ECOLOGICAL FACTORS ASSOCIATED WITH BARK THICKNESS IN *Pinus taeda* L.

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ABSTRACT

Data taken from two hundred loblolly pines (Pinus taeda L.) in the ten-inch diameter class were analyzed in regard to possible correlations between single bark thickness at diameter at breast height and a number of other factors. Sample trees used in the study were chosen from a wide variety of ecological habitats in the Coastal Plain and the Piedmont of North Carolina. The relationship of age, aspect, radial growth rate, stand position, crown shape, site quality, tree lean, and exposure to both total and minimum single bark thickness was studied. From this study the following conclusions were drawn:

1. There was a statistically significant relationship between age and minimum single bark thickness, but there was no significant relationship between age and total single bark thickness.
2. There was a statistically significant relationship between stand density and minimum single bark thickness, but there was no significant relationship between stand density and total bark thickness.
3. There was no significant variation in bark thickness on the north, east, south, and west sides of the sample trees.
4. There was a significant relationship between radial growth rate and minimum bark thickness, but no significant relationship occurred between radial growth rate and total single bark thickness.
5. There was no significant relationship between expression of dominance and either total single bark thickness or minimum bark thickness.
6. There was no significant correlation between crown shape and either total or minimum single bark thickness.

7. An inverse relationship existed between site quality and both total and minimum single bark thickness. As site quality increased, bark thickness decreased.

8. When sample trees were located on the edge of a stand of trees, the opening had no correlation with bark thickness. Bark thickness in the direction of the opening was not significantly different from bark thickness in other directions.

9. There was no significant correlation between tree lean and bark thickness. Bark thickness was statistically the same on the leaning side of the tree as on the other three sides.

TABLE OF CONTENTS

INTRODUCTION

Minor (1953), McCormack (1955), and Renfro (1956), have demonstrated rather conclusively that bark thickness in loblolly pine (*Pinus taeda* L.) can be closely correlated with tree diameter. All three developed regression formulae based primarily on tree diameter at breast height for determining single bark thickness in loblolly pine. Diameter at breast height is usually abbreviated dbh and is a measurement of tree diameter taken at a point on the bole of the tree four and one-half feet above the ground.

The purpose of this study was to determine whether or not variations in bark thickness in loblolly pine in eastern North Carolina can be correlated with any factor or factors other than dbh. In order to eliminate the diameter factor from the study, all sample trees chosen were in the ten-inch diameter class. The ten-inch diameter class ranges from nine and five-tenths inches through ten and four-tenths inches. Sample trees were selected from a wide variety of stands in the North Carolina counties of Franklin, Greene, Halifax, Nash, Pitt, and Wayne. Most of the sampling was done by permission on privately-owned land, although some samples were taken on State-owned lands controlled by the North Carolina Forest Service. The ecological factors studied for possible effects on bark thickness included: age, aspect, radial growth rate, stand position, crown shape, site quality, lean direction, expression of dominance, and exposure. The relationship of these factors to both total and minimum bark thickness was studied. No literature was found on minimum bark thickness, but it was thought that this factor might have some bearing on insulation value of the bark of loblolly pine which in turn may influence fire resistance of the species.

REVIEW OF LITERATURE

Esau (1953) defines bark as "all tissues outside the vascular cambium of the axis, in either primary or secondary state of growth. In this usage bark includes primary phloem and cortex in axes with primary tissues only, and secondary and primary phloem, various amounts of cortex and periderm in axes with secondary tissue." This above definition will apply to the term "bark" used throughout the remainder of this study.

The main source of information on bark thickness is the work of forest mensurationists. Their work seems to indicate that the primary factor correlating with bark thickness is tree diameter. By plotting bark thickness against tree diameter, the mensurationists have been able to show that this bark thickness-tree diameter relationship generally yields straight lines passing through or near the origin. Minor (1953), McCormack (1955), and Renfro (1956) have developed regression equations for loblolly pine from field data. These regression equations are based on tree diameter and, in some cases, tree age, though relation of bark thickness to age was found to be much less than that of tree diameter. Examples of these equations where B = single bark thickness in inches, D = diameter at breast height in inches and A = age of the tree in years are:

1. $B = 0.241 + 0.037D$ — Minor (1953)
2. $B = 0.321 + 0.043D$ — McCormack (1955)
3. $B = 0.250 + 0.043D - 0.003A$ — Minor (1953)
4. $B = 0.4679 + 0.0771D - 0.01176A$ — Renfro (1956)

To use one of these formulae in the field, the needed factor is or factors are measured on the tree selected for determination of single bark thickness. The factor is or factors are then applied to the above formulae to determine single bark thickness. For example, if we wish to use formula 1 ($B = 0.241 + 0.037D$), we determine dbh on the tree and apply this to the formula. If for example dbh is found to be 10.0 inches: $B = 0.241 + 0.037D$, substituting 10.0 for D; $B = 0.241 + 0.037(10.0)$. Estimated single bark thickness $B = 0.611$ inches.

Bark thickness may be reduced by fire. Both MacKinney (1955) and Wahlenburg (1936) in independent research found that fires reduce bark thickness significantly in longleaf pine.

A number of researchers have developed factors for computing bark thicknesses of many species of trees based on a percentage of diameter at breast height. Some of the factors that have been developed for estimating single bark thickness in pines can be seen in Table 1.

To use one of these factors to estimate single bark thickness, dbh is measured on the tree selected for bark thickness determination. Percentage of dbh for the appropriate species is then located in Table 1. This percentage of the dbh of the selected tree is estimated single bark thickness. For example to determine single bark thickness of a virginia pine (*Pinus virginiana* Mill.) with dbh of 10.0 inches, the percentage factor for virginia pine (2.7), is located in Table 1. Two and seven-tenths of 10.0 is 0.270. Estimated bark thickness is 0.270 inches.

Stickle (1936) found that in pitch pine, balsam fir, eastern hemlock, sugar maple, and chestnut oak, ratio of outer bark to total bark, expressed as percentage, increased with age.

METHODS AND MATERIALS

A total of 200 loblolly pine trees in the ten-inch diameter class were selected for use in this study. The ten-inch diameter class ranged from nine and five-tenths inches through ten and four-tenths inches. Trees used in the study came from the North Carolina counties of Franklin, Greene, Halifax, Nash, Pitt and Wayne.

The diameter of each tree selected was measured at dbh with a Lufkin steel diameter tape and was recorded to the nearest one-tenth inch. Figure 1 shows a Lufkin diameter tape.

The age of each tree was taken with a Djos increment borer, pictured in Figure 2. With this instrument, a core sample was removed from the tree at the dbh level on the north side of the tree. Annual growth rings, which show as dark lines on the core sample, were counted to determine age. For trees with extremely slow growth, it was necessary to use a hand lens to accurately count the annual rings. Three years were added to actual ring count on each tree to allow for the time it took the tree to reach the dbh level. Age was recorded to the nearest year. To statistically analyze the relationship between age and bark thickness, the analysis of variance was used.

