Foothills Growth and Yield Association
Regenerated Lodgepole Pine Project

Comparison of Pre-harvest and Post-harvest Site Indices

Technical Report

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foothills
MODEL FOREST
research growing into practice.

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ABSTRACT

A site index comparison, based on paired plots in adjacent fire-origin and post-harvest stands, indicated an average upward shift in site index of 24% in stands regenerated after harvesting. Little or no site-index increase was observed on “rich” sites (classified as having high soil nutrient status), while on “poor” sites increases reached over 60%. Post-harvest stands on medium and poor sites are probably becoming established at substantially lower densities (stems per ha) than did their fire-origin predecessors, although no data were available to confirm the initial densities of the mature stands studied.

Data from permanent sample plots, which had been measured both before and after harvesting, also demonstrated substantial shifts in site index following harvest. The effect did not appear to decline with age of regeneration. However, the amount and age-range of true time-series data (acquired from consistently repeated measurements on the same sites) were limited in availability.

Results from spacing trials in Alberta and related research in British Columbia suggest that the site index increases may be attributed to lower initial densities in post-harvest versus fire-origin stands (and hence less height repression resulting from inter-tree competition). Climate change may also be contributing to the effect.

Observed differences between fire-origin and post-harvest stand development have important implications for forest management and silvicultural practice. A number of unanswered questions are identified with high priority for further investigation.

ACKNOWLEDGEMENTS

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Fieldwork was conducted by Normko Resources Inc., under the supervision of Rand McPherson, Field Coordinator of the Foothills Growth and Yield Association (FGYA). Members of the FGYA technical committee who assisted in site selection, data procurement, analyses, and / or review of results included: Pauline Fluet, Colin Scott, Patrick Ewing, Christian Weik, Daryl Price, Tim McCready, Ed Kulcsar, Kent MacDonald, Bob Held, Sharon Meredith, and Greg Behuniak. David Morgan of ASRD (Alberta Sustainable Resource Development), and Tom Terry and Greg Johnson (Weyerhaeuser Company) also assisted by reviewing the draft report.

Important contributions and insights were provided by James Stewart and David Price (Canadian Forest Service), James Goudie (B.C. Ministry of Forests), Shongming Huang (ASRD), and other participants of the FGYA field tour and meeting held in August 2003.

DISCLAIMER

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1. Background and Purpose

The *Regenerated Lodgepole Pine (RLP)* Project of the Foothills Growth and Yield Association (FGYA) was designed to forecast and monitor the growth and yield of regenerated lodgepole pine stands in relation to site, early crop performance and stocking, vegetative competition and density regulation. While monitoring is a long-term undertaking, the FGYA is committed to producing the best forecasts currently possible. Preliminary forecasts of growth and yield in response to site and initial spacing have already been developed as part of the *Project Establishment Report*.[1]

Uncertainty regarding site index change is a serious impediment to initial forecasting of the growth and yield responses being monitored by the RLP Project field trial. In an address to the FGYA on March 15, 2001, Dr. Shongming Huang, Senior Biometrician of the Land and Forest Division of Alberta Sustainable Resource Development (ASRD) suggested that time-series and contemporaneous comparisons of site index between fire origin and post-harvest stands are key to the scientific credibility and reliability of lodgepole pine yield forecasts. He proposed a paired-plot "vertical" and "horizontal" comparison approach, the former based on time-series data from permanent sample plots (PSPs), and the latter from contemporaneous paired plots comparing fire-origin and regenerated (post-harvest) portions of the same original stand and site.

The FGYA's steering committee decided that a site index change study should be undertaken as a cooperative extension to the current RLP Project, involving paired-plot sampling of stands in each of the Project's 5 ecosite categories, preferably in combination with permanent sample plot data contributed by members. The purpose of the study was to provide credible and reliable forecasts of post-harvest site index, for the main site types of interest to members, relative to pre-harvest site index values.

Weldwood of Canada pioneered growth intercept, paired plot, and PSP time series comparisons in Alberta, as reported by Udell and Dempster in 1987.[2] Shongming Huang *et al* (1997)[3] developed reliable site index models from stem-analyses data for lodgepole pine. The models forecast site index from tree height and age, including from young trees with ages older than 2 or 3 years at breast-height. They provided the basis for estimating site index from height and age data in the present study.

2. Data

Paired-plot data were collected during the period July 29 – October 1, 2002, as the basis for contemporaneous comparison between site indices on regenerated and adjacent mature stands.

Existing permanent sample data were acquired from 2 members of the FGYA.

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[1] Dempster, W.R. and R.J.T. McPherson. 2003. *Effects of site, competition, and density management on early crop performance and stand growth and yield of lodgepole pine: establishment report*. Foothills Growth and Yield Association, Foothills Model Forest, Hinton, Alberta.

[2] R.W. Udell and W.R. Dempster. 1987. *Predicting the growth and yield of regenerated lodgepole pine*. CPPA Woodlands Section Paper presented at 67th Annual Meeting of the Woodlands Section, Canadian Pulp and Paper Association, Montreal, 1986.

[3] Shongming Huang, Stephen Titus and Grant Klappstein.. 1997. S*ubregion-based compatible height-site index-age models for young and mature stands in Albert: revisions and summaries (Part 1)..* Forest Management Research Note # 9, Pub No:: T/389, Alberta Environmental Protection.

2.1. Paired Plots

Fifty lodgepole pine stands throughout members' tenures were identified, in which regeneration following harvest had reached at least 5 years breast-height age, and portions of the original parent stand were still standing on the same ecosite[4] as the regeneration (see example in Figure 1). Table 1 shows the breakdown of the stands by ecosite categories. The breast-height (BH) ages of the regeneration varied from 5 to 29 years.

Figure 1. Adjacent fire-origin and post-harvest stands growing on the same ecosite

Photograph courtesy of McPherson Creek Forestry Services Ltd.

