Equations For Estimating Above-Ground Phytomass in the Understory of Appalachian Oak Forests

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ABSTRACT

Regression equations were developed for estimating total aboveground phytomass for 17 tree and shrub species in the understory of second growth Appalachian oak forest stands in southwest Virginia. All possible combinations of three functional forms of the equation and three independent variables, singly and in combination, were tested. The linear model, with stem basal area as the independent variable, provided the best fit to the data for 15 of the 17 species. The exceptions were the blueberries (*Vaccinium stamineum* and *V. vacillans*), where crown area performed better than basal area as the independent variable.

INTRODUCTION

The present study was conducted as part of a project designed to investigate the effects of whole-tree harvesting and skyline cable logging on the long-term productivity of Appalachian oak forests occupying mid to upper mountainous slopes in the Ridge and Valley Physiographic Province of Virginia. The major objective of this phase of the project was to develop regression equations for predicting phytomass of woody plant species from their structural attributes. Application of these equations will provide a non-destructive and efficient means of monitoring phytomass levels at successive time intervals following harvesting operations.

STUDY AREA

The area from which sample stands were selected is situated at midslope (730 m. elevation) on the southeast face of Potts Mountain in Craig County, Virginia. Dominant and co-dominant trees in the overstory average about 60 years of age. The overstory is dominated by chestnut oak (*Quercus prinus*), scarlet oak (*Q. coccinea*), and black oak (*Q. velutina*), except on the more xeric sites where pitch pine (*Pinus rigida*) and table mountain pine (*P. pungens*) become increasingly important (McEvoy et al., 1980). Site index (base age 50) for upland oaks (Olson, 1959) varies from about 30 on the dry sites to about 70 in shallow cove-like positions where moisture conditions are more favorable. Thus, the area encompassed by the sample stands is typical of poor to moderate quality upland sites in the Ridge and Valley Province underlain by acid sandstones and shales. More thorough descriptions of the study area are provided elsewhere (McEvoy et al., 1980; Martin, 1979; Morin, 1978).

METHODS

Four noncontiguous sample stands, located within four km of each other, were selected to represent the major compositional and structural variants occurring along a topographically derived moisture gradient (McEvoy et al., 1980). These variants, in order from mesic to xeric sites, included: (1) mixed hardwoods with ericaceous understory mostly absent; (2) mixed oak with light to moderate ericaceous understory, (3) mixed oak-pine with moderate to heavy ericaceous understory, and (4) mixed pine with heavy ericaceous understory.

A 20 x 20 m area was designated for destructive sampling in each of the four vegetation types. Each 20 x 20 m area was subdivided into 16 5 x 5 m subplots for "shrub stratum" determinations. Basal stem diameter (BSD) at 15 cm above ground level, total height (TH) and crown diameter (CD) were recorded by species for all woody stems between 1 and 5 m in height. These stems and attached foliage were subsequently harvested and returned to the laboratory where they were oven dried at 65°C for 72 hours and weighed. Basal stem diameter and crown diameter were converted to basal area (BA) and crown area (CA) for subsequent analyses of the data. Selection of structural measurements and precision was based on previous studies of a similar nature in other regions (Ohmann et al., 1976; Telfer, 1969; Tappeiner and John, 1973).

Four 1 x 1 m microplots were randomly located within each 5 x 5 m plot, yielding a total of 48 microplots (per 20 x 20 m area) in which all individuals between 0 and 1 m (termed the "herb stratum") were sampled. Determination of the number of microplots to yield statistically reliable results was based on: (1) estimates of variability in structural vegetative attributes previously collected in nine nearby permanent study areas encompassing the range of vegetation types under investigation here, and (2) an estimate of sample size (n) in the first area to be sampled in this study, a mixed pine vegetation type, where n = 3.96 * variance/allowable error of ± 5% of the mean at $\alpha = .05$. In each microplot, all woody stems with attached foliage were clipped at ground level and returned to the laboratory where they were stored at 0°C for 1 week until structural dimensions (BSD, TH, CD) could be measured. Stems were then oven dried and weighed. All phytomass was harvested during a nine week period in July and August.

Phytomass and structural dimension values were used on an individual stem basis for developing species level regression models. Those species that did not include a continuous array of basal stem diameter values were excluded from the analysis. This screening process resulted in the elimination of 15 of the 32 species occurring in the initial sampling. Minimum sample size for any one species retained for analysis was 15 stems.

Selection of the "best regression model" for prediction of total above-ground phytomass was based on comparisons of coefficients of determination (R^2) and relativized standard errors of the regression ($S_{y \cdot x}/\bar{Y}$) involving all possible combinations of three functional forms (linear, exponential and allometric) and three independent variables (TH, BA, CA).

Equations were originally generated by stratum for those species occurring in both the herb and shrub strata. However, as the relationship varied little among strata, or because few individuals of a species attained a height in excess of one meter, data from both strata were subsequently combined in the analyses.

RESULTS

Screening of various models for predicting total above-ground phytomass (Y) indicated that the linear equation $Y = a + bX$, using stem basal area as the independent variable (X) gave the best fit for the majority of the species tested (Table 1). Adding other independent variables (stem height and crown area) did little to improve the initial equation. The blueberries (*Vaccinium vacillans* and *V. stamineum*) were exceptions in that crown area (R^2 = .316 and .950; $Sy \cdot x/\bar{Y}$ = .850 and .339 respectively) was a better predictor of total phytomass than was stem basal area (R^2 = .265 and .704; $Sy \cdot x/\bar{Y}$ = .936 and .824 respectively) and the latter accounted for little additional variation in phytomass beyond that explained by regression on crown area alone.

