Crown-Diameter Prediction Models for 87 Species of Stand-Grown Trees in the Eastern United States

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ABSTRACT: *The mean crown diameters of stand-grown trees were modeled as a function of stem diameter, live-crown ratio, stand basal area, latitude, longitude, elevation, and Hopkins bioclimatic index for 87 tree species in the eastern United States. Stem diameter was statistically significant in all models, and a quadratic term for stem diameter was required for some species. Crown ratio and/or Hopkins index also improved the models for many species. Coefficients of variation from the regression solutions ranged from 18 to 35%, and model* r*-square values ranged from 0.15 to 0.88. Simpler models, based only on stem diameter and crown ratio, are also presented. South. J. Appl. For. 27(4):269–278.*

Key Words: Largest crown width, crown width, crown diameter, tree crown modeling.

Crown-width models formulated from open-grown trees are usually distinguished from those based on stand-grown trees. The dimensions of crowns in open settings approach maximum biological potential, while the crowns of stand-grown trees are generally smaller due to competing vegetation. Terminology used by modelers in the western United States classifies crown-diameter prediction models derived from open-grown trees as "maximum crown width" (MCW) models, and those from stand-grown trees as "largest crown width" (LCW) models (Hann 1997). Both types of models relate to the silhouette of a crown as defined by the vertical projection of its longest branch tips, hence the terms "maximum" and "largest." MCW and LCW approximate the mean diameter of this silhouette from field measurements along two or more axes of the crown.

MCW models predict potential crown size, and are primarily used to develop tree stocking guides (Smith and Gibbs 1970) and crown competition indices (Krajicek et al. 1961). LCW models predict the actual size of tree crowns in forest settings, resulting in a variety of applications that include estimations of crown surface area and volume (Zarnoch et al., in press), tree-crown profiles and canopy architecture (Hann 1999), forest canopy cover (Gill et al. 2000), and wildlife habitat indices (Hays et al. 1981).

The objective of this article is to utilize extensive tree and stand-level data gathered by the USDA Forest Service Forest Health Monitoring program (FHM) in the eastern United States to develop regional LCW prediction models for as many tree species as possible. A similar effort is underway for species endemic to the western United States (Bechtold, in press). Regional LCW prediction models are appealing because the direct measurement of crown diameters in the field is expensive, especially for large-scale inventories such as the USDA Forest Service Forest Inventory and Analysis (FIA) program. The measurement of mean crown diameter with a logger's tape averages more than a minute per tree (Bechtold et al. 2002), which can add an hour or more to the time it takes to complete a typical FIA plot.

Previous Studies

Significant relationships between crown width and stem diameter are well established for open-grown and stand-grown trees of many species (Krajicek et al. 1961, Dawkins 1963, Hetherington 1967). Simple linear relationships between crown width and stem diameter are often adequate, but quadratic expressions of stem diameter are known to improve crown-width models for some species (Paine and Hann 1982). Although diameter at breast height (dbh) is by far the most common variable used in crown-width prediction models, LCW (and occasionally MCW) models have been supplemented with additional tree-level and stand-level variables. Moeur (1981) utilized total height and crown length in models for 11 species in the northern Rocky Mountains. Bechtold et al. (2002) found vertical crown ratio to be significant in models for 13 tree species in North Carolina. Bragg (2001) improved crown-diameter models for 20 species in the upper

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lake states by adding a term for localized basal-area competition. Crown width has also been shown to vary by geographic location. Paine and Hann (1982) improved crown-width models for 11 of 15 species in southwest Oregon with the introduction of coordinates relating trees to a geographic reference point. These studies demonstrate that measures of vertical tree dimension, stand density, and geographic location can improve crown-width models for some species over the use of stem diameter alone.

Methods

The Data

Between 1991 and 1999, the FHM program established a network of 1/6 ac plots systematically distributed across 24 eastern states (AL, CT, DE, GA, IL, IN, ME, MD, MA, MI, MN, MO, NH, NJ, NY, NC, PA, RI, SC, TN, VT, VA, WV, and WI). In addition to crown diameters, a variety of other tree and stand parameters were measured for use as indicators of forest ecosystem productivity and sustainability. The FHM plot network was integrated with the FIA sampling grid in 2000 (Stolte 2001), at which time the measurement of crown diameters was terminated because it was prohibitively expensive. Some plots were remeasured multiple times between 1991 and 1999. To avoid problems with autocorrelation, only the most recent measurement of each tree was used for this analysis. After deleting species with less than 25 observations and applying additional screening restrictions as discussed below, the FHM dataset yielded a total of 42,040 observations from 1,741 forested plots in 24 eastern states.

The crown diameters utilized for this analysis conform to the LCWs of stand-grown trees. To ensure that only stand-grown trees were included, those with an "open grown" crown class were deleted. For each sampled tree with a stem diameter of at least 5.0 in., field crews measured (with logger's tape) the horizontal diameter of the widest axis of the crown, plus the dimension perpendicular to the widest axis. The mean diameter calculated from these two field measurements is the dependent variable in the prediction equations that follow.

Live-crown ratio was investigated as a measure of vertical crown dimension potentially correlated with the crown diameters of species encountered in this study. Tree length, crown length, and height to crown base are similar variables used by other modelers, but not available in the FHM dataset. The crown ratios used in this analysis adhere to the rules for "uncompacted" live crown ratio as specified by the USDA Forest Service (2002). The term "uncompacted" means that estimates of crown ratio were not reduced to compensate for gaps between the base of the live crown and the top of a tree.

Stand-level basal area per acre was selected to quantify the effect of stand density on crown diameter. Basal areas were computed from all live tally trees with stem diameters of 5.0 in. and larger.

Latitude, longitude, and elevation are potentially useful for integrating the effect of geographic location. Because there is much interaction between these variables, especially in mountainous areas, an index comprised of all three was identified as an additional candidate variable. Hopkins (1938) studied the phenologic occurrence of springtime and concluded that relative to a given geographic position, spring is delayed by 1 day for every 100 ft of elevation, 4 days for every 1° of northward latitude, and by 1 1/4 days for every 1° of westward longitude. Based on these relationships, Hopkins bioclimatic index (i.e., the number of days spring is delayed) was computed for each tree sampled relative to the mean elevation (887 ft), lat. (39.54°), and long. (–82.52°) of all plots in the 24 state region:

$$HI = \left(\frac{(E-887)}{100}\right)1 + (LAT - 39.54)4 + (-82.52 - LONG)1.25 \quad (1)$$

where

E = elevation (ft)

LAT = latitude (decimal degrees)

$LONG$ = longitude (decimal degrees)

A positive H value means that spring is delayed relative to the reference position, while a negative value indicates that spring is advanced.

