CO-OP REDWOOD YIELD RESEARCH PROJECT
*Department of Forestry and Conservation*
*College of Natural Resources*
*University of California*
*Berkeley, California 94720*

Lee C. Wensel
*Associate Professor*

Bruce Krumland
*Assistant Specialist*

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# EVALUATION OF DOUGLAS FIR SITE INDEX CURVES FOR THE NORTH COASTAL REGION OF CALIFORNIA

by

Bruce E. Krumland and Lee C. Wensel

In the transition from old growth to young growth forest management, the emphasis of management planning shifts from estimates of standing volumes to estimates of future yields as primary determinants of harvest regulation. As site quality is a major factor influencing stand performance, accurate and consistent measures of this item are desirable.

Age-height relationships have long been accepted as a means of forest stand site classification. The "site index" (height of a specific stand component at an arbitrary base age) is used as a measure of the productive capacity of the site. Several sets of site index curves have been constructed for Douglas fir. With the exception of the curves by Schumacher (1930), all of the samples used in construction were taken north of the Oregon-California border or in other countries.

In view of the diversity of shapes of site curves developed by different investigators and the possibility of different growth patterns between stands in different geographical areas, an analysis was performed to evaluate the applicability of existing Douglas fir site curves to forest conditions in the North Coastal Region of California.

## I. General Site Index Concepts

### A. Interpretation

Given the three variables, age(A), height(H), and site index(S), two forms of the relationship between these variables are useful:

$$H = f_1(A,S) \qquad (1)$$

$$S = f_2(H,S) \qquad (2)$$

where $f_1$ and $f_2$ are mathematical functions defining the respective relationships.

In the construction of site index curves, the first form is commonly used and in practice, site index is estimated by inverting this relationship.

This form may be more correctly noted as a height growth relationship. The second form leads to direct estimation of site index.

It should be noted that constructing age-height-site relationships in these two forms from the same sample basis will not lead to the same estimates of site index unless there is perfect correlation between variables. Curtis et.al. (1974) have provided a study and discussion of the differences and possible implications arising out of the use of these two different relationships.

Of practical importance, estimates of site index by both of these methods will coincide at the site index base age. Divergence in site index estimates increase with the age difference between the site index base age and the actual age of the stand for which site index is being estimated. Consequently, selection of a site index base age somewhere around the probable rotation age for the region (50-70 years) seems desirable.

B. Construction Methods

1. Proportional Guide Curve Method

This method is the traditional method of constructing site index curves. Essentially, the sample consists of single age-height measurements on trees and/or stands. A single curve of $H = f(A)$ is derived for the whole sample giving a guide curve with a site index value where this curve intercepts the base age. Curves for other sites are derived by a proportional adjustment of this curve. Principal shortcomings of this method are:

a) Sampling is done without knowledge of site index. Consequently, if the site sample is not evenly distributed within age classes, the shape of the guide curve may be distorted.

b) Proportional shifting of the guide curve precludes the possibility that the shape of the age-height curve for different sites may change.

2. Polymorphic Stem Analysis Methods

In this method, trees older than the site index base age are sampled and heights at various ages including the base age are determined by stem analysis. Thus, the site index of the tree is known before curve construction takes place rather than being a product of fitting method as with guide curves. Usually, relationships of the implicit form; $H = f(S,A)$ are subsequently fitted by regression techniques. The form of the site model equation selected is usually general enough to allow the shape of height-age relationship to vary with site (e.g., polymorphic curves). This method is generally considered to be superior, though more costly.

