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Site Index Adjustment for Old-growth Coastal Western Hemlock Stands in the Kalum Forest District

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ABSTRACT

Inventory information indicates that the average site index of old-growth western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) leading stands in the CWH portion of the Kalum Timber Supply Area is 13.3 m. Field observations by many foresters suggest that second-growth stands are performing much better than the inventory information indicates. Therefore, a study was conducted to examine the change in estimated site index when old-growth hemlock stands are harvested and regenerated to managed hemlock. The site indices of old-growth stands were compared to those of regenerated stands by spatial (paired plot technique) and temporal (relocated temporary sample plot) methods. Site indices measured in the managed stands were 11.3 m greater than those measured in the old-growth stands. The application of the results is discussed.

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1 INTRODUCTION

Based on inventory information, the average estimated site index for old-growth[1] western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) leading stands in the Kalum Timber Supply Area (TSA) (Coastal Western Hemlock [CWH] biogeoclimatic zone only) is 13.3 m (minimum 8.2 m; maximum 25.4 m). The maritime influence of this area (Banner et al. 1993) and casual field observations suggest to many foresters that the true average site index is much higher. An increase in the estimated site indices could have major impacts on forest management decisions. For example, higher site indices may lead to increased long-term timber supply because estimated future mean annual increments and timber volumes will be greater. Based on promising results from other related research (Goudie 1996), a study was undertaken to investigate the reliability of the estimated site indices from old-growth hemlock stands. There were two closely related objectives to this study:

1. Quantify the change (increase or decrease) in estimated site index when an old-growth hemlock stand is harvested and the replacement hemlock stand is managed; and
2. If the site index changes, derive a site index adjustment for old-growth stands for forest-level planning.

A distinction needs to be made between site productivity, site index, and estimated site index. Site productivity is the capacity of land to produce timber volume (Vanclay 1992). Site index, which is the top height of a stand at breast height age 50, is used as a measure of potential site productivity. The productivity of a site and hence the true site index should not change significantly when an old-growth stand is harvested. However, the estimated site index may change when the replacement stand is managed. This is because our ability to estimate site index depends on the condition of both the stand and the trees in the stand, either of which may change drastically after harvesting. The most common problem in estimating site index for most species is selecting and measuring inappropriate site trees in old-growth stands, such as those with early suppression or excessive top damage. A serious problem in a few species, most notably lodgepole pine (*Pinus contorta* spp. *latifolia*), is excessive density after wildfire (Goudie 1996) reducing dominant height growth. These problems lead to underestimated site indices. Good forest management should reduce the occurrence of these problems and hence bias in site index, but it does not ensure that they are eliminated.

2 DATA

The purpose of the sampling was to locate plot pairs spatially or temporally on sites of equal inherent productivity so that the estimated site index of old-growth and managed regenerated stands could be directly compared. We assume that the estimated site index in the managed stand plot reflects the inherent productivity of the plot pair. Because of the difficulty in establishing a sampling frame, the sample selection process does not follow any predefined design, and therefore does not follow any conventional selection process such as simple random sampling (Kish 1965).

1 An old-growth stand is defined as an age class 8 or 9 stand; that is, a stand over 140 years in total age.

2.1 Paired Plot Installation

Potential sampling locations were identified from forest cover maps and from field reconnaissance. Potential locations consisted of adjacent old-growth and managed western hemlock leading stands in the CWH portion of the Kalum TSA, Tree Farm Licence (TFL) 1, and TFL 41. The potential locations were visited and the boundary between the old-growth and managed stands was checked to ensure that three plot pairs could be successfully established. If the boundary passed the preliminary check, the three plot pairs were established systematically along the stand boundary at a minimum 50 m interval. If any plot pair establishment was initially unsuccessful, then further attempts were made at 25 m intervals until a pair was successfully established (Figure 1 illustrates an example installation). One sample is composed of the three plot pairs.

