TESTING TREE INDICATOR SPECIES FOR CLASSIFYING SITE PRODUCTIVITY IN SOUTHERN APPALACHIAN HARDWOOD STANDS

W.H. McNab, D.L. Loftis, and R.M. Sheffield

ABSTRACT. Composite indices of site moisture and fertility regimes, site variables, and individual tree species were tested for their relationship with site productivity on forest survey plots in the southern Appalachian Mountains. Mean annual basal area increment was significantly associated with the fertility index and site variables including elevation, slope gradient, and stand merchantable size. Four species, including *Fraxinus americana*, and *Liriodendron tulipifera*, were individually significantly associated with sites of high productivity. Sites of low productivity were indicated by the presence of *Quercus coccinea, Q. prinus*, or several other species. Results of this exploratory study suggest that tree indicator species may be useful for evaluating forest site quality in hardwood-dominated, many-aged, multi-species stands of the southern Appalachians.

KEY WORDS. Fertility, indicator species, moisture regime, site classification.

INTRODUCTION

Forest site quality, the productivity capacity of a site, strongly influences the benefits obtained from silvicultural activities and forest management decisions (Smith 1962). Site index (the average total height of a crop species at a reference age, usually 50 years in hardwood stands of the Eastern U.S.) is perhaps the most widely used indirect method of expressing site quality (Jones 1969). Site index works reasonably well in even-aged stands dominated by shade-intolerant, single-stemmed conifers, and by some shade-intolerant, excurrent-crowned hardwood species such as *Liriodendron tulipifera*. The use of site index, however, is problematic in most hardwood-dominated stands in the southern Appalachians because many potential crop species are present, suitable sample trees are often lacking, and for other reasons (Beck and Trousdell 1973). In some forest types and regions, the presence of some species is associated with particular site properties (Leak 1979). Use of such indictor species for estimation of site quality can overcome problems associated with site index estimation in hardwood stands (Jones 1969). Results of a recent study (McNab et al., 2002) suggest that productivity is associated with tree indicator species in the southern Appalachians, but little other specific information is available.

Foresters, however, are typically familiar with certain indicator species through their knowledge of silvical characteristics of forest trees. Using expert judgment and results of other studies (Ulrey 2002) McNab and Loftis[60] devised a moisture classification index (MCI) and fertility classification index (FCI) based on the occurrence of common tree species on sites that vary in perceived moisture or fertility characteristics. Used together MCI and FCI provide a two-dimensional grid approach to site classification of moisture and fertility regimes based on vegetation. Informal evaluation of MCI and FCI suggests the indices are useful for site classification in a small southern Appalachian watershed. However, the two indices have not been evaluated with independent data. The objectives of the study described here were to determine the relationship of site productivity with (1) MCI and FCI, (2) site and stand characteristics, and (3) presence of individual tree species. Our study excluded conifers and was limited to a cursory examination of relationships among hardwoods for use in planning a follow-up investigation; our results are therefore preliminary.

METHODS

The study area consisted of 21 predominantly mountainous counties in western North Carolina. These counties form Survey Unit 4 delineated by the Forest Inventory and Analysis (FIA) Research Work Unit at the Southern Research Station (Hansen et al. 1992). Field data were obtained for 831 FIA plots measured in 1984 and remeasured in 1990. Plots were omitted if they were understocked (< 40 ft^2 basal area / ac), or planted, or if they had been partially or completely harvested between 1984 and 1990, or if the merchantable timber stand was smaller than poletimber. Stand data consisted of an inventory by species and size of trees ≥ 1 inch in diameter at breast high (dbh). Site data for each plot included elevation (ft), aspect (degrees azimuth transformed for analysis using cosine), slope gradient (percent), and latitude and longitude (nearest 100 seconds). Stand merchantability was classified as poletimber or sawtimber (Hansen et al. 1992). MCI and FCI were calculated for each plot using the species weights in Table 1. Calculation of MCI and FCI requires only a list of arborescent species present on each plot. For example, MCI is 1.75 for a plot occupied only by *Q. coccinea* and *O. arboretum*, which have moisture weights of 1.5 and 2.0, respectively.

We developed an index of productivity to use for the dependent response variable. First, mean annual productivity of each plot was calculated as the total basal area increment of live trees, ingrowth of new trees, and mortality divided by the number of years between successive inventories. Then, the productivity index of each plot ($MAIba_S$) was calculated by dividing mean annual productivity by initial basal area. $MAIba_S$ is expressed in units of $ft^2/ac/yr/ft^2$.

