W O R K I N G   P A P E R   3 7

Site Index Adjustments for Old-growth Stands Based on Paired Plots

1 9 9 8

British Columbia

Ministry of Forests Research Program

Site Index Adjustments for Old-growth Stands Based on Paired Plots

Albert F. Nussbaum

British Columbia

Ministry of Forests Research Program

Citation:
Nussbaum, A.F. Site index adjustments for old-growth stands based on paired plots.
Res.Br., B.C. Min. For., Victoria, B.C.
Work Pap. 37/1998

Prepared by:
Albert F. Nussbaum
B.C. Ministry of Forests
Research Branch
P.O. Box 9519, Stn. Prov. Govt.
Victoria, B.C. V8W 9C2
for
B.C. Ministry of Forests
Research Branch
712 Yates Street
Victoria, B.C. V8W 1L4

Copies of this report may be obtained, depending upon supply, from:
B.C. Ministry of Forests
Forestry Division Services Branch
Technical Communications Section
595 Pandora Avenue
Victoria, B.C. V8W 3E7

ABSTRACT

Regional studies support foresters' perceptions that site indices, the measure of forest site productivity in British Columbia, are underestimated in old-growth stands. When old-growth (total age > 140 years) stands regenerate following harvest, site index estimates generally rise. As a result of these regional studies, a province-wide study was initiated to derive adjustments, or corrections, for old-growth site indices with application guidelines for timber supply planning. Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) and interior spruce (*Picea glauca* (Moench.) Voss, *P. engelmannii* Parry ex. Engelm., and *P. glauca* x *P. engelmannii*) were examined in this study. Data came from paired plots installed in old-growth stands and adjacent logged and regenerated (LAR) stands of the same productivity. Site index was estimated for both the old-growth and LAR plots and comparisons were made. Equations to correct the old-growth site index for each species were derived using the two site indices from the plot pairs. No equation was derived for western hemlock due to poor sampling success. The analysis shows that on average, the old-growth site indices were being underestimated. Correction equations and application guidelines are provided. The results of this study should be useful in forest level planning until more reliable methods of estimating site index become available for old-growth stands.

ACKNOWLEDGMENTS

Many people contributed to this project including contractors, and Ministry of Forests personnel who were involved in the project at the Branch, Region and District level. The project was managed by Resources Inventory Branch with involvement from both Research and Timber Supply Branches. The Regional Growth and Yield Foresters and Sampling Coordinators implemented the sampling plan and carried out quality control for the project. A large number of contractors were involved in the project with tasks ranging from mapping to ground sampling. The project was funded by Forest Renewal British Columbia. The project team thanks everyone who assisted with this project.

CONTENTS

INTRODUCTION

Mounting evidence and foresters' perceptions suggest that the site indices of British Columbia's old-growth (total age > 140 years) stands are being underestimated. Regional pilot studies confirmed that site indices were being underestimated for western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) (Nigh and Love 1997) and lodgepole pine (*Pinus contorta* Dougl. ex loud. var. *latifolia* Engelm.) (Goudie 1996) with the results for lodgepole pine being comparable to those from Alberta (Udell and Dempster 1987). The potential impacts of underestimating site indices on forest level planning decisions warranted a province-wide study to develop site index adjustments, or corrections, for application after the harvest of old-growth stands. The two main objectives of the study are to:

1. Collect data and derive regional old-growth site index adjustment equations for use in forest management planning; and
2. Provide application guidelines for the adjustment equations.

Initially, the study focused on four major species: Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*); western hemlock (*Tsuga heterophylla* (Raf.) Sarg.); lodgepole pine (*Pinus contorta* Dougl. ex loud. var. *latifolia* Engelm.) and spruce (*Picea glauca* (Moench.) Voss, *P. engelmannii* Parry ex. Engelm., and *P. glauca* x *P. engelmannii*). Due to limited paired-plot sampling opportunities, the project did not yield an adjustment equation for western hemlock.

Paired plots are considered the most reliable approach for developing short-term old-growth site index adjustments as data quality can be assured through rigorous screening. It is unlikely, however, that enough paired-plot samples could be obtained to develop a correction equation for species not considered in the provincial study. Old-growth site index correction equations for species other than the three covered in the paired-plot project are still required, and are being addressed by an alternative approach (Nigh 1998).

This report describes the data, analysis methods, and results of the paired-plot study. Equations to correct old-growth site index estimates of coastal Douglas-fir and interior lodgepole pine and spruce are presented for use in forest level planning.

DATA

The purpose of the sampling was to locate a pair of plots (paired plot) on sites of equal inherent productivity so that the estimated site index of old-growth and logged and regenerated (LAR) stands could be directly compared. The estimated site index in the LAR plot is assumed to reflect the inherent productivity of the pair.

Sampling Approach

The detailed sampling design initially proposed (Anon. 1996) was modified as the project progressed due to the difficulty in establishing paired plots. The following steps outline how samples were selected and provides an overview of the sampling approach.

1. The province was divided into 6 regions[1] and target species were determined for each.
2. Mapsheets (1:20 000 forest cover maps) were identified where sampling could take place.
3. Potential lines were identified on the selected mapsheets by species and site class (Table 1 shows the site classes). A potential line was the interface between the old-growth and LAR stands (polygons). The potential lines were found as follows:
   a. We identified all LAR stands that were:
   - regenerated with the target species;
   - not in parks, reserves, or other protected areas;
   - at least 11 years total age;
   - on crown land;
   - not overly dense; and
   - not fertilized.
   b. A neighbor analysis was performed to determine which LAR stands had adjacent undisturbed age class 8 (total age 141 to 250 years) and 9 (total age > 250 years) stands of the same target species.
   c. The selected LAR/old-growth stands were examined on air photos to determine suitability for pairing. All potential lines had to be at least 100 metres long.
4. Potential lines were then screened by air with attention paid to species composition, topography, slope and aspect. Edges that passed the air screening were inspected on the ground and if suitable, an attempt was made to establish a paired plot along the acceptable lines.

