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A Site Index System for Redwood and Douglas-fir in California's North Coast Forest

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ABSTRACT

This article evaluates and compares existing site index equations applicable to redwood and Douglas-fir in California's north coast redwood forest. The authors find previous site index models for redwood to be biased, particularly in younger age classes. They therefore developed new polymorphic site index equations for this species, using both stem analysis and permanent plot data from Humboldt, Del Norte, and Mendocino counties. The new curves use a 50-year breast-height (4.5-foot) age as a base.

For Douglas-fir, tests showed King's site index model for Douglas-fir in Washington and Oregon to be unbiased and adequate for Douglas-fir site index estimation in the north coast. Also, for cases in which appropriate site index trees are available for only one species, the authors give equations to predict redwood site index from Douglas-fir site index or to predict Douglas-fir site index from redwood site index.

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Lee C. Wensel and Bruce Krumland

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INTRODUCTION

THE SITE QUALITY of forestland is the average capacity of a designated land area to grow forest trees (Ford-Robertson 1983). Because site quality is a major factor influencing forest stand performance, an accurate and consistent measure is important to the forest manager. Site quality evaluation methods have been reviewed elsewhere by Jones (1969) and Hagglund (1981). Direct measures of site quality, such as volume production capacity (Hagglund 1981), are not usually available for most sites. Even if they are available, from a previous rotation for instance, they may be measures for a different species mix and stand structure than presently exist on the site.

Without direct measures of forestland productivity, foresters have long used age-height relationships to classify forest stand productivity in what is conventionally called a site index system. The purpose of our research was to evaluate existing site index systems and, where necessary, to develop new ones for application to redwood (*Sequoia sempervirens* [D. Don] Endl.) and Douglas-fir (*Pseudotsuga menziessii* [Mirb.] Franco) in California's north coast redwood forest.

FOREST SITE INDEX SYSTEMS

The average height of a specific forest stand component at a specified base age constitutes a site index (Husch, Miller, and Beers 1972). Tree height evolved as an index of site productivity from the general observations that better sites produce taller trees and that the height growth of upper canopy trees is relatively independent of stand density. The latter observation is a basic assumption necessary for testing the validity of any site index system.

Four main factors define a site index system. These are (1) a stand component definition, (2) a base age definition, (3) a site index model, and (4) a stand site prediction rule.

Stand Component

Researchers have suggested and used various stand component definitions in site index applications over the years. Assman (1970) cites the following European definitions: the 100 tallest trees per hectare (Hart's top height), trees from the upper 20 percent of the stand in diameter at breast height (Weise's top height), and the average height of all trees in a stand, weighted by tree basal area (Lorey's top height). Realistically, these definitions can be applied only to even-aged stands. North American practices traditionally use trees from either the dominant crown class (Lindquist and Palley 1961; and others) or the dominant and codominant crown classes (McArdle and Meyer 1961; and others).

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Base Age

The site index equations in our study use a base age of 50 years, measured at breast height (4.5 feet). In this respect they contrast to the 100-year total age systems given elsewhere (Lindquist and Palley 1961; McArdle and Meyer 1961), but hold consistent with the work of King (1966) for Douglas-fir in the Pacific Northwest (see below). Breast height is the standard point on the tree for measuring age by counting rings on a sample core taken with an increment borer. This convention eliminates the necessity of estimating how many years the tree took to reach breast height.

The base age chosen influences the accuracy of site index estimates to the extent that the actual age of a tree for which site index estimates are desired differs from the base age. In general, if the tree age is close to the base age, a shorter projection is required, and so the site index estimate is more accurate. Site index estimates are seldom required for stands younger than 20 years, and the rotation age in the north coast region tends to be around 70 or 80 years, so 50 years is a reasonable choice for a base age.

Site Index Models

As shown by Curtis, DeMars, and Herman (1974), the functional relationship between tree age (A), height (H), and site index (S) can be defined either by expressing height as a function (f) of age and site index,

$$H = f(A,S), \qquad [1]$$

or by expressing site index as a function (g) of age and height,

$$S = g(A,H). \qquad [2]$$

Curtis and coworkers (1974) discuss the possible implications arising from the use of each equation type. Equation 1 is preferred here because it makes possible the direct estimate of tree heights for growth and yield modelling. Since the regression surfaces differ, equations 1 and 2 will usually lead to slightly different estimates of site index—except when the tree age is equal to the site index base age. Then, if properly conditioned, the two equations give the same result. Curtis (personal communication) notes that "differences between the two equations are usually fairly minor except for quite young stands (less than one half of the base age)." This observation is further explored by Monserud (1984) who found, within the range of the data sampled, relatively minor differences between height and site index models.