Stand density may be defined as the degree of stocking of a given stand. In this study, stand density was measured in terms of basal area per acre. Basal area is the breast height cross sectional area of a single tree, or all trees in a stand expressed in square feet. Basal area was chosen for use in this study because of ease in taking the measurement and because it is one of the most commonly used measurements of stand density. Basal area per acre was measured with a ten factor wedge prism. Although several instruments are available for taking basal area, the wedge prism was chosen because it is the simplest instrument to use and carry. Figure 3 shows a ten factor wedge prism. The wedge prism is a precise optical instrument made from a thin wedge of glass. It bends the ray of light passing through it by a fixed angle, establishing the critical angle by the lateral displacement of the transmitted image of the viewed tree. If the displacement was greater than the diameter of the tree, the tree was not counted. If the displacement was less than the diameter of the tree, the tree was counted. The total number of trees counted at each plot was multiplied by 10 to determine basal area per acre, and the result was recorded. Basal area was taken at a point three feet north of each sample tree. Basal area taken at this point gave a measurement of stand density representative of the stand of trees surrounding the sample tree. Sample trees were taken in both thinned and unthinned stands. To statistically analyze the correlation between basal area and bark thickness, the analysis of variance was used.

To measure the effect of aspect on bark thickness, bark thickness was measured on the north, east, south, and west sides of each sample tree. The sides were identified by means of a Suunto compass. Figure 4 shows a Suunto compass. After locating a side with the compass, the bark was measured on the bark ridge nearest the compass point. Bark thickness was taken with a Djos bark gauge pictured in Figure 5. Bark thickness was recorded to the nearest twentieth of an inch. To statistically analyze the relationship between aspect and bark thickness, the analysis of variance was used.

The recent radial growth rate of the tree was measured by counting the number of annual growth rings in the last inch of radial growth of each sample tree which was examined when the core sample was removed from the tree for age analysis. One inch was measured on the core beginning at the cambium, and the annual rings occurring within this area were counted. Where growth rings were extremely close together, it was necessary to use a hand lens to count them. The number of annual growth rings in the last inch of radial growth was recorded. To statistically analyze the relationship between radial growth rate and bark thickness, the analysis of variance was used.

The effect of stand position on bark thickness was studied by assigning each tree to either the dominant or suppressed position class category. Suppressed trees were those with crowns definitely beneath the main forest canopy. All other trees were classed as dominant. Most crown classifications list several intermediate classes between the suppressed and dominant classes. For this study, however, it was decided that only dominant and suppressed classes would be used; since it was felt that any difference in bark thickness would show up if the dominant and suppressed trees were compared. Crown classifications were recorded for analysis. To statistically analyze the effect of stand position on bark thickness, the Student's t-test was used.

Crown shape was recorded by making a sketch of the crown of each tree. All crown sketches were made by standing beneath the tree and sketching crown shape. Each crown sketch was oriented as to direction with a Suunto compass. Only horizontal shape was sketched. The possible relationship between crown shape and bark thickness was statistically analyzed by comparing bark thickness on the side of the tree having the majority of the crown with bark thickness on the other three sides of the tree using the analysis of variance. Trees having symmetrical crowns were not used in the statistical analysis.

Site quality measurements were recorded in terms of site index. Site index is defined as a measurement of site quality based on the total height that a dominant tree of a species will attain on a particular site in a given number of years. For example, a site index of 80 for loblolly pine on a 50-year base simply means that dominant loblolly pine trees will attain a height of 80 feet in 50 years on the site. To determine site index it was necessary to determine age and total height of each sample tree. The site index curves of Schumacher and Coile(1960) for loblolly pine were used for determining site indices at various ages and heights. Figure 6 shows the site index curves used in this study. To use the curves, age and height of the sample trees were located on the curves to determine site index. Age was taken with the Djos increment borer, and total height was taken with the Haga altimeter. The Haga altimeter was used at a measured distance of 66 feet. From this distance readings were taken on the base and top of the tree with the altimeter. Figure 7 shows the Haga altimeter. From the two readings, total height was computed and recorded to the nearest foot. It is necessary to determine site index from dominant trees only. Site indices for suppressed trees in this study were taken from the dominant trees nearest the suppressed trees. Site index was recorded and data was analyzed using the analysis of variance.

When a sample tree was on the edge of a stand or when there was an opening in the forest canopy on one side of a tree, this fact was noted along with compass direction of the open side. To determine whether or not the opening had any effect on bark thickness, bark thickness on the side of the tree facing the opening was statistically compared with bark thickness on the other sides of the tree by using the Student's t-test.

If a sample tree was leaning, this was noted along with the compass direction in which the tree leaned. Direction of lean was determined with a Suunto compass. To determine whether or not lean had any effect on bark thickness, the bark thickness on the side of the tree in the direction of lean was statistically compared with bark thickness on the other three sides of the tree using the Student's t-test.

In addition to studying factors affecting total bark thickness, it was also decided to see whether or not these same factors had any influence on minimum bark thickness. To measure minimum bark thickness, it was necessary to construct a special tool consisting of a calibrated shaft and a flange as illustrated in Figure 8. To use the tool, the shaft was positioned in the bark crevice and the flange was pushed down the shaft until it came into contact with the bark. The depth of the crevice was read on the calibrated shaft to the nearest one-tenth inch. Crevice depths were taken on the north, east, south, and west sides of each tree. To obtain minimum bark thickness, the crevice depth was subtracted from the corresponding total bark thickness.

In all statistical analysis, the five per cent level was considered biologically significant.

RESULTS

Average total bark thickness of two hundred trees used in this study was found to be 0.861 inches. Average minimum bark thickness of all sample trees was found to be 0.272 inches. The sample trees ranged from 18 to 73 years in age. Mean age of the sample trees was 35.66 years. For the purpose of analysis of the effect of age on bark thickness, the sample trees were grouped into seven age classes. The age classes were: 11 - 20 years, 21 - 30 years, 21 - 40 years, 41 - 50 years, 51 - 60 years, 61 - 70 years and 71 - 80 years. Figure 9 shows the number of trees in each age class. Statistical analysis of the relationship between total single bark thickness and age using analysis of variance gave an F value of 0.81. Relationship between age and total single bark thickness was not statistically significant. Statistical analysis of the relationship between tree age and minimum single bark thickness using analysis of variance yielded an F value of 4.17, indicating statistical significance between age and minimum single bark thickness. Table 2 illustrates the relationship between age and minimum and maximum bark thickness.

Stand density from which sample trees were taken was measured in units of square feet of basal area per acre. Mean basal area was found to be 105.9 square feet per acre. Basal area per acre ranged from 30 square feet per acre to 210 square feet per acre. Figure 10 gives the distribution of sample trees by basal area per acre. Statistical analysis of the relationship between basal area per acre and single bark thickness using the analysis of variance gives an F value of 1.24. This value is not significant at the five per cent level, indicating no significant relationship between basal area per acre and single bark thickness. Statistical analysis of the relationship between basal area per acre and minimum single bark thickness using the analysis of variance yields an F value of 9.08. This shows a significant positive relationship between basal area per acre and minimum single bark thickness.

There was no significant statistical difference in either total single bark thickness or minimum single bark thickness between different compass directions. Average total single bark thickness on the north side of the sample trees was found to be 0.861 inches, on the east side 0.863 inches, on the south side 0.858 inches and on the west side 0.861 inches. Average minimum single bark thickness to the north was found to be 0.271 inches and 0.273 inches to the east, south, and west respectively. Statistical analysis of the relationship between single bark thickness and aspect using the analysis of variance gave an F value of 0.087. There is no significant relationship between single bark thickness and aspect. Statistical analysis of the relationship of minimum single bark thickness and aspect using analysis of variance yielded an F value of 0.918. No significant statistical relationship exists between minimum single bark thickness and aspect.