Simple relationships between $MAIba_S$ and MCI, FCI, topographic, and stand variables were determined through correlation analysis. We used multiple regression to quantify the combined effects of MCI, FCI, topographic, and stand variables on $MAIba_S$. For hardwood species occurring on ≥ 30 plots, t-tests were used to determine if $MAIba_S$ differed significantly on the set of plots where each species was present compared to all other plots where that species was absent. The t-tests of indicator species were restricted

[60] McNab, W.H., and D.L. Loftis. Field form for classification of forest sites by moisture and fertility regimes in Bent Creek Experimental Forest using a species list. Unpublished information. USDA Forest Service. Southern Research Station, Bent Creek Experimental. Forest. Asheville, NC.

to the elevation range in which each species occurred. All tests were made at the significance level of $P<0.05$

RESULTS AND DISCUSSION

Of the 831 plots in the Survey Unit, 631 were retained for analysis because they were natural in origin, adequately stocked, and undisturbed. Elevation of the retained plots averaged 2940 ft and ranged from 900 to 6100 ft. Among 56 species that occurred on the sample plots, 25 hardwood species were found on ≥ 30 plots and were retained for analysis (Table 1). *Acer rubrum* was the most widespread species, occurring on 72 percent of the plots followed by *Q. prinus*. Overall stand basal area averaged 96 ft^2/ac in 1984 and 108 ft^2/ac in 1990. $MAIba_S$ averaged 0.056 $ft^2/ac/yr/ft^2$ and ranged from 0.004 to 0.280. MCI averaged 2.6 and ranged from 1.6 to 3.9; FCI averaged 1.1 and ranged from 1 to 1.7.

Simple correlation analysis indicated $MAIba_S$ was not associated with MCI ($r=-0.03$, $P = 0.44$) or with the FCI ($r = 0.05$, $P = 0.20$). However, $MAIba_S$ was significantly correlated with elevation ($r = -0.11$, $P = 0.004$), slope gradient ($r=-0.16$, $P=0.001$), and stand merchantability size ($r = -0.18$, $P = 0.0001$). Multiple regression analysis indicated that productivity was significantly associated with FCI and three of the independent site variables:

$$MAIba_S = 0.0520 + 0.0394(FCI) - 0.0042(ELE) - 0.0003(SLO) - 0.0151(MER) \quad (1)$$

where $MAIba_S$ is the productivity index, FCI is the fertility classification index, ELE is elevation (in thousands of feet), SLO is slope gradient (in percent), and MER is the stand merchantability classification (0 if poletimber, 1 if sawtimber). All variables in equation (1) were highly significant ($P<0.01$). Coefficients of equation (1) indicate that sites of higher productivity are directly associated with FCI but are inversely related to higher elevations, steeper slopes, and stands of larger trees. Standard error of the estimate was 0.034 and $R^2=0.068$.

T-tests indicated that some species were associated with sites of significantly higher or lower productivity than other sites in the same range of elevation where that species was absent. Four species (*F. americana*, *L. tulipifera*, *P. serotina*, and *R. pseudoacacia*) indicated highly productive sites. For example, *F. americana* occurred on 71 plots ranging between 1700 and 4520 feet elevation, but was absent on 488 other plots in that same elevation range. $MAIba_S$ of plots with *F. americana* was 0.069±0.006 $ft^2/ac/yr/ft^2$ (Figure 2) but only 0.054±0.001 $ft^2/ac/yr/ft^2$ on plots without *F. americana*, a small but significant ($P=0.007$) difference. Seven species (*H. carolina, M. acuminata, M. fraseri, Q. coccinia, Q. prinus, Q. rubrum,* and *T. americana,*) were present on plots with significantly lower $MAIba_S$.

Species indicating either high or low productivity would logically not be expected to occur on the same site, and generally they did not. However, co-occurrence of opposite indicator species on the same site might not be contradictory for productivity classification; co-occurrence may simply suggest a site of average productivity. For example, *F. americana* and *T. americana* were assigned the same moisture weight (Table 1) and occurred over similar ranges of elevations on 99 of the sample plots. The two species co-occurred on 20 percent of the 99 plots. On the 20 plots where both species were present, average MAI_{bas} was about midway between that of plots where only one species was present. The co-occurrence of opposite indicator species often can be attributed to past disturbance or stochastic events.

