Estimating Forest Productivity: the 10m Site Index Method
By
James D. Arney, Brian L. Kleinhenz, and Kelsey S. Milner

Abstract

Traditional site index curves (height/age) have served well in past decades, but it is now clear that these methods contain significant biases depending on their application. The 10-meter Site Index method applies Zeide’s (1978) two-point principle by measuring ring count at 34 and 67-foot (10 and 20-meter) heights on a site-potential tree. Site index is simply a transformation of the number of years required to grow that segment of the tree in height. This removes most of the variation in site classification due to silvicultural treatment history, planting stock, under-aged site trees and uneven-aged management. This approach has been successfully applied in eleven forests in six Western States.

Keywords: Site Index, Productivity, Yield Capacity, 10m Site, Growth Types

Introduction

Height growth is perhaps the most widely used basis for indexing site quality. Most commonly, a reference set of site index curves is used to determine how a species will trend in height through time on a given piece of ground. As management decisions have increased in complexity, the need for accurate site productivity classification has also increased. There are at least three major problems with traditional site index curves that are causing serious concerns; they are summarized as follows:

- First, application of site index curves often results in errors due to plantation intensive culture or overstory suppression. There appears to be no way to distinguish early silvicultural effects from “native” or macro” site effects.
- Second, site curves, as traditionally constructed, are broad averages which are insufficient to identify the site specific variation in height growth patterns.
- Third, current management (or the lack thereof) has reduced the population of suitable “site trees” so that it is difficult to obtain reliable site index estimates for each stand in an inventory.

The Ten-Meter (10m) Site Class method is offered here as a direct solution to the first and second concerns. It defines a method to determine the “natural” potential productivity of any forested site independent of silvicultural effects, and the estimates of potential height growth are based solely on site specific measurements. When combined with a soil/site equation, the method addresses concern three by providing robust estimates of potential height growth rates from bio/geo/climatic variables. This paper describes the analytic details of the new approach and provides a set of application tools.

---

1 James D. Arney, Ph.D., Senior Biometrician; Brian L. Kleinhenz, Lead Project Biometrician; and Kelsey S. Milner, Ph.D., Senior Biometrician. All from Forest Biometrics Research Institute, Corvallis, Oregon. Dr. Milner is also retired Champion Professor of Forestry, College of Forestry, University of Montana.
Objectives

This article addresses these objectives:

- Describe the analytical details of this new approach to site classification.
- Demonstrate how traditional site curves are confounded by early silvicultural conditions (early height/age trends).
- Draw attention to the significance in macro-site height growth patterns (late height/age trends)?

The 10m Site Approach

The “two-point” principle was described and published by Boris Zeide (1978). Once the forester has determined two significantly different height/age pairs on a given tree; then this principle is sufficient to determine both the appropriate site index level and growth type (shape) for that tree of any species. Zeide presented a tabular approach wherein two observations of height and age, at points separated by 30 years, are then sufficient to completely define the H/A curve. Theoretically, any two Height/Age pairs are sufficient to define the level and shape. However, due to measurement error and early stand effects; the approach is most stable when the first Height/Age pair is located above approximately 30 feet and the second at a point at least 20 years distant.

The importance of Zeide’s work is two-fold. First, the potential Height/Age curve may be identified, for a species, at a specific location, without reference to a set of site curves! Second, both shape and level of the potential Height/Age curve are quantified. Thus, shape and level can be modeled, and each location can have its own, unique, site (height/age) curve.

Arney (1985) fitted Zeide’s tabular data to a series of non-linear Height/Age equations for each shape index, and then interpolating across parameter values until a match for any observed set of Height/Age pairs was found. This implementation provided the ability to rapidly apply Zeide’s two-point principle to large databases and published site curves. Arney (1985) went on to standardize published site curves (Height/Age) for most species in the West using the Zeide (1978) two-point principle.

Any two points and the associated years between these points are sufficient to determine the site classification of any species given that a series of site curves already exist for this species. If we accept the existing site curves, then total or breast height age is not necessary; only the number of years between the two height measurements is necessary.