A sample consisted of a single paired plot. The proposed target sample sizes were 90 samples per region and species for a total of 1080 samples (90 × 6 regions × 2 species). The 90 samples were to be distributed evenly among the site classes. A maximum of eight samples, distributed by site class, could be established per mapsheet to ensure plots were not highly clustered.

Paired Plot Installation

Attempts at paired-plot establishment were made at 25 m intervals along the line until a pair was established or the target line exhausted (Figure 1 illustrates an example installation). At each attempt, one plot of each pair was established 20 m perpendicular to the stand boundary in the old-growth stand and 30 m or 40 m for interior and coastal sites respectively, perpendicular to the stand boundary in the LAR stand. The larger distance into the LAR stand was designed to minimize edge effects. Each pair of plots had the same biogeoclimatic site series or site series complexes (site series proportions were within 20% of each other), and had the same slope and aspect class (Figure 2). Up to two 20 metre offsets further into the stand were permitted to increase the chance of successfully establishing a paired plot. One offset could be used in both the old-growth and LAR stands or the two offsets could be used in either stand. The resulting maximum distance that a paired plot could be apart was 90 m in the interior and 100 m on the coast. Samples could not be established within 50 m of a cutblock corner or ditched or ballasted road. The rigorous plot pairing criteria and restriction of the distance between pairs helped ensure that they were on sites with similar inherent productivity.

1 The six regions are: the Cariboo, Kamloops, Nelson, and Prince George Forest Regions, the interior districts of the Prince Rupert Forest Region, and the coastal districts of the Prince Rupert/Vancouver Forest Regions.

Plot installation commenced once a paired plot was successfully located. The plot had a radius of 11.28 m (area of plot 0.04 ha). The target species was confirmed as leading by basal area using a prism (variable plot sampling) in the old-growth plot, and with tree counts taken by species and 2 cm diameter classes within a 5.64 m radius sub-plot for the LAR plot. The tree count within the 5.64 m radius sub-plot also allowed field crews to estimate establishment density in the LAR plot.

Establishment density of the LAR plot was estimated by comparing the current density to the density of a simulated stand established at 10 000 stems per ha (Table 2). If the density of the LAR plot exceeded the density of the simulated stand at the same height, the establishment density was then assumed to exceed 10 000 stems per ha and the LAR plot was rejected. LAR sample plots with establishment densities above 10 000 stems per ha were unacceptable because of the possibility of height growth repression in the sample trees (Mitchell and Goudie 1980).

A full ecological description (Luttmerding et al. 1990) was done at each plot. The four largest diameter trees of the target species were chosen in both the old-growth and LAR plots as potential site (also referred to as top height or sample) trees and inspected to ensure they were vigorous and free of significant insect, disease or height damage (height damage less than 5%). Damage not visible in old-growth was considered acceptable. A minimum of three suitable sample trees were required for each plot of the pair; otherwise the plot location was abandoned. Site trees in the LAR plot also had to be free of suppression, with at least five years of height growth above breast height (1.3 m above the ground). Sample trees in LAR plots were felled, a breast height disk taken and their height measured with a tape. For all sample trees in the old-growth plots, increment cores or disks were taken and height was measured using a clinometer or tape. Tree rings were counted in the laboratory.

METHODS

All data were entered into a data base and checked against the field cards for errors in data entry. The heights and breast height ages of the sample trees in the old-growth plots were averaged and the site index (SI_{OG}) was estimated using height–breast height age models (Bruce 1981 for Douglas-fir, Goudie 1984 for lodgepole pine and spruce). In the LAR plots, site index was estimated for each sample tree using the growth intercept model for each species (Nigh 1997a, 1997b) and averaged to give a site index for the plot (SI_L). Growth intercept models were used to estimate site index in LAR stands because they work better than height–breast height age models for young trees. The difference between the LAR site index and old-growth site index was calculated ($\Delta SI = SI_L - SI_{OG}$).

The change in site index (ΔSI) was plotted against the old-growth site index, height, and breast height age to detect trends. SI_L was regressed against the SI_{OG} across all regions to generate a base model for each species. SI_L was then regressed against SI_{OG}, SI^2_{OG}, breast height age and height of the old-growth, elevation, slope and aspect using a selection procedure that picked variables in order of significance until a pre-defined significance level was met.

Refinement in the linear relationship between SI_L and SI_{OG} was attempted by developing regressions by region, biogeoclimatic zone and subzone/variant, and testing the resulting regressions for differences. Where regressions were not different, data was grouped and regressions refitted. Region, zone and subzone/variant were picked as additional prediction variables because they are often available to forest level planners. An objective of the project was to develop separate old-growth site index correction equations for each forest region. This was not possible due to low sample sizes attained in some regions. Three additional non-linear models (exponential, logistic and power function) were also fitted for SI_L against SI_{OG}.

RESULTS

The target sample sizes were not met due to the unexpected difficulty in meeting sample selection criteria, especially for coastal hemlock. All potential lines on all mapsheets were examined for suitability and paired plots were established where possible. In total, 431 samples were established for the four target species (37 for Douglas-fir, 7 for western hemlock, 296 for lodgepole pine and 91 for spruce). The number of samples by species, region and site class is provided in Table 1.

Table 3 presents summary statistics by species. Tables 4 and 5 present site index statistics by species and region and by species and zone.

Figures 3, 4 and 5 show the LAR site indices plotted against the old-growth site indices by species. The 45° line shows the relationship if the old-growth and LAR site indices were equal. Data points above this line indicate that the LAR site index estimate is greater than the old-growth site index estimate; the opposite being the case for points below the line. Note that most points are above the line. The fitted regression of SI_L against the SI_{OG} (base equation) is overlaid by species. Figures 6, 7 and 8 show the residuals of the regression of SI_L against the SI_{OG} by species. No pattern is apparent in the residuals, and the plots show they are normally distributed with equal variance for all SI_{OG} values.