Table 1. Number of stands sampled with paired-plots

#	Ecosite category	# of stands sampled
1	Bearberry/lichen/hairy wild rye *(submesic/subxeric, medium-low)*	12
2	Labrador tea –mesic *(mesic-poor)*	12
3	Billberry/cranberry/sarsaparilla/rhododendron *(mesic-medium)*	15
4	Honeysuckle/fern *(subhygric-rich)*	8
5	Labrador tea-hygric *(hygric-poor)*	3
	Total	50

[4] Ecological classifications, such as *ecosite*, soil *moisture regime*, and soil *nutrient regime*, have been assessed and used in this study as prescribed and defined in the following publications pertaining to the study area:

- J.H. Archibald, G.D. Klappstein, and I.G.W. Corns, 1996. *Field guide to ecosites of southwestern Alberta*, Special Report 8, Can. For. Serv., Northern Forestry Centre, Edmonton.
- J.D. Beckingham, I.G.W. Corns, and J.H. Archibald, 1996. *Field guide to ecosites of west-central Alberta*, Special Report 9, Can. For. Serv., Northern Forestry Centre, Edmonton.

For each selected stand, the field crew identified pre- and post-harvest areas that had similar physiographic site characteristics. Selection of sample sites within the post-harvest stand was confined to modal density areas. (Modal density was defined as the most frequently occurring density of pine in thousands of stems per ha, as indicated by counting stems within 1.78 m of the observer.) Three pairs of plots were located within these candidate sampling areas, each with one plot in the regenerated portion and one in the parent portion of the stand. The first and second plots in each pair were located in the same soil moisture and nutrient regime. The location of the initial plot was randomly located in the regenerated stand along a transect running parallel to the stand edge, at a minimum distance from the stand edge equating to the required buffer (see below). The second plot was located systematically by proceeding into the residual stand at right angles to the transect. The second plot was placed the same distance from the stand edge as the first. However, if this resulted in it failing to occur in the same soil moisture and nutrient regime, it was relocated until it did.

Plots were located sufficiently distant from cut-block boundaries, roads, pipelines, power lines, and leases, to avoid edge effects. A guideline of 20 m was used for buffering to mitigate edge effect, unless the residual stand was taller than 20 m, in which case the minimum buffer was equated to at least the height of the stand. The plots were circular, with a radius of 9.77 m, (area $300m^2$).

At each plot the crew undertook the following tasks:

1. Using procedures described in the latest published field guides to ecosites of West-central and Southwestern Alberta[4], identify the moisture regime, nutrient regime, and ecosite. (If the moisture or nutrient regime differed between the two plots, one or both plots were re-located.)
2. Measure and record the breast-height diameter (DBH) and species of all trees exceeding 1.3-m height.
3. Select the 3 largest DBH lodgepole pine trees as potential site trees. If one of these trees did not meet the site tree criteria (see below), 2 site trees were considered sufficient. If more than one of the 3 potential site trees did not meet the criteria, the plot was re-located.
4. Measure the total height (from ground to base of terminal bud) and breast-height age of each site tree.
5. On the plot falling in the regenerated stand, also record the last (i.e. highest) 5 annual internode lengths of the site trees.

The selection and measurement of 3 site trees on a 300 m^2 plot facilitated the computation of top height, as recommended[5] by the developers of Alberta's site index models. A *site tree* was defined to:

- have no damage affecting height growth (dead top, broken stem, fork, crook);
- be standing and alive, with good vigor;
- be a dominant or co-dominant;
- be accurately measurable for breast-height age;
- not be a veteran (remnant) or wolf tree.

Measurements were made following terminal bud set in the 2002 growing season.

[5] See Section 5 of: S. Huang, S.J. Titus, and T.W. Lakusta, 1994, *Ecologically based site index curves and tables for major Alberta tree species*, Alberta Environmental Protection, Pub. No. T/307, Edmonton.

2.2. Permanent Sample Plots

Two member companies of the FGYA, Weldwood of Canada Limited (Hinton Division) and Weyerhaeuser Company Limited (Grande Prairie Operations), provided permanent sample plot (PSP) data that:

- occurred in pure pine stands;
- had been measured both before and after harvest;
- had reached at least 1.3 m in stand height since harvest.

Repeat measurements from 43 Weldwood PSP's met the above criteria, and included the necessary information for computing and comparing site index between the pre-harvest and post-harvest measurements. In 39 of these plots the regeneration was at least 5 years BH age, ranging up to 27 years.

The Weldwood PSPs were originally established on a systematic grid, in clusters of 4, with a plot size of 1/5 acre (0.08 ha). Plots were re-established in regenerated stands with a plot size of 1/10 acre (0.04 ha). Candidate top height trees were identified as the largest-diameter 4 or 8 lodgepole pine trees per plot (depending on plot size). Thus the number of candidate trees per plot differed between measurements and from those in the paired-plot study, but always equated to the 100 largest DBH trees per ha. Top height for each plot was computed as the average height of those candidate trees that were damage-free.[6] The data set provided a rare opportunity for evaluating changes in site index using true time-series information, and for comparing this information with that obtained from contemporaneous paired plots. However, the following limitations in the data should be noted.

- Regeneration was measured within the former 0.08 ha fire-origin plots, but in smaller (0.04 ha) sub-plots.
- Heights were recorded for all trees, but height measurement techniques changed over time, and some tree heights were based on ocular estimation.
- BH age was measured for all regeneration plots used in the analysis but, to avoid sampling damage, the trees measured for age typically were immediately outside the plots, rather than being the selected top height trees within the plots.
- In the fire-origin stand condition, plot age was generally based on field assessment of stand origin. Therefore direct assessments of BH age were not usually available for fire-origin measurements. Weldwood found that total age and BH age were well-correlated, and computed BH age from total age by subtracting 8 years, which was the average years to breast-height based on a sample of 1056 lodgepole pine trees.[7]
- Tag limits (minimum tree diameters) were lowered over successive re-measurements, creating the potential for bias in top height tree selection in plots with higher limits (see Section 3.2).