## II. Evaluation

### A. Site Index Curves Compared

Three sets of site index curves were chosen for evaluation. All are of the form H = f(A,S)

1. McArdle et.al. (1961)

| | |
|---|---|
| geographical basis; | samples collected in Oregon and Washington |
| construction method; | proportional guide curve |
| base age; | one hundred years total age |
| stand component; | average height of dominant and codominant trees |
| remarks; | commonly used for Douglas fir site classification in the North Coast Region |

2. Schumacher (1930)

| | |
|---|---|
| geographical basis; | samples collected in California. Eighty-seven percent of the sample plots were located in the North Coast Region. |
| construction method; | proportional guide curve |
| base age; | fifty years total age |
| stand component; | average height of dominants |
| remarks; | only Douglas fir site curves constructed from samples collected in California. Little used in practice. |

3. King (1966)

| | |
|---|---|
| geographical basis; | samples collected in Washington |
| construction method; | polymorphic stem analysis |
| base age; | fifty years breast high age |
| stand component; | ten trees with the largest breast high diameters in fifty. |
| remarks; | generally accepted as being most accurate for Douglas fir in the Pacific Northwest |

To facilitate evaluation, the tabled total age values of Schumacher's and McArdle's site curves were adjusted to breast high ages by the following factors (King, 1966).

| Site Index (100 yrs) (feet) | Adjustment (feet) |
|---|---|
| 190-210 | -6 |
| 160-180 | -7 |
| 130-150 | -8 |
| 100-120 | -9 |
| 80-90 | -10 |

Site index values were subsequently expressed as height at a breast high age of fifty years. To simplify numerical analysis the adjusted age-height-site tabulations for both curve sets were reduced to exponential equations.1/ King's site index study was accompanied by equations which were used directly.

Table 1. shows the difference in the shape of these curves for a site index of 120, roughly comparable to what is commonly known as site II in the region. Note that McArdle's and Schumacher's curves are almost coincident with King's curve starting lower and ending higher than the other two.

Curtis (1966) compared McArdle's and King's site curves with successive site estimates on permanent growth plots in the Pacific Northwest. Although height growth patterns for specific plots differed significantly from either curve set, he found that King's curves fit the sample data best. His sample was largely from stands over forty-five years of age. From Table 1., this would indicate that the curves of Schumacher and McArdle would underestimate site index at ages less than base age and produce overestimates for older age classes.

Table 1. Total tree heights in feet by breast high age for site index of 120. Site index base is fifty years breast high age.

| Age | King | McArdle | Schumacher |
|---|---|---|---|
| 15 | 46 | 56 | 56 |
| 20 | 59 | 68 | 69 |
| 30 | 83 | 89 | 89 |
| 40 | 103 | 106 | 106 |
| 50 | 120 | 120 | 120 |
| 60 | 134 | 132 | 132 |
| 70 | 146 | 142 | 142 |
| 80 | 156 | 150 | 151 |
| 90 | 164 | 157 | 158 |
| 100 | 172 | 163 | 164 |

B. Sample Basis for Comparison

The sample consisted of 92 dominant and 26 codominant Douglas fir trees with two or more breast high age-total height measurements taken over an interval of 10-25 years. The samples were extracted from records of growth plots maintained by members of the Redwood Yield Research Cooperative and supplemented with field work during the Spring and Summer of 1976. The plots were located in Del Norte, Humboldt, and Mendocino Counties. Tree ages ranged between ten and seventy years at the time of sampling with the average age being approximately forty years. Crown classification and height measurements were made by a variety of personnel over the years. In some cases, obvious errors on field measurements were evident (e.g., "negative" height growth). All data points however were used as recorded and errors in field measurements were assumed to be random.

C. Analysis

If a given set of site index curves accurately portrayed the height growth patterns of forest trees (stands), it would be expected that successive site estimates made from measured height growth would be the same. No formal hypothesis however was developed to accept or reject any of the site curves. Rather, a framework was adopted to provide a basis for comparing the three site curves and provide some indication of where differences, if any, between sample data and individual site curves lie.

Several regressions of successive estimates of site index on age for single trees over intervals of 15-20 years indicated strong linear trends. As there was no common time interval for which deviations from average site values could be compared and the probability that the use of more than one observation from a single tree would lead to serial correlation of residuals, an average site index value was computed for all measurements on a single tree. One of these measurements was chosen at random for further consideration.