Zeide’s basic idea can be applied to any sequence of data where it is desirable to quantify curve level and shape. Arney (1985), Hoyer & Chaws (1980), Milner (1987) have all demonstrated the utility of Zeide’s two-point approach.
Defining 10-meter Site Index

The opportunity in using two height / age pairs (which are beyond approximately thirty feet in height) is that early silviculture and/or crown suppression should have little impact on the determination of site index capacity. This is because total age or breast height age is not used. In fact, the sample tree could have been suppressed at breast height and the two-point method will still provide a good site classification even though breast height age is un-attainable. The implicit assumption is that some existing series of site curves are accepted as being representative for this species in this region.

The problem is that current use of the two-point principle continues to rely on the growth rate being determined by the number of years from ground level (total age) or 4.5 feet (1.37 meters) high (breast-height age) to a height at some future age (e.g., 50 years). This is the implicit assumption when accepting any previously existing site curve. As mentioned earlier, early stand development is highly dependent on early silviculture and competition from other vegetation and animals. These other factors may severely impact the determination of site growth capacity when accepting the existing site curve.

The point being emphasized here is that by accepting an existing site curve “the entire height/age profile from age zero is assumed correct”. This is the assumption being questioned in this article.

Reference Heights – Due to the possible overriding influence of early silvicultural practices, let us consider shifting the first reference point up the tree from breast height. For this 10-meter method, the initial point of reference has been shifted up the tree from 4.5 feet (1.37 meters) to a height of 32.8 feet (10 meters). To facilitate field measurements the reference height is identified in this analysis as 33.8 feet (34 nominal feet) which incorporates nominal stump heights and trim allowances for log merchandizing once the sample tree is on the ground.

The second point of reference is fixed at 67-feet (20 meters) up the tree. This provides the opportunity to establish an absolute site capacity index with no other information. This corresponds to Zeide’s two-point method except that the two heights are pre-specified with number of years between then becoming the variable of interest. See Figure 1 to visualize the height steps.

In the 10-meter approach presented in this paper, a third point of reference is fixed at 100-feet (30 meters) up the tree. The number of years between 10 and 20 meters becomes the site capacity parameter and the number of years between 20 and 30 meters determines the site shape parameter (comparable to Zeide’s shape approach).

Justification for selecting these height measurement points are as follows:
1) Sampling two heights to apply the two-point principle required a minimum interval to exclude annual growth variations. An interval of 10 meters of height purposely forced a minimum acceptable interval for reliable site determination. The lowest 10-
meter site class is 1.0 meter per decade which requires 100 years to accomplish. An upper bound is 20 meters per decade requiring 5 years to accomplish.

2) Trees are often sampled that are too young or influenced by early silvicultural treatments. Requiring the second measurement at 20 meters of height purposely excludes sampling trees that are too young or too short. The tree must be at least 20 meters (67 feet including stump) to qualify as a site tree sample.

3) Height growth rates below 10 meters of height are purposely excluded to remove possible bias due to early silvicultural impacts.

4) Culmination of height growth plays a significant role in volume and value discounting. An interval of 10 meters from 20 to 30 meters in height provides a robust determination of growth decline due to soils, climate and topography in conjunction with site level obtained from the 10 to 20 meter interval.

5) Three simple height steps of 10, 20 and 30 meters are simple to remember, apply and provide favorable log bucking intervals to salvage merchantable segments.

This 10-meter height intercept approach is called the 10m Site Index Method.

**Site Level and Shape** – The measure of site level is the height growth rate (meters / decade) between the first and second reference points. As an aid in interpretation, consider a set of traditional site curves. It can easily be shown that there is a one-to-one correspondence between a published site curve and a measured growth increment. This correspondence is why the “height intercept” method is valid when using traditional site curves. If the height/age pattern of growth follows the published site curve, then any two points observed along the height growth profile of a standing tree will define the site index level for that tree from the published site curve. Zeide (1978) confirmed this by applying the two-point principle to over one hundred published site curves from a broad array of species and regions. Breast height or total age is not necessary.

In this study coastal Douglas-fir (*Pseudotsuga menziesii*) (King, 1966) and interior Douglas-fir (Monserud, 1985) was the primary species of interest in testing the 10m Site Method. For each species sampled, the appropriate published height/age curve was used to define the 10m Site Index level for each site level from the published equations.