Regression Models

A preliminary model consisting of terms associated with stem diameter, vertical crown dimension, stand density, and geographic location was proposed:

$$LCW = b_0 + b_1(D) + b_2(CR) + b_3(B) + b_4(LAT) + b_5(LON) + b_6(E) + b_7(HI) \quad (2)$$

where

LCW = largest crown width (i.e., mean crown diameter, ft)

D = dbh (in.)

CR = live crown ratio (percent)

B = stand-level basal area (ft^2/ac)

LAT = latitude (decimal degrees)

$LONG$ = longitude (decimal degrees)

E = elevation (ft)

HI = Hopkins index (days)

$b_0 \ldots b_7$ = regression parameters estimated from the data

The candidate variables in Equation (2) were then evaluated with a series of fixed and stepwise regressions designed to identify the best model for each species. The ranges of the

Table 1. Ranges of data used to fit crown-diameter prediction models for 87 species in the eastern United States

		Crown diameter* (ft)		Stem diameter† (in.)		Crown ratio (%)		Latitude		Longitude		Elevation (ft)		Hopkins Index†† (days)	
Species	*n*	min	max	min	max	min	max	min	max	min	max	min	max	min	max
								(decimal deg)							
Softwood species															
Balsam fir (*Abies balsamia*)	1,268	1	34	5.0	18.6	5	99	42.74	48.61	−95.38	−67.30	0	4,000	−8	54
Easern redcedar (*Juniperus virginiana*)	329	4	34	5.0	23.2	10	99	31.18	44.61	−93.85	−70.91	0	1,733	−37	28
Tamarack (*Larix laricina*)	163	3	30	5.0	14.6	5	99	43.08	48.70	−95.28	−68.01	100	1,500	−5	56
Norway spruce (*Picea abies*)	100	5	27	5.0	18.8	10	99	42.38	45.31	−76.98	−67.65	100	1,487	−10	9
White spruce (*P. glauca*)	200	3	30	5.0	21.0	15	99	40.18	48.61	−95.23	−67.65	0	2,000	−1	54
Black spruce (*P. mariana*)	349	3	27	5.0	15.8	10	99	42.74	48.69	−95.00	−68.32	0	1,900	−4	55
Red spruce (*P. rubens*)	817	4	31	5.0	22.4	5	99	38.60	47.41	−79.76	−67.30	0	5,000	−6	46
Jack pine (*Pinus banksiana*)	174	4	25	5.0	16.2	5	99	43.84	48.02	−95.03	−83.55	600	1,700	20	53
Shortleaf pine (*P. echinata*)	606	4	35	5.0	24.0	10	90	31.66	40.99	−92.64	−74.76	0	3,000	−35	10
Slash pine (*P. elliottii*)	766	3	38	5.0	27.4	5	80	30.59	35.24	−88.12	−79.11	0	700	−45	−28
Longleaf pine (*P. palustris*)	211	6	51	5.1	25.1	20	75	30.59	34.80	−88.35	−77.05	0	1,400	−42	−15
Red pine (*P. resinosa*)	540	5	30	5.0	22.0	15	99	36.17	48.33	−94.42	−67.30	100	1,885	−7	52
Pitch pine (*P. rigida*)	165	4	34	5.0	15.8	10	90	35.43	43.84	−84.05	−70.10	0	4,006	−21	16
Pond pine (*P. serotina*)	64	7	29	5.1	16.2	20	80	31.10	43.66	−83.86	−75.26	20	1,493	−39	12
Eastern white pine (*P. strobus*)	1,215	3	45	5.0	36.3	5	99	34.59	48.33	−92.86	−67.30	0	5,000	−21	53
Scotch pine (*P. sylvestris*)	87	5	27	5.0	15.0	10	99	36.34	44.98	−86.10	−72.20	100	1,950	−17	27
Loblolly pine (*P. taeda*)	5,099	2	56	5.0	34.6	5	99	30.68	39.14	−88.41	−75.29	0	3,104	−44	5
Virginia pine (*P. virginiana*)	919	2	34	5.0	19.8	5	99	32.48	41.17	−88.07	−74.95	0	4,800	−29	32
Baldcypress (*Taxodium distichum*)	81	5	38	5.0	29.1	10	99	30.65	38.13	−88.27	−75.55	0	300	−42	−23
Northern white cedar (*Thuja occidentalis*)	1,238	3	27	5.0	23.5	5	99	43.73	49.18	−95.12	−67.30	0	1,900	−5	56
Eastern hemlock (*Tsuga canadensis*)	750	4	40	5.0	29.6	10	99	35.15	47.15	−90.28	−67.47	0	5,000	−21	46

(continued)

variables used in the final models resulting from regression analyses are provided in Table 1.

Results and Discussion

Stem diameter and crown diameter are known to be highly correlated, so stem diameter was entered first into the ordinary least squares (OLS) regression:

$$LCW = b_0 + b_1(D) \quad (3)$$

Examination of the residuals from the regression solutions indicated heteroscedasticity with respect to D for many species. A weighted least squares (WLS) approach was thus used for this and subsequent regressions to counter the effect of increasing variation with increasing stem diameter. Appropriate weights were determined by modeling the variance of the residuals from OLS solutions as a function of D. The reciprocal of the estimated variance for each D value was then used to weight the WLS solutions.

The D coefficients were not statistically significant at a probability value (P) of 0.05 for five species: striped maple (*Acer pennsylvanicum*), gray birch (*Betula poulifolia*), sugarberry (*Celtis levigata*), apple (*Malus spp.*), and black willow (*Salix nigra*). Since dbh is known to be the main driver of crown-diameter prediction models, these five species

Table 1. (continued)

