SHORTLEAF PINE SITE INDEX--SOILS AND PLANT ASSOCIATIONS ON THE COASTAL PLAIN OF SOUTHEASTERN OKLAHOMA

By

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CHAPTER I

INTRODUCTION

With expanding demands for the production of goods, there is an increasing need for more knowledge about basic natural resources. Means of meeting these needs and demands must be developed. The productive capabilities of our soils must be defined before effective management plans can be made.

Forested land in eastern Oklahoma was estimated at 5.5 million acres in 1966. Approximately 4.8 million acres of the total are classified as commercial forest land. Much of this commercial acreage is thought to have considerable potential for the production of shortleaf pine (Pinus echinata), but there is increasing need to delineate land management classes more definitely.

Proper forest management has been largely nonexistent in much of eastern Oklahoma. Large portions of the forest acreage are now "cutover lands." Currently there is a trend in the eastern part of the state to convert the lowgrade upland hardwoods and increase the stocking of the pine stems. There is a real need for better procedures to evaluate site potential within the area.

Much of eastern and southeastern Oklahoma's pine land is subject to environmental tension because it is on the fringe of the southern pine range. The area is prone to frequent droughty periods. Careful consideration of site quality must be made before expensive type conversion operations can be undertaken on some sites.

This study attempts to evaluate the relationships between shortleaf pine site index, soil characteristics, and plant group associations on Coastal Plain sites. The study area is located in McCurtain County in the vicinity of Broken Bow, along the northern margin of the Southern Coastal Plain. Here shortleaf pine sites range from very high to non-commercial in quality.

CHAPTER II

LITERATURE REVIEW

"Forest site" is a well established concept among American foresters. The meaning of site quality has changed little since the advent of professional forestry practice in the United States. Tansely (22) defines habitat, which is the ecologist's equivalent to site, as "the sum of the effective conditions under which a plant or plant community lives." Site is the resultant of the action and interaction of many variables, many of which are not fully understood. However, some procedures have been devised to estimate forest site quality.

Heiberg et. al. (11) states that site quality can be evaluated in three ways:

1. Directly in terms of quality and magnitude of the various site factors, such as light and temperature, that influence the vegetation in question.

2. Indirectly in terms of some measurable index that reflects the quality or magnitude of the site factors or the vegetation itself. Soil and vegetation evaluation are examples of this approach.

3. In terms of actual production of the vegetation in question, such as volume and height growth.

The direct approach to site evaluation is very difficult because of measurement problems, the determination and inconsistency of variables and the assessment of the role of interactions.

Direct Measurement of Site Index Method

The height-age relationship, or site index method, is probably the most common tool used to evaluate site quality in the southern forests today. Site index is the height a dominant or codominant tree will attain at age 50. This assumes the tree has been subjected to normal forest competition, it has never been suppressed and is not a genetically inferior individual. In 1929 the United States Forest Service published a set of site index curves for the southern pines. These curves were based on height-age data submitted by foresters throughout the region.

The curves were developed from growth and yield studies from even-aged second growth stands, but they tend to overestimate well stocked young stands. They may also lead to underestimation of cut-over areas, for the "leave trees" measured may not have been dominant or codominant (4). A study by Hodgkins (14) yielded similar results. He found that all sites may not have the same shape of site index curves, and some variation exists in stands that have the same site index at age 50. He indicated that measurements taken from stands of ages 40 to 65 should yield quite precise estimates of sight index and that measurements from stands under 25 should generally be considered unreliable (except for predicting growth patterns for shorter rotations).

Many situations require site quality knowledge of lands that no longer support well-stocked pine stands. A common example might be the decision to reforest abandoned farm lands; here another method of site

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*Misc. Pub. #50, U.S. Dept. of Agric. Volume, yield, and stand tables for second-growth Southern pines. Office of Forest Exp. Stations, U.S. Forest Service. 1929.

evaluation must be used.

Soil-Site Evaluation Methods

The relationship between soil properties and site quality has been the subject of intensive study during the past two decades. Earlier studies included one by Haig (10) in which he reported on the relation between the site index of young red pine (Pinus resinosa) plantations in Connecticut and the "colloidal content" of the various soil horizons. He found that the site index of red pine increased as the percentage of the finer fractions (silt plus clay) increased in the A horizon.

Coile (3) published a thorough investigation of soil-site relations for the North Carolina Piedmont. He measured: (1) Thickness (or depth) of the surface soil (A horizon), (X_1). (2) Ratio of silt plus clay to the moisture equivalent of the subsoil (B horizon), (X_2). (3) Total depth of soil to the substratum (C horizon), (X_3). (4) Imbibitional water value of the sub-soil (the difference between moisture and xylene equivalents of a soil sample), (X_4) and (5) combinations of the above variables (X_2^2). The relation of these variables was described by a regression analysis technique expressed by the model $Y = \alpha + \beta x + \epsilon$. Y represents the logarithm of the site index and $\beta x + \epsilon$ represents the variables plus the experimental error.

The regression analysis showed variables X_1, X_2^2, and X_4 to be significantly related to the site index. The prediction equation for the logarithm of the site index of shortleaf pine was found to be

$$Y = 80.67 - \frac{44}{X_1} - 2.50 X_2 - 1.08 X_2^2 - 1.19 X_4.$$

Coile found no relation between slope position and site quality. He explains this by assuming the depth of surface soil tends to increase from ridge position to lower slope due to erosion and this is reflected by variable X_1. Also, he believes the topographic position of land influences drainage and over long periods of time affects soil development, particularly subsoil characteristics. This is reflected in the variables X_2, ${X_2}^2$ and X_4.

Coile and Schumacher (4) applied Coile's findings to the Forest Service site index curves and developed a revised set of site index curves. These curves were used as guide values for the data presented in this study.

Gaiser (9) applied Coile's technique to the loblolly pine (Pinus teada) forests of the Southern Coastal Plain from South Carolina to Virginia and obtained very similar results. Ralston (7) applied the method in a longleaf pine (Pinus palustris) study conducted in Florida and Georgia. Again, similar results were obtained when a variable for latitude was added to the regression equation.

Zahner (24) modified Coile's method and applied it to the Coastal Plain soils of East Texas, Arkansas, and Northern Louisiana. He made it a more practical tool for field foresters by estimating the imbibitional water value by obtaining a measurement for soil consistency. In another study in approximately the same area Zahner (25) collected data on four different soil types: (1) Coastal Plain; (2) river terrace; (3) alluvium and (4) loess. He found the following variables to have a significant effect on site index on zonal soils: (1) imbibitional water value of the subsoil, (2) percent clay in the subsoil, (3) percent silt-plus-clay in the subsoil, (4) thickness of the surface soil, and (5) slope. The azonal sites were affected by: (1) percent silt in the surface soil, (2) imbibitional water value of the subsoil, (3) percent clay in the subsoil, (4) percent silt in the subsoil, (5) percent silt-plus-clay in the subsoil, and (6) slope. This study prompted the development of a non-technical field guide using texture of surface soil, thickness of surface soil, texture of subsoil, and slope to estimate site index for both loblolly and shortleaf pines.

Barnes and Ralston (1) and McGee (17) studied the soil-site relationships of slash pine (Pinus elliottii) in Georgia and Florida and found that they could be correlated with the depth of subsoil and depth to a fine textured horizon. Kormanik (15) added Virginia pine (Pinus virginiana) to the list of species whose site index can be correlated with soil variables.

The Soil Conservation Service has developed a procedure for classifying soil series into woodland suitability groups. An example of this is the Dean and Case (7) study for southern Arkansas. The average pine site index is found for a soil type and this is combined with several factors: (1) degree of plant competition, (2) equipment limitations, (3) planted seedling mortality, (4) windthrow hazard and (5) erosion hazard. These are placed in an empirical equation and the result is a woodland suitability group. Although the Soil Conservation Service procedure has many advantages, this system can be too broad. An example would be when both deep and shallow phases are common within a soil series.

The soil-site relationship technique has received wide acceptance and has been shown to be applicable to a wide range of species as well as a wide range of soil types. The procedure is relatively simple and accurate, but its field application requires considerable training and experience in soil science and texture determination. The procedure can be complicated by soil series that contain large percentages of gravel in the horizons. Another method, vegetative interpretation can help to simplify and perhaps speed up site and management classifications in southern forests.

Soil-Site Vegetation Methods (Total Site)

The potential uses of associate vegetation as a means of site evaluation has been studied periodically for the past 50 years. Cajander (2) was perhaps the first to advocate the use of "plant indicators" as a forest site evaluation tool. Plant indicators are now in common use by European and Canadian foresters (20,12).

Westveld proposed that what the forester needs is a simple yet dependable guide that will enable him to direct his silviculture toward the production of those species that are best suited to the site. He adds that such a guide can be found in climax-forest associations. A climax forest is nature's verdict of the tree species or combination of tree species best adapted to the site. Climax vegetation types are in complete harmony with the soil and the plant and animal life they produce (23).

"Total site" evaluation is an attempt to classify all the variables that affect site and plant species requirements. Hodgkins (13) adds, "when one understands that a given site index for a given species may occur on more than one site, he has taken a long step toward understanding the concept of total site classification. In total site classification, site index is relegated to the status of one of many attributes of the site, and is no longer the basis for classification. This does not constitute a de-emphasis of site index, but rather a recognition that other attributes of the site are also important.

The use of plant indicators generally coincides with the continuum climax theory of plant ecology. A plant may be able to survive over a wide range of sites but it will show maximum expression, in relative frequencies to associate plants, only on its climax site. Theoretically the vegetation of a climax area develops on sites that are relative, like an equilateral triangle. The most zeric plants start at the lower left angle, the apex represents the mesic or absolute climax, while the angle on the right side represents the hydrophytic plants. Thus, an ecological ladder of plant species is formed, relating species on the poorest to the best sites.

Spurr (21) approached the problem of classifying northeastern spruce (Picea spp.) and fir (Abies spp.) stands by setting up an "indicator plant spectrum" (Table I). Groups of indicators are given for each of four site classes. These site classes are arranged, in order, from the driest and most infertile site at the top of the list to the more moist and most fertile sites at the bottom. Plant indicator species are checked as present, common, or abundant and the weight of the checks of the various indicator groups determines the site classification.