Equations to estimate SI_L are provided in Table 6, 7 and 8 by species (significant for $\alpha = 0.05$). Several models are available for Douglas-fir and lodgepole pine, depending on the information available to users. The best model for Douglas-fir is linear and uses one of two sets of parameters depending on target subzone/variant. The best model for lodgepole pine is non linear, requiring elevation in addition to SI_{OG} and SI^2_{OG} to predict SI_L. The R^2 values for all models are low as data are highly variable. The average difference in site index between the LAR and old growth plot pairs is 7.7 m for Douglas-fir, 4.3 m for lodgepole pine and 6.6 m for spruce.

TABLE 1. *Number of samples established (target number).*

Region and Species	Site Index Range (metres) 0-15	16-20	21+
Cariboo Forest Region			
Lodgepole pine	2 (30)	44 (30)	14 (30)
Spruce	0 (30)	3 (30)	2 (30)
Total	**2 (60)**	**47 (60)**	**16 (60)**
Kamloops Forest Region			
Lodgepole pine	0 (30)	34 (30)	22 (30)
Spruce	0 (30)	16 (30)	10 (30)
Total	0 (60)	50 (60)	32 (60)
Nelson Forest Region			
Lodgepole pine	1 (30)	8 (30)	1 (30)
Spruce	3 (30)	14 (30)	17 (30)
Total	**4 (60)**	**22 (60)**	**18 (60)**
Prince George Forest Region			
Lodgepole pine	0 (30)	34 (30)	62 (30)
Spruce	2 (30)	1 (30)	8 (30)
Total	**2 (60)**	**35 (60)**	**70 (60)**
Prince Rupert Forest Region (Interior Portion)			
Lodgepole pine	0 (30)	44 (30)	30 (30)
Spruce	0 (30)	11 (30)	4 (30)
Total	**0 (60)**	**55 (60)**	**34 (60)**

Region and Species	Site Index Range (metres) 0-20	21-30	31+
Vancouver Forest Region and the Coastal Districts of the Prince Rupert Forest Region			
Douglas-fir	0 (30)	19 (30)	18 (30)
Western hemlock	0 (30)	5 (30)	2 (30)
Total	**0 (60)**	**24 (60)**	**20 (60)**

Provincial Total: 431 (1,080)

Note: Site index classes vary by coast and interior sites and are assigned based on LAR site index measured in the field.

TABLE 2. *Density limits (trees per hectare) based on TASS runs.*

Average Height of Sample Trees (m)	Douglas-fir	Hemlock	Lodgepole Pine	Spruce
1	10 000	10 000	10 000	10 000
2	10 000	10 000	10 000	10 000
3	10 000	10 000	10 000	9000
4	10 000	10 000	9000	9000
5	10 000	10 000	9000	9000
6	10 000	9000	9000	9000
7	10 000	9000	9000	9000
8	10 000	9000	8000	8000
9	9000	9000	8000	8000
10	9000	9000	7000	8000
11	9000	9000	6000	8000
12	8000	9000	6000	7000
13	8000	9000	5000	6000
14	7000	9000	4000	5000
15	6000	8000	4000	5000
16	5000	8000	3000	4000
17	4000	7000	3000	4000
18	4000	7000	3000	3000
19	4000	6000	3000	3000
20	3000	5000	2000	3000
21	3000	4000	2000	3000
22	3000	4000	2000	2000
23	3000	3000	2000	2000
24	3000	3000	2000	2000
25	2000	3000	2000	2000
26	2000	2000	2000	2000
27	2000	2000	2000	2000
28	2000	2000	1000	2000
29	2000	2000	1000	2000
30	2000	2000	1000	1000
31	2000	2000	1000	1000
32	2000	2000	1000	1000
33	2000	2000	1000	1000
34	2000	2000	1000	1000
35	2000	2000	1000	1000
36	1000	2000	1000	1000
37	1000	2000	1000	1000
38	1000	1000	1000	1000
39	1000	1000	1000	1000
40+	1000	1000	1000	1000

Note: If the observed density, for a given height, is less than the maximum allowable density from the table, then the initial density is estimated to be less than 10 000 stems per hectare.

TABLE 3. *Sample summary statistics by species.*

Species & Stand Type		n	Mean	Std. Dev.	Range Min.	Range Max.
Douglas-fir						
LAR stand	Height (m)	37	13.3	7.57	5.0	39.3
	BHA (yr)	37	19.1	11.30	6	58
	SI (m @ bha 50)	37	30.5	4.07	20.5	38.0
Old-growth stand	Height (m)	37	41.2	11.73	24.6	68.0
	BHA (yr)	37	245.8	78.30	137	570
	SI (m @ bha 50)	37	22.8	6.41	13.3	40.7
Lodgepole pine						
LAR stand	Height (m)	296	7.0	1.67	3.1	13.3
	BHA (yr)	296	12.4	3.53	5	30
	SI (m @ bha 50)	296	20.1	1.79	14.6	24.7
Old-growth stand	Height (m)	296	26.0	3.75	16.5	37.6
	BHA (yr)	296	173.8	33.78	129	302
	SI (m @ bha 50)	296	15.8	3.45	7.3	26.7
Spruce						
LAR stand	Height (m)	91	5.4	1.73	2.7	11.5
	BHA (yr)	91	11.5	4.44	4.0	30.0
	SI (m @ bha 50)	91	20.1	2.67	13.6	27.4
Old-growth stand	Height (m)	91	31.8	4.38	21.7	45.1
	BHA (yr)	91	202.9	45.92	136	338
	SI (m @ bha 50)	91	13.5	4.52	5.7	25.4

Note: n = number of samples

TABLE 4. *Sample site index (m at breast height age 50) statistics by region and species.*