Our study uses equation 1 as a model. Curve fitting was with a polymorphic stem analysis method (King 1966; Biging 1984). In this method, trees are sampled, and heights at various ages, including the base age, are determined by *stem analysis* (dissection of the tree to determine height at various past ages). Since the tree age is greater than or equal to the index age, the site index can be determined for each tree.

Stand Site Prediction Rules

The guide curve method of constructing site index curves can be implemented in two ways. The first method used the dominant height and age of individual trees. In the second method, average dominant height and average age of trees on individual sample plots are used. The stem analysis method uses data from individual trees.

Similar choices exist for subsequent estimation of stand or plot site index. Either the sample heights and ages are averaged and the site index is estimated from the averages, or the site index is estimated for *each* sample tree, and the resulting estimates of site index are averaged together. These two methods produce different results unless either the relationship between height and age is linear or the trees are all the same age. Over most of the age range of forest trees, the relationship between height and age is a convex curve, so the former method will produce a smaller estimate of site index than the latter. The degree of difference depends on the age range of the sample and the degree of curvilinearity in the age range. For even-aged stands, those differences may be minor, since the age range of samples will be small and the height-age curve segments will be fairly linear over small age ranges. In uneven-aged stands, the age range may be wider, so the divergence in estimate between the two methods may become significant. As a consequence, we recommend that individual tree estimates of site index be averaged when stand site indices are being determined. This will give consistent results regardless of the age range of the sample or degree of curvilinearity of the site curves.

REDWOOD SITE INDEX

Previous Studies

Two redwood site index curves are evaluated briefly and compared to our own in table 1. Early work by Donald Bruce (1923) derived young growth site curves from the proportional guide curve method. Bruce had extensive data from 135 redwood stands throughout the redwood region, including Del Norte, Humboldt, Mendocino, Sonoma, Butte, Alameda, and Santa Cruz counties. Stand age varied from 24 to 67 years.

Lindquist and Palley (1961) also used the guide curve method, but allowed for variable proportional growth rates at each age (Osborne and Schumacher 1935). Working 38 years after Bruce, Lindquist and Palley were able to sample older young-growth stands. Thus they extended the range of the curves from 60 years (total age) to 100 years (breast-high age), and used the latter as the base age for their curves.

While the Lindquist and Palley curves have been used widely, when we evaluated successive measurements of forest growth plots we noted regular changes in site index as the plots got older. Lindquist and Palley based their analyses upon single measurements of temporary plots, so they were not able to observe this phenomenon. We therefore constructed new site index curves for use with our growth models (1) to eliminate the possible bias in the Lindquist and Palley curves (see *Curve tests*), (2) to change the base age from 100 years (total age) to 50 years (breast height), and (3) to reflect the potential growth of individual dominant tree sprouts. Trees of seedling origin were considered a "minor" component in the stands sampled.

TABLE 1. SUMMARY OF SITE INDEX CURVES FOR YOUNG-GROWTH REDWOOD

Study and parameter	Specification
Bruce (1923)	
Geographical basis	"throughout the range of the species"
Construction method	proportional guide curve
Base age	total age, 50 years
Stand component	stand age and average height of selected tallest trees
Lindquist and Palley (1961)	
Geographical basis	Del Norte, Humboldt, and Mendocino counties
Construction method	guide curve with variable proportions
Base age	breast-high age, 100 years
Stand component	average age and average height of five to eight dominant trees that were "in" on a point sample
Current study	
Geographical basis	Del Norte, Humboldt, and Mendocino counties
Construction method	polymorphic stem analysis
Base age	breast-high age, 50 years
Stand component	individual dominant redwood sprouts

Data Sources

The initial data set used to develop the new curves came from two sources, stem analysis and permanent plot data.

