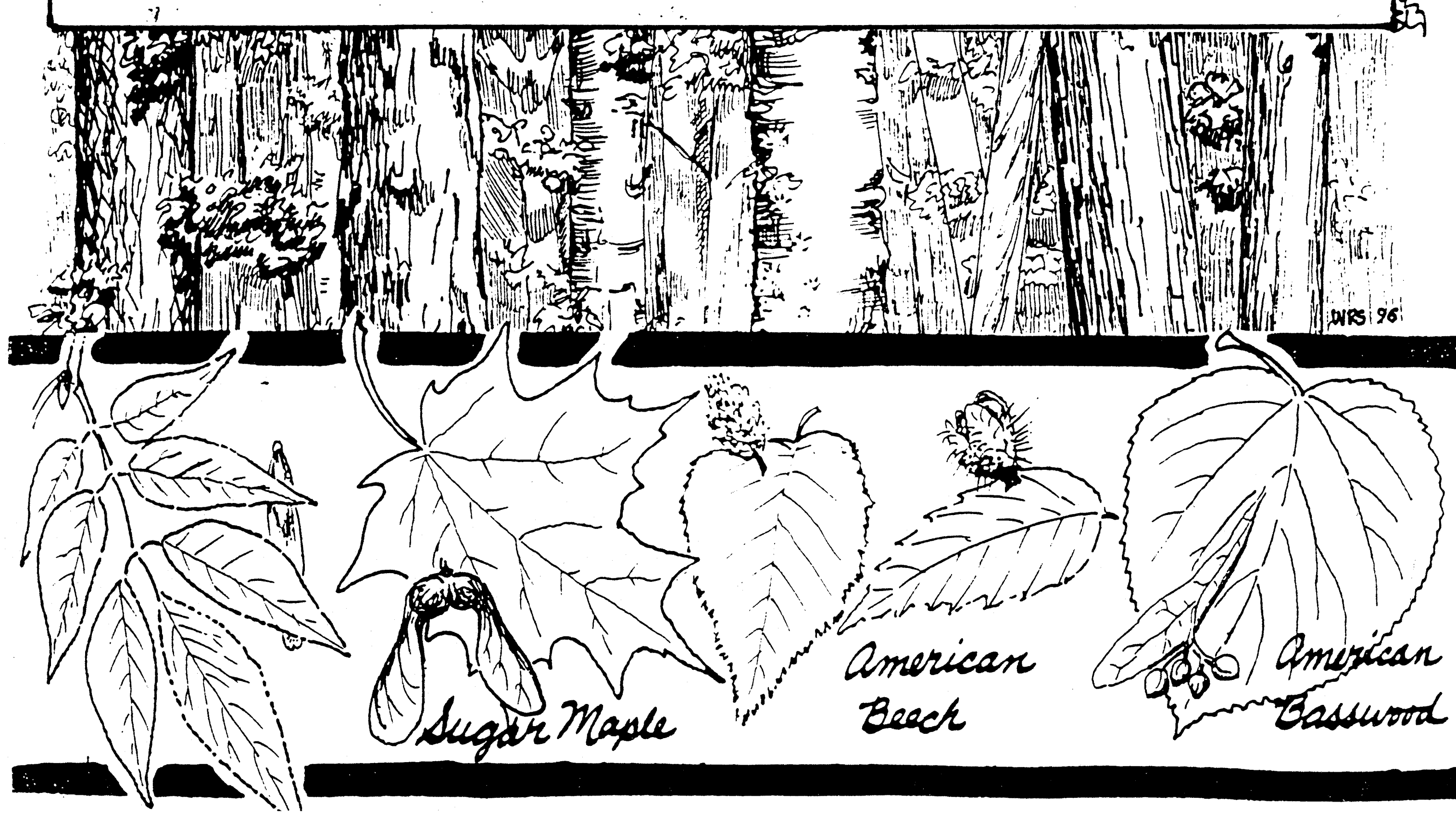
BARK FACTOR EQUATIONS FOR NORTHERN HARDWOODS IN MICHIGAN

BY: GARY W. FOWLER, ,NEMAH G. HUSSAIN,
DAVID J. COHEN, AND DEEPAK KHATRY-CHHETRI

1999



Bark Factor Equations For Northern Hardwoods in Michigan

by

Gary W. Fowler, Nemah G. Hussain,

David J. Cohen, and Deepak Khatry-Chhetri

1999

Forest Information Leaflet
Forest Management Division
Michigan Department of Natural Resources
and
School of Natural Resources and Environment
The University of Michigan

FORESTRY INFORMATION LEAFLET
FOREST MANAGEMENT DIVISION
MICHIGAN
DEPARTMENT OF NATURAL RESOURCES

NUMBER - 1-99

SUBJECT - BARK FACTORS

DATE - 31 October 99

TITLE - BARK FACTOR EQUATIONS FOR NORTHERN HARDWOODS IN MICHIGAN

AUTHORS - Gary W. Fowler, Professor of Biometrics, School of Natural Resources and Environment, University of Michigan; Nemah G. Hussain, Timber Sales Program Leader, Forest Management Division, Michigan Department of Natural Resources; and David J. Cohen and Deepak Khatry-Chhetri,* Ph.D. graduate students, School of Natural Resources and Environment, University of Michigan.

BACKGROUND

Bark factor (BF) is the ratio of diameter inside bark (DIB) to diameter outside bark (DOB) at a given tree height. Even though bark factor does increase with height for many species, a constant bark factor, usually determined at breast height, has been assumed, in many cases, for all tree heights for many species. Thus, the use of a constant bark factor for all tree heights will usually lead to underestimates of most tree and log solid wood volumes and overestimates of bark volume for many species.

Bark factor equations have been developed for aspen (Fowler and Hussain 1987b, Fowler 1991), jack pine (Fowler and Hussain 1991, Fowler 1993), and red pine (Fowler and Hussain 1987a, Fowler and Damschroder 1988) in Michigan where bark factor was regressed on tree height (TH). In all cases, there was a very strong relationship between BF and TH. Bark factor equations were also developed for oaks (Fowler et al. 1997) and paper birch (Fowler and Hussain 1997) in Michigan where BF was regressed on TH and DOB. These relationships were relatively weak with the relationship to DOB being somewhat stronger.

---

* Current position: Research Associate, Carnegie Department of Plant Biology, Stanford University.

PURPOSE

The purpose of this paper is to present bark factor equations for northern hardwood tree species in Michigan and show how the prediction equations may be used.

METHODS AND MATERIALS

As part of a larger study to develop new volume equations for hardwoods in Michigan, felled tree measurements were made on a total of 568 northern hardwood trees from 15 hardwood stands in Michigan: (1) 369 trees from 9 stands in the Upper Peninsula (1, 5, and 3 stands from the Copper Country, Escanaba River, and Superior state forests, respectively), and (2) 199 trees from 6 stands in the Lower Peninsula (4 and 2 stands from the Mackinaw and Pere Marquette state forests, respectively). The numbers of trees measured by species are shown below.

Species	No. of Trees Measured		
	U.P.	L.P.	Michigan
Sugar Maple (SM)	161	87	248
Red Maple (RM)	92	46	138
Basswood (BW)	54	7	61
White Ash (WA)	38	21	59
Black Cherry (BC)	7	20	27
American Beech (AB)	6	17	23
Yellow Birch (YB)	11	0	11
American elm (AE)	0	1	1

All trees were measured during May-August 1995.

