A PRELIMINARY ABOVEGROUND LIVE BIOMASS MODEL FOR UNDERSTORY HARDWOODS FROM ARKANSAS, LOUISIANA, AND MISSISSIPPI

Don C. Bragg and D. Andrew Scott[1]

Abstract.—Hardwood understories can contribute significantly to total ecosystem biomass and fuel loads, but few models are available to directly quantify this component. In part, this is due to the small size of the hardwoods. Many understory trees simply do not reach the height required to determine diameter at breast height (d.b.h.), so conventional models (e.g., the National Biomass Estimators [NBE]) that rely on this predictor are unavailable. Further, understory hardwoods can be present in such numbers or have inconvenient growth forms such that biomass estimates based on diameters are impractical. However, a quick and easily measured attribute, stem length, can be used instead of diameter to facilitate understory hardwood biomass estimation. We destructively sampled 513 small hardwood shrubs and trees in Arkansas, Louisiana, and Mississippi and oven dried their aboveground live biomass (stems, branches, leaves) to a constant weight. The high degree of variability in plant form, branch patterning, and wood density among the 31 different taxa sampled suggested that a single hardwood grouping would be as effective as more specific equations. Nonlinear ordinary least squares regression was then used to predict aboveground live biomass with a modified version of the NBE (using stem length rather than d.b.h.). The coefficient of determination of the resulting model was reasonably high ($R^2 = 0.71$), particularly for data comprising such varied individuals. Further confirmation of the utility of this understory biomass model followed a comparison of several species with varying wood density.

INTRODUCTION

Research into the characterization of biomass resources has increased greatly in recent years as witnessed by a proliferation of articles, and even entire research journals, dedicated to this field. There are many practical reasons to study biomass, including the estimation of commercial product yields, quantification of fuel loads, determination of carbon sequestration trends, or description of habitat conditions. To date, most efforts have concentrated on the more economically valuable species. The commercial importance of forests in the southeastern United States, for example, has supported the development of scores of biomass-related predictions (Baldwin 1987, Bullock and Burkhart 2003, Parresol 1999).

Because trees constitute the majority of the aboveground biomass in most forest ecosystems, the prediction of individual stem biomass has been a high priority for most modelers. This has led to the development of a range of models, from finely tuned local designs (e.g., McElligott and Bragg, in press) to more widely developed regional (e.g., Bullock and Burkhart 2003) and national models (e.g., Jenkins et al. 2003, Ruiz-Peinado et al. 2012). These approaches have their strengths and weaknesses, and virtually all of them rely on the use of diameter at breast height (d.b.h.) to predict

[1] Research Forester (DCB), U.S. Forest Service, Southern Research Station, P.O. Box 3516 UAM, Monticello, AR 71656; Research Soil Scientist (DAS), U.S. Forest Service, Southern Research Station. DCB is corresponding author: to contact, call 870-367-3465 or email at dbragg@fs.fed.us.

the aboveground biomass of major tree species. Although hardwood biomass research has generally lagged behind that of conifers, a growing number of predictive models have been developed recently, such as those for the United States (Jenkins et al. 2003) and Europe (Ruiz-Peinado et al. 2012, Zianis et al. 2005).

The low value of smaller trees in the central hardwoods has limited commercial development and constrained silvicultural practices, although biomass-based markets could present new opportunities (Kabrick et al. 2013). To take advantage of these opportunities, a better accounting of the entire forest biomass resource is required. However, as in conifers, most hardwood research has focused almost entirely on larger stems. This tendency overlooks one potentially major source of biomass, understory hardwood trees and shrubs. Unfortunately, these hardwoods are a difficult resource to assess. Only a handful of models capable of directly estimating the biomass of understory trees and shrubs with a measurable d.b.h. exist. For example, Phillips (1981) predicted aboveground biomass of understory hardwoods between 2.5 and 12.5 cm d.b.h., and the National Biomass Estimator (NBE) hardwood groups extend down to 3 cm d.b.h. (Jenkins et al. 2003). Given the use of d.b.h. in most allometric relationships, the scarcity of biomass models for hardwoods that fail to reach this height threshold (1.37 m) is understandable. Height and some measure of diameter have also been used in combination to improve biomass estimation (Joosten et al. 2004, Phillips and Saucier 1979, Ruiz-Peinado et al. 2012). Such an effort requires the measurement of two variables (height and diameter), which can add to the time it takes to measure this component in the field.