Stem analysis

Records of 177 felled dominant redwood sprouts with ring counts and cumulative height measurements taken at intervals along the tree bole were available for analysis. These data were collected between 1898 and 1967 in Del Norte, Humboldt, and Mendocino counties. The measurements were converted to give paired breast-high age and total height observations for each tree.

Permanent plot data

Observations were also available from 53 permanent plots with at least four dominant redwood sprouts each. The redwoods were measured for breast-high age and total height at least twice over a 15- to 25-year time span. The observations were made between 1952 and 1976 on plots maintained by members of the Redwood Yield Research Cooperative in Del Norte, Humboldt, and Mendocino counties.

Analysis

Preliminary methods

The stem-analysis section cuts were at variable age intervals. Therefore, the height at age 50, the base age of the site index, had to be interpolated from adjacent section cuts. For the permanent plot data used, height at age 50 had to be interpolated or, for trees with no section cuts including the 50-year base age, the site index had to be extrapolated. The required interpolation and extrapolation were done in conjunction with the data screening. In this process, several functions were fitted to the observations for each tree. Observations with obvious errors in measurement or recording were discarded.

For data sets with an age range that did not include the site index base age, the equations were further examined for reasonableness of fit when extrapolated to 50 years. If the extrapolation appeared unreasonable, the set was discarded. Tree or plot data sets that had to be extrapolated more than 20 years were discarded outright.

These procedures left 123 stem analysis trees and 37 permanent plot records for further analysis. The equations for each data set were used to estimate site index (total height) at 50 years (breast-high age) and to generate paired age-height observations at 10-year intervals throughout the age range of each observation set. No observations were generated for ages of less than 10 or more than 80 years. This gave a total of 564 observations of breast-high age, total height, and site index. The numbers of samples by age and site groups are shown in table 2.

TABLE 2. NUMBER OF OBSERVATIONS BY AGE AND SITE INDEX GROUPS

Site index group, 50-year base age	Breast-high age (years)								
	10	20	30	40	50	60	70	80	Total observed
71-80	3	4	5	4	4	3	3	3	29
81-90	3	5	5	5	5	2	1	1	27
91-100	6	8	10	12	12	9	8	6	71
101-110	10	14	14	15	15	13	9	8	98
111-120	25	29	31	34	37	30	23	20	229
121-130	5	6	8	12	12	12	10	10	75
131-140	4	4	5	5	5	4	4	4	35
Total	56	70	78	87	90	73	58	52	564

Model specifications

After considerable experimentation with several possible model forms, we settled on a modified version of the sigmoidal exponential function described by Richards (1959) to express total height (H) as a function of breast-high age (A) and site index (S). The form used here is

$$H = S_1 \left\{1 - \left[1-(S/S_1)^{S_3}\right] e^{(A-50)S_2}\right\}^{1/S_3}, \qquad [3]$$

where

$$S_1 = a_1S^{a_2},\ S_2 = a_3S^{a_4},\ S_3 = a_5S^{a_6},$$

and the constants $a_1, a_2, \ldots a_6$, estimated by nonlinear least squares, are $a_1 = 9.4366$, $a_2 = 0.6817$, $a_3 = -0.0011842$, $a_4 = 0.46112$, $a_5 = 0.62885$, and $a_6 = 0.14567$ (standard deviation = 4.1 feet).

Equation 3 is conditioned to predict a total height equal to the site index when the breast-high age is 50 years. The form of the equation is general enough to allow expression of polymorphic curve patterns, and variants of this model have been applied