Hodgkins (13) developed a plant indicator site index system for longleaf pine in Alabama. Using ground flora, forest floor brush, and some overstory hardwoods, he assigned a number rating system to reflect their frequency. After making the species inventory, a mean tree site index was calculated for each indicator species by finding the average longleaf site index for all the plots containing the species. In doing this, the site index on any one plot on which the indicator occured was

TABLE I

INDICATOR PLANT SPECTRUM, NORTHEASTERN SPRUCE AND FIR[1]

Genus or Species	Present	Common	Abundant
Site A			
Myrica			
Vaccinium			
Gaultheria			
Hylocomium			
Hypnum			
Chiogenes			
Pteridium			
Site B			
Coptis			
Bazzania			
Corylus			
Maianthemum	X		
Cornus	X		
Site C			
Aralia		X	
Clintonia			
Oxalis			
Dryopteris			X
Acer saccharum		X	
Site D			
Asplenium			
Smilacina			
Mitchella			
Viola			
Oakesia			

[1]Relative frequency of key species as tallied on specific forest sites. From Spurr (21).

weighted according to the dominance rating of this species on that plot. For any one indicator species, then, the mean longleaf site index for the plots containing that species was as follows:

$$S.I. = \frac{\text{(tree-site index x dominance of the species)}}{\text{(all of the dominance values for the species)}}.$$

The indicator species were then ranked from the lowest to the highest on the basis of their mean longleaf site index values. Further examination of individual plot data indicated that this approach would not be productive, however, so species ranking was rearranged to represent progression in the moisture regime, from the driest to the wettest sites.

Dyrness and Youngberg (8) appraised five brush associations that can be used for site quality estimation of ponderosa pine (Pinus ponderosa) in the pumice region of central Oregon. They found that each plant association is indicative of a completely different effective environment and is accompanied by changes in the amounts of advanced timber regeneration, timber stand density, supplies of forage available to livestock, and other factors important in forest and range management, even though all five plant groups occured on the same soil mapping unit. They reported that differences in the forest environment are often not reflected in readily discernible soil characteristics, and the understory vegetation serves as a much more sensitive indicator of changes in the many variables regulating tree growth. The Weyerhaeuser Timber Company is currently utilizing information about the understory vegetation types in the study area as an aid in mapping forest management classes and formulating management plans.

Daubenmire (5) conducted a similar study on ponderosa pine in eastern Washington and northern Idaho and obtained similar results. He found that most forest stands have been burned or grazed, and thus support an admixture of species indicative of their disturbance. Yet the valuable indicators remain for those who know what to look for. Many American foresters believe that the lower vegetation has limited prediction value for delineating management classes on disturbed lands. This view is not founded on detailed studies but usually upon impressions resulting from the great differences in physiognomy that are induced by disturbances.

Silker (19) developed an ecological ladder using understory and overstory hardwoods for pine site evaluation in east Texas and southeastern Oklahoma. Silker proposed the use of hardwoods as indicators rather than ground flora for the following reasons:

1. Soil moisture is usually the most important factor controlling plant adaption to a site, when other minimums are met.

2. The most critical period for soil moisture demand appears to be in the early seedling stage.

3. Groups of hardwoods are practical, natural statistical expressions of total site factors affecting physiological minimums or maximums. Or, we might say that species frequency and commercial bole length and form are mirror images of what the total environment may express.

4. Hardwoods used to assay site should be common species that will occur throughout broad geologic, physiographic, and climate provinces.

5. Hardwoods should be reliable indicators because (a) most are climax plants; (b) they are less subject to rapid change than ground flora that are readily affected by fire, cutting and grazing; (c) they usually reflect an age or minimum expression of 50 to 150+ years; and

(d) they are usually conspicuous and readily identified by foresters.

Silker developed a wedge chart (Figure 1) for Coastal Plain soils to illustrate relationships between thickness of the A horizon and hardwood and pine order by apparent increasing or decreasing moisture storage and retention capacity.

The objective of this study is an attempt to determine if apparent moisture availability rating by specific plant groups on Silker's wedge chart will relate to site index of shortleaf pine growing within those groups. The study also makes an assessment of the relationship between site index and soil characteristics.

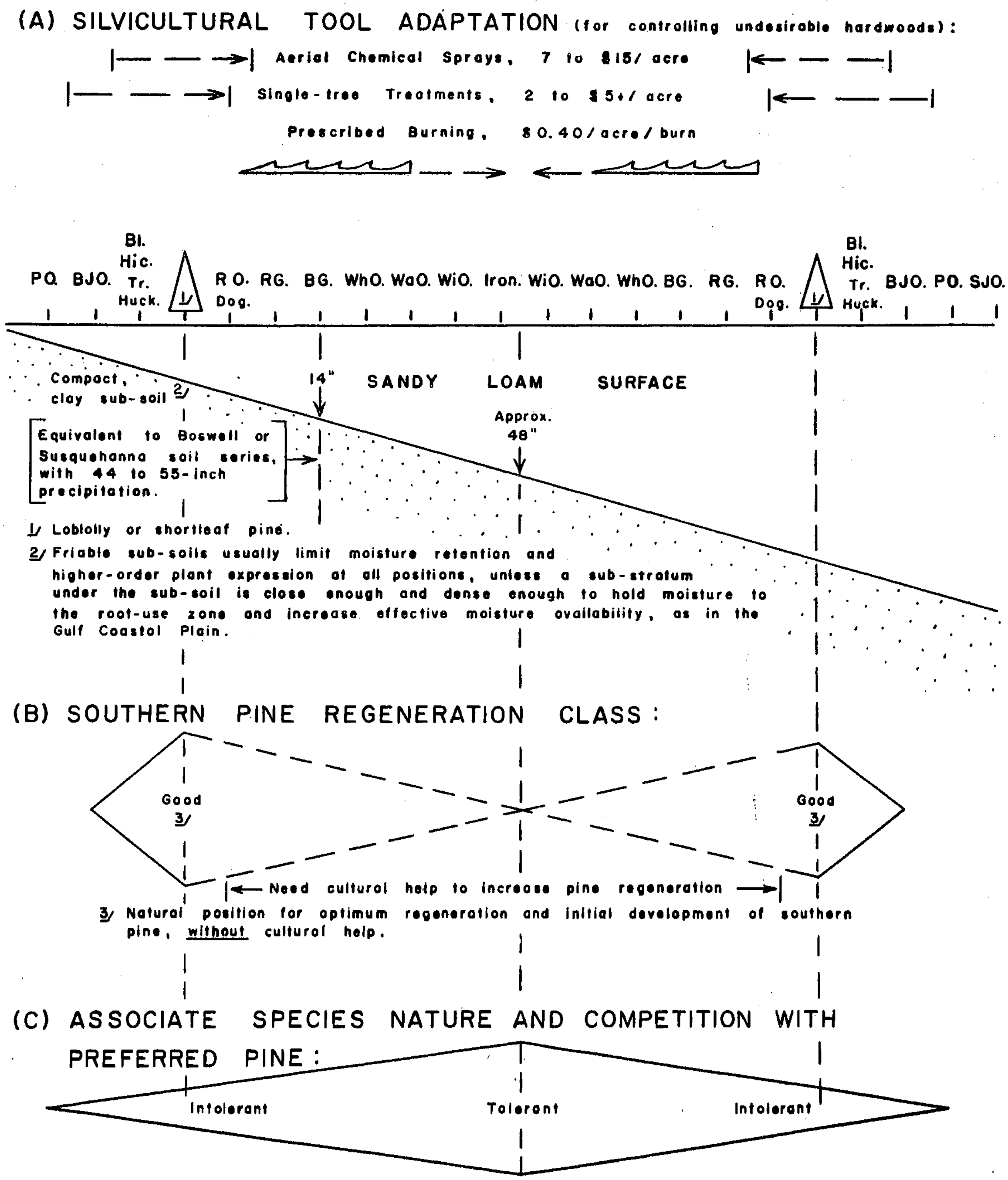


Figure 1. "Total Site Classification" by the Use of Plant Indicator Sequence. Tentative Rating and Relative Position of Predominant and Common Hardwoods in Reflecting Soil Moisture Availability. From Silker (19).

TABLE II

AN EXPLANATION OF SPECIES ABBREVIATIONS USED IN SILKER'S WEDGE CHART (FIGURE 1) (19). PERSONAL COMMUNICATION.

Abbreviation on Wedge Chart	Common Name	Generic Name
P.O.	Post Oak	Quercus stellata
B.J.O.	Blackjack Oak	Quercus marilandica
Bl. Hic.	Hickory	Carya spp.
Tr. Huck.	Tree Huckleberry	Vaccinium arboreum
	Pine	Pinus echinata or P. taeda
R.O.	Southern Red Oak	Quercus falcata
Dog.	Flowering Dogwood	Cornus florida
R.G.	Red or Sweetgum	Liquidambar styraciflua
B.G.	Black Gum	Nyssa sylvatica
Wh.O.	White Oak	Quercus alba
Wa.O.	Water Oak	Quercus nigra
Wi.O.	Willow Oak	Quercus phellos
Iron.	Ironwood	Ostrya virginiana
S.J.O.	Sandjack Oak	Quercus cinerea

CHAPTER III

METHODS AND PROCEDURES

The area studied is located in McCurtain County in the vicinity of Broken Bow, Oklahoma. The climate is humid, warm, and temperate. Average annual precipitation is 46 inches and is usually evenly distributed, but severe summer droughts are common. Frost free days for the area range from 220 to 240.

The Gulf Coastal Plain land surface was formed during several recent geologic periods of inundation with subsequent periods of emergence and sedimentation of materials from other areas. The lithological material consists largely of unconsolidated or weakly cemented sands and clays, and some chalk and marl.

Topography varies from level to rolling and varies in elevation from 300 to 700 feet above sea level. The level areas occur adjacent to streams and drainage ways. The rolling topography is found in the uplands between such areas.

