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Site quality indices for the Emory oak woodlands of southeastern Arizona

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SITE QUALITY INDICES FOR THE EMORY OAK WOODLANDS OF SOUTHEASTERN ARIZONA

by

James Charles Callison

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As members of the Final Examination Committee, we certify that we have read the dissertation prepared by James C. Callison

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and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

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ABSTRACT

Site index curves were constructed for the Emory oak (*Quercus emoryi*) woodlands of the San Rafael Valley in southeastern Arizona. The woodlands primarily consisted of trees that were of sprout origin. Growth was rapid for 10 years, moderate from 10 to 20 years, and slow after 20 years. No trees in the study area were more than 40 feet tall.

Stepwise regression analysis was used to analyze the relationship between site index and site factors. Important variables included available soil water holding capacity, percent volume of coarse fragments, radiation index, percent sand, litter depth, and soil pH. Two models were developed; the r^2 values were 0.56 and 0.49, respectively.

Analysis of variance was used to test for differences between site index on different soil types and slope positions. All statistical tests were conducted using a 0.10 level of significance. The sample consisted of 100 trees.

Most of the factors were involved with availability of water to the tree roots. Emory oak grows in a dryland area where water is a limiting factor. Therefore, the effect that soil and terrain has on the availability of water to tree roots is an

important impact on the site index for Emory oak woodlands.

INTRODUCTION

The evergreen oak woodlands of southeastern Arizona have been used by man for longer than we have records. The native American used the oaks for fuel, shelter, and food. The Spaniards used the oakwood for fuel and fenceposts. And, the miners of the 19th century used the wood extensively to fuel smelters. However, in recent years, pressure on the oak woodland resource has threatened to become greater than at any time in the past.

A combination of factors, including higher energy prices, population increases, and social trends, have made oak more attractive as a fuelwood. Utilization of the oak woodlands for fuelwood increased sharply during the 1970s, and demand has remained high during the 1980s. As demand increases, proper management becomes more important to maintain a healthy resource. From the standpoint of the fuelwood user, a healthy resource means that both the quantity and quality of fuelwood from the oak woodlands can be maintained indefinitely. As an aid to management, the indices contained in this dissertation have been prepared.

When a site is being considered in management, one of the first steps is to determine it's productive capacity. If a site has low productivity, then the harvest will be lower for a given length of time. Sites with low productivity often are difficult places for commercial operations to make any profit. On the other hand, sites with high productivity can be managed more intensively without long term deterioration. The outlook for commercial operations usually is brighter on the more productive lands.

In the early part of the 20th century, foresters in the United States began to look at ways to assess the productivity of forest sites. Some favored the use of volume as the best measure of productivity (Bates 1918). Some favored the use of forest site types, similar to those developed in Finland (Daniel, Helms, and Baker, 1979). Others felt that site index based on the height-age relationship was the most practical method for American forestry (Watson 1917, Frothingham 1918). With time, site index came to be viewed as the best measure of site productivity; and today, site index based on height growth is the method most widely used for assessing forest site productivity in the United States.

Methods for measuring and calculating site index are still being refined (Carmean 1975). Jones (1969) points out that site index can be used for silvicultural prescriptions as well as for predicting productivity.

Site index should be based on the height and age of freegrowing, uninjured, dominant and codominant trees. Theoretically, these trees represent the maximum growing potential of the site. Tree height usually is considered to be independent of stand density except at relatively low or high levels (McComb and Thompsen 1957, Collins 1967). More accurate growth curves can be obtained if age estimates are obtained at breast height instead of stump height (Husch 1956). This probably is because young seedlings are subject to damage that can suppress growth, and disguise the true growth potential of the site. But, by the time a seedling is at breast height, it is likely to be growing at a normal rate.

Smith and Schuler (1988) used height vs. age to estimate site index in stands of pinyon-juniper in northern Arizona. They found that height and age can be used to successfully estimate site index in the pinyon-juniper woodlands even though pinyon and juniper seldom have straight central trunks.

Estimating the error associated with a particular estimate of site quality is difficult. Torres-Uriarte and Uriarte (1987) explained that error can be minimized by careful measurement of site trees, careful selection of trees designated as site trees, and selection of site index formulas which accurately predict the growth of the trees being studied. Genetic factors can introduce variation that is not related to site growth potential (Zahner and Crawford 1963, Jones 1969). For example, clonal variation in aspen can mask differences in site potential.

Site index can for a species can be estimated from a second species (McQuilkin 1974). However, the site index of both species needs to be measured and compared to insure that a correlation exists between the species.

In some cases, growth intercept for a particular time period may yield more information about site index than the height-age relationship (Beck 1971). For example, if a tree has been subject to weed competition, insect damage, or snow damage, the 5 years of growth after the tree reaches DBH (diameter at breast height) will be a more accurate indication of site index than total height vs. age. For growth intercept to be used, a tree must form branch whorls from which age estimates can be obtained.

Detailed studies have shown that growth curves usually are polymorphic (Carmean 1975); this is because trees in different site quality classes often grow on different soils. However, harmonic growth curves are useful for identifying broad classes of site quality.

In uneven-aged stands, the heights of mature dominants have been used as a measure of site index. McClintock and Bickford (1957) used total height at a DBH of 14 inches as a measure of site index. Their study was based on red spruce and was located in the upper portion of Maine. They were operating on the assumption that trees with a DBH of 14 inches or greater had not been suppressed. Standiford and Howitt (1988) used total height vs. DBH to estimate site index for oaks on California rangelands. Heart rot in the oak trees made it difficult to age the trees by counting tree rings.