DIB and DOB were measured to the nearest 0.01 in. at stump height, which varied from 2-40 in. except for one unusual tree that had a stump height of 95 in., the top of each 8.3-ft. bolt (100-in. stick), or other nominal bolt length varying from 6-16 ft., cut out of the stem of each tree to an approximate 3.6-in. diameter top limit (i.e., stemwood), and at the bottom and top of each 8.3-ft. bolt, or other nominal bolt length varying from 7-16 ft., cut out of limbs and top forks of each tree to an approximate 3.6-in. diameter top limit (i.e., topwood). DBH was measured to the nearest 0.1 in., and bark thickness at DBH height was measured to the nearest 0.01 inch. DBH height was 4.5 ft. from the ground except for trees forked below 4.5 ft. where DBH height was approximately 4.5 ft. above the fork. DBH varied from 3.8-24.2 in. with a mean of 9.3 in. for the data set of 568 trees.

Stemwood

The prediction data set included 528 trees distributed by state forest and species as described above. This yielded 1,488, 829, 398, 410, 178, 131, 66, and 6 bark factor measurements for SM, RM, BW, WA, BC, AB, YB, and AE, respectively. There were a total of 3,506 bark factor measurements for the 568 trees.

The mean, minimum, and maximum DBH in in. and merchantable height (MH) in ft. for the trees of each species are shown below. MH is the height of the tree from the ground to an approximate 3.6-in. merchantable diameter top limit.

Species	No. of Trees	DBH		MH	
		$\bar{x}$	Min.– Max.	$\bar{x}$	Min. –Max.
SM	248	9.2	3.8-24.2	34.38	8.58-63.67
RM	138	7.9	8.5-17.9	33.95	8.50-58.75
BW	61	11.8	4.6-21.8	41.92	8.67-72.25
WA	59	8.9	4.3-20.7	41.71	8.67-82.00
BC	27	9.9	7.0-16.1	38.67	17.08-58.83
AB	23	11.6	5.1-18.9	34.45	8.75-50.42
YB	11	12.4	9.0-18.3	34.88	18.33-43.92
AE	1	12.0	———	36.08	———

The following table shows the mean, minimum, and maximum BF, tree height to measurement in ft. (TH), and DOB at TH for the set of bark factor measurements for each species.

Species	No. of BF Measurements	BF		TH		DOB at TH	
		$\bar{x}$	Min.– Max.	$\bar{x}$	Min. –Max.	$\bar{x}$	Min. –Max.
SM	1488	0.976	0.890–0.997	17.18	0.25–63.67	8.34	2.59–25.50
RM	829	0.980	0.876–0.998	17.11	0.17–58.75	6.93	2.77–19.68
BW	398	0.970	0.917–0.999	21.14	0.25–72.25	10.40	3.51–23.42
WA	410	0.932	0.844–0.994	21.15	0.17–82.00	7.92	3.06–25.11
BC	178	0.965	0.927–0.994	18.37	0.33–58.83	8.11	3.15–19.03
AB	131	0.995	0.960–0.999	16.84	0.17–50.42	10.77	3.20–22.76
YB	66	0.991	0.979–0.998	16.60	0.50–43.92	10.33	3.50–20.05
AE	6	0.964	0.956–0.977	16.58	0.67–36.08	11.33	8.74–15.21

Topwood

The prediction data set included the following numbers of trees with topwood and associated bark factor measurements by species.

Species	No. of Trees	No. of Measurements
SM	61	342
RM	18	74
BW	8	38
WA	13	75
BC	9	32
AB	5	44
YB	7	26
AE	0	0
Total	121	631

The mean, minimum, and maximum DBH in in., MH in ft., and number of topwood sticks for the trees of each species are shown below.

Species	No. of Trees	DBH		MH		No. of Topwood Sticks	
		$\bar{x}$	Min.-Max.	$\bar{x}$	Min.-Max.	$\bar{x}$	Min.-Max
SM	61	13.5	6.8-24.2	35.79	9.25-63.67	3.7	1-13
RM	18	11.7	7.5-17.9	36.69	9.33-50.58	2.7	1-12
BW	8	15.3	10.7-18.7	42.40	25.67-51.92	3.0	1-7
WA	13	12.8	6.1-20.7	47.08	17.42-82.00	3.7	1-12.625
BC	9	12.2	10.1-16.1	38.97	17.08-58.83	2.3	1-4
AB	5	16.6	13.2-18.9	25.18	17.92-34.33	6.2	3-10.25
YB	7	13.8	9.4-18.3	35.18	18.33-43.92	2.1	1-4
AE	0	——	——	——	——	——	——

The following table shows the mean, minimum, and maximum BF and DOB at the BF measurement point for the set of bark factor measurements for each species.

Species	No. of BF Measurements	BF		DOB	
		$\bar{x}$	Min.– Max.	$\bar{x}$	Min. –Max.
SM	342	0.977	0.913-0.998	6.71	2.90-17.06
RM	74	0.981	0.907-0.997	5.66	2.58-13.24
BW	38	0.962	0.945-0.991	7.77	3.76-11.13
WA	75	0.935	0.886-0.990	6.27	3.36-13.18
BC	32	0.974	0.951-0.991	6.31	3.40-11.16
AB	44	0.994	0.984-0.999	7.96	3.98-13.26
YB	26	0.989	0.979-0.994	6.21	3.44-10.34
AE	0	——	————	——	————

RESULTS

The best prediction equations, based on simplicity, meeting the assumptions of normality and homogeneity, and having among the smallest standard errors of the estimate ($s_{y \bullet x}$) and the largest coefficients of determination (R^2), were:

Stemwood

Red Maple (n=829)

	Equation	R^2	$s_{y \bullet x}$	P
(1)	$\hat{BF}=0.996730-0.002397 \bullet DOB$	0.164	0.014339	<0.001
(2)	$\hat{BF} = 0.972344 + 0.003554 \bullet \ln TH$	0.106	0.014828	<0.001
(3)	$\hat{BF} = 0.989060 - 0.001923 \bullet DOB + 0.002002 \bullet \ln TH$	0.191	0.014112	<0.001

White Ash (n=410)

	Equation	R^2	$s_{y \bullet x}$	P
(4)	$\hat{BF} = 0.922166 + 0.001198 \bullet DOB$	0.032	0.023334	<0.001
(5)	$\hat{BF} = 0.937036 + 0.000805 \bullet TH - 0.009279 \bullet \ln TH$	0.121	0.022265	<0.001
(6)	$\hat{BF} = 0.922785 + 0.001429 \bullet DOB + 0.000838 \bullet TH - 0.008356 \bullet \ln TH$	0.161	0.021780	<0.001

Sugar Maple (n=1,488)

		R^2	$s_{y \bullet x}$	P
(7)	$\hat{BF} = 0.988318 - 0.001497 \bullet DOB$	0.165	0.013699	<0.001
(8)	$\hat{BF} = 0.970865 + 0.002264 \bullet \ln TH$	0.046	0.014645	<0.001
(9)	$\hat{BF} = 0.985763 - 0.001396 \bullet DOB + 0.000779 \bullet \ln TH$	0.170	0.013665	<0.001
	Basswood (n=398)			
(10)	$\hat{BF} = 0.974486 - 0.000403 \bullet DOB$	0.016	0.013026	0.012
(11)	$\hat{BF} = 0.970312 + 0.000072 \bullet TH - 0.000631 \bullet \ln TH$	0.008	0.013097	0.214
(12)	$\hat{BF} = 0.975340 - 0.000409 \bullet DOB + 0.000052 \bullet TH - 0.000770 \bullet \ln TH$	0.018	0.013048	0.070
	Black Cherry (n=178)			
(13)	$\hat{BF} = 0.971912 - 0.000841 \bullet DOB$	0.027	0.014924	0.029
(14)	$\hat{BF} = 0.954777 + 0.004557 \bullet \ln TH$	0.197	0.013561	<0.001
(15)	$\hat{BF} = 0.942909 + 0.001075 \bullet DOB + 0.005950 \bullet \ln TH$	0.222	0.013381	<0.001
	Yellow Birch (n=66)			
(16)	$\hat{BF} = 0.987390 + 0.000307 \bullet DOB$	0.106	0.003544	0.008
(17)	$\hat{BF} = 0.990354 - 0.000111 \bullet TH + 0.000885 \bullet \ln TH$	0.036	0.003710	0.317
(18)	$\hat{BF} = 0.984658 + 0.000400 \bullet DOB - 0.000060 \bullet TH + 0.001192 \bullet \ln TH$	0.143	0.003527	0.022
	American Beech (n=131)			
(19)	$\hat{BF} = 1.027382 - 0.103065/DOB - 0.009012 \bullet \ln DOB$	0.159	0.004220	<0.001
(20)	$\hat{BF} = 0.994075 - 0.000047 \bullet TH + 0.000896 \bullet \ln TH$	0.034	0.004524	0.111
(21)	$\hat{BF} = 1.020317 - 0.097775/DOB - 0.007077 \bullet \ln DOB + 0.000014 \bullet TH + 0.000841 \bullet \ln TH$	0.240	0.004043	<0.001