For the smallest hardwoods, measuring diameter means sampling something other than d.b.h. since they may not reach the necessary height (1.37 m). Typically, this means ground line (root collar) diameter or basal diameter, which is often defined as stem thickness at 15 cm above the ground surface. A few studies have evaluated the biomass of woody shrubs and understory trees in terms of these alternative forms of stem diameter or some other measure of plant size. For example, Brown (1976) and Smith and Brand (1983) used basal diameter (stem diameter at ground line or 15 cm above the ground) to predict biomass for a number of shrubs in the northern latitudes of North America, and Bentley et al. (1970) and Vora (1988) both predicted the biomass of some California shrubs using measures of crown volume.

These dimensions can be challenging to measure, especially in dense understories or for multi-stemmed specimens, leaving a regrettable knowledge gap. Understory hardwoods can contribute significantly to total ecosystem biomass and related properties such as fuel loading, nutrient accumulation, or carbon sequestration. More choices for modeling understory hardwood biomass compatible with existing assessments without unduly burdensome measurement requirements are needed. Height classes are frequently used in understory inventories (Bragg and Heitzman 2009, Brose 2011, Gould et al. 2006), making stem length a convenient and logical option. Preliminary work by Scott et al. (2006) suggested that stem length alone may prove an effective alternative for diameter for understory hardwoods. Hence, our work represents a further exploration of the utility of a stem length-based aboveground biomass model for understory hardwood trees and shrubs from the middle southern states.

METHODS

Study Locations and Sampling Protocols

Samples were opportunistically selected from a number of sites in Arkansas, Louisiana, and Mississippi. Hardwood trees and shrubs growing in the understory of naturally regenerated, pine-dominated stands (both even and uneven aged) from compartments across the Crossett Experimental Forest in southeastern Arkansas were sampled during the summer of 2012. Small trees and shrubs were also harvested during the summers of 2003 and 2004 from 5- and 12-year-old loblolly pine plantations on the Palustris Experimental Forest in central Louisiana and from a 10-year-old loblolly pine plantation on the DeSoto National Forest in southeastern Mississippi.

Over 500 understory hardwood trees and shrubs were destructively collected to provide the aboveground live biomass (stems, branches, leaves) for this study, encompassing a range of different sizes for the most common species found at each site (Tables 1 and 2). Most sampled hardwoods were individual stems. For the specimens that had more than one stem, the samples were weighed based on total biomass for the whole plant, but only the length of the longest stem was used for that variable. To standardize for individual stems, the total biomass was then divided by the number of stems in these multi-stemmed understory hardwoods, and each was assigned the measured longest length. Stem length of each specimen was measured to the nearest centimeter in the field prior to being cut flush at ground level and packed into paper bags for further lab processing. Biomass samples were oven dried (at temperatures of at least 70 °C) to a constant weight, which was recorded to the nearest gram.

Model Selection and Evaluation

For this project, the following exponential function based on the NBE equation (Jenkins et al. 2003) was fit to the data:

$$AGB = e^{b_1 + b_2 \ln(L)} \quad (1)$$

where AGB is the oven-dry weight of aboveground live biomass (kg), L is the stem length (cm), and b_1 and b_2 are coefficients fit using nonlinear ordinary least squares regression. The following coefficient of determination for this general equation was provided by the fitting software:

$$R^2 = 1 - \sum(y - \hat{y})^2 / \sum(y - \bar{y})^2 \quad (2)$$

Because Equation 1 is nonlinear, Equation 2 cannot be interpreted in the same fashion as in linear regression, so the coefficient of determination is called a fit index or "pseudo-R^2". Even though it is commonly generated by statistical software packages, the use of Equation 2 for nonlinear regression has been roundly criticized as a tool to compare models (e.g., Kvålseth 1985, Spiess and Neumeyer 2010). However, because we are describing a specific predictive tool rather than making comparisons, we present R^2 as a simple expression of goodness of fit between the model and data.

Note that Equation 1 provides results on a per stem basis. Determining the total biomass for a multi-stemmed hardwood (e.g., a clump of stump sprouts) would require summing individual stem estimates. The high degree of variability in plant form, branch patterning, wood density, and limited

Table 1.—Understory hardwood trees and shrubs sampled from stands in Arkansas, Louisiana, and Mississippi used to develop the aboveground biomass model

