# Comparison and Development of Height Growth and Site Index urves for Douglas-Fir in the Inland Northwest[1]

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*ABSTRACT. Stem analysis data from Douglas-fir* (Pseudotsuga menziesii) *collected throughout the inland Northwest were used for testing height growth and site index equations. The equations performed well in northern and central Idaho, northeast Oregon, and northeast Washington on vegetative types similar to those sampled in model development. However, if the equations were applied on drier sites outside the original geographic study area, overestimates of height growth and underestimates of site index could result. Therefore, revised height growth and site index equations are presented for western Montana and central Washington.*

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Reliable estimates of forest yield depend on accurate assessment of the productive potential of forest sites. Site index is an accepted method of expressing the productivity of forestland. Development of more refined site index curves for Douglas-fir has been the subject of recent research in the inland Northwest. Monserud (1984) conducted an extensive stem analysis of Douglas-fir in northern Idaho and adjacent western Montana and northeastern Washington. However, as Monserud (1985) stated, "Considering the variability in curve shape due to habitat type within this study area . . . there can be little doubt that the shape of the site index and height growth curves will change in other regions of Douglas-fir's range."

The primary objective of the current study was to determine whether Monserud's (1984) site index and height growth equations could be relied on in inland areas of the Northwest outside the geographic range of his study. New curves were developed for those areas where regional differences were found.

## METHODS

The database for this paper originated from Intermountain Forest Tree Nutrition Cooperative (IFTNC) study sites. The IFTNC study area was delineated into six geographic regions: (1) northern Idaho, (2) western Montana, (3) central Idaho, (4) northeast Oregon, (5) central Washington, and (6) northeast Washington. Ninety-four stands were selected and 572 permanent sample plots installed by fall 1982. Research sites (installations) were selected to represent a range of site and stand conditions. The experimental design included the destructive sampling of two to three representative dominant and codominant Douglas-fir trees near each plot to obtain pretreatment foliage samples and growth data. This resulted in a sampling intensity of approximately 5 to 10 trees/ac, which is roughly the same proportion of the population sampled by Monserud's (1984) six trees/ac. Topographic and vegetative information was collected at each plot. From each felled tree, 13 height-age pairs were obtained (at breast height, base of the active crown and for each of the past 11 years). A total of 578 trees throughout the six regions remained for further analysis after screening for suppression, stem defects, and insect or disease influences. In determining site index, the site rather than an individual tree is of primary interest. Therefore, an average growth curve (height vs. age) was determined for each installation from the individual tree stem analysis data. This is similar to the procedure followed by Monserud (1984). The trees from each installation were used to fit a site-specific height-age equation. Evaluating this equation for each site at index age of 50 yields an estimate of site index for the installation. Since the data is from second-growth Douglas-fir stands with a mean age of 63 years, obtaining height-age data points for the past 11 years resulted in many of the sample trees having a direct height measurement at age 50. This was important in minimizing extrapolations in calculating site index values. These site index values were then used in all subsequent analyses for deriving height growth and site index equations. The means and ranges of various site factors encountered at installations within each region are given in Table 1.

## RESULTS

A residual analysis was conducted comparing "observed" decadal heights obtained from each site-specific height-age function to those "predicted" from Monserud's habitat-type-specific height growth equation. When each region was compared across all age classes, northern and central Idaho, northeast Oregon, and northeast Washington showed good agreement. However, those for Montana and central Washington revealed some bias and suggested a height growth pattern different than Monserud's equation (Figure 1). Negative values on the graphs indicate an overprediction by Monserud's equation. The vertical line through each data point represents the standard error of Monserud's height growth function for that decade. Based on these findings along with the fact that the IFTNC sites in Montana and central Washington are the farthest from the area sampled by Monserud, new height growth and site index curves were developed for those regions from IFTNC data. The new curves for Montana were compared to Monserud's (1984) Douglas-fir series curves, and the new curves for central Washington were compared to both Monserud's and Cochran's (1979).