Four plant associations were chosen for study; these can be identified on Silker's (19) wedge chart as follows: 1. post oak-blackjack oak-hickory-tree huckleberry. 2. post oak-blackjack oak-red oak. 3. red oak-sweetgum and 4. sweet gum-black gum-white oak. Ten field plots were studied for each of the plant associations*. The plots were located

*Two black gum-white oak plots and one sweet gum plot were damaged by logging operations before the complete vegetation tally could be made and were not used.

irrespective of soil series or phase, slope position or aspect, in a zone of similar topography and climatic conditions or an area about 30 miles long and 15 miles wide.

One tenth acre plots were selected because of the extreme variability in site quality and rapid change in soil characteristics over a small area.

Physical Plot Data

All plants on the plot over 4.5 feet in height were tallied. Those plants over 4.5 feet in height, but less than 3.6 inches in diameter were tallied by species, vigor class and diameter at breast height to the nearest one inch. Those plants over 3.6 inches in diameter at breast height were tallied by species, vigor class and crown class. Regeneration of 0.5 to 4.5 feet in height was tallied by species on eight 0.001 acre sub-plots located 20 feet from the plot center, at 45 degree intervals clockwise from north.

Plant frequency was rated for each species, as to predominant, common or scattered nature. A species was rated as predominant if several plants occured in each of the four quadrants of a plot. A "common" frequency rating required a tally of at least one plant in each of three quadrants of a plot. When stems occured in only one or two quadrants the species was given a "scattered" frequency rating.

Other information tallied for each plot included slope percent, slope length, distance to top and bottom of slope, and aspect, fire history, grazing history, and timber stand improvement history.

The actual site index of each plot was determined by plotting annual growth ring counts and measured heights of the three dominant and codominant pine trees on the site index curves (Figures 2,3,4,5). The ages of the pine trees sampled ranged from 35 to 52 years. The average age was 43. These ages fall within and near the range in which Hodgkins (14) and other foresters find that actual site indices can be considered reliable.

One or more soil profiles were examined and sampled for each plot. Soil Conservation Service soil scientists described the soil profile and classified the soil series. Soil samples were taken by horizon for analysis in the laboratory.

Soil Physical Analysis

The soil samples were air dried in the laboratory and forced through a 2 mm. sieve. Fifty gram soil samples were weighed and dispersed in a ten percent $NaCO_3$ solution. The total sand was separated from the sample by sieving through a standard 270 (0.053 mm.) sieve. Sand separates were determined by wet sieving (1-0.5, 0.5-0.25, 0.25-0.11, 0.11-0.092 mm.) and weighing the sand fraction retained on the respective sieve. Silt and clay determinations were made using a Bouyoucos hydrometer and the Day (6) procedure. All calculations were made on an oven-dry weight basis.

Soil Chemical Analysis

Soil cation exchange capacity was determined by saturation with ammonium acetate and then determining the amount of exchange ammonium ion by Kjeldahl distillation (15). The NH_4OAc. leachate was used for the determination of the exchangeable sodium, potassium, and magnesium cations on a Perkin-Elmer Model 303, Atomic Absorption Spectrophotomer.

CHAPTER IV

RESULTS AND DISCUSSION

Shortleaf Pine Site Index - Plant Association Relationships

The measured height-age averages for three pine trees on each plot are arranged by plant groups given in Tables III, IV, V, and VI. A simple linear additive model was used in the statistical analysis.

Variation in the site indices for the black gum-white oak plant association ranged from 80 to 97 feet at fifty years, around the mean of 89.7. A calculated mean standard variation and a tabulated "Student's t" value with seven degrees of freedom was used to make the statement P $(94.9 \geq \mu \geq 84.5) = 0.95$. It can be concluded that there is a 95 to five chance that the mean site index for the black gum-white oak plant association will fall between 94.9 and 84.5. The confidence statement for the 0.01 level is P $(97.4 \geq \mu \geq 82.0) = 0.99$.

Variation for the red oak - sweet gum plant association site indices ranges from 74 to 82, around a mean of 78.7. The same method used above is used to make the confidence statements P $(81.9 \geq \mu \geq 75.5) = 0.95$ and P $(83.3 \geq \mu \geq 74.0) = 0.99$.

The mean site index for the post oak-hickory-red oak plant association samples is 71.3. Actual site indices ranged from 65 to 80. The confidence statements for this plant association are P $(74.4 \geq \mu \geq 68.2) = 0.95$ and P $(75.7 \geq \mu \geq 66.9) = 0.99$.

The post oak-hickory-tree huckleberry plant association site indices

TABLE III

PREDICTION STATEMENTS FOR THE MEAN POPULATION SHORTLEAF PINE SITE INDEX FOR THE HICKORY-TREE HUCKLEBERRY PLANT ASSOCIATION

Plot Number	Site Index
233	67
243	62
249	71
763	62
767	61
777	64
781	64
786	59
790	67
798	63

X	640.0
$\bar{x}$	64.0
X^2	41070.0
s^2	12.2
$s^2_{\bar{x}}$	1.2
$s_{\bar{x}}$	1.1

$P(66.5 \geq \mu \geq 61.5) = 0.99$

$P(67.6 \geq \mu \geq 60.4) = 0.95$

TABLE IV

PREDICTION STATEMENTS FOR THE MEAN POPULATION SHORTLEAF PINE SITE INDEX FOR THE RED OAK PLANT ASSOCIATION

Plot Number	Site Index
5	71
17	80
21	73
51	74
222	68
229	73
238	73
753	69
757	67
760	65

X	713.0
$\bar{x}$	71.3
X^2	51003.0
s^2	18.4
$s^2_{\bar{x}}$	1.8
$s_{\bar{x}}$	1.4
$P(75.7 \geq \mu \geq 66.9)$ =	0.99
$P(74.4 \geq \mu \geq 68.2)$ =	0.95

TABLE V

PREDICTION STATEMENTS FOR THE MEAN POPULATION SHORTLEAF PINE SITE INDEX FOR THE SWEET GUM PLANT ASSOCIATION

Plot Number	Site Index
1	83
9	80
13	78
33	81
36	79
254	74
914	74
918	86
923	74

X	708.0
$\bar{\bar{x}}$	78.7
X^2	55843.0
s^2	17.3
s	4.2
$s^2_{\bar{x}}$	1.9
$s_{\bar{x}}$	1.4

$P(81.9 \geq \mu \geq 75.5) = 0.99$

$P(83.3 \geq \mu \geq 74.0) = 0.95$

TABLE VI

PREDICTION STATEMENTS FOR THE MEAN POPULATION SHORTLEAF PINE SITE INDEX FOR THE WHITE OAK PLANT ASSOCIATION

Plot Number	Site Index
371	83
375	80
379	83
387	94
354	87
801	88
805	96
808	97

X	718.0
$\bar{x}$	89.7
X^2	64712.0
s^2	38.7
s	6.3
$s^2_{\bar{x}}$	4.8
$s_{\bar{x}}$	2.2

$P(97.4 \geq \mu \geq 82.0) = 0.99$

$P(94.9 \geq \mu \geq 84.5) = 0.95$

ranged from 59 to 71, around a mean of 64.0. Here the statements P $(66.5 \geq \mu \geq 61.5) = 0.95$ and P $(67.6 \geq \mu \geq 60.4) = 0.99$ apply.

Note that the greatest amount of variation occurs in the black gum-whiteoak association. Here two separate plant associations; sweet gum-black gum, and sweet gum-black gum-white oak are grouped into one sample class. Perhaps these sites should have been divided in two separate management classes and sampled separately to limit range in variation. At the time the experiment was planned this separation was not considered desirable.

The relationships between shortleaf pine site indices and plant associations can be further illustrated by the site index curves (4) shown in Figures 2,3,4,5 and 6. Figure 2 represents the height and age averages for three shortleaf pine trees sampled on each of ten plots for the post oak-hickory-tree huckleberry plant association. Figure 3 represents the post oak-hickory-red oak plant association. Figure 4 represents the red oak-sweet gum association and Figure 5 represents the sweet gum-black gum-white oak association. Figure 6 illustrates the mean age and heights for each of the four plant associations.

From Figure 6 it can be concluded that the mean shortleaf pine site index, taken from the curves at age 50, for the respective plant associations is 64, 71, 79, and 90.

Individual species occurence and frequency are illustrated in relation to shortleaf pine site index and plant association in Tables VII and VIII. The species are listed in the order of apparent moisture demand, as illustrated in Silker's wedge chart (19). The continuum climax theory of plant ecology can be illustrated here. Figures 7 and 8 can also help to illustrate the relationships between hardwood species