Chojnacky (1986) used total height vs. DBH to estimate site index in the pinyon-juniper woodlands of western Nevada. There was a linear relationship between his estimate of site index and an independent estimate of long term yield for the same sites. The r^2 value was 0.76.

If trees have been removed temporarily from a site, soil-site studies are useful for estimating site index. Soil-site studies generally consist of measuring site index where trees are present, and relating site index to a variety of soil and topographic features through multiple regression analysis. Soil-site studies also are useful where soil and stand conditions are variable. If enough factors are measured, precise models can be developed. However, many of the precise models are cumbersome to use in the field. Parameters that are measured easily in the field give less precise results, but the accuracy is usually still acceptable.

Coile (1952) surveyed a number of soil-site studies and found that the most important soil features included depth, texture, drainage, and the amount of stone in the profile. He also found that the most important topographic features were aspect, slope position, slope steepness, shape of slope, elevation and latitude. Jayne (1986) found that slope, climate, and parent material can overshadow the effects of nutrient concentrations when using site factors to predict site index in the pinyon-juniper woodlands of northern Arizona.

Jones (1969) looked at the correlation between soil classification units in published soil surveys and site index. The results were mixed, with some studies showing no correlation between surveys and site index, and other studies have shown a connection. According to Jones (1969), Germany has had some success in predicting site index from soil surveys because their surveys focused on soil effects on trees rather than on soil taxonomy. Carmean (1975) concluded that soil surveys are potentially valuable to foresters. He stated that more coordination is needed between foresters and soil scientists, and statistical statements of precision should be included in studies that relate soil surveys to site index. Summerfield et al. (1986) found that climax stands of singleleaf pinyon were correlated with specific soil series.

There does not seem to be one method of estimating site index that is best for all situations. Alban (1976) found that the site index of red pine could be successfully estimated by site index curves, growth intercept, soil properties, or inter-species relationships. The best method depended on the combination of site factors and tree growth patterns encountered at each site.

DESCRIPTION OF INVESTIGATION

Objectives

The objectives of this study were twofold. The first objective was to develop a direct site quality index based on the relationship between tree height and age of Emory oak sprouts. The second objective was to develop indirect indices based on the relationship between the direct site index and factors measured at the site.

Site Description

The study area was located in the San Rafael Valley, south of the Huachuca Mountains in Cochise County, Arizona. Location of the site is shown in Figure 1. The site was bounded on the north by the Huachuca Mountains, on the east by the Coronado National Monument, on the south by the international border, on the west by grasslands, and is bisected by Arizona State Highway 83. The area mainly consisted of old, dissected alluvial fans. Ridgetops generally were flat and were bordered by steep sided gullies. The portion of the site north of State Highway 83 had steep slopes with occasional rock outcrops.

Three soil series occurred within the study area as determined from SCS Soil Survey of Santa Cruz and

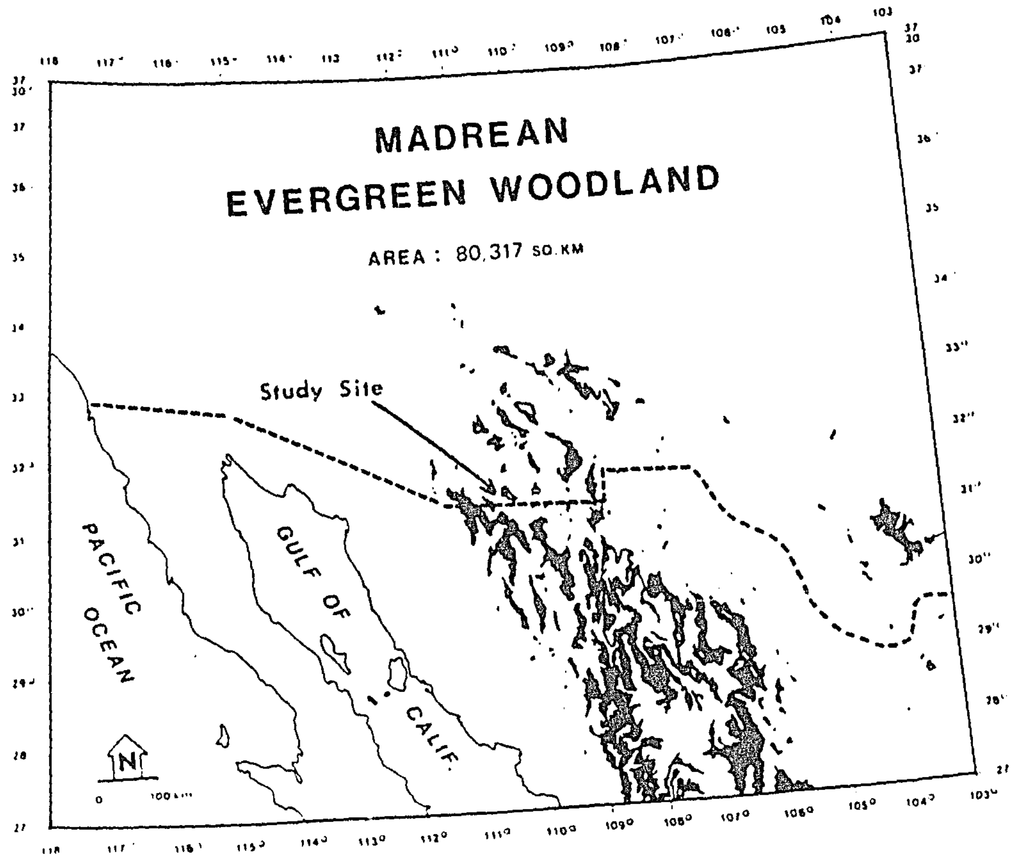

Figure 1. Location of the study site.