Weyerhaeuser Canada has installed a system of permanent sample plots in its Grande Prairie forest management agreement area. The plots are 0.08 ha in area, with nested sub-plots. Measurements from 9 Weyerhaeuser PSP's met the Project criteria. Regeneration was estimated to exceed 5 years BH age in only 1 of the 9 plots. The utility of the data was further limited because BH age (necessary for site index calculation) was not measured, and had to be estimated from stump or total age.

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[6] Trees were considered damage-free if they did not exhibit die-back, broken or missing tops, dead tops, or forks.

[7] Forestry Corp., 2004. *Pure pine data re-compilation analysis for GYPSY localization.* Internal report prepared for Weldwood of Canada.

3. Analysis and Results

3.1. Paired Plots

Data were collected for 150 plot-pairs (3 pairs x 50 stands). Pairs were rejected from the analysis where both plots in the pair did not have identical soil moisture and nutrient regimes. This resulted in a retained data base of 144 plot-pairs.

Table 2 compares overall differences between the estimated site indices of pre-harvest and post-harvest sample plots. All results, unless stated otherwise, were based on unadjusted ages and provincial (combined) parameter estimates (Huang *et al* 1997[3]). Site indices calculated using adjusted[8] versus unadjusted BH ages showed slightly larger differences between pre-harvest and post-harvest estimates. The use of unadjusted age was therefore considered to produce a more conservative estimate of the pre- / post-harvest effect.

The comparison indicated a 3.65 m (24%) difference in site index between regenerated and mature stands across all sites. The estimated site index was subject to both sampling and prediction errors, so the analysis should be interpreted with caution. Note that the site index in the mature stands showed higher variability (as indicated by the standard deviation and error estimates) than that in the regeneration. However, an examination of the distribution of within-plot differences between regenerated and mature stand site index showed no evidence of non-normality, skewness, or kurtosis, so the paired-plot t-test was considered applicable.

Table 2. Result of paired sample t-test comparing pre-harvest and post-harvest site indices (paired-plot data)

	n	Mean	SD	SE
Site index of regeneration	144	18.613	2.352	0.1960
Site index of mature stand	144	14.963	4.138	0.3448
Difference	144	3.650	3.374	0.2811

Difference between means	3.650	
95% CI	3.094	to 4.206
t statistic	12.98	
2-tailed p	<0.0001	

[8] Adjusted ages are reduced by 0.5 years to a correct for possible bias resulting from age being based on ring counts, as described by Huang et al 1997.

A major concern regarding the interpretation of such differences is whether the difference will be maintained as the regeneration ages. Figure 2 shows the variation in the ratio of post-harvest / pre-harvest site index plotted against regeneration age. There is no discernable correlation between the ratio and ages of the stands. However, because the paired-plot approach uses space as a surrogate for time, this does not necessarily imply that the ratio, or site index itself, remains constant over time in the regenerated stands (hence the importance of the analysis of true time series data described in Section 3.2).

Figure 2. Age of regeneration and the proportional difference in pre- and post-harvest site index (paired plots)

n	144	(number of plots)
r statistic	-0.02	(Pearson correlation)
95% CI	-0.18	to 0.15
2-tailed p	0.8392	(t approximation)

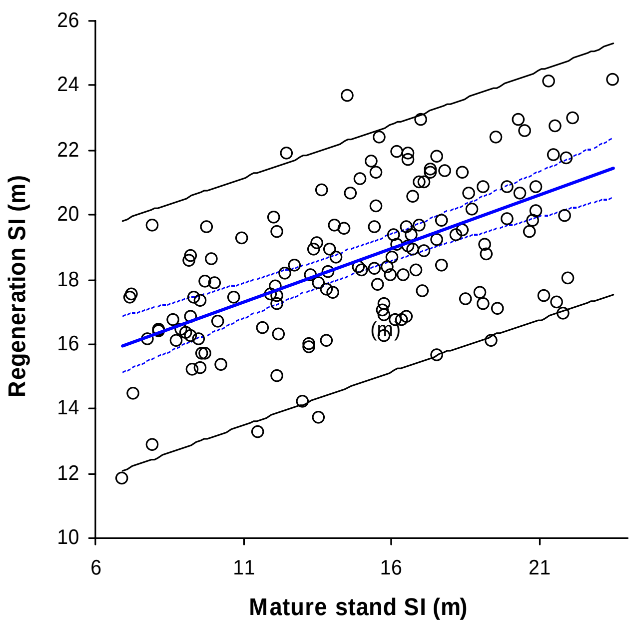
Figure 3 shows the general relationship between regeneration and mature-stand site index estimates, as indicated by the scatter diagram and simple linear regression. Note that the regression had a significant and positive intercept, and a slope of less than 1, suggesting that the site indices of regenerated stands did not increase by the same proportion across all sites.

Figure 3. Relationship between site indices of regenerated and mature stands (paired plots)

n	144
R^2	0.34
Adjusted R^2	0.33
SE	1.9239

Term	Coefficient	SE	p	95% CI of Coefficient	
Intercept	13.6882	0.6034	<0.0001	12.4953	to 14.8811
Slope	0.3291	0.0389	<0.0001	0.2523	to 0.4060

Source of variation	SSq	DF	MSq	F	p
Due to regression	265.217	1	265.217	71.66	<0.0001
About regression	525.578	142	3.701		
Total	790.795	143			



This apparent effect was further investigated by partitioning the data by soil moisture regime and soil nutrient regime. Table 3 shows site index averaged by stand type (mature and regenerated), soil moisture regime (SMR), soil nutrient regime (SNR).