	Stand	n	Mean	Std. Dev.	Range Min.	Range Max.
Cariboo Forest Region						
Lodgepole Pine	LAR	60	19.2	1.91	14.6	23.7
	Old Growth	60	13.3	3.31	7.3	22.5
Spruce	LAR	5	20.1	2.51	18.6	24.7
	Old Growth	5	13.7	2.71	11.3	17.7
Kamloops Forest Region						
Lodgepole Pine	LAR	56	19.8	1.56	16.6	23.2
	Old Growth	56	15.7	2.88	10.3	22.3
Spruce	LAR	26	20.1	2.34	15.7	25.4
	Old Growth	26	12.9	5.46	6.9	25.4
Nelson Forest Region						
Lodgepole Pine	LAR	10	18.7	1.87	15.2	21.4
	Old Growth	10	14.8	3.49	7.9	19.5
Spruce	LAR	34	19.8	2.73	13.6	24.2
	Old Growth	34	14.6	4.51	5.7	23.5
Prince George Forest Region						
Lodgepole Pine	LAR	96	21.0	1.58	17.6	24.7
	Old Growth	96	17.0	3.38	9.3	26.7
Spruce	LAR	11	21.0	4.04	13.9	27.4
	Old Growth	11	13.8	4.10	9.4	21.2
Prince Rupert Forest Region (Interior Portion)						
Lodgepole Pine	LAR	74	20.1	1.50	16.9	23.4
	Old Growth	74	16.5	2.97	10.3	23.4
Spruce	LAR	15	19.9	1.99	15.6	24.0
	Old Growth	15	11.9	3.04	7.13	18.8
Vancouver Forest Region and the Coastal Districts of the Prince Rupert Forest Region						
Douglas-fir	LAR	37	30.5	4.07	20.5	38.0
	Old Growth	37	22.8	6.41	13.3	40.7

Note: n = number of samples

TABLE 5. *Sample site index (m at breast height age 50) statistics by species and zone.*

	Stand	n[1]	Mean	Std. Dev.	Range Min.	Max.
Douglas-fir						
CWH	LAR	37	30.5	4.07	20.5	38.0
	Old Growth	37	22.8	6.41	13.3	40.7
Lodgepole pine						
BWBS	LAR	2	19.4	0.54	19.0	19.7
	Old Growth	2	15.5	0.40	15.2	15.8
ESSF	LAR	23	19.4	1.56	15.2	21.6
	Old Growth	23	15.2	2.42	7.9	19.5
ICH	LAR	1	21.4	–	–	–
	Old Growth	1	15.3	–	–	–
IDF	LAR	4	18.6	2.60	15.8	22.0
	Old Growth	4	12.9	2.84	8.9	15.6
MS	LAR	53	19.3	1.73	15.3	23.2
	Old Growth	53	14.8	3.82	7.3	22.3
SBPS	LAR	33	18.9	1.61	14.6	22.3
	Old Growth	33	12.4	1.89	9.3	16.9
SBS	LAR	180	20.7	1.61	16.9	24.7
	Old Growth	180	16.9	3.16	9.3	26.7
Spruce						
ESSF	LAR	52	19.6	2.31	13.6	24.2
	Old Growth	52	12.5	4.15	5.7	22.0
ICH	LAR	7	21.5	2.25	18.1	24.7
	Old Growth	7	20.3	4.16	14.9	25.4
MS	LAR	9	21.1	3.17	15.3	25.4
	Old Growth	9	14.9	4.93	8.8	23.5
SBS	LAR	23	20.3	3.18	13.9	27.4
	Old Growth	23	13.2	3.45	8.8	21.2

Note: n = number of samples

TABLE 6. *Correction equations for coastal Douglas-fir.*

Data Required	Equation	Root MSE	R^2	Parameter	Estimate	Std. Error
SI_{OG}	$SI_L = a + b \times SI_{OG}$	2.894	0.508			
				a	20.22	1.78
				b	0.4523	0.0752
SI_{OG}	$SI_L = a + b \times SI_{OG}$	2.49	0.657			
Zone[1]				a	-1.1057	5.76
Subzone/variant –				b	1.3	0.2441
Group A[2]						
SI_{OG}	$SI_L = a + b \times SI_{OG}$					
Zone[1]				a	21.709	1.60
Subzone/variant –				b	0.40237	0.0675
Group B[3]						

Notes:

Equations apply to an SI_{OG} range of 13.3 to 40.7m in site index.

1 Applies to the CWH biogeoclimatic zone only.

2 Includes the Central Dry Submaritime (ds2) and Submontane Very Wet (vm1) biogeoclimatic subzones/variants.

3 Includes the Dry Maritime (dm), Southern Dry Submaritime (ds1), Submontane Moist Maritime (mm1), Montane Moist Maritime (mm2), Southern Moist Submaritime (ms1), and Very Dry Maritime (xm) biogeoclimatic subzones/variants.

TABLE 7. *Correction equations for interior lodgepole pine.*

Data Required	Equation	Root MSE	R^2	Parameter	Estimate	Std. Error
SI_{OG}	$SI_L = a + b \times SI_{OG}$	1.55	0.248			
				a	16.04	0.42
				b	0.2583	0.0262
SI_{OG}	$SI_L = a + b \times SI_{OG} + c$	1.48	0.324			
Elevation (m)	$\times (SI_{OG})^2 + d \times$			a	15.72	1.51
	elevation			b	0.6	0.1762
				c	-0.0124	0.0054
				d	-0.00168	0.0003
SI_{OG}	$SI_L = a + b \times SI_{OG}$	1.52	0.286			
Region Group A[1]				a	14.25	0.74
				b	0.3606	0.0530
SI_{OG}	$SI_L = a + b \times SI_{OG}$					
Region Group B[2]				a	17.38	0.54
				b	0.1849	0.0323
SI_{OG}	$SI_L = a + b \times SI_{OG}$	1.51	0.302			
Zone Group A[3]				a	7.83	3.37
				b	0.8399	0.2578
SI_{OG}	$SI_L = a + b \times SI_{OG}$					
Zone Group B[4]				a	15.12	0.62
				b	0.2930	0.0437
SI_{OG}	$SI_L = a + b \times SI_{OG}$					
Zone Group C[5]				a	17.65	0.60
				b	0.1740	0.0351

Notes:

Equations apply to an SI_{OG} range of 7.3 to 26.7m in site index.