Common name	Scientific name	Specific gravity [a]	n
Sweetgum	*Liquidambar styraciflua*	0.52	54
Red maple	*Acer rubrum*	0.54	53
Common persimmon	*Diosypros virginiana*	0.74	43
American beautyberry	*Callicarpa americana*	n/a	43
White oak	*Quercus alba*	0.68	30
Water oak	*Quercus nigra*	0.63	30
Southern red oak	*Quercus falcata*	0.59	29
Winged sumac	*Rhus copallinum*	n/a	23
Winged elm	*Ulmus alata*	0.66	20
Post oak	*Quercus stellata*	0.67	19
Mockernut hickory	*Carya tomentosa*	0.72	18
Gallberry	*Ilex glabra*	n/a	18
Sassafras	*Sassafras albidum*	0.46	18
American holly	*Ilex opaca*	0.57	16
Flowering dogwood	*Cornus florida*	0.73	15
Ash	*Fraxinus* spp.	n/a	15
Horse-sugar	*Symplocos tinctoria*	n/a	15
Buckthorn	*Rhamnus* spp.	n/a	11
Black hickory	*Carya texana*	n/a	8
Oak	*Quercus* spp.	n/a	5
Wax myrtle	*Morella cerifera*	n/a	5
Blueberry	*Vaccinium* spp.	n/a	4
Privet	*Ligustrum* spp.	n/a	4
Blackgum	*Nyssa sylvatica*	0.50	3
Viburnum	*Viburnum* spp.	n/a	3
Baccharis	*Baccharis halimifolia*	n/a	3
Yaupon	*Ilex vomitoria*	n/a	2
Black cherry	*Prunus serotina*	0.50	2
Chinese tallowtree	*Triadica sebifera*	n/a	2
Willow oak	*Quercus phellos*	0.69	1
Devil's walkingstick	*Aralia spinosa*	n/a	1

[a] Specific gravity of wood only, based on oven-dry weight and 12 percent moisture content for volume; adapted from Table 1A in Miles and Smith (2009); n/a = not available.

sample size for some species among the 31 different taxa sampled suggests that a single hardwood predictive model is probably as useful as more specific equations in this study. To further consider the utility of Equation 1 for a given species, actual data from the following three hardwood species with relatively large sample sizes (at least 25 individuals) and a range of wood specific gravities (SGs) were visually compared to the predictions from the equation: sweetgum (SG = 0.52), southern red oak (SG = 0.59), and persimmon (SG = 0.74). See Table 1 for scientific names and SGs for all species.

Table 2.—Range of stem length and aboveground live oven-dry (OD) biomass data used to derive understory hardwood model

	Stem length				Aboveground live OD biomass			
Common name	Min.	Max.	Avg.	Standard deviation	Min.	Max.	Avg.	Standard deviation
	------------------ *centimeters* -------------------				---------------------*kilograms* ---------------------			
Sweetgum	30	427	118.5	74.7	0.003	1.460	0.123	0.2202
Red maple	32	396	108.0	62.6	0.015	1.333	0.081	0.1810
Common persimmon	30	549	134.3	115.7	0.003	3.336	0.256	0.6330
American beautyberry	35	225	116.1	50.5	0.010	0.475	0.072	0.0840
White oak	32	176	84.9	44.3	0.016	0.229	0.063	0.0584
Water oak	31	213	109.1	53.9	0.016	0.330	0.090	0.0915
Southern red oak	41	216	99.0	41.4	0.021	0.264	0.104	0.0767
Winged sumac	43	222	102.8	48.4	0.020	0.520	0.117	0.1264
Winged elm	37	216	107.0	66.2	0.013	0.212	0.078	0.0727
Post oak	35	170	81.9	37.5	0.019	0.345	0.107	0.1014
Mockernut hickory	37	182	94.8	42.3	0.016	0.245	0.106	0.0579
Gallberry	30	351	151.6	96.9	0.002	0.501	0.067	0.1130
Sassafras	41	381	119.3	77.5	0.003	1.000	0.130	0.2311
American holly	34	229	109.6	56.2	0.018	0.440	0.145	0.1312
Flowering dogwood	39	290	126.2	69.2	0.019	0.505	0.141	0.1559
Ash	40	189	96.0	42.9	0.019	0.206	0.069	0.0592
Horse-sugar	33	168	89.6	41.7	0.014	0.227	0.072	0.0565
Buckthorn	32	224	92.3	56.6	0.014	0.282	0.080	0.0949
Black hickory	40	175	121.0	54.3	0.035	0.522	0.215	0.1725
Oak	46	427	213.4	162.4	0.020	2.020	0.685	0.8238
Wax myrtle	30	274	140.2	123.5	0.000	0.821	0.258	0.3678
Blueberry	76	107	91.4	12.4	0.020	0.167	0.080	0.0655
Privet	107	457	304.8	148.8	0.040	1.690	0.789	0.7101
Blackgum	91	305	213.4	109.9	0.060	0.840	0.470	0.3915
Viburnum	152	244	203.2	46.6	0.093	0.310	0.217	0.1116
Baccharis	107	168	147.3	35.2	0.010	0.240	0.150	0.1229
Yaupon	122	213	167.6	64.7	0.047	0.820	0.433	0.5468
Black cherry	290	351	320.0	43.1	0.480	1.540	1.010	0.7495
Chinese tallowtree	61	366	213.4	215.5	0.005	0.428	0.216	0.2991
Willow oak	81	81	81.0	--	0.026	0.026	0.026	--
Devil's walkingstick	229	229	228.6	--	0.200	0.200	0.200	--