American Elm (n=6)

		R^2	$s_{y \bullet x}$	P
(22)	$\hat{BF} = 0.925851 + 0.003400 \bullet DOB$	0.908	0.002658	0.003
(23)	$\hat{BF} = 0.975815 - 0.000058 \bullet TH - 0.004696 \bullet \ln TH$	0.968	0.001801	0.006
(24)	$\hat{BF} = 0.987215 - 0.000786 \bullet DOB - 0.000073 \bullet TH - 0.005707 \bullet \ln TH$	0.970	0.002132	0.044

Prediction Equations 1, 4, 7, 10, 13, 16, 19, and 22 for RM, WA, SM, BW, BC, YB, AB, and AE, respectively, yield the following estimated bark factors.

Prediction Equations 1, 4, 7, 10, 13, 16, 19, and 22

DOB	$\hat{BF}$							
(in.)	RM	WA	SM	BW	BC	YB	AB	AE
3.0	0.990	0.926	0.984	0.973	0.969	0.988	0.983	0.936
4.0	0.987	0.927	0.982	0.973	0.969	0.989	0.989	0.939
5.0	0.985	0.928	0.981	0.972	0.968	0.989	0.992	0.943
6.0	0.982	0.929	0.979	0.972	0.967	0.989	0.994	0.946
7.0	0.980	0.931	0.978	0.972	0.966	0.990	0.995	0.950
8.0	0.978	0.932	0.976	0.971	0.965	0.990	0.996	0.953
9.0	0.975	0.933	0.975	0.971	0.964	0.990	0.996	0.956
10.0	0.973	0.934	0.973	0.970	0.964	0.990	0.996	0.960
11.0	0.970	0.935	0.972	0.970	0.963	0.991	0.996	0.963
12.0	0.968	0.937	0.970	0.970	0.962	0.991	0.996	0.967
13.0	0.966	0.938	0.969	0.969	0.961	0.991	0.996	0.970
14.0	0.963	0.939	0.967	0.968	0.960	0.992	0.996	0.973
15.0	0.961	0.940	0.966	0.968	0.959	0.992	0.996	0.977
16.0	0.958	0.941	0.964	0.968	0.958	0.992	0.996	0.980
17.0	0.956	0.943	0.963	0.968	0.958	0.993	0.996	0.984
18.0	0.954	0.944	0.961	0.967	0.956	0.993	0.996	0.987
19.0	0.951	0.945	0.960	0.967	0.956	0.993	0.995	0.990
20.0	0.949	0.946	0.958	0.966	0.955	0.994	0.995	0.994
21.0	0.946	0.947	0.957	0.966	0.954	0.994	0.995	——
22.0	0.944	0.949	0.955	0.966	0.953	0.994	0.995	——
23.0	0.942	0.950	0.954	0.965	0.953	0.994	0.995	——
24.0	0.939	0.951	0.952	0.965	0.952	0.995	0.994	——
25.0	0.937	0.952	0.951	0.964	0.951	0.995	0.994	——

Prediction Equations 2, 5, 8, 11, 14, 17, 20, and 23 for RM, WA, SM, BW, BC, YB, AB, and AE, respectively, yield the following estimated bark factors.

Prediction Equations 2, 5, 8, 11, 14, 17, 20, and 23

TH	$\hat{BF}$							
(ft.)	RM	WA	SM	BW	BC	YB	AB	AE
0.25	0.970	0.950	0.971	0.971	0.948	0.989	0.993	0.982
0.5	0.971	0.944	0.971	0.971	0.952	0.990	0.993	0.979
1.0	0.973	0.939	0.972	0.970	0.955	0.990	0.994	0.976
2.0	0.974	0.932	0.972	0.970	0.958	0.991	0.995	0.972
3.0	0.975	0.929	0.972	0.970	0.960	0.991	0.995	0.970
4.5	0.977	0.927	0.973	0.970	0.962	0.991	0.995	0.968
8.5	0.979	0.924	0.974	0.970	0.965	0.991	0.996	0.965
17.0	0.981	0.924	0.976	0.970	0.968	0.991	0.996	0.962
25.5	0.984	0.928	0.978	0.970	0.970	0.990	0.996	0.959
34.0	0.986	0.932	0.980	0.971	0.971	0.990	0.996	0.957
42.5	0.988	0.936	0.982	0.971	0.972	0.989	0.995	0.956
51.0	0.989	0.942	0.984	0.972	0.973	0.988	0.995	0.954
59.5	0.991	0.947	0.986	0.972	0.973	0.987	0.995	0.953
68.0	0.993	0.953	0.988	0.973	0.974	0.987	0.995	0.952
76.5	0.995	0.958	0.990	0.973	0.975	0.986	0.994	0.951

The ranges of predicted BF values for DOB from 3.0 to 25.0 in. based on Equations 1, 4, 7, 10, 13, 16, 19, and 22 are 0.053, 0.026, 0.033, 0.009, 0.018, 0.007, 0.011, and 0.058 for RM, WA, SM, BW, BC, YB, AB, and AE, respectively. Note that no bark factors are given for DOB≥21.0 in. for AE because the estimated values are greater than one. This is due to the small sample size (i.e., one tree with 6 measurements) and the largest DOB being no larger than 15.21 inches. The ranges of predicted BF values for TH from 0.25 to 76.5 ft. based on Equations 2, 5, 8, 11, 14, 17, 20, and 23 are 0.025, 0.034, 0.019, 0.003, 0.027, 0.005, 0.003, and 0.031 for RM, WA, SM, BW, BC, YB, AB, and AE, respectively. Because of these moderate to small ranges, the low R^2 values of the prediction equations, and some of the prediction equations not being significant at $\alpha = 0.05$, you might argue that the mean bark factor yields an adequate prediction model for each species.

			s_y
(25)	RM:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{829} BF_i/829 = 0.980$	0.015671
(26)	WA:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{410} BF_i/410 = 0.932$	0.023692
(27)	SM:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{1,488} BF_i/1,488 = 0.976$	0.014991
(28)	BW:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{398} BF_i/398 = 0.970$	0.013115
(29)	BC:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{178} BF_i/179 = 0.965$	0.015086
(30)	YB:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{66} BF_i/66 = 0.991$	0.003720
(31)	AB:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{131} BF_i/131 = 0.995$	0.004566
(32)	AE:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{6} BF_i/6 = 0.964$	0.007831

See the above two tables to find where Equations 25-32 over- and underestimate related to Equations 1-2, 4-5, 7-8, 10-11, 13-14, 16-17, 19-20, and 22-23, respectively.

