Estimating Leaf Area and Leaf Biomass of Open-Grown Deciduous Urban Trees

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ABSTRACT. Logarithmic regression equations were developed to predict leaf area and leaf biomass for open-grown deciduous urban trees based on stem diameter and crown parameters. Equations based on crown parameters produced more reliable estimates. The equations can be used to help quantify forest structure and functions, particularly in urbanizing and urban/suburban areas. For. Sci. 42(4):504–507.

Additional Key Words. Allometric equations, urban vegetation, urban ecology.

Measurement of tree leaf area and leaf biomass are important prerequisites to studying gas-exchange processes and modeling ecosystems. Few researchers have evaluated leaf area or leaf biomass of open-grown trees, particularly in urban environments (Gacka-Grzesikiewicz 1980). Accurate estimates of tree leaf area and leaf biomass in both urban and surrounding natural areas are critical in assessing evapotranspiration, atmospheric deposition, biogenic volatile organic emissions, light interception, and other ecosystem processes.

Equations or ratios often are used to estimate leaf area or leaf biomass from easily measured tree traits such as stem diameter (dbh) or cross-sectional area of sapwood (e.g., Gholz et al. 1979, Waring et al. 1982). Unfortunately, there are few equations based on stem diameter and/or for species commonly encountered in urban areas. Measurement of sapwood area is limited in urban environments because permission to core trees is required from multiple owners across the urban landscape and because the relatively high values placed on individual trees limit owner's willingness to permit trees to incur coring damage. The objective of this study was to develop and compare regression equations to predict leaf area and leaf biomass of open-grown, deciduous urban trees based on dbh and crown parameters.

Materials and Methods

In July 1992, data were collected from 54 healthy, open-grown park trees in Chicago, Illinois, that were selected specifically for full tree crowns in excellent condition. The sampled trees included 10 American elm (*Ulmus americana* L.), 10 green ash (*Fraxinus pennsylvanica* Marsh.), 10 hackberry (*Celtis occidentalis* L.), 10 honeylocust (*Gleditsia triacanthos* L.), and 14 Norway maple (*Acer platanoides* L.). Data were collected on dbh, tree height, height to base of live crown, and crown width. The dbh ranged from 11 to 53 cm, crown height (base of crown to crown top) from 3.4 to 9.1 m, and crown width from 4.1 to 14.0 m.

The dimensions of each tree crown were mapped with a telescoping measuring rod. Height and distance from the tree base were measured at crown boundary points every 1.5 m vertically and at every 45° azimuth radially to map the crown shape. Crown volume was calculated from these geometric measurements. Random distances along x, y, and z coordinates from the tree base were selected to determine sampling locations within each tree crown. Ten 0.4m^3 samples of foliage were collected from a high-lift truck. Sample locations in the tree crown were approached with the high-lift truck bucket so as not to disturb the sample prior to leaf collection.

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The number of leaves per sample were counted. For samples with 40 or fewer leaves, all leaves were analyzed for leaf area; otherwise, 30 leaves were subsampled randomly for analysis of leaf area. Subsample analyses were extrapolated to the individual sample total to allow for proportional weighting of the original samples. Single-sided leaf area was measured with a leaf-area meter (CID Inc., Conveyor Area Meter CI-251). Following leaf-area analyses, all leaves were dried at 65°C for 24 hr and then weighed. For each tree, the ratios of leaf dry-weight biomass and leaf area per cubic meter of sample were multiplied by crown volume to calculate total tree leaf biomass and leaf area.

Data on total leaf-surface area and leaf dry-weight biomass for 34 smaller urban trees (12 species) were obtained from Gacka-Grzesikiewicz (1980). These trees ranged in crown height from 0.7 to 12.8 m and in crown width from 0.5 to 4.6 m. Data from these trees were combined with data from the 54 trees measured in Chicago to produce equations for estimating total leaf-surface area and leaf dry-weight biomass of open-grown urban trees based on crown parameters.

