LANDFORM AND TERRAIN SHAPE INDICES ARE RELATED TO OAK SITE INDEX IN THE MISSOURI OZARKS

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Abstract.—In the Southern Appalachians, metrics for quantifying the geometric shape of the land surface (terrain shape index or "tsi") and of the landform (land form index or "lfi") were developed and found to be correlated to yellow-poplar site index. However, the utility of these metrics for predicting site index for oaks in the Ozark Highlands has not been evaluated. We examined the relationship between black oak site index and the tsi and lfi with other measures of terrain, including the slope position and the (transformed) slope-aspect using data collected in 120 0.12-ac experimental units at the Sinkin Experimental Forest in southeastern Missouri. The tsi and lfi were each significant ($P<0.05$) parameters in models predicting site index. Concave land forms had greater tsi and lfi values and higher site index values than did convex land forms. The AICC scores indicated that the best models included parameters for slope position and aspect along with the tsi, lfi, or both. Models with the tsi were statistically indistinguishable from models that included the lfi. Overall, the tsi and lfi each appear to be useful for quantifying terrain shape and its influence on the productivity of upland hardwood stands in the Ozark Highlands.

INTRODUCTION

Site index remains the most commonly used measure of site quality by practicing foresters. In the Central Hardwood Region, it is used to determine species suitable for management and to predict oak regeneration potential and stand development patterns (Johnson and others 2002). Volume equations often include site index along with diameter to estimate stand volume (Hahn and Hansen 1991). Despite its utility and common use, site index cannot be determined unless suitable trees are present in the stand. Suitable site index trees are those that have remained as canopy dominants or codominants; are relatively free of disease, pests, or other health problems; and, ideally, are growing in even-age stands that are approximately the index age (McQuilkin and Rogers 1978). Field estimates of site index are difficult to make when adequate site index trees cannot be found because of past disturbances or past pest or disease problems, or because the age of the trees in the stand greatly exceeds those used to develop site index curves (Monserud 1984, Berguson and others 1994). To deal with these situations, equations have been developed to estimate site index from soil, topographic, and other site factors. Although some of these equations can account for 70-85 percent of the observed variation in site index, these equations can sometimes be difficult to apply because they require detailed site-specific information about soil characteristics (Johnson and others 2002).

In the eastern United States, variation in site index, species composition, and forest productivity has long been attributed to changes in topography (Trimble and Weitzman 1956; McNab 1989, 1993; Johnson and others

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2002). Slope aspect also affects forest productivity due to its influence on solar radiation and microclimate, but aspect alone does not completely explain the variability in productivity across a landscape (Trimble and Weitzman 1956, Trimble 1964, Rosenberg and others 1983, Fekedulegn and others 2003). Soil scientists use slope shape in addition to slope position to infer water movement and subsequently to map the kinds of soils formed in different locations on the landscape (Ruhe 1975, Hudson 1990). Taking into account the influence of slope shape on water movement, forest scientists have developed methods to correlate those relationships with measures of forest productivity such as site index (Johnson and others 2002).

Despite the documented relationships between slope shape and forest productivity, descriptions of slope shape have largely remained qualitative. Land units are allocated into a slope position class such as summit, shoulder, backslope, footslope, or toeslope, defined by their position along a hillslope and by the degree of concavity or convexity they exhibit in the down-slope direction. Slope positions are sometimes assigned an additional modifier to describe the degree of concavity or convexity they exhibit along the contour (e.g., headslopes, noseslopes, or sideslopes) (Schoenenberger and others 2002). In the southern Appalachians, McNab (1989, 1993) developed methods for quantifying the geometric shape of the land surface with the land form index (lfi) and the terrain shape index (tsi). These metrics are determined in the field by making a few measurements with a clinometer and do not require the application of geographic information system (GIS) terrain modeling techniques. Each of these indices was found to be correlated to yellow-poplar (*Liriodendron tulipifera* L.) site index in the southern Appalachians and therefore useful for predicting site index in stands where suitable yellow-poplar site index trees were lacking. Because suitable site index trees frequently are not available in oak stands in the Missouri Ozarks due to high-grading or other past land use, a simple means for predicting site index would be helpful for forest management planning in this region. McNab's (1989, 1993) success correlating simple terrain metrics with yellow-poplar site index suggested that this approach may be applicable to the Missouri Ozarks. However, these metrics have not been evaluated in the drier oak-hickory (*Quercus* L.-*Carya* Nutt.) forests, where relationships between site quality and terrain characteristics potentially differ from those of the southern Appalachians. Our objectives were to examine relationships between the tsi and lfi, and black oak site index, in the Missouri Ozarks. In this region, site index for most oak species is commonly converted to and expressed on a black oak basis for comparing stand site quality.