As previously described, there is only one traditional site level required to define the published number of years to reach 10-meters, 20-meters and 30-meters in height. As a result, the reciprocal condition is that traditional site index is defined by only observing the number of years between 10 and 20 meters of height (the two-point principle). The only underlying assumption is that the published site curve represents the height/age trend observed in the forest. Table 1 demonstrates this condition for published site curves. Arney (1985) successfully used this two-point principle to incorporate all published site curves into one common growth model architecture for western growth modeling. This has been Dr. Arney’s standard growth modeling architecture for over thirty years in both the Stand Projection System (SPS) (Arney, 1988) and Forest Projection System (FPS) (Arney, Milner & Kleinhenz, 2007) growth models used throughout the West.
Field and Analytical Methods

Felled-Tree Measurements

*Site tree selection* – As with traditional site curves, the success of the 10-meter approach depends on selecting suitable site trees. For the 10m Site Method, selections had to:

- Appear healthy and free of defect and damage, particularly above the 34-foot (10 meter) reference point;
- Appear to represent a dominant or co-dominant crown position;
- Appear to contain a crown ratio of at least 40%; and,
- Were approximately 100 feet (30 meters) in total height.

*Measurements and calculations* – The essential measurements were ring counts at approximately 10, 20, and 30 meters up the tree bole, and the actual heights at each measurement point. Figure 2 shows an example for a Douglas-fir tree.

From Figure 2 the site calculations are as follows:

1. Site level = height growth per decade = (10m/12 yrs) X 10 years) = 100/12 = 8.3 meters/decade.
2. Site shape = (years in first period) / (years in second period) = 12/15 = 80%

This sample tree is easily found for 10m Site and Shape using 12 and 15 years to access Table 2. This 8.3 meters/decade interpolates to traditional site 118 using Table 1. Rates of decline (Table 2) from 90 to 30 percent were observed to occur in both published site curves and observed felled-tree measurements. This is simply the additional years to grow the next 10-meter height interval divided into the years to grow the first interval.

The range of shapes associated with a given 10m Site Level is displayed in Figure 3 using a 10m Site of 8.3 meters/decade from the previous sample tree example and information from Table 2.

We are now no longer concerned with the age of the tree, but only the number of years to achieve a given height growth interval (10 to 20 meters in height) as a *rate index*. Then the number of years to achieve from 20 to 30 meters becomes a *shape index* when computed as a ratio to number of years for the rate index (10 to 20m) / (20 to 30m).

Only the Field Form (Figure 2.) was required to determine 10m Site Index and Shape for each tree in the dataset gathered for the analyses in this paper. No equations were used and no previous published site curves were used to determine either 10m Site or 10m Shape parameters. Both of these parameters are results of direct measurements on each tree.

Field samples within each sampled location are based on a minimum of a three-tree sample of the same species which are located near enough to one another to minimize the risk of entering a new physical site condition. Two or more trees are necessary to control variation in site estimation due to genetic variation and micro-site fluctuations. If the means of three trees is more than ten percent (10%) different than the mean of two trees,
then additional trees were typically sampled. Sampling was completed when the rolling average changed by less than ten percent.

Data sources

These objectives required a detailed stem analysis. A total of eleven regional datasets were gathered across six western States (Alaska, Washington, Idaho, Montana, Oregon and California). All sample trees were compiled to compute 10m Site Index and Shape for each tree at each location. Sample trees with obvious measurement errors were excluded from further analytical steps. Approximately 24% of all felled-trees did not include measurements to a height of 30 meters for shape statistics. This was due to sampling significant areas of low site productivity in some regions.

<table>
<thead>
<tr>
<th>Forests / Regions</th>
<th>Number of Plots</th>
<th>Number of Trees</th>
<th>Number of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>448</td>
<td>1,423</td>
<td>8,461</td>
</tr>
</tbody>
</table>

There was an average of 40 plots and 129 trees per region. Species were typically Douglas-fir (*Pseudotsuga menziesii*) (47%) as the primary selection with Western Larch (*Larix occidentalis*), Western Hemlock (*Tsuga heterophylla*), Ponderosa Pine (*Pinus ponderosa*), Sitka Spruce (*Picea sitchensis*), Grand Fir (*Abies grandis*), White Fir (*Abies concolor*) and Lodgepole Pine (*Pinus contorta*) as secondary selections (more than 10% per species). Other notable species included Engelmann Spruce (*Picea engelmannii*) and Western Red Cedar (*Thuja plicata*). Nine other species were sampled occasionally.