The lack of correlation of MAI_{bas} with either MCI or FCI suggests that different weights must be assigned to some species, particularly those that were individually significant. From the limited scope of this study, however, it is not clear if the species significantly associated with productivity were indicating a response to moisture or fertility. Our field observations in the southern Appalachians indicate that some of the significant indicator species identified in this study are clearly associated with moisture (e.g. *L. tulipifera*, *R. pseudoacacia*) while the occurrence of others (e.g. *F. americana*) seems more closely related to fertility. Quantitative species-fertility relationships are not available, but Leak (1979) suggests that *F. americana* has higher-than-average nutrient needs. The association of *T. americana* with sites of low productivity was surprising and contradictory with observations by ourselves and others (Wessels 1999, Ulrey 2002). However, because *T. americana* occurred on few plots, our contradictory results could simply be artifacts of the data set. Further analysis of this data set is desirable but data from other sources are needed to confirm these results.

CONCLUSIONS

Foresters have long recognized that some tree species are indicators of site conditions associated with certain moisture, fertility, and temperature regimes. For example, Leak (1979) reported that *F. americana* and other species indicated sites of higher than average fertility and productivity in the northern Appalachians. However, little information is available to establish quantitative relationships of these and other species with site productivity, particularly in the southern Appalachians. In this preliminary study of tree indicator species in the southern Appalachians, we found that site productivity tended to be higher where one or more of four species was present. Productivity was lower where one or more of seven species was present. From knowledge gained in this exploratory study, we are encouraged to pursue the development of a site productivity classification system based on indicator species.

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Table 1. Moisture and fertility weights, occurrence, and productivity ratings of common hardwood tree species in the Southern Appalachian Mountains. Species plotting labels for Figure 1 (first two letters of genus and species) are in parentheses.

Tree species (Genus and species code)	Moisture weight[1]	Fertility weight[1]	Percent occurrence[2]	Productivity rating[3]
Acer rubrum L. (Acru)[4]	0.0	1	72	N
Acer saccharum Marsh. (Acsa)	3.5	2	12	N
Aesculus octandra Marsh. (Aeoc)	4.0	2	6	N
Betula alleghaniensis Britton (Beal)	3.5	1	6	N
Betula lenta L. (Bele)	3.5	1	27	N
Carya spp. Nutt. (Casp)[5]	2.5	1	42	N
Cornus florida L. (Cofl)	3.0	1	42	N
Fagus grandifolia Ehrh. (Fagr)	3.0	1	12	N
Fraxinus americana L. (Fram)	4.0	2	11	H
Halesia carolina L. (Haca)	3.5	1	7	L
Liriodendron tulipifera L. (Litu)	3.5	1	46	H
Magnolia acuminata L. (Maac)	3.5	1	7	L
Magnolia fraseri Walt. (Mafr)[6]	--	--	6	L
Nyssa sylvatica Marsh. (Nysy)	2.0	1	32	N
Oxydendrum arboreum (L.) DC. (Oxar)	2.0	1	47	N
Prunus serotina Ehrh. (Prse)	3.5	1	8	H
Quercus alba L. (Qual)	2.5	1	38	N
Quercus coccinea Muenchh. (Quco)	1.5	1	37	L
Quercus falcata Michx. (Qufa)	2.0	1	5	N
Quercus prinus L. (Qupr)	2.0	1	60	L
Quercus rubra L. (Quru)	3.0	1	39	L
Quercus velutina Lam. (Quve)	2.0	1	30	N
Robinia pseudoacacia L. (Rops)	3.0	1	29	H
Sassafras albidum (Nutt.) Nees (Saal)	2.0	1	8	N
Tilia americana L. (Tiam)	4.0	2	8	L

[1]Moisture and fertility weights from McNab and Loftis (see text footnote 60).
[2]Expressed as a percent of the total 631 field plots used in the study.
[3]Species productivity ratings derived in this study: H, significantly higher where species present; N, not significant; L, significantly lower where species present. Productivity was expressed as the mean annual basal area increment (ft^2/ac) per square foot of initial site basal area.
[4]Red maple is nearly ubiquitous and was assigned a moisture weight of 0.
[5]Includes *C. cordiformis* (Wangenh.) K. Koch, *C. glabra* (Mill.) Sweet, *C. ovata* (Mill.) K. Koch, and *C. tomentosa* (Poir.) Nutt.
[6]This species has not been assigned moisture or fertility weights.