STUDY SITE

The study was conducted in the Sinkin Experimental Forest located about 30 miles south of Salem, MO, within the Current River Hills Subsection of the Ozark Highlands (Keys and others 1995). This region has narrow ridges and steep side slopes with a relief of around 200 ft and soils formed from Ordovician and Cambrian dolomite and sandstone (Nigh and Schroeder 2002). Data accessible through the Missouri Cooperative Soil Survey (www.soilsurvey.org) indicated that the soils on the ridge tops and upper hillsides developed in parent materials derived from the Roubidoux and upper Gasconade formations and are highly weathered, droughty, and strongly acid, and contain a high percentage of rock fragments. Common soil series on ridge tops and upper slopes were Coulstone and Clarksville (both Typic Paleudults), Hobson (Oxyaquic Fragiudalfs), Lebanon (Typic Fragiudults), and Nixa (Glossic Fragiudults). Soils on the lower hillsides developed in parent materials that were derived from the lower Gasconade or Eminence formations generally are less weathered. Some of these soils are influenced by the underlying dolomite and consequently contain clayey residuum that has a greater cation exchange capacity, fewer rock fragments, and a greater water holding capacity. The soil series on lower hillsides were Clarksville and Doniphan (both Typic Paleudults) and Moko (Lithic Hapludolls). Outcrops of dolomite occur with some of the Moko soils.

We examined the relationships between topographic variables and site index in the Missouri Ozarks as part of a comprehensive oak regeneration study named the "Regional Oak Study" (ROS). The ROS is a regional, multi-disciplinary research project being implemented by both the Northern and Southern Research Stations of the U.S. Forest Service at sites located in North Carolina, Tennessee, and Missouri (Greenberg and others 2007). The study consists of 20 rectangular 12-acre treatment units that were each established across a moisture gradient from ridge top to footslope. Each treatment unit has six circular, 0.12-acre sampling plots positioned evenly within the 20 12-acre treatment units, providing a total of 120 sample locations. The treatment units are in oak-pine and mixed oak forests having an average age of 82 years for the overstory. Inventories in these plots revealed that oaks were the dominant species, contributing 59 percent of the basal area. Of the oak species present, white oak (*Quercus alba* L.) contributes 22 percent of the basal area, black oak (*Q. velutina* Lam.) 21 percent, scarlet oak (*Q. coccinea* Muenchh.) 12 percent, and northern red oak (*Q. rubra* L.) 4 percent. Shortleaf pine (*Pinus echinata* Mill.) makes up 22 percent of the basal area. Other species by basal area include hickory species (*Carya* spp.) (7 percent), slippery elm (*Ulmus rubra* Muhl.) (2 percent), flowering dogwood (*Cornus florida* L.) (2 percent), blackgum (*Nyssa sylvatica* Marsch.) (2 percent), black walnut (*Juglans nigra* L.) (2 percent), and red maple (*Acer rubrum* L.) (1 percent).