Radial growth rate in this study was expressed in number of annual growth rings per last inch of radial growth. The mean number of annual rings per last inch of growth was found to be 14.9. Figure 11 shows the distribution of sample trees by annual rings per last inch of radial growth. When the relationship between single bark thickness and radial growth rate was analyzed using the analysis of variance, an F value of 1.00 resulted. This indicates no significant relationship between single bark thickness and radial growth rate. When the relationship between minimum bark thickness and radial growth rate was analyzed using analysis of variance, an F value of 7.67 resulted, giving a statistically significant relationship between minimum single bark thickness and radial growth rate.

Of the 200 sample trees, 42 were classed as suppressed and 158 were classed as dominant. Average total single bark thickness for dominant trees was 0.857 inches and for suppressed trees was 0.879 inches. Average minimum single bark thickness for dominant trees was found to be 0.271 inches and for suppressed trees 0.280 inches. Statistical analysis of the relationship between single bark thickness and expression of dominance using Student's t-test yielded a t value of 0.571. No statistically significant relationship between expression of dominance and single bark thickness was found. When the relationship between expression of dominance and minimum single bark thickness was statistically analyzed using Student's t test, a t value of 0.631 resulted, showing no statistical relationship between expression of dominance and minimum single bark thickness.

For the analysis of a possible relationship between crown shape and bark thickness, the bark thickness in the compass direction of the greatest amount of crown was compared with the bark thickness on the other three sides of the tree. The compass direction of the greatest amount of crown was determined from the sketches which were made of the crowns of the sample trees. For this analysis, only trees having asymmetrical crowns could be used. Of the 200 sample trees, 87 were found to have asymmetrical crowns. Average single bark thickness in the direction of greatest amount of crown was 0.864 inches, while average single bark thickness of the other three directions was 0.878 inches. Average minimum bark thickness in the direction of the greatest amount of crown was found to be 0.280 inches, while average minimum single bark thickness for the other three directions was 0.283 inches. When either single bark thickness or minimum bark thickness in direction of most crown was statistically compared with that of the other three directions using analysis of variance, no statistical relationship (between bark thicknesses and crown configuration was found.

Site quality was determined in units of site index for each sample tree. A 50-year base was used in determining site indices. Site indices of sample trees ranged from 60 to 100. Distribution of sample trees by site index is shown in Figure 12. Site quality, expressed as site index, was one of the major ecological factors affecting bark thickness. An inverse relationship exists between site index and both total and minimum single bark thickness. (As site index increases, both total and minimum single bark thickness decreases as illustrated in Table 3). If site index is plotted against bark thickness in a graph, a straight line relationship results. Figure 13 shows this straight line relationship between site index and total and minimum single bark thickness. A comparison of the relationship between total single bark thickness and site index gave an F value of 59.75, while an F value of 2.45 was obtained by analyzing the relationship between site index and minimum bark thickness. There is a statistically significant relationship between site index and both total and minimum single bark thickness.

Of the 200 sample trees, 13 were located on the edge of the stand or on the edge of an opening in the stand. To analyze this factor in relation to bark thickness, the thickness of the bark on the side of the tree facing the opening was compared with the bark thickness on the other three sides of the tree. Sides of the tree were located with the Suunto compass. Average single bark thickness on the side of the sample trees facing the opening was 0.881 inches, while average single bark thickness on the other three sides was 0.875 inches. Average minimum single bark thickness for the side of the trees facing the opening was found to be 0.296 inches, while average single bark thickness for the other three sides was found to be 0.273 inches. Statistical analysis of data using Student's t-test gave a t value of 0.896 when single bark thickness on the side facing the opening was compared with single bark thickness in the other three directions and a t value of 0.531 when minimum single bark thickness on the side of the opening was compared with minimum single bark thickness in the other three directions. There is no significant statistical relationship between either minimum or total single bark thickness and exposure to an opening.

Of the 200 sample trees, 100 had some degree of lean. Average single bark thickness in the direction of tree lean was 0.858 inches while average single bark thickness for the other three directions was 0.865 inches. Average minimum bark thickness was 0.277 inches in the direction of tree lean while it averaged 0.301 inches in the other three directions. To statistically analyze the relationship between lean and single bark thickness, bark thickness on the side of the tree in the direction of lean was compared with bark thickness on the other three directions using Student's t-test. The resulting t value of 1.26 is significant at the 25 per cent level, but not at the 10 per cent level. It is therefore concluded that there is no significant statistical relationship between single bark thickness and tree lean. When the relationship between minimum single bark thickness and tree lean was statistically analyzed, a t value of 1.69 resulted. This value is significant at the 10 per cent level but not at the 5 per cent level. Since for the purpose of this study a 5 per cent level was considered significant, it was concluded that there is no statistical relationship between tree lean and minimum single bark thickness.

DISCUSSION

There was an extremely wide variation in bark thickness of sample trees. Individual total single bark thickness varied from a high of 1.60 inches to a low of 0.35 inches. Minimum single bark thickness was found to vary from a high of 0.75 inches to a low of 0.05 inches. Sample trees in this study conformed more closely to the regression equation developed by Renfro (1956) for prediction of bark thickness than equations offered by others. Renfros' equation is B = 0.4679 + 0.0771D - 0.01176 A, where B is single bark thickness in inches, D is dbh in inches, and A is age in years. Using data from this study, Renfros' equation gives an anticipated bark thickness of 0.820 inches. This compares favorably with actual mean value for bark thickness in this study which was 0.861 inches. Minor's (1953) equation which is B = 0.241 + 0.037 D yields an anticipated bark thickness of 0.617 inches which is much lower than the mean bark thickness of the sample trees used in this study. Another equation developed by Minor (1953) that also takes into account tree age is B = 0.250 + 0.043D + 0.003 A. When data from sample trees in this study were applied to this equation, a bark thickness of 0.573 inches was predicted. This predicted bark thickness is again much lower than mean bark thickness as indicated by this study. McCormack's (1955) equation B = 0.321 + 0.043D gives an anticipated bark thickness of 0.751 inches which is much lower than mean bark thickness found in this study. Since Renfro's work was done in North Carolina while Minor and McCormack worked in other areas, there may be some geographical variation in bark thickness of loblolly pine.

It was thought that where one side of a tree was more exposed to the sun than the other sides, a thicker bark might develop on the exposed side.

In this study the two factors concerned with exposure to sun were aspect and opening. Analysis of these factors indicated no development of thicker bark on the side exposed to sun.

When the data in this study were collected and grouped, it was found by inspection that differences existed in mean bark thickness between groups. In order to determine whether these differences were biologically significant, it was decided to analyze the data statistically. Where data from only two factors were involved, the Student's t-test was used for statistical analysis. Figure 14 is an example of the calculations used in Student's t-test. Where data from more than two factors were involved, analysis of variance was used for statistical analysis. Figure 15 is an example of the calculations used in analysis of variance. In the use of Student's t-test and analysis of variance the five percent level was considered biologically significant. Table 4 summarizes the statistical results of the study.

