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TB18: Mensuration Methods for Site Classification of Shade Tolerant Tree Species

Leigh E. Hoar Jr.
Harold E. Young

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MENSURATION METHODS FOR SITE CLASSIFICATION OF SHADE TOLERANT TREE SPECIES

Leigh E. Hoar, Jr. and Harold E. Young

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## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>3</td>
</tr>
<tr>
<td>Methods</td>
<td>4</td>
</tr>
<tr>
<td>Mensuration concepts</td>
<td>4</td>
</tr>
<tr>
<td>Free growing period</td>
<td>4</td>
</tr>
<tr>
<td>Individual tree</td>
<td>4</td>
</tr>
<tr>
<td>Volume growth</td>
<td>5</td>
</tr>
<tr>
<td>Data Analysis by sites</td>
<td>5</td>
</tr>
<tr>
<td>Site classification scheme</td>
<td>5</td>
</tr>
<tr>
<td>Tree selection and sampling procedures</td>
<td>6</td>
</tr>
<tr>
<td>Data analysis</td>
<td>7</td>
</tr>
<tr>
<td>Results</td>
<td>7</td>
</tr>
<tr>
<td>Discussion</td>
<td>12</td>
</tr>
<tr>
<td>Conclusions</td>
<td>14</td>
</tr>
<tr>
<td>Forestry publications</td>
<td>15</td>
</tr>
</tbody>
</table>
FOREWORD

The pulp and paper mills of Maine are currently in a second expansion program since the termination of World War II. This expansion is expected to increase the annual consumption of pulpwood by thirty percent. Another similar expansion would bring the annual timber harvest fairly close to the annual growth.

The expansion of pulp mill facilities and the need and desire for more income from forest lands are causing land owners to have more interest in the production possibilities of their land. The net effect will be the need for more intensive forest management in order to produce more timber.

Almost all of the major tree species in Maine are shade tolerant and thereby present a difficult problem in the assessment of forest sites. Aware of the difficulties of total age as a factor in site determination, the authors have developed a different hypothesis for the mensuration of site evaluation. It needs considerable testing before becoming an acceptable method. However, it is presented now to stimulate interest in another possible approach to the solution of this difficult problem.

A. D. Nutting
Director
School of Forestry

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the following:
Director Albert D. Nutting for his assistance in obtaining financial support and continued interest in the project.
Professor Russell Altenberger for programming and analytical assistance with the IBM Data Processing System.
MENSURATION METHODS FOR THE SITE CLASSIFICATION OF SHADE TOLERANT TREE SPECIES

Leigh E. Hoar, Jr. and Harold E. Young

INTRODUCTION

Today there is ample forest land to produce a steady supply of forest products for our increasing population. As forest land becomes more valuable and wood less plentiful, interest in methods of producing a steady and profitable supply of wood has increased. It has been well recognized for some time that there is considerable variation in the productivity of forest land from place to place. Every particular place, essentially homogenous in nature, is referred to as a "site" due to consideration of all of the environmental factors that affect tree growth.

Site evaluation constitutes a quantitative method for determining the potential productivity of a site for tree growth. Without site evaluation forest management can only be extensive, therefore minimizing profit possibilities. With site evaluation forest management can be highly intensive, maximizing use of the forest. This is accomplished by planning road construction, silvicultural practices and multiple use of the forest directly proportional to the productivity of the land.

Literally hundreds of papers have been published on site evaluation in the past 65 years. Only a few have concerned themselves with the development of new techniques. The vast majority demonstrate the applicability or lack of applicability of the various methods to the hundreds of commercial tree species in the world. Coile and Rennie have summarized the major variations in methods and in their respective bibliographies list important papers for each.

Despite the apparent differences in the site evaluation methods there are certain fundamental similarities among them all. These are:

1. Use of sample plots involving many trees
2. Use of total age
3. Use of height growth as the indicator of site productivity
4. Tendency to pool data of all sites rather than analysis by sites as defined in a site classification scheme

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1 Information taken in part from the senior author's thesis in partial fulfillment of the requirements for the Master of Science in Forestry degree.
2 Graduate student in forestry and Professor of Forestry, respectively. Senior author is now at the Horace Albright Training Center, Grand Canyon, Arizona.
All of the climax species in Maine are shade tolerant. This means that they have the capacity of surviving and growing slowly in the seedling, sapling and pole size stages. As a result none of the established methods employing total age are applicable. In searching for a way to overcome this problem an entirely new approach to quantitative site evaluation was conceived.