For the purpose of this analysis, let:

$Y_j$ = estimated average annual change in site index for the $j^{th}$ tree.

$A_j$ = estimate of the average age of the $j^{th}$ tree for which $Y_j$ was computed.

Initial plotting of $Y_j$ against site class revealed no significant trends largely because the dispersion of site values was small relative to $Y_j$. Plots against age however indicated significant trends. The following model was chosen for comparative purposes after examining the residuals of several functional forms.

$$Y_j = a + b(\log A_j) + \text{error term}$$

This is similar to the model used by Curtis (1966) in his comparison. Statistical tests show a significant relationship between age and annual change in site index for both the McArdle and Schumacher curves, but not for King's.2/

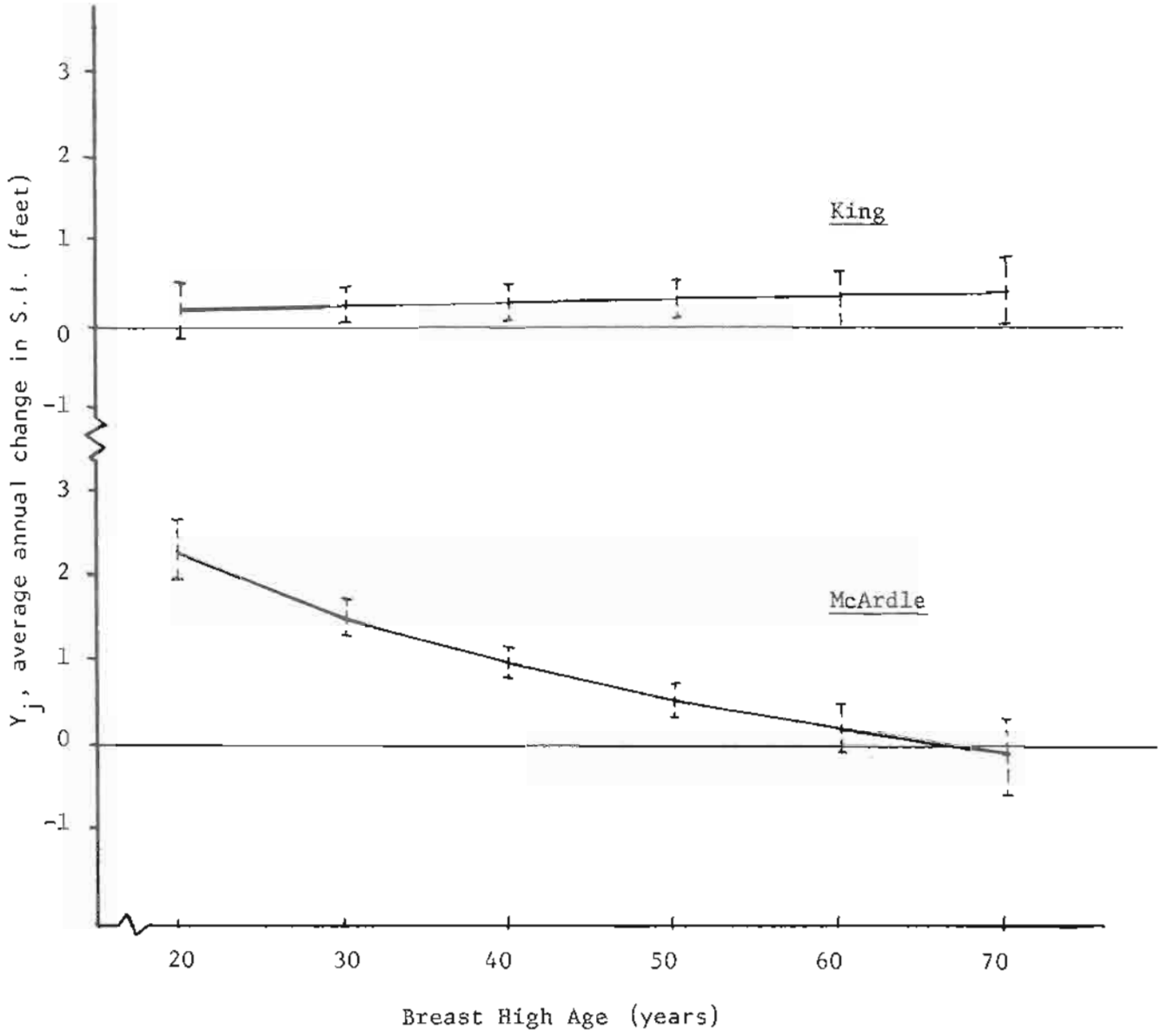


Figure 1. Predicted annual change in site index ($Y_j$) at different ages for different site curves. Vertical dashed lines denote one standard error above and below the regression line.

These results are comparable with those of Curtis (1966). As an indication of the differences by age, Figure 2. shows predicted values of $Y_j$ at different ages along with standard errors of estimate. There was no significant difference between the estimated "a" and "b" coefficients for McArdle's and Schumacher's site curves so only $Y_j$ predictions for the McArdle comparison are shown.

## III. Discussion and Conclusions

While the comparisons made here do not provide conclusive grounds for accepting or rejecting any of the site curves, they do indicate that the site curves of King fit the sample data best.

It is noteworthy that all three sets of site curves call for an estimate of site index to be made as an average for some stand component. The comparisons here were made on the basis of site values for individual trees largely because sufficient information was unavailable to provide consistent successive site samples on growth plots by the methods recommended by individual investigators. The samples used were largely dominants, located in the upper tenth percentile of the diameter and usually taller in height than the average stand component basis recommended by all investigators for site determination. As the differentiation of trees into different crown classes becomes more pronounced with advancing age, the predicted deviations shown in Figure 2 may be overestimated. This possibility would tend to support King's curves although those of Schumacher and McArdle would still probably underestimate site index at ages less than the base age and overestimate them at older ages.