parts of Cochise and Pima Counties, Arizona. The Casto series was represented by the Casto gravelly sandy loam and consisted of soils with a high content of gravel and cobbles. They occurred on ridgetops and the sides of slopes. Some of the Casto soils have an acid subsoil. The Faraway series was represented by the Faraway-Tortugas-rock outcrop association. Those soils occurred on steep slopes, were cobbly, and had numerous rock outcrops. The Martinez series was represented by the Martinez gravelly loam. Slopes usually were less than five percent and the Martinez gravelly loam had fewer cobbles than the Casto or Faraway soils.

Average annual precipitation ranges from 15 to 20 inches (38 to 51 cm). The mean annual temperature ranges from 53 to 57 degrees Farenheit (12 to 14 degrees Centigrade). There are 140 to 200 frost free days per year.

The overstory vegetation consisted of evergreen oaks, junipers, and a few pinyon. The majority of the overstory was Emory oak. The understory consisted of shrubs, grasses, forbs, and infrequent cacti.

Wildlife in the area include whitetail deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), coyotes (*Canis latrans*), kit fox (*Vulpes macrotis*), jackrabbits (*Lepus* spp.), ringtailed cats

(*Bassariscus astutus*), javelina (*Pecari angulatus*), birds, and reptiles. The study area had been used in the past for cattle grazing, fuelwood cutting, camping, and hunting.

Field Procedures

The first step in the field work was the selection of site trees. A site tree was a dominant or codominant tree that was free from interferences such as disease, fire, mechanical injury, or excessive runoff water from manmade structures. After a site tree had been selected, the following measurements were recorded. Total height of the tree was measured with a tape after the tree had been felled and was lying on the ground. Diameter at breast height (DBH) was measured with a diameter tape.

Slope of the site was measured in percent with a clinometer. Aspect was measured with a magnetic compass. Elevation in feet was measured with an aneroid altimeter. Slope position was recorded as ridgetop, midslope, or bottomland. Litter depth was measured in inches.

The area occupied by coarse fragments at the ground surface was estimated ocularly. Then, a hole was dug and the volume of coarse fragments was estimated.

The soil was passed through a two millimeter sieve to separate the coarse fragments before the estimate was made. Soil depth was set arbitrarily at 59 inches (150 cm) in depth unless bedrock was encountered at shallower depths. All of the measurements were taken within a plot equal in radius to the height of the site tree.

At each plot, sample materials were collected. A cross section from each site tree was taken at breast height. Cross sections were used rather than increment cores for two reasons. First, oak wood is hard enough that there is a high probability of breaking the increment borer. Second, oak wood has such copius ray tissue that the ring structure often is obscured completely in a narrow increment core. Whittaker and Neiring (1975) found Emory oak difficult to age. Cross sections help to overcome that difficulty.

A composite soil sample was taken at four directions from the site tree. For the soil sample, a one-foot hole was dug and a slice was taken from the side of the hole. Then, the soil was passed through a two millimeter sieve and placed in sample bags. The sample consisted of 100 site trees.

Lab Analysis

The annual rings on the oak cross sections were counted using a procedure recommended by Tom Harlan of the Tree Ring Lab at the University of Arizona. The cross sections were sanded with a power sander, using successively finer grades of paper up to 220 grit. Then, the cross sections were given a final sanding by hand with 0000 steel wool. After sanding, the cross sections were dusted off with compressed air to remove wood dust from the larger vessel cells. A thin coat of black from a felt tip pen was applied to half of the cross section. Once the black ink had dried thoroughly, chalk was scrubbed across the blackened surface. Then, the chalk was rubbed off leaving the larger vessel cells filled with chalk dust. This technique highlighted the annual rings in white against a black background.

Attempts to crossdate, as recommended by Swetnam, Thompson, and Sutherland (1985), were futile. Crossdating insures the accuracy of the tree ring count. However, not all trees have a ring structure that lends itself to crossdating. Some of the trees were from areas that had been cabled or clearcut, and the age of those trees was known. The age from the ring counts matched the known age in all cases, with an error of no more than one year. Based on that evidence, it was concluded that the ring counts were accurate.

The soils were analyzed for texture and pH. The texture analysis began by wet sieving the sand fraction out of the soil. Then, the clay fraction was estimated using the feel method (Foth et al. 1980). Results of the clay estimation were checked against a set of reference samples. Soils were prepared for pH measurement by mixing two parts water with one part soil. The resulting mixture was allowed to sit for 30 minutes before measurement. Measurements were made with a Hach digital pH meter. After the probe had been inserted in the soil-water mixture, the readings were allowed to stabilize before the final reading was recorded.

Statistical Analysis

The analysis included a number of computations. Site index curves were prepared using the guide curve method described by Clutter et al. (1983). The site index value for each individual tree also was calculated.