Regression equations for predicting total leaf dry-weight biomass and leaf area were of the form:

$$\ln Y = b_0 + b_1 X + b_2 S$$

when based on dbh, and of the form:

$$\ln Y = b_0 + b_1 H + b_2 D + b_3 S + b_4 C$$

when based on crown parameters, where Y is leaf area (m^2) or leaf dry-weight biomass (g), X is dbh (cm), H is crown height (m), D is average crown diameter (m), S is the average shading factor for the individual species (percent light intensity intercepted by foliated tree crowns) (McPherson 1984), and C is based on the outer surface area of the tree crown ($\pi D(H+D)/2$) (Gacka-Grzesikiewicz 1980). Residual analyses indicated that a linear model was appropriate, that one model fits all species, and that errors were distributed with homogeneous variance. To correct for logarithmic bias in the regression equations (Crow 1988), a correction factor of one-half of the estimated variance should be added to the untransformed value ($y = e^{x + \mathrm{var}(x)/2}$) for each equation.

Results and Discussion

Regression equations (Table 1) based on crown parameters are more reliable estimators of leaf area and leaf biomass than equations based on dbh, as indicated by higher coefficients of determination and smaller mean-square errors. The greater reliability in predicting leaf area and leaf biomass based on crown parameters might be expected given that crown size (and its associated amount of leaves) is more directly related to crown parameters than dbh.

One of the first attempts to estimate leaf-surface area of urban trees was based on the assumption that total leaf surface area approaches the crown outer surface area (Gacka-Grzesikiewicz 1980). Although crown outer surface area was a significant variable in the equations estimating ln leaf area and ln leaf biomass based on crown parameters, it alone could not provide the most reliable estimate of leaf area ($r^2 = 0.61$; $MSE = 0.9840$) or leaf biomass ($r^2 = 0.64$; $MSE = 1.0147$).

Data for the equations estimating leaf area and leaf biomass were collected from small to moderate-size trees. The equations can be reasonably used for trees with a crown height of 1 to 12 m, crown width of 1 to 14 m, crown height to crown width ratio of 0.5 to 2, dbh of 11 to 53 cm, and species shading factor of 0.67 to 0.88. Shading factors for various species generally fall within this range (Table 2).

Species shading factors are based on the proportion of light intensity intercepted by the tree canopy: I/Io, where I = light intensity beneath canopy and Io = light intensity above canopy. These species specific factors correspond to the method of estimating leaf-area index (LAI) from light intensity using the Beer-Lambert Law:

$$\mathrm{LAI} = \ln(I/Io)/-k$$

where k = light extinction coefficient (Smith et al. 1991).

TABLE 1. Equations predicting total tree leaf area and leaf dry-weight biomass for open-grown deciduous urban trees. Two sets of equations were developed (*E*), one based on tree dbh (*n* = 53), the other on crown parameters (*n* = 88 for leaf area; *n* = 74 for leaf biomass). Standard errors of coefficients are given in parentheses.

E	*Y*	b_0	b_1	b_2	b_3	b_4	R^2	*MSE*
Dbh	Leaf area	0.2102 (0.8368)	0.0586 (0.0085)	4.0202 (1.0711)	na	na	0.64	0.3386
Dbh	Leaf biomass	7.6109 (0.2355)	0.0643 (0.0081)	ns	na	na	0.54	0.3616
Crown	Leaf area	–4.3309 (0.7227)	0.2942 (0.0253)	0.7312 (0.0579)	5.7217 (0.8147)	–0.0148 (0.0018)	0.91	0.2317
Crown	Leaf biomass	1.9375 (0.709)	0.4184 (0.057)	0.6218 (0.0709)	3.0825 (0.7918)	–0.0133 (0.0018)	0.92	0.2145

NOTE: Equations based on dbh are of the form $\ln Y = b_0 + b_1X + b_2S$; equations based on crown parameters are of the form $\ln Y = b_0 + b_1H + b_2D + b_3S + b_4C$ for the different dependent variables Y (leaf area in m^2, leaf dry-weight in g) and independent variables, X (dbh in cm), H (crown height in m), D (average crown diameter in m), S (percent light intensity intercepted by foliated tree crowns) (Table 2), and C ($\pi D(H + D)/2$) (Gacka-Grzesikiewicz 1980), where b_0–b_4 are regression coefficients, R^2 is the coefficient of determination and MSE is the mean square error. A correction factor of $MSE/2$ should be added to the untransformed estimate to correct for logarithmic bias; ns = not significantly different from zero at alpha = 0.05, na = not applicable.