Hardwood species														
Boxelder (*Acer negundo*)	164	3	58	5.0	36.8	15	99	33.37	45.24	−95.68	−74.86	0	4,000	−34	40
Red maple (*A. rubrum*)	4,186	2	53	5.0	32.1	5	99	30.63	48.26	−95.11	−67.30	0	5,250	−43	53
Silver maple (*A. scharinum*)	133	2	45	5.2	31.8	10	95	37.56	45.91	−94.06	−76.84	0	1,000	−15	38
Sugar maple (*A. sacharum*)	2,259	2	55	5.0	38.0	5	99	31.52	47.63	−95.93	−67.83	0	5,250	−37	53
Serviceberry (*Amelanchier arborea*)	26	10	28	5.1	10.9	20	90	35.52	45.38	−88.46	−74.25	0	3,700	−11	26
Yellow birch (*Betula alleghaniensis*)	542	6	39	5.0	29.6	10	95	35.29	47.41	−91.99	−67.47	0	4,611	−21	45
Sweet birch (*B. lenta*)	299	8	55	5.0	26.5	15	99	32.54	44.02	−84.57	−70.59	0	4,611	−34	23
River birch (*B. nigra*)	53	11	69	5.0	22.7	20	90	32.15	43.08	−94.06	−77.80	0	4,000	−37	20
Paper birch (*B. papyrifera*)	889	4	43	5.0	19.2	10	99	40.95	48.61	−95.72	−67.30	0	5,000	−9	54
American horn-beam (*Carpinus caroliniana*)	95	4	42	5.0	18.5	20	99	30.81	44.46	−88.75	−70.59	0	2,100	−40	17
Bitternut hickory (*Carya cordiformis*)	110	9	41	5.0	25.1	20	95	33.09	44.13	−94.49	−71.59	0	2,300	−30	33
Pignut hickory (*C. glabra*)	284	6	53	5.0	23.9	15	95	31.60	42.77	−91.38	−70.91	0	4,800	−35	32
Shagbark hickory (*C. ovata*)	236	7	55	5.0	25.3	15	95	33.61	44.38	−94.06	−70.91	0	2,700	−25	31
Black hickory (*C. texana*)	63	8	35	5.0	16.7	20	95	36.50	39.15	−93.81	−90.05	421	1,380	−6	8
Mockernut hickory (*C. tomentosa*)	275	5	56	5.0	23.0	15	95	30.89	41.67	−93.74	−76.53	0	3,500	−41	13
Hackberry (*Celtis occidentalis*)	136	10	51	5.0	26.1	10	99	32.90	45.24	−95.68	−76.29	0	4,000	−34	40
Dogwood (*Cornus florida*)	152	4	37	5.0	9.6	5	99	30.77	40.54	−94.49	−75.27	0	4,611	−39	23
Persimmon (*Diospyros virginiana*)	64	8	36	5.0	15.5	15	99	32.15	39.60	−93.45	−77.37	0	3,000	−34	7
American beech (*Fagus grandifolia*)	777	1	80	5.0	30.3	5	99	31.72	47.20	−88.62	−67.47	0	5,000	−34	46
White ash (*Fraxinus americana*)	701	5	63	5.0	46.7	5	99	33.48	47.15	−94.49	−67.47	0	4,000	−31	43
Black ash (*F. nigra*)	376	4	34	5.0	17.0	5	99	40.57	48.26	−95.79	−68.17	0	1,600	−4	54
Green ash (*F. pennsylvanica*)	273	5	62	5.0	25.9	10	95	31.18	47.08	−95.68	−68.71	0	2,600	−39	51
Honeylocust (*Gleditsia triacanthos*)	29	11	46	5.2	20.0	25	95	33.69	43.24	−94.90	−79.27	0	1,100	−36	24
American holly (*Ilex opaca*)	100	9	31	5.0	19.3	20	99	30.65	46.53	−95.93	−74.03	0	1,400	−38	50
Black walnut (*Juglans nigra*)	110	1	38	5.0	18.4	5	99	31.48	42.71	−94.90	−76.61	0	2,400	−33	18

(continued)

were subsequently deleted from the analysis, reducing the number of species available for modeling to 87 from a previous total of 92.

Further examination of the residuals from Equation (3) indicated that a quadratic term might improve the models for some species. All species were thus refitted with the model:

$$LCW = b_0 + b_1(D) + b_2(D^2) \qquad (4)$$

using WLS regression, and the quadratic term was retained for nine species where the P-value associated with the D^2 coefficient was significant at $P = 0.05$.

Upon fixing D and D^2 in those models, where significant, all models were then refitted with an additional term for crown ratio (CR):

$$LCW = b_0 + b_1(D) + b_2(D^2) + b_3(CR) \qquad (5)$$

Tabe 1. (continued)

Sweetgum (*Liquidambar styraciflua*)	1,115	4	50	5.0	26.6	5	99	30.63	39.87	−90.43	−74.81	0	3,000	−45	−2
Yellow poplar (*Liriodendron tulipifera*)	1,154	4	61	5.0	31.0	5	99	30.59	42.43	−88.92	−72.88	0	4,611	−40	23
Cucumber tree (*Magnolia acuminata*)	32	10	39	5.3	18.5	30	90	31.83	42.03	−87.00	−79.19	25	3,500	−31	20
Sweetbay (*M. virginiana*)	117	6	41	5.0	26.1	10	75	30.59	38.35	−88.27	−75.42	0	1,200	−41	−23
Red mulberry (*Morus rubra*)	34	7	46	5.0	21.8	15	90	31.71	40.55	−94.77	−78.36	0	4,000	−32	14
Water tupelo (*Nyssa aquatica*)	100	8	38	5.0	18.5	25	80	31.10	37.07	−91.46	−77.45	0	1,000	−40	2
Blackgum (*N. sylvatica*)	480	6	51	5.0	33.0	10	99	30.77	44.26	−91.61	−69.06	0	3,400	−44	14
Swamp tupelo (*N. sylvatica var. biflora*)	212	4	41	5.0	27.4	5	90	30.59	37.36	−88.62	−75.98	0	700	−43	−15
Eastern hophorn-beam (*Ostrya virginiana*)	124	7	39	5.0	22.5	15	95	31.64	46.79	−95.93	−67.98	0	2,200	−41	50
Sourwood (*Oxydendron arboreum*)	283	5	37	5.0	15.0	10	99	31.76	42.06	−88.78	−76.80	0	3,700	−32	20
Redbay (*Persea borbonia*)	29	3	25	5.3	15.4	5	85	30.89	36.36	−88.35	−75.98	10	1,040	−40	−14
Sycamore (*Platanus occidentalis*)	77	11	67	5.5	31.5	20	99	32.10	46.55	−94.06	−76.85	0	2,000	−29	37
Balsam poplar (*Populus balsamifera*)	111	5	26	5.0	23.2	10	95	44.19	48.79	−95.91	−70.48	600	1,600	10	56
Eastern cotton-wood (*P. deltoides*)	38	9	80	5.2	57.9	20	99	39.37	44.10	−91.75	−73.10	480	1,885	1	30
Bigtooth aspen (*P. grandidentata*)	286	4	44	5.0	21.8	5	75	38.00	48.16	−94.39	−67.30	10	5,000	−21	51
Quaking aspen (*P. tremuloides*)	1,375	5	40	5.0	24.2	5	99	40.50	48.79	−96.33	−68.01	0	4,000	−12	56
Black cherry (*Prunus serotina*)	737	1	52	5.0	31.6	5	99	30.71	47.74	−95.58	−68.89	0	5,250	−39	53
White oak (*Quercus alba*)	1,586	5	69	5.0	35.7	5	99	30.71	47.74	−95.58	−70.69	0	5,250	−44	53
Scarlet oak (*Q. coccinea*)	401	5	67	5.0	26.9	5	90	32.34	41.92	−93.40	−71.54	0	5,250	−34	32
Northern pin oak (*Q. ellipsoidalis*)	52	4	44	5.5	22.4	5	90	35.97	46.84	−94.92	−78.55	600	1,500	−20	50
Southern red oak (*Q. falcata*)	285	4	57	5.0	35.1	5	95	30.77	41.31	−91.61	−74.62	0	2,400	−41	15
Shingle oak (*Q. imbricaria*)	31	10	55	5.0	25.5	40	99	37.46	41.31	−94.19	−80.46	10	1,090	−4	15
Turkey oak (*Q. lavis*)	30	9	30	5.1	13.5	25	90	30.89	35.01	−88.35	−78.28	50	700	−39	−28

(continued)

CR was then retained for 69 species where its coefficient was significant ($P = 0.05$). Mean *r*-square values across all species from the regression solutions of Equations (4) and (5) were 0.46 and 0.52, respectively. This suggests that the addition of crown ratio (to species where it was found to be statistically significant) increases partial *r*-squares by an average of 0.06 across the 87 species tested. The increase was quite dramatic for some species—ranging up to 0.26 for jack pine (*Pinus banksiana*).