Within each of the eleven forests, sample stands were located to fill cells in a sampling matrix defined by factorial combinations of elevation, solar radiation, precipitation and soil depth. Latitude, elevation, aspect and slope were collected at each sample location. These four parameters were used to calculate growing season length and temperature on each site using mechanistic computations via the MT-CLIM model developed by Running et al. (1987). Rooting depth and available water capacity were estimated for each location using the Natural Resources Conservation Service Soil Survey Geographic (SSURGO, USDA undated) database. Precipitation data came from data distributed by the Oregon Climate Service (Daly & Taylor, undated). These topographic / climate / soil parameters were used to pre-stratify the potential felled-tree sample locations.

Without question, this database is the largest collection of felled-tree measurements for site productivity ever gathered across the West using a single sample design and data collection set of criteria. The stringent distribution of sample locations and selection of upper-stem sample points have created a unique and robust analytical database to evaluate the biometrics of site tree measurement and site productivity assessment. Synthesis of all past research, discussed earlier in this report, has lead to the development of this matrix of sample sets and measurements. This sample frame has produced three (2-7) felled-trees per plot with 40 (27-48) plots per forest in eleven regions (six States).
Results

Separating Early Silviculture Effects from Site Estimation

Table 1 provides the Computed Site Index (Breast Height Site and 10m Site) determined by using the two-point principle for the number of years from 10 to 20 meters in height on each of the 1,423 felled trees from this study’s datasets.

With this assignment of both Breast Height Site Index and 10m Site Index firmly in place on each felled-tree, it is now possible to compare the observed and expected number of years to grow from stump height to 34 feet (10 meters). The observed number of years was taken directly from each felled-tree. The expected number of years is taken from the published height/age curve (Table 1, # of years 0 to 10 meters). Figure 4 displays the expected total years to reach 10 meters in height for a selection of published Western Species Site Curves.

The number of years in Figure 4 by species is the direct observation from each individual published site curve which are the results of the model form selected by each author and the silvicultural history of the datasets used in each of those analyses. The actual number of years to achieve a height of 10 meters from all felled-tree observations is presented in Figure 5. The dashed line is the expected relationship between observed and expected growth rates. The solid line is the actual average trend from these analyses. All species are included in the display. Results are similar for each species and author individually and therefore are not presented independently.

Standard deviations of plot averages were computed by site level (expected years) in Figure 6. This confirms the assumption that variation in early height growth may potentially confound estimates of native site capacity when breast height age is used.

Figures 5 and 6 demonstrate: a) high variance (R-square = 0.3422) among all samples depending on the silvicultural history imbedded in the stand height development; and b) a biased regression line through the scatter of observations. Figure 6 demonstrates for butt logs with a 30-year expected growth interval, it may actually take anywhere from 10 to 50 years (two standard deviations) to grow the 10 meter height. That 40-year variation is extremely significant if it were imbedded in a traditional application of breast height age and total height to estimate the native site capacity.

Separating Regional Shape Profile Effects from Site Estimation

With the relationship in Table 1 between Breast Height Site Index and 10m Site Index firmly defined on each felled-tree, it is also now possible to compare the observed and expected number of years to grow from 20 to 30 meters in height. The observed number of years was taken directly from each felled-tree. The expected number of years is taken from the published height/age curve (Table 1, # of years 20 to 30 meters). Figure 7 displays the expected site curve shape for a selection of published Western Species Site Curves.
It is curious to notice the wide variety of relationships found in these published site curves (King, 1966; Monserud, 1985; Meyer, 1938; Summerfield, 1980; Barrett, 1978) when extracted to the essence of site level and shape. The Redwood (Lindquist & Palley, 1963) and Western White Pine (Haig, 1932) shapes are likely a result of guide curve methods applied independently to individual levels of site index. The trend in shapes of the other species is likely due to the equation form selected by each author at the time of analysis. Additionally, there is no way to determine the state of soil, climate and topography present in the sampled stands of each author and analysis. Therefore, there is little basis available to determine if those factors imbedding in those analyses could be similar or different from sampling stands for site capacity today.