Prediction Equations 1, 4, 7, 10, 13, 16, and 22 are significantly different (Bartlett's χ^2-test for equal variances, P<0.005; F-test for equal slopes, P<0.001). Prediction Equations 2, 8, and 14 are significantly different (Bartlett's χ^2-test for equal variances, P<0.10; F-test for equal slopes, P<0.001). Prediction Equations 5, 11, 17, 20, and 23 are significantly different (Bartlett's χ^2-test for equal variances, P<0.005; F-test for equal slopes, P<0.001). Prediction Equations 27-32 related to mean bark factors are also significantly different (Bartlett's χ^2-test for equal variances, P<0.005; F-test for equal means, P<0.001). All Bonferroni pairwise comparisons of means are significantly different (P<0.003) except for (RM, AE), (SM, AE), (BW, AE), (BC, AE), and (YB, AB). Note that the sample size for AE is only 6.

Topwood

			R^2	$s_{y \bullet x}$	P	n
(33)	RM:	$\hat{BF} = 1.006791 - 0.004569 \bullet DOB$	0.245	0.016815	<0.001	74
(34)	WA:	$\hat{BF} = 0.936727 - 0.000206 \bullet DOB$	0.000	0.023230	0.866	75
(35)	SM:	$\hat{BF} = 0.995302 - 0.002757 \bullet DOB$	0.201	0.013598	<0.001	342
(36)	BW:	$\hat{BF} = 0.979121 - 0.002155 \bullet DOB$	0.135	0.010484	0.023	38
(37)	BC:	$\hat{BF} = 0.977830 - 0.000604 \bullet DOB$	0.017	0.009709	0.478	32
(38)	YB:	$\hat{BF} = 0.987032 + 0.000281 \bullet DOB$	0.012	0.004606	0.593	26
(39)	AB:	$\hat{BF} = 1.038966 - 0.131661/DOB - 0.012832 \bullet \ln DOB$	0.463	0.002353	<0.001	44

Prediction Equations 33-39 for RM, WA, SM, BW, BC, YB, and AB, respectively, yield the following estimated bark factors.

Prediction Equations 33-39

DOB	$\hat{BF}$						
(in.)	RM	WA	SM	BW	BC	YB	AB
3.0	0.993	0.936	0.987	0.973	0.976	0.988	0.981
4.0	0.989	0.936	0.984	0.971	0.975	0.988	0.988
5.0	0.984	0.936	0.982	0.968	0.975	0.988	0.992
6.0	0.979	0.935	0.979	0.966	0.974	0.989	0.994
7.0	0.975	0.935	0.976	0.964	0.974	0.989	0.995
8.0	0.970	0.935	0.973	0.962	0.973	0.989	0.996
9.0	0.966	0.935	0.970	0.960	0.972	0.990	0.996
10.0	0.961	0.935	0.968	0.958	0.972	0.990	0.996
11.0	0.957	0.934	0.965	0.955	0.971	0.990	0.996
12.0	0.952	0.934	0.962	0.953	0.971	0.990	0.996
13.0	0.947	0.934	0.959	0.951	0.970	0.991	0.996
14.0	0.943	0.934	0.957	0.949	0.969	0.991	0.996
15.0	0.938	0.934	0.954	0.947	0.969	0.991	0.995
16.0	0.934	0.933	0.951	0.945	0.968	0.992	0.995
17.0	0.929	0.933	0.948	0.942	0.968	0.992	0.995
18.0	0.924	0.933	0.946	0.940	0.967	0.992	0.995
19.0	0.920	0.933	0.943	0.938	0.966	0.992	0.994
20.0	0.915	0.933	0.940	0.936	0.966	0.993	0.994

The ranges of predicted BF values for DOB from 3.0 to 20.0 in. are 0.078, 0.003, 0.047, 0.037, 0.010, 0.005, and 0.015 for RM, WA, SM, BW, BC, YB, and AB, respectively. Because of these moderate to small ranges, the low R^2 values of the prediction equations, the moderate sample sizes and some of the prediction equations not being significant at $\alpha=0.05$, you might argue that the mean bark factor yields an adequate prediction model (except possibly for RM).

			s_y
(40)	RM:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{74} BF_i/74 = 0.981$	0.019213
(41)	WA:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{75} BF_i/75 = 0.935$	0.023077
(42)	SM:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{342} BF_i/342 = 0.977$	0.015190
(43)	BW:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{38} BF_i/38 = 0.962$	0.011118
(44)	BC:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{32} BF_i/32 = 0.974$	0.009633
(45)	YB:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{26} BF_i/26 = 0.989$	0.004540
(46)	AB:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{44} BF_i/44 = 0.995$	0.003135

See the above table to find where Equations 40-46 over- and underestimate reflected to Equations 33-39, respectively.

Prediction Equations 33-38 are significantly different (Bartlett's χ^2-test for equal variances, $P<0.005$; F-test for equal slopes, $P=0.001$). Prediction Equations 40-46 related to mean bark factors are also significantly different (Bartlett's χ^2-test for equal variances, $P<0.005$; F-test for equal means, $P<0.001$). All Bonferroni pairwise comparisons of means are significantly different ($P<0.05$) except for (RM, SM), (RM, BC), (RM, YB), (SM, BC), and (YB, AB).

Pooled prediction equations

The stemwood and topwood BF prediction equations with DOB as the independent variable were compared for each of the species except for AB where the independent variables were 1/DOB and ln DOB. The resulting P-values are as follows:

Species	Bartlett's χ^2-test for Equal Variances*	F-test for Equal Regression Coefficients*
RM	P=0.054	P=0.001
WA	P=0.961	P=0.267
SM	P=0.862	P<0.001
BW	P=0.094	P=0.120
BC	P=0.005	P=0.854
YB	P=0.106	P=0.954
AB	P<0.001	P=0.942

* Bonferroni level of significance $\alpha=0.05/7=0.007$.

The above results indicate that the two equations for WA, BW, BC, YB, and AB can be pooled, while some prediction accuracy will be lost if the two equations for RM and SM are pooled (See the two equations shown for each species earlier in this paper). Note that there is no topwood for the one AE tree in the data set. Therefore, the pooled equation is the stemwood equation for AE.

The pooled prediction equations are:

			R^2	$s_{y \bullet x}$	P	n
(47)	RM:	$\hat{BF} = 0.997087 - 0.002476 \bullet DOB$	0.166	0.014604	<0.001	903
(48)	WA:	$\hat{BF} = 0.924553 + 0.001003 \bullet DOB$	0.021	0.023385	0.001	485
(49)	SM:	$\hat{BF} = 0.988615 - 0.001568 \bullet DOB$	0.164	0.013748	<0.001	1,830
(50)	BW:	$\hat{BF} = 0.972865 - 0.000320 \bullet DOB$	0.010	0.013085	0.040	436
(51)	BC:	$\hat{BF} = 0.974512 - 0.001028 \bullet DOB$	0.041	0.014455	0.003	210
(52)	YB:	$\hat{BF} = 0.986997 + 0.000334 \bullet DOB$	0.107	0.003825	0.001	92

		R^2	$s_{y \bullet x}$	P	n
(53)	AB: $\hat{BF} = 1.028314 - 0.105996/DOB - 0.009288 \bullet \ln DOB$	0.201	0.003819	<0.001	175

Prediction equations 47-53 for RM, WA, SM, BW, BC, YB, and AB, respectively, yield the following estimated bark factors.

