The effects of stocking on estimated site index in the Morice, Lakes and Vanderhoof timber supply areas in central British Columbia

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INTRODUCTION

Lodgepole pine (*Pinus contorta* ssp. *latifolia* [Engel.]) is well known for its ability to regenerate at extreme densities after wildfire, due in large part to its serotinous cones that can shower millions of seeds per ha. Casual observations along openings and roads shows that height growth of all trees can be greatly reduced in these conditions. Figure 1 shows the condition (often termed "repression" or "stagnation") along a road in an 18-year-old stand near Prince George, B.C. Dominant trees along the immediate edge are 4 to 5 m tall but quickly reduce to 1–2 m a short distance into the stand, yet all trees in the photograph regenerated immediately after a 1961 fire. Mitchell and Goudie (1980) found that, in the Cariboo and Prince George regions, the likelihood that height growth of dominant trees is reduced more than 50 000 stems survive is very high (Figure 2). Additional sampling in untreated stands (Goudie 1981) and retrospective studies by J.S. Thrower and Assoc (1993a, 1993b) in precommercially thinned stands suggested that repression can occur at densities between 10 000-50 000/ha.

Carlson and Johnstone[1] (1984) established a field experiment (Barnes Creek trial) to mimic repression under more controlled conditions. Trees were planted at square spacing in replicated 100-tree plots ranging in density from 2500 to 160 000 stems per ha (2.00–0.25 m spacing). Seeds were sown in 1983 and out-planted in 1985. Figures 3 and 4 show annual height growth and cumulative height of the tallest five trees/plot (5%) identified in the last measurement. The dominant height growth of densities above 40 000/ha is already significantly different from the lower four densities ten years after germination. Figure 4 shows that repression becomes apparent before the dominant trees reach 2 m in height, confirming Mitchell and Goudie (1980) findings from stem analysis studies.

A number of tree, stand, and fire factors governs the amount of post-fire regeneration. Anderson and Romme (1991) found that, after the 1988 Yellowstone fires, plots classified as moderately burned had almost seven times greater lodgepole pine regeneration than on severely burned plots. Cone serotiny may increase with tree age (Armit 1964, Crossley, 1956). Parker (1942) related natural regeneration to the age of the parent stand. Regeneration was greater after 180 year-old stands burned than after both 70 year-old and 228 year-old stands. Tinker and Romme (1994) showed that pre-fire density of trees classified as "serotinous" was the most important predictor of post-fire seedling density.

[1] Information included with permission of W. Johnstone

Worrall (1995) reported that repressed trees produce excessively long tap roots relative to unrepressed. Assuming the tap root reflects total root biomass, he suggested that trees react as if they are growing on poor site and shift resources from shoots to roots in an attempt to capture sufficient moisture and nutrients. The increased relative production of root biomass in trees growing on poor sites has been frequently reported (e.g. Keyes and Grier 1981, Grier et al.1986, Santantonio and Hermann. 1985, Kurz 1989). Stemwood relative density measurements suggest that high proportions of relatively impervious latewood in repressed stems may also contribute to reduced height growth (Keane and Weetman 1987).

Mitchell and Goudie (1980) used stem analysis techniques to estimate the range of effect in a 70-year-old stand near Williams Lake, B.C. Figures 5 and 6 show height growth trajectories of 6 dominant trees growing on apparently uniform site under varying densities. Site index declines from a potential of 14 m to 7 m as the number of live trees increases from 2000 to 18 000. Notice that the height growth trajectories of the trees follows the site curves in Figure 6. This illustrates the difficulties in determining whether site index in mature stands is a result of site productivity or stand history.

The potential range of effects on stand yield and mean annual increment (MAI) can be estimated if two simulated natural stands are grown in unrepressed (5000/ha on site 14 m) and extremely repressed (80 000/ha on site 7 m) conditions. Yield estimates were generated at Research Branch, Ministry of Forests by the Tree and Stand Simulator (TASS, Mitchell 1975, Goudie 1980). TASS predicts that at the extreme, repressed merchantable volume yields fall to 0–36% of the potential levels (Figure 7). Culmination of mean annual increment occurs almost 100 years later and is about one-fourth of unrepressed conditions (Figure 8).

