A PRELIMINARY TEST OF ESTIMATING FOREST SITE QUALITY USING SPECIES COMPOSITION IN A SOUTHERN APPALACHIAN WATERSHED

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Abstract—Characteristic arborescent communities of mesophytic or xerophytic species have long been recognized as indicative of forest site quality in the Southern Appalachians, where soil moisture availability is the primary environmental variable affecting productivity. But, a workable quantitative system of site classification based on species composition is not available. We devised a prototype expert system by assigning a relative moisture weight to upland forest tree species according to their position of modal occurrence on a soil moisture gradient ranging from xeric to mesic. We classified forest sites by their position on the gradient, which was quantified by an index representing the average moisture weight for all species present. We determined the relationship of the moisture index with upland oak site index on permanent plots dominated by even-aged stands of either mixed oaks (*Quercus* spp.) or yellow-poplar (*Liriodendron tulipifera*). Regression analysis indicated the moisture index was significantly ($P < 0.001$) associated with observed site index and explained 62 percent of its variation. Validation of the model with an independent dataset resulted in a mean absolute error in oak site index of 6.9 feet. Results of this exploratory study suggest that estimation of site index based on species composition has potential for application in mixed upland hardwood stands of the Southern Appalachians.

INTRODUCTION

The productive capacity of forest stands strongly influences their response to silvicultural treatments (Smith 1962). Site index is the method most used to evaluate site quality in eastern upland hardwood stands (Carmean 1970) and Beck and Trousdell (1973) provide a thorough description of the method, particularly its underlying assumptions and limitations. Estimation of site index in mixed hardwoods is often problematic, however, because suitable sample trees are often lacking, particularly on sites of intermediate or lower quality where oaks (*Quercus* spp.) and hickories (*Carya* spp.) predominate (Carmean 1970). Estimated site index may be biased in many stands, therefore, resulting in erroneous classifications of productivity. Replacement of conventional site index estimation based on sample trees with an alternate method is highly desirable for ecosystems where oaks are important. One such method is a procedure reported by Whittaker (1956) for arraying stands on environmental gradients based on composition of the tree stratum.

Forest productivity in the Southern Appalachian Mountains is associated primarily with temperature and moisture gradients (Whittaker 1966) and somewhat with fertility. Whittaker (1966) reported that ". . . an index of site moisture conditions based on weighted averages of stand composition . . ." was highly correlated with forest production. He subdivided the topographic-soil moisture gradient within broad elevation zones into four soil moisture classes (mesic, submesic, subxeric, and xeric) and assigned a weight to each class. Each tree species was assigned to a soil moisture class based on its modal frequency of occurrence along the gradient. Whittaker used the weighted average of each species present >1-inch d.b.h. as an index of the soil moisture conditions for a site. The index, which was a means for quantifying the relative position of sites on the moisture gradient, was highly correlated with primary forest production for vegetative communities occupying environments ranging from xeric to mesic in the Great Smoky Mountains National Park (Whittaker 1966). The simplicity of such a site classification system is appealing for a number of reasons: it can be readily applied with data typically collected from sample plots in a systematic inventory of stand conditions, it is easily adapted to other ecosystems with their associated species, it can be extended to other environmental gradients of temperature and nutrients, the system has an ecological basis because it is not based on commercial timber species as is site index, and its underlying basis is easily conveyed to other audiences.

This report describes results of a method of forest site classification based on arborescent species composition of upland hardwood stands in the Southern Appalachians. Previous work on the method (McNab and others 2002, 2003) utilized landscape scale datasets to explore possibilities of using species composition for site classification, but our current study is the first assessment using field data appropriate for model development and accuracy testing. This exploratory study investigated the question: Is a measure of species composition correlated with site index? Because methodology for the proposed method of site classification has not been evaluated, the purpose of this investigation was to obtain information on the type of vegetation data to collect. Such information included the strata of vegetation to inventory, e.g., saplings, trees, and the diagnostic value of rare species and ubiquitous species. Other important questions dealing with appropriate species weight values and if an index of moisture regime is more strongly related to growth response of silvicultural treatment or other ecological responses than to site index, will be addressed in future studies. Therefore, the intent of this exploratory study was the initial assessment of a new technique to determine if further evaluation and development is warranted and not to report a new method of site classification for immediate application.