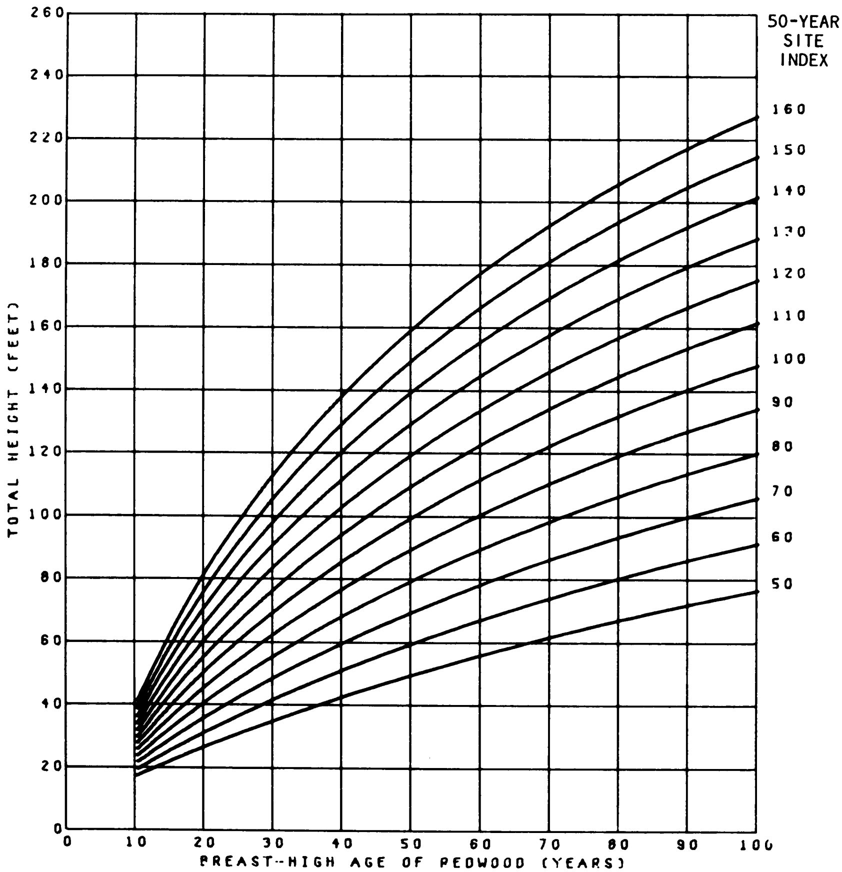

Fig. 1. Fifty-year base age site index curves for dominant young-growth redwood sprouts.

successfully to several other species. Curves generated from equation 3 are shown in figure 1, while figure 2 shows the relationship between the new curves and those of Lindquist and Palley (1961). Major differences between these curves occur in the younger age classes and in the lower site classes.

Curve tests

Both the height-growth curves developed in this study and those developed by Lindquist and Palley were tested to detect any biases resulting from improper methods of determining site index or poor specifications of curve shape. Measurements of total height and breast-high age taken at two different times over intervals of 10 to 15 years were available from 142 dominant redwood sprouts. These measurements came from