For height growth model development, variations of a logistic used by Monserud (1984) for predicting height from age and site index were selected and tested. Nonlinear regression was used to estimate the parameters. The resulting height growth equation for Douglas-fir in Montana is:

$$HT = ((1.9965{*}S)/(1 + e{**}(5.479 - 1.4016{*}\ln A))) + 4.5 \quad (1)$$

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**Table 1. Means and ranges of site and stand characteristics encountered within each region at IFTNC installations used in the study.**

| | Geographic region | | | | | | |
|---|---|---|---|---|---|---|---|
| | North Idaho | Montana | Central Idaho | Northeast Oregon | Central Washington | Northeast Washington | Overall |
| Number of sites | 20 | 14 | 15 | 8 | 16 | 16 | 89 |
| Number of sample trees | 112 | 78 | 97 | 71 | 77 | 143 | 578 |
| Number of ht-age observations | 1283 | 929 | 1159 | 843 | 917 | 1708 | 6839 |
| Site index (ft) | 87 | 68 | 57 | 66 | 72 | 69 | 71 |
| | (74-102) | (56–86) | (43–63) | (57–79) | (47–92) | (50–84) | (43–102) |
| Elevation (ft) | 3295 | 3735 | 4816 | 4250 | 2931 | 2928 | 3575 |
| | (2500–4600) | (3200–4800) | (4200–5700) | (2400–5900) | (2200–4500) | (1500–3800) | (1500–5900) |
| Slope (%) | 26 | 27 | 25 | 32 | 24 | 31 | 25 |
| | (4–46) | (4–58) | (12–39) | (18–51) | (0–79) | (5–45) | (0–79) |
| Total Age | 49 | 61 | 70 | 70 | 75 | 62 | 63 |
| | (27–88) | (32–80) | (58–92) | (42–90) | (64–87) | (34–100) | (27–100) |

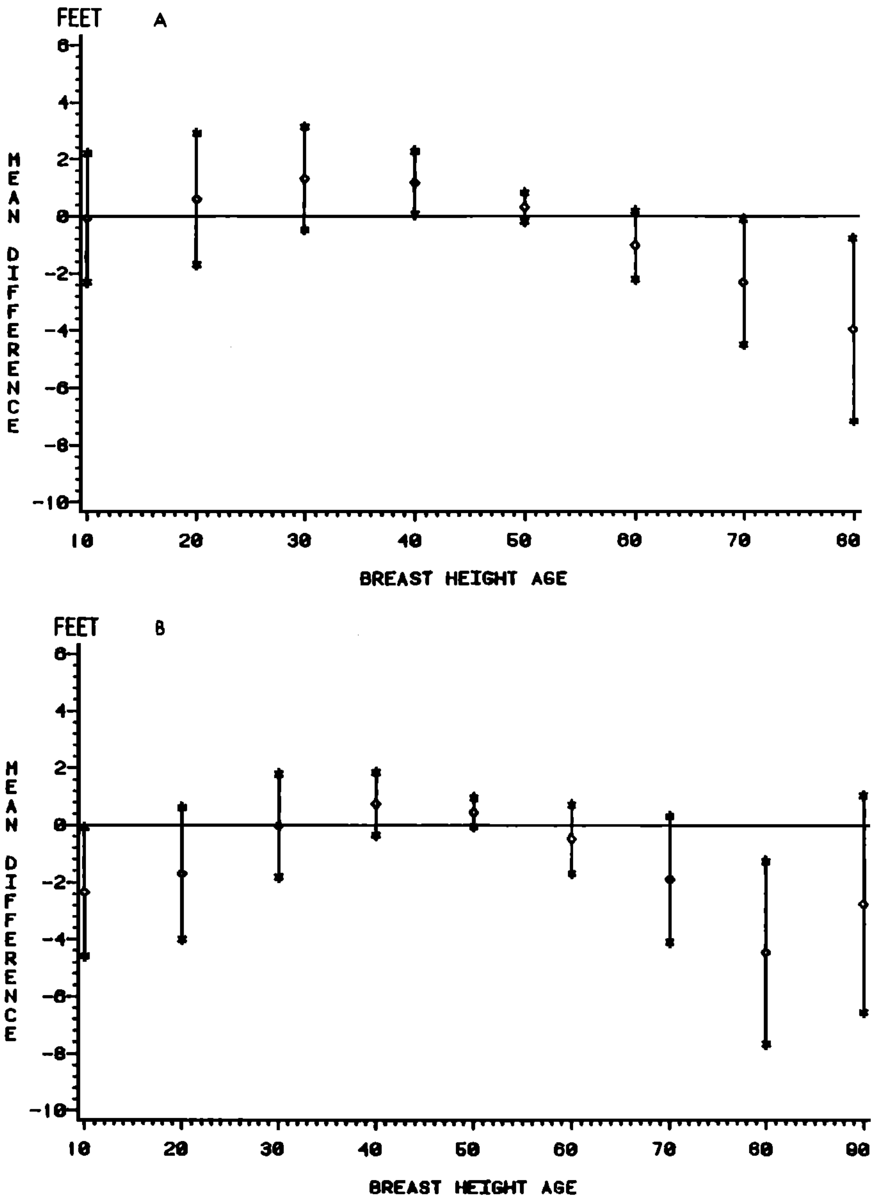


**Figure 1. The average difference between Douglas-fir heights predicted by Monserud's equations and those observed for Montana (A) and central Washington (B).**

where

$HT$ = total height (ft)