METHODS

Study Area

The study was conducted in Bent Creek Experimental Forest—a 5,500-acre watershed located about 10 miles southwest of Asheville, NC. This area is characterized by

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short, mild winters and long, warm summers. Elevation ranges from 2,200 to 4,000 feet. Annual precipitation ranges from about 45 to 55 inches, depending on elevation and is evenly distributed throughout the year. Geologic formations consist of gneisses and schists of Precambrian age that have weathered to form a complex, dissected land surface. Soils, which consist mainly of Ultisols on gentle slopes and lesser areas of Inceptisols on steeper terrain, are generally deep and support over 50 hardwood species. The arborescent overstory canopy on dry slopes and ridges typically consists of communities dominated by scarlet oak (*Q. coccinea* Muenchh.), white oak (*Q. alba* L.), chestnut oak (*Q. prinus* L.), and black oak (*Q. velutina* Lam.). Typical mesophytic species occurring on moist slopes and in coves include yellow-poplar (*Liriodendron tulipifera* L.), northern red oak (*Q. rubra* L.), white ash (*Fraxinus americana* L.), eastern hemlock (*Tsuga canadensis* L.), cucumbertree (*Magnolia accuminata* L.), and black locust (*Robinia pseudoacacia* L.). Midstory species include flowering dogwood (*Cornus florida* L.), blackgum (*Nyssa sylvatica* Marsh.), sourwood [*Oxydendrum arboreum* (L.) DC.]; shortleaf pine (*Pinus echinata* L.) or pitch pine (*P. rigida* Mill.) may occur on heavily disturbed dry sites. Several species of hickory occur on dry and moist sites. Red maple (*Acer rubrum* L.) is usually present on sites of all moisture regimes. American chestnut [*Castanea dentata* (Marsh.) Borkh.] was a major component of most stands, particularly on dry slopes, before it was lost as a canopy species resulting from an introduced disease in the 1920s. Frothingham (1931) suggested that mountain forests below 4,000 feet elevation may be classified in two broad groups: moist slope and cove, and dry slope and ridge.

Most stands in the Bent Creek Experimental Forest have been affected by past settlement. Extensive areas of gentle slopes were cleared for subsistence farming from 1800 until about 1900, when land abandonment resulted in establishment of pine-hardwood mixtures on dry sites and yellow-poplar on moist sites. Timber stands on areas of steeper slopes, which were not cultivated or cleared for pasture, were typically burned, grazed, and periodically harvested by high-grading. Following acquisition of the watershed by the U.S. Forest Service around 1916, burning ceased and timber stand improvement work was done in selected areas to reduce stocking of undesirable species such as red maple, sourwood, and dogwood. Natural fires resulting from lightning is not common.

Field Plots

Field plots for our study had been established originally for two other investigations, one dealing with site index of upland oaks on dry sites and the other to study growth and yield of yellow-poplar on moist sites. In the site index study, Doolittle (1957) established 114 0.2-acre plots in even-aged stands of upland oaks where site index averaged 62 feet (range 36 to 87). All arborescent vegetation on the plots in the regeneration, sapling, and tree size strata was inventoried by species in 1970. The growth-and-yield study consisted of 34 0.25-acre plots established in even-aged stands dominated by yellow-poplar (Beck and Della-Bianca 1970) where site index averaged 99 feet (75 to 116). We pooled field data from the two studies to form a dataset extending over the mid- to upper range of site qualities occurring in the watershed. The group of plots established for the growth-and-yield study are dominated by mesophytic species and are considered representative of highly productive stands on mesic and submesic sites. The group of plots established for the study of site index was dominated primarily by oaks and other xerophytic species on xeric and subxeric sites. Site index relationships developed by Schnur (1937) for upland oak stands in the central hardwood region were used as the standard measure of productivity. We converted yellow-poplar site index to oak site index using the relationships presented by Doolittle (1958). Across all 148 plots, oak site index averaged 65 feet and ranged from 36 to 96 feet.