The values in Table 3 are tree (as distinct from plot) averages. Results are further illustrated in Figures 4 and 5. The differences in site index between regenerated and fire origin stands, when explored by analysis of variance and t-tests, were found to be highly significant on poor and medium nutrient regimes, but there was no significant difference on the rich sites.

Table 3. Site index averages by stand type, soil moisture regime (SMR), and soil nutrient regime (SNR) for paired plot site trees

Stand type	SMR	SNR			Total
		B (poor)	C (medium)	D (good)	
Mature	3	9.3			9.3
	4	11.6	15.2		14.7
	5	11.8	16.4	20.3	15.6
	6	9.1		19.3	13.9
Mature Total		11.0	15.9	19.9	15.1
Regeneration	3	15.9			15.9
	4	17.4	18.1		18.0
	5	17.9	19.2	21.0	19.1
	6	17.9		18.7	18.2
Regeneration Total		17.7	18.7	20.2	18.6

Figure 4. Average site indices by soil moisture regime (paired plot site trees)

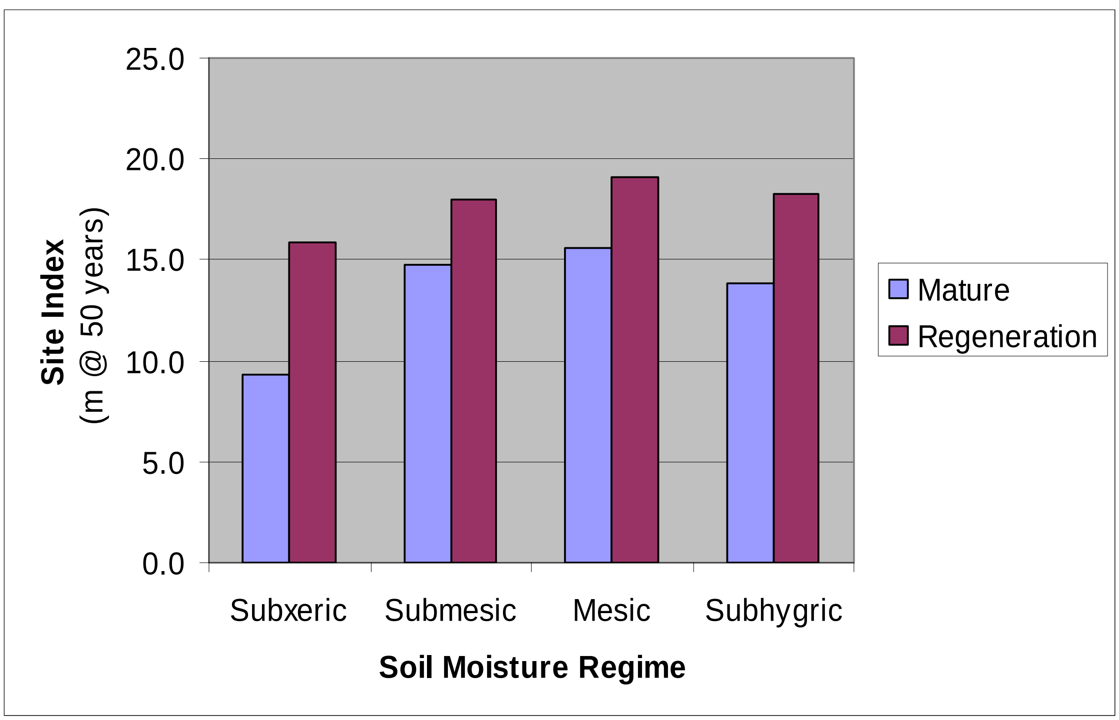
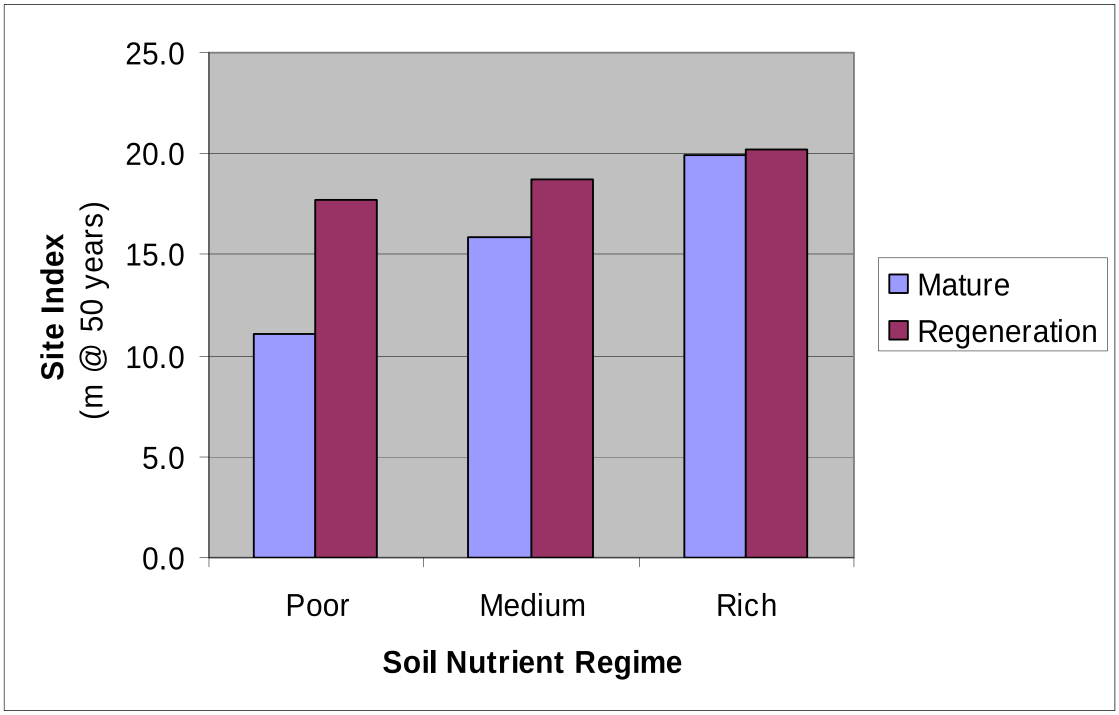


Figure 5. Average site indices by soil nutrient regime (paired plot site trees)



In regenerated sample plots, the lengths of the last 5 internodes on each of the site trees were measured. This enabled comparison between actual periodic height increment and that forecast by the height and site index model. It also provided an opportunity to evaluate whether predictions of height and site index were related to measurement age. Results are summarized in Tables 4 and 5.