At this stage, the signs of all coefficients were consistent and biologically reasonable. The coefficients associated with D were all positive, confirming a positive correlation between stem diameter and crown diameter. The coefficients associated with D^2 were all negative, meaning that crown diameter approaches an upper biological limit as stem diameter increases. The coefficients associated with *CR* were all positive, indicating that large crowns tend to be large in all dimensions.

Table 1. (continued)

Laurel oak (*Q. laurifolia*)	89	9	55	5.0	21.0	30	99	30.95	36.37	−88.32	−76.23	0	3,000	−40	−4
Bur oak (*Q. macrocarpa*)	194	2	62	5.0	32.4	10	95	37.87	48.46	−96.33	−80.46	10	1,600	−4	55
Blackjack oak (*Q. marilandica*)	73	3	37	5.0	20.1	10	90	31.28	40.13	−93.27	−74.03	0	1,400	−37	8
Chinkapin oak (*Q. muehlenbergii*)	81	12	46	5.0	17.6	20	85	34.84	39.90	−93.81	−82.77	0	1,500	−20	8
Water oak (*Q. nigra*)	476	4	58	5.0	32.1	10	99	30.63	38.57	−88.35	−75.29	0	4,000	−44	12
Pin oak (*Q. palustris*)	30	12	63	5.0	29.4	25	95	37.84	46.76	−94.92	−74.35	360	2,400	−7	50
Willow oak (*Q. phellos*)	107	9	75	5.0	41.2	20	90	30.99	38.59	−88.12	−76.23	0	3,000	−44	−4
Chestnut oak (*Q. prinus*)	997	4	68	5.0	32.8	5	95	32.47	42.93	−87.91	−71.72	0	5,250	−26	32
Northern red oak (*Q. rubra*)	1,191	2	82	5.0	42.8	5	95	30.77	47.74	−95.58	−68.89	0	5,250	−41	53
Post oak (*Q. stellata*)	341	6	45	5.0	24.6	10	95	30.77	39.15	−94.55	−75.55	0	2,000	−40	10
Black oak (*Q. velutina*)	770	5	53	5.0	31.9	5	99	32.05	46.43	−94.55	−71.07	0	4,800	−35	47
Live oak (*Q. virginiana*)	36	8	67	5.0	32.9	35	95	30.63	33.52	−88.07	−79.08	0	300	−43	−33
Black locust (*Robinia pseudoacacia*)	199	3	48	5.0	21.8	5	99	35.08	44.59	−94.19	−73.62	0	5,250	−23	28
Sassafras (*Sassafrass albidum*)	218	4	29	5.0	15.9	10	85	32.26	43.69	−94.55	−70.01	0	3,515	−35	20
American bass-wood (*Tilia americana*)	456	2	61	5.0	31.7	5	99	33.05	47.63	−95.93	−69.24	0	3,790	−28	53
Winged elm (*Ulmus alata*)	70	10	40	5.0	16.4	30	95	32.10	46.53	−95.93	−78.21	0	2,000	−36	50
American elm (*U. americana*)	418	4	99	5.0	27.1	10	99	31.45	47.81	−95.93	−68.18	0	4,000	−42	54
Slippery elm (*U. rubra*)	132	9	49	5.0	18.7	15	95	31.18	47.25	−95.72	−76.35	0	1,600	−36	53

* Largest crown width of stand-grown trees (i.e., mean crown diameter).
† Diameter at breast height (dbh).
†† Hopkins Index is the number of days spring is delayed relative to latitude 39.54°, longitude −82.52°, and elevation 887 ft.

After fixing D, D^2, and CR in models where these terms were significant, all models were then refitted with an additional term for stand-level basal area (B). A negative correlation between stand density and crown diameter was expected, but the B term produced a mixture of positive and negative coefficients. In the few models with B coefficients that were negative and statistically significant, the partial r-squares resulting from the addition of B were generally less than 0.02. Because D and CR are tree-level variables highly correlated with stand density, the instability and weak significance of the B term was attributed to collinearity with D and CR. It was thus concluded that an additional term for density was not necessary, and B was dropped from the list of candidate variables.

Again after fixing D, D^2, and CR in models, where significant, all models were refitted with stepwise regressions where additional terms for LAT, $LONG$, and E were entered as candidates. The stepwise procedure selected one or two of these geographic variables as statistically significant for many species, but there was no clear consistency. Different geographic terms were selected for different species, coefficient signs fluctuated between positive and negative for a given geographic variable, and some of the model intercepts changed dramatically. Overparameterization, as well as interactions among latitude, longitude, and elevation made it impractical to include up to three different terms for geographic location, so Hopkins (1938) bioclimatic index was investigated as an alternative.

With D, D^2, and CR fixed in models where significant, all models were then refitted with an additional term for Hopkins index (HI):

$$LCW = b_0 + b_1(D) + b_2(D^2) + b_3(CR) + b_4(HI) \quad (6)$$

The HI term was statistically significant ($P = 0.05$) in models for 29 species, but the additional variation quantified by this variable was somewhat marginal. Mean r-square values across all species from the solutions of Equations (5) and (6) indicate that Hopkins Index increased partial r-squares by an average of only 0.01. The need for geographic adjustment was likely diminished because some of the variance associated with location was restricted by the natural ranges of species within the study area, and some was quantified by other

Table 2. Model statistics and parameter estimates from crown-diameter prediction Equation (6), for 87 species in the eastern United States.