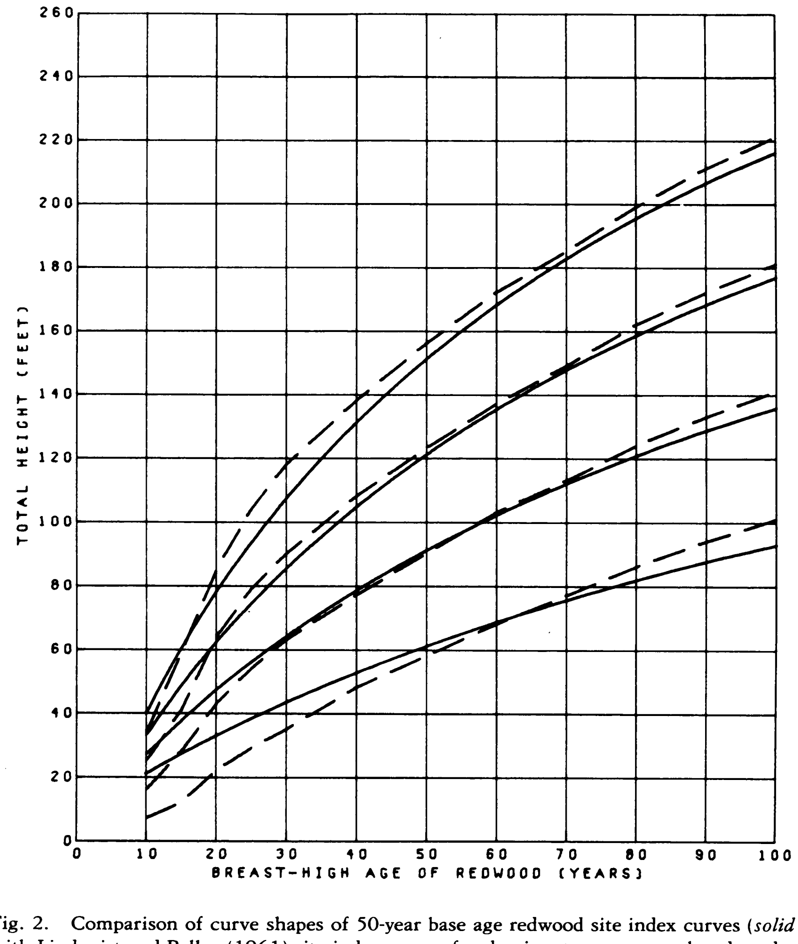

Fig. 2. Comparison of curve shapes of 50-year base age redwood site index curves (*solid lines*) with Lindquist and Palley (1961) site index curves for dominant young-growth redwood sprouts (*broken lines*).

permanent plot and stem analysis records not available at the time of the initial analysis. The initial measurements on each tree were used to estimate site index, and the resulting site value was then used to predict height at the second measurement. The average annual prediction error was then estimated by following ratio:

$$x = \frac{H_2 - \hat{H}_2}{A_2 - A_1} \qquad [4]$$

where A_1 and A_2 are the ages at the first and second measurements, H_2 is the actual tree height for the second measurement, and $\hat{H}_2$ is the height predicted at the second measurement from a height-age curve that is supposed to represent the growth pattern on that plot. If periodic height growth from the fitted curves selected on the basis of the younger height-age measurement matches the observed growth, then we expect the average of each group of x_{ij} to be zero.

These prediction errors were then grouped within three site and three age groups. The Lindquist and Palley curves showed significant prediction errors for all three site groups within the 10- to 30-year age group, but no significant errors in the 30- to 60-year or the 60-year plus age groups. The new curves showed no significant errors for any of the age-site groups.

A parallel examination was made using regression analysis to see if the prediction errors were correlated with either age or site index over the entire data set. No significant correlations were detected (0.05 level) for the new curves, but the correlation of the prediction error with site index was quite large ($r = 0.63$) for the Lindquist and Palley curves.

Thus, as tested against this independent data set, the new 50-year curves show no bias and appear to provide significantly better results than the Lindquist and Palley 100-year base site curves. As a result, the authors adopted the new curves for use in their growth modelling efforts (Krumland and Wensel 1982).

DOUGLAS-FIR SITE INDEX

Previous Studies

The Douglas-fir site curves that we evaluated are summarized in table 3. Site curves were developed by Schumacher (1930) for California and by McArdle and Meyer (1961) for the Pacific Northwest. Both systems used the proportional guide curve method of construction, with base ages 50 years and 100 years (total age), respectively. Most of Schumacher's sample data (85 percent) came from California, whereas McArdle's and Meyer's data came from Oregon and Washington.

King (1966) produced a site index system for Douglas-fir using a polymorphic stem analysis method, using the equation

$$H = \frac{A^2}{a_1 + a_2A + a_3A^2} + 4.5, \qquad [5]$$

TABLE 3. SUMMARY OF SITE INDEX CURVES FOR DOUGLAS-FIR

Study and parameter	Specification
Schumacher (1930)	
Geographical basis	California, with 87 percent of the sample plots located in the north coast region
Construction method	proportional guide curve
Base age	total age, 50 years
Stand component	average height of dominants
Remarks	the only Douglas-fir site curves from California data
King (1966)	
Geographical basis	Washington
Construction method	polymorphic stem analysis
Base age	breast-high age, 50 years
Stand component	10 trees with largest diameter at breast height in 50
Remarks	generally accepted for Douglas-fir in the Pacific Northwest
McArdle and Meyer (1930, revised 1961)	
Geographical basis	samples collected in Oregon and Washington
Construction method	proportional guide curve
Base age	total age, 100 years
Stand component	average height of dominant and codominant trees
Remarks	commonly used for Douglas-fir in the north coast region of California

where H = total height of site trees,

$a_1 = -.954038 + .109757(Z)$,

$a_2 = .0558178 + .00792236(Z)$,

$a_3 = -.0007333819 + .000197693(Z)$,

$Z = \dfrac{2{,}500}{S - 4.5}$,

A = breast-high age in years, and

S = site index (50-year age base).

