HARDWOODS AND SITE QUALITY

W. Henry McNab

Research Forester
USDA Forest Service
Southeastern Forest Experiment Station
Asheville, NC 28806

ABSTRACT

Species composition of hardwood stands in the Appalachians is closely related to site quality, which itself is correlated with available soil moisture during the growing season. Mesophytic species, such as yellow-poplar and sugar maple, dominate moist, high-quality sites, while drought-tolerant species such as the oaks dominate drier, lower quality sites. Some species, such as red maple and sassafras, occur on all sites. Site quality is commonly expressed by site index, but many potential sources of error may seriously bias estimates. Soil-site relationships are discussed as an alternative method of site quality evaluation.

Introduction

The varied climate, topography, and soils of the Appalachians create a wide range of habitats for an estimated 150 indigenous tree species. Foresters have a variety of options available for stand regeneration depending on the site requirements, shade tolerance, and other silvical characteristics of the desired management species. Perhaps the first question that the forester planning harvest and regeneration needs to ask is: "Which species should I attempt to regenerate on this site?" Sometimes, however, the manager does not ask a followup question: "Which species are likely to occupy the site naturally?" If the two answers do not agree, the manager will face an uphill battle against nature that cannot be won economically. Much of the time, the correct answers depend on site quality, because in the Appalachians there is a strong relationship between site and species composition. The first purpose of my paper is to review the general relationships between species composition and site quality in the Appalachian region, which includes the Appalachian, Allegheny, and Cumberland Mountains, their associated plateaus, and the Ridge and Valley Province. The second part of my paper concerns estimation of site quality using site index and soil-site relationships.

The Effect of Site Quality on Species Composition

About 90 percent of the tree species in the region are hardwoods. In the mountains hardwood species occur in various mixtures, forming many forest cover types. For example, over 16 principal cover types are recognized in the Appalachians (Society of American Foresters 1980). Some cover types are easily identifiable because few species are present and types change abruptly with slight changes in site. Others consist of many species, have overlapping boundaries, and appear to be less site dependent. Many cover types, however, have one thing in common that we can use to understand the interrelationship between species composition and site quality: most species in a stand respond similarly to the site's soil moisture regime. Although other silvical characteristics are also important, such as shade tolerance, I will mainly use the moisture relationship to group species according to the site conditions necessary for their establishment and growth.

In 1926, the Society of American Foresters developed a very general classification of Appalachian forest vegetation based largely on site and species moisture relationships. Three types of hardwood forests were recognized: (1) moist slope and cove forest, (2) dry slope and ridge forest, and (3) northern forest. The northern forest is found above 4,500 feet elevation in the southern Appalachians and at lower elevations in the central Appalachians. Because the northern forest consists of mesophytic species, some of which are also found at lower elevations, I combine it with the moist slope forest. Awareness and recognition of these forest types is important because, with several exceptions, species composition of regeneration generally will closely resemble that of the overstory. For each type of forest, I briefly describe the general species composition of the mature overstory. Other authors in this workshop describe expected species of regeneration in greater detail.

Moist Slope and Cove Forest

About a third of the commercial forest area consists of moist slopes and coves, which may be characterized as having a cool environment with generally adequate to marginal soil moisture during the growing season. Cove forests occur at elevations between 2,000 to 4,500 feet elevations in the southern Appalachians, and extend up to about 3,500 feet in the central Appalachians. The cove forest is a mixture of many species, and throughout the region typically consists mostly of yellow-poplar, northern red oak, and white oak. Other mesophytic canopy species present in smaller numbers, or not at all, are: white ash, black locust, basswood, walnuts, buckeye, black cherry, red maple, sweet birch, blackgum, cucumbertree, and hickories. Understory tree and shrub associates commonly include flowering dogwood, Fraser magnolia, eastern hophornbeam, sassafras, American hornbeam, striped and mountain maples, serviceberries, redbud, rhododendrons and witch-hazel. Carolina silverbell is a midstory constituent of some stands in the southern mountains. Eastern hemlock and eastern white pine are sometimes also present. Ground vegetation in coves usually consists of a dense herbaceous layer of ferns and spring ephemerals including squirrel corn, springbeauty, mayapple, and other moist-site species.

