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Equations for Estimating Biomass of Herbaceous and Woody Vegetationin Early-Successional Southern Appalachian Pine-Hardwood Forests

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Abstract

Allometric equations were developed to predict aboveground dry weight of herbaceous and woody species on prescribe-burned sites in the Southern Appalachians. Best-fit least-square regression models were developed using diameter, height, or both, as the independent variables and dry weight as the dependent variable. Coefficients of determination for the selected total biomass models ranged from 0.620 to 0.992 for herbaceous species and from 0.698 to 0.999 for the woody species. Equations for foliage biomass generally had lower coefficients of determination than did equations for either stem or total biomass of woody species.

Keywords: Mountain-laurel, *Kalmia latifolia*, xeric upland forests, oak-pine, prescribed fire, disturbance.

Introduction

Estimation of total aboveground biomass is important in studies of ecosystem processes and disturbances. Weighing vegetation to measure biomass or to develop prediction equations is time consuming and expensive, and requires destructive sampling.

This paper provides regression equations for predicting total aboveground dry weight. of some common herbaceous and woody species found on disturbed sites in the Southern Appalachians. The most common method for determining total aboveground biomass or productivity is through the use of allometric equations. These equations predict biomass of individual plants or their components from some easily measured variables such as diameter or height,. Although many regression equations exist for large trees (Crow 1913. Monk and others 1970, Pastor and others 1983. Schreuder and Swank 1971, Swank and Schreuder 1974, Whittaker and Woodwell 1968, Young 1976). few equations are available for herbaceous plants and small trees (Boring 1982, Boring and Swank 1986, Hitchcock 1978).

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Methods

Site Description

Two research sites, each covering approximately 5.25 ha, were chosen from areas previously designated for site-preparation burning by the Land Management Plan for the Wayah Ranger District of the Nantahala National Forest in western North Carolina. The two sites, Jacob Branch East (JE) and Jacob Branch West (JW), are in the Blue Ridge physiographic province of the Southern Appalachians (lat. 35°11'44" N., long. 83°24'14" W.). JE is on a west aspect and JW is on a south aspect. Midslope elevations, are about 755 m. Soils are in the Cowee-Evard complex, which includes fine loamy, mixed, mesic Typic Hapludults with only scattered rock outcrops and a clay-loam layer at about 30- to 60-cm depth. The overstory vegetation before treatment consisted primarily of scattered pitch pine (*Pinus rigida* Mill.), scarlet oak (*Quercus coccinea* Muenchh.), and chestnut, oak (*Q. prinus* L.). Overstory basal area ranged from 9 to 19 $m^2 ha^{-1}$ Basal area of the shrub understory, which was dominated by mountain-laurel (*Kalmia latifolia* L.), ranged from 18 to 35 $m^2 ha^{-1}$.

On both sites, all vegetation was cut, in June and July 1990 and left on site. After the cut vegetation had cured, the sites were burned on separate days (September 18 and 19, 1990). Consumption of dry foliage, loose forest floor litter, and fine woody material was complete except along the shaded margins of the cut area (well outside of the established plots). Large woody material (>75-mm diameter) was reduced by 31 percent on JE and 14 percent on JW (Swift and others, in press). During the first growing season after the burn, vegetative reproduction of most woody species and many grasses and herbs was substantial.

Sample Collection and Data Analysis

Random samples of plants of all species and sizes were collected from both sites in August 1991 (table 1). Total height (II) to the nearest 0.1 cm and diameter (D) to the nearest 0.01 cm at 1.0 cm above ground level were measured on each plant before the plants were clipped at ground level. Due to prolific sprouting in *Kalmia*, average diameters of the crowns of sprout clumps were measured in lieu of individual stem diameters. Crown diameters were measured by taking two perpendicular measurements through the center of each plant. Samples were dried to a constant weight at 70 °C (approximately 72 h) then weighed to the nearest 0.01 g to determine total aboveground dry weight. The tree and shrub samples were separated into foliage and wood components.

Best-fit least-square regression models were developed using PROC GLM (SAS Institute 1987) for the 49 species present on these sites. We considered the following eight models:

linear:

$$\widehat{Y} = \beta_1 + \beta_2 D$$
$$\widehat{Y} = \beta_1 + \beta_2 D + \beta_3 H$$
$$\widehat{Y} = \beta_1 + \beta_2 D^2 H$$
$$\widehat{Y} = \beta_1 + \beta_2 H$$
$$\widehat{Y} = \beta_1 + \beta_2 D^2 + \beta_3 H$$

transformed nonlinear:

$$ln\widehat{Y} = ln\beta_1 + \beta_2 lnD$$
$$ln\widehat{Y} = ln\beta_1 + \beta_2 lnH$$
$$lnY = ln\beta_1 + \beta_2 ln\, D + \beta_3 ln\, H$$

To test for site differences, we included site as a dummy variable in all the regression models. In all cases, we found that site did not affect. regressions significantly ($p<0.05$), so data were pooled to develop regression equations for individual species across sites. Models were selected based on graphical and residual analysis, comparisons of standard errors, and comparisons of coefficients of determination (r^2).