Note in Table 4 that average predicted height increment was less than actual increment, especially if predictions were based on unadjusted ages. Regression analysis was used to examine whether the ratio of predicted to actual height increment varied with age. When unadjusted ages were used, the ratio of predicted to actual height increment was less that 1 initially, but increased slightly with age (see Table 5a). There was no significant age effect when adjusted ages were used to predict height (see Figure 6 and Table 5b).

Table 4. Results of paired sample t-tests comparing predicted and actual height increments[9] of paired plot site trees

(a) Based on unadjusted ages

	n	Mean	SD	SE
Actual increment	361	0.4334	0.0990	0.00521
Predicted increment	361	0.4070	0.0792	0.00417
Difference	361	0.0264	0.0598	0.00315

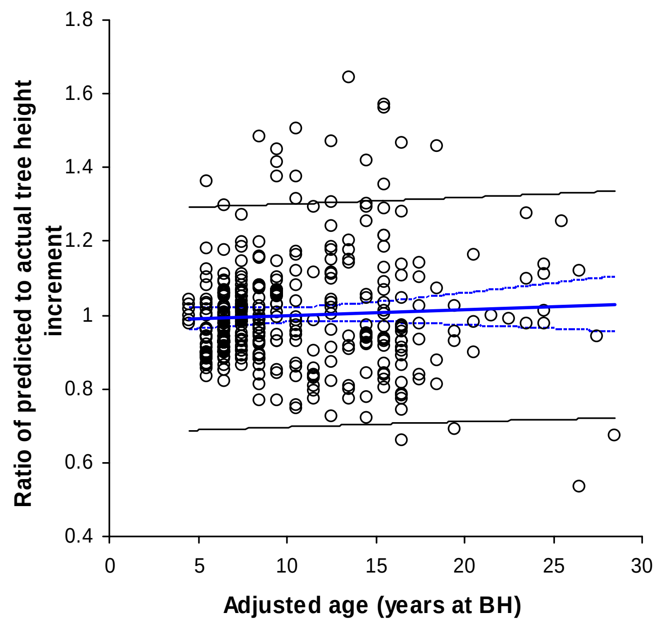
Difference between means	0.0264	
95% CI	0.0202	to 0.0326
t statistic	8.37	
2-tailed p	<0.0001	

(b) Based on adjusted ages

	n	Mean	SD	SE
Actual increment	361	0.4334	0.0990	0.00521
Predicted increment	361	0.4254	0.0832	0.00438
Difference	361	0.0080	0.0596	0.00314

Difference between means	0.0080	
95% CI	0.0018	to 0.0142
t statistic	2.54	
2-tailed p	0.0114	

Figure 6. Ratios of predicted to actual height increments (site trees in regenerated paired plots)



[9] Periodic annual increment for the last 5 years, expressed in m per year

Table 5. Relationship between the ratio of predicted to actual increment and age of regeneration (paired plot site trees)

(a) Based on unadjusted ages

R^2	0.01
Adjusted R^2	0.01
SE	0.1481

Term	Coefficient	SE	p	95% CI of Coefficient	
Intercept	0.9176	0.0194	<0.0001	0.8795	to 0.9558
Slope	0.0035	0.0016	0.0276	0.0004	to 0.0067

Source of variation	SSq	DF	MSq	F	p
Due to regression	0.1073	1	0.1073	4.90	0.0276
About regression	7.8724	359	0.0219		
Total	7.9797	360			

(b) Based on adjusted ages

R^2	0.00
Adjusted R^2	0.00
SE	0.1535

Term	Coefficient	SE	p	95% CI of Coefficient	
Intercept	0.9827	0.0193	<0.0001	0.9446	to 1.0207
Slope	0.0016	0.0017	0.3313	-0.0016	to 0.0049

Source of variation	SSq	DF	MSq	F	p
Due to regression	0.0223	1	0.0223	0.95	0.3313
About regression	8.4589	359	0.0236		
Total	8.4812	360			

3.2. *Permanent Sample Plots*

Table 6 summarizes the results of paired t-tests comparing pre-harvest and post-harvest indices computed from Weldwood's PSP data. Note that the overall site index difference (4.4 m or 34% in stands of BH age at least 5 years) was greater than that observed in the paired-plot data. The larger difference was consistent with the lower average mature-stand site index, and previous observations that the difference appears to vary inversely with site index of the mature stand.

Table 6. Results of paired sample t-tests comparing pre-harvest and post-harvest site indices (Weldwood PSP data)

(a) All plots

	n	Mean	SD	SE
Site index of regeneration	43	16.953	3.423	0.5220
Site index of mature stand	43	12.988	3.064	0.4672
Difference	43	3.965	3.876	0.5911

Difference between means	3.965	
95% CI	2.772	to 5.158
t statistic	6.71	
2-tailed p	<0.0001	

(b) Plots with regeneration of at least 5 years BH age

	n	Mean	SD	SE
Site index of regeneration	39	17.349	2.934	0.4698
Site index of mature stand	39	12.954	3.062	0.4903
Difference	39	4.395	3.177	0.5087

Difference between means	4.395	
95% CI	3.365	to 5.425
t statistic	8.64	
2-tailed p	<0.0001	

Table 7. Computed site indices for Weyerhaeuser PSPs

Plot ID	Estimated site index	
	pre-harvest	post-harvest
606105000001	20.0	18.3
606204000022	21.4	21.2
606209000033	12.7	14.2
606409000036	13.2	16.7
606508000019	15.8	18.7
606805000003	17.7	11.1

Table 7 indicates the site index values computed for the 6 Weyerhaeuser PSPs in which the regeneration was 3 years BH age or more. The low outlier value for the last post-harvest observation (site index = 11.1 m) may be attributable to incorrect estimation of BH age. The low and approximate BH ages of the regeneration, and the small sample size, precluded further analysis and interpretation of the data at this time.