	Equation (6)*: $LCW = b_0 + b_1(D) + b_2(D^2) + b_3(CR) + b_4(HI)$							
	Model statistics†			Parameter estimates††				
Species	*RSQ*	*RMSE*	*CV*	b_0	b_1	b_2	b_3	b_4
Softwood species								
Balsam fir	0.44	2.8	23	0.6564	0.8403	—	0.0792	—
Easern redcedar	0.44	3.5	24	1.2359	1.2962	—	0.0545	—
Tamarack	0.45	3.2	25	−0.3276	1.3865	—	0.0517	—
Norway spruce	0.68	2.3	18	1.8336	0.9932	—	0.0431	0.1012
White spruce	0.51	3.0	23	0.3789	0.8658	—	0.0878	—
Black spruce	0.40	2.8	28	−0.8566	0.9693	—	0.0573	—
Red spruce	0.56	3.0	23	−1.2151	1.6098	−0.0277	0.0674	−0.0474
Jack pine	0.44	3.0	24	0.7478	0.8712	—	0.0913	—
Shortleaf pine	0.64	3.3	23	−2.2564	1.3004	—	0.1031	−0.0562
Slash pine	0.70	2.8	20	−6.9659	2.1192	−0.0333	0.0587	−0.0959
Longleaf pine	0.70	3.9	24	−12.2105	1.3376	—	0.1237	−0.2759
Red pine	0.60	2.5	20	−3.6548	1.9565	−0.0409	0.0577	—
Pitch pine	0.52	3.9	24	−0.9442	1.4531	—	0.0543	−0.1144
Pond pine	0.70	3.1	19	−8.7711	3.7252	−0.1063	—	—
Eastern white pine	0.68	3.9	24	0.3914	0.9923	—	0.1080	—
Scotch pine	0.34	3.5	26	3.5522	0.6742	—	0.0985	—
Loblolly pine	0.71	2.8	21	−0.8277	1.3946	—	0.0768	—
Virginia pine	0.61	3.2	22	−0.1211	1.2319	—	0.1212	—
Baldcypress	0.58	4.7	31	−1.0183	0.8856	—	0.1162	—
Northern white cedar	0.52	2.8	25	−0.0634	0.7057	—	0.0837	—
Eastern hemlock	0.44	4.8	26	6.1924	1.4491	−0.0178	—	−0.0341
Hardwood species								
Boxelder	0.44	5.5	27	6.4741	1.0778	—	0.0719	−0.0637
Red maple	0.43	4.8	26	2.7563	1.4212	−0.0143	0.0993	−0.0276
Silver maple	0.69	4.5	26	3.3576	1.1312	—	0.1011	−0.1730
Sugar maple	0.48	5.0	25	4.9399	1.0727	—	0.1096	−0.0493
Serviceberry	0.22	4.0	22	6.9814	1.6032	—	—	—
Yellow birch	0.45	5.1	26	−1.1151	2.2888	−0.0493	0.0985	−0.0396
Sweet birch	0.48	4.7	24	4.6725	1.2968	—	0.0787	—
River birch	0.39	7.0	31	11.6634	1.0028	—	—	—
Paper birch	0.41	4.4	28	2.8399	1.2398	—	0.0855	−0.0282
American hornbeam	0.44	5.4	26	0.9219	1.6303	—	0.1150	−0.1113
Bitternut hickory	0.57	4.3	21	8.0118	1.4212	—	—	—
Pignut hickory	0.60	4.9	24	3.9234	1.5220	—	0.0405	—
Shagbark hickory	0.54	4.6	24	4.5453	1.3721	—	0.0430	—
Black hickory	0.53	4.2	24	−5.8749	4.1555	−0.1343	—	—
Mockernut hickory	0.61	5.0	24	1.5838	1.6318	—	0.0721	—
Hackberry	0.55	4.9	23	7.1043	1.3041	—	0.0456	—
Dogwood	0.23	4.7	25	2.9646	1.9917	—	0.0707	—
Persimmon	0.48	3.7	23	3.5393	1.3939	—	0.0625	—
American beech	0.53	5.9	27	3.9361	1.1500	—	0.1237	−0.0691
White ash	0.57	4.8	26	1.7625	1.3413	—	0.0957	—
Black ash	0.24	4.1	30	5.2824	1.1184	—	—	—
Green ash	0.44	5.2	31	2.9672	1.3066	—	0.0585	—
Honeylocust	0.67	4.6	20	4.1971	1.5567	—	0.0880	—
American holly	0.33	4.0	22	4.5803	1.0747	—	0.0661	—
Black walnut	0.35	5.6	28	3.6031	1.1472	—	0.1224	—
Sweetgum	0.55	3.9	25	1.8853	1.1625	—	0.0656	−0.0300
Yellow poplar	0.58	4.9	24	3.3543	1.1627	—	0.0857	—
Cucumber tree	0.72	3.5	18	4.1711	1.6275	—	—	—
Sweetbay	0.41	4.3	26	8.2119	0.9708	—	—	—

(continued)

variables already in the model. Hopkins Index was ultimately retained because improvements (albeit minor) were realized for a number of species, and the parameter estimates were generally stable and logical. Nearly all of the coefficients were negative, indicating that tree crowns are smaller in harsher climates where spring is delayed. The few that were positive were probably due to spurious correlations, but could also be attributed to competing species dropping out of the stand-level species mix under more extreme climatic conditions.

Equation (6) was thus chosen as the best biologically justifiable model attainable from the available data, with terms included or excluded for various species on the empirical basis of whether or not their associated coefficients were significant ($P = 0.05$). Fit statistics and

Table 2. (continued)

Red mulberry	0.33	5.9	26	13.3255	1.0735	—	—	—
Water tupelo	0.29	4.4	26	5.3409	0.7499	—	0.1047	—
Blackgum	0.38	4.5	25	5.5037	1.0567	—	0.0880	0.0610
Swamp tupelo	0.55	4.7	26	1.3564	1.0991	—	0.1243	—
Eastern hophornbeam	0.42	4.2	23	7.8084	0.8129	—	0.0941	−0.0817
Sourwood	0.15	4.3	26	7.9750	0.8303	—	0.0423	−0.0706
Redbay	0.40	3.9	26	4.2756	1.0773	—	0.1526	0.1650
Sycamore	0.63	6.1	24	−1.3973	1.3756	—	0.1835	—
Balsam poplar	0.35	3.4	24	6.2498	0.8655	—	—	—
Eastern cottonwood	0.88	5.8	21	3.4357	1.4092	—	—	—
Bigtooth aspen	0.57	3.8	24	0.6847	1.1050	—	0.1420	−0.0265
Quaking aspen	0.59	3.5	22	0.7315	1.3180	—	0.0966	—
Black cherry	0.48	4.9	27	3.0237	1.1119	—	0.1112	−0.0493
White oak	0.69	4.7	22	3.2375	1.5234	—	0.0455	−0.0324
Scarlet oak	0.64	5.5	24	0.5656	1.6766	—	0.0739	—
Northern pin oak	0.58	5.4	25	4.8935	1.6069	—	—	—
Southern red oak	0.65	5.0	23	2.1517	1.6064	—	0.0609	—
Shingle oak	0.59	6.6	29	9.8187	1.1343	—	—	—
Turkey oak	0.36	3.5	22	5.8858	1.4935	—	—	—
Laurel oak	0.68	4.7	23	6.3149	1.6455	—	—	—
Bur oak	0.79	4.8	22	1.7827	1.6549	—	0.0343	—
Blackjack oak	0.50	4.6	29	0.5443	1.4882	—	0.0565	—
Chinkapin oak	0.66	4.4	22	0.5189	1.4134	—	0.1365	−0.0806
Water oak	0.53	5.8	27	1.6349	1.5443	—	0.0637	−0.0764
Pin oak	0.80	5.2	19	−5.6268	1.7808	—	0.1231	0.1578
Willow oak	0.71	5.3	25	1.6477	1.3672	—	0.0846	—
Chestnut oak	0.55	5.2	25	2.1480	1.6928	−0.0176	0.0569	—
Northern red oak	0.63	5.6	25	2.8908	1.4077	—	0.0643	—
Post oak	0.64	4.2	21	1.6125	1.6669	—	0.0536	—
Black oak	0.64	4.7	23	2.8974	1.3697	—	0.0671	—
Live oak	0.69	8.2	29	5.6694	1.6402	—	—	—
Black locust	0.39	5.1	34	3.0012	0.8165	—	0.1395	—
Sassafras	0.24	4.2	30	4.6311	1.0108	—	0.0564	—
American basswood	0.58	4.5	25	1.6871	1.2110	—	0.1194	−0.0264
Winged elm	0.45	4.8	23	4.3649	1.6612	—	0.0643	—
American elm	0.44	7.1	35	1.7296	2.0732	—	0.0590	−0.0869
Slippery elm	0.42	5.5	26	9.0023	1.3933	—	—	−0.0785