METHODS

Measurements at each of the 120 sampling plots included site index, aspect, slope position, tsi, and lfi. Site index was determined using a representative dominant or co-dominant tree within each plot. Site index trees included red oaks (*Quercus* spp. L.; *section Lobatae*), white oaks (*Quercus* spp. L.; *section Quercus*), and shortleaf pine. The height of each site index tree was measured to the nearest foot using an Impulse™ 200 (Laser Technology Inc., Centennial, CO) laser. A core was removed at breast height using an increment borer and rings were counted with the aid of a hand lens. Site index in feet was calculated for each species using relationships developed by McQuilkin (1974, 1978) for oaks and Nash (1963) for shortleaf pine. Following the convention, all site index values were converted to black oak site index basis using the relationships developed by McQuilkin (1976).

Aspect was measured from plot center using a handheld compass and taken in the direction of the steepest down-slope direction. Slope position was also recorded in each plot and given a categorical value of shoulder, backslope, or footslope following the definitions originally proposed by Ruhe (1975) and now routinely used in soil mapping (Schoeneberger and others 2002). Briefly, shoulders occur on upper slopes and generally are convex in profile. Backslopes occur mid-slope and are nearly linear in profile but can vary in shape along the contour and include sideslopes (linear along the contour), noseslopes (concave along the contour), and headslopes (convex along the contour). Footslopes occur on lower slopes and generally are concave in profile.

We measured the tsi and lfi from the center of each plot using a hand-held clinometer. At each plot, measurements were taken starting in the direction of the aspect and then rotating clockwise in 45° increments for a total of eight slope measurements. For the tsi, the slope from the plot center to the plot perimeter (41 ft) measured parallel to the land surface was recorded. For lfi, the slope from the plot center to the horizon was measured. Slopes were recorded as a percent; down-slope measurements were recorded as negative values and up-slope measurements as positive values. All eight measurements were then averaged to determine the tsi or lfi value. McNab (1989, 1993) found that estimates of tsi or lfi almost always stabilized when measuring four directions and changed little when eight or more measurements were taken.

DATA ANALYSIS

We used an Information-Theoretic approach (Burnham and Anderson 1998) to compare the models predicting black oak site index (response variable) and the lfi, tsi, and other measures of terrain including slope position and aspect (explanatory variables). As per the Information-Theoretic approach, we developed a series of candidate models for estimating site index by including the lfi or tsi singly or in combination with the slope position and aspect. These models were used to evaluate the hypotheses that including the lfi or tsi improves predictions of site index compared to using only the traditional descriptive measures of slope position and/or slope aspect. Models were compared using Akaike's information criterion (or AIC). The AIC = nln(RSS/n)+2k, where n is the sample size, ln is the natural log, RSS is the residual sums of squares, and k is the number of parameters in the model. Lower AIC scores indicate a better fit and models having AIC scores more than two units apart are generally considered significantly different from each other (Burnham and Anderson 1998). We applied the correction for small sample size (creating an AICC score) by adding 2k(k+1)/(n–k–1) to the AIC score as per the recommendations of Burnham and Anderson (1998).

We used the MIXED procedure in SAS™ statistical software, version 9.1 (SAS Institute, Inc. Cary, NC) to estimate model parameters and to generate AICC scores for each model. The mixed procedure was used to accommodate models that included categorical and continuous data and to account for both fixed effects (i.e., terrain variables) and random effects (i.e., 12-acre treatment units). The model form was $Y= \beta o + B_1X_1 + B_2X_2 + \ldots + B_nX_n$ where Y was the black oak site index in feet, βo was the intercept, and subsequent parameters were for the lfi or tsi, slope position, and/or slope aspect. Prior to analyses, the distribution of site index was examined; this variable was found to be normally distributed so there was no need for transformation. During analyses, the slope position was included as a categorical variable (i.e., shoulders, backslopes, and footslopes) and the slope aspect was included as a continuous variable after it was transformed to a linear value ranging from 0 (azimuth of 225 degrees) to 2 (azimuth of 45 degrees) following the model by Beers and others (1966) where the Transformed aspect = cos(45–Aspect) + 1.