This equation is plotted in figure 3.

To facilitate the comparison of these three site index systems, the total age values of Schumacher's and McArdle's and Meyer's site curves were adjusted to breast-high ages by the following factors (King 1966):

Site index (100 years)	Adjustment
feet	*years*
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 50 years.

A comparison of McArdle's and Meyer's and Schumacher's curves shows them to be almost coincident, but differing from King's curve, with King's curve starting lower and ending higher than the other two. It is particularly interesting that Schumacher's guide curve results in California and McArdle's and Meyer's in Oregon and Washington give similar results, and that these results differ from King's where polymorphic curves were used. This may be due as much to the nature of the data used (single measurements versus time series) as to the analytical procedures (Biging 1984; Monserud 1984).

Curtis (1966) compared McArdle's and Meyer's site curves 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

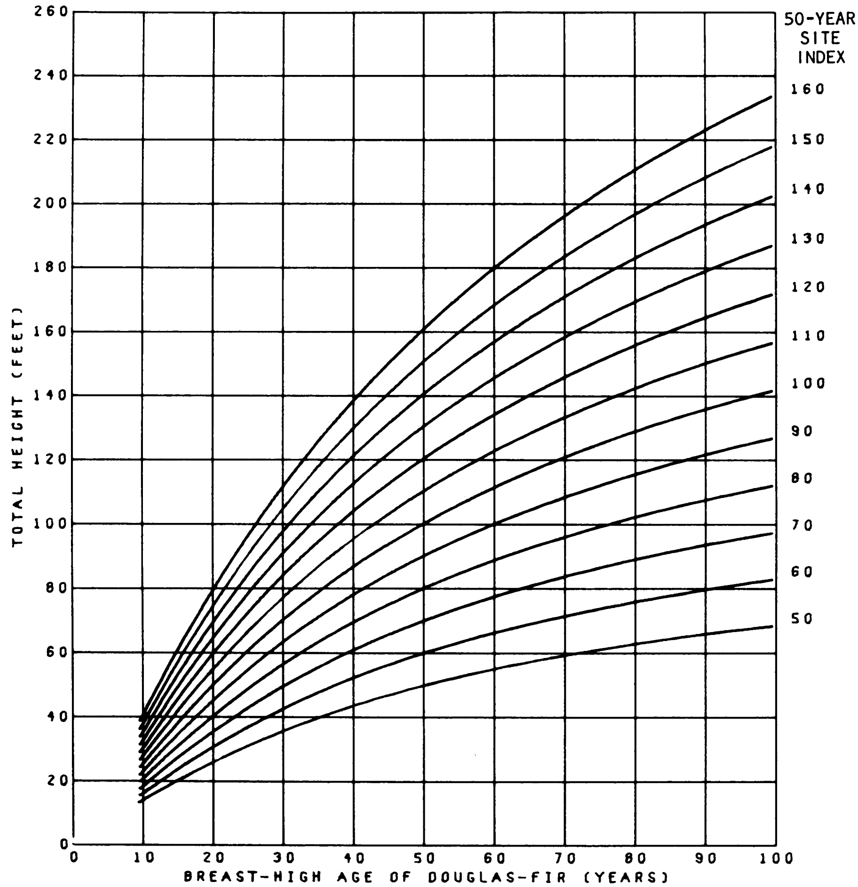

Fig. 3. King's (1966) site index curves for Douglas-fir.

curve set, he found that King's curves fit the sample data better. His sample was largely from stands over 45 years of age. Thus, compared to King's curves, McArdle's and Meyer's curves underestimate the site index for ages less than base age, and overestimate for older age classes. Using different methods and data consisting of remeasured heights of permanent Douglas-fir sample plots, David Bruce (1981) produced curves nearly identical to King's. This amounts to an independent endorsement of the relationships established by King.

Sample Basis for Evaluation

The sample used to evaluate these three site curves consisted of 92 dominant and 26 codominant Douglas-fir trees with two or more measurements of breast-high age and total height taken over an interval of 10 to 25 years. The samples were extracted from growth plot records maintained by members of the Redwood Yield Research Cooperative and were 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 10 and 70 years at the time of sampling, with an average age of approximately 40 years. In some cases, errors in field measurements were evident (e. g., "negative" height growth estimated for some trees where the second height measurement was less than the first). However, since deleting only the negative differences would introduce bias, all data points were used as recorded, and errors in field measurements were assumed to be random.