1 Includes Cariboo and Nelson Forest Regions.

2 Includes Kamloops, Prince George and interior portions of the Prince Rupert Forest Regions.

3 Includes the Interior Douglas-fir (IDF) zone.

4 Includes the Montane Spruce (MS) and Sub-Boreal Pine – Spruce (SBPS) zones.

5 Includes the Boreal White and Black Spruce (BWBS), Engelmann Spruce – Subalpine Fir (ESSF), Interior Cedar – Hemlock (ICH) and Sub-Boreal Spruce (SBS) zones for lodgepole pine.

TABLE 8. *Correction equations for interior spruce.*

Data Required	Equation	Root MSE	R^2	Para-meter	Estimate	Std. Error
SI_{OG}	$SI_L = a + b \times SI_{OG}$	2.54	0.109			
				a	17.46	0.84
				b	0.1948	0.0592

Notes:
Equation applies to an SI_{OG} range of 5.7 to 25.4m in site index.

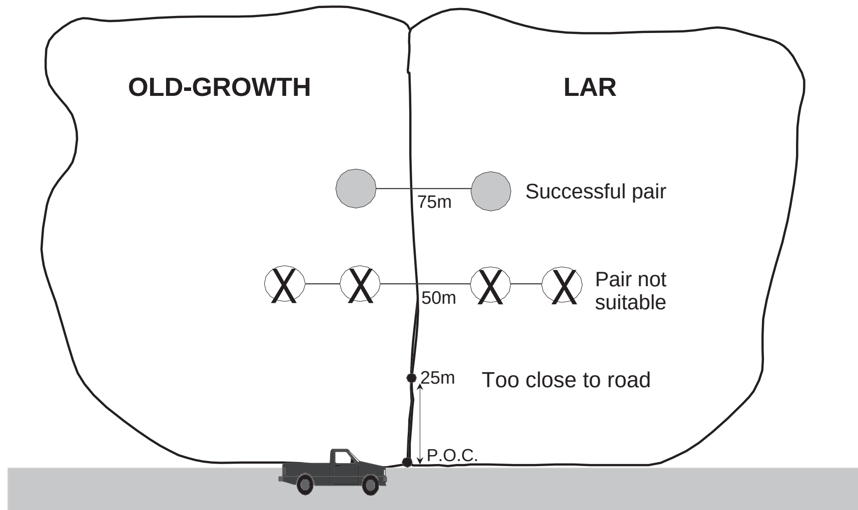
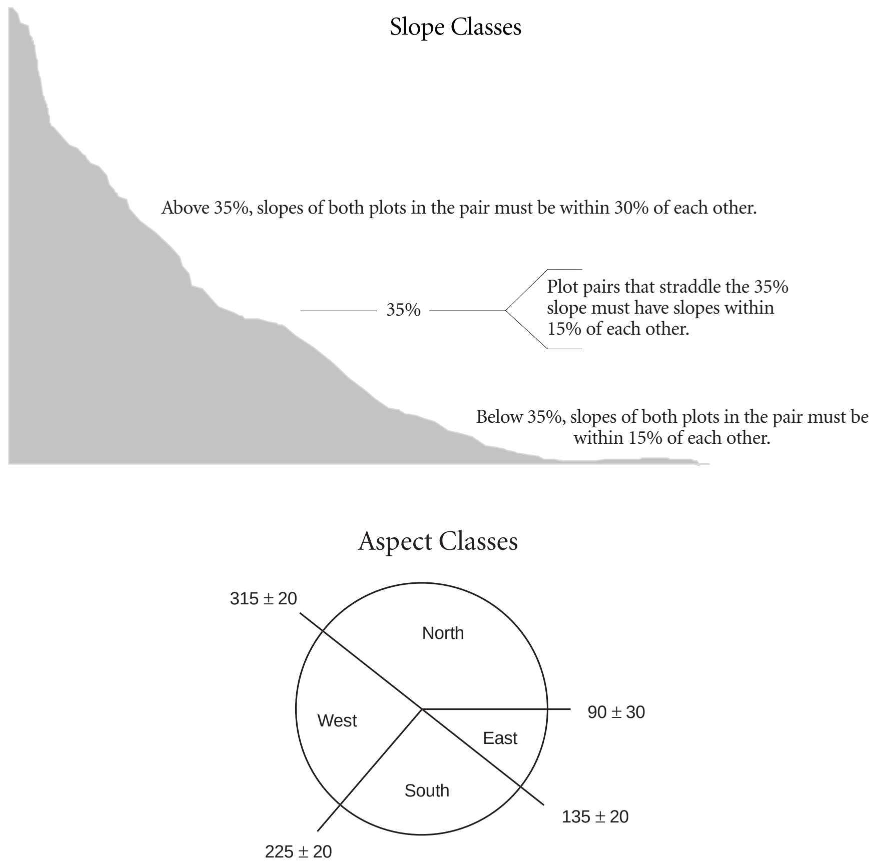


FIGURE 1. *Example of a paired plot installation.*



Each plot of the pair must fall within one of the four aspect classes: North, East, South, West.

- For slopes less than or equal to 10%, the aspect criteria are not included as suitability criteria.
- If the plot pair straddles an aspect class boundary, the pairs must not exceed the specified tolerance; e.g., at aspect 90 degrees the tolerance is +/- 30 degrees.