We used the Information-Theoretic approach for model selection because the AICC score accounted for the number of parameters in models. Thus, the method discriminated against models having more parameters and thereby reduced the risk of overfitting the models. This approach offered an advantage over the stepwise regression procedure, where overfitting generally increases the apparent goodness of fit. One disadvantage of the method, however, is that typical measures of goodness of fit (e.g., R-values) are not provided. As a remedy, we also fit models using the glm procedure (SAS version 9.1). The glm procedure produced model parameters similar in magnitude to those produced by the mixed procedure (they were not exactly the same because glm cannot account for random effects) and provided R values as an additional estimate of goodness of fit.

RESULTS

Both the terrain shape index (tsi) and landform index (lfi) were related to the slope position with a few outliers (Fig. 1). Generally, the tsi and lfi were each positive and larger in magnitude on footslopes, indicating a more concave land surface shape, and were lower in magnitude or negative in value on backslopes and shoulders, indicating a linear or slightly convex shape. The lfi was generally greater in magnitude and more positive than the tsi. This relationship occurred largely because the lfi is determined by measuring the slope angle to the surrounding horizon, which usually appears above the surrounding ridge tops. Consequently, slope measurements made from below a ridge top are very likely to have large and positive values. There also were differences in the magnitude of the variation between the lfi and tsi. The lfi was most variable on backslopes while the tsi was most variable on footslopes.

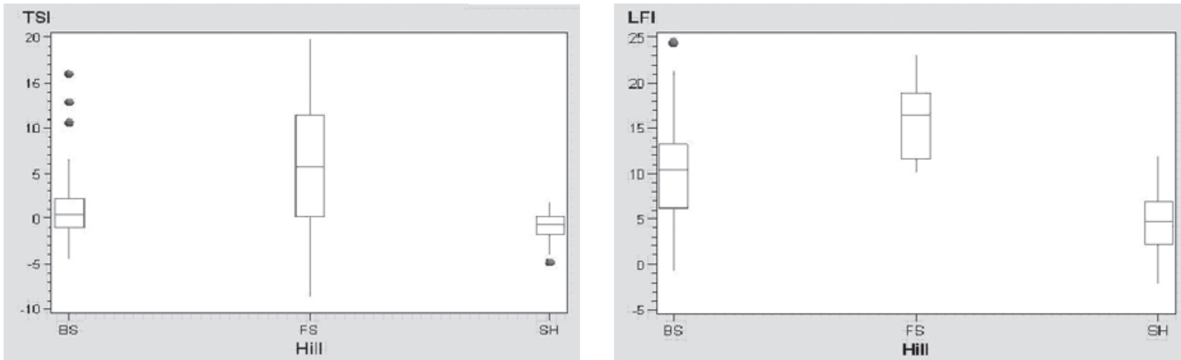


Figure 1.—Box-and-whisker diagrams displaying terrain shape index (tsi) and landform index (lfi) values by slope position. Note: “BS” denotes backslope, “FS” denotes footslope, and “SH” denotes shoulderslope. Both tsi and lfi values are in percent gradient.

The tsi and lfi were each significant ($P<0.05$) parameters in models predicting site index (Table 1). The AICC scores indicated that the best models included parameters for the slope position and aspect along with the tsi (model 2), the lfi (model 3), or both the lfi and tsi together (model 1). However, the AICC scores also indicated that models including either the tsi or lfi along with slope position and aspect were statistically indistinguishable from each other. Furthermore, models including both the slope position and aspect in addition to the tsi or lfi were better than those that did not include slope position and aspect.

The parameters for models that included the slope position, aspect, and the tsi (model 2) or the lfi (model 3) shown in Table 2 were used to illustrate relationships between them and the black oak site (Figs. 2 and 3). These models indicated that northeast-facing slopes generally had greater site index values than southwest-facing slopes and that shoulder and backslopes had greater site index values than did footslopes. They also indicated that for a given slope position or aspect, increasing the tsi or the lfi (i.e., increasing the concavity) generally increased the site index estimate. However, the wide scatter in the actual data plotted in Figures 2 and 3 and low R values for the models (Table 1) indicated considerable variation in the site index data.