A solar radiation index, based on slope percent and aspect, was calculated using the procedure described by Frank and Lee (1966). The solar radiation index is the ratio of the annual radiation total to the annual maximum potential solar beam radiation which is 525,600 Langleys, regardless of latitude. Frank and Lee (1966) explain that the radiation index is a theoretical quantity, and they suggest that it may be valuable in forestry because it is a permanent site factor that can be compared with other sites at other latitudes. The actual annual radiation total (in thousands of Langleys) can be obtained by multiplying the radiation index by 525.6.

Available water holding capacity was calculated using the following procedure. The percent water by weight at one third bar for each textural class was obtained from Post (1981). Subtractions were made for soils shallower than 59 inches (150 cm) and for soils with more than 15 percent coarse fragments. For the soil-site study, a correlation matrix was prepared after which the continuous variables were analyzed with multiple regression.

Variables included in the multiple regression model were site index, radiation index, sand percent, clay percent, pH, volume of coarse fragments, area occupied by coarse fragments at the ground surface, litter depth, and the available water holding capacity. The discrete variables were analyzed using analysis of variance. Variables included in the analysis of variance were slope position and soil type.

RESULTS AND DISCUSSION

Site Index Curves

The site index curves for the Emory oak in the San Rafael Valley are shown in Figure 2. The range in heights was narrow enough that four curves were sufficient to show the site quality classes present in the study area. The equations for the site index curves were:

Site Class 10 $\ln(H) = 2.73 - 8.57\ A^{-1}$ (1)

Site Class 15 $\ln(H) = 3.14 - 8.57\ A^{-1}$ (2)

Site Class 20 $\ln(H) = 3.42 - 8.57\ A^{-1}$ (3)

Site Class 25 $\ln(H) = 3.64 - 8.57\ A^{-1}$ (4)

where: H = total height of tree in feet

A = age of tree in years at DBH

The r^2 values for equations (1), (2), (3), and (4) were 0.46, 0.42, 0.64, and 0.96 respectively. The site index of an individual tree can be found with the following equation:

$\ln(S) = \ln(H) + 8.57\ (A^{-1} - Ao^{-1})$ (5)

where: S = site index value for individual tree

H = total height of tree in feet

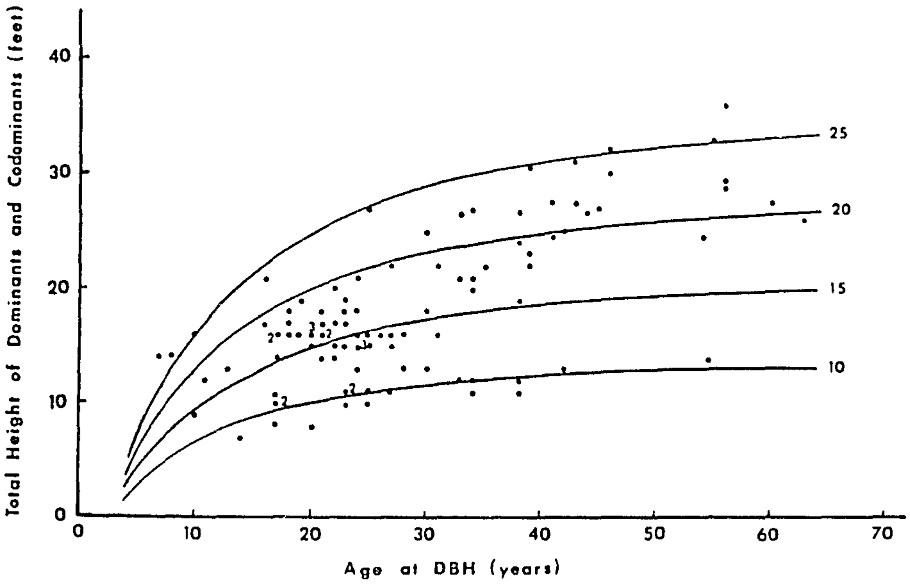

Figure 2. Site index curves for Emory oak in southeastern Arizona. Multiple trees with the same height-age data are indicated by numbers.

A = age of tree in years

Ao = index age (20 years)

An index age of 20 years was selected for this study. The age of 20 years was based on the estimate of rotation age of 25 years for Emory oak sprouts prepared by Touchan (1986). Figure 2 shows that the growth is fairly rapid in the first 10 years. Growth is moderate from 10 to 20 years, and after 20 years height growth is slow. The tallest trees in this study were less than 40 feet tall. As with all site index curves, the relationships probably are not reliable for the youngest trees.

These curves show that Emory oaks are small, slow growing trees with size and growth rates not too different from species such as pinyon and juniper. Zahner and Myers (1984) found that oak sprouts in the Piedmont area of the southeastern United States grew rapidly at first, and then growth slowed markedly after 30 years. The trees in their study were approximately twice as tall as those in the San Rafael Valley, yet there is a parallel between the growth of oak sprouts in both areas.

It is possible that a more detailed study would show that site index curves for the oak woodlands are polymorphic. However, harmonized curves are useful for identifying broad classes of site quality (Carmean 1975). In addition, there did not appear to be any correlation between soil type and site quality class. That means that the variation within a site quality class is probably as great as the variation between classes. In such a case, there would be no advantage in using polymorphic curves.

Soil-Site Relationships

Frequently it is necessary to estimate site index in the absence of trees. For this reason, an indirect site index was prepared based on the relationship between soil features and site index. Two analyses were undertaken, one using the continuous variables and a second using the discrete variables. The continuous variables were analyzed using multiple regression. The correlation matrix was used as guide to which variables would be included in the regression models. Table 1 shows the correlation coefficients for the measured variables. The percent volume of coarse fragments and the available water holding capacity were correlated, so two regression models were developed to allow those variables to be analyzed separately. The equation for the first model was:

Table 1. Correlation matrix for continuous variables measured in the San Rafael Valley, Arizona.

