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SITE QUALITY RELATIONSHIPS FOR THE OAK-HICKORY FOREST TYPE

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The oak-hickory forest type, which covers some 111 million acres and is the largest single forest type in the United States, includes a variety of upland oak and associated hardwood species and is found on most upland soils and physiographic divisions of the central forest area.

Quantity and quality of yield of our oak-hickory forest varies greatly with site quality. To gauge returns from silvicultural treatments and to recommend species for management on a given site, forest land managers need reliable site quality estimates for a variety of tree species. Information about site quality relationships for species in the oak-hickory type, although lacking for much of the central forest area, has steadily increased over the past several years (Carmean 1970a, 1971a, 1975).

Site quality is usually expressed as site index (the height of the dominant and codominant trees at an index age of usually 50 years), which can be measured either directly by site curves or species comparisons or indirectly by soil survey methods or soil-site relationships.

DIRECT MEASUREMENT

Site Index Curves

With the site index curve method of direct estimation, height and age measurements from free-growing dominant and codominant trees are compared with published site index curves or tables to estimate how tall trees were or will be at the index age. The site index curve method is both simple and accurate when suitable trees and stands exist for measurement, and when reliable site index curves and tables are available.

In addition to the regional upland oak curves of Schnur (1937), locally derived site index curves or tables are available for upland oaks in the Piedmont and Southern Appalachians (Olson 1959); red oak in the Lake States (Gevorkiantz 1957); black, scarlet, and white oaks in southeastern Missouri (McQuilkin 1974); black, red, and white oaks in northern Arkansas (Graney and Bower 1971); and black, white, scarlet, and chestnut oaks in the Central States (Carmean 1971b). The importance of accurate localized curves has been indicated by several recent studies which have shown that height growth patterns for the upland oaks may vary considerably by species, locality, soil condition, and site index class (Carmean 1970b, 1972, Graney and Bower 1971, McQuilkin 1974).

Errors caused by inaccurate curves are greatest in very young or very old stands. So, when uncertainty exists as to the reliability of regionwide or local harmonized curves, select trees as near the 50-year index age as possible to minimize possible error (Carmean 1970a). McQuilkin (1975) observed that using trees appreciably younger or older than the main stand could also cause errors in site index estimates, because such trees often have height growth patterns different from that of the main stand.

Carmean (1972) demonstrated that height growth patterns differ between oak species, so use of general oak site index curves may cause erroneous predictions for oaks with height growth patterns different from the general oak site index curves. For example, if average height of 50-year-old dominant and codominant black and white oaks is 60 feet, Schnur's (1937) general site index curves indicate a height of 79 feet at 100 years of age. But Carmean's (1971b) polymorphic curves for black oak and white oak in the Central States indicate that black oak would be 83 feet tall and white oak 96 feet tall at 100 years of age. This potential difference in tree height will also influence yield because predominantly white oak stands will have taller trees and more volume at rotation age than stands containing mostly black oak. Height growth differences between white oak and various red oak species in the Ozarks of Missouri

(McQuilkin 1974) and in northern Arkansas (Graney and Bower 1971) generally agree with those described by Carmean (1972), but are not as pronounced.

Species Comparisons

Many even-aged oak-hickory stands are suitable for site index measurement but may not contain a particular species in the dominant or codominant crown classes. For such species, site index can often be estimated by measuring the site index of existing species and then using comparison graphs or equations to determine site index of the desired species. Such comparison graphs, equations, or ratios are available for upland oaks and associated hardwoods in the Piedmont (Olson and Della-Bianca 1959, Nelson and Beaufait 1956), the Appalachians (Doolittle 1958, Trimble and Weitzman 1956), and the Missouri Ozarks (McQuilkin 1974). Although comparison procedures help extend the application of direct site index measurement, such height comparisons at age 50 may not hold true for older ages (Carmean 1971a). For example, white oak growth does not slow as much as that of black oak in later years, so white oak with a site index 5 feet lower than that of black oak at age 50 may be as tall as or taller than black oak at age 100.

INDIRECT METHODS

Where suitable site index trees are not available, managers need methods of site quality estimation that can be used regardless of species composition or existing stand conditions. Soil survey and soil-site techniques have received the most attention as indirect methods of site quality estimation.

