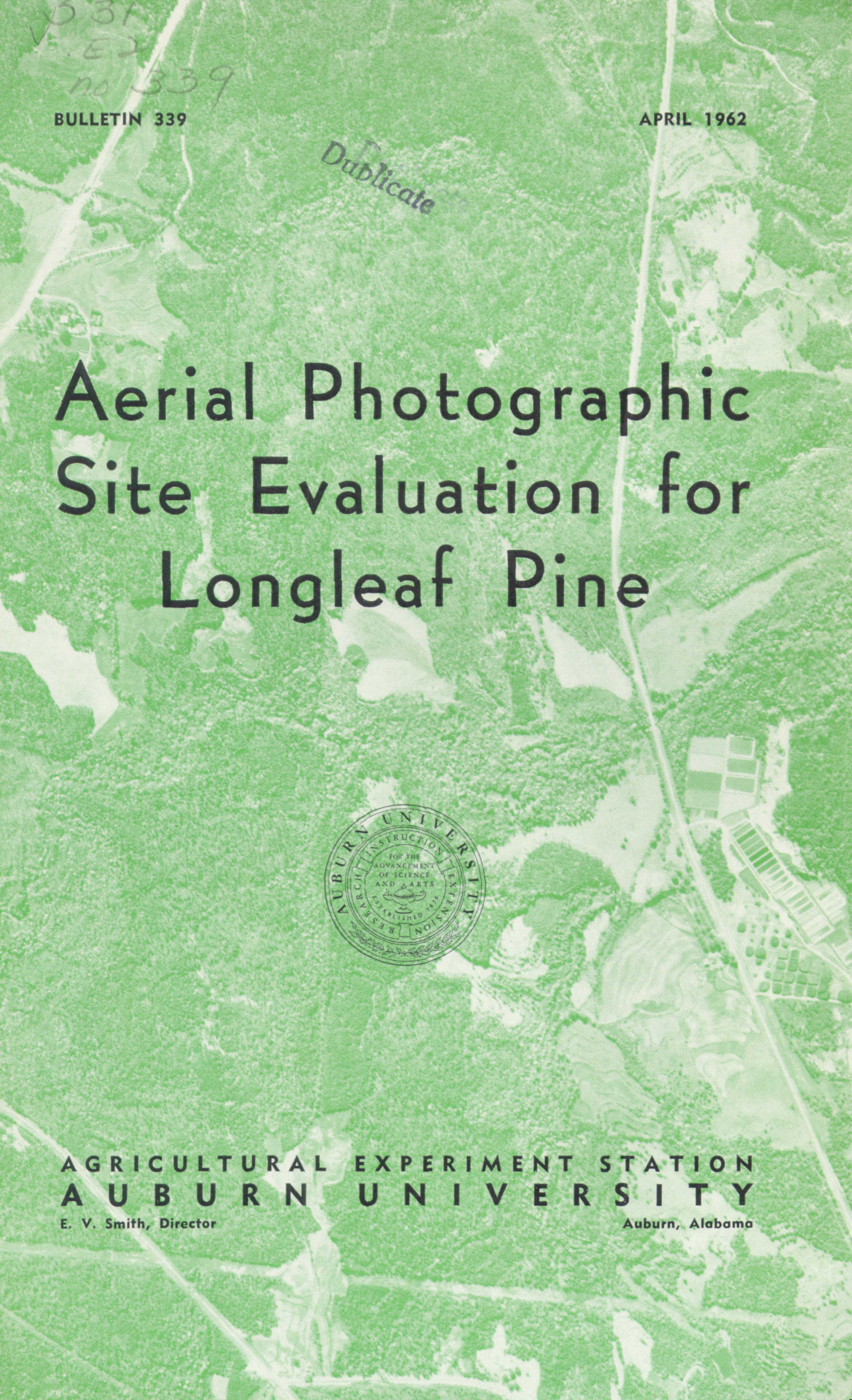
BULLETIN 339 APRIL 1962



Aerial Photographic Site Evaluation for Longleaf Pine

AGRICULTURAL EXPERIMENT STATION
AUBURN UNIVERSITY
E. V. Smith, Director
Auburn, Alabama

CONTENTS

FIRST PRINTING 3M APRIL 1962

AERIAL PHOTOGRAPHIC SITE EVALUATION for LONGLEAF PINE[1]

EVERT W. JOHNSON, *Associate Forester*

RECOGNITION AND CLASSIFICATION of forest site quality is a fundamental requirement for most phases of forest management, including mensurational, silvicultural, and business operations.

In an article published in 1917, Watson *(53)* made a clear and concise statement concerning the utility of the concept of site to the forest manager: ". . . site is an important factor in deciding upon the species which may be used to best advantage, the yield table which may be applied, the rotation which may be used, and the method of regeneration which may be followed."

The increasing dependence on aerial photographs in these operations has stimulated an interest in the development of a method of evaluating site quality from aerial photographic evidence. Several attempts have been made to develop such site evaluation methods. Some have been quite successful, although none has been comparable in sensitivity with the standard site index determination procedure. The purpose of this study was to explore some of the possible leads to sensitive methods of aerial photographic site evaluation.

The study was designed to establish fundamental relationships between site quality, expressed as site index, and independent variables that could be measured or evaluated on aerial photo-

---

[1] Condensed from a thesis submitted to the State University College of Forestry at Syracuse University, Syracuse, New York, in partial fulfillment of the requirements for the Ph.D. degree, June 1957.

graphs. The study was limited to a single species and a small and relatively homogeneous portion of that species' range. Longleaf pine (*Pinus palustus*, Miller) was chosen as the species, and the area was limited to a portion of the Lower Coastal Plain in southern Alabama and northwestern Florida.

PAST WORK

Solutions for the forest site evaluation problem using aerial photographic evidence have been devised. One involves site quality determination along ground cruise lines traversing the area. Site class boundaries are established on cruise strips, then extended and connected between strips on the basis of photographic evidence, such as topography and distribution of vegetation *(14, 42, 43)*. This procedure is considered standard in Finland *(21)*. It has been used successfully in the United States in the Forest Survey of California *(2, 50, 54, 55)*, and in the site mapping of certain national forests *(25)*.