Vegetation Inventory

Arborescent vegetation occurring on each sample plot was inventoried to determine the species present by size classes and an assessment of their abundance. The number of species present was determined by inventory of arborescent vegetation in three size classes: regeneration (stems 0.1 to 4.5 feet tall), sapling (0.01 inch to 4.5 inches d.b.h.), and tree (>4.5 inches d.b.h.). The number of individuals of a species occurring in a size class, or abundance, was of particular importance in our study. Although Whittaker (1956) determined the abundance of each species by counting density, we used the less subjective method of presence or absence for several reasons. First, other ecological studies have shown presence is an easily quantified objective measure of a species occurrence that provides analysis capability equal or superior to density counts as a measure of abundance (Strahler 1977). More important, however, a conventional measure of density, e.g., stems per acre, was not used because we have observed abundance of some tree species tends to be associated with the intensity of recent disturbance rather than response of the species to effects of environmental factors (Beck and Hooper 1986, McGee and Hooper 1975, see table 1). We used a modified measure of density to determine if species rarity was an important source of variation. To account for the occurrence of a species resulting from a random, stochastic event unrelated to the environment, a maximum of two individuals of each species were recorded in each size class, which provided a measure of rareness. A species was classified as rare if it was represented by only one individual, e.g., $n = 1$, in the three combined vegetation size classes, or common if it occurred more than once, e.g., $n > 1$. For example, if only one sapling of Virginia pine (*P. virginiana* Mill.) was inventoried on a sample plot ($n = 1$), that species was classified as rare for that sample. If, however, both a seedling and a sapling were found on a sample plot ($n > 1$), then Virginia pine was classified as a common species. Evaluation of appropriate methods for inventory of tree species was an important part of our study.

Moisture Regime Classes and Index Values

Following the rationale of Whittaker (1956) we subdivided the observed upland soil moisture gradient in the Bent Creek watershed into four classes ranging from xeric to

Table 1—Moisture regime class, moisture weight assigned, and description of typical upland sites along a moisture gradient in Bent Creek Experimental Forest

Class	Weight	Description
Xeric	1	Usually ridge sites exposed to excessive moisture loss through wind and solar radiation; precipitation is primary source of soil moisture; moisture deficits may be common during parts of each growing season; typical arborescent species are xerophytes such as Virginia pine, blackjack oak, and post oak.
Subxeric	2	Upper to middle side slopes that receive a small amount of soil moisture from the downslope movement of subsurface water; moisture deficits may occur annually during the middle to late growing season; typical tree species are black oak, chestnut oak, and sourwood.
Submesic	3	Middle to lower sideslopes that receive a moderate amount of soil moisture from downslope movement of water; moisture deficits occur occasionally in the late-growing season during years of lower than average rainfall; typical species are black locust, dogwood, and northern red oak.
Mesic	4	Coves or northerly lower slopes protected from wind; important source of soil moisture is downslope movement from higher landforms; moisture deficits seldom occur except during exceptional drought; typical species are mesophytes such as white ash.

mesic (table 1). We subjectively assigned each tree species occurring in the watershed to a moisture regime class based on its perceived location of modal occurrence along the gradient. The binomial distribution represents the probability of occurrence for a species at various positions along the moisture gradient (fig. 1). Under the assumption that species are distributed individually in relation to their physiological characteristics, each species should have a unique binomial distribution.

Each of the four moisture classes, from xeric to mesic, was assigned a weight value ranging from 1 to 4, respectively. The weight can be viewed as either the relative availability of soil moisture for that position on the gradient during the frost-free season or the relative moisture requirements of a species. We refined the moisture weights by assigning half values to some species. White oak, for example, was assigned a weight of 2.5 because we have observed that its modal occurrence tends to occur between subxeric and submesic moisture classes.

