

# Site Index Adjustments for Old-growth Stands Based on Veteran Trees

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Ministry of Forests Research Program

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Gordon D. Nigh



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## ABSTRACT

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Regional studies are supporting foresters' perceptions that the site indices of British Columbia's old-growth stands are being underestimated. A province-wide paired-plot study resulted in old-growth site index adjustments for coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), interior spruce (*Picea glauca* (Moench.) Voss, *P. engelmannii* (Parry) Engelm., and *P. glauca* x *P. engelmannii*), and interior lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.). The objective of this study is to develop adjustments for species not covered in the provincial project. Adjustments for the species in the provincial project are also derived for comparison purposes. The data for this study come from temporary and permanent sample plots with a veteran and a main stand component. The site indices for the two components were estimated and an adjustment equation for each species was derived using the two site indices in a linear regression analysis. The veteran component represents an old-growth stand and the main stand component represents a managed stand. The analysis showed that the veteran site indices were being underestimated. Some guidelines on the application of these adjustments to old-growth site indices are provided.

## **ACKNOWLEDGEMENTS**

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## INTRODUCTION

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There is mounting evidence that the site indices of British Columbia's old-growth (total age > 140 years) stands are being underestimated. This conjecture was initially based on foresters' perceptions. Later, local studies were carried out confirming that the site indices were being underestimated for western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) (Nigh and Love 1997) and lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) (Goudie 1996). These results prompted a province-wide study to develop site index adjustments, or corrections, using the paired-plot technique<sup>1</sup> for application after the harvest of old-growth stands. Initially, the study focused on four major species: coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), western hemlock, interior lodgepole pine and spruce (*Picea glauca* (Moench.) Voss, *P. engelmannii* (Parry) Engelm., and *P. glauca* x *P. engelmannii*). The paired-plot project did not yield a provincial site index adjustment equation for western hemlock because of a small sample size for this species. Based on the difficulty in finding samples for the major species in the province, it is unlikely that enough paired-plot samples could be obtained for the remaining species.

Old-growth site index adjustments for species other than the three covered in the paired-plot project are still required. An ad hoc working group was established in the spring of 1997 to address this need. The group recommended several alternatives<sup>2</sup>, the most preferable being the veteran approach. However, all of the proposed alternatives were considered to be less reliable than the paired-plot method of deriving adjustments. Briefly, the veteran approach uses existing sample plot data that has a veteran component and a second growth component. The site indices for the two components are compared and an adjustment is derived, if warranted.

This report describes the data, analysis methods, and results of the veteran study. Site index adjustments are recommended for many species not covered in the paired-plot study.

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<sup>1</sup> B.C. Ministry of Forests. 1997. Paired plot provincial implementation project plan. OGSI Adjustment Project Team, Subcommittee to the Site Productivity Working Group.

<sup>2</sup> B.C. Ministry of Forests. 1997. Site index estimates for old-growth stands. Report of the Working Group.

## DATA

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The data for this study comes from the B.C. Ministry of Forests Resources Inventory Branch's collection of temporary and permanent sample plots. These plots were screened for suitability based on the following criteria:

1. The plots had a veteran component and a main stand component.
2. The veteran and main stand components were of the same species.
3. The total age of the main stand was between 30 and 140 years. An accurate managed stand site index is difficult to obtain from stands outside this age range.
4. The stand was not selectively logged or had a complex stand structure.
5. The site index of the main or veteran layer was not greater than 50 m for the coast or 30 m for the interior. Site indices outside these ranges are unusual and probably indicate an error in the data.

The screening resulted in data for six coastal species and 13 interior species. Table 1 lists the species that were available for analysis. The sample sizes ( $n$ ) for Sitka spruce ( $n = 2$ ), yellow cedar ( $n = 1$ ), black cottonwood ( $n = 3$ ), paper birch ( $n = 1$ ), whitebark pine ( $n = 1$ ), and black spruce ( $n = 1$ ) were too small to produce reliable adjustments. Therefore, no analysis was done for Sitka spruce and black spruce. Whitebark pine and yellow pine were combined and analyzed as yellow pine. Trembling aspen, black cottonwood, and paper birch were combined and analyzed as hardwoods.

Site indices were estimated for the veteran and main stand components. The site index for the main stand component ( $SI_m$ ) is assumed to be indicative of the potential productivity of the site. The veteran-based site indices ( $SI_v$ ) are assumed to be representative of the estimated site indices from old-growth stands. However, some of the veteran trees may actually be younger than 140 years. Many trees were classified as veterans in the field but accurate ages were not always obtained. For the main stand, top height is the average height of the 100 largest diameter trees per ha. The heights of the top height trees were estimated with a height-diameter model. Top height, along with total age and the Ministry of Forest's recommended height-age model (Nigh 1998, Nussbaum 1996, Thrower et al. 1994), were used to estimate site index. The site index for the veteran component was obtained by averaging the estimated site indices for each veteran tree with a measured height and total age. Again, the recommended height-age models were used in the estimation procedure. Table 2 presents summary statistics for the data after grouping and eliminating species for which there were few data.

## METHODS

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The data were stratified by region (coast, interior) and species. The region/species combinations were analyzed separately. Based on the results of similar research, I postulated that there is a linear relationship between  $SI_s$  (second growth site index) and  $SI_o$  (old-growth site index). A linear model (1) was fit to the data to test this hypothesis.

$$(1) SI_s = a_0 + a_1 \times SI_o + \epsilon$$

where:  $SI_s$  = second growth site index (m @ breast height age 50),  
 $SI_o$  = old-growth site index (m @ breast height age 50),  
 $a_0, a_1$  = model parameters, and  
 $\epsilon$  = random error term.