The evaluation of site quality by photographic information alone is based on experimental work done in ecological mapping by Bourne *(10)* and Robbins *(40)*. They found it possible to identify vegetation complexes and classify land according to its best potential use based on geological formations, topography, and tonal differences between soils. This approach entails the theory that site quality within an area of uniform climate and geology is dependent on topography and soil, particularly as these factors affect soil moisture. Topography is easily evaluated from photographs. Sufficient geological and soil characteristics are obtained from photographic evidence to provide the basis for broad soil groupings. This information makes it possible to determine site quality classes that can be identified on the photographs.

Others who have reported on application of this reasoning to specific problems are Krueger *(28)*, Losee *(29, 30, 31, 32)*, Seely *(44)*, Becker *(4)*, Moessner *(35, 36, 37)* and Moessner and Jensen *(38)*. In most cases these applications have been relatively crude, yet quite effective. Hills *(22, 23, 24)*, introducing more variables in an attempt to evaluate more completely the total environment, has developed a procedure receiving favorable comment from its application to Canadian forests *(5, 15)*.

The Swedish Committee on Forest Photogrammetry (*Kommittén för skoglig fotogrammetri*) *(27)* has reported results of an investigation in which stereograms were used in addition to the usual topographic criteria. These results were promising, but demands on the photo-interpreters were heavy. Wilson *(56)*, working in old-growth stands of ponderosa pine (*Pinus ponderosa*, Laws.) in Idaho, also used stereograms and topographic criteria for site determination purposes.

A novel approach to site evaluation has been attempted in Sweden by Bäckström and Welander *(3)*. They attempted to correlate the reflectance capacity of tree foliage, as revealed on spectrophotometric curves, with tree age and site quality. Unfortunately, this method was ineffective and impractical.

Spurr *(48)* suggested the use of the ratio of tree height to crown diameter as a measure of site quality. The theory underlying this approach is best stated in Spurr's own words: "A tree of a given height growing on a poor site will be older than a tree of the same height and species growing on a nearby good site. Furthermore, the tree on the poor site, being older, will tend to have a larger crown, and, therefore, to have a lower height:crown diameter ratio."

METHOD of STUDY

The basic problem required (1) testing of a series of variables to determine their relative and absolute capacities to indicate site quality and *(2)* the assembly of the variables found useful in an efficient evaluation mechanism. The statistical design followed the pattern of a classic multiple regression study as described by Fisher *(19)*, Snedecor *(46)*, and Schumacher and Chapman *(41)*. The dependent variable was site index. The independent variables were: total tree height, visible crown diameter, stand density, degree of slope, aspect, slope position, length of growing season, amount of rainfall during the six warmest months of the year, and number of dominant and codominant trees per acre.

The ratio, total height: crown diameter, suggested by Spurr was intensively tested as an independent variable by both graphical and mathematical curve-fitting procedures.

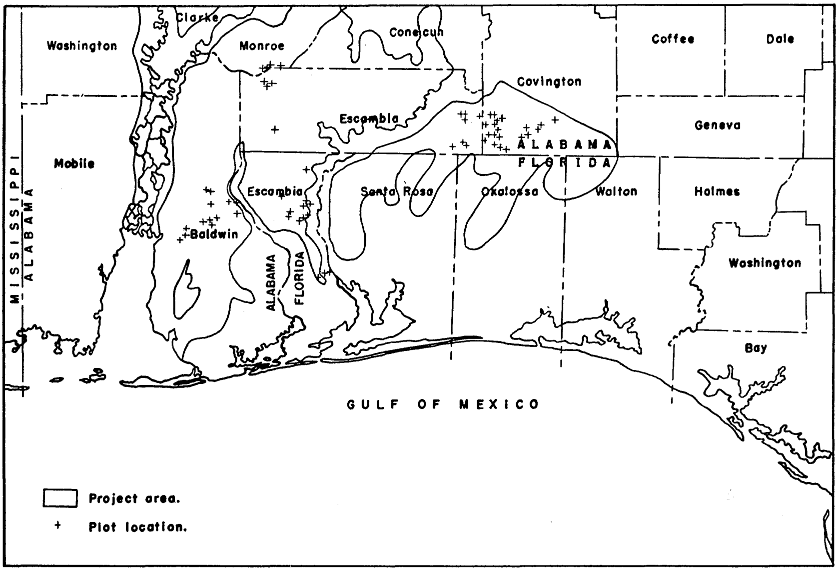
These variables were chosen because they could be measured on stereoscopic pairs of aerial photographs or could be obtained from readily available literature (e.g. "Climate and Man," Yearbook of Agriculture for 1941, U.S. Department of Agriculture).

Most of the variables were measured on the ground rather than on photographs.

THE STUDY AREA

Boundaries

The primary bounds of the study area, see Figure, were the northern limit of occurrence of the longleaf pine-slash pine type *(20)* and the southern boundary of the "rolling uplands" soil association described by Smith and Henderson *(45)*. The study was confined to the portion of this area lying west of a line extending west-northwesterly from the southeast corner of Covington County and east of the Mobile-Alabama River system—the so-called "Pine Hills" region.



The study area and the location of the sample plots are shown above.

Geology and Soils

Topography is variable in the study area. From Monroeville southward into Escambia County, Florida, is a belt of flat tableland with an average elevation of 300 feet sloping gently toward the south. The surface of these tablelands is composed of Citronelle formation, a reddish sand dating from either Pliocene *(1, 17)* or Pleistocene *(39)* time. The surface is underlain by undifferentiated gray and white Miocene sands (Catahoula sandstone and Paynes Hammock sand). This formation, in turn, is underlain by heavy, impermeable Hattiesburg clays. Only relatively deep cut stream valleys penetrate the latter formation.

The original surface of the tablelands has been cut by several major streams, the Mobile-Alabama system in the west, the Conecuh and Yellow rivers in the east, and many smaller streams. This has reduced large portions of the original flat surface to a complex pattern of hills and valleys. The topography is more distinct in the north, and becomes progressively gentler toward the south. In the dissected area the Miocene sands dominate the surface, while the Citronelle formation occupies only tops of ridges and small residual areas of tableland. In some instances the overlying Citronelle and Miocene formations have been removed by erosive action to such an extent that the ground surface approaches or even penetrates Hattiesburg clays. This occurrence has caused ground water concentrations immediately above the impermeable clays to form bogs or side-hill seeps. Soils developed under these bog conditions are grouped in the Plummer soil series.