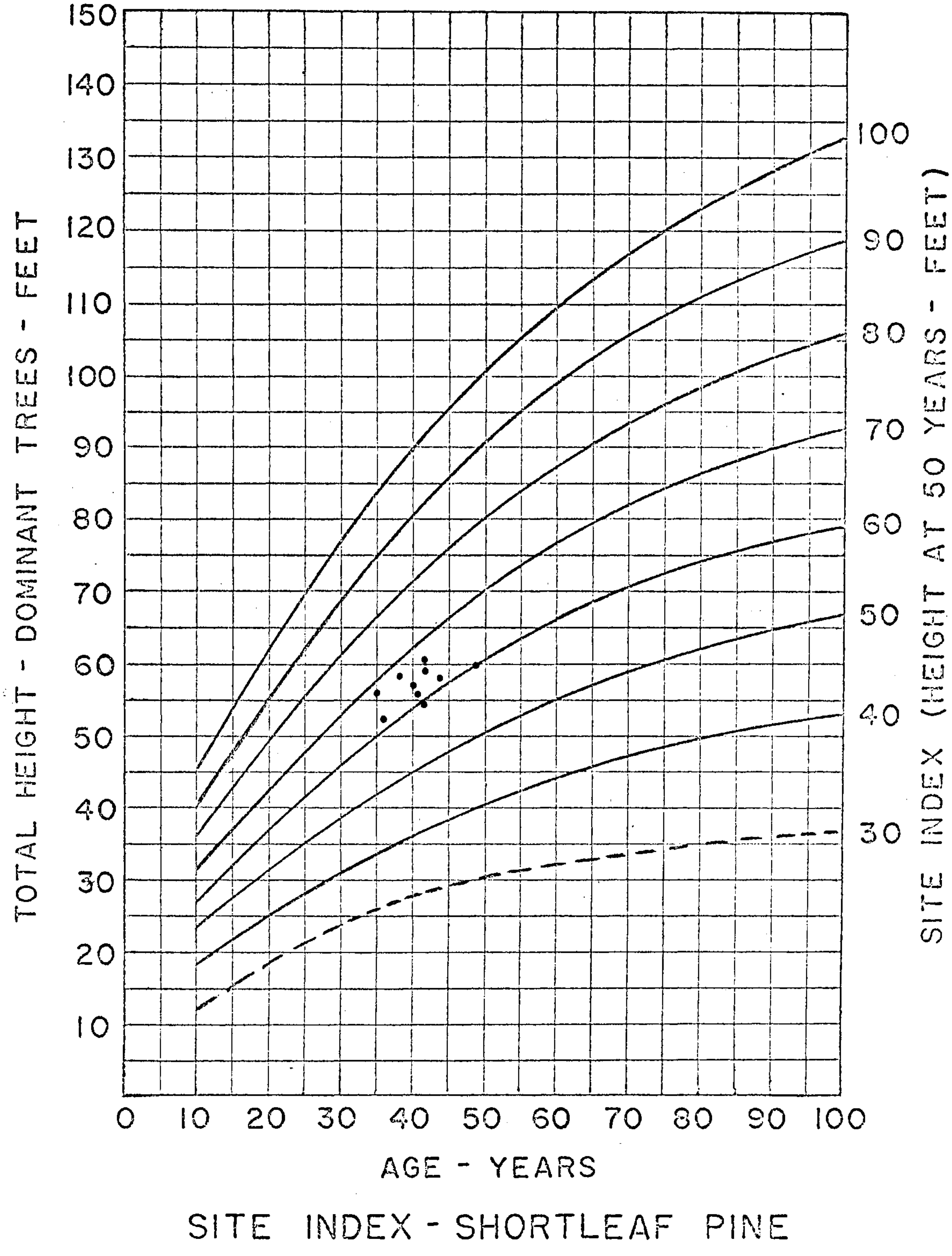
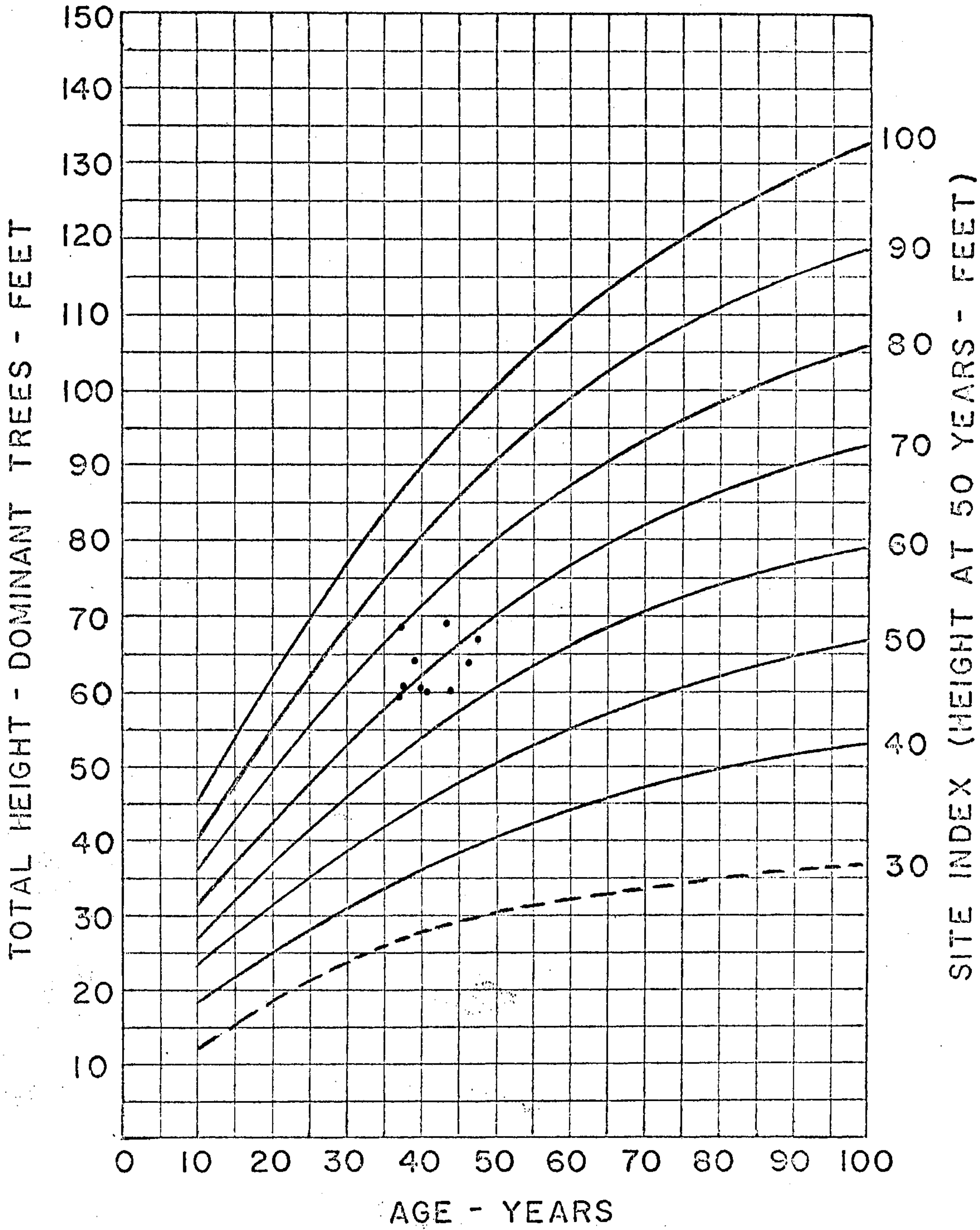