Analysis

If a given set of site index curves accurately portrays 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. To evaluate the site curves, no formal hypothesis 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 to provide some indication of where differences, if any, between sample data and individual site curves lay.

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

For the purpose of this evaluation of Douglas-fir site index systems, let Y_j equal estimated average annual change in site index for the j^{th} tree, and A_j 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 (fig. 4), and the following model was chosen for comparative purposes after examining the residuals of several functional forms:

$$Y_j = a + b(\log A_j) + \text{error term.} \qquad [6]$$

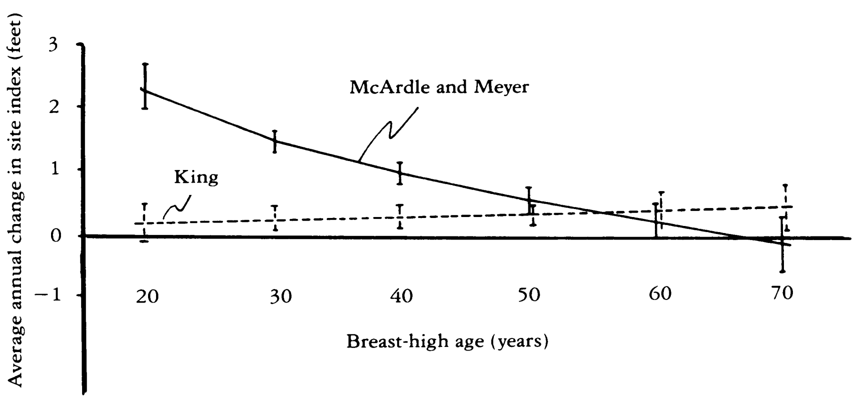

Fig. 4. Predicted annual change in site index (Y_j) at different ages for different site curves. Vertical lines denote one standard error above and below the regression line.

This is similar to the model used by Curtis (1966) in his comparison. Tests show a statistically significant relationship between the logarithm of age and the annual change in site index for both the McArdle and Meyer and the Schumacher curves, but not for the King curves (Student's t statistics of 6.0, 5.7, and 0.4 for the McArdle and Meyer, Schumacher, and King curves, respectively, with 1 and 117 degrees of freedom). Thus, our data support the use of King's Douglas-fir site index curves for the north coast of California.

Discussion

It is particularly interesting that the guide curve results of Schumacher in California and of McArdle and Meyer in Oregon and Washington give similar results, even though Schumacher used a 50-year base and McArdle and Meyer used a 100-year base. Similarly, the polymorphic curves of King, using only Washington data, are supported by the current study that used California data. This suggests that the height growth patterns of dominant Douglas-fir are similar in the regions compared, and that the differences in curves are due to the analytical techniques used. For these reasons, King's site index curves are recommended for use in the north coast region of California.

RELATIONSHIPS BETWEEN SPECIES

Douglas-fir and Redwood

Where too few redwood or Douglas-fir sample site trees are available for direct site index estimates of both species, the site index of one species may be estimated indirectly from the site index of the other. Regression analysis of paired redwood–Douglas-fir site index estimates from 123 growth plots in Del Norte, Humboldt, and Mendocino counties yielded the following estimation equations:

$$\text{redwood site index} = 46.5 + .465\ (\text{Douglas-fir site index}), \text{ and} \qquad [7]$$

$$\text{Douglas-fir site index} = 80.15 + .471\ (\text{redwood site index}), \qquad [8]$$

where for both equations, the correlation is 0.54 ($R^2 = 0.29$) and the standard deviation about the line is about 14 feet. In the first equation, Douglas-fir site index is assumed fixed (given), and redwood site index is random. The converse is true for the second equation. As a result, one would not expect both equations to give compatible predictions of pairs of site indices, unless the correlation between site indices for the two species is high. If site index is estimated in the field for only one species, it should be the one most important for that location.

For each observation, site index estimates for each species were based on 3 to 12 trees. For both of these equations, the constant terms were significantly different from zero and the slope terms were significantly different from one at the 1 percent level of probability. Various transformations of both dependent and independent variables resulted in no improvement in the predictive power of the relationship between the redwood and Douglas-fir site index values.