It is not the goal of this analysis to critique the robustness of these existing site curve publications for their original goals as regional guides. They are what they are and they have served us well over the forty plus years when we have applied them for site capacity and growth projection. They represented the whole life profile of height/age development for each species and site class at the time of development. This analysis seeks to evaluate the assumption that there is only one height/age profile per site class.

If there is only one height/age profile per site class, then Figure 5 and Figure 8 would display very tight trends between Observed and Expected numbers of years per segment. Figures 8 and 9 demonstrate: a) high variance (R-square = 0.0017) among all samples likely depending on the macro-site conditions of soil, climate and topography; and b) a biased regression line through the scatter of observations. Results of all individual species are similar to those presented here for averages by plot.

Standard deviations of plot averages were computed by site level (expected years) in Figure 9. The results are obvious that observed height/age development is nowhere near the expected trends found in existing published site curves. These results are common among all species and regions. Therefore the individual species are not displayed.

**Conclusions on 10m Site and Shape**

It is expected that there should be a high correlation between height growth rates from the butt 10-meter segment to the second 10-meter segment and finally to the third 10-meter segment if one is to accept traditional site height / age curves as robust indicators of the macro-site growth potential. However, it is obvious from these analyses that early height growth (the butt segment) and late height growth (the third segment) are poorly correlated with traditional site classification. Traditional site curves for all species contain significant bias when applied to any individual stand as demonstrated from these analyses. It is not known whether this bias is high or low due to the unique combination of historical silviculture and macro-site (soil / climate / topography) found on each stand.

First, factors other than site capacity are major influences on observed height growth up to 10 meter heights. Every species sampled in this analysis demonstrated these same impacts of early silviculture on height growth. These correlation coefficients (R-square)
to 10m Site Index should be very high if it is expected that height growth in the butt segment should follow the height / age profile of published site index curves. This is not the case. Results from these analyses demonstrate only a 34% correlation of early height growth with site class (expected years by site class). It appears that silvicultural history may be a more important factor than site index in determining early height growth rates.

Second, factors other than site growth rate alone contribute major influences on extended height/age trends. Every species sampled in this analysis demonstrates broad ranges in height curve shape within each level of site capacity. Correlation coefficients (R-square) across traditional Breast Height Site Class should be very high if it is expected that observed height growth in the upper segment (20 to 30 meter heights) should follow the height / age profile of published site curves (height/age curves). This is not the case. Results from these analyses demonstrate that there is absolutely no correlation of site curve shape with site class. It appears that local soil / climate / topographic levels may be more important factors than site index alone for determining shape of height growth profiles. These conclusions are the same for all species and regions sampled.

As well stated by Monserud (1985), the evolution of site curve development over the past seventy years has resulted in classification differences within a given species and region depending on which report is being referenced. He stated, “Differences that are methodological rather than biological are clearly causes for concern.” Both the Haig (1932) and Meyer (1938) methodologies of applying guide curves to develop site curves are early examples of Dr. Monserud’s conclusions. Most currently published site curves continue to demonstrate this concern as demonstrated for Douglas-fir in this report.

The pivotal work by Zeide (1978) opened the door to this article’s authors with the concept that height curve shapes could and should be defined completely independently from site levels. This concept provided a universal modeling structure that could encompass multiple combinations of silvicultural history and site productivity levels. Natural stands and plantations did not require completely separate datasets and analyses to discover the underlying macro-site capacity of that stand at that location. This provided the means to model all species using a single architecture with localization of only one or two parameters per species or region.

Zeide referred to a two-point principle given a known height/age curve. If the curve was unknown at the time of data collection, then three points (heights) with associated years between them provided a height/age curve without the requirement of a previously known site curve. It is this three-point principle which 10-meter site is based. This 10-meter site classification method requires no previously published site curves, reference charts, tables or equations.