	SI_a	RI_b	sand	clay	pH	VF_c	SA_d	LD_e
			%	%				
RI	0.35							
sand	0.38	NS						
clay	NS	0.22	0.52					
pH	0.29	0.71	0.35	0.27				
VF	0.61	NS	0.34	NS	NS			
SA	0.61	0.39	0.22	NS	NS	0.55		
LD	NS	NS	NS	0.23	NS	NS	NS	
$AWHC_f$	0.44	NS	NS	NS	NS	0.83	0.52	NS

(a) site index, feet at 20 years
(b) radiation index, dimensionless
(c) percent volume of coarse fragments
(d) percent of area at ground surface contributed by coarse fragments
(e) litter depth, inches
(f) available water holding capacity, inches

$$Y = 9.7 + 0.19(X1) + -0.099(X2) + 0.13(X3) + -33.0(X4) + 2.2(X5) + 1.7(X7) \quad (6)$$

where: Y = estimated site index

X1 = available water holding capacity, in inches

X2 = percent of surface area consisting of coarse fragments

X3 = percent sand

X4 = radiation index, dimensionless

X5 = soil pH

X6 = litter depth, in inches

The r^2 for equation (6) was 0.56, and the degrees of freedom were 93. The coefficients in equation 6 yield some clues about what determines site index for Emory oak in the San Rafael Valley. As available water holding capacity increased, site index increased. That relationship is normal for a dryland situation. Although significant at alpha = 0.10, the percent of surface area consisting of coarse fragments had a coefficient close to zero. There was a negative relationship between the radiation index and site index. It seems natural in a dryland setting that areas protected from full sunshine would support trees with more growth. As soil pH increased, the site index increased. Some of the soils in the study area were acidic (pH of 4.9). If the optimum pH for evergreen oak was neutral or slightly alkaline, it would explain the positive relationship between pH and site index. There is a positive relationship between litter depth and site index. Empirical regression models do not necessarily indicate a cause and effect relationship. The relationship between litter depth and site index probably is due to greater accumulation of litter on the more productive sites. But, regardless of cause and effect, litter depth still has predictive value in a regression model.

The equation for the second model was:

$$Y = 36.0 + -0.15(X1) + -48.0(X2) + 2.1(X3) \qquad (7)$$

Where: Y = estimated site index

X1 = percent volume of coarse fragments

X2 = radiation index, dimensionless

X3 = pH

The r^2 for equation (7) was 0.49 and the degrees of freedom were 96. The r^2 for equations (6) and (7) were both in the reported range for soil-site studies (Chojnacky 1986, Jones 1969). The coefficients for equation (7) suggest relationships of interest. The percent volume of coarse fragments was related negatively to site index. Coarse fragments, if present in significant quantity, have a strong influence on available water holding capacity. Most of the soils in this study did contain a large amount of coarse fragments. As coarse fragments increase, water holding capacity decreases. Therefore, it is only natural that there would be a negative relationship between the volume of coarse fragments and site index. As with equation (6), there was a negative relationship between the radiation index and the site index. And, the positive relationship between pH and site index also resembled that found in equation (6). In equations (6) and (7), the percent clay did not have a significant impact. That may be because there was not much variation in clay amounts among the soils sampled. Mouat (1974) found that the evergreen oaks of southeastern Arizona were affected more by terrain variables (slope percent, aspect, and elevation) than were plants such as cacti, mesquite, and ocotillo growing in the same area.

Discrete Variables

In the analysis of the discrete variables, soil type and slope position, some differences emerged. Figure 3 shows the effect of slope position and soil type on site index. Across all soil types, bottomlands