It is the purpose of this study to evaluate this new mensurational approach to site evaluation for shade tolerant trees. It will be tested utilizing a simplified site classification scheme.

METHODS

Mensuration concepts

Due to the shade tolerance of the major tree species in Maine, site evaluation techniques involving total age have not been successful. Considerable thought was given to alternate time periods that might be more meaningful than total age for site evaluation. The most promising time period indicated the desirability of recasting the mensurational approach to site evaluation. Each aspect will be separately described in such a manner that the four major factors present a single new approach.

Free growing period

From the observation of the tree rings on the stumps of red and white spruce trees on many logging operations, it was apparent that almost every tree in the forest goes through an extended period of suppression. In order to follow up these observations a number of trees were felled and cut at breast height. The data showed that very few trees were suppressed after the tree had attained a diameter of four inches at breast height and that the period of time to reach this diameter was extremely variable. By stem analysis of the felled trees it was observed that the tree was about 45 feet in height when it became four inches in diameter at breast height. Apparently when the tree had attained these dimensions it obtained enough sun in the forest canopy and sufficient space in the ground for roots to develop at a more rapid rate than during the period of suppression.

The free growing period is now defined as the number of years from the time the tree was four inches in diameter until the time the tree was felled for stem analysis.

Individual tree

Foresters have attached importance to plots varying in size from one eighth acre to an entire acre on the assumption that the average of
a number of trees will best represent a site. This is a sound argument but it has resulted in few measurements of often questionable accuracy on a per tree basis. In sharp contrast to this it was decided to use a single tree to represent a particular site so that a considerable number of careful measurements could be made on that tree. It was anticipated that the time per tree on this study might equal the time per plot on more conventional studies.

**Volume growth**

From the earliest times foresters have used volume for sales and professional purposes. Site evaluation fifty years ago was sought in terms of height growth because of the simplicity of height measurement and the low value of forest products at that time. With forest research on a more scientific basis, forest products of greatly increased value, and the tree on the ground for stem analysis, the necessary measurements for calculation of the volume are easily obtained. At the beginning of the free growing period the tree is four inches in diameter at breast height so that there is one pulpwood bolt between the stump and the breast height point that is four inches in diameter at the small end. Volume is calculated from the stump to the upper limit of four inches by Smalian's formula. The volume growth during the free growing period is the merchantable volume at the time the tree is felled, less the volume of the single pulpwood bolt in the tree at the beginning of the free growing period.

**Data analysis by sites**

Conventional methods of site evaluation have taken the data from all sites under consideration and prepared a base curve and then by one of several methods developed curves for sites as defined in terms of height growth. In this study the sites are classified according to a simplified scheme and the data for each site is analyzed separately. Regression analysis is employed to obtain equations for each site in the classification scheme, and the equations are compared to ascertain if there are significant differences between the sites as defined.

**Site classification scheme**

A simple soil site classification system was devised to minimize the total number of categories into easily recognizable units.

1. *Peat*—partially decomposed organic matter in excess of 30 inches in depth, water table at or near the ground surface most of the year.
2. *Swamp*—decomposed organic matter less than 12 inches in
depth, generally underlain with fine grained materials. Water
table near the surface most of the year.
3. **Fines**—silty or clayey soil of marine, lacustrine or alluvial
origin, generally better drained than swamp soils.
4. **Till**—unstratified glacial deposits varying in depth, generally
containing boulders, variable drainage.
5. **Ledge**—bedrock areas having less than a 2 foot soil cover,
drainage generally excessive.
6. **Granular**—sand and/or gravel of glacio-fluvial, alluvial or
aeolian origin, internal drainage generally excessive.

Areas of possible site selection were first designated on soils maps
of the University of Maine Forest, Stillwater, Maine, prepared by the
Soil Conservation Service. Inasmuch as the Soil Conservation Service
recognizes over 70 soil series included in the simplified site classification
scheme of this study it was necessary to adapt the SCS map for field
use. Prior to the field season several soil pits were dug to relate soil
map information to ground condition. Airphotos were also used to
eliminate hardwood stands. It was then possible to use the airphotos
in conjunction with the soils maps to locate tentative sites for the study
with final determinations to be made in the field. The field classification
was made on the basis of a small pit approximately 18 inches square
and 18-24 inches deep, located as closely as possible to the tree bole.
Several soil-auger samples were also taken to permit a rapid estimation
of the soils as the use of an auger is much more rapid than the soil pit
method. As a result, reconnaissance time in locating sample trees was
reduced. Despite this, most of the field time was used in locating usable
sites and sample trees.