FIGURE 2. *Slope and aspect class definitions for plot pairs.*

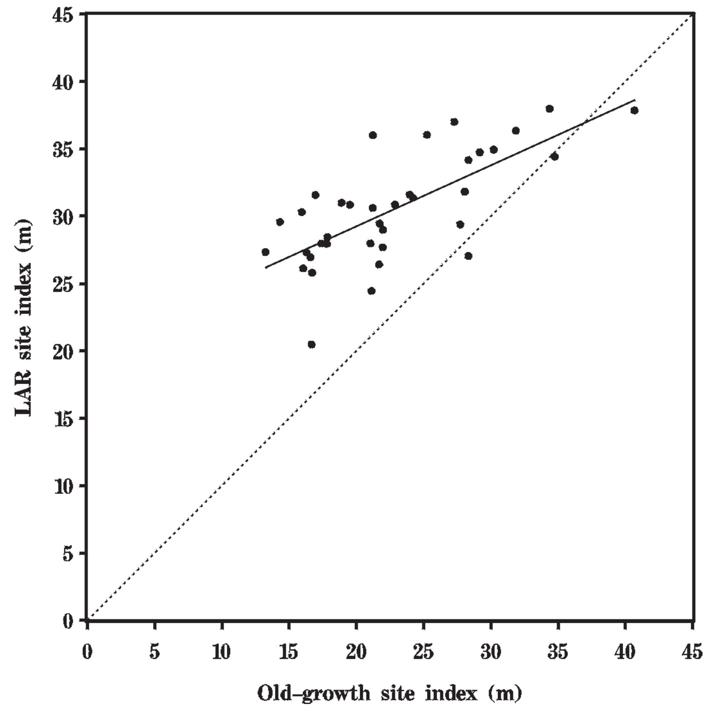


FIGURE 3. *Fitted base equation (——) overlaid on the data points (•) for Douglas-fir. The dashed line (– – –) shows the relationship between the old-growth and LAR site indices if no adjustment is needed.*

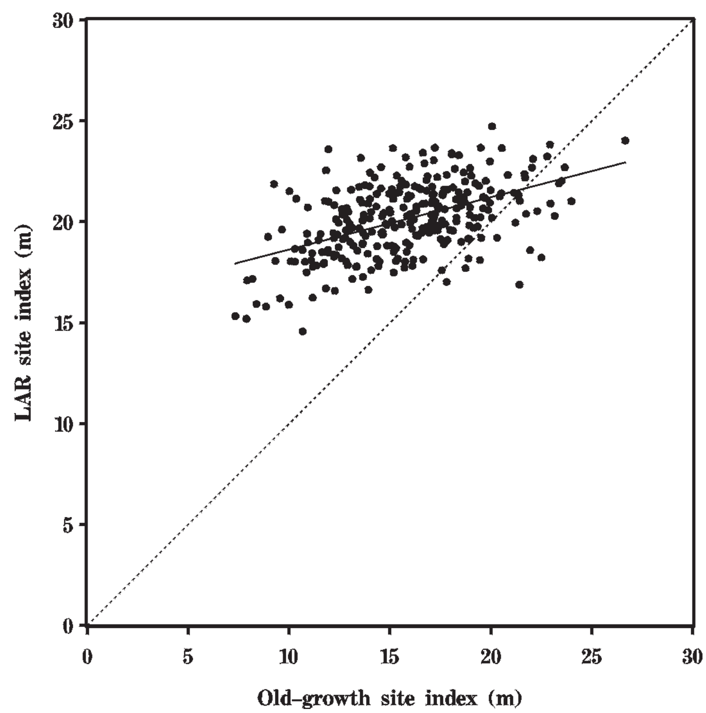


FIGURE 4. *Fitted base equation (——) overlaid on the data points (•) for lodgepole pine. The dashed line (– – –) shows the relationship between the old-growth and LAR site indices if no adjustment is needed.*

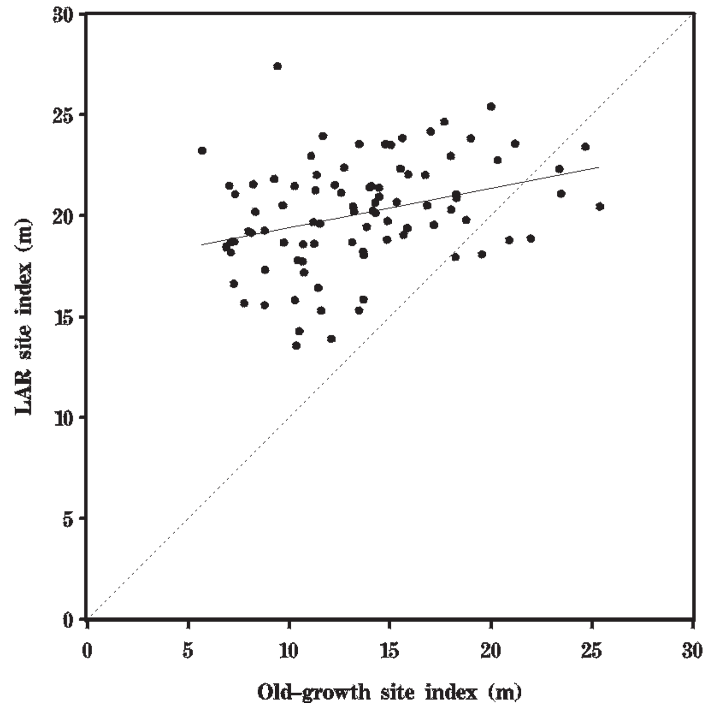


FIGURE 5. *Fitted base equation (——) overlaid on the data points (•) for spruce. The dashed line (– – –) shows the relationship between the old-growth and LAR site indices if no adjustment is needed.*

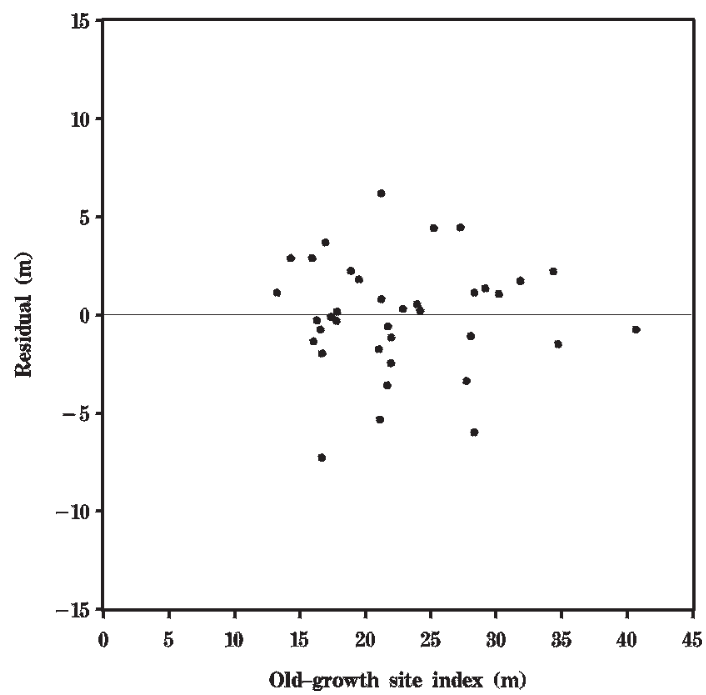


FIGURE 6. *Plot of residuals from the base equation (regression of old growth-site index against LAR site index) by plot pair (•) for Douglas-fir.*