Results and Discussion

Probably because of the variation in growth forms of the herbaceous species, four models were needed to reasonably predict total biomass for the herbaceous vegetation (table 2). Only two models were necessary to predict total and component biomass for the woody vegetation (table 3). Coefficients of determination for the selected total biomass models ranged from 0.620 to 0.992 for herbaceous species (table 2) and from 0.698 to 0.999 for the woody species (table 3). Equations for foliage biomass generally had lower coefficients of determination than did equations for either stem or total biomass of woody species. All of the selected equations were highly significant, (1~0.02). Standard errors of the estimate ($S_{y \cdot x}$) are provided to correct for bias in the logarithmic equations (Baskerville 1972) and to show the relative variation between equations. $S_{y \cdot x}$ were generally smaller for the herbaceous species than for the woody species. Height, was included in all but 12 of the species-specific equations to improve the predictability. In some cases, the sample sizes were small ($n<8$ for five herbaceous and two woody species). We chose to include equations for individual species rather than combining species with similar growth forms because there are few equations available for herbaceous plants. Even though sample sizes were small, the coefficients of determination were large ($r^2>0.80$ in all cases), the equations were highly significant, and the $S_{y \cdot x}$ were small (tables 2 and 3).

Hitchcock (1978) developed regression equations for predicting total aboveground dry and green weights of hardwood seedlings and saplings 4, 6, and 8 years after clearcutting oak-hickory forests in Tennessee. However, most of the species in his study originated from propagules. On burned sites in the Southern Appalachians, much of the regeneration is in the form of sprouts originating from stumps or roots (Van Lear and Waldrop 1988). Stored nutrient reserves support fast early-growth rates in sprouts. This initial surge of growth results in diameter to height ratios that are probably different from ratios found in seedlings. Moreover, in Hitchcock's (1978) study, densities were on the order of 6,000 to 12,000 stems/ha compared with 45,000 to 68,000 stems/ha in our study.

These differences in age, regeneration mode, and density result in variations in growth form that make Hit&cock's (1978) equations inappropriate for conditions on our site. For example, basal diameters for tree species ranged from 1.4 to 4.0 cm in Hitchcock's study and from 0.10 to 1.50 cm in our study. Heights ranged from 30 to 640 cm in Hitchcock's study and from 3.0 to 161 cm in our study. When considering sprout regeneration, allometric relationships developed by Hitchcock would overpredict biomass using diameter and height. For example, using Hitchcock's equations for wood and median values of height and basal diameter from our study would overestimate stem biomass by 37 percent for blackgum (*Nyssa sylvatica* Marsh.) and 14 percent for red maple (*Acer rubrum* L.).

Extremely productive sites normally have proportionally greater height than diameter growth. Equations developed on these sites overpredict biomass on poor sites. Boring (1982) developed biomass equations for tree sprouts on a relatively mesic and productive site in the Coweeta Basin 1 to 3 years after clearcutting. Using a double logarithmic transformation, he measured stem diameters 40 cm above ground on fast-growing species such as red maple and yellow-poplar (*Liriodendron tulipifera* L.) and 2 cm above ground on slow-growing species such as hickory (*Carya* spp.), sourwood (*Oxydendrum arboreum* (L.) DC.), and blackgum. Application of Boring's (1982) equations to the median diameters of three slow-growing species in our study resulted in overestimates of 5, 28, and 53 percent for blackgum, sourwood, and hickory, respectively. Hence, when estimates of biomass are desired, it is important to match the size-class ranges, regeneration mode. successional stage, and site productivity.

Developing biomass predictors is time consuming and expensive. Regardless of the approach and the scale of application, therefore, the possibility of using existing predictors should be considered before making a. big investment in collecting new data. Although it is desirable to develop equations for individual sites, doing so may not be possible or practical. The prediction models presented here are most. likely to be useful for stand and site conditions and ranges in plant sizes similar to those under which they were developed. Our regression equations were developed for studies in disturbed early-successional forests in the Southern Appalachians.