* *LCW* = Largest crown width of stand-grown trees (i.e., mean crown diameter); *D* = diameter at breast height; *CR* = uncompacted vertical crown ratio (percent); *HI* = Hopkins Index (days spring is delayed relative to latitude 39.54 degrees, longitude −82.52°, and elevation 887 ft).

† *RSQ* = adjusted *r*-square; *RMSE* = root mean squared error from the regression solutions; *CV* = coefficient of variation from the regression solutions: *CV* = (*RMSE/mean LCW*) * 100, where mean *LCW* = mean crown width from the data.

†† Terms where parameter estimates are missing were excluded from the regression solutions due to nonsignificance at the 0.05 probability level. Nonsignificant model intercepts were retained in the solutions.

parameter estimates from the solutions of Equation (6) are presented in Table 2. Parameter estimates with missing values were excluded from the regressions for species where they were determined to be statistically nonsignificant. Although some of the model intercepts were nonsignificant, these were retained to ensure that the resulting models were BLUE (best linear unbiased estimators).

The root mean squared errors (RMSE) shown in Table 2 provide estimates of the average error in crown-diameter predictions in terms of feet. RMSE is a common measure of model variability, most useful for comparing similar models for similar species among different studies. Comparisons among models involving dissimilar species are better evaluated with the coefficient of variation (CV), which ranged from 18 to 35%. As expected, the softwood models were slightly better than those for hardwoods. The mean CV from the regression solutions of the softwood models was 23%, as compared to 25% for hardwoods.

Model *r*-square values from the solution of Equation (6) ranged from 0.15 for sourwood (*Oxydendron arboreum*) to 0.88 for eastern cottonwood (*Populus deltoides*).

Other modelers have concluded that dbh alone is adequate for modeling crown width (Gering and May 1995), even though additional independent variables slightly improved some of their models (Gill et al. 2000). Recognizing that simplicity is advantageous for some applications, and that geographic location or crown-ratio data may not be available to some users, the regression solutions from Equations (4) and (5) are provided in Table 3. By individual species, gains in model precision resulting from the addition of crown ratio and Hopkins index can be evaluated by comparing the model statistics from Equations (4), (5), and (6) in Tables 2 and 3.

Conclusions

Dbh is the strongest predictor of crown diameter for most tree species in the eastern United States. Beyond dbh, moderate improvements to models for most species are attained with the addition of vertical crown ratio. Further

Table 3. Model statistics and parameter estimates from crown-diameter prediction equations (4) and (5), for 87 species in the eastern United States.