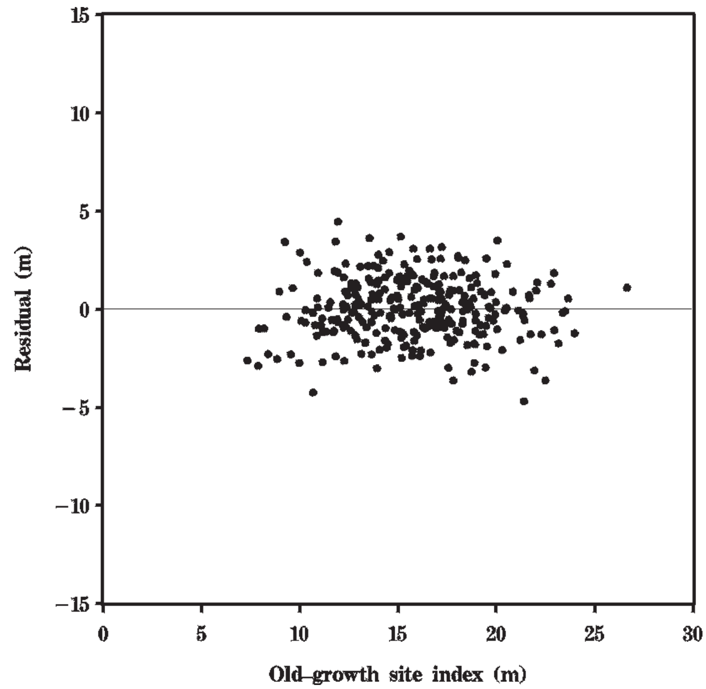


FIGURE 7. *Plot of residuals from the base equation (regression of old growth-site index against LAR site index) by plot pair (•) for lodgepole pine.*

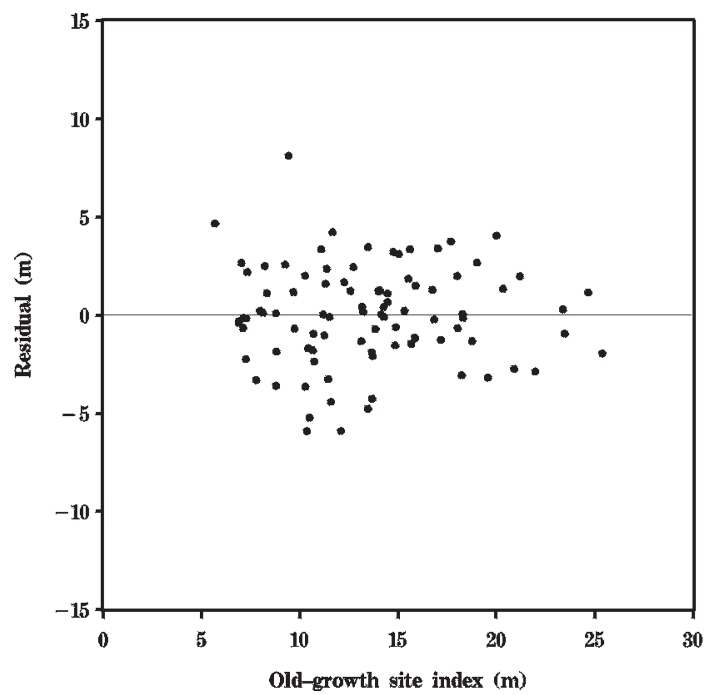


FIGURE 8. *Plot of residuals from the base equation (regression of old growth-site index against LAR site index) by plot pair (•) for interior spruce.*

DISCUSSION

The results of this study indicate that the estimated site indices associated with old-growth stands are underestimated for all species considered. There are many factors that could contribute to the underestimation of site index in old-growth stands. Some of these factors are:

1. Suppression or repression in the top height trees which results in the trees not expressing the growth potential of the site.
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, which leaves less suitable trees being chosen as top height trees.
5. Other biotic and abiotic factors such as insect infestations and disease, that may reduce the height growth of the top height trees below potential.

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 contribute, in varying degrees, to the underestimation of site index in old-growth Douglas-fir, lodgepole pine and spruce stands in British Columbia.

Care was taken during sampling to select only trees that reflect the potential productivity of the site in the LAR plots. Not all LAR stands will achieve their potential productivity due to factors such as suppression, repression, brush competition and damage from insects and disease. Therefore, a number of LAR stands in Timber Supply and Tree Farm License Areas will not exhibit the height growth that is implied by the site index corrections. Furthermore, the height growth of Douglas-fir, lodgepole pine and spruce stands that initially reflect the productivity of the site may not continue to do so as they mature because of brush competition, pest-related damage, suppression, etc.

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

1. Bias in the growth intercept models.
   The growth intercept model may give biased LAR plot site index estimates.
2. Improper matching of the old-growth and LAR plots with respect to site productivity.
   Comparisons of the site index of old-growth to the LAR plot would be invalid if plots of different productivity were paired.
3. 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. The correction equations deal with this bias, if any exists, in the height-age model.