The standard regression assumptions (Sen and Srivastava 1990, p. 11-13) were tested using the following tests:

1. Expected value of the residuals is zero: t-test;
2. Residuals are normally distributed: W statistic (Shapiro and Wilk 1965); and
3. Residuals are homoscedastic: plots of residuals against  $SI_o$ .

If the W statistic indicated that the residuals were not normally distributed, the transform-both-sides methodology (Carroll and Ruppert 1988, p. 115-133) with the modified power transformation (Box and Cox 1964, Carroll and Ruppert 1988, p. 116) was used to induce normality. The standard errors were calculated using the fixed  $\lambda$  approach (Carroll and Ruppert 1988, p. 127). In this approach, the regression parameter  $\lambda$  is estimated. The estimated value is fixed and the regression is re-done to obtain the standard errors.

If parameter  $a_0$  or  $a_1$  was not statistically significant during the analysis, the term associated with the non-significant parameter was deleted and the analysis was re-done.

## RESULTS

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The full linear model fit the data for western hemlock (coastal and interior), subalpine fir, Douglas-fir (coastal and interior), lodgepole pine, white spruce, interior hardwoods, and yellow pine. A no-intercept model was appropriate for coastal western redcedar, while a constant site index model was used for the remaining species: amabilis fir, interior western redcedar, and western larch. There was evidence in the initial analyses that the residuals from the interior Douglas-fir and lodgepole pine models were not normally distributed, so the transform-both-sides methodology was applied to the model for these species. This transformation was successful in that the residuals from the transformed model were normally distributed. Table 3 presents the results of the analysis. Figures 1 – 13 show the fitted adjustment equation overlaid on the data points for all the species considered in this study. As well, the 45° line is drawn to show the relationship between the old-growth and managed stand site index if no adjustment is appropriate.

TABLE 1. Common and Latin names for the species available for analysis.

Common name	Latin name
Amabilis fir <sup>a</sup>	<i>Abies amabilis</i> (Dougl.) Forbes
Western redcedar <sup>a,b</sup>	<i>Thuja plicata</i> Donn.
Western hemlock <sup>a,b</sup>	<i>Tsuga heterophylla</i> (Raf.) Sarg.
Sitka spruce <sup>a</sup>	<i>Picea sitchensis</i> (Bong.) Carr.
Yellow cedar <sup>a</sup>	<i>Chamaecyparis nootkatensis</i> (D. Don) Spach.
Douglas-fir <sup>a</sup>	<i>Pseudotsuga menziseii</i> (Mirb.) Franco var. <i>menziseii</i>
Douglas-fir <sup>b</sup>	<i>Pseudotsuga menziseii</i> var. <i>glauca</i> (Beissn.) Franco
Black cottonwood <sup>b</sup>	<i>Populus trichocarpa</i> Torr. & Grey
Trembling aspen <sup>b</sup>	<i>Populus tremuloides</i> Michx.
Subalpine fir <sup>b</sup>	<i>Abies lasiocarpa</i> (Hook.) Nutt.
Paper birch <sup>b</sup>	<i>Betula papyrifera</i> Marsh.
Western larch <sup>b</sup>	<i>Larix occidentalis</i> Nutt.
Lodgepole pine <sup>b</sup>	<i>Pinus contorta</i> var. <i>latifolia</i> Dougl.
White spruce <sup>b</sup>	<i>Picea glauca</i> (Moench) Voss
Whitebark pine <sup>b</sup>	<i>Pinus albicaulus</i> Engelm.
Yellow pine <sup>b</sup>	<i>Pinus ponderosa</i> Laws.
Black spruce <sup>b</sup>	<i>Picea mariana</i> (Mill.) B.S.P.

<sup>a</sup> coastal

<sup>b</sup> interior

TABLE 2. Summary statistics from the analysis data.

Species code <sup>a</sup>	Number of observations	Average old-growth site index (m) (range)	Average second-growth site index (m) (range)
Coast			
Fd	65	20.1 (10.0 - 35.3)	26.4 (13.3 - 41.4)
Ba	7	13.2 (7.3 - 20.5)	22.6 (14.9 - 30.9)
Cw	12	16.2 (9.0 - 25.2)	22.1 (10.2 - 30.1)
Hw	61	16.2 (5.0 - 30.0)	27.1 (10.3 - 39.4)
Interior			
Hwd	28	14.9 (8.4 - 28.5)	19.1 (12.4 - 28.5)
Bl	80	11.2 (4.5 - 22.0)	15.2 (7.8 - 23.4)
Cw	12	15.7 (11.6 - 23.2)	20.7 (15.2 - 28.6)
Fd	409	13.2 (6.4 - 25.2)	16.6 (4.1 - 30.0)
Pl	163	12.4 (4.1 - 21.7)	16.9 (8.8 - 26.0)
Sw	121	12.0 (3.4 - 27.3)	16.8 (6.4 - 28.4)
Hw	32	10.5 (4.7 - 17.5)	17.1 (9.9 - 24.4)
Lw	23	17.7 (11.0 - 28.3)	22.1 (18.3 - 28.3)
Py	21	10.7 (4.3 - 19.2)	14.8 (8.4 - 23.8)

<sup>a</sup> Ba – amabilis fir, Cw – western redcedar, Hw – western hemlock, Hwd – hardwoods, Bl – subalpine fir, Fd – Douglas-fir, Pl – lodgepole pine, Sw – white spruce, Lw – western larch, Py – yellow pine.