Young regenerated stands are typically highly dynamic. They are subject to irregular mortality and top damage.[10] Trees that meet the criteria for being selected as site trees may differ from one measurement to the next.[11] This has raised the concern that site index may decline over time, if initial site trees are replaced by slower-growing ones. Further analyses of Weldwood data were therefore conducted to assess the stability of site index estimation in the regenerated permanent sample plots. Figure 7 shows for the Weldwood regeneration data the overall between-plot scatter in site index relative to plot age (at the latest re-measurement).

Figure 7. Age of regeneration and estimated site index (Weldwood PSP data)

n	43	(number of plots)
r statistic	0.13	(Pearson correlation)
95% CI	-0.18	to 0.41
2-tailed p	0.4102	(t approximation)

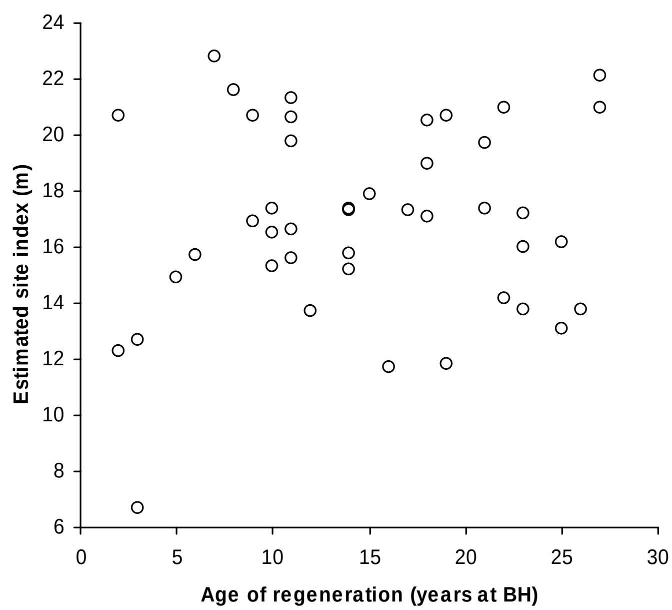


Figure 8 illustrates trends in estimated site index for individual plots between measurements. The average interval between re-measurements was about 6 years.[12]

[10] W.G.H. Ives and C.L. Rentz, 1993. *Factors affecting the survival of immature lodgepole pine in the foothills of west-central Alberta.* Inform. Report NOR-X-330, Forestry Canada, Northern Forestry Centre, Edmonton.
[11] Reported by D. Morgan and G. Klappstein (ASRD), based on analysis of provincial stand dynamics data (personal communication, May 16, 2003), and confirmed by inspection of Weldwood PSP data contributed to this study.
[12] Average BH ages at measurements 1, 2, 3, and 4 were 7, 12, 18 and 25 years respectively.

Figure 8. Trends in estimated site index between regeneration measurements (Weldwood PSP data)

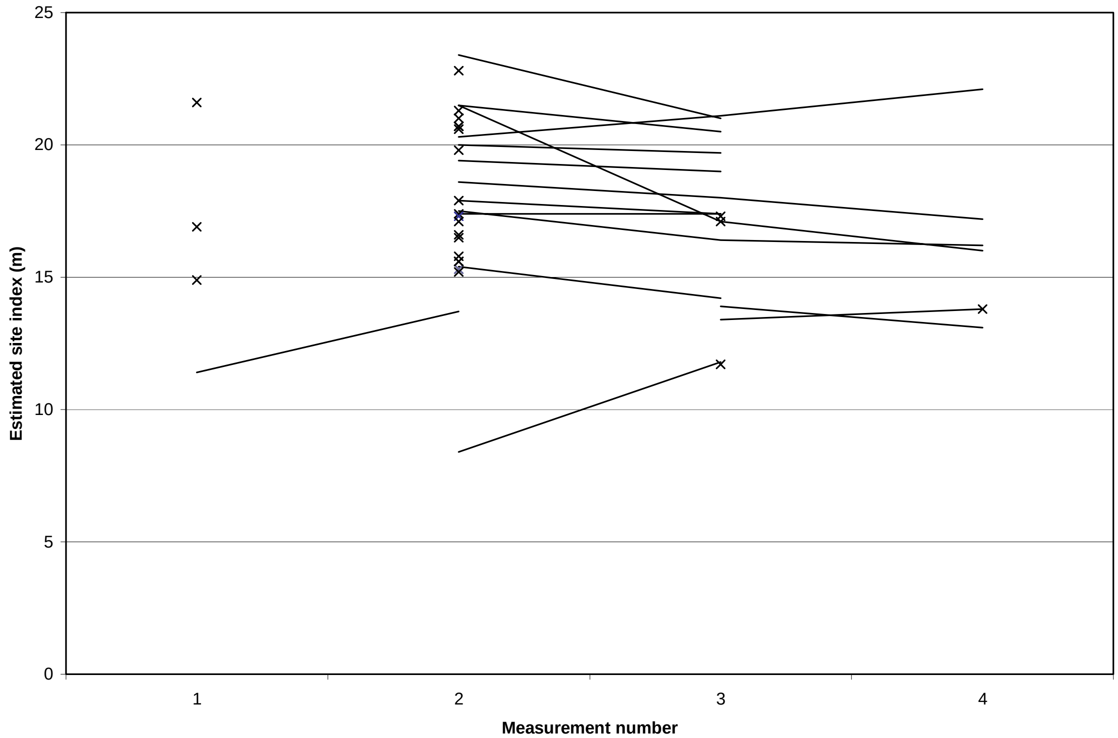


Table 8. Statistical comparisons of successive site index assessments in regenerated permanent sample plots