One plot of each pair was established 20 m perpendicular to the stand boundary in the old-growth stand and the other plot was established 40 m perpendicular to the stand boundary in the managed stand. The increased distance helped minimize edge effects. If an old-growth plot could not be established for any reason, up to two 20-m offsets further into the stand were permitted to increase the chance of successfully establishing a pair. All six plots had to be in the same site series or similar site series complexes. The rigorous plot pairing ensured that all plots were on sites with similar inherent site productivity, otherwise the resulting site index adjustments may be biased.

Plot installation commenced once the plot pair was located. The plots had 10.75-m radii. The three largest-diameter, vigorous trees that were free of suppression and mechanical, insect, or disease damage were chosen as the site trees (exception: suppression, rot, and top damage not clearly visible was acceptable in the old-growth trees). The managed stand sample trees had at least five years of height growth above breast height. Sample trees were felled and their height and breast height age were recorded. Breast height age is the number of annual growth rings at breast height. Disks were taken from the old-growth trees for ring counting in the laboratory. Species composition and density were calculated from dot tallies. In the managed stands, tallies were taken by species and 2-cm diameter class in a 5.64-m radius sub-plot. Tallies were done by species and 5-cm diameter class in the old-growth plots using the full plot. Managed stand plots with estimated establishment densities above 10 000 stems per ha were unacceptable as sample plots because of the possibility of height growth repression in the sample trees. A full ecological description (Luttmerding et al. 1990) was done at each plot.

2.2 Temporary Sample Plot Re-establishment

Temporary sample plots (TSPs) established in old-growth western hemlock leading stands in the CWH portion of the Kalum TSA, TFL 1, and TFL 41 were identified. Of these TSPs, only plots harvested and regenerated with western hemlock and with heights and breast height ages recorded on the TSP tally sheets for the site index sample trees were identified for potential TSP re-establishment. These potential samples were relocated from photos and access notes. If the current stand was western hemlock leading and the site trees were above five years breast height age at the TSP location, then managed stand site index sample plots were established and measured, as described above.

In total, 25 paired plot samples were established and measured: 12 were established in the summer and fall of 1994 and the remainder were done in the summer and fall of 1995. The field crew carrying out the work in 1995 checked the plots established in 1994. They recommended that one sample be

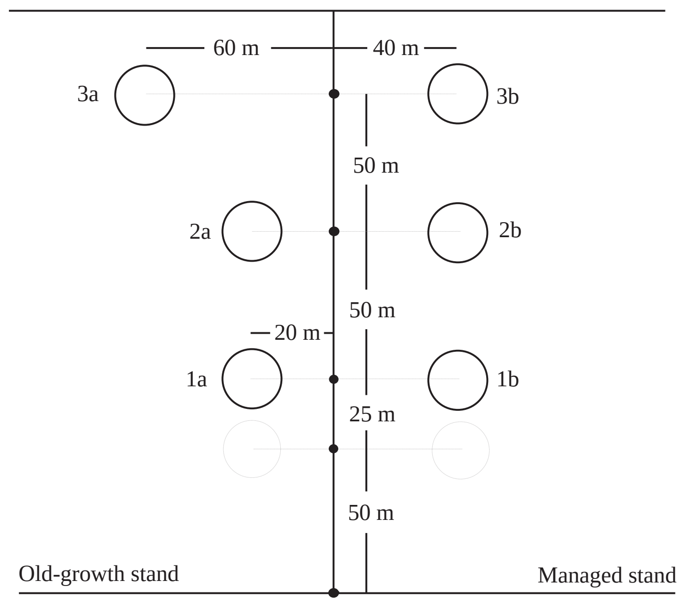

FIGURE 1 *Example paired plot installation. Plot pair 1 was moved 25 m further along the stand boundary because the first attempt at establishing a plot pair was unsuccessful (due to improper site series matching, poor site trees, etc.). Plot 3a was offset twice (20 m each time) before a successful matching was accomplished.*

rejected because of suppression in the managed stand plots and another sample be rejected because of highly variable site series, which cast doubt on the suitability of the matching of the productivity of the plots. In addition to rejecting the two samples, some sample trees and plots were rejected because of suppression or excessive rot, which made ring counting impossible.