Figure 2. Hickory-Tree Huckleberry Plant Association Plot Site Indices



SITE INDEX - SHORTLEAF PINE

Figure 3. Red Oak Plant Association Plot Site Indices

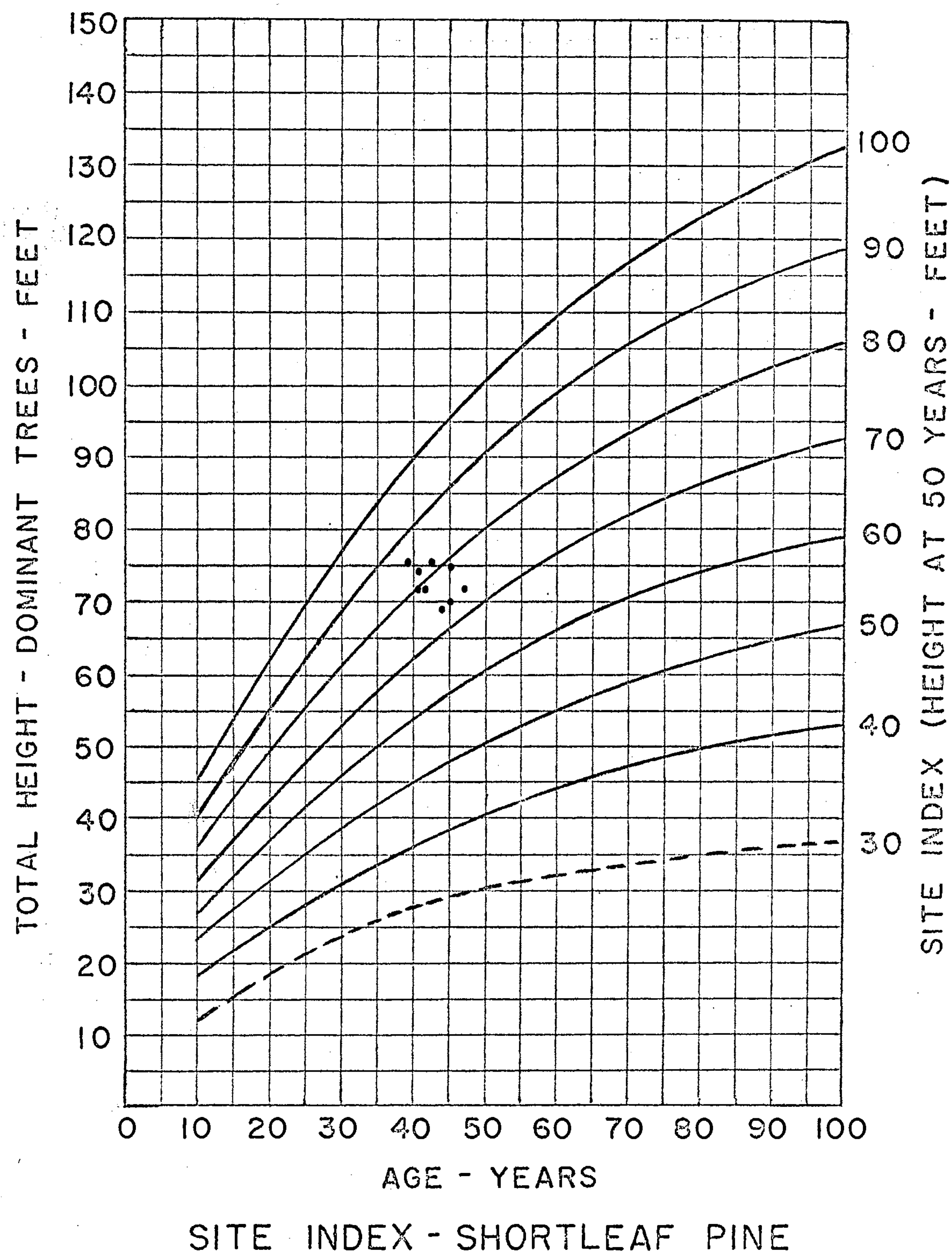


Figure 4. Sweet Gum Plant Association Plot Site Indices

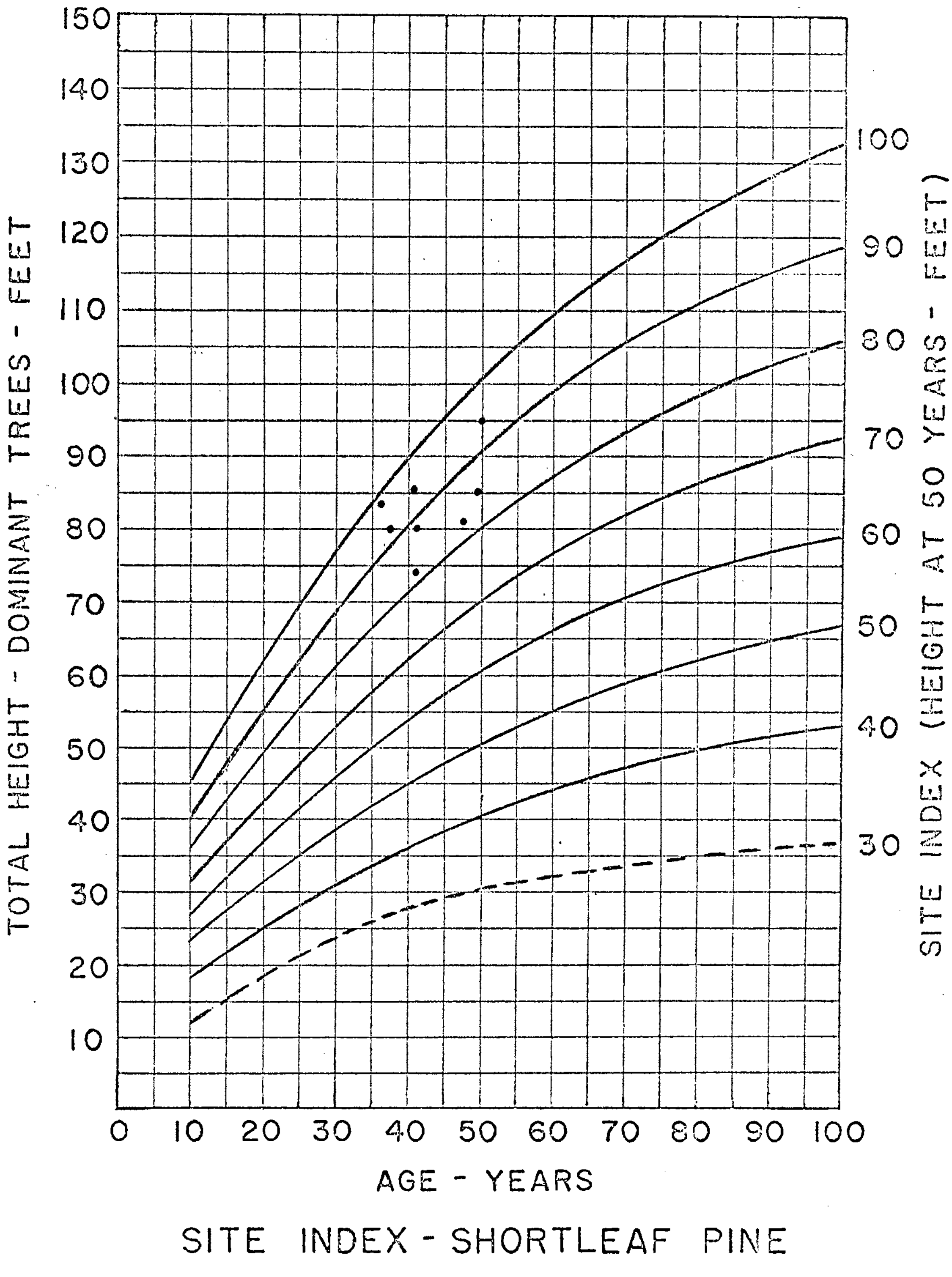


Figure 5. Black Gum-White Oak Plant Association

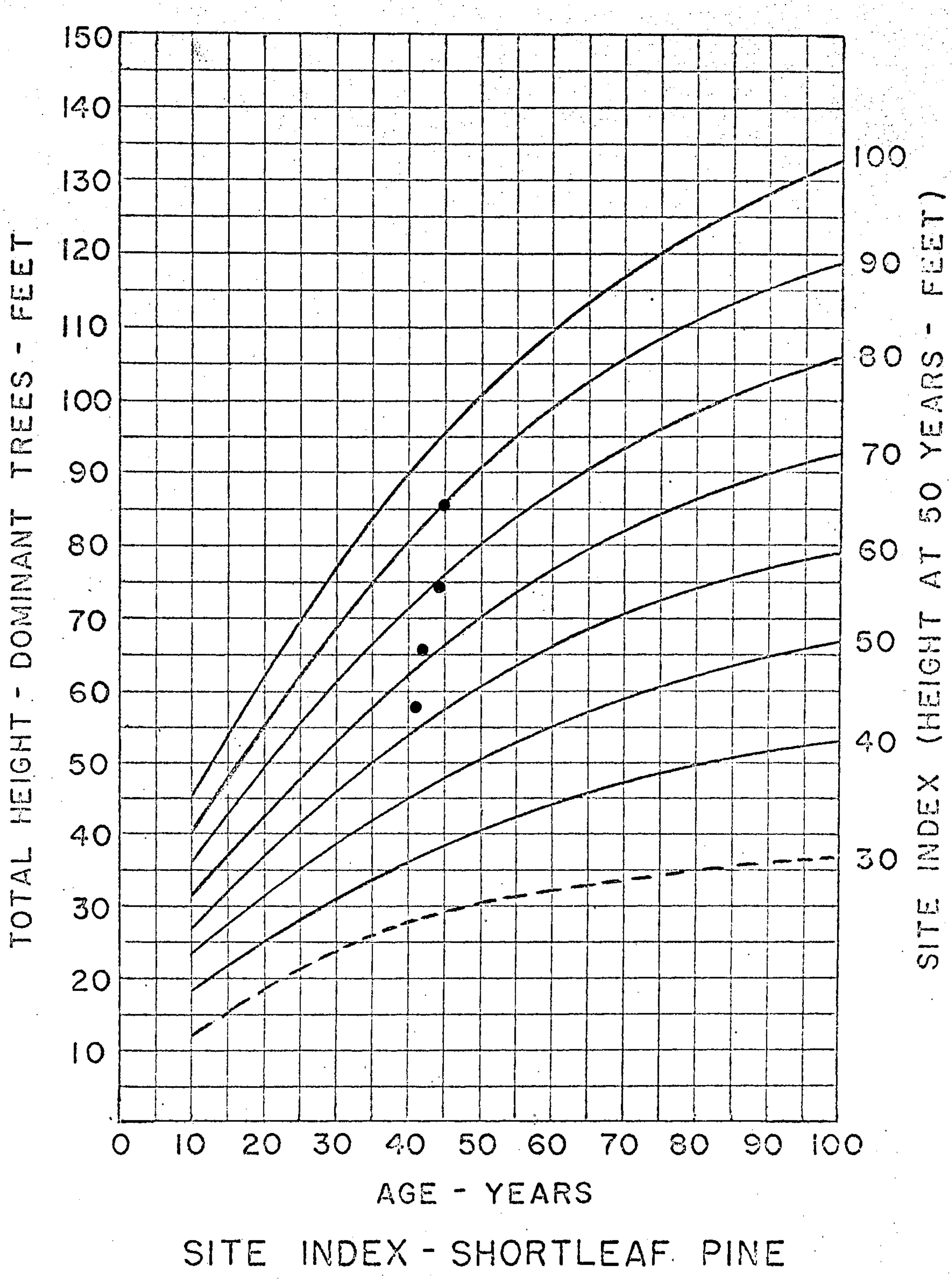


Figure 6. Mean Site Indices for Plant Groups

occurence, frequecy and shortleaf pine site index.

The graphs in Figures 7 and 8 show the plotting of the average frequencies of species for a plant association by species. Note that some species such as hickory, and to some extent post oak, tend to occur throughout the site quality ranges studied while others such as black oak and white oak have a more limited range. Hickory frequency appears to be correlated more with past land-use history and the competition from other plants rather than site quality. Blackjack oak follows the reverse pattern and its frequency seems to depend upon site quality. This could be attributed to its intolerance to the more severe competition of the higher quality sites. Tree huckleberry also follows this pattern.

Note that black oak frequency is quite limited. It does not express until shortleaf pine site index exceeds 63 feet and numbers are severely limited after pine site index exceeds 80 feet.

Sweet gum, black gum and white oak appear to thrive and reproduce profusely once their minimum site quality is reached. Figure 8 illustrates the abruptness of the minimum threshhold for these species. That is, sweet gum frequency does not materially increase until soil moisture is adequate to provide a shortleaf pine site index exceeding 75 feet. Black gum and white oak do not express with any regularity until shortleaf pine site index exceeds 80 feet. Dogwood frequency appears to be very sensitive to site quality. Its frequency steadily increases as the site quality increases.

The data in Tables VII and VIII indicate that shortleaf pine site quality can be related to individual plant frequency as proposed by Silker (19). Groups and frequencies of hardwood species can be used to