Challenges and Opportunities

The 10-meter site method as laid out in this discussion is essentially a simplified method for building site curves directly from stem analysis data. In this way, each tree defines its own growth trajectory. 10-meter site has one major draw back, the requirement to
destructively sample selected site trees. This approach offers several opportunities including: direct measurement of site, greater freedom for the selection of site trees, the ability to compare species regardless of total age or tolerance, applicability in all-age or uneven-age forest types and independence from early stand silviculture.

A destructive sample of site trees will no doubt slow the widespread implementation of the methods outlined in this paper. Many forest managers will likely hesitate at the thought of cutting down three of the best dominant trees in the stand, even if the result is vastly improved information. The authors anticipate that there are two main factors that will mitigate this concern: a) use of a soil-site equation to generate estimates for all stands in the forest; and, b) creation of a relatively permanent site stratification map that will eliminate the need to collect site data as part of regular forest inventory work. There is also the possibility of developing a non-destructive field technique to determine 10m Site Index.

Very few (if any) managers have measured site calls for every stand on their ownership. Foresters have always been faced with the problem that often many of the stands in the forest are not old enough, tall enough or have questionable treatment history to sample for site. Often, measured site calls may be as un-reliable as or worse than soil-site estimates. This may be due to improper tree selection or use of an inappropriate site curve. Traditional site classification methods (breast height age and total height) combine the variation in the butt log segment (0 to 10 meters) with the growth rate of the second segment (10 to 20 meter height). As demonstrated in these analyses, this inserts significant variation and potential bias in the estimated site index. The result may be termed “Expressed Site Index” for the specific history of the sampled stand. 10-meter site provides more consistent results as a site classification method than traditional breast height methods. This is likely due to minimizing the influences of silvicultural history and variability in the various limiting factors of soils, climate and topography.

Recommendations

These analyses have confirmed that the 10m Site Classification method should replace all current methods utilizing total or breast height age. It provides a permanent assessment of the natural productivity of any forest bio/geo/climatic region. In other words, this method attempts to classify the macro-site level and distribution of forest productivity independent of all silvicultural or genetic effects.

If we (foresters, landowners, biometricians, geneticists, tax assessors) are to determine a consistent, robust and permanent classification of productivity, then that basis is height growth capacity as defined by the 10m Site Classification method.

1) Height growth from 0 to 10 meters has more correlation with silvicultural history than with site index capacity. Height growth should be estimated from a silvicultural treatment model rather than a site index model.

2) References to native site capacity for land evaluation, taxation, genetic research, nutrition research and vegetation management research should be reviewed and
revised. The current assumptions may well be significantly biased as demonstrated in this report.

3) Traditional height/age curves for site classification have served well in prior decades, but it is now clear that these methods indeed contain significant biases depending on their application.

4) Many growth models already treat small-tree growth separately, but continue to use site curves to develop height/age projections. The 10-meter approach appears to be the natural evolution of improved growth modeling development.

It is time to progress from the “Practice of Forestry” to the “Science of Forestry”. Building empirical site curves based only on local observation of a current dataset will never progress beyond the practice of forestry. Only by building on basic principles that relate to all species, growth dynamics and regions will we discover the science of forestry².

² Dr. Boris Zeide. Personal correspondence November 1, 2007 regarding his draft manuscript, “The Science of Forestry”.
References


5. Daly, C., Taylor, G. Oregon State University and the Oregon Climate Service at Oregon State University. Average Monthly or Annual Precipitation, Water and Climate Center of the Natural Resources Conservation Service. [http://www.ocs.oregonstate.edu/](http://www.ocs.oregonstate.edu/)


Table 1. Parameters derived from published site curves (King, 1966 example).