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Table I--Ranges in height and diameter of sampled species

Species	Ranae	
	Height	Diameter
	---------cm---------	
Herbaceous		
Acalypha rhomboidea Raf.	27-56	0.20-0.40
Andropogon virginicus L.	13-125	0.35-5.50
Aralia spinoss L.	3-33	0.20-0.80
Aster divaricatus L.	22-83	0.20-0.60
Aureolaria laevigata (Raf.) Raf.	38—148	0.20-0.60
Baptisia tinctoria (L.)R. Br.	19-50	0.20-0.60
Carex spp.	3-10	0.20-4.50
Cassia fasciculata Michx.	10-44	0.20-0.30
Coreopsis major Walt.	20-96	0.30-0.90
Desmodium cuspidatum Muhl. ex Willd.	3-51	0.10-0.30
Erechtites hieracifolia (L.) Raf.	22-240	0.30-4.10
Galax aphylla L.	2-4	0.45-5.50
Helianthus atrorubens L.	67-155	0.20-0.90
Hypoxis hirsuta (L.) Coville	14-35	0.20-l .oo
Lespedeza hirta (L.)Hornem.	21-85	0.20-0.50
Lespedeza intermedia (S. Wats.) Britt.	3-43	0.10-0.30
Panicum commutatum Schultes	3-45	0.75-5.00
Panicum dichotomum L.	2-19	0.25-3.50
Phytolacca americana L.	7-205	0.40-2.30
Po ten tilla canadensis L.	2-69	0.25-0.60
Pteridium aquilinum (L.) Kuhn	13-62	0.10-0.30
Scleria triglomerata Mic hx.	4-57	0.20-0.50
Smilax glauca Walter	4-140	0.10-0.40
Smilax ro tundifolia L.	24-95	0.20-0.50
Solidago odora Aiton	68-140	0.40-0.90
Trillium catesbaei Eli.	8-20	0.20-0.30
Viola pedata L.	2-10	0.20— 1.25
Viola palmata L.	4-26	0.25— 1.50
Vitis sp p	S-26	0.10-0.30
Woody		
Acer rubrum L.	11-108	0.20-0.90
Betula lenta L.	6-40	0.20-0.40
Carya glabra (Mill.) Sweet	7-42	0.30— 1.20
Castanea pumila (L.) Mill.	29-95	0.40-l .60
llex ambigua var. *montana* (T&G) Ahles	7-76	0.10-0.60
Kalmia latifolia L.	5-43	0.20-25.0
Liriodendron tulipifera L.	3-60	0.20— 1.20
Nyssa sylvatica Marsh.	8-82	0.10-l .oo
Oxydendrum arboreum (L.) DC.	14-161	0.30— 1.90
Pyrularia pubera Michx.	2-23	0.10-0.65
Quercus alba L.	13-87	0.30-0.70
Quercus coccinea Muenchh.	10—81	0.30— 1.20
Quercus prinus L.	4-96	0.20— 1.20
Quercus velutina Lam.	6-65	0.20-1.10
Rhus glabra L.	3-48	0.10-0.90
Robinia pseudoacacia L.	3-138	0.10-1.50
Rubus argutus Link	4-38	0.20-0.60
Rubus occidentalis L.	5-70	0.30-0.60
Sassafras albidum (Nutt.) Nees	3-73	0.10-l .oo
Vaccinium vacillans Torr.	8-46	0.20— 1.50

Table 2--Equations for predicting biomass for herbaceous vegetation on Southern Appalachian clearcut and burned sites