The composition of the cove forest varies with geographical area and from stand to stand, with species and abundance depending on local topographic conditions, soils, elevation, and past stand management. The moist slope forest occurs on northerly aspects and has a species composition dominated by yellow-poplar, other cove hardwoods, and, previously, American chestnut. Below 3,500 feet in the southern region, and lower in the central region, white oak is associated with a large number of other species on benches and lower slopes; in the Piedmont, it is on the better soils. The northern forest occurs on moist, northerly slopes at elevations above 4,500 feet elevation in the southern Appalachians, and has a species composition similar to that found on moist sites at lower elevations in the central mountains. In the central Appalachians, the northern forest may also enter coves. Sugar maple, American beech, and yellow birch make up much of the stand. Other associated species are buckeye, basswood, cucumbertree, white ash, black cherry, and northern red oak. Hemlock, and sometimes red spruce and balsam fir are associated conifers. On the Cumberland and Allegheny Plateaus, sugar maple can predominate at lower elevations. Perhaps the best development of the mixed mesophytic forest is in the Cumberland Mountains, where an exceptionally uniform mixture of moist-site species occurs on all but the driest slopes. The moist slope and cove forest may be described as occupying good to excellent sites. Site index of stands on these sites exceeds 105 for yellow-poplar and is above 75 for northern red oak.

Dry Slope and Ridge Forests

Over half of the forest in the Appalachians is on ridges and dry slopes with southerly and westerly aspects, where soil moisture deficits typically occur during the middle to late part of the growing season. This forest type is characterized by drought-tolerant species, mostly oaks, and often includes small stands of mesic-site species in ravines. Chestnut oak and black oak are widespread dry-site species that can occur in extensive, almost pure stands. Chestnut oak occupies a range from below 1,000 in the central Appalachians to about 4,500 feet in the southern mountains. Black oak is found at elevations to 4,000 feet and is an important hardwood in the foothills. Other associated species include scarlet and white oaks, black locust, black cherry, blackgum, and red maple. Southern red oak is a component on dry plateau sites below 1,000 feet in the north and 2,000 feet in the south. Post and blackjack oaks are found on very dry, poor quality sites, usually below 2,000 feet elevation. Understory trees include flowering dogwood, sourwood, sassafras, and American hornbeam. Bear oak is common on dry upper slopes in the ridge and valley province. Shrub associates include mountain-laurel, flame azalea, trailing arbutus, blueberries and huckleberries. Oatgrass may be present in the herbaceous layer along with New Jersey tea, pussytoes, and other dry-site species. White pine is an associate of chestnut oak in the Appalachians. Shortleaf and pitch pines can become a more important canopy component on dry sites in the intermountain basins and plateaus.

Implications for Management

The commercial values of timber species change along with consumer preferences, but recommendations can be made about the relative values of hardwood species for management. Because certain groups of hardwoods are likely to be associated with specific sites in the Appalachians, it would be a mistake to favor the presently popular "right species" on the wrong site. For example, yellow-poplar is a mesophytic species that grows and develops best in coves and on lower elevation moist slopes. Yellow-poplar also occurs on lower quality sites, but its growth, form, and high value there is less than that of the oaks, which are better adapted to dry sites. Dry-site species can grow well on moist sites, but the reverse is not generally true. Likewise, some species, such as dogwood and striped maple are well adapted to moist sites, but are not desirable from a timber standpoint because of their poor form, small size, and low quality. In 1931, Frothingham developed a list of desirable and undesirable timber species for moist and dry sites in the Appalachians, Table 1. Now, over 50 years later, I think it is still generally applicable for forest management.

In summary, because general species composition is so closely correlated with site quality, classifying sites is one of the first steps necessary in planning for management and regeneration. Both timber yields and product quality will be improved if mesophytic species are favored on moist sites, and oaks are grown on dryer slopes. The forester should recall that in mixed species stands, site quality alone will not indicate exact species composition; more detailed ecological models are needed for that. On moist sites oaks and other species with intermediate shade tolerance will likely not be successfully regenerated without special attention. And evaluation of site quality is not always easy. In general, however, the species occupying a stand before harvest are good indicators of site quality and potential future composition of regeneration on that site.