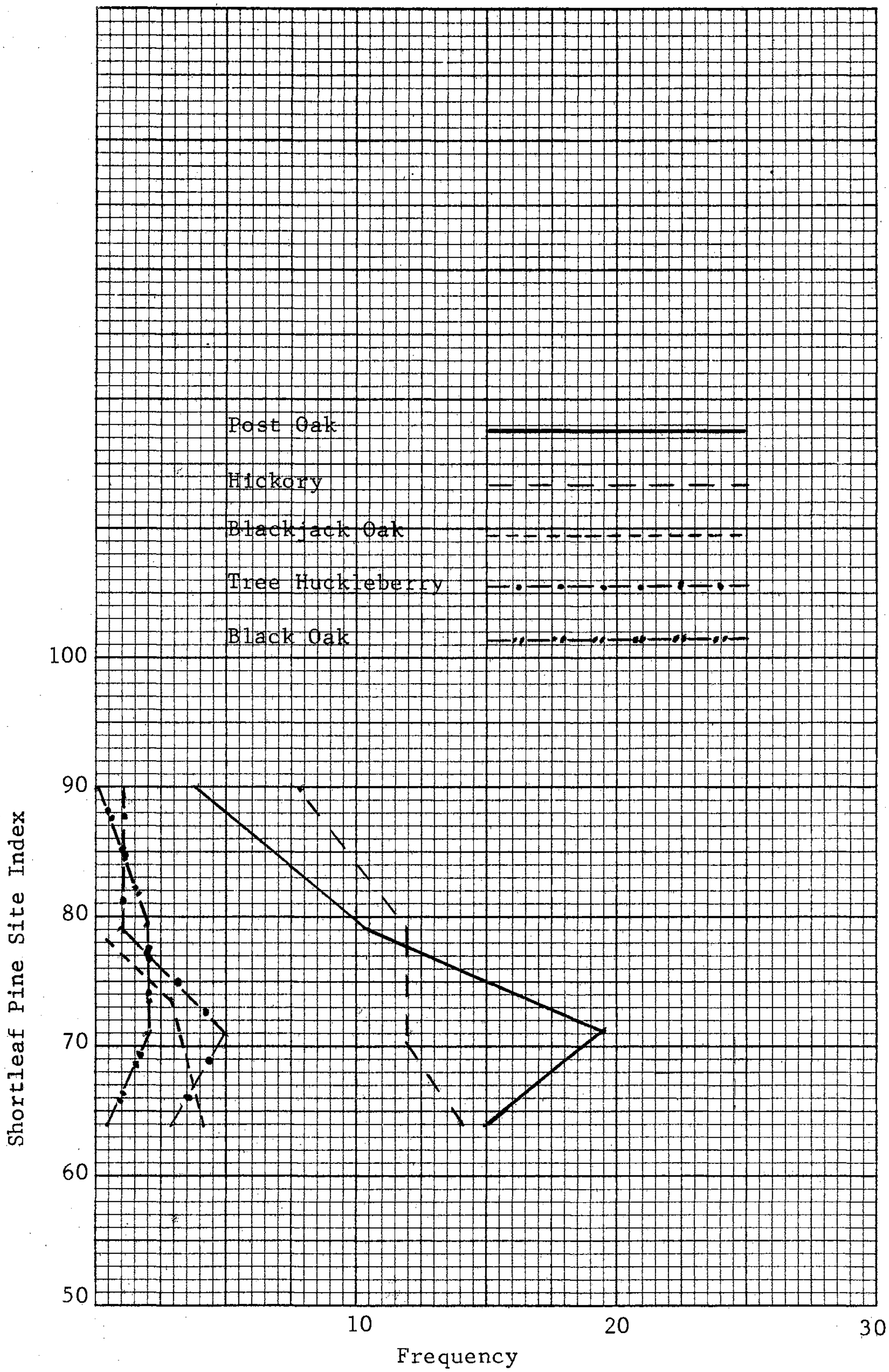


Figure 7. Mean Frequencies of Species for Plant Associations

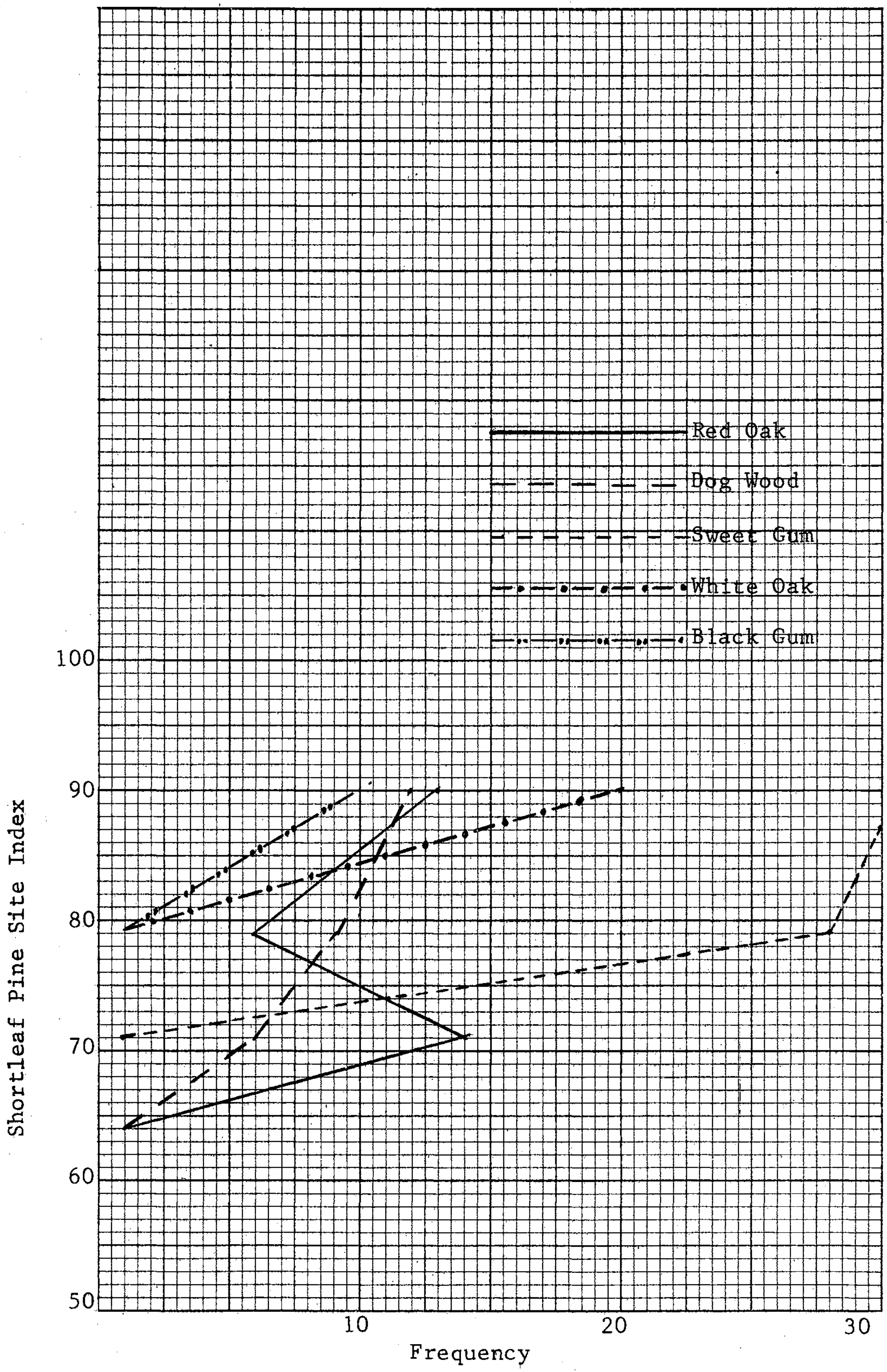


Figure 8. Mean Frequencies of Species for Plant Associations

TABLE VII

SPECIES FREQUENCY OF TREES FOR PLOTS STUDIED

Plot Number	Site Index	Plant Assoc-iation	P. O.	B. J. O.	Hic.	T. H.	B. O.	D. O.	R. O.	S. G.	B. G.	W. O.	Wa. O.
763	62	HTH	2	6	14	6						2	
767	61		19	3	1	14	1	1					
243	62		6	4	9	4	1						
249	71		34	3	8								
777	64		4	2	59				3				
781	64		7	8	11								
786	59		22	2	13	4							
790	67		18	15	15								
798	63		14	9	1	12			1				
233	67		28	4	8	1			1				
5	71	RO	11	3	3	1	4	48	31	2			
17	80		17	4	9		6		29				
21	73		47	11		2		4	23				
51	74		3		7	10	3		17				
222	68		10	7	5		2		2				
238	73		8	4	43	2	2	1	11				
753	69		18		5			1	6	3		1	2
757	67		10		27				10	1			1
760	65		6	6		1	4		3	3			
229	73		54		15	40	2		8				1

TABLE VIII

SPECIES FREQUENCY OF TREES FOR PLOTS STUDIED

Plot Number	Site Index	Plant Association	P. O.	B. J. O.	Hic.	T. H.	B. O.	D. O.	R. O.	S. G.	B. G.	W. O.	Wa. O.
1	80	S.G.	16	1	8		5	13	4	12		1	
9	82		2	1	11		5	44	6	5			
13	78		25		1		2	1	5	39			2
33	81		2		21			1	7	21			
254	74		11		7	1	5	1	4	16	3	2	
36	79		11		10			1	15	28		1	1
914	74		5		31	4	3	1	6	26	1		
918	86		13		6	1	1	2	7	80	3		
923	74		9	6	11	4	2		2	24			
354	87	B.G. W.O.	1		1	1	1	29	2	1	7	9	
371	83		15		4				18	33	4	4	
375	80				23	5		6	3	5		7	
379	93		6		2			5	18	58	23	73	
387	94				4		4	13	21	48	1	9	
801	88		1		5	1		23	13	52	11	15	
805	96				2		1	24	12	21	17	21	
808	97		5		24	1		10	8	43	16	17	

predict accurately site quality for shortleaf pine on Coastal Plain and related sites in southeastern Oklahoma.

Soil and Physical Plot Characteristics Analysis

Eighteen variables were treated in a multiple linear regression analysis. They are identified as follows:

X_1 = Slope Percent

X_2 = Slope position

X_3 = Depth to a constricting B horizon

X_4 = Percent silt plus clay in the A horizon

X_5 = Depth of the A horizon

X_6 = Percent sand in the A horizon

X_7 = Percent silt in the A horizon

X_8 = Percent clay in the A horizon

X_9 = Percent gravel in the A horizon

X_{10} = Cation exchange capacity of the A horizon

X_{11} = Magnesium in the A horizon

X_{12} = Sodium in the A horizon

X_{13} = Potassium in the A horizon

X_{14} = Percent gravel in the B horizon

X_{15} = Cation exchange capacity in the B horizon

X_{16} = Magnesium in the B horizon

X_{17} = Sodium in the B horizon

X_{18} = Potassium in the B horizon

Simple correlation coefficients that are significant at the 0.10 level and greater are given in Appendix Table I.