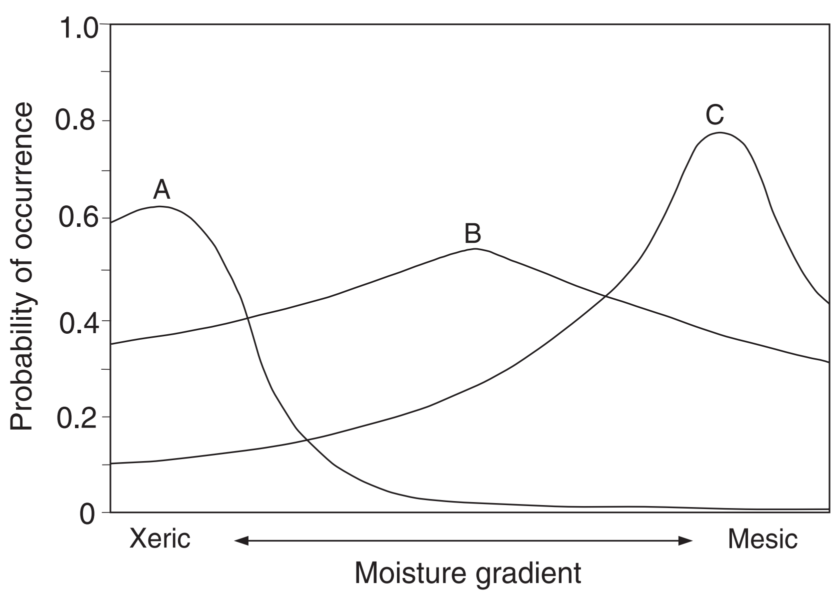

Figure 1—Examples of characteristic binomial probability distributions for tree species classified as (A) xerophytic, (C) mesophytic, or (B) ubiquitous.

Moisture Index

The cumulative information presented by all species occurring on a sample plot serves to locate its position on the moisture gradient. The position of each plot was quantified as the weighted average of the species in a value we termed moisture regime index (MRI):

$$MRI = \sum(species_i * MW_i + \ldots + species_j * MW_j)/N\ species \quad (1)$$

where

species = each tree species present on a sample site (value either zero or 1)

MW = moisture weight value for each species (values range 1 to 4)

N = number of species used in calculation of the index

MRI was calculated using 12 methods based on combinations of sample data from: three size strata for each species, e.g., tree, tree plus sapling, tree plus sapling plus regeneration; two levels of species abundance, e.g., rare (n = 1) and common (n > 1); and two levels of species ubiquity (intentional inclusion of a ubiquitous species or exclusion of the species). Red maple was selected as a trial ubiquitous species because our observations, and those of Whittaker (1956), suggest that it is a generalist species in this region and commonly occurs across all soil moisture classes, from xeric to mesic.

Data Analysis

We used a completely randomized design where sample plots had been established previously in stands meeting criteria for study of forest productivity. Correlation analysis was used to determine the association of site index with each of the 12 methods for calculation of the moisture index. A simple linear regression model was developed for site index as a function of the moisture index values for each field plot calculated by the method that produced the highest correlation. The statistical significance of the independent variable in the regression model was assessed at the probability level of P = 0.05.

Accuracy of the selected regression model for predicting site index from the moisture index was tested using holdout validation. The validation dataset was obtained by systematic exclusion of 10 percent (n = 15) of the total 148 plots from the analysis. The validation data consisted of 12 samples from the xerophytic sites and 3 from the mesophytic sites. The remaining data consisting of 133 observations formed the training data used for derivation of the relationship between site index and the moisture index.

RESULTS AND DISCUSSION

Thirty-one tree species were present on the 148 sample plots (table 2). Although dry-site and moist-site species occurred on plots of all moisture regimes, the frequencies of occurrence were consistent with the perceived soil moisture conditions, e.g., xerophytic oaks tended to dominate plots characterized by xeric and subxeric soil moisture regimes.

Little variation in strength of relationship occurred among the 12 correlations of site index and the MRI; coefficients of correlation ranged from 0.75 to 0.79 (n = 133, P < 0.01) (table 3). Correlations of site index and moisture index were highest (r = 0.77 to 0.79) for calculation of the index using the combined tree and sapling-size classes and lowest (r = 0.75) when the regeneration class of tree species was included. Including red maple as a ubiquitous species resulted in slightly higher correlations between site index and the moisture index (r = 0.77 to 0.79) compared to the exclusion of red maple (r = 0.77 to 0.78).