<table>
<thead>
<tr>
<th>BH Site Index</th>
<th># Years 0-10 meters</th>
<th># Years 10-20 meters</th>
<th># Years 20-30 meters</th>
<th>10m Site Index</th>
<th>10m Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>52.4</td>
<td>191.6</td>
<td>8770.0</td>
<td>0.5</td>
<td>0.02</td>
</tr>
<tr>
<td>50</td>
<td>41.4</td>
<td>64.7</td>
<td>1356.9</td>
<td>1.5</td>
<td>0.05</td>
</tr>
<tr>
<td>60</td>
<td>35.1</td>
<td>38.1</td>
<td>127.9</td>
<td>2.6</td>
<td>0.30</td>
</tr>
<tr>
<td>70</td>
<td>30.4</td>
<td>27.3</td>
<td>59.6</td>
<td>3.7</td>
<td>0.46</td>
</tr>
<tr>
<td>80</td>
<td>27.1</td>
<td>21.2</td>
<td>37.8</td>
<td>4.7</td>
<td>0.54</td>
</tr>
<tr>
<td>90</td>
<td>24.3</td>
<td>17.5</td>
<td>27.2</td>
<td>5.7</td>
<td>0.64</td>
</tr>
<tr>
<td>100</td>
<td>21.9</td>
<td>14.9</td>
<td>21.3</td>
<td>6.7</td>
<td>0.70</td>
</tr>
<tr>
<td>110</td>
<td>19.8</td>
<td>13.2</td>
<td>17.6</td>
<td>7.6</td>
<td>0.75</td>
</tr>
<tr>
<td>120</td>
<td>17.8</td>
<td>11.8</td>
<td>14.9</td>
<td>8.5</td>
<td>0.78</td>
</tr>
<tr>
<td>130</td>
<td>15.8</td>
<td>10.6</td>
<td>13.2</td>
<td>9.4</td>
<td>0.80</td>
</tr>
<tr>
<td>140</td>
<td>14.0</td>
<td>9.7</td>
<td>11.7</td>
<td>10.4</td>
<td>0.82</td>
</tr>
<tr>
<td>150</td>
<td>13.3</td>
<td>9.0</td>
<td>10.5</td>
<td>11.1</td>
<td>0.85</td>
</tr>
<tr>
<td>160</td>
<td>12.7</td>
<td>8.5</td>
<td>9.6</td>
<td>11.8</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Table 2. Height Growth Rates (Level) and Decline (Shape) – All Species & Regions.

<table>
<thead>
<tr>
<th>10m Site</th>
<th>10 to 20m</th>
<th>90%</th>
<th>80%</th>
<th>70%</th>
<th>60%</th>
<th>50%</th>
<th>40%</th>
<th>30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years</td>
<td>20 to 30 meters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>100.0</td>
<td>111.1</td>
<td>125.0</td>
<td>142.9</td>
<td>166.7</td>
<td>200.0</td>
<td>250.0</td>
<td>333.3</td>
</tr>
<tr>
<td>2.0</td>
<td>50.0</td>
<td>55.6</td>
<td>62.5</td>
<td>71.4</td>
<td>83.3</td>
<td>100.0</td>
<td>125.0</td>
<td>166.7</td>
</tr>
<tr>
<td>3.0</td>
<td>33.0</td>
<td>36.7</td>
<td>41.3</td>
<td>47.1</td>
<td>55.0</td>
<td>66.0</td>
<td>82.5</td>
<td>110.0</td>
</tr>
<tr>
<td>4.0</td>
<td>25.0</td>
<td>27.8</td>
<td>31.3</td>
<td>35.7</td>
<td>41.7</td>
<td>50.0</td>
<td>62.5</td>
<td>83.3</td>
</tr>
<tr>
<td>5.0</td>
<td>20.0</td>
<td>22.2</td>
<td>25.0</td>
<td>28.6</td>
<td>33.3</td>
<td>40.0</td>
<td>50.0</td>
<td>66.7</td>
</tr>
<tr>
<td>6.3</td>
<td>16.0</td>
<td>17.8</td>
<td>20.0</td>
<td>22.9</td>
<td>26.7</td>
<td>32.0</td>
<td>40.0</td>
<td>53.3</td>
</tr>
<tr>
<td>7.1</td>
<td>14.0</td>
<td>15.6</td>
<td>17.5</td>
<td>20.0</td>
<td>23.3</td>
<td>28.0</td>
<td>35.0</td>
<td>46.7</td>
</tr>
<tr>
<td>8.3</td>
<td>12.0</td>
<td>13.3</td>
<td>15.0</td>
<td>17.1</td>
<td>20.0</td>
<td>24.0</td>
<td>30.0</td>
<td>40.0</td>
</tr>
<tr>
<td>9.1</td>
<td>11.0</td>
<td>12.2</td>
<td>13.8</td>
<td>15.7</td>
<td>18.3</td>
<td>22.0</td>
<td>27.5</td>
<td>36.7</td>
</tr>
<tr>
<td>10.0</td>
<td>10.0</td>
<td>11.1</td>
<td>12.5</td>
<td>14.3</td>
<td>16.7</td>
<td>20.0</td>
<td>25.0</td>
<td>33.3</td>
</tr>
<tr>
<td>11.1</td>
<td>9.0</td>
<td>10.0</td>
<td>11.3</td>
<td>12.9</td>
<td>15.0</td>
<td>18.0</td>
<td>22.5</td>
<td>30.0</td>
</tr>
<tr>
<td>12.5</td>
<td>8.0</td>
<td>8.9</td>
<td>10.0</td>
<td>11.4</td>
<td>13.3</td>
<td>16.0</td>
<td>20.0</td>
<td>26.7</td>
</tr>
<tr>
<td>14.3</td>
<td>7.0</td>
<td>7.8</td>
<td>8.8</td>
<td>10.0</td>
<td>11.7</td>
<td>14.0</td>
<td>17.5</td>
<td>23.3</td>
</tr>
<tr>
<td>16.7</td>
<td>6.0</td>
<td>6.7</td>
<td>7.5</td>
<td>8.6</td>
<td>10.0</td>
<td>12.0</td>
<td>15.0</td>
<td>20.0</td>
</tr>
<tr>
<td>20.0</td>
<td>5.0</td>
<td>5.6</td>
<td>6.3</td>
<td>7.1</td>
<td>8.3</td>
<td>10.0</td>
<td>12.5</td>
<td>16.7</td>
</tr>
</tbody>
</table>
Figure 1. Traditional Breast Height Site Curves by King (1966)