SUMMARY

The purpose of this work was to study possible relationships between a number of factors and bark thickness in *Pinus taeda* L. Two hundred trees from eastern North Carolina forests in the 10-inch diameter range were studied. No significant correlations were found between total single bark thickness and age and stand density, aspect, radial growth rate, dominance, crown shape, stand opening or tree lean. In addition there were no statistically significant results between minimum bark thickness and aspect, dominance, crown shape, stand opening, or tree lean.

There were significant statistical relationships between total bark thickness and site quality, as well as between minimum bark thickness and age, stand density, radial growth rate, and site quality.

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Table 1. Some Factors for Computing Single Bark Thickness Based on Percentage of Dbh

Species	Percentage of Dbh	Researcher Who Developed Factor
Pinus resinosa Ait.	5.2	Chamberlain and Meyer (1950)
Pinus virginiana Mill.	2.7	Chamberlain and Meyer (1950)
Pinus strobus L.	5.0	Meyer (1946)
Pinus strobus L.	5.2	Gevorkiantz and Duerr (1938)
Pinus banksiana Lamb	4.8	Gevorkiantz and Duerr (1938)
Pinus contorta var. *latifolia* Englem.	1.6	Finch (1948)
Pinus ponderosa Laws.	4.1	Finch (1948)

Table 2. Relationships between Age and Total Average Bark Thickness and Minimum Average Bark Thickness in *Pinus taeda* L.

Age (years)	Average Total Bark Thickness (inches)	Average Minimum Bark Thickness (inches)
11 - 20	0,760	0.263
21 - 30	0.836	0.264
31 - 40	0.841	0.268
41 - 50	0.952	0.261
51 - 60	0.862	0.282
61 - 70	0.764	0.259
71 - 80	0.820	0.220

Table 3. Relationships between Site Index and Total Single Bark Thickness And Minimum Single Bark Thickness in *Pinus taeda* L.

Site Index (in feet attained on 50 year base)	Total Single Bark Thickness (inches)	Minimum Single Bark Thickness (inches)
60	0.936	0.299
70	0.863	0.279
80	0.807	0.246
90	0.748	0.246
100	0.660	0.160

Table 4

Summary Of Statistical Results

Factor For Which Data Analyzed	Test Used	F or t Value	Significance At 5% Level
Relationship between age and single bark thickness	Analysis of Variance	.81	Not Significant
Relationship between age and minimum single bark thickness	Analysis of Variance	4.17	Significant
Relationship between Stand density and single bark thickness	Analysis of Variance	1.24	Not Significant
Relationship between Stand density and minimum bark thickness	Analysis of Variance	9.08	Significant
Relationship between aspect (direction) and single bark thickness	Student's t-test	.087	Not Significant
Relationship between aspect and minimum bark thickness	Student's t-test	.918	Not Significant
Relationship between radial growth rate and single bark thickness	Analysis of Variance	1.00	Not Significant
Relationship between radial growth rate and minimum single bark thickness	Analysis of Variance	7.67	Significant
Relationship between expression of dominance and single bark thickness	Student's t-test	0.571	Not Significant
Relationship between expression of dominance and minimum single bark thickness	Student's t-test	0.631	Not Significant
Relationship between site quality and single bark thickness	Analysis of Variance	59.75	Significant

Relationship between site quality and single bark thickness	Analysis of Variance	2.45	Significant
Relationship between exposure to opening and single bark thickness	Student's t-test	0.896	Not Significant
Relationship between exposure to opening and minimum single bark thickness	Student's t-test	0.531	Not Significant
Relationship between lean and single bark thickness	Student's t-test	1.26	Not Significant
Relationship between lean and minimum bark thickness	Student's t-test	1.09	Not Significant
Relationship between crown shape and single bark thickness	Analysis of Variance	.56	Not Significant
Relationship between crown shape and minimum bark thickness	Analysis of Variance	1.21	Not Significant