TABLE 3. Results of the data analysis.

Species	Parameter estimate (standard error)		W (p-value)	Root mean squared error (m)
	$a_0$	$a_1$		
Coast				
Fd	8.883 (2.581)	0.8688 (0.1244)	0.983 (0.787)	5.08
Ba	22.59 (2.031)	—	0.982 (0.968)	5.37
Cw	—	1.326 (0.09362)	0.883 (0.091)	5.48
Hw	15.47 (2.186)	0.7144 (0.1293)	0.981 (0.731)	4.79
Interior				
Hwd	12.67 (2.593)	0.4279 (0.1673)	0.981 (0.876)	3.69
Bl	8.824 (1.099)	0.5682 (0.09317)	0.970 (0.217)	3.17
Cw	20.69 (1.214)	—	0.956 (0.679)	4.21
Fd	8.215 (0.6681)	0.6211 (0.05034)	0.988 (0.862)	— <sup>a</sup>
Pl	7.885 (0.8217)	0.7167 (0.06828)	0.974 (0.109)	— <sup>a</sup>
Sw	9.303 (0.6837)	0.6212 (0.05113)	0.971 (0.121)	3.30
Hw	11.42 (1.885)	0.5430 (0.1693)	0.950 (0.171)	3.44
Lw	22.08 (0.5842)	—	0.945 (0.229)	2.80
Py	8.311 (2.013)	0.6081 (0.1753)	0.928 (0.122)	3.41

<sup>a</sup> The transformation to the model makes the root mean squared error meaningless, therefore, it is not reported here.

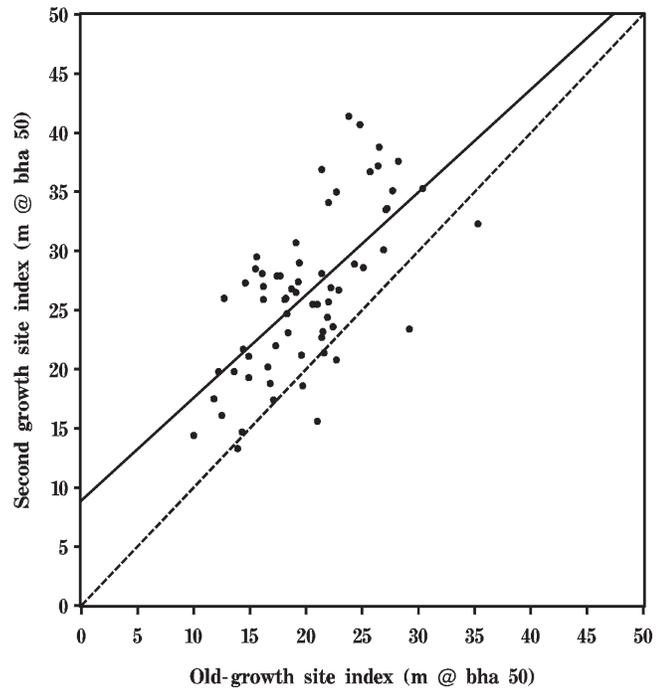


FIGURE 1. Fitted adjustment equation (—) overlaid on the data points (•) for coastal Douglas-fir. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

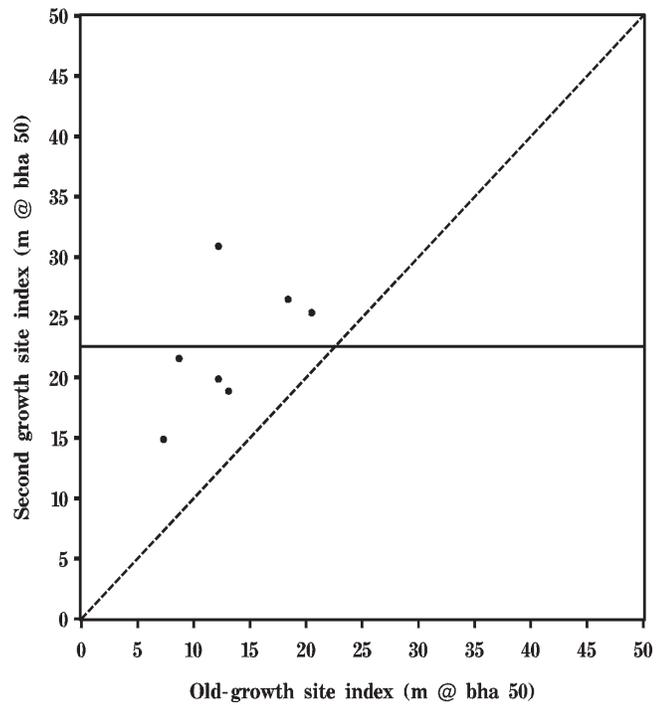


FIGURE 2. Fitted adjustment equation (—) overlaid on the data points (•) for coastal amabilis fir. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