Soil Survey

Although soil surveys for agricultural lands have been made for more than 75 years, only recently has much attention been given to forest lands. In most states, modern soil maps are now prepared for both agricultural and forested lands.

Most modern soil survey reports include an average site index or a range in site index values for each soil series or mapping unit. When these average site index values are based on many measurements over a range of site conditions common to a given soil, comparisons of average values can provide general productivity levels for a given tree species on different soils or for a number of species on the same soil series. Often, however, average site index values for various species and soils are based on few actual site index measurements, so estimates of productivity can be misleading.

A greater problem in using soil taxonomic unit site index averages arises from the often excessive variation in site index within a given soil series (Carmean 1961, Graney 1977, Ike and Huppuch 1968, Van Lear and Hosner 1967, Watt and Newhouse 1973). Much of this site index variation is caused by wide variations in the soil or topographic factors within the mapping unit. Features such as surface soil depth, subsoil texture, aspect, slope position, and slope shape, which are strongly correlated with hardwood site quality, should be incorporated as phases of established mapping units. Based on site studies for black oak in southeastern Ohio, Carmean (1967) suggested topographic phases that could aid in defining differences in oak site quality. Hartung and Lloyd (1969) found that a correction for aspect explained much site index variation within Clarksville soil mapping units in southeastern Missouri. A soil-site study in the mountains of northern Arkansas also indicated that including aspect and slope shape-position phases in present soil mapping units would help in evaluation of oak site quality (Graney 1977).

A recent National Forest soil survey in Missouri (Gott 1975) is a good example of an attempt to incorporate site information into a soil survey. Mapping intensity in this survey was high, and units were slope phases of each soil type. Productivity estimates were presented by land site groups, which were determined by soils, topographic position, aspect, and microclimate. With such a productivity rating system, site quality estimates for each land site group could be refined as additional site index data and soil-site information become available.

Soil-site relationships

A recent comprehensive review of forest site quality evaluation in the United States (Carmean 1975) listed 43 papers on soil-site relationships for eastern upland oaks and associated species. Even with the wealth of information contained in this summary, site relationships for most species of the oak-hickory type are not well understood, because many species cover a wide geographic range that includes extreme variation in physiography, soils and climate. These soil-site studies, however, have provided some general trends concerning soil and topographic site features most often associated with changes in site quality for many of the oaks and associated species. Most upland tree species respond similarly to the same general site conditions although the degree of response for any one site factor can vary widely among species and with other interacting soil, topographic, or climatic conditions.

Soil features most often correlated with site quality are surface soil depth, total soil depth, and surface and subsoil textures. The surface soil, or A horizon, is generally considered the soil layer most favorable for fine root development and absorption of nutrients and moisture. The relationship between surface soil depth and site quality is often curvilinear and where surface soils are shallow, small increases in surface soil depth can cause large increases in site quality.

Best sites are usually on medium-textured soils. Texture and stone content relationships are probably associated with available moisture, nutrient levels, soil drainage, and aeration. Coarse-textured soils generally have lower site qualities because soil moisture holding capacity and nutrient levels are limited. Medium-textured soils are good sites because they have adequate available moisture and nutrient levels, good soil structure, internal drainage, and good aeration, which favors root development. Fine-textured soils generally have adequate soil moisture and nutrients but are often of lower site qualities than the medium-textured soils because they commonly have dense clay subsoils with poor structure, drainage, and aeration, factors that limit root development.

Topographic variables usually associated with site quality are: aspect, slope position, slope gradient, slope shape, and elevation. Best sites are generally north- and east-facing, gently sloping, concave, or lower slope positions while poorest sites are narrow ridge tops and south- and west-facing steep, convex upper slopes. Topographic features are often closely correlated with soil depth and profile development, amounts of available soil moisture and nutrients, and microclimate (Carmean 1975, Lee and Sypolt 1974). In rough hilly and mountainous terrain, topographic features have generally produced highest correlations with site quality; on more level terrain, soil variables have usually indicated highest correlations with site quality.

In most site studies throughout the oak-hickory area, aspect has consistently indicated strong correlations with site quality. The pattern of better sites on north to east aspects and poorer sites on south to west aspects has held true for most of the oak-hickory area. Correlations between aspect and site quality can be modified by interactions with other variables such as slope gradient. In southeast Missouri, Hartung and Lloyd (1969) indicated that aspect affected pine and oak site quality little when slopes were less than 14 percent. In southeastern Ohio, Carmean (1967) showed that black oak site index increased from southwest-facing slopes to northeast-facing slopes; these increases were very pronounced for steep slopes but were minor on gentle slopes. For southwest-facing slopes, site index decreased drastically with increased steepness; however, on northeast-facing slopes site index increased slightly as slopes become greater.