Figure 1

Lufkin Diameter Tape

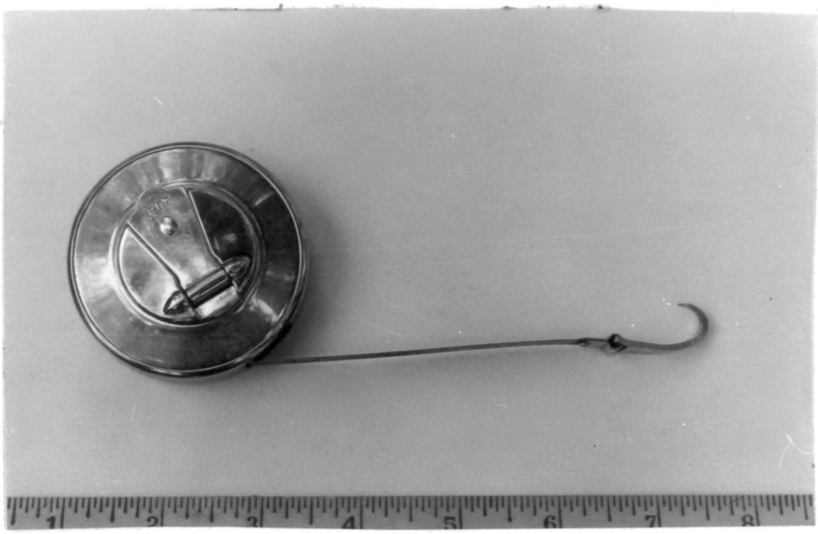

Figure 2

Djos Increment Borer

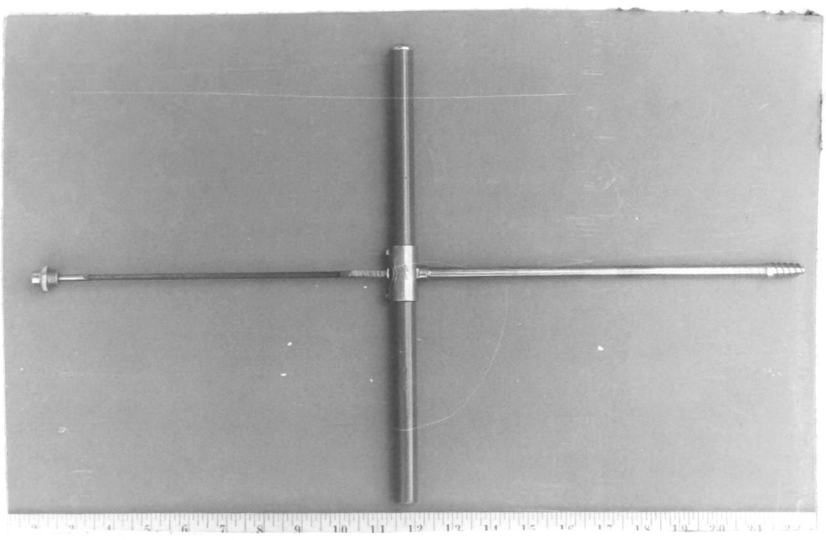

Figure 3

Ten Factor Wedge Prism

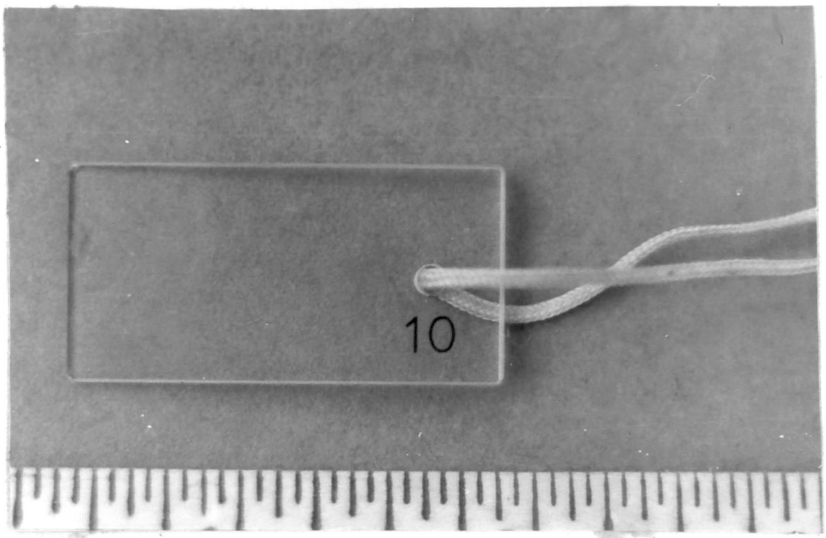

Figure 4

Suunto Compass

Figure 5

Djos Bark Gauge

Figure 6

Site Index Curves For

Loblolly Pine (Pinus taeda L.)