Estimation of Site Quality

Site quality is the inherent biological capability of an area to be productive, and for most forest land is considered a fixed quantity that depends mainly on environmental variables. Two approaches are commonly used in estimation of site quality: site index and soil-site relationships. In the former approach, the tree serves as a long-term, continuous recorder of previous environmental characteristics of the site. In the soil-site technique, the forester attempts to predict tree performance from existing site characteristics which have biological implications about the moisture and fertility levels of the site. Each technique has advantages and disadvantages of use. Another method, growth intercept, is based on a relationship between site quality and the first 5 years of height growth after trees have reached breast height. This method is occasionally used to predict site quality for stands between 15 to 20 years of age, and mainly for conifers which produce annual whorls of branches.

Table 1. Desirability of Appalachian hardwood trees for timber production on moist and dry sites (from Frothingham 1931).

Desirable timber even-aged species[a]	Less desirable species: Timber species	Less desirable species: Minor species[b]
	MOIST-SITE SPECIES	
Ash (sp)	Beech	Birch, river
Basswood (sp)	Buckeye	Blue beech
Birch, sweet	Butternut	Cherry, pin
Birch, yellow	Chestnut*	Chinquapin*
Cherry, black	Coffeetree	Crab apple
Gum, red	Elm (sp)	Dogwood*
Hickory, mockernut	Gum, black*	Hawthorns
Hickory, pignut*	Hickory, bitternut	Holly
Hickory, shagbark	Honeylocust	Hophornbeam
Locust, black*	Maple, red*	Maple, striped
Magnolia, cucumber	Maple, silver	Mulberry, red
Maple, sugar	Oak, pin	Persimmon*
Oak, chinquapin	Oak, shingle	Sassafras*
Oak, northern red	Oak, water	Serviceberry*
Oak, white	Sycamore	Silverbell
Walnut, black		Sourwood*
Yellow-poplar		Willow, black
	DRY-SITE SPECIES	
Hickory, pignut*	Chestnut*	Chinquapin*
Locust, black*	Gum, black*	Dogwood*
Oak, black	Maple, red*	Oak, blackjack
Oak, chestnut	Oak, post	Persimmon*
Oak, southern red	Oak, scarlet	Sassafras*
		Serviceberry*
		Sourwood*

[a] Most of the species that are desirable on moist sites are less desirable where they occur on dry sites.
[b] Generally small tree.
* Species common on both moist and dry sites.

Site Index

Site index (base 50 years) is the most common measure of forest site quality in Appalachian forests. For example, at the first workshop (Smith and Eye 1986), on immature stand management, the papers that referred to site quality used site index classes to quantify it. Foresters sometimes question whether site index is the best measure of site quality and whether a different measure of potential production, such as total cubic volume or mean annual basal area increment, might be more appropriate. At least for the near future, site index is likely to remain in widespread use in the Appalachians.

Because estimates of site index depend largely on the choice of sample trees, foresters should remember the following criteria when using it to estimate site quality:

1. Applicable only to even-aged stands.
2. Sample trees should not have been previously suppressed.
3. Species should be well suited to the site.
4. No evidence of insect-, disease-, fire-, or weather-caused damage.

Even if the above criteria are satisfied, other sources of error are inherent in many site index curves. These errors include sampling bias during curve construction and imprecise curve fitting. In comparison with guide curves, polymorphic curves are generally considered to predict rates of height growth more accurately over a range of sites.

Improper use of site index curves is probably the most common source of error when estimating site quality. Site curves should be applied in the same manner in which the curves were constructed. As a minimum, the user should sample as many trees per site as the researcher used in developing the curves. The effect of sample size on accuracy of predictions is illustrated by Lamson (1980), who developed site index prediction tables for West Virginia oaks and presented estimates of accuracy that can be expected with their application. As shown in Table 2, at least five trees should be sampled in a 50-year-old stand of red oaks to achieve a half-width confidence interval of 3.3 feet. A greater number of trees should be sampled in younger or older stands to achieve a comparable confidence interval.