Table 1.—Site index models with effects for slope position (including shoulder, backslope, or footslope), Beers-transformed aspect (taspect), terrain shape index (tsi), and land form index (lfi).

Model[a]	AICC	Delta AICC[b]	R
1. Slopeposition* + taspect* + tsi + lfi	861	0	0.36
2. Slopeposition + taspect + tsi***	862	1	0.32
3. Slopeposition* + taspect** + lfi***	862	1	0.33
4. Slopeposition + taspect	867	6	0.22
5. Slopeposition* + tsi**	867	6	0.29
6. Slopeposition* + lfi**	867	6	0.27
7. Taspect* + tsi**	874	13	0.25
8. Taspect* + lfi**	874	13	0.24
9. Tsi**	878	17	0.20
10.Lfi**	880	19	0.17

[a] Model form $Y = \beta o + B_1X_1 + B_2X_2 + \ldots + B_nX_n$

[b] Change in AICC score from the lowest. Lower AICC scores indicate better models and a change in AICC score greater than 2 indicates a model is statistically different from other models.

* effect significance P ≤0.10

** effect significance P ≤0.05

*** effect significance P ≤0.01

Table 2.—Parameters for site index models 2 and 3 in Table 1 for estimating black oak site index in feet.

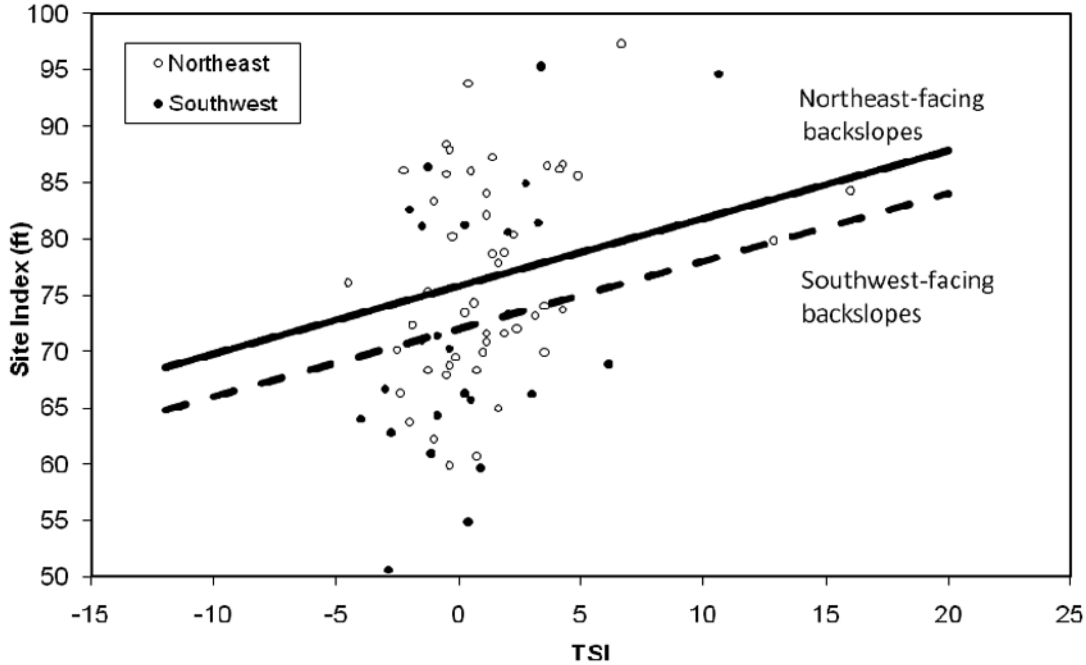
Effect	Estimate	Standard error	P-value
Model 2—TSI			
Intercept	70.60	2.35	<0.01
Slope position			
Backslope	1.41	1.92	0.47
Footslope	-4.72	3.42	0.17
Shoulder	--	--	--
Transformed aspect	1.93	1.27	0.13
TSI	0.57	0.23	0.01
Model 3—LFI			
Intercept	67.40	2.60	<0.01
Slope position			
Backslope	-0.19	2.14	0.93
Footslope	-7.02	3.82	0.07
Shoulder	--	--	--
Transformed aspect	2.27	1.28	0.08
LFI	0.50	0.20	0.01