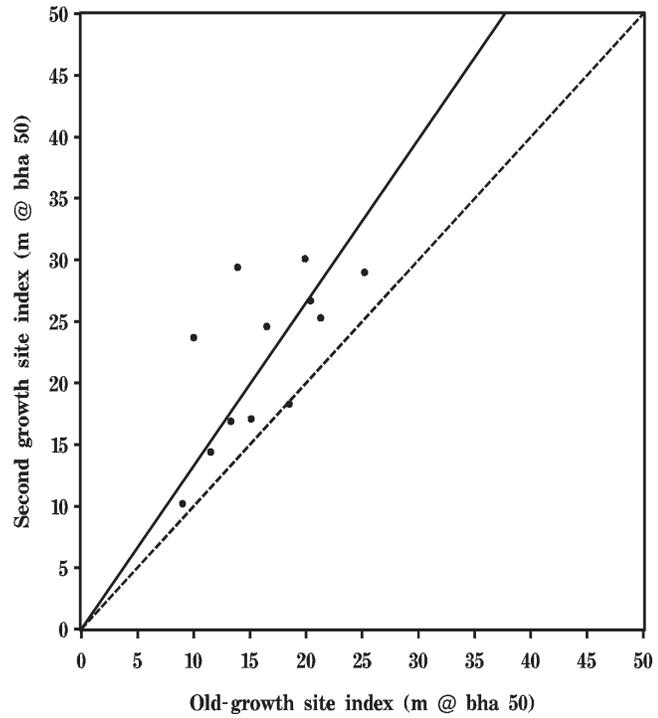


FIGURE 3. Fitted adjustment equation (—) overlaid on the data points (•) for coastal western redcedar. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

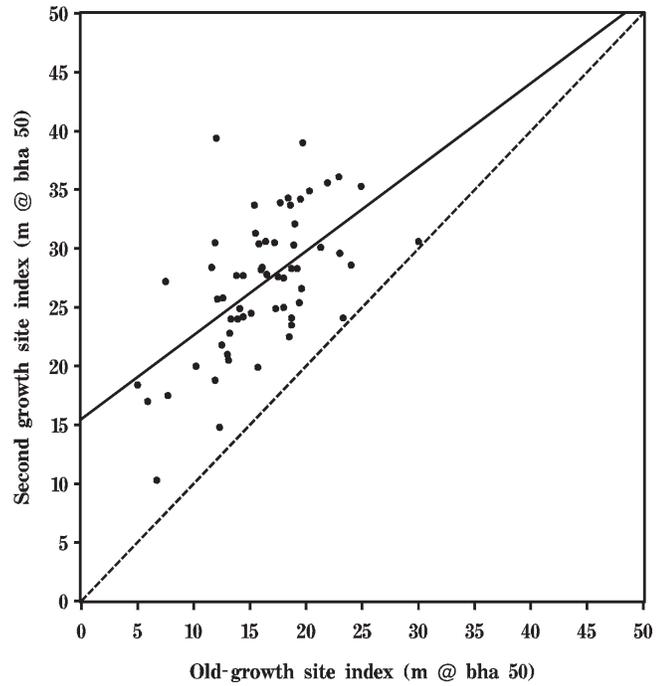


FIGURE 4. Fitted adjustment equation (—) overlaid on the data points (•) for coastal western hemlock. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

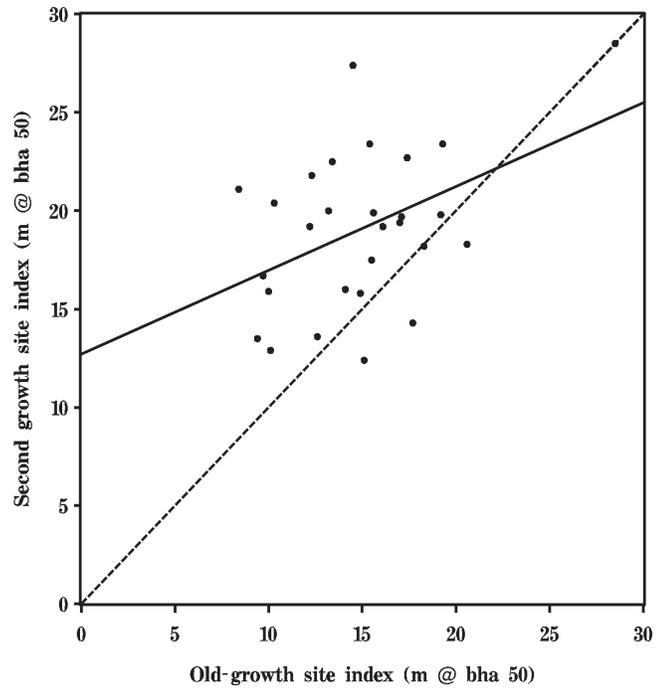


FIGURE 5. Fitted adjustment equation (—) overlaid on the data points (•) for interior hardwoods. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

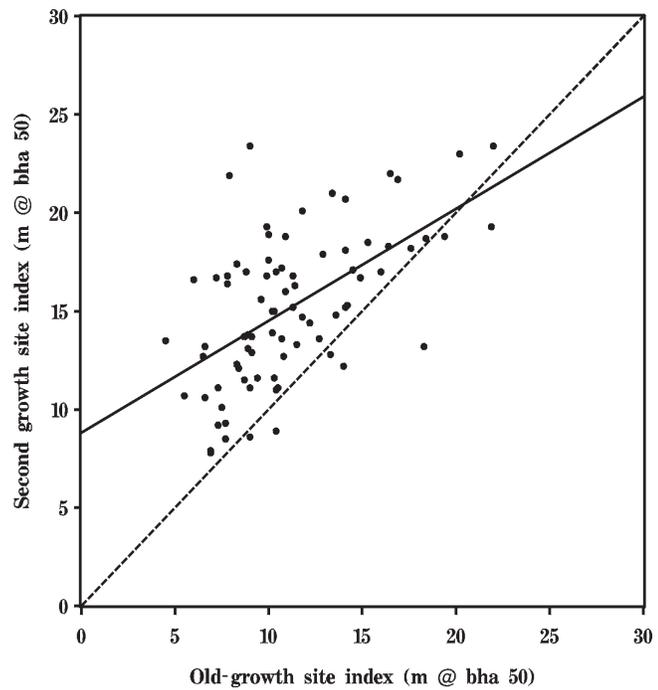


FIGURE 6. Fitted adjustment equation (—) overlaid on the data points (•) for interior subalpine fir. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