Species	Model	r^2	p	n	$S_{y \cdot x}$
Acalypha rhomboidea	$Y = 0.20091 + 0.50335\ D^2H$	0.972	0.0003	6	0.282
Andropogon virginicus	$Y = -0.1970 + 0.0072\ D^2H$	0.983	0.0001	10	1.242
Aster divaricatus	$Y = -4.7462 + 23.8467\ D + 0.0252\ H$	0.742	0.0337	a	1.705
Aralia spinosa	$\ln(Y) = 2.31932 + 2.54267\ \ln D$	0.821	0.0008	9	0.744
Aureolaria laevigata	$\ln(Y) = 4.24777 + 2.72641\ \ln D$	0.958	0.0001	a	0.234
Baptisia tinctoria	$Y = 0.18389 + 2.07840\ D^2H$	0.870	0.0001	11	4.340
Carex spp.	$Y = -0.5077 + 0.1006\ D^2 + 0.1352\ H$	0.924	0.0010	a	0.397
Cassia fasciculata	$Y = -2.0669 + 9.9003\ D + 0.0585\ H$	0.927	0.0004	9	0.292
Coreopsis major	$\ln(Y) = 3.82856 + 2.32476\ \ln D$	0.802	0.0005	10	0.527
Desmodium cuspidatum	$Y = 0.11574 + 0.94497\ D^2H$	0.962	0.0032	5	0.281
Erechtites hieracifolia	$\ln(Y) = 2.34273 + 2.57110\ \ln D$	0.956	0.0001	13	0.499
Galax aphylla	$Y = -0.48231 + 0.40338\ D + 0.16388\ H$	0.931	0.0003	9	0.217
Helianthus atrorubens	$\ln(Y) = 3.17208 + 1.90949\ \ln D$	0.816	0.0135	6	0.585
Hypoxis hirsuta	$\ln(Y) = 0.00826 + 1.64219\ \ln D$	0.620	0.0040	11	0.735
Lespedeza hirta	$Y = 0.75458 + 0.46254\ D^2H$	0.919	0.0001	13	0.866
Lespedeza intermedia	$\ln(Y) = -3.0108 + 0.5348\ \ln D + 1.0367\ \ln H$	0.810	0.0006	12	0.512
Panicum commutatum	$Y = 0.59040 + 0.01769\ D^2H$	0.796	0.0001	12	2.715
Panicum dichotomum	$Y = -1.62756 + 2.04282\ D + 0.14607\ H$	0.922	0.0001	13	0.718
Phytolacca americana	$\ln(Y) = 2.75839 + 3.00346\ \ln D$	0.865	0.0001	13	0.680
Potentilla canadensis	$Y = -0.6357 + 3.7505\ D^2 + 0.0101\ H$	0.679	0.0187	lo	0.322
Pteridium aquilinum	$Y = -0.4938\ 1.7262\ D + 0.0716\ H$	0.930	0.0001	13	0.286
Scleria triglomerata	$Y = -0.3398 + 0.8090\ D + 0.0131\ H$	0.876	0.0001	14	0.071
Smilax glauca	$Y = 0.48144 + 0.44240\ D^2H$	0.962	0.0001	14	0.663
Smilax rotundifolia	$Y = -2.7891 + 6.2733\ D + 0.1060\ H$	0.978	0.0005	7	0.674
Solidago odora	$Y = 1.98681 + 0.41984\ D^2H$	0.992	0.0001	6	1.714
Trillium catesbaei	$Y = 0.13064 + 0.30293\ D^2H$	0.880	0.0002	9	0.063
Viola palmata	$Y = 0.20743 + 0.04288\ D^2H$	0.966	0.0001	a	0.182
Viola pedata	$Y = -0.60562 + 0.29282\ D + 0.18503\ H$	0.784	0.0046	10	0.376
Vitis spp.	$Y = -0.9289 + 0.8012\ D + 0.0953\ H$	0.934	0.0001	11	0.148

Note: $S_{y \cdot x}$ = standard error of the estimate.

Y = total aboveground biomass;

H = height;

D = diameter measured at ground level

Table 3--Equations for predicting foliage, stem, and aboveground biomass for woody vegetation on Southern Appalachian clearcut and burned sites