DISCUSSION

Much has been written about the effects of slope shape on the height growth or site index of trees (Carmean 1967, Hannah 1968, Hartung and Lloyd 1969, Auchmoody and Smith 1979, McNab 1989). Most of these studies showed that height growth or site index is generally greater on lower slopes or in concave "cove" positions, where the soil's ability to supply nutrients and particularly water is generally greater (White 1958, Fralish 1994). Despite the influence of terrain on site productivity, few have developed approaches for quantifying terrain shape to accompany other more descriptive assessments of topography for predicting site index. McNab (1989, 1993) developed a method for quantifying terrain shape by averaging the slopes in four or more directions from a plot center to its perimeter parallel to the land surface (tsi) or to the horizon (lfi). In the mesophytic forests of the southern Appalachians, yellow-poplar site index was significantly correlated with tsi (McNab 1989) and lfi (McNab 1993). In the Missouri Ozarks, we also found significant relationships between black oak site index and tsi and lfi. Our three most significant models for explaining variation in black oak site index were parameters for slope position; Beers-transformed aspect; and tsi, lfi, or both. These three models were statistically indistinguishable from each other, suggesting all were equally useful for predicting site index. However, foresters are more likely to measure a single index and our findings suggest that tsi and lfi work equally well. Slope position and aspect were also important parameters in these models and our analysis suggested that both should be included with either tsi or lfi to render the best estimates of site index in similar landscapes of the Missouri Ozarks.

Despite the statistical significance of the parameters, the R values for our data were generally quite low, indicating considerable variation not accounted for with the models that we developed. McNab (1989, 1993) generally found stronger relationships between the yellow-poplar site index and the lfi (R between 0.45 and 0.65) and the tsi (R=0.71) in the southern Appalachians. This difference in R values may be due to the wider range in site index values and in the tsi and lfi values encountered in the Appalachian region compared to the