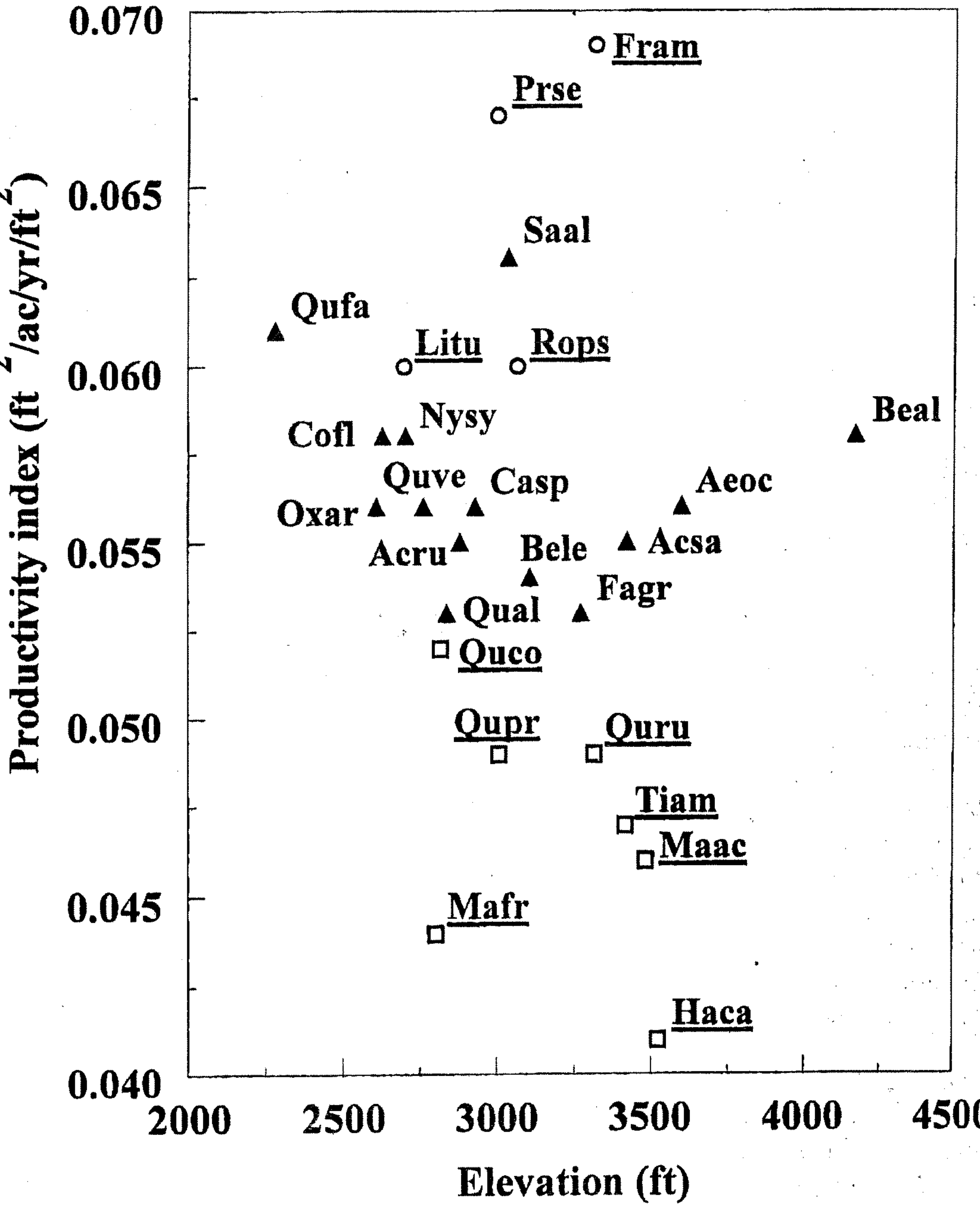

Figure 1. Relationship of mean site productivity index and elevation of occurrence for the 25 species studied. See Table 1 for plotting point labels. An underlined species label indicates higher (○) or lower (□) productivity on sites where the species was present compared to sites where the species was absent