RESULTS AND DISCUSSION

The fitted understory hardwood biomass model and original data are shown in Figure 1. For the species evaluated (Table 1), b_1 = -12.764 and b_2 = 2.161 with a reasonably high (0.71) coefficient of determination. Although Equation 1 was not as good as some understory hardwood equations (e.g., Bentley et al. 1970, Phillips 1981, Telfer 1969, Vora 1988), this multispecies equation performed well, particularly given the known variation in growth form between a number of apically dominant taxa such as sweetgum and those with more spreading forms or multiple stem species such as baccharis or American beautyberry. Growth form dissimilarity (including branch patterns, proportions of foliage and bark to stem and branch wood, vigorous versus stunted, differential browsing) undoubtedly contributed to added noise in our understory hardwood biomass measurements. Other researchers have found similar levels of variation in their data (Brown 1976, Smith and Brand 1983, Vora 1988). The broad geographic distribution of the sampled hardwoods (encompassing multiple sites from three different states) would incorporate localized variation in form and growth habit, further contributing to the modest fit of Equation 1.

Nevertheless, this model should prove useful for many applications, particularly if needed to predict biomass for large-scale or aggregated assessments as opposed to projecting for specific individuals. For example, Equation 1 should adequately yield stand or landscape level predictions of understory hardwood fuel loadings or carbon sequestration. A distinct advantage of this model design is that measuring stem length is easier and quicker than diameter for understory hardwoods, especially in dense vegetation or when the plant form is shrubby. This should permit more efficient sampling of understory hardwood biomass, thereby reducing overall uncertainty when using aggregate applications of this model design.

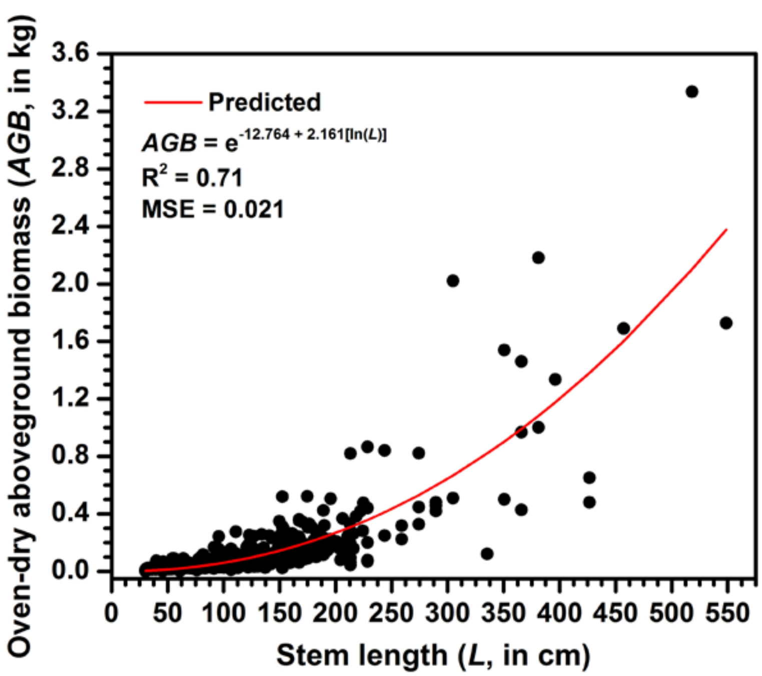

Figure 1.—Predicted (line) understory hardwood oven-dry aboveground live biomass (*AGB*) as a function of stem length (*L*) based on Equation 1, with all 513 data points included.