Table 2. Half-width of the 95-percent confidence interval of the predicted site index when the number of sample trees ranges from 5 to 25 trees (From Lamson 1980).

Stand age	Half-width of confidence interval (± feet) when number of sample trees is				
	5	10	15	20	25
	NORTHERN RED, SCARLET, AND BLACK OAKS				
20	6.2	4.8	4.2	3.8	3.6
50	3.3	3.1	2.9	2.7	2.6
70	5.1	4.0	3.5	3.3	3.1
	WHITE AND CHESTNUT OAKS				
20	7.6	5.9	5.1	4.7	4.4
50	3.4	3.2	3.0	2.8	2.7
70	4.8	3.7	3.2	3.0	2.8

Estimation of site quality in very young stands can also present problems. Many site index curves were developed using data from mature stands where most sample trees were clustered around the basis age of 50 years. Extrapolation of these curves to younger stands, especially stands of sprout origin, can result in overestimates of site index because the period of rapid juvenile height growth is ignored (Zahner et al. 1982).

Assuming that sources of error in sample-tree selection have been controlled or accounted for, two final sources remain: determination of tree age and height. I do not have an easy solution to the problems of accurately determining tree age, which includes counting indistinct annual rings in diffuse porous species, and in trees with heartrot, or trees with false and extra rings. One solution is to use a height-diameter relationship, instead of height and age, to estimate site class (Lamson 1987).

Many errors in site index determination result from errors in tree height measurement. A technique is available that reduces time and increases accuracy when measuring tree height in stands with steep slopes and dense understory shrubs. Long and Mohai (1986) describe a simple method of measurement based on a variable slope distance (not horizontal distance) of the observer from the sample tree. This method allows the user to proceed up the slope from the sample tree to any convenient place where the top is clearly visible. The observer can not only get closer to the tree top, but also can choose an easy travel route without having to maintain a specific horizontal base distance from the tree. Also, the base of the tree does not have to be visible, but the observer must see a point equal to his or her own height. An inexpensive calculator with square root and reciprocal functions is useful to solve the formula for height. The tangent method of measuring tree height (Larsen et al. 1987) is also useful in mountainous terrain and has the advantage of not requiring a distance measurement from the tree or correction for slope. However, a reference pole of known length must be placed against the tree and two equations with trigonometric functions must be solved to determine tree height.

A species desired for management, such as northern red oak, may not be present for site index determination in some stands. Doolittle (1958) prepared site index comparison tables for 10 species in the Southern Appalachians.

Soil-Site Relationships

Site quality may also be evaluated by observing topography and soil characteristics of the stand. Advantages to this approach are:

1. Sample trees are not required.
2. Present rather than past site factors are evaluated.
3. Prediction models can be used in geographical information systems.

Disadvantages are:

1. Published results usually are not available in tabular form, for ease in field application.
2. Relationships may not be available for a desired species or geographical area.
3. Subjective estimates of some topographic variables may be required.
4. Laboratory analysis may be needed for some soil variables.

Perhaps the most serious limitation of soil-site relationships is that the results may be applicable only to a limited geographic regions. Large errors may result if soil-site equations are applied beyond the area where the study was made.

Soil-site studies have been carried out in many parts of the Appalachian region, Table 3. Most have dealt with yellow-poplar and oaks, and have attempted to predict total tree height at 50 years using similar field measurements. Findings from many studies, however, are applicable only to small geographic areas. Especially noteworthy are four field guides developed by Smalley (1979, 1982, 1984, 1986) for classification, evaluation, and mapping of forest sites throughout the Cumberland Mountains and Plateau. The principles developed by Smalley are being tested by industry to identify and evaluate forest productivity in the Allegheny Mountains and Plateau of West Virginia.