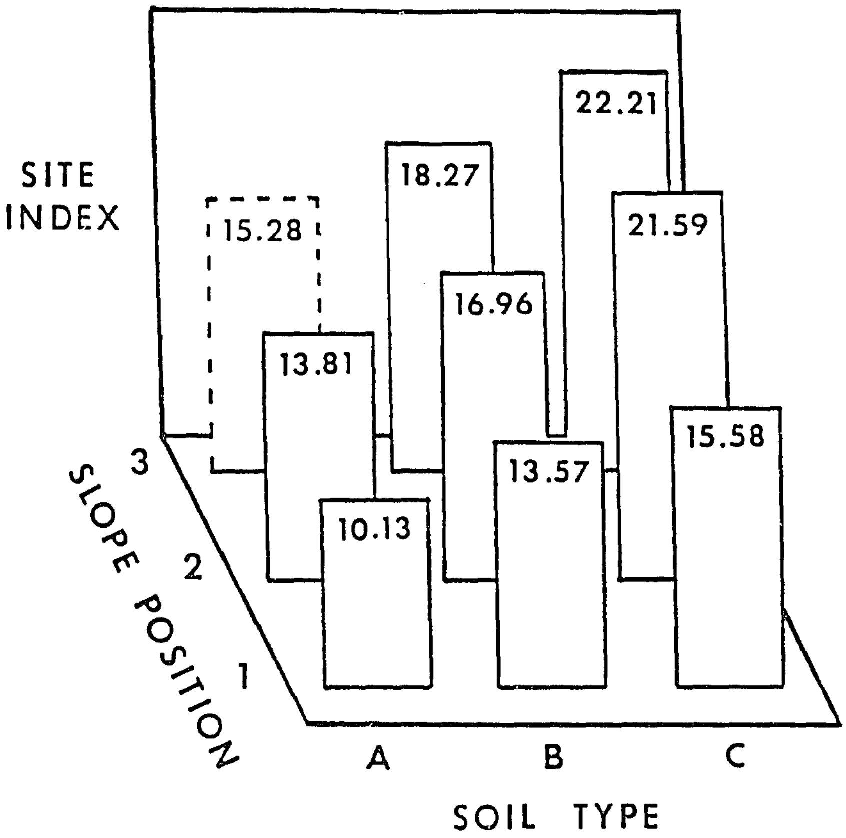

Figure 3. Effect of slope position and soil type on site index for Emory oak in southeastern Arizona. Soil type A was the Faraway-Tortugas-rock outcrop association, B was the Casto gravelly sandy loam, and C was the Martinez gravelly loam. Slope position 1 was the ridgetops, 2 was the midslopes, and 3 was the bottomlands. The site index value for soil A-slope 3 was estimated using the formula for missing cells given by Freese (1980).

had higher site index than midslopes, and midslopes had higher site index than ridgetops. And, if slope position is taken into account, Martinez gravelly loam had higher site index than Casto gravelly sandy loam, and Casto gravelly sandy loam had higher site index than the Faraway-Tortugas-rock outcrop association. Martinez gravelly loam in the bottomlands had the highest site index, while the Faraway-Tortugas-rock outcrop association had the lowest site index. These relationships were predictable. Ridgetops usually have less available water than midslopes, which have less water than bottomlands. The Faraway-Tortugas-rock outcrop association is a shallow rocky soil, the Casto gravelly sandy loam can be deep but is often cobbly, and the Martinez gravelly loam generally has a smaller portion of coarse fragments than the other two soils.

The analysis of variance shows significant differences between soil types and slope positions. The data were distributed unevenly among the categories to the point that two-way analysis of variance was not feasible. Instead, two one-way analyses of variance were performed. The results for the slope position are shown in Table 2. Clearly, the effect of slope position on index was significant. The results for the analysis of variance for soil type are shown in Table

3. The effect of soil type on site index also was significant.

Table 2. Analysis of variance for the effect of slope position on site index

source of variation	sum of squares	degrees of freedom	mean square	F-ratio	p
slope position	1020.75	2	510.37	48.26	.01
error	1004.49	95	10.57		

When interpreting Tables 2 and 3, one precaution should be taken. There were examples of Martinez gravelly loam outside of the study area that had no trees at all. Other factors, such as climate and elevation, have a strong effect on oak distribution and productivity. However, within the areas that oaks normally grow, soil type and slope position had a major effect on site quality.

Table 3. Analysis of variance for the effect of soil type on site index.

source of variation	sum of squares	degrees of freedom	mean square	F-ratio	p
soil type	1119.71	2	559.86	58.73	.01
error	905.54	95	9.53		

Total Height and Site Index

Occasionally, one may want an estimate of site quality without taking a cross section from an oak tree. It normally takes at least a week for the wood to dry to where it can be sanded properly. And, oak wood is unsuited for the taking of increment cores (Harlan 1985). For these reasons, a third indirect index was prepared. This index was based on the relationship between site index and total height of a tree, which becomes linear after the tree reaches a certain age. This allows regression analysis to be used to analyze the relationship.

Figure 2 shows that after trees pass the age of 20 years, the curves become asymptotic. It is not possible to know the age of a tree without counting the rings, but a minimum age can be assured by using a diameter limit. For example, McClintock and Bickford (1957) used total height as a measure of red pine site index after trees had exceeded a DBH of 10 inches.

In this study, a 4 inch lower DBH limit was used. The rationale for a 4 inch DBH limit is twofold. First, in the sample of cross sections taken for the direct site index, less than 5 percent of the trees with a DBH of more than 4 inches were less than 20

years old. Second, on most sites, except those which have been clearcut quite recently, it is possible to find trees with a DBH of at least 4 inches. On some sites, trees with a DBH of more than 4 inches were scarce. The
results of the regression between site index and total height are shown in Figure 4. If time allows, it is more reliable to measure site index directly. However, when a quick estimate is needed, the formula given in Figure 4 may be useful.