Slope position and slope shape are often correlated with many of the soil features that have also indicated correlations with site quality. Lower slopes and concave slopes generally have deep, colluvial soils with relatively thick surface soil layers. Upper slope soils are usually shallow and have relatively thin surface soil horizons. In mountainous areas with bench and bluff type topography, alternating upper and lower slope conditions at many positions on the mountain side are common. In these situations, site quality can change drastically within a matter of a few feet, and combining slope shape and position variables is often necessary to define the relationship between site quality and topographic features (Bowersox and Ward 1972, Graney 1977).

Although generalizations about the soil and topographic site features related to site quality of oak-hickory forests are possible, many species differ in their response to given soil and topographic site features. For example, in the mountains of northern Arkansas, Graney (1977) found that northern red and black oaks grew best on northeast-facing, concave, inner-bench positions with deep soils that had medium-textured subsoils and thick surface soil horizons. White oak, however, was less responsive to changes in aspect and surface soil thickness, and indicated about the same site quality over a wide range in soil depths and subsoil textures. Such information about variability of species response to soil and topographic features can help the land manager decide which species to favor for management on various sites. In the above study, both red oak species and white oak were recommended for management on deep medium-textured, north slope soils while white oak was recommended for the fine-textured soils and on south and west-facing slopes.

One major source of error in indirect estimation of site index comes from using soil-site prediction equations and tables from outside the specific geographic area, or on soil and topographic conditions different from where the soil-site study was made. Errors can also occur if derived site prediction equations do not accurately represent the true correlations between site conditions and site index in the study area. Few published soil-site prediction equations have been tested with independent sets of soil-site data to determine whether equations produce reasonably accurate predictions of site quality within the study area. The coefficient of determination (R^2) and standard error of the estimate have generally been the measure of success for a derived equation. But, these statistics simply show how well the equation fits that particular data set without indicating how accurately the equation will predict for all data sets.

Soil-site equations have shown mixed success in predicting site index on plots not used in deriving the equations. Equations for bottomland hardwoods in the lower Mississippi Valley (Broadfoot 1969) and black oak in the Missouri Ozarks (McQuilkin 1976) were inaccurate when tested with additional plot data from within the study areas. But equations for upland oaks in the Ridge and Valley Region of Pennsylvania (Bowersox and Ward 1972) and for red oaks and white oak in the mountains of northern Arkansas (Graney 1977) produced accurate site index predictions on check plots. Such conflicting results concerning the reliability of derived soil-site equations indicate that all existing and new soil-site equations should be adequately tested for reliability before use for site quality estimation.

CONCLUSIONS

Estimates of site quality, whether from direct tree measurements or indirect estimates based on soil and site features, are simply local observations for many points on the landscape. To be of value to the land manager, a system of site quality evaluation based on some identifiable unit of landscape must be devised. Such a system should include all available knowledge of soils, site index, and soil-site relationships for each species that can be reasonably managed in a given area. Such a system would sacrifice some precision in site quality estimation but would have the advantage of identifying a manageable portion of the landscape. A logical start in devising such a system would be intensive mapping of our forested areas with mapping units based on soil and topographic site features that are correlated with site quality.

LITERATURE CITED

Bowersox, T. W., and W. W. Ward. 1972. Prediction of oak site index in the ridge and valley section of Pennsylvania. For. Sci. 18:192-195.

Broadfoot, W. M. 1969. Problems in relating soil to site index for southern hardwoods. For. Sci. 15:354-364.

Carmean, W. H. 1961. Soil survey refinements needed for accurate classification of black oak site quality in southeastern Ohio. Soil Sci. Soc. Am. Proc. 25:394-397.

Carmean, W. H. 1967. Soil survey refinements for predicting black oak site quality in southeastern Ohio. Soil Sci. Soc. Am. Proc. 31:805-810.

Carmean, W. H. 1970a. Site quality for eastern hardwoods. In: The Silviculture of Oaks and Associated Species. USDA For. Serv. Res. Pap. NE-144, p. 36-56. Northeast. For. Exp. Sta., Upper Darby, Pa.