In general, the soils evolved from the Citronelle formation are sands or sandy-loams with sandy-clay or sandy-clay-loam subsoils. They include the Red Bay, Orangeburg, Ruston, Norfolk, Bowie, and Tifton soil series. The soils resulting from the Miocene sands belong in the Americus and Lakeland series. The Miocene clays include the Boswell and Susquehanna, found on well-drained lower slopes; the Cahaba, found on colluvial benches; and the Bibb, found in the bottoms *(11, 12, 13, 16)*.

Climate

The growing season in the study area ranges from 230 days in the north to 290 days in the south, U.S. Department of Agriculture *(52)*. Midwinter temperatures average approximately 50° F. and reach occasional lows of 10° F. Freezing temperatures are of short duration. During the growing season, daily temperatures are relatively high. They average about 81° F. and occasionally attain highs of 108° to 109° F.

The average annual precipitation varies from 64 inches in southern Baldwin County to 56 inches in Covington and Conecuh counties *(52)*. Precipitation from April through September ranges from 28 to 38 inches.

Forest Cover Types

At least four forest cover types recognized by the Society of American Foresters *(47)* are found in the study area. The longleaf pine type (Type 70), covers an appreciable portion of the whole. Other types are: longleaf pine-scrub oak (Type 71), found mostly adjacent to the deep sands in the south-central portion of the study area and elsewhere along the tops of dry ridges; loblolly pine (Type 81), found usually in small, isolated patches and old fields; and longleaf pine-slash pine (Type 83), found on the flanks of north-facing ridges, along margins of ponds and branches, and on flats adjacent to streams.

In some cases longleaf pine is found growing in pure stands on flat areas adjacent to streams. These areas probably more nearly represent flatwoods conditions than those associated with the rolling uplands. However, a few plots were established in such stands because they occurred within the boundaries of the study area.

SAMPLE PLOT PROCEDURES

Number and Selection of Plots

Data were taken on 61 sample plots distributed over the study area, see Figure.

To be acceptable, stands had to meet the following requirements:

(1) They had to be in the longleaf pine type (S.A.F. Type 70).

(2) They had to be over 25 years of age at breast height.

(3) Stocking had to equal or exceed 50 per cent of normal basal area per acre, based on the stand exceeding 2 inches d.b.h. Yield tables in U.S. Department of Agriculture Miscellaneous Publication 50 *(51)* were accepted as standard.

(4) Stands must not have been turpentined. Although occasional turpentined trees were permitted on the plots, they were never tallied as sample trees.

(5) Stands had to consist of trees that were not residuals left after logging.

(6) Stands must not have been thinned, except possibly for salvage thinnings of small material, such as fence posts. No thinning must have been made within the past 5 years.

The actual selection of the stands for sampling purposes was subjective in nature. Stands were chosen to provide as wide a range as possible of independent variables to be considered. These variables included tree height, stand density, degree and aspect of slope, and position on slope.

Data Collection

One-fifth acre, rectangular plots were used. Dimensions were 1 × 2 chains. Each plot was oriented so that its long axis formed a right angle with the general trend of contours.

Ground slope direction from upper to lower end of the plot axis was determined by hand compass. Degree of slope was measured from the same point with an Abney hand level. Slope position was defined as the ratio (expressed as a percentage) of the distance from ridge top to plot center to the total length of slope. Distance and length were measured on an aerial photograph along a line formed by extending the plot axis to the ridge line at one end and the thread of the watercourse (intermittent or constant flow) in the valley floor at the other end.

Climatic information was obtained from the maps in the U.S. Department of Agriculture Yearbook for 1941 *(52)*.

The following tree measurements and observations were made on each plot:

(1) D.B.H. All trees were calipered in two directions, and diameters to the nearest 0.1 inch were recorded.

(2) CROWN CLASS. All trees were classified.

(3) AGE AT BREAST HEIGHT. The 4 largest dominants and 2 largest codominants were bored. If there were fewer than 4 dominants on the plot, codominants were substituted. The 6 trees bored for age were included in the group measured for height and crown diameter.

(4) TOTAL HEIGHT. All dominants, one-half the codominants, and one-fourth of the intermediates were measured with an Abney hand level.

(5) VISIBLE CROWN DIAMETER. Two diameters, at right angles to each other, were measured and averaged for the trees whose heights had been measured. The perimeter of the crown was assumed to be at the actual edge of a free-growing crown area or half way into an interlocked crown area.

ANALYSIS and DISCUSSION of RESULTS[2]

Preliminary Computations

Site Index. The site index computations were based on the second procedure described in the yield table *(51)*.

Stand Density. Stand density usually is expressed as per cent crown closure (percentage of ground area obscured by tree crowns) when measured or estimated from aerial photographic evidence. A second measure of stand density is the number of trees per unit area. A review of literature reveals that both methods of stand density evaluation are subject to considerable error *(33, 48)*. The error varies with different photographic specifications, measurement techniques, and photo-interpreters. It had to be eliminated or the fundamental relationships between variables probably would be obscured. For this reason, percentage of normal basal area of trees 2 inches d.b.h. and larger, and number of dominant and codominant trees per acre were selected as measures of stand density.

Estimation of Site Quality by Regression Techniques

Total Height: Crown Diameter Ratio. Initial attempts to find a means of evaluating site index from aerial photographs were centered on the total height:crown diameter ratio suggested by Spurr *(48)*. One ratio was computed for each plot using the mean total height and mean crown diameter of dominant and codominant trees. The ratio was based on these trees since they were most likely to be seen and measured on aerial photographs.

The simple regression equation of site index on the height:crown ratio was found to be:

$$Y = 4.947X + 54.79$$

The coefficient of determination was 0.1920, indicating that height:crown ratio accounted for 19.20 per cent of the total observed variation in site index. This relatively small coefficient indicated that, in its unmodified form, the total height:crown diameter ratio was not a sufficient measure for estimating site index.

In a description of this approach to site index determination, Spurr stated that stand density probably would have to be included as part of the height:crown diameter function to compen-

---

[2] Acknowledgment is made of the assistance of E. Fred Schultz, former Station biometrician, in this phase of the study.

sate for the effect of stand density on crown diameter. To gain insight into the pattern of this interrelationship, a series of graphical studies was made following the procedures outlined by Ezekiel *(18)*. These studies indicated that the problem was exceedingly complex, possibly insoluble with the limited data available. The studies also indicated that height was more strongly correlated with site index than any other variable.