Table 2. Average shading factors (percentage of light intensity intercepted by foliated tree canopies) (derived from McPherson 1984).[a]

Tree species	Shading factor
Acer Ginnala Maxim. (Amur maple)	0.91
Acer platanoides L. (Norway maple)	0.88
Acer rubrum L. (red maple)	0.83
Acer saccharinum L. (silver maple)	0.83
Acer saccharum Marsh. (sugar maple)	0.84
Aesculus hippocastanum L. (horsechestnut)	0.88
Albizia julibrissin Durazzini (silktree)	0.83
Amelanchier arborea (Michx. f.) Fern. (downy serviceberry)	0.77
Betula pendula Roth. (European white birch)	0.82
Carya ovata (Mill.) K. Koch (shagbark hickory)	0.77
Catalpa speciosa Warder ex Engelm. (northern catalpa)	0.76
Celtis australis L. (European hackberry)	0.92
Celtis occidentalis L. (hackberry)	0.88
Crataegus × *Lavallei* Herincq. (Carriere hawthorn)	0.89
Crataegus oxyacantha L. (English hawthorn)	0.86
Crataegus phaenopyrum (L.f.) Medic. (Washington hawthorn)	0.76
Elaeagnus angustifolia L. (Russian-olive)	0.87
Fagus sylvatica L. (European beech)	0.88
Fraxinus excelsior L. (European ash)	0.85
Fraxinus holotricha Koehne. cv. Moraine (Moraine ash)	0.78
Fraxinus pennsylvanica Marsh. (green ash)	0.83
Ginkgo biloba L. (maidenhair tree)	0.81
Gleditsia triacanthos f. inermis Schneid. (honeylocust)	0.67
Gymnocladus dioicus (L.) K. Koch (Kentucky coffeetree)	0.86
Juglans nigra L. (black walnut)	0.91
Koelreuteria bipinnata Franch. (Chinese flame tree)	0.9
Koelreuteria paniculata Laxm. (goldenrain tree)	0.81
Liquidambar styraciflua L. (sweetgum)	0.82
Liriodendron tulipifera L. (yellow-poplar)	0.9
Malus spp. Mill. (apple)	0.85
Parkinsonia aculeata L. (Jerusalem-thorn)	0.85
Pistacia chinensis Bunge. (Chinese pistache)	0.85
Platanus × *acerifolia* (Ait.) Willd. (London planetree)	0.86
Platanus racemosa Nutt. (California sycamore)	0.91
Populus deltoides Bartr. ex Marsh. (eastern cottonwood)	0.85
Populus tremuloides Michx. (quaking aspen)	0.74
Pyrus communis L. (pear)	0.8
Quercus alba L. (white oak)	0.75
Quercus palustris Muenchh. (pin oak)	0.77
Quercus robur L. (English oak)	0.81
Quercus rubra L. (northern red oak)	0.81
Sapium sebiferum (L.) Roxb. (tallowtree)	0.83
Sophora japonica L. (Japanese pagoda tree)	0.78
Tilia cordata Mill. (little-leaf linden)	0.88
Ulmus americana L. (American elm)	0.87
Ulmus pumila L. (Siberian elm)	0.85
Zelkova serrata (Thunb.) Mak. (Japanese zelkova)	0.8

[a] Summary of literature on species shading factors based on measurements with light meters, pyranometers, and photographs and optical scanners.

The regression equations were derived from data on healthy, full-crown, open-grown urban trees. Thus, the equations are estimating near-maximum leaf area and leaf biomass for individual open-grown urban trees. The equations will tend to overestimate leaf area and biomass for trees exhibiting leaf loss due to such factors as tree decline, insect defoliation, pruning, etc.

Conclusions

The regression equations based on tree crown parameters provide a more reliable means to estimate leaf-surface area and leaf biomass of open-grown deciduous trees than equations based on dbh. Additional research is needed to quantify how leaf area and leaf biomass of individual open-grown trees change based on tree condition, pruning and other factors that influence total crown mass.

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