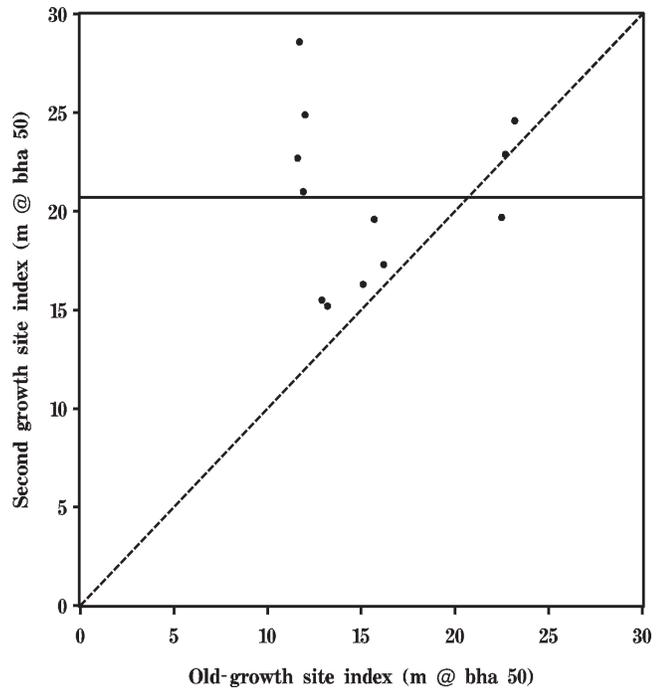


FIGURE 7. Fitted adjustment equation (—) overlaid on the data points (•) for interior western redcedar. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

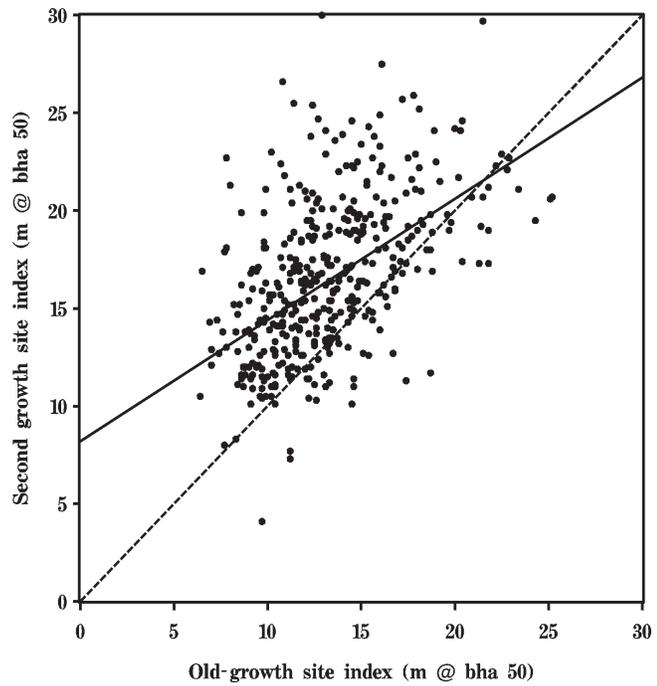


FIGURE 8. Fitted adjustment equation (—) overlaid on the data points (•) for interior Douglas-fir. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

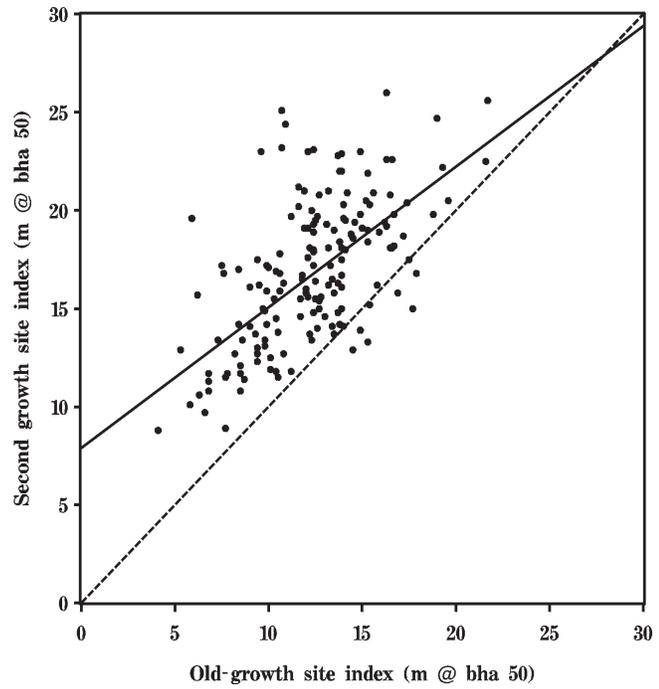


FIGURE 9. Fitted adjustment equation (—) overlaid on the data points (•) for interior lodgepole pine. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