Conventional Site Curves based on Breast Height Age
Height Intercepts - Overlayed at 10, 20 and 30 meters

Breast Height Age (years)

Total Height (meters)

Figure 2. 10m Site Field Form (required measurements in bold print)

Tree #: 101
Species: DF

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Height</th>
<th># Rings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>100.8</td>
<td>0</td>
</tr>
<tr>
<td>100-ft</td>
<td>99.6</td>
<td>2</td>
</tr>
<tr>
<td>67-ft</td>
<td>66.5</td>
<td>17</td>
</tr>
<tr>
<td>34-ft</td>
<td>32.3</td>
<td>29</td>
</tr>
<tr>
<td>Breast Ht</td>
<td>4.5</td>
<td>38</td>
</tr>
<tr>
<td>Stump Ht</td>
<td>1.0</td>
<td>46</td>
</tr>
</tbody>
</table>

Increment:
34 to 67     34.2  12
67 to 100     33.1  15
Site Index¹: 8.3
Shape Index²: 80%
Figure 3. Example – A 10m Site of 8.3 meters/decade is displayed in the following chart.

Standardized 10m Site Level = 8.3 meters/decade
Variations in Shape to Achieve 30-meter Total Height

10m Site: 8.3
12 Years
95% 87% 79% 72% 65% 59% 53% 46% 38%

20-year range in shape

Figure 4. Expected number of years to reach 10-meter height by Site Class.

Total Years to 10m Height by Site Class
Western Species Published Trends

King DF
Monserud DF
Meyer PP
Barrett PP
Summerfield PP
White Pine
Redwood
Figure 5. Expected and Observed Years to 10-meter height averaged by plot location.

![Plot Averages - Expected and Observed Years](image)

Plot Averages - Expected and Observed Years
Butt Log Segment (0 - 10 meters)

Figure 6. Magnitude of One Standard Deviation across the range of observed plots.

![Plot Averages - Expected and Observed Years](image)

Plot Averages - Expected and Observed
Butt Segment Years (0 - 10 meters)
Figure 7. Expected Shape by Author and Species for some Western Species.

![Graph showing expected shape by site class, with Western Species published trends.]  

Figure 8. Expected and Observed 10m Shape for sample plot averages.

![Graph showing plot averages - expected and observed site shape for 3rd log segment (20-30 meters).]  

\[ R^2 = 0.0017 \]
Figure 9. Magnitude of One Standard Deviation across the range of observed plots.