a) slope aspect



b) slope position

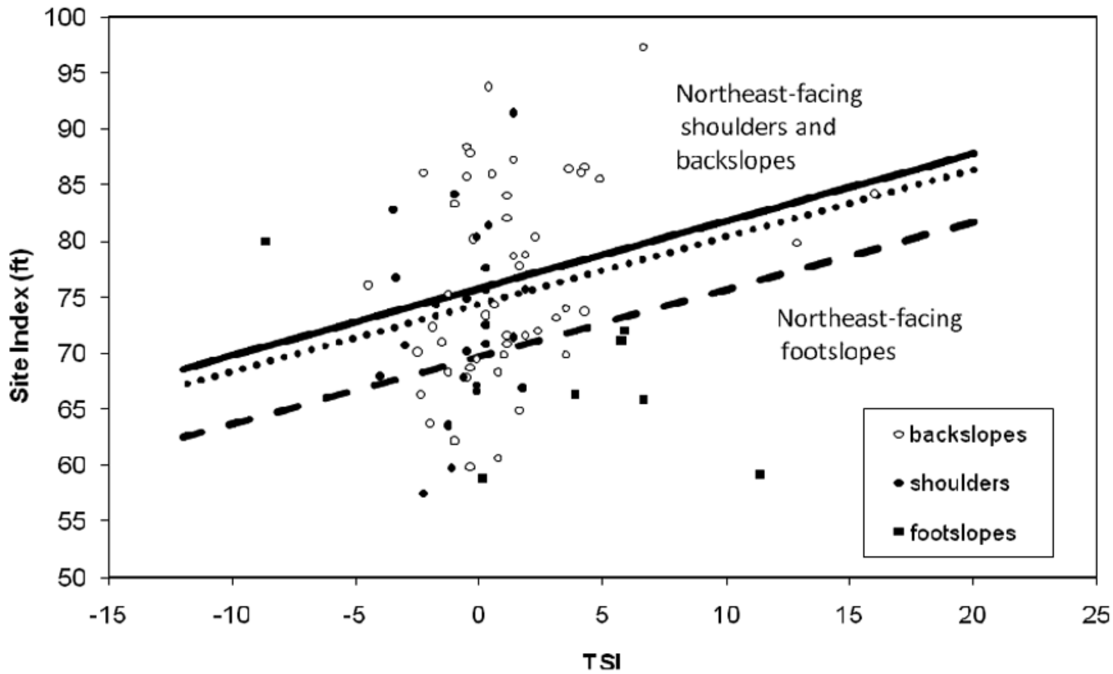
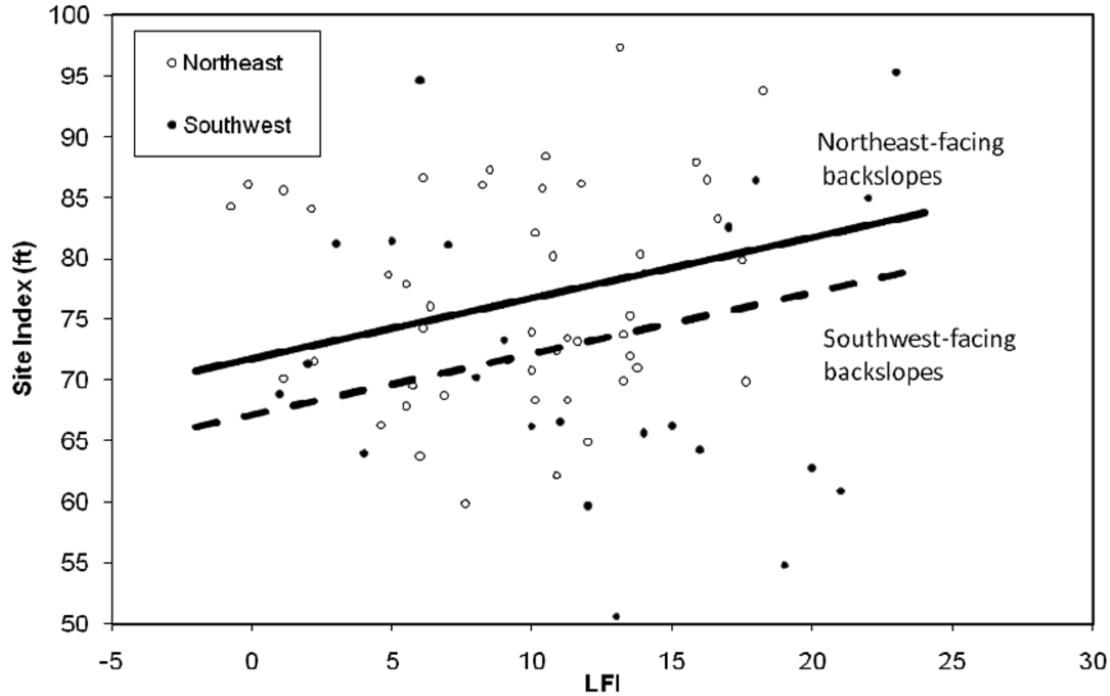


Figure 2.—Black oak site index and terrain shape index (tsi) by a) slope aspect, and b) slope position.