In addition to the 23 paired plot samples, five TSPs were re-established and measured in the summer and fall of 1995. Therefore, there were 28 observations available for analysis. The samples ranged in elevation from approximately 150 to 800 m (average: 400 m), their slopes ranged from approximately 0 to 90% (average: 35%), and they had aspects that included all four quadrants of the compass and flat.

3 METHODS

All data were entered into a spreadsheet and checked against the field cards for errors in data entry and in calculating heights from clinometer measurements. The heights and breast height ages of the sample trees in the old-growth plots were averaged and the site index was estimated from the coastal western hemlock height–breast height age model (Wiley 1978). In the managed stand plots, site index was estimated for each sample tree with the growth intercept model for western hemlock (Nigh 1996). The site indices from the sample trees within each plot were then averaged to give a site index for the plot. The old-growth site indices (SI_O), heights, breast height ages, and the managed stand site indices (SI_M) were averaged by sample, and the difference in site index, ΔSI (= SI_M - SI_O), was calculated.

The change in site index (ΔSI) was plotted against the old-growth site index, height, and breast height age to detect trends in the changes. As well, SI was regressed against the same variables in an attempt to establish an adjustment equation. The potential adjustment equations were:

$$\Delta SI = a + b \ SI_O \quad (1)$$
$$\Delta SI = a + b \ H_O \quad (2)$$
$$\Delta SI = a + b \ BHA_O \quad (3)$$

where: H_O = average height (m) of the old-growth sample,
BHA_O = average breast height age (years) of the old-growth sample,
a, b = model parameters to be estimated by linear regression, and
all other variables are as previously defined.

All analyses assumed that the data were collected by simple random sampling.

4 RESULTS

Table 1 presents summary statistics for the 28 samples. Tables 2 and 3 present the same information by sample type (paired plot or TSP) and biogeoclimatic site series, respectively.

Figure 2 shows the managed stand site indices plotted against the old-growth site indices. The line in the graph shows the relationship that would occur if the managed stand site indices were the same as the old-growth site indices. Data points above this line indicate that the managed stand site index is greater than the old-growth site index, the opposite being the case for points below the line. Note that all points are above the line. Figures 3, 4, 5, and 6 are plots of the change in site index against the old-growth site index, height, breast height age, and biogeoclimatic site series, respectively.

The results of the analysis of the three potential adjustment equations are in Table 4. None of the explanatory variables (old-growth site index, height, and breast height age) had any statistically significant predictive ability. The data were then analyzed using a paired t-test. The average difference in site index between the managed stand plots and the old-growth stand plots is 11.3 m (number of observations = 28; standard deviation = 2.96 m; standard error of the mean = 0.559; t [H_O: no change in site index] = 20.12 $\Rightarrow p \leq 0.0001$). This indicates that the managed stand site indices are statistically significantly greater than the old-growth site indices.

TABLE 1 *Sample summary statistics*

		n	Mean	Std. dev.	Range Min.	Max.
Managed stand	Height (m)	28	8.7	2.12	5.4	14.6
	bha (yrs)	28	16	4.41	6	24
	SI (m @ bha 50)	28	24.9	3.45	17.1	34.3
Old-growth stand	Height (m)	28	34.3	5.88	21.0	45.3
	bha (yrs)	28	300	77.7	151	435
	SI (m @ bha 50)	28	13.7	2.26	9.5	18.0

TABLE 2 *Sample summary statistics by sample type*

			n	Mean	Std. dev.	Range Min.	Max.
Paired plots	Managed stand	Height (m)	23	8.7	2.16	5.4	14.6
		bha (yrs)	23	16	4.36	6	24
		SI (m @ bha 50)	23	24.7	3.47	17.1	34.3
	Old-growth stand	Height (m)	23	34.6	4.81	26.7	45.3
		bha (yrs)	23	316	70.6	151	435
		SI (m @ bha 50)	23	13.5	2.07	9.5	16.7
TSPS	Managed stand	Height (m)	5	9.2	2.12	5.6	10.7
		bha (yrs)	5	16	5.18	10	24
		SI (m @ bha 50)	5	25.9	3.58	20.5	29.8
	Old-growth stand	Height (m)	5	33.0	10.17	21.0	45.0
		bha (yrs)	5	225	69.3	155	315
		SI (m @ bha 50)	5	14.3	3.20	10.3	18.0