	Equation (4)*: $LCW = b_0 + b_1(D) + b_2(D^2)$						Equation (5)*: $LCW = b_0 + b_1(D) + b_2(D^2) + b_3(CR)$						
	Model statistics†			Parameter estimates††			Model statistics†			Parameter estimates††			
Species	*RSQ*	*RMSE*	*CV*	b_0	b_1	b_2	*RSQ*	*RMSE*	*CV*	b_0	b_1	b_2	b_3
Softwood species													
Balsam fir	0.20	3.3	28	5.3870	0.8927	—	0.44	2.8	23	0.6564	0.8403	—	0.0792
Easern redcedar	0.38	3.7	25	4.5904	1.3444	—	0.44	3.5	24	1.2359	1.2962	—	0.0545
Tamarack	0.39	3.4	26	1.9502	1.4938	—	0.45	3.2	25	–0.3276	1.3865	—	0.0517
Norway spruce	0.58	2.6	21	4.5152	1.0654	—	0.66	2.3	19	2.0993	0.9639	—	0.0502
White spruce	0.30	3.6	28	6.1834	0.8567	—	0.51	3.0	23	0.3789	0.8658	—	0.0878
Black spruce	0.24	3.1	31	2.8233	0.9797	—	0.40	2.8	28	–0.8566	0.9693	—	0.0573
Red spruce	0.47	3.3	25	1.2033	1.6862	–0.0291	0.54	3.1	23	–1.6171	1.5637	–0.0258	0.0715
Jack pine	0.18	3.7	29	6.0831	0.7894	—	0.44	3.0	24	0.7478	0.8712	—	0.0913
Shortleaf pine	0.56	3.6	25	2.0510	1.3728	—	0.62	3.3	23	–1.1951	1.2874	—	0.1044
Slash pine	0.68	2.8	21	–1.1210	2.1472	–0.0344	0.70	2.8	21	–3.2947	2.1564	–0.0350	0.0567
Longleaf pine	0.61	4.4	27	3.0262	1.2932	—	0.66	4.1	25	–1.3896	1.3068	—	0.0995
Red pine	0.50	2.8	22	–0.2629	1.9810	–0.0457	0.60	2.5	20	–3.6548	1.9565	–0.0409	0.0577
Pitch pine	0.39	4.4	27	3.0705	1.3812	—	0.46	4.1	25	–0.0438	1.3616	—	0.0746
Pond pine	0.70	3.1	19	–8.7711	3.7252	–0.1063	0.70	3.1	19	–8.7711	3.7252	–0.1063	—
Eastern white pine	0.55	4.6	28	4.7990	1.0655	—	0.68	3.9	24	0.3914	0.9923	—	0.1080
Scotch pine	0.20	3.9	29	6.3738	0.8917	—	0.34	3.5	26	3.5522	0.6742	—	0.0985
Loblolly pine	0.66	3.1	22	2.5689	1.3817	—	0.71	2.8	21	–0.8277	1.3946	—	0.0768
Virginia pine	0.45	3.7	26	3.5229	1.3035	—	0.61	3.2	22	–0.1211	1.2319	—	0.1212
Baldcypress	0.53	5.0	33	2.3475	1.0519	—	0.58	4.7	31	–1.0183	0.8856	—	0.1162
Northern white cedar	0.35	3.2	29	4.0504	0.8377	—	0.52	2.8	25	–0.0634	0.7057	—	0.0837
Eastern hemlock	0.44	4.8	26	5.6624	1.5041	–0.0204	0.44	4.8	26	5.6624	1.5041	–0.0204	—
Hardwood species													
Boxelder	0.39	5.8	28	9.7918	1.1363	—	0.42	5.6	27	5.7445	1.0745	—	0.0710
Red maple	0.35	5.1	27	7.3445	1.4311	–0.0129	0.42	4.8	26	2.5898	1.4092	–0.0135	0.1011
Silver maple	0.57	5.3	30	3.4320	1.3447	—	0.65	4.8	27	0.2047	1.1096	—	0.1161
Sugar maple	0.38	5.4	27	9.9644	1.0545	—	0.47	5.0	25	3.4866	1.0720	—	0.1180
Serviceberry	0.22	4.0	22	6.9814	1.6032	—	0.22	4.0	22	6.9814	1.6032	—	—
Yellow birch	0.38	5.4	27	3.2765	2.3808	–0.0530	0.44	5.2	26	–1.6117	2.2582	–0.0485	0.1013
Sweet birch	0.43	4.9	25	8.6304	1.3364	—	0.48	4.7	24	4.6725	1.2968	—	0.0787
River birch	0.39	7.0	31	11.6634	1.0028	—	0.39	7.0	31	11.6634	1.0028	—	—
Paper birch	0.34	4.7	29	5.2177	1.3332	—	0.40	4.4	28	2.2657	1.2617	—	0.0776
American hornbeam	0.31	6.1	29	8.1415	1.8533	—	0.40	5.6	27	0.8129	1.8674	—	0.1236
Bitternut hickory	0.57	4.3	21	8.0118	1.4212	—	0.57	4.3	21	8.0118	1.4212	—	—
Pignut hickory	0.59	4.9	24	6.0596	1.5281	—	0.60	4.9	24	3.9234	1.5220	—	0.0405
Shagbark hickory	0.54	4.6	24	7.1016	1.3729	—	0.54	4.6	24	4.5453	1.3721	—	0.0430
Black hickory	0.53	4.2	24	–5.8749	4.1555	–0.1343	0.53	4.2	24	–5.8749	4.1555	–0.1343	—
Mockernut hickory	0.59	5.2	25	5.6155	1.6273	—	0.61	5.0	24	1.5838	1.6318	—	0.0721
Hackberry	0.54	4.9	23	9.3254	1.3217	—	0.55	4.9	23	7.1043	1.3041	—	0.0456
Dogwood	0.16	4.9	26	4.1231	2.4072	—	0.23	4.7	25	2.9646	1.9917	—	0.0707
Persimmon	0.47	3.8	23	5.2247	1.5386	—	0.48	3.7	23	3.5393	1.3939	—	0.0625
American beech	0.38	6.8	31	11.5347	1.1368	—	0.52	6.0	27	2.5609	1.1705	—	0.1350
White ash	0.53	5.1	27	6.1054	1.3213	—	0.57	4.8	26	1.7625	1.3413	—	0.0957
Black ash	0.24	4.1	30	5.2824	1.1184	—	0.24	4.1	30	5.2824	1.1184	—	—
Green ash	0.42	5.3	32	5.4733	1.2998	—	0.44	5.2	31	2.9672	1.3066	—	0.0585
Honeylocust	0.68	4.5	20	7.7439	1.6690	—	0.67	4.6	20	4.1971	1.5567	—	0.0880
American holly	0.28	4.2	23	9.4474	1.0772	—	0.33	4.0	22	4.5803	1.0747	—	0.0661
Black walnut	0.24	6.0	30	9.3378	1.1537	—	0.35	5.6	28	3.6031	1.1472	—	0.1224
Sweetgum	0.50	4.1	26	6.0299	1.1569	—	0.54	3.9	25	2.6693	1.1630	—	0.0652
Yellow poplar	0.55	5.1	25	7.6220	1.1550	—	0.58	4.9	24	3.3543	1.1627	—	0.0857
Cucumber tree	0.72	3.5	18	4.1711	1.6275	—	0.72	3.5	18	4.1711	1.6275	—	—
Sweetbay	0.41	4.3	26	8.2119	0.9708	—	0.41	4.3	26	8.2119	0.9708	—	—

(continued)

minor improvements are gained when Hopkins Index is used to quantify the effect of geographic location. Because stem diameter is correlated with stand density, a term for stand density is not generally needed—especially for models that contain additional tree-level variables correlated with stand density, such as crown ratio. The correlation between stem diameter and crown diameter is high enough that crown-diameter models based only on dbh are probably adequate for most applications if crown ratio and/or Hopkins Index are not available.

Literature Cited

Bechtold, W.A., M.E. Mielke, and S.J. Zarnoch. 2002. Comparison of field methods and models to estimate mean crown diameter. North. J. Appl. For. 19(4):177–182.

Bechtold, W.A. In press. Largest-crown-width prediction models for 53 species in the western United States. West. J. Appl. For.

Table 3. (continued)