Species	Model	r^2	P	n	$S_{y \cdot x}$
Acer rubrum	Total = 1.73221 + 0.35811 D^2H	0.965	0.0001	13	1.973
	Foliage = 1.42077 + 0.18400 D^2H	0.943	0.0001	13	1.316
	Stem = 0.31144 + 0.17411 D^2H	0.957	0.0001	13	1.074
Betula lenta	Total = 0.03532 + 0.43961 D^2H	0.940	0.0001	10	0.303
	Foliage = 0.13673 + 0.22872 D^2H	0.755	0.0011	10	0.356
	Stem = -0.10140 + 0.21089 D^2H	0.877	0.0001	10	0.217
Carya glabra	ln(Total) = 3.5464 + 2.5956 lnD	0.892	0.0001	12	0.449
	ln(Foliage) = 3.0535 + 2.3755 lnD	0.821	0.0001	12	0.552
	ln(Stem) = 2.3091 + 3.0985 lnD	0.797	0.0001	12	0.779
Castanea pumila	Total = -0.34568 + 0.55872 D^2H	0.962	0.0001	11	7.808
	Foliage = 2.3370 + 0.28912 D^2H	0.966	0.0001	11	4.579
	Stem = -2.6827 + 0.26960 D^2H	0.945	0.0001	11	3.824
Ilex ambigua	Total = 1.6503 + 0.41170 D^2H	0.773	0.0001	15	1.873
	Foliage = 1.2387 + 0.18937 D^2H	0.622	0.0008	14	1.288
	Stem = 0.55820 + 0.21836 D^2H	0.870	0.0001	14	0.735
Kalmia latifolia	Total = 4.7570 + 0.00879 D^2H	0.991	0.0001	13	6.701
	Foliage = 4.2674 + 0.00617 D^2H	0.985	0.0001	13	6.185
	Stem = 0.48861 + 0.00262 D^2H	0.996	0.0001	13	1.316
Liriodendron tulipifera	Total = 0.37855 + 0.30788 D^2H	0.999	0.0001	10	0.255
	Foliage = 0.33588 + 0.19829 D^2H	0.998	0.0001	10	0.230
	Stem = 0.04267 + 0.10958 D^2H	0.999	0.0001	10	0.045
Nyssa sylvatica	Total = 2.7869 + 0.32181 D^2H	0.880	0.0001	20	2.624
	Foliage = 2.0739 + 0.18181 D^2H	0.813	0.0001	20	1.926
	Stem = 0.71297 + 0.14001 D^2H	0.911	0.0001	20	0.964
Pyrularia pubera	ln(Total) = 2.9598 + 2.7704 lnD	0.698	0.0014	11	0.430
Oxydendrum arboreum	Total = 4.3222 + 0.29848 D^2H	0.971	0.0001	13	8.315
	Foliage = 3.9818 + 0.10234 D^2H	0.904	0.0001	13	5.396
	Stem = 0.34041 + 0.19614 D^2H	0.989	0.0001	13	3.362
Quercus alba	Total = -0.0008 + 0.9838 D^2H	0.985	0.0001	10	1.625
	Foliage = 1.5105 + 0.42193 D^2H	0.920	0.0001	10	1.688
	Stem = -1.5063 + 0.56171 D^2H	0.979	0.0001	10	1.124
Quercus coccinea	Total = 7.2843 + 0.38518 D^2H	0.828	0.0017	8	7.367
	Foliage = 6.0265 + 0.19565 D^2H	0.682	0.0115	8	5.609
	Stem = 1.2578 + 0.18952 D^2H	0.947	0.0001	8	2.565
Quercus prinus	ln(Total) = 3.92693 + 2.97911 lnD	0.930	0.0001	13	0.588
	ln(Foliage) = 3.2388 + 2.6804 lnD	0.924	0.0001	13	0.554
	ln(Stem) = 3.1858 + 3.5281 lnD	0.903	0.0001	13	0.832
Quercus velutina	ln(Total) = 3.59651 + 2.43293 lnD	0.863	0.0001	15	0.593
	ln(Foliage) = 3.1641 + 2.2713 lnD	0.840	0.0001	15	0.606
	ln(Stem) = 2.5322 + 2.8710 lnD	0.899	0.0001	15	0.588

Table 3--Equations for predicting foliage, stem, and total aboveground biomass for woody vegetation on clearcut and burned sites in the Southern Appalachians--Continued

Species	Model	r^2	p	n	$S_{y \cdot x}$
Rhus glabra	Total = 1.5130 + 0.62920 D^2H	0.974	0.0001	7	1.587
	Foliage = 1.2388 +0.44405 D^2H	0.974	0.0001	7	1.126
	Stem = 0.27415 + 0.18516 D^2H	0.964	0.0001	7	0.548
Robinia pseudoacecia	ln(Total) = 3.50859 + 2.81508 lnD	0.984	0.0001	8	0.313
	ln(Foliage) = 2.7481 + 2.6673 lnD	0.965	0.0001	8	0.455
	ln(Stem) = 2.8293 + 2.9739 lnD	0.984	0.0001	8	0.336
Rubus argutus	Total = 0.30682 + 0.65899 D^2H	0.869	0.0001	12	0.698
	Foliage = 0.29750 + 0.46901 D^2H	0.854	0.0010	8	0.631
	Stem = -0.02260 + 0.18560 D^2H	0.947	0.0001	8	0.141
Rubus occidentalis	Total = 0.71972 + 0.13954 D^2H	0.794	0.0071	7	0.680
Sassafras albidum	Total = 2.63829 + 0.75199 D_2H	0.885	0.0001	15	4.589
	Foliage = 2.1520 + 0.40803 D^2H	0.831	0.0001	15	3.105
	Stem = 0.48632 + 0.34397 D^2H	0.911	0.0001	15	0.964
Vaccinium vacillans	Total = 1.4023 + 0.04855 D^2H	0.764	0.0001	14	0.754
	Foliage = 0.78760 + 0.02516 D^2H	0.674	0.0011	12	0.535
	Stem = 0.48738 + 0.02336 D^2H	0.897	0.0001	12	0.241

Note: $S_{y \cdot x}$ = standard error of the estimate;
H = height;
D = diameter measured at about 1 .O cm from ground level.

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