TABLE 3 *Sample summary statistics by biogeoclimatic site series*

			n	Mean	Std. dev.	Range	
						Min.	Max.
CWHws1/01	Managed stand	Height (m)	11	8.4	1.65	5.4	10.7
		bha (yrs)	11	15	5.12	6	24
		SI (m @ bha 50)	11	25.7	4.20	19.5	34.3
	Old-growth stand	Height (m)	11	34.0	6.73	21.0	45.0
		bha (yrs)	11	312	78.0	155	431
		SI (m @ bha 50)	11	13.3	2.59	9.5	18.0
CWHws1/01(03)	Managed stand	Height (m)	1	10.1	-	-	-
		bha (yrs)	1	20	-	-	-
		SI (m @ bha 50)	1	23.4	-	-	-
	Old-growth stand	Height (m)	1	31.3	-	-	-
		bha (yrs)	1	151	-	-	-
		SI (m @ bha 50)	1	16.0	-	-	-
CWHws1/01(04)	Managed stand	Height (m)	2	8.9	0.58	8.5	9.3
		bha (yrs)	2	16	1.10	15	17
		SI (m @ bha 50)	2	25.1	2.55	23.3	26.9
	Old-growth stand	Height (m)	2	41.6	5.28	37.9	45.3
		bha (yrs)	2	378	80.8	320	435
		SI (m @ bha 50)	2	15.7	1.46	14.6	16.7
CWHws1/01(10)	Managed stand	Height (m)	1	6.1	-	-	-
		bha (yrs)	1	18	-	-	-
		SI (m @ bha 50)	1	17.1	-	-	-
	Old-growth stand	Height (m)	1	28.8	-	-	-
		bha (yrs)	1	297	-	-	-
		SI (m @ bha 50)	1	10.9	-	-	-
CWHws1/03	Managed stand	Height (m)	4	8.6	2.74	5.6	11.4
		bha (yrs)	4	17	5.86	10	24
		SI (m @ bha 50)	4	23.7	2.15	21.7	26.3
	Old-growth stand	Height (m)	4	31.7	6.14	24.0	39.0
		bha (yrs)	4	260	83.7	155	356
		SI (m @ bha 50)	4	13.1	2.34	11.4	16.5
CWHws1/04	Managed stand	Height (m)	3	9.0	1.59	7.5	10.7
		bha (yrs)	3	15	4.50	12	20
		SI (m @ bha 50)	3	27.0	2.49	24.1	28.6
	Old-growth stand	Height (m)	3	35.4	2.90	32.2	37.9
		bha (yrs)	3	287	57.9	253	354
		SI (m @ bha 50)	3	14.1	0.79	13.3	14.8

TABLE 3 *Continued*

			n	Mean	Std. dev.	Range Min.	Range Max.
CWHws1/04(01)	Managed stand	Height (m)	1	14.6	-	-	-
		bha (yrs)	1	24	-	-	-
		SI (m @ bha 50)	1	27.7	-	-	-
	Old-growth stand	Height (m)	1	41.3	-	-	-
		bha (yrs)	1	311	-	-	-
		SI (m @ bha 50)	1	16.4	-	-	-
CWHws1/05	Managed stand	Height (m)	1	12.4	-	-	-
		bha (yrs)	1	21	-	-	-
		SI (m @ bha 50)	1	25.9	-	-	-
	Old-growth stand	Height (m)	1	32.9	-	-	-
		bha (yrs)	1	269	-	-	-
		SI (m @ bha 50)	1	13.3	-	-	-
CWHws2/01	Managed stand	Height (m)	2	7.9	0.84	7.3	8.5
		bha (yrs)	2	15	0.55	14	15
		SI (m @ bha 50)	2	24.6	1.26	23.7	25.5
	Old-growth stand	Height (m)	2	33.5	9.55	26.7	40.2
		bha (yrs)	2	351	78.5	295	406
		SI (m @ bha 50)	2	12.4	3.13	10.2	14.6
CWHws2/01(04)	Managed stand	Height (m)	2	7.1	1.10	6.3	7.9
		bha (yrs)	2	15	1.89	13	16
		SI (m @ bha 50)	2	22.5	0.87	21.9	23.1
	Old-growth stand	Height (m)	2	35.3	0.80	34.7	35.9
		bha (yrs)	2	290	113.6	210	371
		SI (m @ bha 50)	2	14.3	2.36	12.6	16.0