Prediction Equations 47-53

DOB	$\hat{BF}$						
(in.)	RM	WA	SM	BW	BC	YB	AB
3.0	0.990	0.928	0.984	0.972	0.971	0.988	0.983
4.0	0.987	0.929	0.982	0.972	0.970	0.988	0.989
5.0	0.985	0.930	0.981	0.971	0.969	0.989	0.992
6.0	0.982	0.931	0.979	0.971	0.968	0.989	0.994
7.0	0.980	0.932	0.978	0.971	0.967	0.989	0.995
8.0	0.977	0.933	0.976	0.970	0.966	0.989	0.996
9.0	0.975	0.934	0.975	0.970	0.965	0.990	0.996
10.0	0.972	0.935	0.973	0.969	0.964	0.990	0.996
11.0	0.970	0.936	0.971	0.969	0.963	0.991	0.996
12.0	0.967	0.937	0.970	0.969	0.962	0.991	0.996
13.0	0.965	0.938	0.968	0.968	0.961	0.991	0.996
14.0	0.962	0.939	0.967	0.968	0.960	0.992	0.996
15.0	0.960	0.940	0.965	0.968	0.959	0.992	0.996
16.0	0.957	0.941	0.964	0.968	0.958	0.992	0.996
17.0	0.955	0.942	0.962	0.967	0.957	0.993	0.996
18.0	0.953	0.943	0.960	0.967	0.956	0.993	0.996
19.0	0.950	0.944	0.959	0.967	0.955	0.993	0.995
20.0	0.948	0.945	0.957	0.966	0.954	0.994	0.995
21.0	0.945	0.946	0.956	0.966	0.953	0.994	0.995
22.0	0.943	0.947	0.954	0.966	0.952	0.994	0.995
23.0	0.940	0.948	0.953	0.966	0.951	0.995	0.995
24.0	0.938	0.949	0.951	0.965	0.950	0.995	0.994
25.0	0.935	0.950	0.949	0.965	0.949	0.995	0.994

Note that the pooled BF estimates for each species are close to those of Equations 1, 4, 7, 10, 13, 16, and 19 for stemwood. This makes sense since the stemwood sample sizes were considerably larger than the topwood sample sizes for each species. For topwood, the pooled BF estimates for YB and AB are very close to Equations 38 and 39, respectively, for topwood. However, there are some larger differences for the other species over the range of DOB from 3.0-20.0 inches.

- RM – Pooled BF estimates are lower than those of Equation 33 for DOB < 5.0 in. and higher for DOB ≥ 5.0 in. (from 0.003 lower to 0.033 higher).

- WA – Pooled BF estimates are lower than those of Equation 34 for DOB < 10.0 in. and higher for DOB > 10.0 in. (from 0.008 lower to 0.012 higher).

- SM – Pooled BF estimates are lower than those of Equation 35 for DOB < 6.0 in. and higher for DOB > 6.0 in. (from 0.003 lower to 0.017 higher).

- BW – Pooled BF estimates are lower than those of Equation 36 for DOB < 4.0 in. and higher for DOB ≥ 4.0 in. (from 0.001 lower to 0.030 higher).

- BC – Pooled BF estimates are lower than those of Equation 37 for all values of DOB (from 0.005 to 0.012 lower).

The ranges of the pooled predicted BF values for DOB from 3.0 to 25.0 in. are 0.055, 0.022, 0.035, 0.007, 0.022, 0.007, and 0.013 for RM, WA, SM, BW, BC, YB, and AB, respectively. Because of these moderate to small ranges, the low R^2 values of the prediction equations, and some of the prediction equations not being significant, you might argue that the mean bark factor yields an adequate prediction model.

The stemwood and topwood mean BFs were compared for each of the species. The resulting P-values are as follows:

Species	Bartlett's χ^2-test for Equal Variances*	F-test for Equal Regression Coefficients*
RM	0.013	0.681
WA	0.770	0.202
SM	0.775	0.287
BW	0.196	0.004
BC	0.004	0.001
YB	0.222	0.055
AB	0.005	0.542

* Bonferroni level of significance $\alpha_{PC} = 0.005/7 = 0.007$.

The above results indicate that the two means for RM, WA, SM, YB, and AB can be pooled, while some prediction accuracy will be lost if the two means for BW and BC are pooled (See the two means shown for each species earlier in the paper). Note that there is no topwood for the one AE tree in the data set. Therefore, the pooled mean is the stemwood mean for AE.

The pooled mean bark factors are:

			s_y
(54)	RM:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{903} BF_i/903 = 0.980$	0.015980
(55)	WA:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{485} BF_i/485 = 0.932$	0.023614
(56)	SM:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{1,830} BF_i/1,830 = 0.976$	0.015029
(57)	BW:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{436} BF_i/436 = 0.970$	0.013134
(58)	BC:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{210} BF_i/210 = 0.966$	0.014725
(59)	YB:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{92} BF_i/92 = 0.990$	0.004025
(60)	AB:	$\hat{BF} = \overline{BF} = \sum_{i=1}^{175} BF_i/175 = 0.995$	0.004248

See the table based on Equations 47-53 to see where Equations 54-60 under- and overestimate, respectively.

Bark thickness

For the stemwood data set (n=3,506), BT was significantly different for the eight different species (Bartlett's χ^2-test for equal variances, P<0.001; F-test for equal means, P<0.001). All Bonferroni pairwise comparisons of means are significantly different except for (RM, YB), (RM, AE), (WA, AE), (SM, AE), (BW, AE), (BC, AE), (YB, AB) and (BW, BC). Note that the sample size for AE is only 6.

Average, minimum, and maximum BTs and Pearson's correlations of BT with DOB, DBH, and TH are shown below for the eight species.

Species	BT		BT, DOB		BT, DBH		BT, TH		n
	$\bar{x}$	Min.– Max.	r	P	r	P	r	P	
RM	0.077	0.005-0.525	0.678	<0.001	0.484	<0.001	−0.369	<0.001	829
WA	0.263	0.012-1.760	0.632	<0.001	0.428	<0.001	−0.329	<0.001	410
SM	0.113	0.008-0.672	0.794	<0.001	0.685	<0.001	−0.293	<0.001	1,488
BW	0.158	0.005-0.525	0.738	<0.001	0.633	<0.001	−0.192	<0.001	398
BC	0.145	0.012-0.438	0.653	<0.001	0.169	0.024	−0.683	<0.001	178
YB	0.046	0.020-0.115	0.448	<0.001	0.234	0.058	−0.383	0.002	66
AB	0.024	0.005-0.395	0.236	0.007	0.067	0.448	−0.229	0.009	131
AE*	0.195	0.170-0.228	−0.511	0.300	——	——	0.405	0.425	6

*AE data consists of six measurements from one tree.

BT was significantly positively related to DOB for all species except for AE where there was a negative relation that was not significant. BT was significantly positively related to DBH for all species except for YB and AB where the positive relations were not significant. BT was significantly negatively related to TH for all species except for AE where there was a positive relationship that was not significant.

Average BTs for various DOB and TH classes for the eight species are as follows.

DOB Class (in.)	BT							
	RM	WA	SM	BW	BC	YB	AB	AE
≤4.00	0.017	0.091	0.024	0.032	0.058	0.020	0.022	——
4.01 to 8.00	0.054	0.220	0.060	0.093	0.101	0.032	0.019	——
8.01 to 12.00	0.134	0.321	0.141	0.150	0.192	0.048	0.019	0.200
12.01 to 16.00	0.239	0.394	0.225	0.219	0.252	0.060	0.020	0.170
>16.00	0.236	0.468	0.324	0.268	0.199	0.058	0.048	——

TH Class (ft.)	BT							
	RM	WA	SM	BW	BC	YB	AB	AE
≤0.50	0.134	0.208	0.146	0.114	0.263	0.038	0.036	——
0.51 to 4.50	0.110	0.338	0.161	0.199	0.192	0.057	0.038	0.180
4.51 to 10.00	0.080	0.296	0.105	0.165	0.169	0.047	0.021	——
10.01 to 20.00	0.065	0.278	0.106	0.153	0.140	0.049	0.016	0.210
20.01 to 30.00	0.060	0.250	0.094	0.146	0.102	0.041	0.016	0.200
30.01 to 40.00	0.045	0.220	0.089	0.134	0.087	0.037	0.014	0.190
40.01 to 50.00	0.038	0.220	0.062	0.153	0.061	0.025	0.015	——
≥50.00	0.016	0.159	0.047	0.136	0.038	——	0.016	——

In general, BT is smallest for AB, followed by YB, RM, SM, BC, BW, and AE in increasing order, with BT for WA being the largest. In general, BT increases with DOB and decreases with TH. Most of the anomalies are due to small sample sizes.