Regression analysis of site index as a function of the moisture index calculated by the method resulting in the highest correlation coefficient produced the relationship:

$$Oak\ SI\ (\text{ft}) = -18.3638 + 35.0359 * (MRI) \quad (2)$$

where

SI = site index (50 years) in feet for mixed species of oaks (Schnur 1937)

MRI = moisture regime index based on trees and saplings, red maple present, and species count N > 1.

As expected from the correlation analysis MRI was highly significant (P < 0.0001). This equation has a coefficient of determination of r^2 = 0.62 and mean square error of 8.11 feet. The pattern of residuals from the regression appeared to be uniformly distributed, suggesting a prediction equation with little bias (fig. 2).

We evaluated accuracy of the prediction equation using the validation data from 15 sample plots excluded from the analysis. Site index predicted by equation (2) was strongly correlated with observed values (r = 0.90) (fig. 3). The validation test produced site index estimates with a mean absolute error of 6.9 feet. Site index estimates for the validation plots, however, did not group around the diagonal line of perfect correlation, but formed a linear trend with deviations similar to the pattern displayed in figure 2. One explanation for the unusual pattern of estimated values is an artifact associated with the small size (n = 15) of the validation dataset. Examination of the validation data overlaid on the training data (fig. 2) indicates a pattern of higher than average site index for higher quality sites and lower than average site index for sites of lower quality. Another explanation for the unusual pattern is variation in site index associated with some samples that was not explained by the independent variable (MRI). Different validation results would likely have been obtained by drawing a second systematic sample, increasing sample size, or using another validation method, such as jackknifing or bootstrapping.

The species composition method we tested is similar to the indicator species approach that is widely used for ecological classification, where the presence of certain species indicates a site property such as moisture regime. The species composition approach, however, utilizes all

Table 2—Arborescent species present (>4.5 inch d.b.h.) on plots utilized in this study, weights assigned to each species relative to its modal position of occurrence on a local moisture gradient, and their frequencies of occurrence (percent of total plots sampled) on plots installed previously for two studies of xerophytic or mesophytic vegetation in Bent Creek Experimental Forest

			Species moisture class	
Common name	Scientific name	Moisture weight	Xerophytic[a]	Mesophytic[b]
			percent of plots	
Post oak	*Quercus stellata* Wangenh.	1.0	1	0
Virginia pine	*Pinus virginiana* Mill.	1.0	0	6
Scarlet oak	*Q. coccinea* Münchh.	1.5	75	0
Black oak	*Q. velutina* Lam.	2.0	60	32
Blackgum	*Nyssa sylvatica* Marsh.	2.0	32	21
Chestnut oak	*Q. prinus* L.	2.0	71	15
White pine	*P. strobus* L.	2.0	0	18
Persimmon	*Diospyros virginiana* L.	2.0	1	0
Sassafras	*Sassafras albidum* (Nutt.) Nees	2.0	2	15
Shortleaf pine	*P. echinata* Mill.	2.0	32	9
Sourwood	*Oxydendrum arboreum* (L.) DC.	2.0	86	56
Southern red oak	*Q. falcata* Michx.	2.0	2	0
Hickory spp.	*Carya* spp. Nutt.	2.3	0	62
American holly	*Ilex opaca* Aiton	2.5	0	3
White oak	*Q. alba* L.	2.5	80	32
Red maple	*Acer rubrum* L.	2.5	74	82
American beech	*Fagus grandifolia* Ehrh.	3.0	3	3
Black locust	*Robinia pseudoacacia* L.	3.0	37	71
Flowering dogwood	*Cornus florida* L.	3.0	42	47
Frazier magnolia	*Magnolia fraseri* Walter	3.0	0	6
White mulberry	*Morus alba* L.	3.0	0	3
Northern red oak	*Q. rubra* L.	3.0	31	35
Black cherry	*Prunus serotina* Ehrh.	3.5	0	3
Cucumber-tree	*Magnolia acuminata* (L.) L.	3.5	2	0
Eastern hemlock	*Tsuga canadensis* (L.) Carrière	3.5	3	21
American hornbeam	*Carpinus caroliniana* Walter	3.5	1	0
Sweet birch	*Betula lenta* L.	3.5	3	74
Yellow-poplar	*Liriodendron tulipifera* L.	3.5	39	100
Black walnut	*Juglans nigra* L.	4.0	0	3
White ash	*Fraxinus americana* L.	4.0	4	26
Yellow birch	*B. alleghaniensis* Britton	4.0	0	3

[a] One hundred fourteen 0.2-acre plots situated in stands dominated by xerophytic species, such as oaks.