TABLE 4 *Results of the analysis of potential adjustment equations*

Equation	Root MSE	R^2	Parameter	Estimate	Std. error
$\Delta SI = a + b\ SI_O$	2.983	0.022			
			a	13.9	3.51
			b	-0.192	0.254
$\Delta SI = a + b\ H_O$	3.01	0.006			
			a	12.6	3.43
			b	-0.0394	0.0984
$\Delta SI = a + b\ BHA_O$	3.013	0.002			
			a	10.7	2.31
			b	0.00179	0.00746

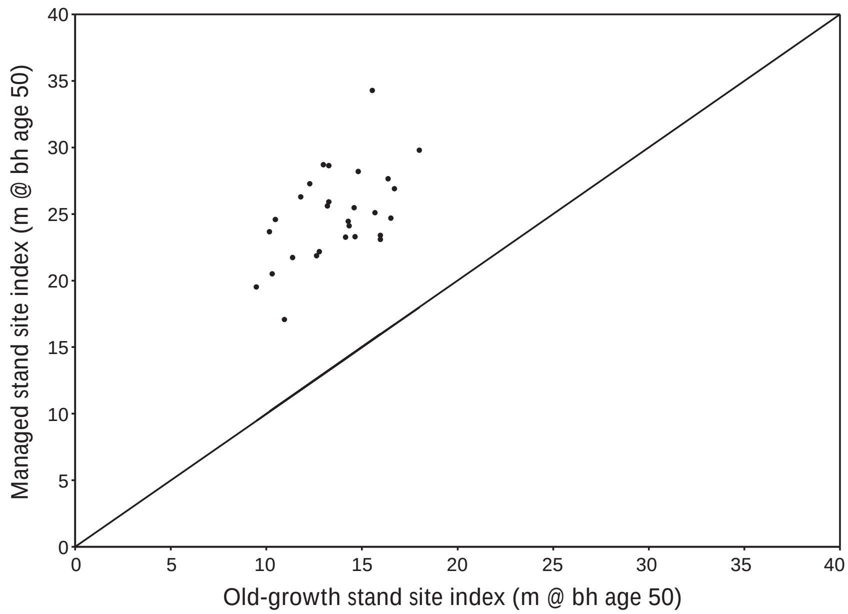

FIGURE 2 *Plot of managed stand site indices against old-growth stand site indices(•). The 45° line indicates where the managed stand site index is the same as the old-growth stand site index; that is, no adjustment in site index is apparent.*