For the topwood data set (n=631), BT was significantly different for the seven different species (Bartlett's χ^2-test for equal variances, P<0.001; F-test for equal means, P<0.001). All Bonferroni pairwise comparisons of means are significantly different except for (RM, SM), (RM, BC), (RM, YB), (SM, BC), (BC, YB), and (YB, AB).

Average, minimum, and maximum BTs and Pearson's correlations of BT with DOB and DBH are shown below for the seven species.

Species	BT		BT, DOB		BT, DBH		n
	$\bar{x}$	Min.– Max.	r	P	r	P	
RM	0.064	0.008-0.385	0.680	<0.001	0.549	<0.001	74
WA	0.203	0.022-0.458	0.723	<0.001	0.360	0.002	75
SM	0.086	0.005-0.362	0.768	<0.001	0.440	<0.001	342
BW	0.150	0.018-0.262	0.813	<0.001	0.588	<0.001	38
BC	0.083	0.018-0.175	0.723	<0.001	0.380	0.032	32
YB	0.034	0.015-0.075	0.464	0.017	0.216	0.290	26
AB	0.019	0.008-0.038	0.051	0.744	0.661	<0.001	44

BT was significantly positively related to DOB for all species except for AB, and to DBH for all species except for YB.

Average BTs for various DOB classes for the seven species are as follows:

DOB Class	BT						
(in.)	RM	WA	SM	BW	BC	YB	AB
≤5.00	0.018	0.126	0.033	0.054	0.051	0.024	0.021
5.01 to 7.00	0.073	0.212	0.061	0.105	0.086	0.032	0.019
7.01 to 9.00	0.152	0.281	0.111	0.170	0.115	0.057	0.015
9.01 to 11.00	0.158	0.255	0.177	0.193	0.114	0.043	0.020
11.1 to 13.00	0.122	0.345	0.222	0.205	0.135	——	0.026

In general, BT is smallest for AB, followed by YB, BC, RM, SM, and BW in increasing order, with BT for WA being the largest. In general, BT increases with DOB. Most of the anomalies are due to small sample sizes.

Comparison with other BF equations

Fowler (1993) showed that while there were significant species differences between BF equations for aspen, jack pine, and red pine, there was a very strong relationship between BF and tree height for each species (i.e., R^2>0.97 for each species). BF was a function of TH and ln TH, showing that BF increased with TH to some maximum and then decreased for larger THs with the steepness of the decrease depending on the species. For all three species, BF was not strongly related to DBH or DOB at a given TH.

For paper birch (Fowler and Hussain 1997), BF significantly increased with DOB at TH (R^2=0.219) and significantly decreased with ln TH (R^2=0.166) for stemwood, while BF significantly increased with DOB for topwood (R^2=0.218). BF was much more variable than for aspen, red pine, and jack pine.

Fowler et al. (1997) showed that black oak (BO), red oak (RO), and white oak (WO) have BFs that are quite variable and prediction equations with the same independent variables as for paper birch, with the direction of the relations reversed. For stemwood, BF decreased with DOB at TH (R^2=0.270, 0.418, and 0.014 for BO, RO, and WO, respectively) and increased with ln TH (R^2= 0.190, 0.275, and 0.011 for BO, RO, and WO respectively). For topwood, BF decreased with DOB (R^2=0.366, 0.457, and 0.100 for BO, RO, and WO, respectively). These prediction equations were significant, but they were only moderately strong at best, being only somewhat stronger, in general, than the prediction equations for paper birch. The prediction equations based on DOB were somewhat stronger than the prediction equations based on ln TH. The BF equations were significantly different for the three species, and for topwood versus stemwood except for RO.

This study shows that the eight northern hardwood species have BFs that are quite variable with some species having prediction equations with the same independent variables as for paper birch and the three oak species, while other species had different independent variables. For stemwood, BF decreased with DOB at TH for RM, SM, BW, and BC, increased with ln DOB at TH for WA, YB, and AE, and increased and then somewhat decreased with 1/DOB and ln DOB as the independent variables for AB. BF increased with ln TH for RM, SM, and BC, decreased and then increased with TH and ln TH for WA and BW, increased and then decreased with TH and ln TH for YB, AB, and AE. The prediction equations for AE are very suspect as they were based on only six BF measurements from one tree. For topwood, BF decreased with DOB for RM, WA, SM, BW, and BC, increased with DOB for YB, and increased and somewhat decreased with 1/DOB and ln DOB for AB. All prediction equations for stemwood were significant except for the TH equations for BW and YB. For topwood, only the prediction equations for RM, SM, BW, and AB were significant. In general, all prediction equations were only moderately strong at best, and some of them were very weak. The BF equations were significantly different for most species, while the stemwood and topwood BF equations were not significantly different except for RM and SM.

GUIDELINES FOR USERS

We recommend use of the following equations for northern hardwoods when accurate estimates of bark factors are desired:

Stemwood

- Red maple

(1) $\hat{BF} = 0.996730 - 0.002397 \bullet DOB$

(2) $\hat{BF} = 0.972344 + 0.003554 \bullet \ln TH$

- White ash

(3) $\hat{BF} = 0.922166 + 0.001198 \bullet DOB$

(4) $\hat{BF} = 0.937036 + 0.000805 \bullet TH - 0.009279 \bullet \ln TH$

- Sugar maple

(5) $\hat{BF} = 0.988318 - 0.001497 \bullet DOB$

(6) $\hat{BF} = 0.970865 + 0.002264 \bullet \ln TH$

- Basswood

(7) $\hat{BF} = 0.974486 - 0.000403 \bullet DOB$

(8) $\hat{BF} = 0.970312 + 0.000072 \bullet TH - 0.000631 \bullet \ln TH$

- Black cherry

(9) $\hat{BF} = 0.971912 - 0.000841 \bullet DOB$

(10) $\hat{BF} = 0.954777 + 0.004557 \bullet \ln TH$

- Yellow birch

(11) $\hat{BF} = 0.987390 + 0.000307 \bullet DOB$

(12) $\hat{BF} = 0.990354 - 0.000111 \bullet TH + 0.000885 \bullet \ln TH$

- American beech

(13) $\hat{BF} = 1.027382 - 0.103065/DOB - 0.009012 \bullet \ln DOB$

(14) $\hat{BF} = 0.994075 - 0.000047 \bullet TH + 0.000896 \bullet \ln TH$

- American elm

(15) $\hat{BF} = 0.925851 + 0.003400 \bullet DOB$

(16) $\hat{BF} = 0.975815 - 0.000058 \bullet TH - 0.004696 \bullet \ln TH$

Use Equations 1, 3, 5, 7, 9, 11, 13, and 15 if DOB is measured. Use Equations 2, 4, 6, 8, 10, 12, 14, and 16 when only TH is measured.

Topwood

(17) RM: $\hat{BF} = 1.006791 - 0.004569 \bullet DOB$

(18) WA: $\hat{BF} = 0.936727 - 0.000206 \bullet DOB$

(19) SM: $\hat{BF} = 0.995302 - 0.002757 \bullet DOB$

(20) BW: $\hat{BF} = 0.979121 - 0.002155 \bullet DOB$

(21) BC: $\hat{BF} = 0.977830 - 0.000604 \bullet DOB$

(22) YB: $\hat{BF} = 0.987032 + 0.000281 \bullet DOB$

(23) AB: $\hat{BF} = 1.038966 - 0.131661/DOB - 0.012832 \bullet \ln DOB$

The equation for stemwood and topwood pooled could be used if DOB is measured with moderate loss in accuracy for RM and SM and little loss in accuracy for the other five species. The pooled equations, in general, will be more accurate for stemwood compared to topwood, especially for RM and SM.