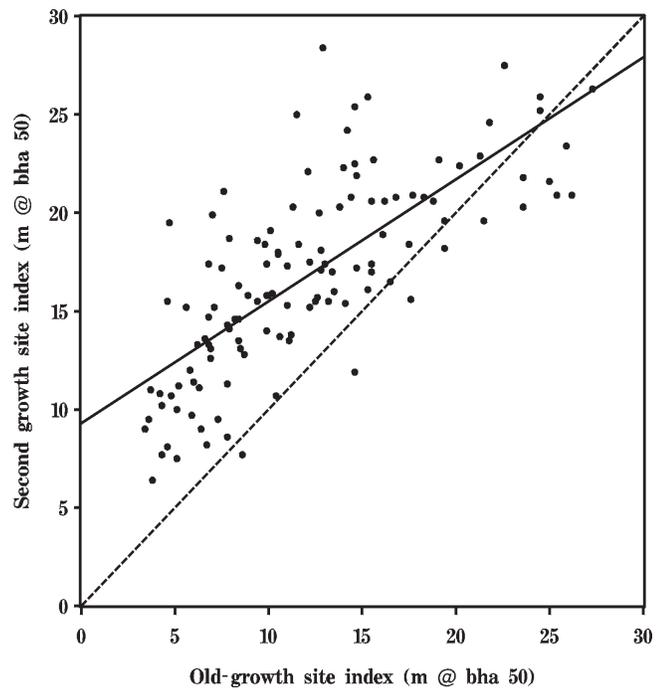


FIGURE 10. Fitted adjustment equation (—) overlaid on the data points (•) for interior spruce. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

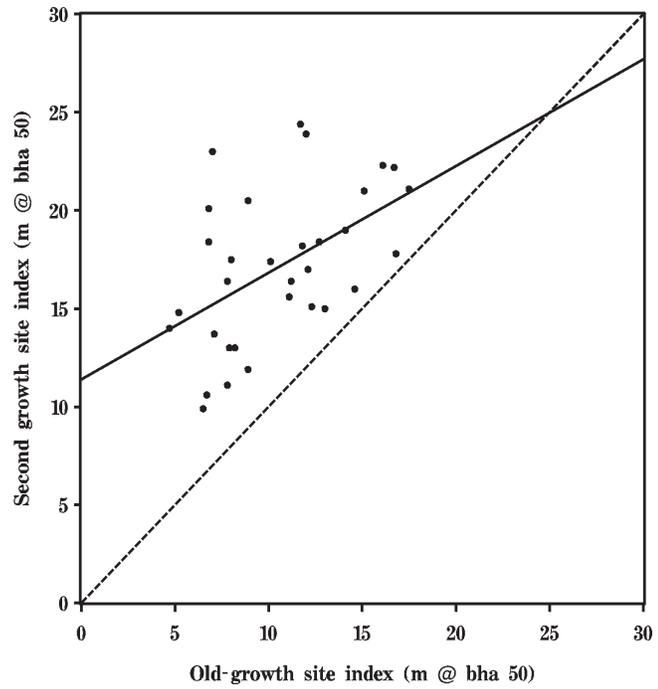


FIGURE 11. Fitted adjustment equation (—) overlaid on the data points (•) for interior western hemlock. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

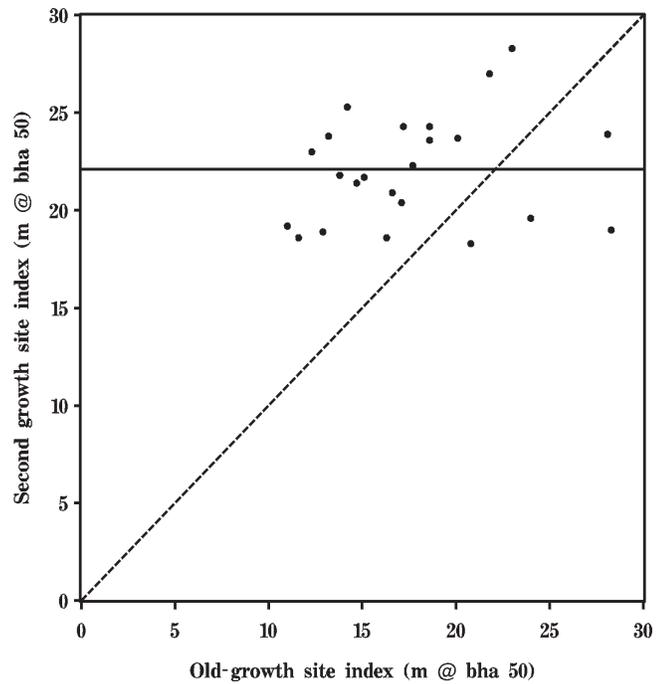


FIGURE 12. Fitted adjustment equation (—) overlaid on the data points (•) for interior western larch. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