Red mulberry	0.33	5.9	26	13.3255	1.0735	—	0.33	5.9	26	13.3255	1.0735	—	—
Water tupelo	0.22	4.6	27	9.9520	0.7448	—	0.29	4.4	26	5.3409	0.7499	—	0.1047
Blackgum	0.26	4.9	28	10.1715	0.9376	—	0.37	4.6	26	4.1812	1.0172	—	0.0983
Swamp tupelo	0.50	4.9	28	7.3553	1.0502	—	0.55	4.7	26	1.3564	1.0991	—	0.1243
Eastern hophornbeam	0.13	5.1	28	12.0606	0.9094	—	0.28	4.6	25	5.6290	0.8518	—	0.1164
Sourwood	0.09	4.4	27	10.8542	0.8188	—	0.13	4.3	26	8.5510	0.7999	—	0.0528
Redbay	0.20	4.5	30	8.0704	0.8519	—	0.36	4.0	27	-0.5004	1.0571	—	0.1416
Sycamore	0.54	6.8	27	9.3683	1.2685	—	0.63	6.1	24	-1.3973	1.3756	—	0.1835
Balsam poplar	0.35	3.4	24	6.2498	0.8655	—	0.35	3.4	24	6.2498	0.8655	—	—
Eastern cottonwood	0.88	5.8	21	3.4357	1.4092	—	0.88	5.8	21	3.4357	1.4092	—	—
Bigtooth aspen	0.46	4.3	27	4.6636	1.0947	—	0.57	3.8	25	0.0660	1.1094	—	0.1427
Quaking aspen	0.51	3.8	24	4.6305	1.2798	—	0.59	3.5	22	0.7315	1.3180	—	0.0966
Black cherry	0.38	5.3	29	8.7282	0.9966	—	0.47	4.9	27	3.3194	1.0603	—	0.1118
White oak	0.68	4.8	23	5.9658	1.5212	—	0.69	4.7	22	3.4123	1.5158	—	0.0464
Scarlet oak	0.63	5.6	25	3.9710	1.6927	—	0.64	5.5	24	0.5656	1.6766	—	0.0739
Northern pin oak	0.58	5.4	25	4.8935	1.6069	—	0.58	5.4	25	4.8935	1.6069	—	—
Southern red oak	0.64	5.1	24	5.1272	1.6178	—	0.65	5.0	23	2.1517	1.6064	—	0.0609
Shingle oak	0.59	6.6	29	9.8187	1.1343	—	0.59	6.6	29	9.8187	1.1343	—	—
Turkey oak	0.36	3.5	22	5.8858	1.4935	—	0.36	3.5	22	5.8858	1.4935	—	—
Laurel oak	0.68	4.7	23	6.3149	1.6455	—	0.68	4.7	23	6.3149	1.6455	—	—
Bur oak	0.79	4.8	22	3.7927	1.6779	—	0.79	4.8	22	1.7827	1.6549	—	0.0343
Blackjack oak	0.49	4.7	29	3.9501	1.4227	—	0.50	4.6	29	0.5443	1.4882	—	0.0565
Chinkapin oak	0.65	4.5	22	5.3653	1.6598	—	0.67	4.4	22	0.6652	1.4759	—	0.1271
Water oak	0.51	5.9	27	7.4254	1.5630	—	0.53	5.8	27	4.0312	1.5516	—	0.0620
Pin oak	0.74	6.0	21	4.3830	1.6030	—	0.78	5.5	20	-4.4393	1.7459	—	0.1268
Willow oak	0.69	5.5	26	5.9791	1.4123	—	0.71	5.3	25	1.6477	1.3672	—	0.0846
Chestnut oak	0.54	5.3	26	4.6382	1.7431	-0.0189	0.55	5.2	25	2.1480	1.6928	-0.0176	0.0569
Northern red oak	0.61	5.7	25	6.2141	1.4026	—	0.63	5.6	25	2.8908	1.4077	—	0.0643
Post oak	0.63	4.3	22	4.1210	1.7018	—	0.64	4.2	21	1.6125	1.6669	—	0.0536
Black oak	0.62	4.9	23	6.2450	1.3744	—	0.64	4.7	23	2.8974	1.3697	—	0.0671
Live oak	0.69	8.2	29	5.6694	1.6402	—	0.69	8.2	29	5.6694	1.6402	—	—
Black locust	0.25	5.7	38	7.5471	0.8546	—	0.39	5.1	34	3.0012	0.8165	—	0.1395
Sassafras	0.20	4.3	30	6.4960	1.0728	—	0.24	4.2	30	4.6311	1.0108	—	0.0564
American basswood	0.46	5.1	28	7.1908	1.1561	—	0.58	4.5	25	1.0573	1.2234	—	0.1136
Winged elm	0.42	4.9	23	8.3991	1.6738	—	0.45	4.8	23	4.3649	1.6612	—	0.0643
American elm	0.40	7.3	37	3.5702	2.1201	—	0.41	7.3	36	0.6036	2.1141	—	0.0539
Slippery elm	0.37	5.7	27	9.8818	1.2909	—	0.37	5.7	27	9.8818	1.2909	—	—

* *LCW* = Largest crown width of stand-grown trees (i.e., mean crown diameter); *D* = diameter at breast height; *CR* = uncompacted vertical crown ratio (percent).

† *RSQ* = adjusted *r*-square; *RMSE* = root mean squared error from the regression solutions; *CV* = coefficient of variation from the regression solutions: *CV* = (*RMSE/mean LCW*) * 100, where mean *LCW* = mean crown width from the data.

†† Terms where parameter estimates are missing were excluded from the regression solutions due to nonsignificance at the 0.05 probability level. Nonsignificant model intercepts were retained in the solutions.

Bragg, D.C. 2001. A local basal area adjustment for crown width prediction. North. J. Appl. For. 18(1):22–28.

Dawkins H.C. 1963. Crown diameters: Their relation to bole diameter in tropical forest trees. Commonw. For. Rev. 42(4):318–333.

Gering, L.R., and D.M. May. 1995. The relationship of diameter at breast height and crown diameter for four species in Hardin County, TN. South. J. Appl. For. 19(4):177–181.

Gill, S.J., G.S. Biging, and E.C. Murphy. 2000. Modeling conifer tree crown radius and estimating canopy cover. For. Ecol. Manage. 126(2000):405–416.

Hann, D.W. 1997. Equations for predicting the largest crown width of stand-grown trees in western Oregon. For. Res. Lab., Oregon State Univ., Corvallis, OR. Res. Contrib. 17. 14 p.

Hann, D.W. 1999. An adjustable predictor of crown profile for stand-grown Douglas-fir trees. For. Sci. 45(2):217–225.

Hays, R.L, C. Summers, and W. Seitz. 1981. Estimating wildlife habitat variables. USDI Fish and Wildl. Serv. FWS/OBS-81/47. 111 p.

Hetherington, J.C. 1967. Crown diameter: Stem diameter relationships in managed stands of Sitka spruce. Commonw. For. Rev. 46(1967):278–281.

Hopkins, A.D. 1938. Bioclimatics, a science of life and climate relations. USDA Misc. Publ. 280. USDA, Washington, DC. 188 p.

Krajicek, J.E., K.A. Brinkman, and S.F. Gingrich. 1961. Crown competition: A measure of density. For. Sci. 7(1):35–42.

Moeur, M. 1981. Crown width and foliage weight of northern Rocky Mountain conifers. USDA For. Serv. Res. Pap. INT-283. 14 p.

Paine, D.P., and D.W. Hann. 1982. Maximum crown width equations for southwestern Oregon tree species. For. Res. Lab., Oregon State Univ., Corvallis, OR. Res. Pap. 46. 20 p.

Smith, H.C, and C.B. Gibbs. 1970. A guide to sugarbush stocking based on the crown diameter/dbh relationship of open-grown sugar maples. USDA For. Serv. Res. Pap. NE-171. 8 p.

Stolte, K.W. 2001. Forest health monitoring and forest inventory analysis programs monitor climate change effect in forest ecosystems. Human Ecol. Risk Assess. 7(5):1,297–1,316.

USDA Forest Service. 2002. Forest inventory and analysis national core field guide, Vol. 1: Field data collection procedures for phase 2 plots, Version 1.6. USDA For. Serv. intern. rep. Available at website http://fia.fs.fed.us/library.htm#manuals.

Zarnoch, S.J., W.A. Bechtold, and K.W. Stolte. In press. Using crown condition variables as an indicator of forest health. Can J. For. Res.