Topographic variables, as a group, are the most important determinants of site quality because of their combined influence on the site moisture regime. Aspect is typically the single most important variable because of its effect on the solar radiation received by the site; north facing slopes receive less direct sunlight than south facing slopes. Position on the slope is usually next in importance and serves as a measure of subsurface water received from landforms further upslope. Slope position also accounts for some soil variation, because deep, colluvial soils are on lower positions while shallow residuals are on mid to upper slopes. Lower slope positions are more protected from the drying effect of winds compared to upper slopes. Other topographic variables, such as shape of the slope and gradient, have yielded inconsistent, but locally important, correlations with site quality. Correlations between site quality and elevation also are inconsistent, likely because many studies are conducted over a limited vertical range.

Soil properties measured in soil-site studies are generally related to the volume available for moisture storage and to physical and chemical properties. Thicknesses of the A-horizon, B-horizon, or both are often correlated with site quality, especially for oaks. Soil texture is the most important physical property; fine-textured soils retain moisture better than coarse soils. Occasionally, soil pH is an important chemical property because of its effect on nutrient availability. Some soil properties, including depth, often must be estimated subjectively. Others may require sample collection and laboratory analysis. Some researchers have found little loss in soil-site correlations by excluding soil variables from prediction equations in the mountains.

Soil mapping designations in the Southern Appalachians generally have not been consistently correlated with site quality, especially for yellow-poplar. Part of the reason seems to be that early soil mapping was based on broad definitions of series which allowed a soil to be placed on many different aspects and slope positions. Another reason is that soil taxonomic criteria may not be important to tree growth. Because weathering of parent rocks is predictable, broad scale geologic maps may be useful in estimation of site quality, at least until more up-to-date maps of mountain soils become available.

Little work has been done on indicator plant species, and some researchers believe they will be of limited value because so much Appalachian forest has been disturbed by past land use. Currently, vegetation is not a very useful indicator of site quality except for very general relationships. For example, ericaceous species are typically associated with dry sites of low quality, while higher quality sites typically have a dense layer of low, herbaceous vegetation which is conspicuous during the early growing season. Information on specific indicator species is not available for most of the Appalachians, but local experience has shown some associations. In the southern Appalachians, for example, blue cohosh and baneberry are typically found on high quality sites. Their absence, however, does not necessarily mean the site is of lower quality.

Where results of soil-site studies are not available, I suggest using topographic and edaphic characteristics as a general indication of the moisture regime and quality of the site. Certain factors are associated with high-quality hardwood sites in the Chattahoochee National Forest (Rightmyer 1987) and should be generally applicable throughout the Appalachians:

Topographic factors

1. Aspect- North and east facing slopes; azimuths from 330 to 120.
2. Position- Lower 1/3 of slopes.
3. Gradient- Gently sloping, 10 to 30 percent.
4. Land surface shape- Concave landforms.

Soil factors

1. Total depth- Over 40 inches.
2. Topsoil (A horizon) thickness- Greater than 6 inches.
3. Texture- Clayey to loamy.

Table 3. Sources of information on forest site classification and hardwood soil-site relationships for various physiographic regions in the Appalachians.

Source	State	Species	Indep. Variables Soil	Topo.	Other
			------Number-----		
	ALLEGHENY MOUNTAINS				
Trimble and Weitzman (1956)	WV,MD	Oaks	1	3	0
Yawney (1964)	WV	Oaks	1	3	0
	ALLEGHENY PLATEAU				
Auchmoody and Smith 1979)	WV	Oaks	1	4	1
Fountain, M.E. (1977)	WV	Oaks	22	3	6
	CUMBERLAND MOUNTAINS				
Smalley (1984)	TN-KY	All	NA	NA	NA
	CUMBERLAND PLATEAU				
Eigel, et al. (1982)	KY	Yel.-Pop.	3	0	2
Honeycutt, et al. (1982)	KY	Wh. Oak	3	2	0
Smalley (1967)	AL	Oaks	0	3	0
Smalley (1979)	AL-GA	All	NA	NA	NA
Smalley (1982)	AL-TN	All	NA	NA	NA
Smalley (1986)	TN-KY	All	NA	NA	NA
	RIDGE AND VALLEY				
Yawney and Trimble (1968)	WV,MD	Oaks	1	2	0
	APPALACHIAN MOUNTAINS				
Doolittle (1957)	NC	Oaks	2	1	0
Ike and Huppuch (1968)	GA	Var.[a]	2	4	2
McNab (1984)	GA-VA	Yel.-Pop.	0	3	1
	PIEDMONT PLATEAU				
Della-Bianca and Olson (1961)	NC-VA	Oaks, YP	4	2	1

[a] Oaks; Virginia, pitch, E. white, shortleaf pines; yellow-poplar.