The multiple correlation coefficient for the eighteen variables is 0.88896. Data show that 79.03 percent of all site index variation is due to interactions of the aforementioned variables. The source of twenty-one percent of the variation is unknown. Undoubtedly, a large portion of this variation is associated with the high degree of variation in soils and the topographic nature of the area studied. An additional number of plots may have improved the precision of the correlation coefficients for several variables. However, prediction equations with a relatively high degree of accuracy were obtained. The actual site index versus predicted site indices, using all eighteen variables, are given in Appendix Table II. A better prediction equation was obtained when only nine variables instead of eighteen were studied. Variables, X_2, X_{18}, X_3, X_{10}, X_5, X_9, X_{13}, X_{16}, and X_{11}, (arranged in order of decreasing correlation with site index,) were used to form the following equation:

$$\text{Site index} = 55.252 + 3.247\ (X_2) + 3.132\ (X_3) - 2.179\ (X_5) - 0.015\ (X_9) - 0.584\ (X_{10}) + 25.998\ (X_{13}) - 2.376\ (X_{16}) + 16.379\ (X_{18}).$$

The results from the prediction equation in the preceding paragraph are given in Appendix Table II. This equation with nine variables reduces the predicted error because at this point the other nine variables account for only a small percent of the variation. The remaining variables continue to lower the "F level" in the same manner as a variable that accounted for significant variation.

Slope position (X_2) accounts for more variation in site index than any other single variable. It has a simple correlation coefficient of -0.5139 and it accounts for 26.4 percent of the variation in site index. Site indices are lowest on the ridge tops and highest on the slopes. The highest site indices are encountered on the terraces, with intermediate site indices occuring in the mid-slope positions. Zahner (22) obtained similar results in southwestern Arkansas. This can be readily observed in the area sampled. In even-aged stands, the tree tops appear to be relatively even in height even though the terrain is rolling.

The corrélation of slope percent with site index is decreased by almost 50 percent when slope position is held constant. This indicates that much of this variation is due to the influence of slope position. The correlations for the nine variables in the aforementioned equation change when any one variable or group of variables is held constant. This indicates that there is interaction among all variables at all levels tested in the regression analysis.

Depth to a constricting B horizon (X_3), depth of the A horizon (X_5) and percent gravel in the A horizon (X_9) each expressed very weak simple correlation coefficients Appendix Table I, but their combined effect greatly increased the correlation, as can be seen in the multiple correlations data in Appendix Table IV through XII. However, the correlation between these variables and site index is relatively low in comparison to what one might expect after reviewing the works of Coile (3), Zahner (25) and others (16,17,18) in this same study area.

Percent gravel in the A horizon, undoubtedly, must explain some of the low correlation for these variables. Unfortunately, the effect of gravel in a profile on total soil moisture availability is very difficult to assess and evaluate.

Another variable that is not included in the regression analysis, which might account for some of the variation, is the percent coarse and very coarse sands in the sand fraction. Perhaps these variables may account for part of the large variation in the predicted site index for plot number 67-S-243 (Appendix Table II). Here a sandy loam A horizon contains 67 percent sand, of which 60 percent is coarse and very coarse fractions. This could reduce the moisture retention to a point where the actual site index would be much lower than the predicted site index for this soil. The point is reaffirmed by the hickory-tree huckleberry plant association that occurs on this plot rather than the black gum-white oak plant association.

Soil chemical properties is an area in forestry that has, for the large part, been over-looked due to the economic and practical aspects of forestry practice. There is very little data with which to compare findings and to use as a guide for this analysis. The results reported here are difficult to support by data published by other investigators due to the paucity of data available. Therefore, these data reported here will be checked by other foresters and soil scientists in other environments before a final decision can be rendered on the significance of these findings.

Several soil chemical characteristics are significantly correlated with site index of shortleaf pine. Following slope position, exchangeable or available potassium is the best correlated single variable used in the multiple regression analysis. Other significant chemical properties are potassium in the A horizon, the cation exchange capacity of the A horizon, exchangeable potassium in the A horizon, magnesium in the B horizon, and magnesium in the A horizon. It is interesting to note that there is a slight negative correlation between site index and the cation exchange capacity of the B horizon. This is partially explained by observing that most high site indices occured on soils with deep heavy loam and light clay and sandy clay loam subsoils. The lower site index plots usually had relatively shallow surface materials above heavy clay subsoils. Coile's hypothesis can be used in explaining this correlation. Downslope water movement and erosion contributes to thinner A horizons in upper slope positions. Underground water movement above the subsoil may also tend to lessen droughty periods for the lower slope sites. It could be speculated that water movement and accumulation of exchangeable ions on lower slope positions may contribute to higher site indices.

Base saturation tended to be low on the lower site index plots. Several of the high percent base saturation plots had high site indices. One plot was an exception, it had a high percent base saturation and a low site index. However, this plot had a shallow limestone R horizon which would tend to influence the high percent base saturation.

Six of the 37 plots studied were classified as Alfisols (soils with well developed profiles containing a clayey illuvial horizon with over 35 percent base saturation). The Alfisols expressed high site indices and supported blackgum-white oak plant associations. The only exception was the above mentioned plot with the limeston R horizon.

The remainder of the plots occurred on soils that are classified as Ultisols (soils with well developed profiles containing a clayey illuvial horizon with less than 35 percent base saturation).

CHAPTER V

SUMMARY AND CONCLUSIONS

The findings of this study indicate that there is a definite correlation between shortleaf pine site index, associate plant groups, and soil characteristics.

The prediction of site quality using soil physical characteristics can not be used as accurately in the Coastal Plains of Southeast Oklahoma as it can be used in many areas of the Southeastern and Southern United States. This may be attributed to the high degree of soil variation in the area studied.

Slope position was the most correlated variable studied. Several soil chemical characteristics accounted for enough variation in site index such that this area might well deserve future study. Nine soil variables were used in deriving a prediction equation accounting for 79 percent of the variation in the site index.

There is a positive and rather precise correlation between plant groups on Coastal Plain soils and shortleaf pine site index. Mean site index values of 64, 71, 78, and 90 feet at age fifty years were determined for shortleaf pine occuring with the four plant groups, respectively. Therefore, it appears specific plant groups will delineate relative but discrete soil moisture-availability classes.

The findings should help with inter-disciplinary interpretations as follows:

a. The interpretation of productivity potential, or management class of various sites.

b. Identification of soil or site changes.

c. Delineatation of shallow or deep phases of a given soil series.

d. Assistance with forest soil mapping and interpretations.

e. Assistance with determination of an allowable base for land tax assessment.

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APPENDIX

TABLE I

SIMPLE CORRELATIONS SIGNIFICANT AT THE 0.10 LEVEL

Correlation	Calculated t
Slope Position Vs. CEC* in B	2.022**
Silt + Clay in A Vs. Gravel in B	1.803*
Percent Sand in A Vs. Percent Silt in A	13.186***
K in A Vs. Site Index	2.068*
Depth to Constricting B Vs. Depth of A	7.411***
Silt + Clay in A Vs. CEC in B	3.149***
Percent Sand in A Vs. Percent Clay in A	2.276**
Percent Gravel in A Vs. Gravel in B	3.825***
Mg in A Vs. K in A	2.514**
Mg in A Vs. Mg in B	3.748***
K in A Vs. K in B	1.980*
Slope Position Vs. Site Index	2.7932**
K in A Vs. Mg in B	2.121**
CEC of B Vs. K in B	1.833*
Percent Gravel Vs. Site Index	1.753*

Significance 0.99***, 0.95**, 0.90*

*CEC - Cation Exchange Capacity

TABLE II

SITE INDEX PREDICTIONS USING NINE VARIABLES

Run No	Actual	Predicted Vs. Actual Results Predicted	Deviation
1.	80.00000	77.89109	2.10891
5.	71.00000	75.70115	-4.70115
9.	82.00000	74.23877	7.76123
13.	78.00000	81.69367	-3.69367
17.	80.00000	76.61471	3.38529
21.	73.00000	71.52790	1.47210
33.	81.00000	78.14519	2.85841
36.	79.00000	85.95720	-6.95720
51.	74.00000	77.85873	-3.85873
222.	68.00000	65.06420	2.93580
229.	73.00000	70.21427	2.78573
233.	67.00000	64.22804	2.77196
238.	73.00000	68.02182	4.97818
243.	62.00000	74.79351	-12.79351
249.	71.00000	68.18745	2.81255
254.	74.00000	76.95497	-2.95497
354.	87.00000	92.86747	-5.86747
371.	83.00000	83.91436	-0.91436
375.	80.00000	78.47743	1.52257
379.	93.00000	86.92409	6.07591
387.	94.50000	91.44359	3.05641
753.	69.00000	67.66873	1.33127
757.	67.00000	68.54603	-1.54603
760.	65.00000	72.97959	-7.97959
763.	62.00000	66.24976	-4.24976
767.	61.00000	62.06170	-1.06170
777.	64.00000	70.54441	-6.54441
781.	64.00000	69.57266	-5.57266
786.	59.00000	63.50307	-4.50307
790.	67.00000	64.85072	2.14928
798.	63.00000	56.46509	6.53491
801.	88.00000	82.86294	5.13706
805.	95.00000	90.61640	4.88350
808.	97.00000	95.04722	1.95278
914.	74.00000	73.33031	0.66969
918.	86.00000	80.10913	5.89087
923.	74.00000	73.87234	0.12766

TABLE III

SITE INDEX PREDICTIONS USING EIGHTEEN VARIABLES

	Predicted Vs. Actual Results		
Run No	Actual	Predicted	Deviation
1.	80.00000	78.41324	1.58676
5.	71.00000	75.50456	-4.50456
9.	82.00000	76.38235	5.61765
13.	78.00000	82.45335	-4.45335
17.	80.00000	76.03267	3.96733
21.	73.00000	70.02419	2.97581
33.	81.00000	77.85763	3.14237
36.	79.00000	83.81987	-4.81987
51.	79.00000	77.57575	-3.57575
222.	68.00000	65.54746	2.45254
229.	73.00000	70.18469	2.81531
233.	67.00000	63.11922	3.88078
238.	73.00000	67.36769	5.63231
243.	62.00000	76.42708	-14.42708
249.	71.00000	66.91715	4.08285
254.	74.00000	75.12605	-1.12605
354	87.00000	91.20817	-4.20817
371.	83.00000	85.62875	-2.62875
375.	80.00000	78.85977	1.14023
379.	93.00000	86.45503	6.54497
387.	94.50000	92.70682	1.79318
753.	69.00000	69.82194	-0.82194
757.	67.00000	68.18787	-1.18787
760.	65.00000	70.92791	-5.92791
763.	62.00000	66.90016	-4.90016
767.	61.00000	64.55973	-3.55973
777.	64.00000	72.21474	-8.21474
781.	64.00000	69.05792	-5.05792
786.	59.00000	66.13279	-7.13279
790.	67.00000	67.04671	-0.04671
798.	63.00000	55.74681	7.25319
801.	88.00000	81.84296	6.15704
805.	95.50000	93.09464	2.40536
808.	97.00000	94.01445	2.98555
914.	74.00000	70.43831	3.56169
918.	86.00000	78.44509	7.55491
923.	74.00000	72.95634	1.04366