(a) 1-way within subjects ANOVA (repeated measures)

Site Index	n	Mean	SD	SE
1st assessment	16	17.319	3.998	0.9994
2nd assessment	16	16.750	3.039	0.7597

Source of variation	SSq	DF	MSq	F	p
Within Site Index	2.588	1	2.588	1.45	0.2476
Between Site Index	351.407	15	23.427	13.10	<0.0001
Within cells	26.817	15	1.788		
Total	380.812	31			

(b) Paired samples t-test

Assessment	n	Mean	SD	SE
1	16	17.319	3.998	0.9994
2	16	16.750	3.039	0.7597
Difference	16	0.569	1.891	0.4727

Difference between means	0.569	
95% CI	-0.439	to 1.576
t statistic	1.20	
2-tailed p	0.2476	

Of the 43 Weldwood plots analyzed, 16 were assessed for site-index more than once, thus permitting true time-series analysis. These 16 plots showed a small decline in average site index between the first and second assessment. The decline did not approach statistical significance when examined by analysis of variance or paired-sample t-test (see Table 8).

Most of the plots in the analyzed time series had been subject to changes in tag limits and other protocols over successive re-measurements. Further examination of regeneration re-measurements in which all trees greater than 1.3 m in height were tallied consistently[13], showed no such decline, and instead a slight but statistically insignificant increase in estimated site-index between measurements (see Table 9).

Table 9. Statistical comparisons of successive site index assessments in regenerated permanent sample plots (identical measurement protocols)

(a) 1-way within subjects ANOVA (repeated measures)

Site Index	n	Mean	SD	SE	
1st assessment	10	15.130	5.506	1.7413	10
2nd assessment	10	15.740	3.903	1.2342	10
Source of variation	**SSq**	**DF**	**MSq**	**F**	**p**
Within Site Index	1.860	1	1.860	0.99	0.3463
Between Site Index	393.011	9	43.668	23.18	<0.0001
Within cells	16.955	9	1.884		
Total	411.826	19			

(b) Paired samples t-test

Assessment	n	Mean	SD	SE
1	10	15.130	5.506	1.7413
2	10	15.740	3.903	1.2342
Difference	10	-0.610	1.941	0.6138
Difference between means				
95% CI	-0.610			
t statistic	-1.999	to 0.779		
2-tailed p	0.3463			

13 10 such plots were identified, including plots with no previous fire-origin measurements not included in the previous analyses.

4. Interpretation of Results

In August 2003 the FGYA shared the results of this and related studies with foresters and researchers from Alberta and B.C. Aided by Weldwood of Canada and Dr. James Stewart of the Canadian Forest Service (CFS), the Association conducted a field tour and follow-up meeting in the Hinton area. The purpose was to review evidence, possible causes, and monitoring of productivity changes in post-harvest stands. Tour participants visited 8 sites including: an example of a Weldwood permanent growth sample plot; an FGYA trial installation for monitoring regeneration growth response to specific site and treatment factors; paired sample plots located in regenerated and mature stands growing on equivalent ecosites (see Figure 9); and the CFS Gregg River spacing trial.

Figure 9. Foothills Growth and Yield Association field tour, August 2003

Tour participants compare post-harvest regeneration (left) with a residual portion of the original fire-origin stand growing on the same ecosite (right). Photographs: G. Behuniak, Weyerhaeuser Company

Results to date of the Gregg River spacing trial[14] suggest that site index increase and changes in other stand variables are related to reduced densities and reduced height repression. Dr. Stewart presented data acquired 38 years after spacing of a 7-year old fire-origin stand. On the low site (poor soil nutrient regime) top heights ranged from 12.2 to 13.0 m in plots that had been spaced between 7900 and 494 stems per ha, but in the non-spaced control plots the average top height was only 8.1 m. Unfortunately, initial densities in the control plots are not known, but the average density at age 45 years was still over 20,000 stems per ha. The data also indicated substantial shifts in average tree heights, diameters, and height-diameter ratios associated with spacing.

Observations by Dr. James Goudie of the B.C. Ministry of Forests Research Branch,[15] based largely on paired plot studies and espacement trials in the B.C. interior, included:

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[14] J. Stewart, Canadian Forest Service, Northern Forestry Centre, presentation to FGYA field tour, August 20, 2003. Earlier published reports include W.C. Johnstone 1981 (NOR-X-236) and R.C. Yang (NOR-X-322).

[15] J. Goudie, B.C. Ministry of Forests, Research Branch, presentation to FGYA technical meeting, August 21, 2003, Hinton, Alberta. Much of Dr. Goudie's presentation was based on his paper: 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 NIVMA Annual General Meeting, Jan. 24-15, 1996, Smithers, BC, Edited by P. Tollestrup. Northern Interior Vegetation Management Association, Prince George, BC.

- Site index shifts after logging in the Morice and Lakes timber supply areas averaging 4.5 m or 29%;
- An associated 65% increase in mean annual volume increment at culmination;
- Attribution of increases to reduced density after harvesting;
- Site index decline occurring at initial densities over approximately 14,000 stems per ha.

Climate change may also be contributing to the effect. As noted by Dr. David Price of the CFS: [16]
- Climate change has occurred over the last 100 years on the sites where comparisons have been made between pre- and post-harvest growth rates;
- The changes include an increase in temperature, notably in minimum temperatures during the growing season;
- These changes may have been beneficial for growth, particularly on cold, wet sites.