**Tree selection and sampling procedures**

Red and white spruce that possessed full symmetrical crowns
were selected. They were assumed to have been dominant or codom-
inant for the free growing period. This was desired to insure that maxi-
mum rather than average productivity of the site would be evaluated.
In addition this would provide the most sensitive data to test for differ-
ences in productivity among the sites of the classification scheme.

Individual trees were felled for stem analysis. Diameter measure-
ments were made inside and outside the bark at the stump, at breast
height and at each eight foot section thereafter until the limit of mer-
chantability of four inches inside bark was reached. Annual ring counts
were made at the stump, breast height, and the upper limit of merchant-
ability. The total tree height, length of the unmerchantable top and
the ground-to-base-of-crown length of the tree was also measured. The
crown was measured to determine its total length, base diameter and the diameter and distance above the base at every point where there was a noticeable change in taper to permit estimation of the crown volume.

**Data analysis**

Regression analysis was used to correlate the free growing period, and the increase in volume during that period, for each soil category. The equation model was as follows:

\[ Y = b_0 + b_1X \]

Where \( Y \) = free growth volume

\( X \) = years of free growth

\( b_0 \) = equation constant

\( b_1 \) = coefficient of \( X \)

Computations were performed on the IBM 1620 in the computer center of the University of Maine. A program was prepared by Prof. Russell A. Altenberger of the computer center to compute volumes of the segments of the merchantable bole utilizing the field measurements. A regression program already available was used for data analysis. It was contemplated that the model equation would be altered in the analytical phases. With the high speed computer and the available program this posed no serious problem.

**RESULTS**

The spruce trees used in this study were distributed over four sample areas. Table 1 indicates the diameter distribution of sample trees in the study areas.

Most of the fine and till soil sites and some of the ledge sample trees were found in the University Forest. The samples representing peat and swamp sites were collected in the Penobscot Experimental Forest, Bradley and in Edinburg township. Most of the samples on Indian Township, Washington County, were taken from ledge sites. The diameter distribution of sample trees according to site are listed in table 2.

The basic equation

\[ Y = b_0 + b_1X \]

was transformed to a logarithm expression

\[ \ln Y = b_0 + b_1 \ln (X) \]
in order to produce a straight line. Table 3 lists the results of this analysis. The analysis of the swamp data shows a poor linear correlation in contrast to the results of the analysis of the other sites.

Table 4 indicates that the regression equations have a highly significant difference in origin and a significant difference in slope.

Equation (2) in graphic form for each site is shown in figure 1. This indicates that spruce on fine or till sites produce more volume.

Table 1. Distribution of 113 spruce sample trees, by area and diameter class, in central and eastern Maine.

<table>
<thead>
<tr>
<th>Location</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>University Forest</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>14</td>
<td>11</td>
<td>16</td>
<td>7</td>
<td>6</td>
<td>2</td>
<td>69</td>
</tr>
<tr>
<td>Penobscot Experimental Forest</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Edinburg Township</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Indian Township</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

![Free-growth volume in cubic feet vs. Free-growth age in years](image)

**Figure 1.** Equation (2) in antilogarithm form for five soil sites in central and eastern Maine for spruce.
Table 2. Distribution of 113 spruce sample trees by site and diameter class, in central and eastern Maine.

<table>
<thead>
<tr>
<th>Site</th>
<th>Diameter in inches</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Fine</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Ledge</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Till</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Swamp</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Peat</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 3. Regression equations and coefficient of determination \( r^2 \) for volume during the free growing period of spruce on five sites in central and eastern Maine.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Equation</th>
<th>( r^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fines</td>
<td>( \ln Y = -1.84815 + 1.22941 \ln X_i )</td>
<td>.740</td>
</tr>
<tr>
<td>Ledge</td>
<td>( \ln Y = -1.79181 + 1.06684 \ln X_i )</td>
<td>.813</td>
</tr>
<tr>
<td>Till</td>
<td>( \ln Y = -1.06098 + 0.96675 \ln X_i )</td>
<td>.724</td>
</tr>
<tr>
<td>Swamp</td>
<td>( \ln Y = -0.17817 + 0.66093 \ln X_i )</td>
<td>.349</td>
</tr>
<tr>
<td>Peat</td>
<td>( \ln Y = -3.12354 + 1.39343 \ln X_i )</td>
<td>.773</td>
</tr>
</tbody>
</table>

**Significant at the .01 level.
*Significant at the .05 level.

Table 4. Analysis of variance between regressions for equation (2).