[b] Thirty-four 0.25-acre plots situated in stands dominated by mesophytic species, such as yellow-poplar.

Table 3—Coefficients of correlation between oak site index and soil moisture regime calculated by all combinations of 3 size strata of trees present, 2 categories of red maple, and 2 categories of rare species on upland sites in Bent Creek Experimental Forest

	Size classes used in calculation of the moisture regime index		
Species ubiquity and rareness[a]	Trees	Trees + saplings	Trees + saplings + regeneration
	---------- *r* ----------		
With ubiquitous red maple			
With rare species	0.77	0.77	0.75
Without rare species	0.77	0.79	0.75
Without ubiquitous red maple			
With rare species	0.77	0.77	0.75
Without rare species	0.77	0.78	0.75

[a] Rareness class = rare: *n* = 1, common: *n* > 1.

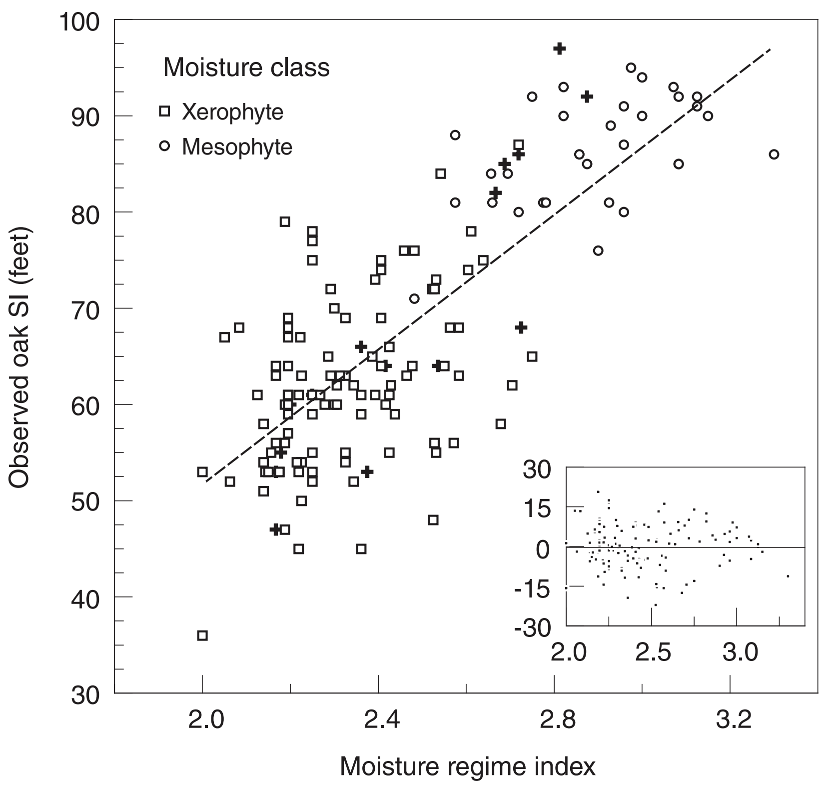

Figure 2—Relationship of observed oak site index with a moisture index on 133 sample plots dominated by species classified as either xerophytic or mesophytic. A simple linear trendline (dashed line) explained 62 percent of the variation in site index. Fifteen sample plots (+) were systematically excluded from the training dataset and reserved for validation. The inset shows residuals of predicted site index in relation to the moisture index.