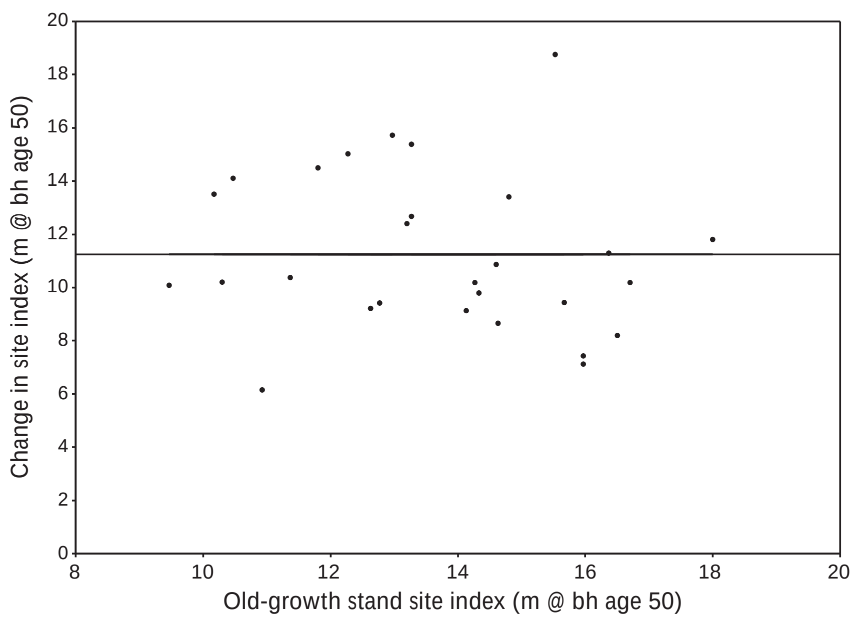

FIGURE 3 *Plot of increase in site index against old-growth site index (•). Average increase is indicated by the line.*

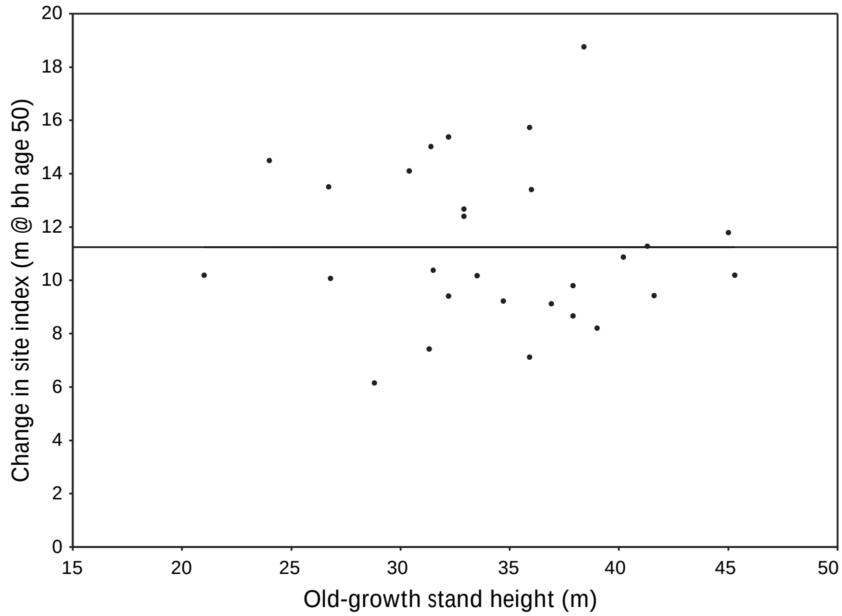

FIGURE 4 *Plot of increase in site index against old-growth height (•). Average increase is indicated by the line.*

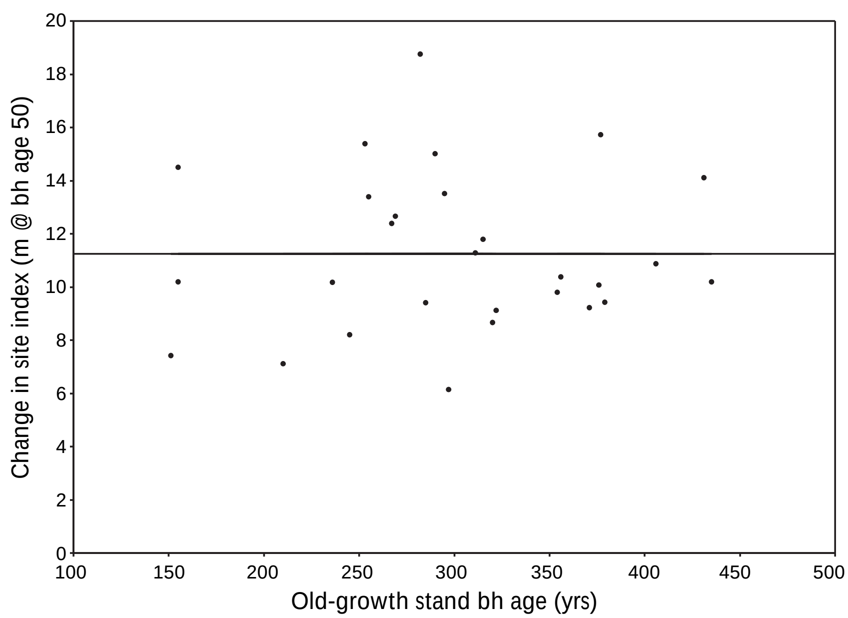

FIGURE 5 *Plot of increase in site index against old-growth breast height age (•). Average increase is indicated by the line.*