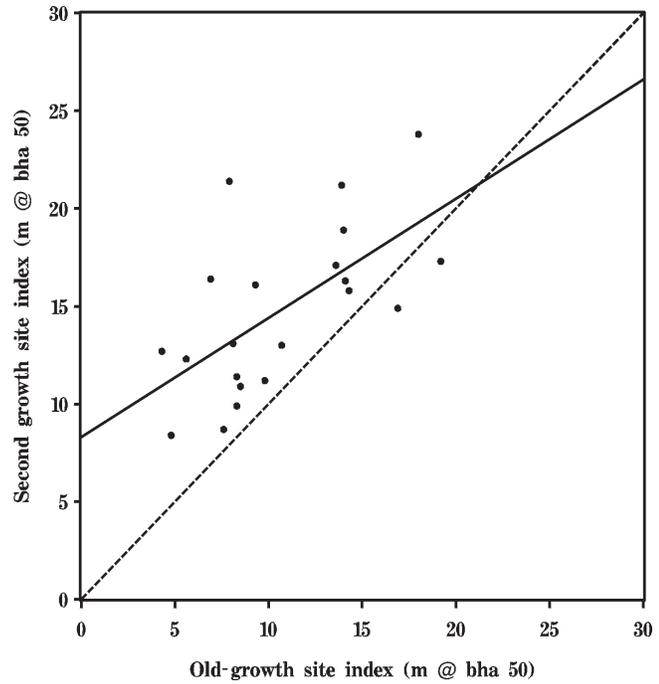


FIGURE 13. Fitted adjustment equation (—) overlaid on the data points (•) for interior Ponderosa pine. The dashed line (---) shows the relationship between the old-growth and second growth site indices if no adjustment is appropriate.

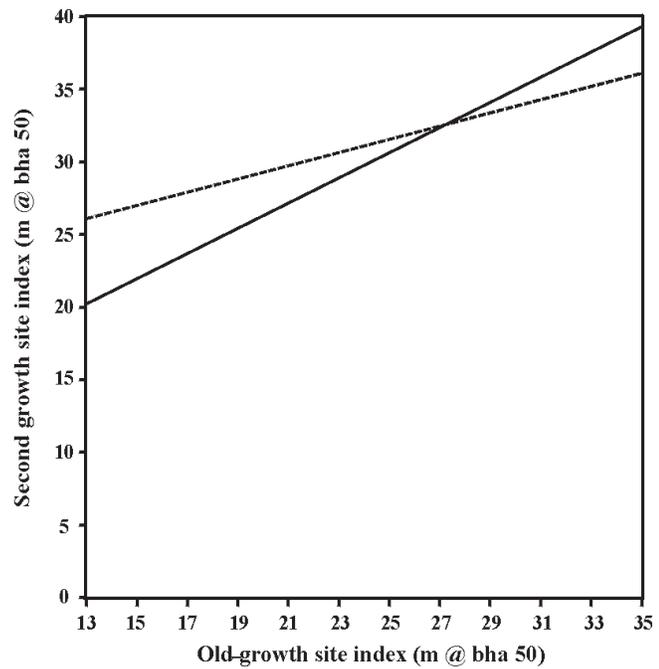


FIGURE 14. Comparison of adjustment equations derived from the veteran study (—) and the paired-plot study (---) for coastal Douglas-fir.

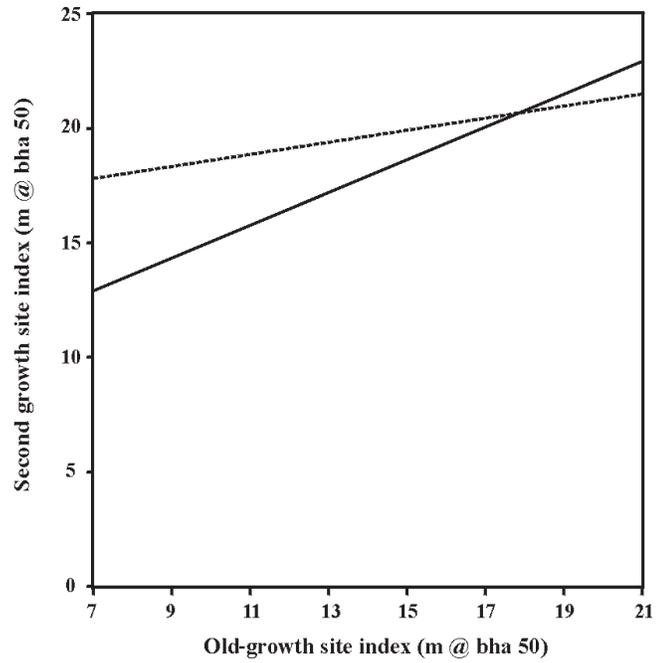


FIGURE 15. Comparison of adjustment equations derived from the veteran study (—) and the paired-plot study (---) for interior lodgepole pine.

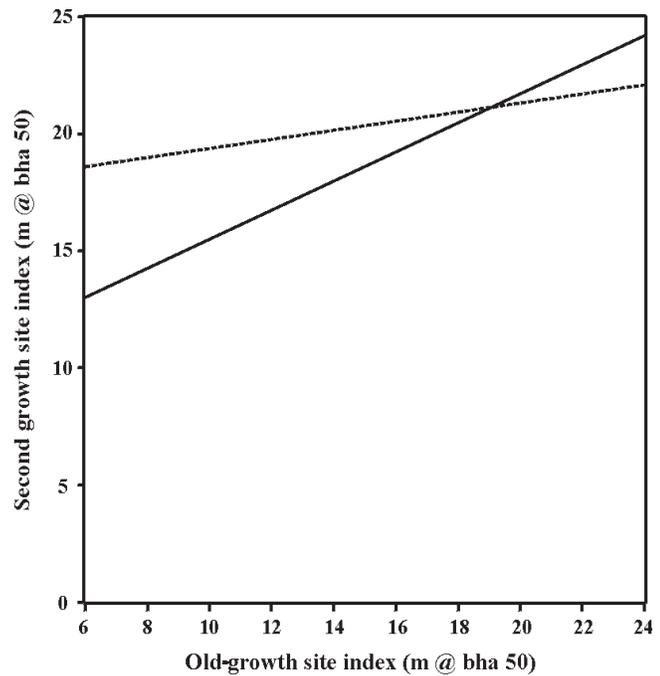


FIGURE 16. Comparison of adjustment equations derived from the veteran study (—) and the paired-plot study (---) for interior spruce.