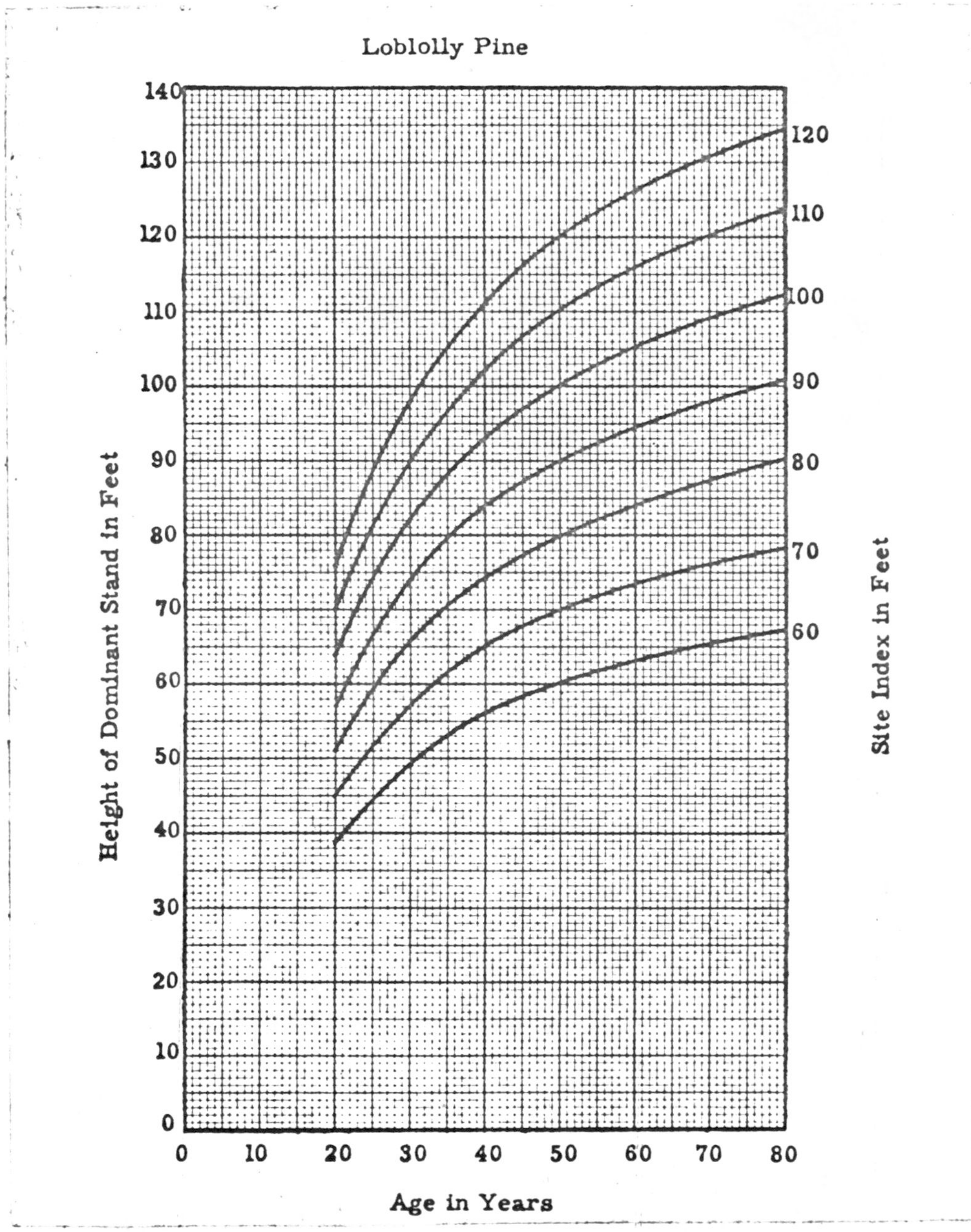

Figure 7

Haga Altimeter

Figure 8

Tool for Finding Crevice Depth

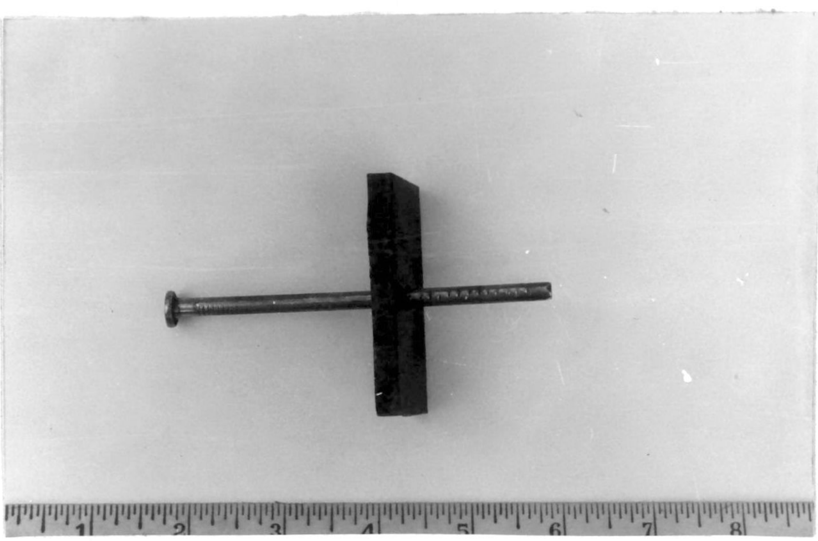

FIGURE 9

DISTRIBUTION OF SAMPLE

TREES BY AGE

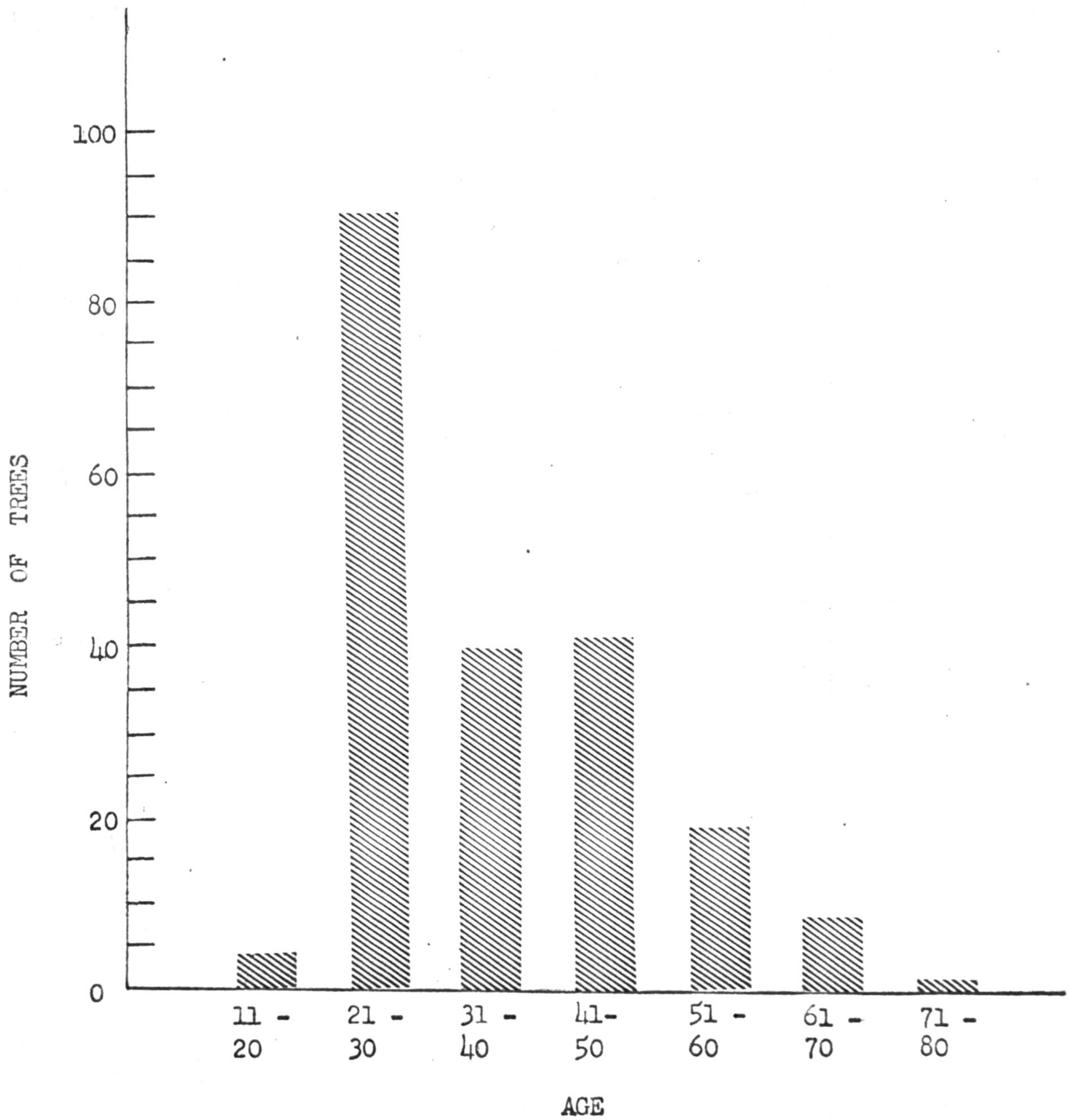

FIGURE 10

DISTRIBUTION OF SAMPLE TREES BY BASAL AREA

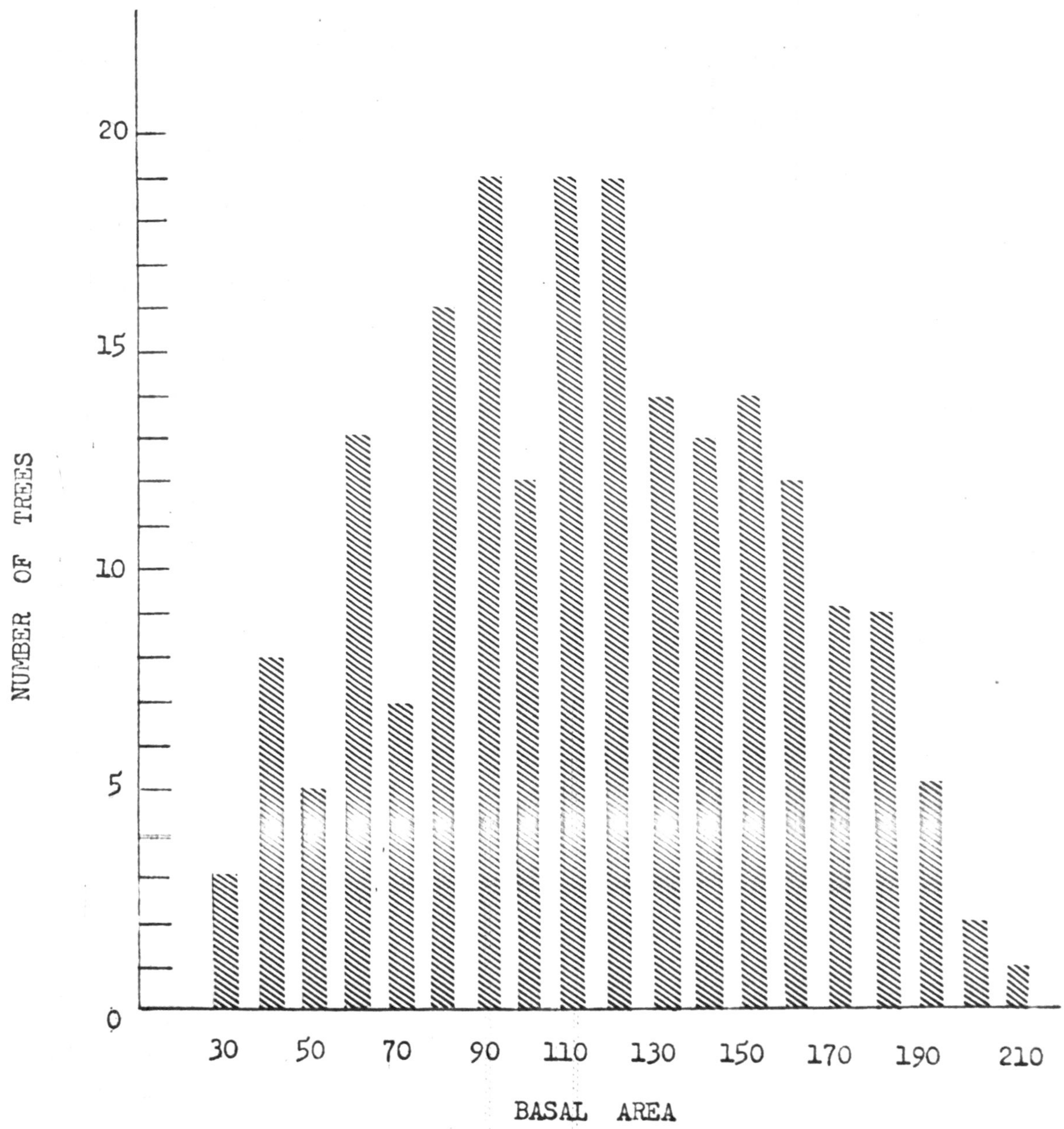

FIGURE 11

DISTRIBUTION OF SAMPLE

TREES BY RINGS IN LAST INCH GROWTH

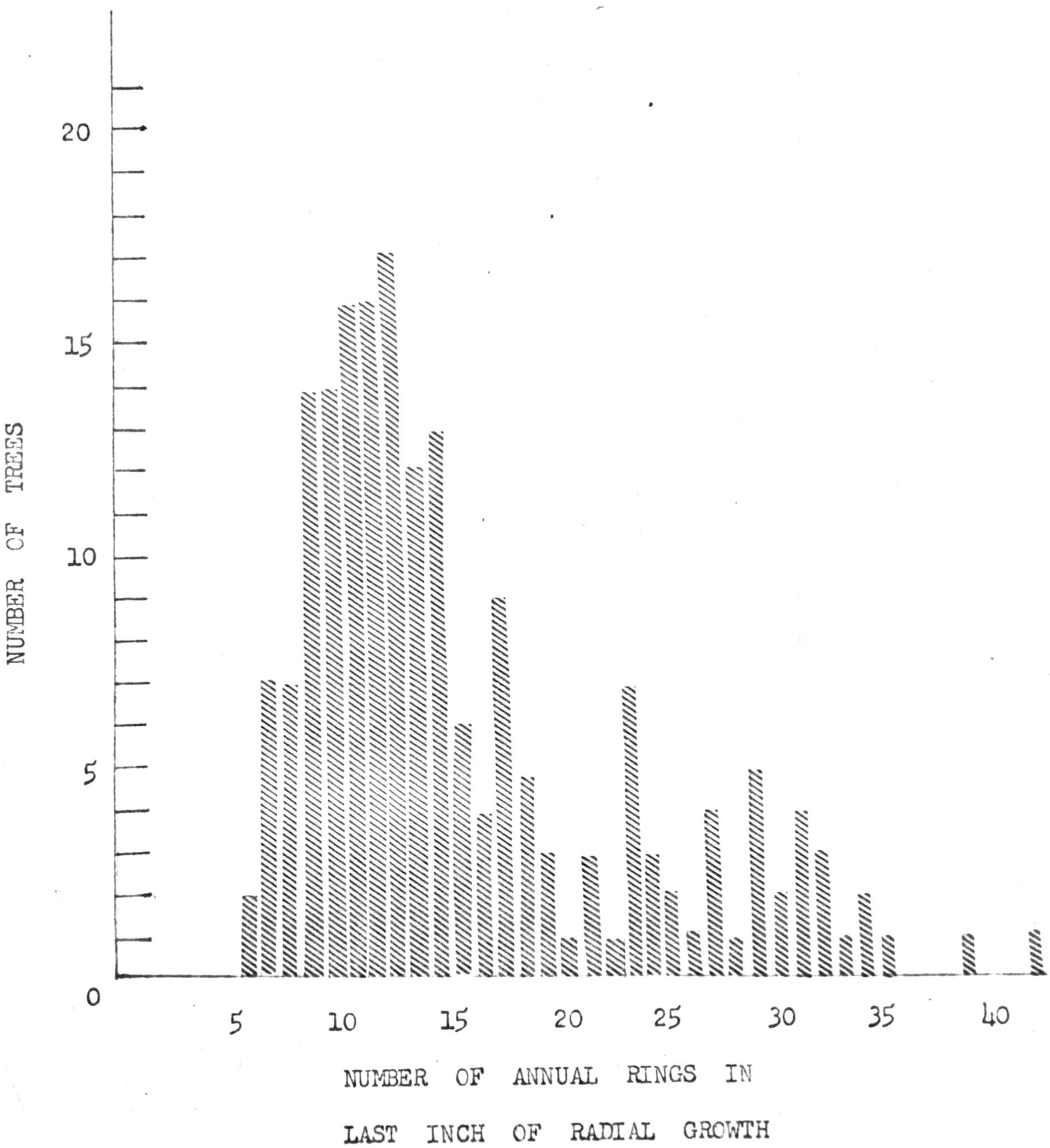

FIGURE 12

DISTRIBUTION OF SAMPLE TREES BY SITE INDEX

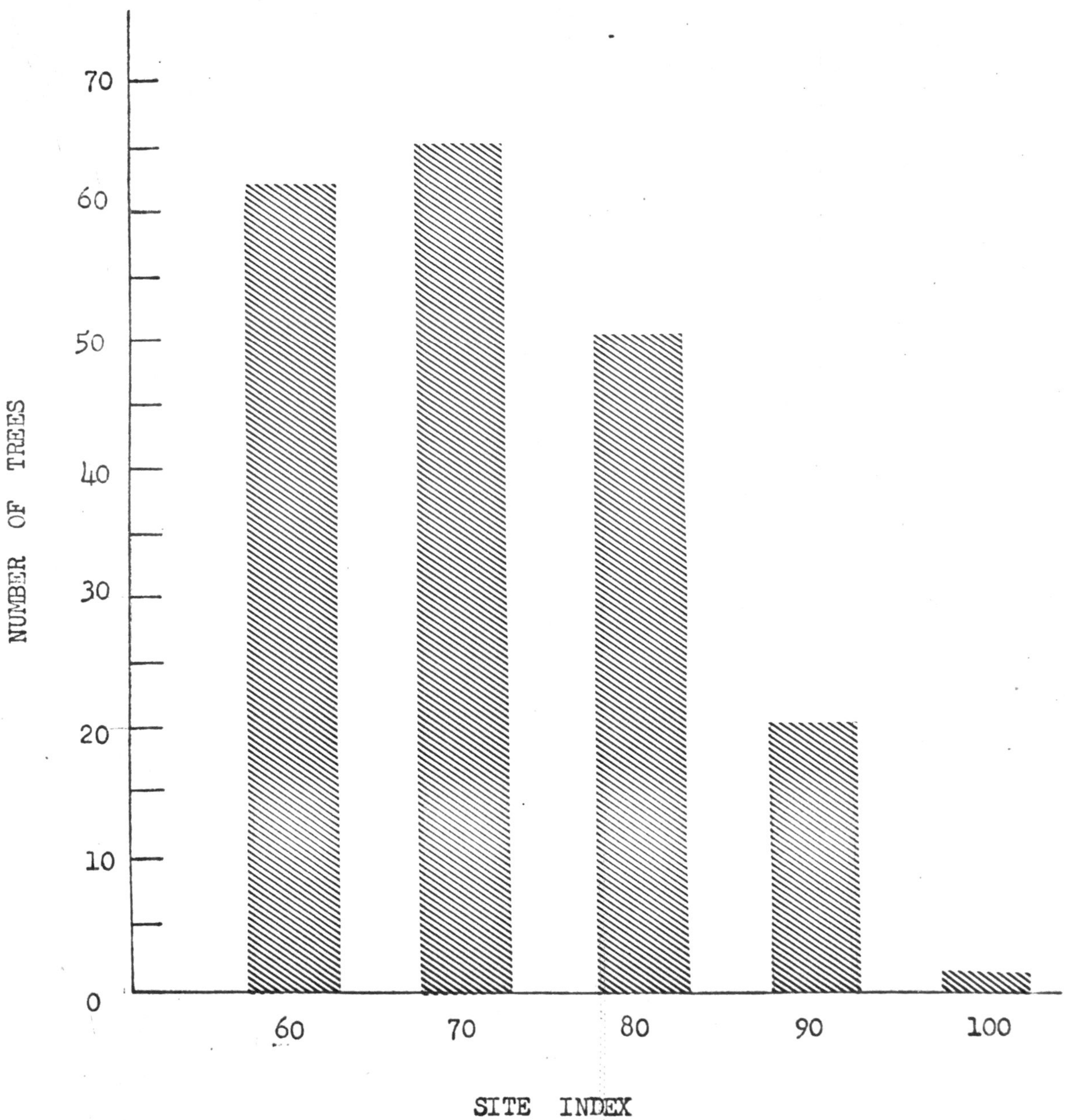

FIGURE 13

RELATIONSHIP BETWEEN

AVERAGE BARK THICKNESS AND SITE INDEX

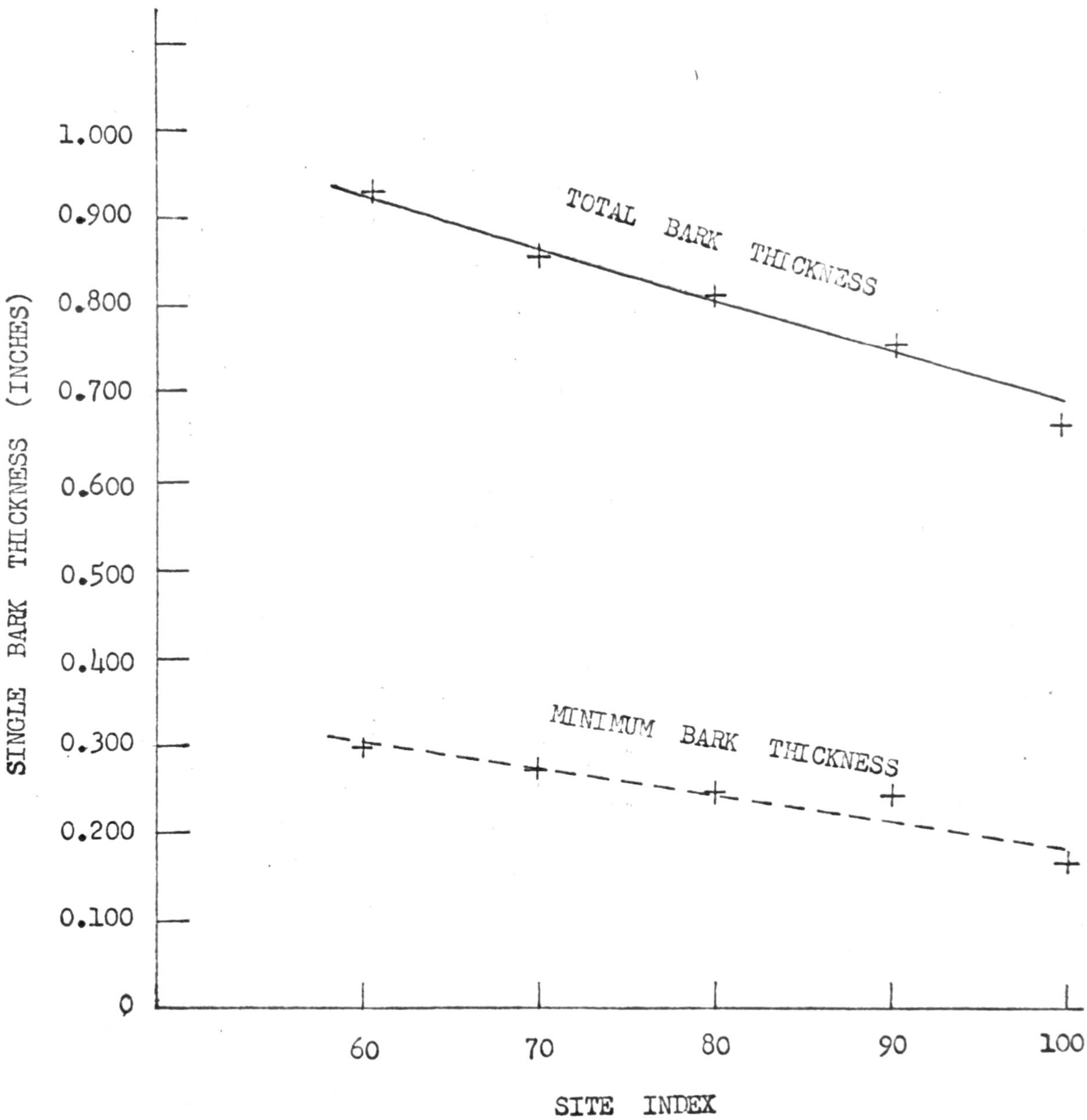

Figure 14

Sample Calculation

Student's t-test

Analysis of Relationship Between Lean and Single Bark Thickness