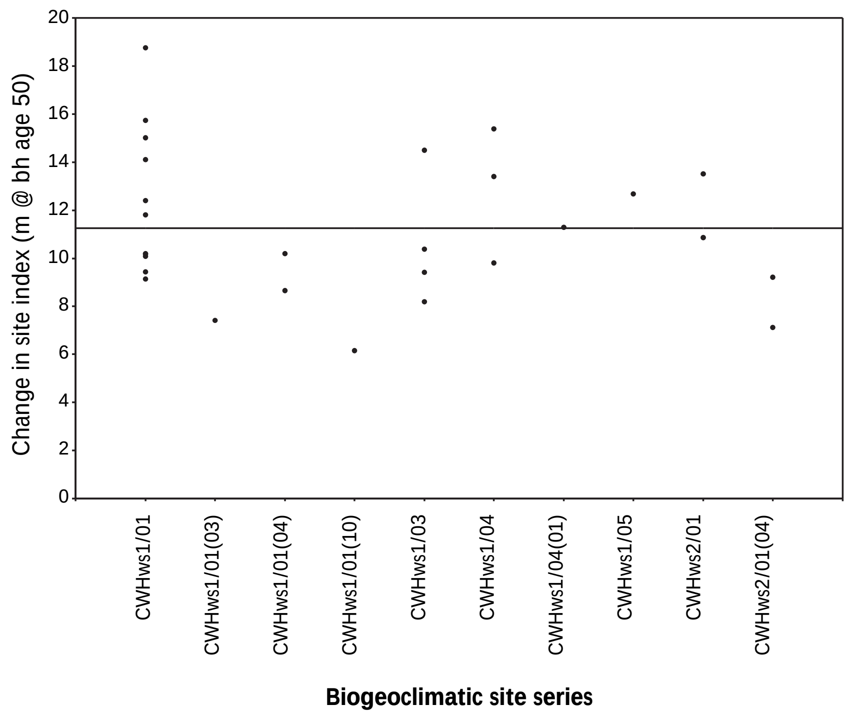

FIGURE 6 *Plot of increase in site index against biogeoclimatic site series (•). Average increase is indicated by the line.*

5 DISCUSSION

The results of this study indicate that the old-growth site indices in the CWH portion of the Kalum TSA, TFL 1, and TFL 41 underestimate the managed stand site indices by 11.3 m, a substantial bias. The average old-growth stand site index from the inventory (13.3 m) is approximately the same as the average old-growth site index from this study (13.7 m). The minimum site index from the two sources is also approximately the same (8.2 versus 9.5 m), although the maximum site index is somewhat higher from the inventory (25.4 versus 18 m). Therefore, the old-growth site indices from the samples in this study roughly reflect the inventory site indices.

There are many factors that could contribute to the underestimation of site index in old-growth stands. Some of these factors are:

1. Suppression in the top-height trees, which results in the trees under-achieving their growth potential.
2. Bias in the height–breast height age model used to estimate old-growth site index.
3. Top damage in the top-height trees, which causes the measured height growth to under-represent the true height growth.
4. Death of the best top-height trees (i.e., trees that best express the potential productivity of the site), leaving less suitable trees being chosen as top-height trees.

Without setting up an experiment to specifically test these factors, it is difficult to determine the influence that each has on the estimated site index. However, it is likely that all of the above factors are contributing to the underestimation of site index in old-growth western hemlock stands in the study area.