## DISCUSSION

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The results of this study indicate that the site indices associated with veteran trees appear to be underestimated for all species considered. This finding may also apply to old-growth stands. The bias may be caused by suppression, repression, biotic or abiotic damage, dead tops, mortality amongst earlier top height trees, or because the height-age model used to estimate the site index is biased in the old-growth age range. The biological factors listed above have a tendency to reduce the height of the trees, resulting in estimated site indices that are too low. Biases in the height-age model may cause the estimated site indices to be too high or too low, but will probably cause the site indices to be too low.

Site index adjustments for coastal Douglas-fir, interior lodgepole pine, and interior spruce are available through the provincial paired-plot project. The veteran data for these species were analyzed and are reported here so that a comparison to the paired-plot results can be made, which lends support to the veteran analysis<sup>3</sup>. Figures 14 – 16 show the veteran and paired-plot adjustments (Nussbaum 1998) over the old-growth site index range common to both projects. Although the differences between the two adjustment equations can be significant, the comparison indicates that the veteran-based adjustment equations are conservative over most of the site index range; that is, they are lower than the paired-plot adjustments.

The site index of the veteran component in a plot is assumed to be representative of the site index of a previous old-growth stand. There are some concerns about using the veteran component to represent a previous old-growth stand. These concerns stem around the inaccurate ages and around our inability to determine whether the veteran component is similar to the previous stand. For example, the veteran component may consist of trees that are so poor that they weren't considered worthy of harvesting and therefore would not be suitable top height trees. If this were the case, the site index of the veterans would likely be lower than the site index of the previous stand. However, many of the plots were likely disturbed by fire, resulting in new regeneration with scattered veteran trees. These trees tend to be larger and have thicker bark, and hence may be suitable site trees.

There are also concerns about the data for the main stand component. This component is assumed to be representative of managed stands. Again, there is little information about these data so repression, damage, and suppression may exist in some of the sample trees. These factors tend to reduce the estimated site index.

The lack of information about the data and the lack of control on the data renders the veteran results less reliable than the paired-plot results. Therefore, the veteran adjustments should be replaced with better techniques for estimating site index when they become available. In particular, the adjustment equations for coastal and interior western redcedar and amabilis fir should be used with caution. The sample sizes for these species are small, therefore, their adjustment equations are not well-defined. However, the equation for coastal western redcedar is not unreasonable. For amabilis fir, western larch, and interior western redcedar, the site index of the old-growth

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<sup>3</sup> The results for these species are for comparison only; the paired-plot results should be used operationally.

stand does not give any indication of the site index of the second growth stand. This result is unexpected, although it has been observed in lodgepole pine (Goudie 1996). For western larch, however, the sample size is adequate and the data covers a wide range of old-growth site indices so there is reasonable evidence that its site index is relatively constant across a wide range of sites.

Not all managed stands will reflect their potential productivity due to factors such as suppression, repression, brush competition and damage from insects and disease. Therefore, many managed stands may not exhibit the height growth that is implied by the site index corrections. Furthermore, the height growth of the stands that initially reflect the productivity of the site may not continue to do so as they mature because of future top damage, pest-related damage, succession, etc.

One potential source of bias in the results may arise if bias exists in the models used to estimate the main stand site index. However, there is presently no evidence of bias in the models. There is also potential for application bias because the results may be applied to a population that is different from the sample population. The veteran layer data may not be representative of the age class 8 and 9 population to which the site index adjustments will be applied, particularly since some of the veteran trees may be from younger age classes. Therefore, an unknown bias may exist between the sample and the target application population. The level of this bias cannot be known until accurate site indices are obtained from future rotations. Application bias may also arise if inventory estimates of old-growth site indices are obtained differently from the paired plot estimates of old-growth site indices. Inventory old-growth site indices are photo-interpreted, not measured as was done in this study, therefore, using them in the correction equations may introduce a bias.

## **APPLICATION GUIDELINES**

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This discussion presents recommendations on how to calculate and apply an estimate of potential site productivity for managed stands.

Equations to estimate a managed stand site index from an old-growth site index are provided and apply to the species in Table 2. The stands to which the adjustments will be applied must be leading in one of those species, and they must be old-growth stands (total age > 140 years) which have been clearcut harvested and regenerated. The old-growth site index must be derived from the height and age of the old-growth stand using the same site curves used to develop the adjustment equations. Application of any equation must be restricted to the range of site indices sampled for the veteran layer. Because of the lower reliability of the data used to develop these adjustments, details of their application will be addressed on a case-by-case basis.

Not all regenerated stands will reflect their potential for growth. Therefore, yield curves and green-up ages calculated using an adjusted old-growth site index should be altered to reflect factors impacting height growth. Regenerated stands with repression should not use a corrected site index. Most old-growth stands that will be clearcut harvested and will meet free to grow requirements should be eligible for a site index correction.

## **CONCLUSION**

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This study yielded site index adjustment equations for the major species found in British Columbia, except for Sitka spruce. These adjustments can be used until better information becomes available; however, users should recognize the lower reliability of the adjustments, particularly for amabilis fir and coastal and interior western redcedar. Future efforts should focus on replacing veteran-based adjustments with better techniques for obtaining site indices.

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