Following the graphical studies, a series of mathematical fits was made to the height:crown diameter, and stand density data. The functions tested were of both additive and exponential form. The best fit was obtained with the exponential function:

$$\text{Site index} = (10)^{0.7983}\ (\text{Height})^{0.5400}\ (\text{Density})^{0.0477}$$

In this case the coefficient of determination ($100R^2$) was 29.20 per cent. Note that crown diameter is not included. The residual errors from the curve defined by this function were plotted over height, per cent normal basal area, number of dominants and codominants per acre, per cent slope, and slope position in an attempt to find additional correlations. These scatter diagrams produced negative results, and it became obvious that neither Spurr's ratio nor any of its derivatives was applicable under the conditions of this study.

This inapplicability of Spurr's theory appears to result from the fact that crown diameter is a very erratic quantity. Even under German conditions, where stand density is carefully regulated, crown diameter is so erratic that the resulting height:crown diameter ratios are subject to considerable variation. This can be seen by examining Zieger's basic data *(57)* that Spurr used in constructing his example. In the typically unmanaged stands of longleaf pine, in the area covered by this study, this is magnified to a point that the ratio has virtually no usable correlation with site.

Estimation of Age

Scatter diagrams made by plotting residual errors from each of the preceding regression studies over age revealed strong correlations between these errors and the average ages of the stands. As a result an attempt was made to derive estimates of age from available data.

Graphical analysis of the data indicated that it would be very difficult, if not impossible, to obtain reliable estimates of age from photographic information. Of a series of regressions tested, the following exponential equation provided the best fit:

$$\text{Difference} = \text{Site Index} - $$

$$\text{Height} = \frac{(\text{Height})^{2.0273}\ (\text{Crown Diameter})^{0.1652}}{(10)^{2.611}\ (\text{Density})^{0.09934}}$$

$100R^2 = 11.26$ per cent
$100R^2_1 = 2.55$ per cent (dropping height)
$100R^2_2 = 11.18$ per cent (dropping crown diameter)
$100R^2_3 = 11.17$ per cent (dropping density)

The correlation between the "difference" and height alone is indicated by:

$$r = 0.3300, \text{ and } 100r^2 = 10.89 \text{ per cent}$$

It is evident that only height among the three variables is correlated with the function of age. This is practically useless since site index cannot be determined on the basis of height alone.

Topographic Variables

Several variables were subjected to individual tests prior to the derivation of an equation for estimating site. These variables were associated with the soil-moisture regime. Strong evidence of a correlation between the soil-moisture regime and productivity of forest sites from earlier investigations created a feeling that consideration of variables bearing on this subject would add strength to the estimate of the site index. The variables, steepness of slope, aspect, slope position, and slope length, were chosen because it was thought that they could be evaluated with some degree of precision on aerial photographs and could be expressed as continuous variables.

Aspect and steepness of slope. The relationship between site index and these two variables was examined by fitting an exponential equation of the following type to the plot data:

$$\text{Site index} = (\text{Gradient})^{U}\ (\text{Aspect})^{V}\ (10)^{W}$$

This type function was chosen as it was thought that it would provide maximum flexibility with respect to curve form.

Within this equation, gradient was expressed in terms of slope per cent. A coding factor of 50 was introduced to prevent the appearance of zeros.

$$(\text{Gradient})^{U} = (50 - \%\ \text{slope})^{U}$$

Reasoning indicates that the axis of maximum heating and drying effect of the sun lies along a line extending from the northeast to the southwest. The best sites lie at the northeastern end and the poorest at the southwestern end. Consequently, aspect was expressed as an azimuth measured clockwise from northeast. The curve form best suited to expressing the relationship was the cosine wave. The factor 2 was introduced into the expression to prevent the appearance of zeroes or negative cosine values.

$$(\text{Aspect})^{V} = (2 + \cos \text{azimuth from NE})^{V}$$

An examination of the raw data, which revealed high site indices on flats, resolved the problem of the discontinuity of the aspect variable. For this reason, flats were assigned an aspect of northeast, theoretically grouping them with the best sites expected on slopes.

The expression was then fitted to the data, and the following equation resulted:

$$\text{Site index} = \frac{(50 - \%\ \text{slope})^{0.7928}\ (10)^{0.558}}{(2 + \cos \text{azimuth from NE})^{0.04835}}$$

$100R^2 = 9.60$ per cent

$100R^2_1 = 0.25$ per cent (dropping per cent slope)

$100R^2_2 = 7.37$ per cent (dropping aspect)

The analysis of variance about this curve indicated that aspect had little effect on the utility of the equation. Therefore, the equation was recomputed with gradient as the only independent variable:

$$\text{Site index} = (50 - \%\ \text{slope})^{0.6629}\ (10)^{0.0129}$$

$100r^2 = 7.37$ per cent

Consequently, aspect was rejected and steepness of slope was retained as a topographic variable to be tested along with the tree variables.

Slope position and length. Since slope position, as previously defined, is a relative quantity, expressed in per cent, it was thought that effect of slope position on the soil moisture regime would be independent of length of slope.

It became evident, when the data were summarized, that no correlation existed between slope position and site quality. This was substantiated in subsequent graphical studies, even when slope length and steepness were introduced as additional variables. The reason for this anomaly can probably be attributed to the impossibility, under certain conditions, of assigning a meaningful slope position classification by means of continuous variables. For example, the position of a stand on an undissected portion of the Pliocene plain cannot be defined in terms used here. In such case there is no distinct watershed divide and the surface drainage pattern is very poorly defined. A similar situation is encountered in the broad flat bottoms of major streams. In the dissected uplands the ridges or divides are more clearly defined than in cases mentioned earlier, but positions of the drains may still be in question. In many cases the stands do not lie above distinct all-weather streams. Instead, they are found above mazes of dry drains or sidehill seeps. Under such conditions it is extremely difficult to define the base of the slopes. The slope position value is subject to considerable variation, depending on the opinion of the photo-interpreter.

Combination of tree data with topographic and climatic variables. The following variables were tested in combination:

X_1 Average total height of the dominant-codominant stand.

X_2 Average crown diameter of the dominant-codominant stand.

X_3 Per cent normal basal area, based on the stand with a d.b.h. of two inches or larger.

X_4 Average warm season precipitation.

X_5 Average length of growing season.

X_6 Per cent slope.

X_7 Number of dominant and codominant trees per acre.