While each of these topographic and soil factors are associated with a good site, combinations of them in the same stand can indicate even higher quality. Effects of these variables, and others not mentioned here, tend to be additive to a point where the biological growth limit of the tree species is reached.

Results of a study of oaks in the Allegheny Plateau, by Auchmoody and Smith (1979) illustrate some important points about soil-site relationships. I extracted a small part of their results, Table 4, to illustrate how oak site index is affected by three of the six variables they found to be important. When slope position, slope gradient, and slope shape are held constant, site quality is high on easterly aspects and increases with increasing precipitation and thickness of the A1 soil horizon. Equivalent site quality can result from various combinations of the same site factors. For example, an estimated site index of 63 can occur in a stand with: (1) south aspect, relatively low precipitation and thick A1 horizon; (2) northeast aspect, moderate precipitation and shallow A1 horizon; or (3) southwest aspect, high rainfall and shallow A1 horizon. Other combinations also can produce sites of equivalent quality.

Table 4. The relationship between site index and selected climatic, soil, and topographic variables for oaks in northwestern West Virginia. Other important site variables are held constant: slope gradient = 50 percent, slope position = upper 25 percent, slope shape = convex. (From Auchmoody and Smith 1979).

Thickness	Aspect								
of A1 (in)	0	45	90	135	180	225	270	315	360
	-----Site Index-----								
	PRECIPITATION = 40 INCHES								
1	55	57	58	56	54	52	51	52	55
2	58	60	61	59	57	54	54	55	58
4	64	66	67	65	63	60	60	61	64
	PRECIPITATION = 42 INCHES								
1	61	63	64	62	60	57	57	58	61
2	64	66	66	65	62	60	60	61	64
4	69	72	72	71	68	66	65	67	69
	PRECIPITATION = 44 INCHES								
1	66	69	69	68	65	63	62	64	66
2	69	72	72	71	68	66	65	67	69
4	75	77	78	77	74	72	71	72	75

I suggest that soil-site relationships be used to confirm estimates of site index classes where few suitable sample trees are present, perhaps due to stand history. If results of site index and soil-site measures are close, then confidence can be placed in the estimate of site quality. However, if the estimates differ by more than 10 to 15 site units, I would reexamine the field data to reduce the possibility of an error that would result in less-than-optimum management during the rotation. First, check the soil-site data by comparing values of the field-measured topographic variables with those obtained from a USGS 7.5 minute quadrangle map. If no obvious errors in the topographic data are found, then revisit the sample points in the stand to determine if less than desirable site trees were selected or if there were errors in measurement and recording of height or site factors. If no apparent source of discrepancy can be found, then I would use the site index estimate as a measure of site quality.

Summary

The soil moisture regime is the single most important site factor to consider when evaluating site quality and regeneration of stands in the Appalachians. While moisture relations of the site cannot be changed, species composition can be altered to match moisture relations. The manager should remember the following:

1. Species composition is closely correlated with site quality.
    a. High quality sites will usually be dominated by yellow-poplar, sugar maple, and other mesophytic species.
    b. Lower quality sites will typically be dominated by oaks and other drought-resistant species.
    c. A few species, such as red maple and sassafras, are adaptable to a variety of sites.
2. Previous stand history often has an important effect on the presence of certain species; such as those with intermediate tolerance on moist sites.
3. Site index estimates in cut-over, high-graded stands should be checked with soil-site relationships.

With attention to site quality and knowledge of the relative moisture requirements of the desirable forest tree species in the area, the forest manager should be able to predict the future composition of the regenerated stand with considerable precision.

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