$\bar{X}_1 = .865$

$\bar{X}_2 = .858$

$N_1 = 100$

$N_2 = 100$

$s_1^2 = .095$

$s_2^2 = .057$

$$t = \frac{(\bar{X}_1 - \bar{X}_2)\sqrt{\frac{N_1 N_2}{N_1 + N_2}}}{\sqrt{\frac{(N_1 - 1)\, s_1^2 + (N_2 - 1)\, s_2^2}{N_1 + N_2 - 2}}}$$

$$t = \frac{.007 \sqrt{\frac{10,000}{200}}}{\sqrt{\frac{99\,(.095) + 99\,(.057)}{100 + 100 - 2}}}$$

$$t = \sqrt{\frac{.007\,(70.1)}{.39}} = 1.26$$

Figure 15

Sample Calculation

Analysis of Variance

Analysis of Relationship Between Direction

And Single Bark Thickness

T_1 = Sum of Bark Thickness North side of tree

T_2 = Sum of Bark Thickness East side of tree

T_3 = Sum of Bark Thickness South side of tree

T_4 = Sum of Bark Thickness West side of tree

$T_1 = 172.32$ $\quad n_1 = 200$ $\quad N = n_1 + n_2 + n_3 + n_4$

$T_2 = 172.60$ $\quad n_2 = 200$ $\quad N = 800$

$T_3 = 171.50$ $\quad n_3 = 200$ $\quad \Sigma_{ij} X_{ij} = 688.75$

$T_4 = 172.33$ $\quad n_4 = 200$ $\quad {}_{ij} X_{ij} = T_1 + T_2 + T_3 + T_4$

$$\text{Total sum of squares} = (X_1)^2+(X_3)^2+(X_3)^2 ---- (X_{200})^2 - \frac{\Sigma_{ij} X_{ij}}{N}$$

Total sum of squares = 628.16 - 592.97 = 35.19

$$\text{Main effect} = \frac{(T_1)^2}{n_1}+\frac{(T_2)^2}{n_2}+\frac{(T_3)^2}{n_3}+\frac{(T_4)^2}{n_4} - \frac{(T_1+T_2+T_3)^2}{N}$$

Main effect = 148.47 + 148.94 + 147.06 + 149.99 - 592.97 = 1.49

Deviation = Total sum of squares - main effect

Deviation = 35.19 - 1.49 = 33.70

	Sum Of Squares	Degrees of Freedom	Mean Square
Main Effect	1.49	3	.49
Deviation	33.70	796	.0423

$$F = \frac{.49}{.0423} = .087$$