Climatic variables cannot be evaluated on aerial photographs. It was decided that these variables would be appropriate for this study since the required data could be obtained from readily available maps. Such maps are published in the Yearbook of Agriculture for 1941 *(52)*. Length of growing season and average warm season precipitation were selected because of their theoretical effect on tree growth. They also were included because of earlier work by investigators such as Hofman *(26)*, who found that the length of the growing season was correlated with site index of pond pine, and McClurkin *(34)*, who found a correlation between average warm season precipitation and the site index of longleaf pine.

Stand density was included as a variable because the relationship between stand density and site quality can be readily observed in the field. The difficulty in visualizing stand density as a site prediction tool results from the fact that stand density is not determined by site quality alone. High stand densities are usually associated with good sites, but low stand densities may be caused by several factors other than poor site. Among these are scanty seed supply, fire, and cutting operations.

The equation. The above variables were combined in a multiple linear regression. Analysis of the resulting variance was made with the result that, in its final form, the equation contained only three independent variables:

$$\text{Site index} = 5.00448\, X_1 - 0.76703\, X_6 + 0.454543\, X_7 - 323.8$$

$$\begin{aligned} 100R^2 &= 35.73 \text{ per cent} \\ 100R^2_1 &= 10.22 \text{ per cent (dropping } X_1) \\ 100R^2_2 &= 29.03 \text{ per cent (dropping } X_6) \\ 100R^2_3 &= 32.20 \text{ per cent (dropping } X_7) \end{aligned}$$

The formula for the 0.05 probability level fiducial limits for an individual estimate is as follows:

$$Y_{ixi} = Y \pm 2.006 \sqrt{52.60 + 52.60\ [1/59 + 2.72887\,(X_1 - 70.4)^2 + 0.32889\,(X_6 - 3.3)^2 + 0.75633\,(X_7 - 108)^2 - 0.01616\,(X_1 - 70.4)\,(X_6 - 3.3) - 0.21622\,(X_1 - 70.4)\,(X_7 - 108) + 0.11024\,(X_6 - 3.3)\,(X_7 - 108)]}$$

The residual errors were plotted over the following independent variables: height, number of dominant and codominant trees per acre, per cent slope, per cent normal basal area, length of growing season, warm season precipitation, crown diameter, slope position, and the height:crown diameter ratio. In no case was correlation evident. The evidence indicated that the expression could not be improved by the re-introduction of any of these variables in any form.

It is noted that the climatological variables had no value as predicting variables. This was probably a result of the generalized nature of climatic maps from which data were drawn.

In this study stand density emerged as the third most effective variable for estimating site quality. It is possible that this was caused by vagaries of sampling and that a second sequence of sample plots would reveal a different situation. However, the probability that there is a relationship between site index and stand density is in the order of 9 chances in 10.

The residual variance about the locus of this equation is so great that little confidence can be placed on site quality estimates made with it.

Non-mathematical Evaluation of Site Quality

Basic theory. Within an area with a uniform climate and geology, site quality depends on topography, aspect, and soil, particularly as these factors affect the soil moisture regime. This theory has its roots in the work done by Bourne *(9)* and Robbins *(40)*, its main development in the work done by Losee *(29)* and Moessner *(35)*, and its culmination in the site quality evaluation philosophy of Hills *(23)*. Its application to the local problem was suggested by Hodgkins[3] when mathematical approach failed to produce a satisfactory evaluation mechanism.

Application to the Present Study

Climate. The previously described regression analyses indicate that the effect of climatic differences on site quality are not large within the study area. It is, of course, possible that the distribution of sample plots was such that any true differences did not become evident. Nevertheless, the available evidence indicates that the effects of climatic differences are not great; and the study area may be considered to lie within a single climatic province.

Geology. The geology of the study area is also essentially uniform, consisting primarily of almost horizontal beds of relatively recent, non-consolidated, sedimentary material. Geologic and accelerated erosion have created three topographic condition classes: (1) the flat to rolling, undissected Pliocene plain, dominated by the Citronelle formation; (2) the hilly, dissected remnants of the Pliocene plain, in which both the Citronelle and the undifferentiated grey and white sand formations are found; and (3) the major river bottoms, with their deposits of recent alluvium.

Topographic site classes. These three topographic condition classes can be further subdivided into eight topographic site classes that can be recognized on aerial photographs:

(1) HIGH FLATS are either the Pliocene plain proper, isolated tablelands that originally were part of the Pliocene plain, or extensive flat hilltops lying somewhat below the general level of the Pliocene plain. These sites are usually under cultivation or have been cultivated and abandoned. The dominant geologic formation is the Citronelle, characterized by red gravelly sands with

---

[3] Hodgkins, E. J., Forester, Auburn University Agricultural Experiment Station.

some admixture of clay. Its topsoil is fine sandy loam and subsoil fine sandy clay loam.

(2) BOTTOMLAND FLATS are made up of recent alluvium. They are usually associated with the larger streams. Regardless of their physical composition, the soils are more or less poorly drained.

(3) BROAD BENCHES are essentially flat lands occurring at any point between the watershed divide and the drainline. In most cases they lie below the Citronelle formation and are characterized by grey and white Miocene sands. The soils are usually deep.

(4) UPPER SLOPES are arbitrarily defined as the portions of slope extending from 11 to 50 per cent of the distance from the crest of the ridge to the thread of the watercourse at the foot of the slope.

(5) LOWER SLOPES are arbitrarily defined as the portions of slope extending from 51 to 100 per cent of the distance from the crest of the ridge to the thread of the watercourse at the foot of the slope.

(6) NARROW RIDGETOPS are ridges without appreciable width. They have been arbitrarily defined to include the upper 10 per cent of the slope. In some cases they show evidence of gully erosion. The higher ridges may be capped by remnants of the Citronelle formation, but in the majority of cases consist of grey and white Miocene sand.

(7) SIDEHILL SEEPS are found only in the dissected portion of the area where the Hattiesburg clays approach or penetrate the surface.

(8) HEAVILY GULLIED AREAS are generally limited to the dissected portions of the area, and usually found at the breaks in terrain near the edges of the Pliocene plain. In some cases they are associated with past mismanagement of the land.

In Table 1 are the results of grouping the field data into the foregoing classes. *t*-tests indicate that, with the exception of the two slope classes, the differences between the means of the classes probably are real.