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>4</td>
<td>1.348**</td>
</tr>
<tr>
<td>Difference between regression coefficients</td>
<td>4</td>
<td>0.403*</td>
</tr>
<tr>
<td>Error</td>
<td>103</td>
<td>0.143</td>
</tr>
</tbody>
</table>

**Significant at the .01 level.
*Significant at the .05 level.

The basic equation was weighted with the reciprocal of age required to reach four inches dbh, in the following manner:

\[
\frac{Y}{X^n} = b_0 \left( \frac{1}{X_i} \right) + b_1 \left( \frac{X_i}{X_n} \right)
\]  

(3)

Table 5 shows the resulting equations and correlations derived from this model. The use of age to reach four inches dbh improved the coefficient of determination quite strongly. The swamp site \( r^2 \) rose from .349 (table 3) to .630 (table 5).

The analysis of variance for this set of equations indicates a highly significant difference in position of each equation (table 6). The slope differences are significant at the .05 level.

The graph of the above equations (figure 2) shows differences in slope from figure 1. This reflects the influence of the weighting factor.
Table 7 is the result of using a natural logarithm transformation of equation (3).

\[
\frac{\ln Y}{X_{10}} = b_0 + \frac{1}{X_{10}} + b_1 \frac{\ln X_i}{X_{10}}
\]

(4)

The transformation resulted in a 0.2 increase in the coefficient of determination for the swamp site, and a moderate increase in the others.

The analysis of variance for the above equations indicates a highly significant difference for equation constants and coefficients (table 8). This is attributable to the use of the natural logarithm transformation.

Figure 3 is the graphical relationship of the tabular data in antilogarithm form presented in table 7. By crossing, this shows that the site indices are quite similar while in the early stages of free growth, but major differences appear by the end of 60 years free growth.
Table 5. Weighted linear regression equations and $r^2$ for the relationship of free-growth volume and the free-growing period.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Equation</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fines</td>
<td>$Y = -0.18762 + 0.36481 X$</td>
<td>.909</td>
</tr>
<tr>
<td>Ledge</td>
<td>$Y = 1.36620 + 0.21183 X$</td>
<td>.935</td>
</tr>
<tr>
<td>Till</td>
<td>$Y = 1.30450 + 0.27706 X$</td>
<td>.953</td>
</tr>
<tr>
<td>Swamp</td>
<td>$Y = 3.29160 + 0.13630 X$</td>
<td>.630</td>
</tr>
<tr>
<td>Peat</td>
<td>$Y = -7.18370 + 0.37746 X$</td>
<td>.923</td>
</tr>
</tbody>
</table>

**Significant at the .01 level.

Table 6. Analysis of variance between regressions for equation (3).

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>4</td>
<td>0.074508**</td>
</tr>
<tr>
<td>Difference between regression coefficients</td>
<td>4</td>
<td>0.045045*</td>
</tr>
<tr>
<td>Error</td>
<td>103</td>
<td>0.018038</td>
</tr>
</tbody>
</table>

*Significant at the .01 level.

Figure 3. Equation (4) in antilogarithm form for five soil sites in central and eastern Maine for spruce.
Table 7. Logarithm transformation of weighted linear regression equations and $r^2$ for the relationship of free-growth volume and the free-growing period.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Equation</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fines</td>
<td>$\ln Y = -1.9206 + 1.2510 \ln X^{**}$</td>
<td>.978</td>
</tr>
<tr>
<td>Ledge</td>
<td>$\ln Y = -1.2205 + 0.9407 \ln X^{**}$</td>
<td>.982</td>
</tr>
<tr>
<td>Till</td>
<td>$\ln Y = -0.9522 + 0.9380 \ln X^{**}$</td>
<td>.991</td>
</tr>
<tr>
<td>Swamp</td>
<td>$\ln Y = 1.4280 + 0.1086 \ln X^{**}$</td>
<td>.824</td>
</tr>
<tr>
<td>Peat</td>
<td>$\ln Y = -3.6825 + 1.5454 \ln X^{**}$</td>
<td>.978</td>
</tr>
</tbody>
</table>

**Significant at the .01 level.

Table 8. Analysis of variance between regressions for equation (4).