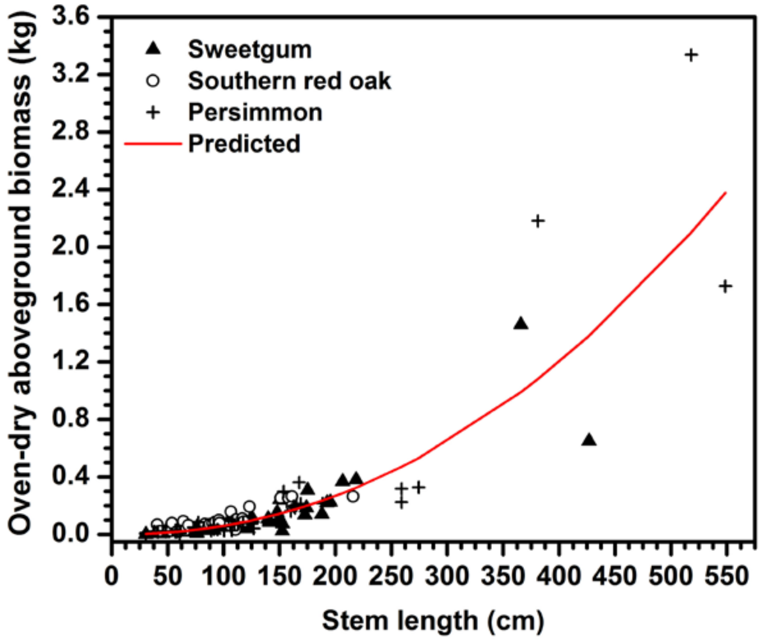

Figure 2.—Predicted and observed values of oven-dry aboveground biomass for three understory hardwood species across a range of specific gravities.

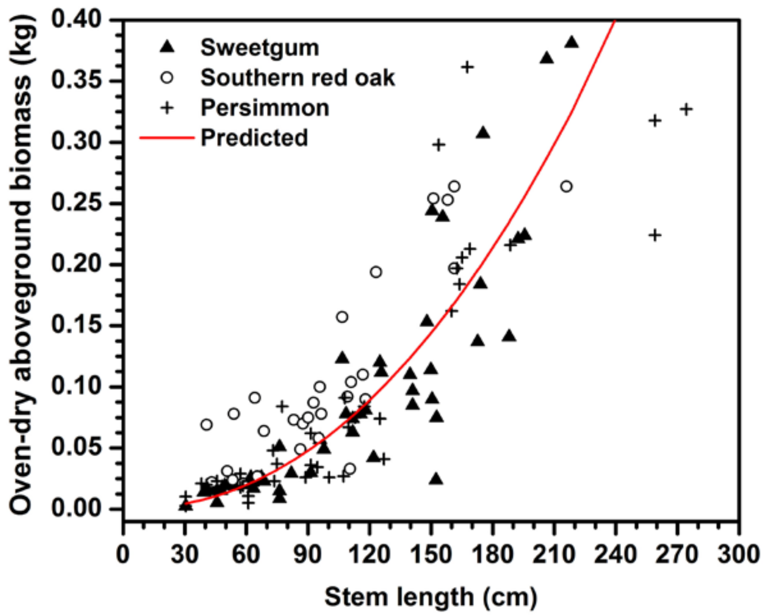

Figure 3.— Predicted and observed values of oven-dry aboveground biomass for a more limited subset (30 to 300 cm stem lengths) of the different understory hardwoods, used to highlight the nature of the fit across the majority of the observations.

Equation 1 predicted sweetgum, southern red oak, and persimmon about equally as well (Fig. 2), with no obvious trend with underestimation of AGB for species with high SG or overestimation of species with low SG. Based on a closer visual examination (no statistical contrasts were run) of the smallest trees (Fig. 3), southern red oak AGB tended to be under predicted using the model. Given that southern red oak was intermediate in SG, this result seemed counterintuitive at first. However, wood density is only one of several factors that contribute AGB for these small stems. We believe the under prediction of southern red oak can be explained by the greater amount of branching of this species in the understory.

CONCLUSIONS

Given the growing interest in describing comprehensive vegetative structure and dynamics for a variety of purposes (e.g., Alaback 1982, Gower et al. 2001, Lugo 1992, Reiner et al. 2010), the use of an understory-specific biomass predictor should help managers and researchers better understand the systems they are evaluating. Large scale or aggregated biomass estimates of regional carbon sequestration patterns or stand level fuel loads, for instance, can be collected quickly and more reliably if less effort is put into time consuming measurements of stem attributes, such as diameter or crown volume, and more time is invested into determining spatial patterns of understory distribution.

Although we anticipate further refinement, our preliminary results show that a simple length-based model can reasonably predict understory hardwood biomass for many different species across a range of site conditions. The noise in our data, even within species, favors the use of a single hardwood biomass model instead of multiple models based on individual taxa. This length-based approach appears to be an acceptable method for estimating biomass or fuel load, even when considering the range of different growth forms and wood densities. Such an aboveground biomass model has considerable utility for managers, permitting them to better quantify the attributes of their hardwood ecosystems.

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