(24) RM: $\hat{BF} = 0.997087 - 0.002476 \bullet DOB$

(25) WA: $\hat{BF} = 0.924553 + 0.001003 \bullet DOB$

(26) SM: $\hat{BF} = 0.988615 - 0.001568 \bullet DOB$

(27) BW: $\hat{BF} = 0.972865 - 0.000320 \bullet DOB$

(28) BC: $\hat{BF} = 0.974512 - 0.001028 \bullet DOB$

(29) YB: $\hat{BF} = 0.986997 + 0.000334 \bullet DOB$

(30) AB: $\hat{BF} = 1.028314 - 0.105996/DOB - 0.009288 \bullet \ln DOB$

There is no pooled equation for AE as there was no topwood for the one AE tree in the data set.

For reasonable accuracy in many situations, the following constants could be used for bark factors.

DOB Class (in.)	Stemwood BF							
	RM	WA	SM	BW	BC	YB	AB	AE
DOB≤5.0	0.988	0.927	0.982	0.973	0.969	0.989	0.988	0.939
5.0<DOB≤10.0	0.979	0.931	0.977	0.971	0.966	0.990	0.995	0.951
10.0<DOB≤15.0	0.967	0.937	0.970	0.969	0.962	0.991	0.996	0.968
15.0<DOB≤20.0	0.955	0.943	0.962	0.967	0.957	0.993	0.996	0.985
DOB>20.0	0.943	0.949	0.954	0.965	0.953	0.994	0.995	0.994

DOB Class (in.)	Topwood BF RM	WA	SM	BW	BC	YB	AB
DOB≤5.0	0.989	0.936	0.984	0.971	0.975	0.988	0.987
5.0<DOB≤10.0	0.970	0.935	0.973	0.962	0.973	0.989	0.995
10.0<DOB≤15.0	0.947	0.934	0.959	0.951	0.970	0.991	0.996
15.0<DOB≤20.0	0.924	0.933	0.946	0.940	0.967	0.992	0.995
DOB>20.0	0.902	0.932	0.932	0.930	0.964	0.993	0.993

TH (ft.)	Stemwood BF RM	WA	SM	BW	BC	YB	AB	AE
TH≤0.5	0.970	0.947	0.971	0.971	0.950	0.990	0.993	0.980
0.5<TH≤4.5	0.974	0.932	0.972	0.970	0.959	0.991	0.995	0.972
4.5<TH≤10.0	0.978	0.925	0.974	0.970	0.964	0.991	0.996	0.966
10.0<TH≤20.0	0.980	0.924	0.976	0.970	0.967	0.991	0.996	0.963
20.0<TH≤30.0	0.984	0.928	0.978	0.970	0.970	0.990	0.996	0.959
30.0<TH≤40.0	0.986	0.932	0.980	0.971	0.971	0.990	0.996	0.957
40.0<TH≤50.0	0.988	0.937	0.982	0.971	0.972	0.989	0.995	0.955
TH>50.0	0.992	0.950	0.987	0.974	0.974	0.987	0.995	0.952

The following constants for bark factor could be used for simplicity with moderately approximate results, especially for a large number of trees/sticks.

Species	Stemwood	Topwood	Stemwood and Topwood
RM	0.980	0.981	0.980
WA	0.932	0.935	0.932
SM	0.976	0.977	0.976
BW	0.970	0.962	0.970
BC	0.965	0.974	0.966
YB	0.991	0.989	0.990
AB	0.995	0.995	0.995
AE	0.964	——	0.964

The above constants would be more accurate for those species that did not have significant prediction equations and/or small sample sizes. Be very careful with using any of the results of this study outside the range of the data set for each species. Since the results for AE are based on six stemwood measurements from one tree, they are, of course, very suspect.

Use of prediction equations

The prediction equations can be used to estimate BF at any DOB and/or TH. Since BF=DIB/DOB, DIB can be estimated as $\hat{DIB} = \hat{BF} \bullet DOB$ and DOB can be estimated as $\hat{DOB} = DIB / \hat{BF}$. Past DOB and DOB growth can be estimated from past DIB growth as follows:

$$\text{Past DOB Growth} = \text{Past DIB Growth} / \hat{BF}$$

and

$$\text{Past DOB} = \text{Present DOB} - \text{Past DOB Growth}$$

where past DIB growth might be obtained with an increment borer.

Specific uses of the prediction equations include: (1) estimation of the solid wood and bark volume of standing trees, (2) estimation of bark volume, or peeled volume from unpeeled volume, of felled tree sections, (3) growth studies, and (4) estimating tree form (e.g., Girard Form Class).

See Husch et al. (1982) for a detailed discussion on bark factors.

LITERATURE CITED

Fowler, G. W. 1991. An aspen bark factor equation for Michigan. North. J. Appl. For. 8(1): 12-15.

Fowler, G. W. 1993. A jack pine bark factor equation for Michigan. North. J. Appl. For. 10(2): 86-89.

Fowler, G. W., and L. J. Damschroder. 1988. A red pine bark factor equation for Michigan. North. J. Appl. For. 5(1): 28-30.

Fowler, G. W., and N. G. Hussain. 1987a. Bark factor equation for red pine. Michigan DNR For. Infor. Leaflet 1-87. 2 p.

Fowler, G. W., and N. G. Hussain. 1987b. Bark factor equation for aspen. Michigan DNR For. Infor. Leaflet 2-87. 2 p.

Fowler, G. W., and N. G. Hussain. 1991. Bark factor equation for jack pine in Michigan. Michigan DNR For. Infor. Leaflet 1-91. 5 p.

Fowler, G. W., and N. G. Hussain. 1997. Bark factor equations for paper birch in Michigan. Michigan DNR For. Infor. Leaflet 1-97. 12 p.

Fowler, G. W., N. G. Hussain, D. J. Cohen, and D. Khatry-Chhetri. 1997. Bark factor equations for oak in Michigan. Michigan DNR For. Infor. Leaflet 2-97. 15 p.

Husch, B., C. I. Miller, and T. W. Beers. 1982. Forest Mensuration. John Wiley and Sons, Inc., NY. 402 p.

FOREST MANAGEMENT DIVISION

John M. Robertson	(517) 373-1275	**DIVISION OFFICE**, P.O. Box 30452, Lansing, MI 48909-7952
Brian Hutchins	(517) 275-5211	Forest Fire Experiment Station, 1337 E. Robinson Lake Rd, Box 68, Roscommon, MI 48653
Rich Mergener	(906) 341-2518	Wyman Nursery, Rt No 2, Box 2004, Manistique, MI 49854
Rich Mergener	(810) 229-9152	State Forest Tree Improvement Center, 4631 Bishop Lake Rd, Howell, MI 48843
Mike Paluda	(906) 228-6561	**Marquette Office**, 1990 US-41 South, Marquette, MI 49855
Bill Maki	(906) 249-1497	Marquette Warehouse & Repair Shop, 110 Ford Rd., Marquette, MI 49855
Edwin Moore	(517) 732-4481	Gaylord Warehouse & Repair Shop, 540 S. Otsego Ave, PO Box 596, Gaylord, MI 49734