$\ln A$ = natural log of breast height age

$S$ = site index (ft) − 4.5

Using the same methodology resulted in the following height growth model for Douglas-fir in central Washington:

$$HT = ((1.79897^*S)/(1 + e^{**}(6.0678 - 1.6085^*\ln A))) + 4.5 \quad (2)$$

where $HT$, $\ln A$, and $S$ are as previously defined. The unweighted standard errors for models (1) and (2) were 2.8 ft and 4.2 ft, respectively The height growth curves for Montana and central Washington are shown in Figure 2.

Site index model development initially used a procedure developed by Dahms (1975). Stepwise regression reduced the number of variables in the model without degrading overall fit. Iteratively reweighted least squares regression was used to obtain the final parameter estimates. Weights were the inverse of the residual variance. The resulting site index equations for Montana and central Washington based on the IFTNC data are:

*Montana:*

$$SI = (111.832 + 0.721^*H - 28.2175^*\ln A - 731.551/(A^*A) + 13.164^*H/A) + 4.5 \quad (3)$$

*Central Washington:*

$$SI = (146.274 + 0.809^*H - 37.218^*\ln A - 1064.4055/(A^*A) + 9.511^*H/A) + 4.5 \quad (4)$$

where

$SI$ = site index (base age 50)

$H$ = total height − 4.5 ft.

$\ln A$ and $A$ are as previously defined.

Models (3) and (4) had unweighted standard errors of 3.7 ft and 5.7 ft, respectively. The site index curves for Montana and central Washington are shown in Figure 3. The central Washington sites sampled both the Douglas-fir and grand fir climax vegetation zones. An examination of the residual plots of the site index model indicated that additional variation could be explained by habitat series. This result is similar to Monserud's