A pattern of relationship between site quality and amount of available soil moisture emerges from these data. In general, as the soil moisture increases the site quality also increases. Thus, the best sites usually are found on the flat bottomlands bordering streams where the water table is high and the supply of water is plentiful throughout the year.

TABLE 1. MEAN SITE INDICES AND OTHER STATISTICAL CHARACTERISTICS OF EIGHT TOPOGRAPHIC SITE CLASSES FOR LONGLEAF PINE IN SOUTHERN ALABAMA AND NORTHWESTERN FLORIDA

Topographic site class	Mean site index	Variance	Plots
	Ft.		*No.*
Bottomland flat	84.3	4.50	3
High flat	80.0	10.57	8
Broad bench	77.0	19.00	3
Entire slope	73.6	88.87	33
Upper slope	74.0	84.42	25
Lower slope	72.4	114.57	8
Narrow ridge	66.8	79.77	14
Sidehill seep	----	----	----
Heavily gullied areas	----	----	----

High flats also comprise good sites. In spite of elevation, they are characterized by good supplies of soil moisture. These supplies result from infiltration of water that could not rapidly run off the flat surface. In addition, the presence of clay in the Citronelle formation prevents the rapid loss of water by percolation past the root development zone.

The broad bench site class has a somewhat lower average site quality than the other flatland categories. This possibly is a result of the fact that the benches are not wide enough to prevent the loss of considerable amounts of water from surface runoff and from lateral subsurface movement.

Standard deviations derived from the data in Table 1 indicate that each of the three classes discussed is relatively uniform in site quality. This results from the fact that the soil moisture gradient is kept fairly constant over large areas by the presence, at uniform depths, of either a water table or a water resistant clay horizon. Homogeneity of varience tests indicated that the variability was essentially the same on all three sites. However, it is probable a heavier sampling would reveal that the broad bench class had greater variability than the others. This would be expected from the fact that such benches may occur within the Citronelle formation, the undifferentiated Miocene sands, or in the transition zone between the two formations. Because of this, depths to water-resistant clay horizons in the soil profile are subject to considerable variation. Theoretically, such variation should have a strong influence on quality of the site.

In the preceding discussion relatively simple topographic site classes have been considered. The slope classes, however, represent much more complex conditions. A large segment of the total range in available soil moisture can be expected on any slope. However, the classic pattern of increasing moisture and, consequently, increasing site quality from top to bottom of a slope is not clear in the study area. Lack of clearness probably is caused by the slopes cutting diagonally through the geologic formations, with their alternating strata of heavy and light textured material. This creates many localized areas of different site quality, depending on depth to a heavy textured horizon. Because of this variation it is possible to find excellent sites in the middle of a slope and poor sites near the base. Variability nullifies any theoretical difference between upper and lower slope classes. A *t*-test of the difference between the mean site indices of the two classes indicated a high probability that both samples were drawn from the same population. Therefore, it appears logical to combine the two slope classes into the "entire slope" class listed in Table 1.

Since it was possible that some of the variability in site index on the slopes resulted from aspect, the 33 plots in the slope class were regrouped into two slope-aspect classes similar to those recognized by Moessner in the Central States Forest Survey *(35, 36)*. These classes were defined as follows:

(1) UPPER SLOPE is the upper one-third of northeasterly facing slopes and the upper two-thirds of southwesterly facing slopes.

(2) LOWER SLOPE is the lower two-thirds of northeasterly facing slopes and the lower one-third of southwesterly facing slopes.

The statistics associated with these classes are presented in Table 2. Tests for the homogeneity of variance indicate that no reduction of variability resulted from the regrouping, and a *t*-test indicated a high probability that both slope-aspect class samples were drawn from the same population.

The narrow ridges represent the driest and poorest sites in the study area. A high proportion of rainfall is lost from these sites through rapid surface runoff. In addition, the soils on most ridges are too shallow because of accelerated erosion to retain much moisture. Consequently, a condition of moisture deficiency is normal for this site class. The relatively large variance associated with the mean site index of the narrow ridges probably is the result of the fact that the ridge crests may lie at any depth below the original level of the Pliocene plain. This means that they may occur in any one of a series of strata of differing texture. The

TABLE 2. MEAN SITE INDICES AND OTHER STATISTICAL CHARACTERISTICS OF UPPER AND LOWER SLOPE—ASPECT SITE CLASSES FOR LONGLEAF PINE IN SOUTHERN ALABAMA AND NORTHWESTERN FLORIDA

Topographic site class	Mean site index	Variance	Plots
	Ft.		*No.*
Upper slope	74.8	94.67	24
Lower slope	70.3	66.42	9

porosity of the surface stratum and the depth to a water-resistant layer control the available moisture and, correspondingly, the quality of the site.

No plots were established in sidehill seeps, since it has long been recognized that such areas are almost completely unproductive for growing longleaf pine.

No plots were established in the heavy gullied areas, primarily because stand densities were so low that valid site indices could not be computed. It is generally accepted by foresters working in the region, however, that these areas are similar in site quality to the narrow ridges.

Utility of the topographic site classes. The topographic site classes recognized here can be identified and their boundaries delineated without much difficulty on standard U.S. Department of Agriculture aerial photographs.

The mean site indices of the high flat, bottomland flat, and broad bench may be used for growth and yield predictions without danger of serious error. This cannot be done with any other classes because of wide ranges in site index. Within these classes, it is necessary to use additional criteria to assign a specific site index to a given area. Aspect seems to have little value as an additional variable. The solution apparently lies in the development of methods of evaluating the soil and its capacity to hold moisture.

A required criterion for evaluation of the moisture holding capacity of soil in the study area is depth to the first water-resistant horizon below the surface. This depth cannot be measured directly on aerial photographs, but there is a possibility that it can be estimated from evidence of the type used by Belcher *(6, 7, 8)* to evaluate the engineering characteristics of soils. Belcher's method of soil evaluation from information on aerial photographs is based on a study of several distinct criteria. Among these are drainage patterns, accelerated erosion, soil color, and vegetational distribution.

In the area covered by this study, the drainage patterns of the subsidiary streams, the ones that are most important for this work, are virtually all dendritic. They show little evidence of variation that could be assigned to soil differences. It is probable that changes in soil texture occur so often and over such short lateral distances that soil texture has little effect on the drainage pattern.