a) slope aspect



b) slope position

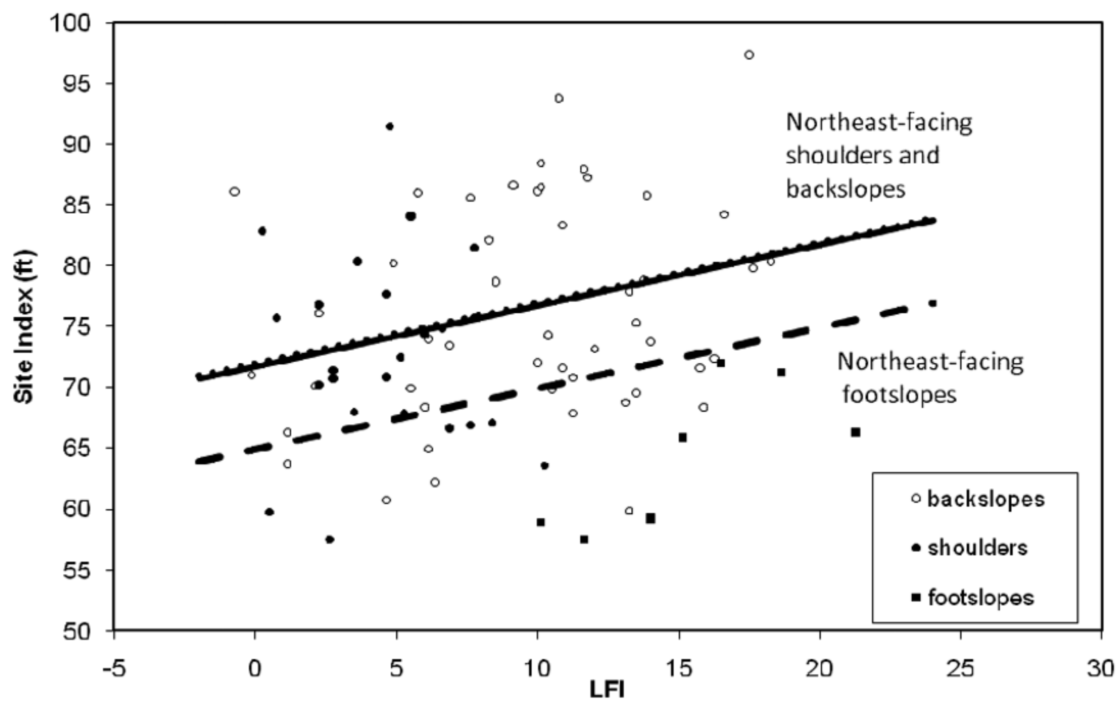


Figure 3.—Black oak site index and land form index (lfi) by a) slope aspect, and b) slope position.

Missouri Ozarks, where the terrain is gentler. In the Missouri Ozarks, greater correlations may have occurred had we accounted for variation in soil properties related to water and nutrient supply.

The models that we developed appear to have utility for estimating black oak site index in the Missouri Ozarks for stands lacking suitable site index trees. For each inventory plot, the slope position and aspect are recorded and the tsi or lfi is determined as described in the "Methods" section of this paper and applied to the models in Table 2. For example, for shoulder slopes having an azimuth of 83° (Beers transformed = 1.79) and a tsi = 2.1, the black oak site index = 75 feet. For backslopes having an azimuth of 180° (Beers transformed = 0.29) and a lfi = 10.7, the black oak site index = 73 feet.

Although the tsi and lfi are determined in the field, the increasing availability of high-resolution terrain information and GIS software has provided alternatives for estimating these and other metrics of slope shape. Some of these terrain metrics have been used along with other remotely-sensed data to estimate site index elsewhere in the Central Hardwood Region. For example, Iverson and others (1997) used GIS software to develop a moisture index model based on soil water-holding capacity, topographic shape, and slope-aspect for the Vinton Experimental Forest in southern Ohio. This moisture index was highly correlated (R > 0.79) to the oak site index, particularly with terrain models derived from fine-resolution (<1:24,000 scale) source data.

Our interest in predicting site index is not limited to the need for estimating potential merchantable volume or biomass production of a stand. In the Central Hardwood Region, site index is also important for identifying where future oak regeneration problems may occur. Further research is needed to determine whether measures of terrain shape such as the tsi or lfi do provide an additional metric for identifying where oak regeneration problems are likely to occur, particularly where suitable site index information is lacking.

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