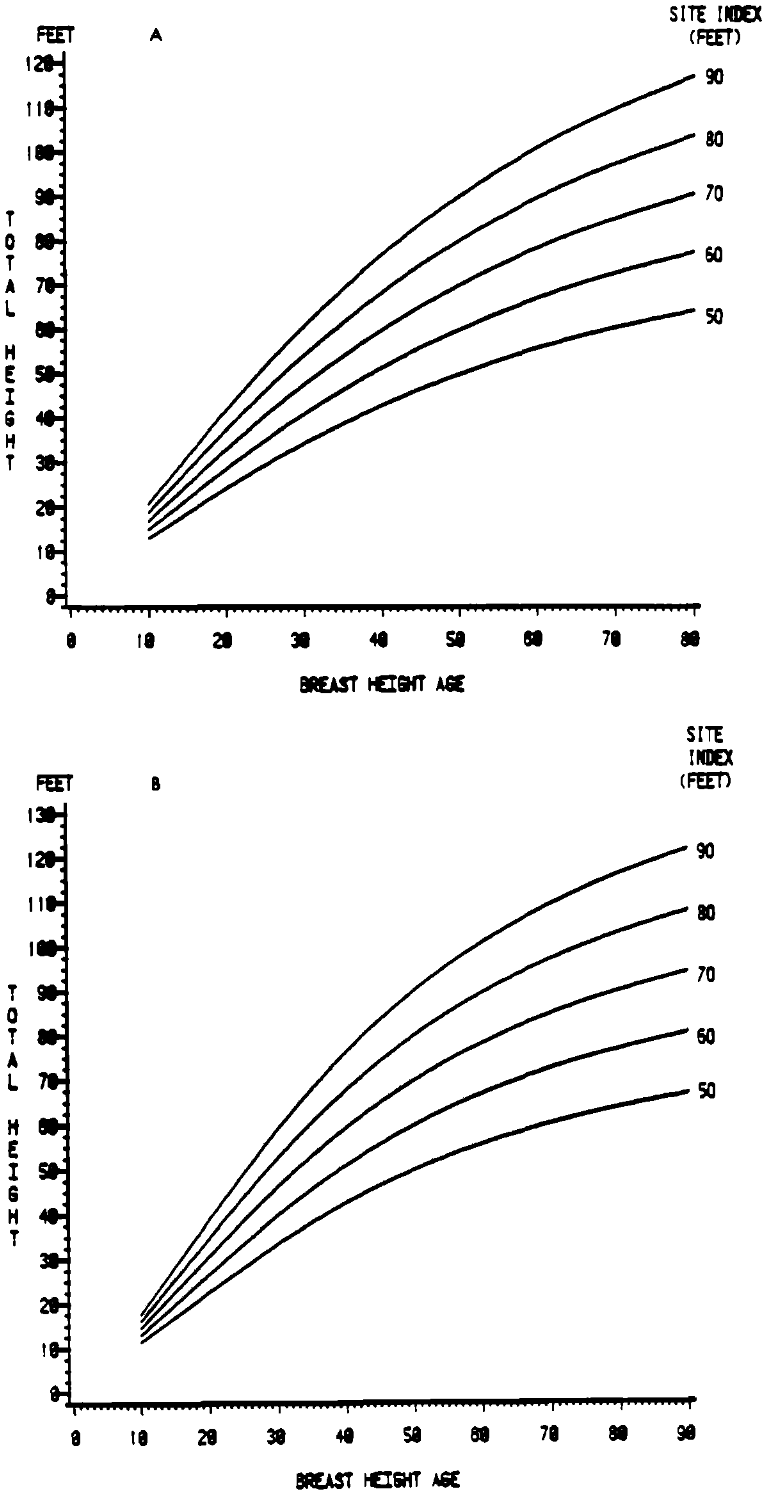


**Figure 2. Douglas-fir height growth curves for Montana (A) and central Washington (B).**

findings in northern Idaho. Weighted linear regression led to a habitat series specific site index model for central Washington as follows:

$$SI = ((160.5635*Z1 + 170.274*Z2) + (0.9139*Z1 + 0.786*Z2)*H - 41.319*\ln A - 1603.947/(A*A) + 5.752*H/A) + 4.5 \quad (5)$$

where $SI$, $\ln A$, and $H$ are as previously defined, and

$Z1 = 1$ if habitat series is Douglas-fir

$Z1 = 0$ otherwise

$Z2 = 1$ if habitat series is grand fir

$Z2 = 0$ otherwise

Model (5) had an unweighted standard error of 4.7 ft. Residual plots were significantly improved by including habitat series.

## DISCUSSION

Comparison of height growth models for both regions showed similar height growth patterns below index age. This suggests that height development of young Douglas-fir is essentially the same from western Montana to the east side of the Cascade crest. However, past index age, existing curves for both regions overestimate height growth, particularly at lower levels of site quality. In Montana, height growth on poor and medium sites slows down more than Monserud's curves predict. Similarly, in central Washington the curves begin to depart at higher ages across all site levels. By age 80 or 90, differences in predicted height were 5 to 8.5 ft for site indices below 85. Many of the IFTNC sites in Montana and central Washington were on Douglas-fir habitat types drier than any of Monserud's sites, so it seems reasonable that the height growth would be slower in older stands.

Habitat series-specific site index curves were developed from the IFTNC sites in central Washington. Although the overall site index equation for central Washington performed adequately, the Douglas-fir (DF) series equation improved predictions on poor and medium sites, while the grand fir (GF) series equation performed well on good sites. Site index for the DF series averaged 66 ft with a range of 47–84, while the GF series averaged 81 with a range of 67–92. High sites are lacking in the DF series and poor sites are missing in the GF series. When Monserud (1985) compared his curves to Cochran's, Monserud used his DF series coefficients for site index less than or equal to 70, and the GF series coefficients for site index higher than 70. Based on the results of this study, site index 70 appears a good choice for the transition from using the DF series equation to the GF series formulation. Therefore, comparisons discussed here used the same approach.

Overall, the new site index curves for central Washington match those of Monserud and Cochran well. The largest differences occur on site index 55 at age 10 (7.8 ft) and site index 85 at age 90 (6.9 ft). More significantly, at higher ages Cochran (1979) overestimates SI on poor sites while both Monserud and Cochran underestimate SI on good sites. For example, a 90-year-old tree 120 ft tall on a grand fir habitat series would indicate a site index of 81.4 ft with Monserud's GF series equation, 84.1 ft using Cochran's model and 86.8 ft according to the new GF series curve.