TABLE IV

MULTIPLE CORRELATIONS OF SLOPE POSITION WITH OTHER VARIABLES

Step No. 1

Variable Entering — Slope Position

F Level 12.5596

Standard Error of Y 9.0463

Multiple Correlation Coefficient 0.51389

Constant 65.01888

Variable	Coefficient	STD Error of Coef.
x - 2	4.49761	1.26909

Partial Correlation

x(1) VS Y	0.19341
x(3) VS Y	0.16878
x(4) VS Y	0.07260
x(5) VS Y	-0.05594
x(6) VS Y	-0.15741
x(7) VS Y	0.10169
x(8) VS Y	0.17027
x(9) VS Y	-0.38919
x(10) VS Y	-0.21503
x(11) VS Y	0.42477
x(12) VS Y	0.09915
x(13) VS Y	0.39670
x(14) VS Y	-0.19995
x(15) VS Y	0.04701
x(16) VS Y	0.33723
x(17) VS Y	0.11348
x(18) VS Y	0.48058

TABLE V

MULTIPLE CORRELATIONS OF POTASSIUM IN THE B HORIZON WITH OTHER VARIABLES

Step No. 2

Variable Entering 18 K in B Horizon

F Level 10.2110

Standard Error of Y 8.0490

Multiple Correlation Coefficient 0.65882

Constant: 59.01941

Variable	Coefficient	STD Error of Coef.
x - 2	4.91237	1.13661
x - 18	19.17741	6.00144

Partial Correlation

x(1) VS Y	0.22852
x(3) VS Y	0.35785
x(4) VS Y	-0.08756
x(5) VS Y	0.12267
x(6) VS Y	-0.04067
x(7) VS Y	0.02621
x(8) VS Y	0.07062
x(9) VS Y	-0.26734
x(10) VS Y	-0.26883
x(11) VS Y	0.30317
x(12) VS Y	-0.05589
x(13) VS Y	0.21029
x(14) VS Y	-0.06589
x(15) VS Y	-0.18903
x(16) VS Y	0.20402
x(17) VS Y	-0.03774

TABLE VI

MULTIPLE CORRELATIONS OF DEPTH TO A CONSTRICTING B HORIZON WITH OTHER VARIABLES

Step No. 3

Variable Entering Depth to a Constricting B Horizon

F Level 4.8466

Standard Error of Y 7.6290

Multiple Correlation Coefficient 0.71171

Constant 48.97573

Variable	Coefficient	STD Error of Coef.
x - 2	5.02701	1.07856
x - 3	0.77644	0.35269
x - 18	22.77855	5.91882

Partial Correlations

x(1) VS Y	0.20633
x(4) VS Y	-0.02011
x(5) VS Y	-0.41159
x(6) VS Y	-0.13831
x(7) VS Y	0.14655
x(8) VS Y	-0.01292
x(9) VS Y	-0.34540
x(10) VS Y	-0.42214
x(11) VS Y	0.28442
x(12) VS Y	-0.04686
x(13) VS Y	0.19940
x(14) VS Y	-0.11575
x(15) VS Y	-0.21923
x(16) VS Y	0.13984
x(17) VS Y	0.00750

TABLE VII

MULTIPLE CORRELATIONS OF C.E.C. IN THE A HORIZON WITH OTHER VARIABLES

Step No. 4

Variable Entering 10 CEC in A Horizon

F Level 6.9392

Standard Error of Y 7.0231

Multiple Correlation Coefficient 0.77102

Constant 52.13106

Variable	Coefficient	STD Error of Coef.
x - 2	4.38407	1.02247
x - 3	1.04511	0.34032
x - 10	-0.72293	0.27444
x - 18	24.64190	5.49449

Partial Correlations

x(1) VS Y	0.19385
x(4) VS Y	-0.03908
x(5) VS Y	-0.42980
x(6) VS Y	-0.11557
x(7) VS Y	0.10231
x(8) VS Y	-0.01660
x(9) VS Y	-0.23525
x(11) VS Y	0.30396
x(12) VS Y	-0.02212
x(13) VS Y	0.16078
x(14) VS Y	-0.11087
x(15) VS Y	-0.10477
x(16) VS Y	0.03337
x(17) VS Y	-0.05419

TABLE VIII

MULTIPLE CORRELATIONS OF DEPTH OF THE A HORIZON WITH OTHER VARIABLES

Step No. 5

Variable Entering — Depth of A Horizon

F Level 7.0241

Standard Error of Y — 6.4428

Multiple Correlation Coefficient — 0.81816

Constant 53.39603

Variable	Coefficient	STD Error of Coef.
x - 2	4.48746	0.93879
x - 3	2.43207	0.60938
x - 5	-1.57845	0.59557
x - 10	-0.68729	0.25212
x - 18	22.04374	5.13495

Partial Correlations

x(1) VS Y	0.05095
x(4) VS Y	-0.00923
x(6) VS Y	-0.17157
x(7) VS Y	0.19595
x(8) VS Y	-0.03157
x(9) VS Y	-0.24877
x(11) VS Y	0.21746
x(12) VS Y	0.06436
x(13) VS Y	0.21374
x(14) VS Y	-0.08189
x(15) VS Y	-0.17340
x(16) VS Y	-0.14924
x(17) VS Y	-0.02201

TABLE IX

MULTIPLE CORRELATIONS OF PERCENT GRAVEL IN THE A HORIZON WITH OTHER VARIABLES

Step No. 6

Variable Entering — Percent Gravel in A Horizon

F Level 1.9790

Standard Error of Y — 6.3434

Multiple Correlation Coefficient — 0.83056

Constant 54.44251

Variable	Coefficient	STD Error of Coef.
x - 2	4.35329	0.92922
x - 3	2.43084	0.59998
x - 5	-1.55789	0.58657
x - 9	-0.01033	0.00735
x - 10	-0.56004	0.26420
x - 18	19.33954	5.40884

Partial Correlations

x(1) VS Y	0.1075
x(4) VS Y	-0.03153
x(6) VS Y	-0.13694
x(7) VS Y	0.15942
x(8) VS Y	0.05010
x(11) VS Y	0.16981
x(12) VS Y	0.06845
x(13) VS Y	0.23227
x(14) VS Y	-0.14352
x(15) VS Y	-0.19255
x(16) VS Y	-0.21100
x(17) VS Y	0.04679

TABLE X

MULTIPLE CORRELATIONS OF POTASSIUM IN THE A HORIZON WITH OTHER VARIABLES

Step No. 7

Variable Entering K in A Horizon

F Level 1.6538

Standard Error of Y 6.2754

Multiple Correlation Coefficient 0.84058

Constant 54.09522

Variable	Coefficient	STD Error of Coef.
x - 2	3.96356	0.96792
x - 3	2.43791	0.59357
x - 5	-1.61227	0.58182
x - 9	-0.01075	0.00727
x - 10	-0.51219	0.26400
x - 13	14.34579	11.15533
x - 18	15.46991	6.13888

Partial Correlations

x(1) VS Y	0.10471
x(4) VS Y	-0.05856
x(6) VS Y	-0.19053
x(7) VS Y	0.19212
x(8) VS Y	0.12971
x(11) VS Y	0.06246
x(12) VS Y	-0.00777
x(14) VS Y	0.17109
x(15) VS Y	-0.20753
x(16) VS Y	-0.37009
x(17) VS Y	0.03796

TABLE XI

MULTIPLE CORRELATIONS OF MAGNESIUM IN THE B HORIZON WITH OTHER VARIABLES

Step No. 8

Variable Entering Mg in B Horizon

F Level 4.4437

Standard Error of Y 5.9330

Multiple Correlation Coefficient 0.86415

Constant 56.57986

Variable	Coefficient	STD Error of Coef.
x - 2	3.32720	0.96360
x - 3	3.13228	0.65071
x - 5	-2.17909	0.61228
x - 9	-0.01450	0.00710
x - 10	-0.58407	0.25192
x - 13	25.99838	11.90751
x - 16	-2.37560	1.12694
x - 18	16.37905	5.81994

Partial Correlations

x(1) VS Y	0.06745
x(4) VS Y	0.21658
x(6) VS Y	-0.21658
x(7) VS Y	0.20795
x(8) VS Y	0.16928
x(11) VS Y	0.29921
x(12) VS Y	0.04389
x(14) VS Y	0.19000
x(15) VS Y	-0.09253
x(17) VS Y	0.00360

TABLE XII

MULTIPLE CORRELATIONS OF MAGNESIUM IN THE A HORIZON WITH OTHER VARIABLES

Step No. 9

Variable Entering Mg in A Horizon

F Level 2.6548

Standard Error of Y 5.7651

Multiple Correlation Coefficient 0.87717

Constant 55.25215

Variable	Coefficient	STD Error of Coef.
x - 2	3.24720	0.93763
x - 3	3.05801	0.63394
x - 5	-2.05286	0.59997
x - 9	-0.01232	0.00703
x - 10	-0.69012	0.25329
x - 11	3.81061	2.33871
x - 13	19.68094	12.20285
x - 16	-3.37088	1.25389
x - 18	16.90369	5.66439

Partial Correlations

x(1) VS Y	-0.09803
x(4) VS Y	0.03575
x(6) VS Y	-0.13915
x(7) VS Y	0.16085
x(8) VS Y	0.06631
x(12) VS Y	0.15593
x(14) VS Y	0.12045
x(15) VS Y	0.12045
x(16) VS Y	--0.04987
x(17) VS Y	0.08945

VITA

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Candidate for the Degree of

Master of Science

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