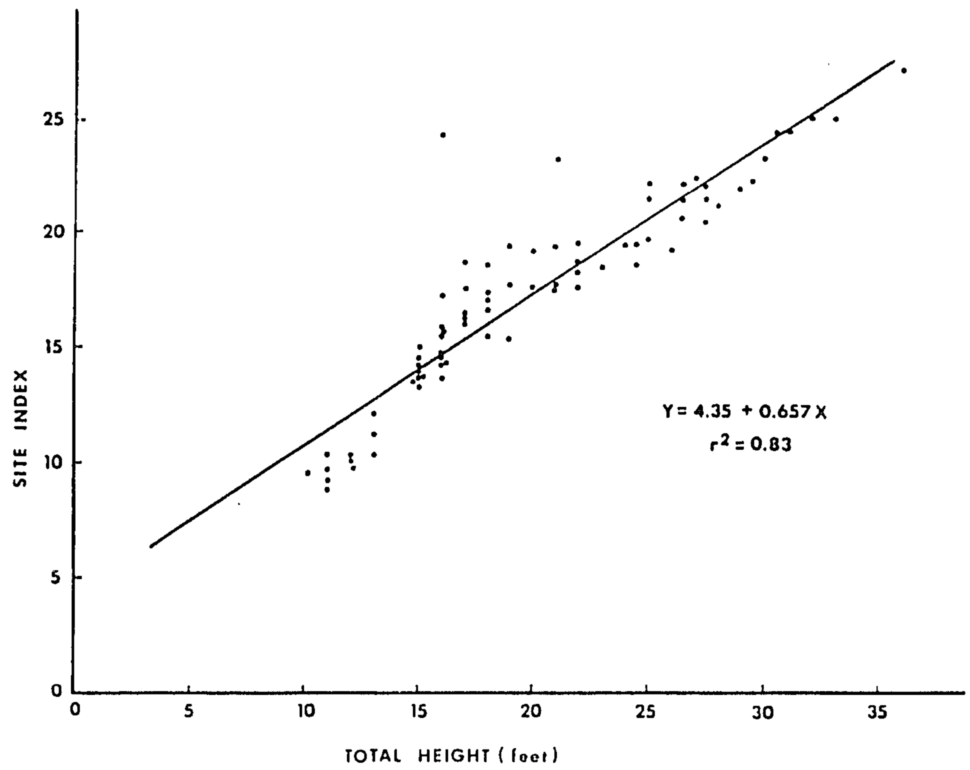

Figure 4. Site index of Emory oak versus total height with lower DBH limit of 4 inches.

SUMMARY AND CONCLUSIONS

In this study, soil water had a significant impact on the site index of trees in the Emory oak woodlands of southeastern Arizona. Many of the factors that affected the supply of water to the tree roots also had a significant impact on site index. For example, soil type and slope position had a marked effect on site index, and they both are involved directly in water-plant relations. Available water holding capacity and coarse fragments, which were correlated in this study, had a significant effect on site index. Both of those factors affect the availability of water to tree roots. The solar radiation index, which is a measure of the potential solar beam insolation for a given point, had a negative impact on site index. In a dryland situation, more sunlight usually means more water is needed for maintenance of the plant and less is available for growth. The overall effect of these factors is that available water has a strong impact on site index in the Emory oak woodlands.

This study also showed that site index in the Emory oak woodlands can be predicted successfully using several methods. A direct index using curves based on the height-age relationship was developed. An indirect index based on soil-site relations was developed. It had two models with r^2 values of 0.56 and 0.49 which were in the normal range for soil-site studies. A second indirect index was prepared using the variables of soil type and slope position. It showed that soil type and slope position are highly significant in predicting site index. A third indirect index using total height with a DBH limit was prepared. It is useful in situations where a rapid estimate of site index is desired.

APPENDIX. Source data used to construct site index curves and indirect indices.

plot no.	SI (a)	RI (b)	sand %	clay %	pH	VF (c)	SA (d)	LD (e)	AWHC (f)
1	22.37	.5441	74	11	6.3	25	30	0.5	11.25
2	19.69	.5456	69	9	5.7	5	10	0.5	14.25
3	17.74	.4867	56	18	6.3	50	10	0.5	7.5
4	13.42	.5261	66	15	5.7	40	25	0.5	9.0
5	15.51	.4808	71	11	5.4	40	10	0.5	9.0
6	18.31	.5149	79	8	5.9	40	5	1.0	6.3
7	31.02	.5533	74	8	6.4	10	1	0.25	13.5
8	18.9	.5604	63	17	6.2	20	30	0.25	12.0
9	26.62	.5050	63	15	5.6	30	20	0.0	10.5
10	17.6	.5261	79	6	6.5	40	25	1.0	6.3
11	16.36	.5013	80	4	6.5	40	40	0.5	9.0
12	16.78	.5513	71	7	6.2	50	10	0.5	7.5
13	16.0	.5706	66	9	6.7	50	15	1.0	7.5
14	18.92	.5513	76	13	5.7	50	15	1.0	7.5
15	17.02	.5533	70	7	6.6	60	20	0.5	6.0
16	17.97	.5533	74	13	6.0	50	10	0.25	7.5
17	17.83	.5533	72	11	5.5	55	10	0.5	6.75
18	16.66	.5533	65	9	6.8	60	10	0.5	6.0
19	15.68	.5533	69	9	6.0	20	5	0.25	12.0
20	13.97	.5533	71	14	5.9	15	5	0.25	12.75
21	19.55	.5513	72	8	5.9	15	10	0.5	12.75
22	12.1	.5533	73	7	6.0	65	30	0.5	5.25
23	15.1	.5533	65	12	6.3	60	10	0.25	6.0
24	13.46	.5513	68	13	5.9	30	5	0.25	10.5
25	14.9	.5533	70	7	6.1	40	15	0.25	9.0
26	21.67	.5456	69	13	6.1	40	10	0.5	9.0
27	14.18	.5513	75	10	6.3	40	20	0.75	9.0
28	16.35	.5533	76	12	6.3	40	15	0.5	9.0
29	17.64	.5456	67	9	6.4	40	10	1.0	9.0
30	15.68	.5456	76	12	6.4	40	5	1.0	9.0
31	17.26	.5456	73	8	6.0	40	25	0.25	9.0
32	13.97	.5533	71	11	6.1	30	5	0.25	10.5
33	16.0	.5368	69	6	6.0	20	5	0.5	12.0
34	18.88	.5456	76	12	6.2	30	15	0.25	10.5
35	19.59	.5533	75	6	6.5	30	10	0.5	7.35
36	24.56	.5368	69	8	6.1	50	5	1.0	7.5
37	13.72	.5513	76	8	5.2	50	10	0.5	7.5
38	16.76	.5604	74	12	6.1	55	30	0.25	6.75
39	17.26	.5513	68	10	6.3	50	10	0.5	7.5
40	14.32	.5368	72	5	5.9	55	20	0.5	6.75
41	16.0	.5456	61	7	6.5	50	20	0.5	7.5
42	16.08	.5533	68	8	6.3	50	10	0.75	7.5
43	23.27	.5261	65	8	6.3	60	20	0.5	6.0