There are many evidences of accelerated erosion in the area. These range from barely visible signs of sheet erosion to spectacular gullies. The heavily gullied areas have already been considered and set aside as a separate site class. In the remaining areas, evidence of erosion can be useful as it is probably associated with poorer than average sites. There is a possibility that changes in gully profiles and cross sections might be valuable for the detection of changes in soil texture. Recognizing these changes would require large scale photography of a type not available during the course of the study.

Soil color cannot be used as an aerial photo-interpretation criterion because vegetation covers the surface except in heavily eroded areas.

Since the work was concentrated in pure stands of longleaf pine, vegetational distribution was of little value as a site quality criterion. Observation during the course of the field work revealed no useful relationship between presence or abundance of the major understory vegetation species and site quality. Therefore, even if suitable photography were available for the evaluation of the understory, site quality information could not be obtained from such evidence.

Belcher *(6, 7, 8)* has used differences in the tone of the foliage of a given species as a guide to the presence of gravel deposits in glaciated areas of the Northeast. It is possible that such a technique could be used in the area covered by this study for detection of differences in soil texture, but it would require careful preparation of the photographic prints. Ordinary prints are so variably processed that they are of little value for this type of work.

The analyses made herein indicate no clearcut approaches to the detection of soil differences for the subdivision of the topographic site classes into more homogeneous units. It is doubtful that even highly trained photo-analysts could detect such differences.

SUMMARY and CONCLUSIONS

The quality of the site, in terms of site index for longleaf pine, was determined on 61 sample plots in the Pine Hills Region of the Lower Coastal Plain of southern Alabama and northwestern Florida.

The following variables were measured on the plots and tested by means of both graphical and mathematical curve-fitting techniques for relationships with site index: average height of dominant and codominant trees, average crown diameter of dominant and codominant trees, per cent normal basal area of the dominant-codominant stand component, number of dominant and codominant trees per acre, degree of ground slope, slope position, average warm season precipitation, and average length of growing season. Considerable attention was given to the ratio of average total height to average crown diameter of the dominant and codominant trees and to the interaction of this ratio with stand density.

Of all the variables tested, only average tree height, per cent slope, and number of trees per acre were found to have value for site index estimation. Only 36 per cent of the total variation in site index of the sample plots could be explained by these factors. Substitution of photogrammetrically determined values for on-the-ground measurements would increase the error of estimate proportionately with the reduction in precision of measurement. For these reasons it appears unlikely that in the area covered by this study satisfactory estimates of longleaf pine site index can be made by means of regression methods with data restricted to those that can be obtained from aerial photographs or climatic maps.

The relationship between site index and topographic classifications also was investigated. Seven topographic classes, intended to represent different soil moisture conditions, were recognized. The mean site index increased as the supply of moisture increased. However, because of a lack of homogeneity of variance between the classes, it was impossible to test for real differences in average site quality. In two cases, the bottomland flat and the upland flat, the variances were sufficiently small that fairly reliable mean site index values could be assigned. In the remaining classes the variation in site index was so great that the average values had little meaning. This is a reflection of the geological structure of the area, in which porous and non-porous strata alternate. Because photo-interpreters cannot identify the relative soil moisture conditions in such a complex situation, it is doubtful that there is hope for more satisfactory site classifications from aerial photographs on the basis of topographic classes than on the basis of a regression equation.

LITERATURE CITED

(1) ADAMS, G. I., BUTTS, C., STEPHENSON, L. W., AND COOKE, W. Geology of Alabama. Geol. Survey of Ala. Spec. Rpt. No. 14. 1926.

(2) ANONYMOUS. The Timber Stand and Vegetation – Soil Maps of California. U.S. Forest Serv., Calif. Forest and Range Expt. Sta. in coop. with Calif. Dept. Nat. Res. 1949.

(3) BACKSTROM, H. AND WELANDER, E. En undersokning av remissionsformagan hos blad och barr av olika tradslag. Norrlands Skogsv. Forb. Tidskr. 1:141-169. 1953.

(4) BECKER, M. E. Forest Survey Procedures for Area and Volume Determination. Jour. Forestry 48:465-69. 1950.

(5) BEDELL, G. H. D. AND MACLEAN, D. W. Nipigon Growth and Yield Survey. Canada Dominion Forestry Branch Silv. Res. Note No. 101. 1952.

(6) BELCHER, D. J. Use of Aerial Photographs in War-time Soils Engineering. Roads and Streets 85:7:35-37. 1942.

(7) ------------------------. Engineering Applications of Aerial Reconnaissance. Bul. Geol. Soc. Amer. 57:727-733. 1943.

(8) ------------------------. Determination of Soil Conditions from Aerial Photographs. Photogrammetric Engin. 14:482-488. 1948.

(9) BOURNE, R. Aerial Survey in Relation to the Economic Development of New Countries, With Special Reference to an Investigation Carried Out in Northern Rhodesia. Oxford Univ. Forestry Mem. No. 9. 1928.

(10) ------------------. Air Survey in Relation to Soil Survey. Imperial Bureau of Soil Science. Rothampsted Expt. Sta. Tech. Com. No. 19. 1931.

(11) BRACKEEN, L. G. Soil Map of Covington County, Alabama. Soil Sur. Div. Ala. Dept. of Agr. and Indus. 1951.

(12) ----------------------------. Soil Map of Baldwin County, Alabama. Soil Sur. Div. Ala. Dept. of Agr. and Indus. 1956.

(13) ----------------------------. Soil Map of Escambia County, Alabama. Soil Sur. Div. Ala. Dept. of Agr. and Indus. Undated.

(14) BRADSHAW, K. E. Summary of World Progress in Photo-Interpretation in Natural Resource Inventories. Photogrammetric Engin. 18:400-417. 1952.

(15) BROWN, W. G. E. Site Classification. Pulp and Paper Magazine of Canada 54:7:146-147. 1953.

(16) BURKE, R. T. A., SNYDER, J. M., O'NEAL, A. M. O., JR., AND KOLB, F. W. Soil Survey of Escambia County, Alabama. Bureau of Soils, U.S. Dept. of Agr. 1915.

(17) CARTER, R. M., WILLIAMS, M. R., LAMOREAUX, P. E., AND HASTINGS, W. W. Water Resources and Hydrology of Southeastern Alabama. Geol. Sur. of Ala. Spec. Rpt. No. 20. 1949.

(18) EZEKIEL, M. Methods of Correlation Analysis, 2nd Ed., New York: John Wiley and Sons, Inc. 1941.