Care was taken in the sampling to select only those trees that reflected the potential productivity of the site on the managed plots. Not all trees in all managed stands will reflect the potential productivity of the site due to factors such as suppression and brush competition. Therefore, on average, the managed stands may not exhibit the height growth implied by the site index adjustment. Furthermore, the height growth of hemlock stands that initially reflect the productivity of the site may not continue to do so as they mature because of top damage, pest-related damage, succession, etc.

There are some sources of potential bias in the results. These sources are:

1. Bias in the growth intercept model.
   The growth intercept model may give biased site index estimates for the managed stand site indices.
2. Improper spatial or temporal matching of the old-growth and managed stand plots with respect to site productivity.
   If the pairing of plots did not result in the plots being on sites with the same productivity, then comparing the old-growth stand site index to the managed stand site index would not be valid. Many of the paired plots were on slopes with the old-growth stand positioned above the managed stand. Therefore, the adjustment would likely be too large if the sites were not matched properly. Improper matching may also occur if the TSPs were not re-established at the original location. Efforts were made to ensure that paired plots were on sites with the same productivity and that TSPs were relocated as accurately as possible.
3. Application of results to a population that is different from the sample population (application bias).
   Only those stands meeting certain selection criteria were sampled. Therefore, an unknown bias may exist between the sample and all possible stands. The level of this bias cannot be known until accurate site indices are obtained from future rotations.
4. Bias in the growth intercept model development technique.
   Magnussen and Penner (1996) recently discussed a well-known potential bias in site index equations derived from stem analysis. The site index estimate from such equations will be biased because, on average, the site trees at the time of sampling are not the same as the site trees in the past. This is because previous site trees have either died or, due to various causes, fallen behind in height growth. This source of potential bias is only relevant to the growth intercept model because the adjustment corrects for any bias in the height-age model.

6 ADJUSTMENT GUIDELINES

This discussion presents our recommendations on how the adjustment should be done to obtain an estimate of the potential productivity of a site.

There was not enough evidence to indicate that the adjustment varies with old-growth site index, height, or breast height age. Therefore, an average adjustment is appropriate. The equations in Table 4 are not significant enough to be used to adjust the site indices.

The adjustment should only be applied to managed western hemlock leading stands in the CWH portion of the Kalum TSA, TFL 1, and TFL 41 that were assigned a site index estimated from Wiley's (1978) height-age model and a height and breast height age from a previously unmanaged old-growth western hemlock stand. As well, the estimated site index from the old-growth stand must have been between 8 and 18 m. The adjusted site index must not be used for estimating the height of the existing old-growth stand because those heights would be biased. Several sources of bias exist, as discussed above, which suggests that a conservative approach to adjusting the site index may be warranted. In general, we believe that the biases may result in the adjustment being overestimated. We do not know how much bias there is in the adjustment, if any, but 1.3 m may be reasonable, leaving an adjustment of 10 m. Further refinements to the adjustment should be made as more information is gleaned about the potential biases in the adjustment.

The adjustment is applied by adding the adjustment factor to a polygon's estimated site index (equation 4).

$$SI_M = SI_O + \Delta SI \quad (4)$$

where: SI_M = estimated managed stand site index (m @ bh age 50),
SI_O = estimated old-growth stand site index (m @ bh age 50), and
ΔSI = site index adjustment (m).

The Ministry of Forests will be forming a working group to discuss the application of study results in forest management analyses.

7 CONCLUSIONS

The paired plot/TSP re-establishment method of identifying biases in old-growth site indices was done for western hemlock in the CWH portion of the Kalum TSA and in TFLs 1 and 41. The results indicate that, on average, site indices estimated from the height and age of old-growth stands underestimate managed stand site indices by 11.3 m. However, due to several sources of potential bias in the adjustment, we recommend an adjustment of 10 m in order to obtain an estimate of potential productivity. Finally, it should be emphasized that the adjustments correspond to potential productivity. For a stand to achieve this potential, as measured in this study, requires that it be subject to ecological and management conditions that led to the observed results. The site index adjustments suggested in this study apply only in particular areas and under management regimes that largely eliminate factors that hinder tree growth, such as competition from pests and other vegetation.

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