Carmean, W. H. 1970b. Tree height growth patterns in relation to soil and site. In:Tree growth and forest soils. Third North Am. For. Soils Conf. Proc.: p. 499-521.

Carmean, W. H. 1971a. Soil-site relationships of the upland oaks. In: Oak Symposium Proc., p. 23-29, USDA For. Serv., Northeast. For. Exp. Sta., Upper Darby, Pa.

Carmean, W. H. 1971b. Site index curves for black, white, scarlet, and chestnut oaks in the Central States. USDA For. Serv. Res. Pap. NC-62, 8 p. North Cent. For. Exp. Sta., St. Paul, Minn.

Carmean, W. H. 1972. Site index curves for upland oaks in the Central States. For. Sci. 18:109-120.

Carmean, W. H. 1975. Forest site quality evaluation in the United States. Adv. Agron. 27:209-269.

Doolittle, W. T. 1958. Site index comparisons for several forest species in the southern Appalachians. Soil Sci. Soc. Am. Proc. 22:455-458.

Gevorkiantz, S. R. 1957. Site index curves for red oak in the Lake States. Lake States For. Exp. Stn. Tech. Note 485, 2 p.

Gott, J. D. 1975. Soil survey of the Mark Twain National Forest Area (Parts of Carter, Oregon, Ripley, and Shannon Counties). USDA For. Serv. and Soil Conserv. Serv. in cooperation with Mo. Agric. Exp. Sta., 56 p.

Graney, D. L. 1977. Site index predictions for red oaks and white oak in the Boston Mountains of Arkansas. USDA For. Serv. Res. Pap. SO-139, 9 p. South. For. Exp. Stn., New Orleans, La.

Graney, D. L., and D. R. Bower. 1971. Site index curves for red and white oaks in the Boston Mountains of Arkansas. South. For. Exp. Stn. Res. Note SO-121, 4 p.

Hartung, R. E., and W. J. Lloyd. 1969. Influence of aspect on forests of the Clarksville soils in Dent County, Missouri. J. For. 67:178-182.

Ike, A. F., Jr., and C. D. Huppuch. 1968. Predicting tree height growth from soil and topographic site factors in the Georgia Blue Ridge Mountains. Ga. For. Res. Counc. Paper 54, 11 p.

Lee, R., and C. R. Sypolt. 1974. Toward a biophysical evaluation of forest site

potential. For. Sci. 20:145-154.
McQuilkin, R. A. 1974. Site index prediction tables for black, scarlet, and white oaks in southeastern Missouri. USDA For. Serv. Res. Pap. NC-108, 8 p. North Cent. For. Exp. Stn., St. Paul, Minn.
McQuilkin, R. A. 1975. Errors in site index determination caused by tree age variation in even-aged oak stands. USDA For. Serv. Res. Note NC-185, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.
McQuilkin, R. A. 1976. The necessity of independent testing of soil-site equations. Soil Sci. Soc. Am. J. 40:783-785.
Nelson, T. C., and W. R. Beaufait. 1956. Studies in site evaluation for southern hardwoods. Soc. Am. For. Annu. Meet. Proc.:66-70.
Olson, D. F., Jr. 1959. Site index curves for upland oak in the Southeast. Southeast. For. Exp. Stn. Res. Note 125, 2 p.
Olson, D. F., Jr., and L. Della-Bianca. 1959. Site index comparisons for several tree species in the Virginia-Carolina Piedmont. Southeast. For. Exp. Stn. Pap. 104, 9 p.
Schnur, G. L. 1937. Yield, stand, and volume tables for evenaged upland oak forests. USDA Tech. Bull. 560, 88 p.
Trimble, G. R. Jr., and S. Weitzman. 1956. Site index studies of upland oaks in the northern Appalachians. For. Sci. 2:162-173.
Van Lear, D. H., and J. F. Hosner. 1967. Correlation of site index and soil mapping units poor for yellow-poplar in southwest Virginia. J. For. 65:22-24.
Watt, R. F., and M. E. Newhouse. 1973. Some soil phases in the Missouri Ozarks have similar site indexes for oaks. USDA For. Serv. Res. Pap. NC-86, 5 p. North Cent. For. Exp. Stn., St. Paul, Minn.