Site index is often used as a predictor variable in growth and yield analysis. Bias in site curves may subsequently result in biased growth models. As an example, if King's curves are assumed to accurately portray height growth, site estimation of a twenty year old stand with McArdle's curves would result in a 14 percent underestimate of site index with a 50 year base age. This difference would increase to 20 percent if the base age were 100 years.

In terms of future comparisons, the most desirable study would be the construction of new site curves by stem analysis techniques. Until that time, King's curves appear to be a reasonable substitute.

## Literature Cited

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## Footnotes

1/ Modified Chapman-Richards growth functions were used to reduce tabled age-height-site values to equations of the form:

$$H = g_1(S)\left[1.-e^{g_2(S)A}\right]^{g_3(S)}$$

where

e = base of the natural logarithms

$g_1(S) = b_{0i} + b_{1i}S$ with the parameters $b_{0i}$ and $b_{1i}$ being estimated by the nonlinear regression of the tabled height values on site and age

S = site index (total height at 50 years)

A = breast high age

Heights predicted by these equations differed at most by 1.08 feet from adjusted tabled values throughout the range of sample data available for comparisons.

2/ For the model

$$Y_j = a + b(\log A_j)$$

The "F" statistic where

$$F = \frac{\text{variance explained by the model}}{\text{unexplained variance}}$$

provides an indicator of the degree that $Y_j$ is related to age. For the three sites compared.

(continued)

2/ (continued)

| | F | F-probability | |
|---|---|---|---|
| McArdle | 36.1 | .001- | Sig |
| Schumacher | 32.3 | .001- | Sig |
| King | .2 | .69 | NS |

degrees of freedom = 1,116

The F-probability values would indicate critical levels required to reject the overall model as being non-significant if hypotheses were being tested (i.e., $Y_j$ is not related to Age). Values of .05 and .01 are commonly used in practice.