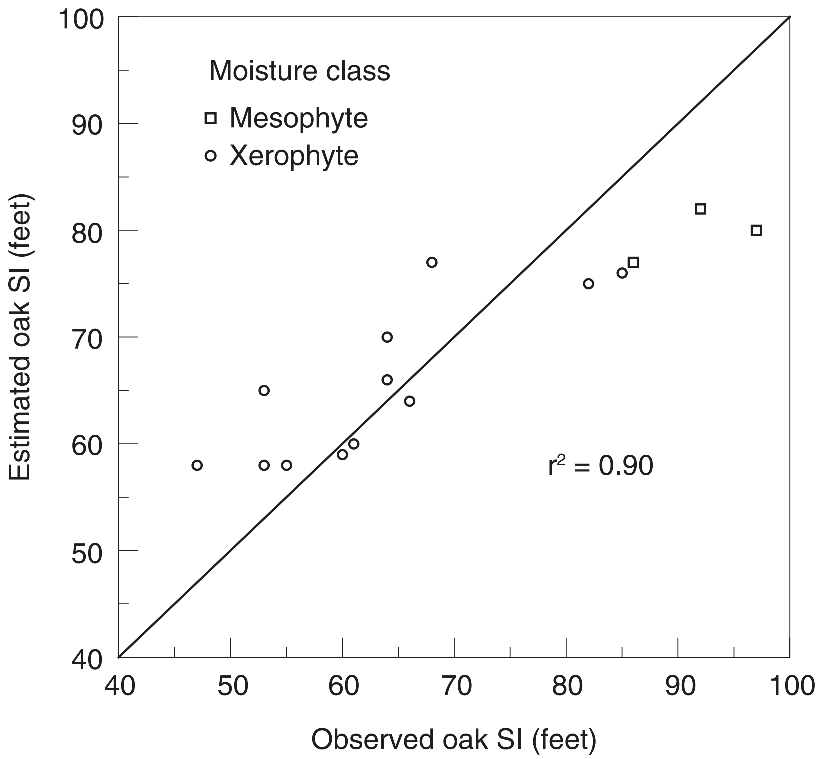

Figure 3—Correlation between oak site index observed on 15 validation plots and estimated from equation 2 was high (r^2 = 0.90). The diagonal line indicates perfect correlation between observed and estimated site index. The relationship was biased, however, with site index underestimated on high-quality sites and overestimated on low-quality sites. An explanation for the apparent bias of the prediction model is provided in the text.

arborescent species present to approximate the position of a site on the moisture gradient. In this species-rich region of the Southern Appalachian Mountains, therefore, an abundance of species associated with a moisture class is beneficial in placing a site in an appropriate position on the gradient and thus minimizes the influence of both ubiquitous and rare species. Although inclusion of shrub species was not part of this investigation, additional study is needed to determine the value of nonarborescent vegetation for estimation of site quality based on species composition.

Application of this method requires several considerations by the resource manager. First, a tree species list must be completed for the area of application. The list we presented in table 2 is limited to species encountered in our study area, which is about a third of those occurring in the Southern Appalachian region. Next, moisture weights assigned to each species should be adjusted for the region in which the method will be applied. The location of some species on the moisture gradient could change somewhat if other areas of application are near the limits of their natural range or compensating conditions are present, such as temperature or fertility. For example, Whittaker (1956) assigned yellow-poplar to his mesic class with a weight of 4. In our area of application, which is somewhat lower in elevation and drier than the region where Whittaker (1956) worked, we placed yellow-poplar between the mesic and submesic classes with a weight of 3.5. Finally, because site quality and species composition is variable in most stands, an adequate field inventory must be devised, such as a systematic grid of sample points or other design suitable for estimation of the timber resources.

In summary, results of this exploratory study demonstrate that arborescent species can be used for estimation of forest site quality in the Southern Appalachian Mountains. More specifically, we found that oak site index was highly correlated with an index based on species composition, which quantifies the location of a site on a xeric to mesic moisture gradient. An equation based only on the moisture index accounted for 62 percent of the variation in oak site index on sample plots in the study area. An unexplained bias in the validation test suggests, however, that additional study and refinement is needed before the method can be recommended for estimation of site index beyond the study area.

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