Equations combined data from both strata for 12 of the 17 species analyzed. Those for *Vaccinium vacillans* and *V. stamineum* were based strictly on herb stratum values, as no individuals greater than a meter in height occurred in the sample plots. Likewise, equations for *Acer rubrum* and *Cornus florida* were generated exclusively from herb stratum data, as sample sizes for the shrub stratum were too small.

DISCUSSION

Other studies of understory phytomass-structural relationships have also found stem diameter (or basal area) to be the best predictor of the independent variables screened (Whittaker and Marks, 1975; Ohmann et al., 1976). In our study, plant height varied relatively little within species, which in the 60 to 80 year old second-growth stands under investigation tend to reach a given height in the understory and then stagnate (Ross et al., 1981). Where disturbances such as cutting or fire occur, individual stems may respond in height increment and thus the variable may take on added significance in accounting for differences in above-ground phytomass.

As indicated earlier, our analysis suggests that blueberries (*Vaccinium vacillans* and *V. stamineum*) exhibit a growth pattern quite different from that of other woody plant species in the understory. For *V. vacillans*, in particular, it was not possible to account for more than 35 percent of the variation in above-ground phytomass using all possible combinations of independent variables tested. Furthermore, crown area performed substantially better than stem basal area in this regard. A comparable allometric equation developed for *V. vacillans* in oak-pine forests in Brookhaven, New York exhibited a higher R^2 (0.75) than did the equation developed here (Whittaker and Woodwell, 1968). However, the relative error of estimate was among the highest of all the species regressions developed in the Brookhaven study. The relatively poor fit to the data may in part stem from the highly clonal growth habit of the blueberries, although the closely related huckleberry (*Gaylussacia baccata*) did not present similar problems (Table 1). Ohmann et al. (1976) likewise found that regressions of above-ground phytomass on stem diameter for beaked hazel (*Corylus cornuta*), a highly clonal shrub species, were

Table 1. Equations for estimating total above-ground phytomass (g) for selected species in the understory of an Appalachian oak forest in southwest Virginia*

Species	a	b	R^2	Sy·x	$\overline{Y}$
*Acer pensylvanicum***	-0.712	0.434	.933	1.1	1.8
*Acer rubrum***	-0.011	0.205	.795	0.5	0.5
Castanea dentata	-81.152	1.506	.989	108.6	580.1
*Cornus florida***	-0.048	0.266	.856	0.2	0.7
Carya glabra	-3.288	1.238	.988	159.0	974.4
Gaylussacia baccata	-1.771	0.566	.821	3.5	7.8
Kalmia latifolia	-60.731	1.377	.894	146.0	330.9
Nyssa sylvatica	-161.358	1.659	.889	489.4	611.5
Oxydendrum arboreum	-30.494	1.208	.875	115.0	288.2
Quercus coccinea	-116.011	2.481	.917	621.8	559.0
Quercus ilicifolia	-10.700	1.375	.974	23.8	92.0
Quercus prinus	-25.110	1.744	.987	140.1	283.8
Quercus velutina	-154.656	2.146	.992	295.9	1387.9
Rhododendron nudiflorum	-6.169	1.147	.986	13.4	15.7
Sassafras albidum	-29.944	1.127	.932	109.6	95.0
*Vaccinium stamineum***	-2.098	0.010	.950	4.4	13.0
*Vaccinium vacillans***	-1.376	0.005	.316	2.2	2.6

* Equation is of the form $Y = a + bX$ where Y = total above-ground phytomass (g) for stems up to 5 m in height and X = basal area (mm^2) for all species except *Vaccinium stamineum* and *V. vacillans*, where X = crown area (cm^2).

** Based on stems $\leq$ 1 m in height.

unsatisfactory. Tappeiner and John (1973) reported R^2s above .90 for the relationship between above-ground phytomass and stem basal area in beaked hazel when both the independent and dependent variables were expressed on a per unit land area basis rather than an individual stem basis. Similar attempts at developing such regressions for *Vaccinium* spp. in the present study areas did not improve the relationship over that developed from individual stem analysis.

Ohmann et al. (1976), in a study of phytomass-structural relationships involving five shrub species in northeastern Minnesota, likewise found that the linear model exhibited a better fit to the data than did the exponential and allometric models. In contrast, Whittaker and Marks (1975), citing numerous studies involving a wide array of woody species, concluded that the allometric model (power function) is generally the most appropriate mode for expressing the relationship between total above-ground phytomass and stem diameter. In the present study the transformation from stem diameter to basal area tended to linearize the relationship and thus improve the fit of the linear model relative to the allometric model. It was also noted that for those tree species that extend well into the 1 - 5 m stratum and thus exhibit a wide range of phytomass values, such as the oaks, the basal area-phytomass relationship is somewhat curvilinear. This suggests that the relationship involving the full range of stem sizes from seedlings to mature trees in the upper canopy may be expressed more accurately by an allometric than a linear function. From a practical standpoint it was easier to sample stems by height classes (<1m, 1-5m, >5m), which facilitates the application of linear models for estimating phytomass.

An attempt was made to utilize a pin frame sampling technique for developing phytomass-structural relationships involving herbaceous plants, as the structural dimensions utilized in woody plant analyses are not practical for such life forms (Anderson, 1963). However, the regressions generated from this approach accounted for little of the variation in phytomass. Thus, there is yet to be found a satisfactory approach for non-distructively estimating herbaceous phytomass in the oak stands under investigation.

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