The new overall site index equation (4) for central Washington should be used if habitat series is not known. If the habitat series is DF or GF then the habitat series specific coefficients can be used. How suitable these curves

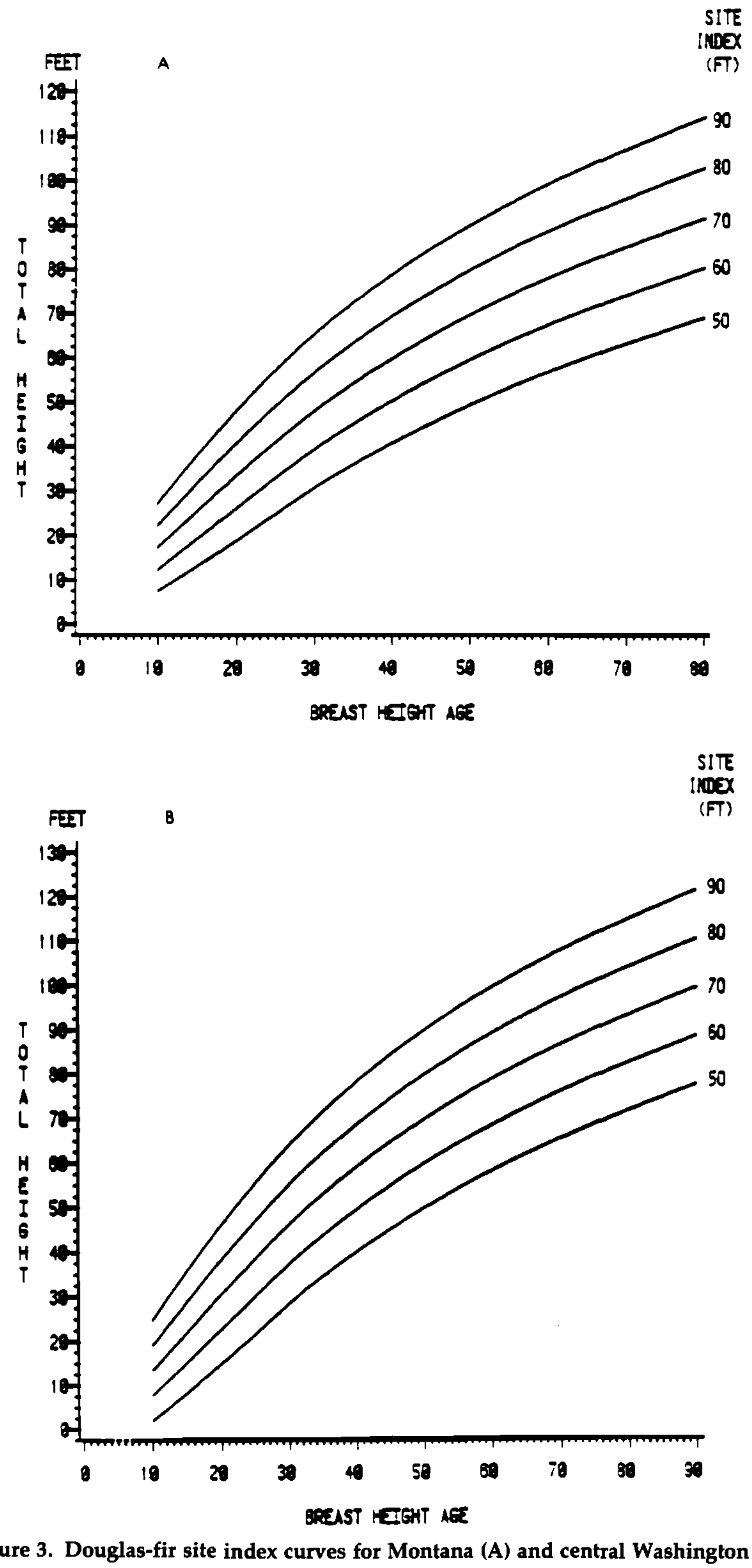


**Figure 3. Douglas-fir site index curves for Montana (A) and central Washington (B).**

would be for habitats wetter than grand fir is not known.

The new site index curves for Montana were compared to Monserud's DF series curves. Poor sites matched well, but by SI 75, noticeable differences in curve form were evident. Past index age (50) Monserud's curves are higher than the proposed curves. Differences are greatest at SI 85 (4 ft at age 80).

Height growth and site index equations presented here for Montana apply only for Douglas-fir habitat types. Milner (1985) has demonstrated that on grand fir and western redcedar types in Montana, Monserud's curves perform quite well. Milner's sample on Douglas-fir types in Montana produced results similar to this study.

In summary, height growth equations developed by Monserud from stem analysis data collected in northern Idaho perform well throughout Idaho, northeast Washington, and northeast Oregon. However, height growth comparisons in Montana and central Washington suggested a different pattern than predicted from Monserud's equations New height growth and site index equations developed for second-growth Douglas-fir stands in those regions indicate that existing curves generally overestimate height growth and underestimate site index past index age. Using the new equations presented here for Montana and central Washington can result in more accurate estimates of productivity in those regions. □

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