081	3,792	.5274
Northern white-cedar	40 (9)	3,280	.6098	3,160	.6329
Other softwoods	49	4,018	.4978	3,871	.5167
White oak	68 (9)	5,576	.3587	5,372	.3723
Red oak	73 (5)	5,986	.3341	5,767	.3468
True hickory	71 (5)	5,822	.3435	5,609	.3566
Pecan hickory	66 (9)	5,412	.3695	5,214	.3836
Basswood	49	4,018	.4978	3,871	.5167
Beech	64 (9,15)	5,248	.3811	5,056	.3956
Yellow birch	68	5,576	.3587	5,372	.3723
Hard maple	70 (15)	5,740	.3484	5,530	.3617
Soft maple	62 (5,15,35)	5,084	.3934	4,898	.4083
Elm	63 (9,15)	5,166	.3871	4,977	.4018
Black ash	57 (9)	4,674	.4279	4,503	.4441
White and green ash	60 (5,15)	4,920	.4065	4,740	.4219
Sycamore	62	5,084	.3934	4,898	.4083
Cottonwood	59	4,838	.4134	4,661	.4291
Willow	56	4,592	.4355	4,424	.4521
Hackberry	60	4,920	.4065	4,740	.4219
Balsam poplar	62 (35)	5,084	.3934	4,898	.4083
Aspen	59 (19,35)	4,838	.4134	4,661	.4291
Paper birch	63 (15,35)	5,166	.3871	4,977	.4018
Sweetgum	69 (5)	5,658	.3535	5,451	.3669
Black tupelo	67 (5)	5,494	.3640	5,293	.3779
Black cherry	54 (9)	4,428	.4517	4,266	.4688
Black walnut	62 (9)	5,084	.3934	4,898	.4083
Butternut	52	4,264	.4690	4,108	.4869
Yellow-poplar	60 (5)	4,920	.4065	4,740	.4219
Other hardwoods	53	4,346	.4602	4,187	.4777
Noncommercial species	58	4,756	.4205	4,582	.4365

[1/] Numbers in parentheses indicate literature source used to establish value estimate.

Using the information described in this paper, consistent above-ground biomass and timber drain values for inventories in the North Central region can be computed from basic forest inventory data such as are stored in FIA data bases described by Hahn and Hansen (1985). Biomass may also be computed on an oven-dry weight basis by using oven-dry weights per cubic foot provided in table 1 for each species.

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