APPENDIX. continued

plot no.	SI	RI	sand %	clay %	pH	VF	SA	LD	AWHC
44	16.76	.5261	66	4	6.7	60	30	0.5	6.0
45	22.63	.5533	74	8	5.9	5	2	0.75	14.25
46	19.43	.5513	74	7	5.5	5	5	0.5	14.25
47	19.24	.5513	78	5	6.0	10	5	0.5	9.45
48	17.85	.5513	74	12	5.5	2	2	1.0	14.7
49	16.37	.5533	75	9	4.9	5	5	0.25	14.25
50	17.04	.5513	74	10	6.5	5	10	1.0	14.25
51	9.18	.5533	77	10	6.9	50	60	0.13	7.5
52	8.0	.5050	47	20	6.1	50	60	0.5	2.25
53	8.63	.5368	74	6	6.5	70	50	0.13	4.5
54	8.41	.5513	71	10	5.0	80	50	0.13	3.0
55	13.81	.5149	70	15	5.6	80	50	0.13	3.0
56	15.6	.5513	72	9	6.5	40	40	0.13	9.0
57	10.78	.5050	74	7	6.0	50	40	0.25	7.5
58	14.69	.5050	72	6	6.3	40	15	0.75	9.0
59	14.43	.5368	75	10	5.9	40	10	0.5	9.0
60	10.78	.5533	80	9	6.0	40	20	0.25	6.3
61	13.79	.5893	64	10	5.6	50	50	1.0	7.5
62	11.27	.5893	68	10	6.3	50	50	1.0	7.5
63	9.65	.5893	70	12	6.5	50	50	0.5	7.5
64	10.4	.5893	70	7	5.6	50	50	0.5	7.5
65	10.39	.5706	68	7	5.9	50	50	1.0	7.5
66	11.32	.5893	63	12	5.5	50	50	0.25	7.5
67	9.96	.5893	67	7	5.9	50	50	0.5	7.5
68	10.4	.5706	69	8	5.3	50	50	1.0	7.5
69	10.1	.5847	65	7	6.2	50	50	0.5	7.5
70	14.16	.5893	74	8	5.9	50	50	0.5	7.5
71	13.68	.5741	69	9	7.0	50	50	0.5	7.5
72	8.98	.5992	76	5	5.4	50	50	1.0	5.25
73	9.84	.5893	64	5	6.3	50	50	1.0	7.5
74	10.14	.5847	67	6	6.9	50	50	0.5	7.5
75	15.1	.5706	72	8	5.4	50	50	0.25	7.5
76	11.5	.5847	63	10	6.3	50	50	1.0	7.5
77	10.06	.5893	73	4	7.1	50	50	0.5	7.5
78	9.22	.5847	63	7	5.8	50	50	0.5	7.5
79	13.74	.5847	65	8	6.1	50	50	0.5	7.5
80	14.49	.5706	65	12	6.0	50	50	0.5	7.5
81	27.33	.5513	86	5	6.7	10	10	2.0	9.45
82	25.12	.5513	95	2	7.6	10	10	0.5	9.45
83	23.55	.5985	67	15	5.7	20	20	0.5	12.0
84	20.67	.5013	75	12	6.6	20	20	0.5	12.0
85	19.41	.5013	65	9	5.8	20	20	0.5	12.0
86	24.75	.5706	85	5	7.1	10	10	1.0	9.45
87	19.97	.5513	94	3	7.6	50	50	0.5	3.38

APPENDIX. continued

plot no.	SI	RI	sand %	clay %	pH	VF	SA	LD	AWHC
88	22.4	.5513	80	7	7.2	30	30	0.5	7.35
89	22.38	.5513	75	8	6.8	30	30	1.0	10.5
90	20.98	.5513	70	11	5.5	30	30	1.0	10.5
91	22.02	.5195	75	15	7.1	30	20	0.5	10.5
92	22.08	.5533	81	5	6.6	30	20	1.0	3.0
93	18.67	.5533	78	7	6.1	30	20	0.25	7.35
94	18.71	.5368	81	9	7.4	25	20	0.5	7.88
95	19.67	.5195	75	13	6.0	20	20	0.5	12.0
96	25.12	.5261	96	4	6.9	20	20	0.5	5.4
97	21.63	.5261	90	4	6.6	20	20	1.0	5.4
98	21.87	.5261	73	12	6.1	20	20	0.5	12.0
99	24.65	.5236	66	15	7.0	20	20	0.75	12.0
100	21.28	.5236	68	12	6.7	20	20	0.75	12.0

(a) site index, feet at 20 years
(b) radiation index, dimensionless
(c) percent volume of coarse fragments
(d) percent of area at ground surface contributed by coarse fragments
(e) litter depth, inches
(f) available water holding capacity, centimeters

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