In addition, there is potential for application bias because:

1. Results may be applied to a population that is different from the sample population.

   Sampling opportunities are limited by requirements for matching. Only age class 8 and 9 stands bordering harvested stands were available for sampling. The resulting samples may not be representative of the age class 8 and 9 population to which the site index adjustments will be applied. 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.
2. Inventory estimates of old-growth site index are different from the paired plot estimates of old-growth site index.

   The inventory (photo-based) estimates of old-growth site index are not measured with the same methodology used in paired plots. Using inventory estimates of old-growth site index in the correction equations introduces a possible bias.

These potential biases are not unique to this project and are found, to some degree, in all site index related projects.

APPLICATION GUIDELINES

Equations to predict SI_L from SI_{OG} are provided for forest level planning and apply to coastal Douglas-fir, and interior lodgepole pine and spruce leading old-growth (total age > 140 years) stands following clearcut harvest and regeneration. To use an old-growth site index in any of the equations provided, it must be derived from the height and age of the old-growth polygon using the same site curves used to develop the equations. For all species, an equation is available to derive a LAR site index from an old-growth site index. If biogeoclimatic zone and subzone/variant data is available for Douglas-fir, additional equations are provided. For lodgepole pine, three additional models are provided; one uses elevation, the second uses region, and the third uses biogeoclimatic zone, in addition to old growth site index, to improve the LAR site index estimate. No additional equations are provided for spruce. The best model to predict LAR site index uses old-growth site index with biogeoclimatic zone and subzone/variant for Douglas-fir, and old-growth site index and elevation for lodgepole pine.

Application of any equation should be restricted to the range of site index sampled for old-growth stands. In addition, if biogeoclimatic zone data are available, application should be restricted to the Coastal Western Hemlock (CWH) zone for Douglas-fir; the Boreal White and Black Spruce (BWBS), Engelmann Spruce – Subalpine Fir (ESSF), Interior Cedar – Hemlock (ICH), Interior Douglas-fir (IDF), Montane Spruce (MS), Sub-Boreal Pine – Spruce (SBPS) and Sub-Boreal Spruce (SBS) zones for lodgepole pine; and the Engelmann Spruce – Subalpine Fir (ESSF), Interior Cedar – Hemlock (ICH), Montane Spruce (MS) and Sub-Boreal Spruce (SBS) zones for spruce.

Since not all old-growth stands that are harvested and regenerated will reflect their potential site index, any yield curves generated or green-up ages calculated using LAR site index should be reduced to reflect factors impacting height growth. Regenerated stands with densities above 10 000 stems/ha, or partially harvested stands, should not use the LAR site index corrections. Most old-growth stands that will be clearcut harvested and will meet “Free to Grow” requirements should be eligible for a site index correction. Monitoring of LAR stands over time is recommended to ensure they reflect the corrected site index estimates.

CONCLUSION

The paired plot method of correcting old-growth site indices was carried out for Douglas-fir, lodgepole pine and spruce in British Columbia. The results indicate that, on average, site indices estimated from the height and age of old-growth stands underestimate LAR stand site indices by 7.7 m for Douglas-fir, 4.3 m in lodgepole pine, and 6.6 m in spruce. However, due to several sources of potential bias, it is possible that the LAR site index overestimates the potential. Guidelines are provided for the application of old-growth site index correction equations, which should be used until more refined estimates of site index (i.e., site index estimated by site series and assigned through site series mapping) become available. Finally, it should be emphasized that the adjustments correspond to *potential* productivity. For a stand to achieve the potential, it must be subject to ecological and management conditions similar to those observed in this study. The site index corrections suggested in this study apply only under management regimes that largely eliminate factors that hinder tree growth, such as competition from pests and other competing vegetation.

LITERATURE CITED

Anon. 1996. Paired plot project plan provincial implementation: Appendix A. B.C. Min. For., Resources. Inv. Br., Victoria, B.C.

Bruce, D. 1981. Consistent height-growth and growth-rate estimates for remeasured plots. For.Sci. 27:711-725.

Goudie, J.W. 1996. The effects of stocking on estimated site index in the Morice, Lakes, and Vanderhoof timber supply areas in central British Columbia. *In* Proceedings of the Northern Interior Vegetation Management Association Annual Meeting, January 24-25, 1996, Smithers, B.C. Ed. by T. Szauer. pp. 9-31.

Goudie J.W. 1984. Height growth and site index curves for lodgepole pine and white spruce and interim managed stand yield tables for lodgepole pine in British Columbia. B.C. Min. For., Res. Br. Unpubl. Rep. 75 p.

Luttmerding, H. A., D. A. Demarchi, E. C. Lea, D. V. Meidinger, and T. Vold. 1990. Describing ecosystems in the field. 2nd ed. M.O.E. Manual 11, B.C. Min. Env., Lands, Parks, Victoria, B.C. 213 p.

Magnussen, S. and M. Penner. 1996. Recovering time trends in dominant height from stem analysis. Can. J. For. Res. 26: 9-22.

Mitchell, K.J., and J.W. Goudie. 1980. Stagnant lodgepole pine. B.C. Min. For. Res. Br., Victoria, BC. Unpubl. Rep. 31 p.

Nigh, G.D. [1998]. Interim site index adjustment for old-growth stands based on veteran trees. B.C. Min. For., Res. Br., Victoria, B.C., In press.

Nigh, G.D. and B.A. Love. 1997. Site index adjustment for old-growth coastal western hemlock stands in the Kalum Forest District. B.C. Min. For., Res. Br., Victoria, B.C., Work. Pap. 27.

Nigh, G.D. 1997a. Growth intercept models and tables for British Columbia: coastal species. 2nd edition. B.C. Min. For. Res. Br. Land Manage. Handb. Field Guide Insert 9.

Nigh, G.D. 1997b. Growth intercept models and tables for British Columbia: interior species. 2nd edition. B.C. Min. For. Res. Br. Land Manage. Handb. Field Guide Insert 10.

Udell, R.W., and W.R. Dempster. 1987. Predicting the growth and yield of regenerating lodgepole pine. Can. For. Ind. 107(2):48-60.

QP 20866