(19) FISHER, R. A. Statistical Methods for Research Workers. Edinburgh, Scotland. Oliver and Boyd. 1938.

(20) Forest Service, U.S. Dept. of Agr. Map of Areas Characterized by the Major Forest Types, State of Alabama. U.S.F.S., For. Sur., Southern Forest Expt. Sta., New Orleans, La. 1934.

(21) Hallert, B. and Fagerholm, P. O. Rpt. of Commission V (Special Applications and Measurements) to the VII Congress of the International Society of Photogrammetry, Washington, D.C. 1951.

(22) Hills, G. A. The Use of Aerial Photography in Mapping Soil Sites. Forestry Chron. 26:4-37. 1950.

(23) ________________. The Classification and Evaluation of Site for Forestry. Ontario, Canada, Dept. of Lands and Forests, Div. of Res. Rpt. No. 24. 1952.

(24) ________________. The Use of Site in Forest Management. Forestry Chron. 29:128-136. 1953.

(25) Hixon, H. J. The Use of Aerial Photographs in Timber Cruising on the National Forests. Photogrammetric Engin. 16:317-321. 1950.

(26) Hofman, J. G. The Effect of Certain Soil Characteristics on the Height Growth and Site Index of Pond Pine in the Coastal Plain of the Carolinas, Georgia, and Florida. Unpublished Doctor of Forestry Thesis, Duke University, Durham, N.C. 1949.

(27) Komitten for Skoglig Fotogrammetri. Flygbilden i Skogbrukets Tjänst. Stockholm, Sweden: Statens Reproduktionsanstalt. 1951.

(28) Krueger, T. Use of Aerial Photos for Timber Surveys in the Rocky Mountain Region. Jour. Forestry 39:922-925. 1941.

(29) Losee, S. T. B. Air Photographs and Forest Sites. Forestry Chron. 18:129-144 and 169-181. 1942.

(30) ____________________. Comment on 'Photo Classification of Forest Sites.' Soc. Amer. Foresters Proc. 291-292. 1948.

(31) ____________________. Some Aspects of Inventory Surveys from Aerial Photographs. Forestry Chron. 25:250-256. 1949.

(32) ____________________. Forest Inventory in Eastern Canada. Forest Photo Interpretation. Portland, Ore.: K. B. Wood and Assoc., Inc. 1955.

(33) ____________________. Measurement of Stand Density in Forest Photogrammetry. Unpublished paper read before the annual meeting of the Canadian Inst. of Surveying and Photogrammetry. February 2, 1956.

(34) McClurkin, D. C. Soil and Climatic Factors Related to the Growth of Longleaf Pine. U.S. Forest Serv., Southern Forest Expt. Sta. Occas. Paper No. 132. 1953.

(35) Moessner, K. E. Photo Classification of Forest Sites. Soc. Amer. Foresters Proc. pp. 278-291. 1948.

(36) ________________________. Stereograms Illustrating Forest Sites. U.S.F.S., Central States Forest Expt. Sta. Misc. Release No. 4. 1949.

(37) ________________________. Photo Interpretation in Forest Inventories. Photogrammetric Engin. 19:496. 1953.

(38) ________________________, and Jensen, C. E. Timber Cruising on Aerial Photos. U.S. Forest Serv., Central States Forest Expt. Sta. Tech. Paper No. 126. 1951.

(39) Potter, P. E. The Petrology and Origin of the LaFayette Gravel. Jour. Geol. 63:1-38 and 115-132. 1955.

(40) Robbins, C. R. Northern Rhodesia: An Experiment in the Classification of Land with the Use of Aerial Photographs. Jour. Ecol. 22:88-105. 1934.

(41) Schumacher, F. X. and Chapman, R. A. Sampling Methods in Forestry and Range Management. Duke Univ. School Forestry Bul. No. 7 (Revised). 1948.

(42) Seely, H. E. Some Developments in the Use of Air Photographs for Forest Surveys. Photogrammetric Engin. 13:443-452. 1947.

(43) ——————. Air Photography and Its Application to Forestry. Canada Dom. Forest Serv. Pub. No. 6. 1949.

(44) ——————. A Forest Survey Method. Canada, Dept. of Northern Affairs and Natural Resources, Forestry Branch, Forest Res. Div. Tech. Note No. 8. 1955.

(45) Smith, F. B. and Henderson, J. R. Florida Soil Associations, Use and Management. Economic Leaflets. Bureau of Economic and Business Research, College of Business Adm. Univ. Florida, Gainesville, Fla. 9:11. 1950.

(46) Snedecor, G. W. Statistical Methods Applied to Experiments in Agriculture and Biology. 4th Ed. Ames, Iowa: The Iowa State Col. Press. 1946.

(47) Society of American Foresters. Forest Cover Types of North America. Washington, D.C. 1954.

(48) Spurr, S. H. Aerial Photographs in Forestry. New York: The Ronald Press. Co. 1948.

(49) ——————. Forest Inventory. New York: The Ronald Press. Co. 1952.

(50) Storie, R. E. and Wieslander, A. E. Rating Soil for Timber Sites. Soil Sci. Soc. Amer. Proc. 13:499-509. 1948.

(51) U.S. Department of Agriculture. Volume, Yield, and Stand Tables for Second-Growth Southern Pines. U.S.D.A. Misc. Publ. No. 50. 1929.

(52) ——————————————————. Climate and Man. U.S.D.A. Yearbook of Agriculture. 1941.

(53) Watson, R. Site Determination, Classification, and Application. Jour. Forestry. 15:552-563. 1917.

(54) Wieslander, A. E. and Storie, R. E. Vegetational Approach to Soil Surveys in Wild-Land Areas. Soil Sci. Soc. Amer. Proc. 17:143-147. 1953.

(55) ————————, and Wilson, R. C. Classifying Forest and Other Vegetation from Air Photographs. Photogrammetric Engin. 8:203-215. 1942.

(56) Wilson, A. K. Delineating Ponderosa Pine Volume and Site Quality Classes from Aerial Photographs. U.S.F.S., Intermountain Forest and Range Expt. Sta. Res. Paper No. 34. 1954.

(57) Zieger, E. Ermittlung von Bestandesmassen aus Flugbildern mit Hilfe des Hugershoff-Heydeschen Autokartographen. Mitteilungen aus der sächsischen forstlichen Versuchsanstalt au Tharandt. 3:97-127. 1928.