UPPER PENINSULA - Bernie Hubbard (Newberry Office) 906-293-5131

	(906) 353-6651	Baraga Office, 427 US-41 North, Baraga, MI 49908
	(906) 786-2351	Escanaba Office, 6833 Hwy 2, 41 & M-35, Gladstone, MI 49837
	(906) 293-5131	Newberry Office, Rte 4, Box 796, M28 / M123, Newberry, MI 49868
Marty Nelson	(906) 353-6651	**BARAGA FOREST MANAGEMENT UNIT**, 427 US-41 North, Baraga, MI 49908
	(906) 288-3321	Twin Lakes Field Office, Rt 1, Box 234, Toivola, MI 49965
	(906) 224-2771	Wakefield Field Office, 1405 East US-2, Wakefield, MI 49968
Debbie Begalle	(906) 875-6622	**CRYSTAL FALLS FOREST MANAGEMENT UNIT**, 1420 US-2 West, Crystal Falls, MI 49920
	(906) 563-9248	Norway Field Office, US-2 West, PO Box 126, Norway, MI 49870
	(906) 246-3245	Felch Field Office, PO Box 188, Felch, MI 49831
Dennis Nezich	(906) 786-2354	**ESCANABA FOREST MANAGEMENT UNIT**, 6833 Hwy 2, 41 & M-35, Gladstone, MI 49837
	(906) 753-6317	Stephenson Field Office, West 5420 River Road, Stephenson, MI 49887
Bill Brondyke	(906) 346-9201	**GWINN FOREST MANAGEMENT UNIT**, 410 West M-35, Gwinn, MI 49841
	(906) 485-1031	Ishpeming Field Office, 1985 US 41 Hwy West, Ishpeming, MI 49849
	(906) 249-1497	Marquette Field Office, 110 Ford Road, Marquette, MI 49855
Gilbert Joy	(906) 293-3293	**NEWBERRY FOREST MANAGEMENT UNIT**, Box 428, 5666 M 123 S., Newberry, MI 49868
Dean Reid	(906) 635-5281	**SAULT STE MARIE FOREST MANAGEMENT UNIT**, Box 798, 2001 Ashmun, Sault Ste Marie, MI 49783
(send Dean Reid mail to Naubinway)	(906) 477-6048	Naubinway Field Office, PO Box 287, US 2, Naubinway, MI 49762
	(906) 297-2581	Detour Field Office, PO Box 92, M134, Detour, MI 49725
Jeff Stampfly	(906) 452-6227	**SHINGLETON FOREST MANAGEMENT UNIT**, M-28 West, PO Box 67, Shingleton, MI 49884
	(906) 499-3346	Seney Field Office, Corner of M-77 & M-28, PO Box 72, Seney, MI 49883
	(906) 341-2518	Wyman Nursery, Rt No 2, Box 2004, Manistique, MI 49854

NORTHERN LOWER PENINSULA - Jim McMillan (Roscommon Office) 517-275-5151

	(517) 732-3541	Gaylord Office, 1732 West M-32, Box 667, Gaylord, MI 49734
	(616) 775-9727	Cadillac Office, 8015 Mackinaw Trail, Cadillac, MI 49601
	(517) 826-3211	Mio Office, 191 S. Mt. Tom Rd, Box 939, Mio, MI 48647
	(517) 275-5151	Roscommon Office, 8717 N. Roscommon Rd, Box 128, Roscommon, MI 48653
Dayle Garlock	(517) 785-4251	**ATLANTA FOREST MANAGEMENT UNIT**, 13501 M-33, Atlanta, MI 49709
	(517) 354-7822	Alpena Field Office, 4343 M-32 West, Alpena, MI 49707
	(517) 733-8775	Onaway Field Office, Hwy M-211, Box 32, Onaway, MI 49765
Bill O'Neill	(517) 731-5806	**GAYLORD FOREST MANAGEMENT UNIT**, 1732 West M-32, Box 667, Gaylord, MI 49734
	(616) 533-8341	Bellaire Field Office, 701 E. Cayuga St., PO Box 278, Bellaire, MI 49615
	(616) 238-9314	Indian River Field Office, PO Box 10, 6984 Wilson, Indian River, MI 49749
	(616) 539-8564	Pellston Field Office, 304 Stimson, Box 126, Pellston, MI 49769
Joe Jarecki	(517) 983-4101	**PIGEON RIVER COUNTRY FOREST MANAGEMENT UNIT**, 9966 Twin Lakes Rd, Vanderbilt, MI 49795
Dennis Vitton	(616) 775-9727	**CADILLAC FOREST MANAGEMENT UNIT**, 8015 Mackinaw Trail, Cadillac, MI 49601
	(616) 745-4651	Baldwin Field Office, Route 2, Box 2810, Baldwin, MI 49304
	(616) 824-3591	Manton Field Office, 521 N. Michigan, Manton, MI 49663
	(616) 734-5840	Evart Field Office, 951 W. 7th Street, Evart, MI 49631
	(616) 861-5636	Oceana Field Office, 1757 E. Hayes Rd, M-20, Shelby, MI 49455
Joe Fields	(616) 922-5280	**TRAVERSE CITY FOREST MANAGEMENT UNIT**, 970 Emerson, Traverse City, MI 49686
	(616) 258-2711	Kalkaska Field Office, 2089 N. Birch St., Kalkaska, MI 49646
	(616) 325-4611	Platte River Field Office, 15210 U.S. 31 Hwy, Beulah, MI 49617
Courtney Borgondy	(517) 426-9205	**GLADWIN FOREST MANAGEMENT UNIT**, 801 N. Silverleaf, PO Box 337, Gladwin, MI 48624
	(517) 539-6411	Harrison Field Office, 708 N. First St., Harrison, MI 48625
	(517) 846-4104	Standish Field Office, 527 N. M76, Box 447, Standish, MI 48658
	(517) 687-7771	Sanford Field Office, 118 W. Saginaw, MI 48657
Susan Thiel	(517) 348-6371	**GRAYLING FOREST MANAGEMENT UNIT**, 1955 N. I-75 BL, Grayling, MI 49738
	(517) 736-8336	Lincoln Field Office, 408 Main St, PO Box 122, Lincoln, MI 48742
	(517) 826-3211	Mio Field Office, 191 S. Mt. Tom Rd, Box 939, Mio, MI 48647
Don Torchia	(517) 275-4622	**ROSCOMMON FOREST MANAGEMENT UNIT**, Box 218, Roscommon, MI 48653
	(517) 422-2897	Houghton Lake Field Office, 180 S. Harrison Rd, Houghton Lake, MI 48629
	(517) 345-0472	West Branch Field Office, 2389 South M-76, West Branch, MI 48661

SOUTHERN LOWER PENINSULA - Ben Kinsey (Lansing-Knapp's Centre) 517-241-9048

	(517) 241-9048	**Southern Lower Peninsula**, PO Box 30028, Knapp's Centre, 3rd Floor, Lansing, MI 48909
Ken Alto	(517) 675-5111	Rose Lake Warehouse and Repair Shop, 9870 W. Stoll Rd, Haslett, MI 48840
	(517) 872-4009	Cass City Field Office, 4017 E. Caro Rd, Cass City, MI 48726
Kim Dufresne	(616) 685-6851	Plainwell Office, 621 N. 10th Street, Plainwell, MI 49080
	(616) 788-5062	Muskegon Field Office, 7550 E. Messinger Rd, Twin Lake, MI 49457
	(616) 673-5819	Allegan Field Office, 4590 118th Avenue, Allegan, MI 49010
	(616) 795-9393	Yankee Springs Field Office, 420 Bassett Lake Road, Middleville, MI 49333
Tim Tennis	(517) 780-7901	Jackson Office, 301 E. Louis Glick Hwy, Jackson, MI 49201
	(810) 724-4804	Imlay City Field Office, 571 East Borland, Imlay City, MI 48444
	(810) 229-5762	Brighton Field Office, 6360 Chilson Rd, Howell, MI 48843

revised March 2, 1999

Forest Management Division

15 Resource Management Units

effective 1/25/98

● - *Resource Management Unit Office*

▌ - *Resource Management Unit Boundaries*

| - *County Boundaries*