Subsequent to the August 2003 field tour, implications of the FGYA paired-plot results (see Section 3.1) were further examined using the simulation model GYPSY.[17] Current densities had been measured on all plots, but no data were available for the initial densities of the fire-origin stands. The stand density function developed by Huang *et al* in GYPSY was used to estimate initial densities from current density, site index and age for each of the soil nutrient and stand origin categories shown in Figure 5. GYPSY was then used to simulate future stand development, and to predict mean annual increment (13/7 utilization standard[18]) and age of m.a.i. maximization. Results are shown in Table 10.

Table 10. Results of GYPSY simulations

Soil nutrient regime / stand origin	Site index (m @ 50 years)	B.H. age (years)	Current density (stems/ha)	Estimated initial density	Max. mai (13/7)	Culmination age (years)
Poor-mature	11.0	120	2287	13187	1.79	110
Poor-regen	17.7	11	2833	2994	3.33	70
Medium-mature	15.9	113	1176	8759	3.15	80
Medium-regen	18.7	12	3844	4194	3.86	70
Rich-mature	19.9	103	504	1297	3.57	70
Rich-regen	20.2	8	1378	1409	3.73	70

Forecast volume productivity increases vary from 4% on rich sites to 86% on poor sites, averaging 23% on medium nutrient regimes. There is little difference between mature stands and regeneration in the initial densities forecast for rich sites, but the differences increase on the medium and poor sites. Note that, even on the poor sites, the average estimated initial densities are below the threshold expected by B.C. researchers to result in height growth repression. However, the absolute values estimated for initial densities should be interpreted with caution. The stand density function currently used in GYPSY is based largely on sample plots with BH ages of over 30 years. Data from the Gregg trial and elsewhere suggest that initial densities in fire-origin stands could be higher than estimated.

[16] D. Price, Canadian Forest Service, Northern Forestry Centre. *Site index of lodgepole pine in a changing climate*. Presentation to FGYA technical meeting, August 21, 2003, Hinton, Alberta.

[17] S. Huang *et al*, 2001. *GYPSY – a growth and yield projection system for natural and regenerated stands within an ecologically-based enhanced forest management framework.* Pub. No. T/485, Alberta Sustainable Resource Development, Edmonton.

[18] Merchantable volume based on a 13 cm minimum outside-bark stump diameter, 7 cm minimum top diameter inside-bark, minimum merchantable length 2.44 m, and 0.3 m stump height.

5. Conclusions and Recommendations

Results suggest that:

- Site index is on average 24% higher in regenerated versus mature stands across the sites evaluated by paired-plot sampling.
- Differences are greatest on poor soil nutrient regimes (average site index about 60% higher in regenerated versus mature stands), and insignificant on rich sites.
- The effect does not appear to decline with age of regeneration. However, the amount and age-range of true time-series data (acquired from consistently repeated measurements on the same sites) were limited in availability.
- The increase is probably associated with differences in establishment densities between stands of fire and harvest origin. Climate change over the last 100 years may also have had an effect.

Observed differences between fire-origin and post-harvest stand development have important implications for forest management and silvicultural practice. The increase in site index indicates the potential for substantial productivity enhancement relative to suppressed fire-origin stands. However, the apparent major changes in stand structure and decrease in densities associated with post-harvest silviculture create risks and uncertainties that need to be addressed. The FGYA technical committee met in Edmonton on December 4, 2003, to discuss what work is required to better assess these implications. Below are listed questions that the committee considered highest priority for further investigation, together with potential sources of information.

1. *Will observed increases in site index be maintained in future?* Only long-term monitoring, as provided for by the FGYA regenerated lodgepole pine (RLP) project, other trials, and the permanent sample plots of member organizations, will answer this question with certainty. Consistent re-measurement protocols, especially regarding selection and measurement of trees for top height and BH age, are crucial to effective monitoring of site index change. The question is made particularly difficult to answer because the effects of initial densities and climate change are confounded. Old CFS spacing trials and new research into climate change impacts offer some opportunities for separating the effects.

2. *How do post-harvest stands differ from fire-origin stands in structure and dynamics?* Permanent sample plot data (some already made available by FGYA members) provide an opportunity to further explore these differences. Depending on results, additional paired-plot data and / or low-level aerial photography may be required for comparing fire-origin and post-harvest stands on similar sites and at similar ages. Answering this question would not only assist in explaining productivity changes, but also provide a basis for assessing differences in fire hazard, biodiversity, and wood quality.

3. *What levels of site occupancy (proportion of area occupied by trees) and density (trees per ha) are being achieved following harvest and will be maintained over the rotation, and what levels should we be targeting?* Several existing data sets and ongoing trials will help to address these questions, including the FGYA's RLP project, ASRD's stand dynamics data, CFS spacing trials, and various ingress studies in both Alberta and B.C.

4. *Why is the shift in site index not apparent on rich sites and greatest on poor sites, and how does control of competing vegetation influence growth response on different sites?* Extending paired-plot sampling to rich-site stands that have undergone strict control of competing vegetation may provide some quick answers to these questions. In the longer term, the RLP experimental trial will shed important light on the relationships between growth response, vegetation control, density management, and site.

5. *How is susceptibility to irregular mortality and damage affected?* Research by the CFS suggests that biotic damage by gall and blister rusts, mammals, root rot, root-collar weevils, and pitch blister moths, can be of serious concern in immature post-harvest lodgepole pine regeneration. Damage and mortality are being monitored in the RLP, some other research trials, and most PSP programs. Observed and forecast stand structures should also be linked to risk rating systems and spread models for fire and mountain pine beetle.

6. *What are the implications of the observed differences in post-harvest stand development for enhanced forest management practices such as fertilization, thinning, and tree improvement (e.g. will the effects be additive)?* Answering this complex question will require not only addressing the preceding questions, but also working closely with experts in tree improvement and forest nutrition.