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
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<td>0.001478**</td>
</tr>
<tr>
<td>Difference between regression coefficients</td>
<td>4</td>
<td>0.000784**</td>
</tr>
<tr>
<td>Error</td>
<td>103</td>
<td>0.000202</td>
</tr>
</tbody>
</table>

**Significant at the .01 level.

DISCUSSION

It is well known that till soils exhibit a wide range of drainage. In this study till soils included many variations. It is suggested that this soil type could be separated into several drainage classes, with a possible increase in the significance of site classification.

Sample tree selections were hampered by the crown requirements. The original intent was to select trees with a full, regular crown. Since spruce has a tendency to survive and grow under adverse conditions with poor crowns, this requirement was altered to permit the selection of the best trees in a stand. This probably did not change the free growth relationships, but will probably show the maximum productivity of merchantable volume growth of the sites under the present conditions, rather than the maximum growth of the sites.

It was noted that sample trees seemed to come in groups on a particular soil site. This is to be expected, because a soil classification boundary may cover an area several acres in extent. Also, stand conditions which favored the establishment of the sample stands were probably quite uniform for any given location.

A minimum of 24 sample trees was desired per soil type. This was not always possible to achieve because of the difficulty of locating sample trees. It took approximately three-quarters of an hour for one man to fell and measure a sample tree. This was reduced to one-half hour by adding another man to the crew.

Stem analysis measurements to support this approach to site evaluation required about as much time per tree as the total plot measure-
ments essential for height-age determination in the more conventional method. Stem analysis in the field, however, is quite rapid, following a brief orientation period.

The equations in figure 3 show a strong differentiation among most of the sites, after the first thirty years of free growth. The greatest difference among the sites may be in their relative moisture-holding capacities. Although peat is apparently a better site than ledge or swamp, it is also the wettest. Spruce on a peat site appeared to have the most shallow rooting system, so the presence of moisture is not an indication by itself of site quality. A better indication might be its availability to the roots.

The swamp trees had a deeper root system, and more intimate contact with the water table. The ledge showed a definite tendency towards dryness in the upper layer. Till and peat are apparently equal in site productivity although varying widely in the availability of their moisture. This is probably related to the fact that the rooting zone of the till sites showed much the same dryness as the top layers of the peat.

The fine soils were quite damp throughout the sampling period, which coincided with the growing season. The fine soils also tended to be of a firm consistency. This appeared to best suit the growth characteristics of spruce, or perhaps were unfavorable to competitive growth. This site was clearly the best in terms of growth.

Very few spruce were observed on the granular sites. Granular soils were well stocked with rapidly growing hardwood stands. The few spruce noted were severely overtopped, and in no instance was a sample tree located.

This technique was designed for red and white spruce. It would not appear unreasonable to apply it to other shade tolerant species as well, such as fir, or even with intolerant species, such as Norway pine. In the latter situation total merchantable volume would be used with age at the stump.

This method of evaluation has two advantages over the usual height-age relationship. First, it overcomes the impact of the variable suppression period on the height-age curve. A long suppression period causes a height-age curve to be very low. Secondly, it permits the differentiation of sites on a soil basis, rather than the forced separation by the anamorphic technique.

The elimination of the sapling stage by the free growth technique seems to be a permissible move. The use of volume and age after the sapling stage reduces the effect of suppression to a minimum. This is in line with the observation that almost all of the sampled trees had reached the free growth stage by the time they were four inches dbh.
Also, the tree is not merchantable until after it has passed this point, so it is at this time the forest stand becomes of interest in terms of intensive management.

CONCLUSIONS

The relationship of free growth volume to free growth age was studied to evaluate site. The following conclusions are based on 113 spruce trees on five sites in central and eastern Maine.

1. Natural logarithms and a weighting factor were combined in the following equation form for the best control of sampling variation:

\[
\frac{\ln Y}{X_{10}} = b_0 + \frac{1}{X_{10}^{10}} + b_1 \frac{\ln X_i}{X_{1i}}
\]

2. There was a highly significant difference among equation constants and coefficients for the sites as defined in the study.

3. Tree growth curves appeared similar at the beginning of the free growing period, but as free growth age increased, differences between sites became more prominent in the following order of decreasing productivity: (1) Fines, (2) Peat, (3) Till, (4) Ledge, (5) Swamp.

4. Site index curves resulting from this study were neither proportional nor parallel.

5. Site index curves sometime crossed due to slow or rapid initial growth, and vice versa after an extended period of time.
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