An extensive analysis of covariance was also made to see whether these relationships were significantly different with respect to topography (flats and valley bottoms, slopes, or ridgetops), aspect (southern exposures or other exposures), and latitude (Del Norte and Humboldt counties or Mendocino County). In no case were any significant differences found.

Other Species

A small sample from 29 even-aged plots, where the average heights of dominant white fir could be compared with average heights of dominant Douglas-fir, indicated that the difference in dominant height between these two species was insignificant. Donald Bruce (1923) reported similar results. The site index of white fir can therefore be obtained by using the Douglas-fir site index. Insufficient data were available to develop relationships for the other species present, but this is a fruitful area for future research.

CONCLUSIONS

Based on analysis of existing site index curves, our work supports the use of King's site index model for Douglas-fir in California's north coast, and proposes a new site index model for use with redwood. The two site index models, together with the equations that relate them, provide a workable site index system for conifers in California's north coast redwood forest. The site index systems are incorporated in our computer program CRYPTOS, the Cooperative Redwood Yield Project Timber Output Simulator (Krumland and Wensel 1982).

LITERATURE CITED

ASSMAN, E.
1970. *The principles of forest yield study.* New York: Pergamon Press.

BIGING, GREG S.
1984. Improved estimates of site index curves using a varying-parameter model. *For. Sci.* 31(1):248-59.

BRUCE, DAVID
1981. Consistent height-growth and growth rate estimates for remeasured plots. *For. Sci.* 27(4): 711-25.

BRUCE, DONALD
1923. Preliminary yield tables for second-growth redwoods. *Univ. Calif. Agric. Exp. St. Bull.* 361. pp. 423-67.

CURTIS, ROBERT O.
1966. A comparison of site curves for Douglas-fir. *U.S. For. Serv. Res. Pap.* PNW-37. 7 pp.

CURTIS, ROBERT O., DONALD J. DeMARS, and FRANCIS R. HERMAN
1974. Which dependent variable in site index-height-age regressions? *For. Sci.* 20:74-87.

FORD-ROBERTSON, F. C.
1983. *Terminology of forest science, technology, practice, and products.* 2d printing. Washington: Society of American Foresters.

HAGGLUND, B.
1981. Evaluation of forest site productivity. *For. Abstr.* 42(11):515-27.

HUSCH, BERTRAN, C. I. MILLER, and T. W. BEERS
1972. *Forest mensuration.* 2d ed. New York: Ronald Press.

JONES, J. R.
1969. Review and comparison of site evaluation methods. *U.S. For. Serv. Res. Pap.* RM-51.

KING, JAMES E.
1966. *Site index curves for Douglas-fir in the Pacific Northwest.* Weyerhaeuser Forestry Paper No. 8. Centralia, Washington: Weyerhaeuser Forestry Research Center.

KRUMLAND, B., and L. C. WENSEL
1982. *CRYPTOS/CRYPT2 user's guide, version 4.0.* Redwood Research Note No. 20, Dept. of Forestry and Resource Management, Univ. Calif. Berkeley (mimeo).

LINDQUIST, JAMES L., and M. N. PALLEY
1961. Site curves for young-growth coastal redwood. *Calif. For. For. Prod.* 29:1-4.

McARDLE, RICHARD, and WALTER H. MEYER
1961. The yield of Douglas-fir in the Pacific Northwest. *U.S. Dep. Agric. Tech. Bull.* 201 (revised).

MONSERUD, ROBERT A.
1984. Height growth and site index curves for inland Douglas-fir based on stem analysis data and forest habitat. *For. Sci.* 30(4):943-65.

OSBORNE, J. G., and F. X. SCHUMACHER
1935. The construction of normal yield curves and stand tables for even-aged timber stands. *J. Agric. Res. Washington, D.C.* 51:547-63.

RICHARDS, F. L.
1959. A flexible growth function for empirical use. *J. Exp. Bot.* 10(29):290-300.

SCHUMACHER, FRANCIS X.
1930. Yield, stand, and volume tables for Douglas fir in California. *Univ. Calif. Agric. Exp. St. Bull.* 491.

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