Growth intercept relationships (Nigh 1995) were used to estimate what the height of the Barnes Creek dominant trees will be at 50 years breast height age. This assumes the height growth of the tallest 5% of trees will parallel the growth of the top height[2] cohort that was used in development of the growth intercept relationship. Figure 9 shows that site index declines at densities greater than about 10 000–20 000/ha. Figure 10 compares the Barnes Creek trial site index estimates with two plantation espacement experiments, EP660[3] and EP671 (Johnstone and Pollack 1990) near Prince George, and an early spacing experiment known as the Gregg Burn trials in western Alberta (Johnstone 1981). Note that site index estimated in these latter trials is that of the top height cohort. One of the three sites of the Gregg Burn trial indicates that repression may in some cases occur below an establishment density of 10 000 stems/ha but trends are otherwise fairly flat between 500 and 10 000 stems/ha.

Unfortunately, the distribution and range of the repression effect is unknown. Inventories consistently underestimate the potential site index of lodgepole pine stands because no method exists in B.C. to estimate the degree of repression in existing stands. Regenerated stands in interior regions are stocked at levels far below the repression levels (Silvicultural Interpretations Working Group 1993) thus site index in the inventory will underestimate the productivity of young lodgepole pine stands. Many second-growth stands are now becoming old enough to provide a reliable estimate of potential site index using growth intercept relationships. The studies reported here were intended to provide a first quantification of the range of repression in the Morice and Lakes Timber Supply Areas (TSAs) for use in long range sustained yield (LRSY)

[2] Top height is the average height of the largest undamaged 100 trees/ha by DBH

[3] Unpublished data on file at the Research Branch, Ministry of Forests, Victoria BC

calculations and for consideration in annual allowable cut (AAC) determinations. A previous study adjusted managed stand site index in the Bulkely TSA (Lloyd-Smith 1993) based on correlation between site index and the Biogeoclimatic Ecological Classification (BEC) system and found that an appreciable increase in LRSY is possible.

METHODS

Figure 11 shows the locations of the Morice and Lakes TSAs relative to the potential range of lodgepole pine in B.C. and western Alberta. Hinton, Alberta and the Merritt TSA are also displayed since parallel studies conducted in these areas are compared later in this paper (Udell and Dempster 1985, Weyerhaeuser, 1994).

Two sampling approaches were adopted. We installed temporary plot pairs along cut boundaries to quantify potential site index in managed, second growth stands. In the Lakes TSA, we were also able to relocate old inventory temporary plots sampled prior to logging .

A Geographic Information System (GIS) was queried to provide a list of all managed cut blocks older than 11 years that were planted or naturally regenerated to lodgepole pine and neighbour analyses selected those with adjacent mature lodgepole pine stands. Surveys of aerial photographs were used to select the cut blocks with at least one straight, compass-line edge to minimize the chance of differing ecological or geological conditions on either side.

The selected edges were surveyed on site by a walk-through to ensure 1) the correct species occurred in both stands, 2) minimal pest or disease impacts were evident and 3) managed stand density was below about 10 000/ha.. If acceptable, either five (Morice) or three (Lakes) plot pairs were established along the cut boundary. The managed stand plot was located 30 m from the tree line and the natural stand plot was 20, 40 or 60 m into the natural stand. The location was not sampled if the managed stand BEC site series (Pojar *et al.* 1987) could not be paired in three attempts. Successful plot pairings were separated by 50 m along the stand boundary.

Circular, 300 m^2 temporary plots were established. The three tallest (Morice) or largest diameter (Lakes), undamaged trees were selected as top height trees (equivalent to 100/ha). The minor difference in tree selection criteria is ignored in this report. The height, breast height age and length of the first five internodes above breast height were recorded in both the natural and managed stand. A concentric, circular, 100 m^2 sub-plot was used to determine the number of trees taller than breast height. The diameters of all sub-plot trees were recorded in the natural stand plot.

RESULTS and DISCUSSION

Field sampling results

A total of 110 edges were sampled in the Morice (42), Lakes (56) and Vanderhoof (12) Forest Districts. Although originally not in the sampling plan, plots were located in the western edge of the Vanderhoof District because of a paucity of cut blocks in the Lakes. The sample polygons were not randomly selected since we were constrained by cutting history 2–3 decades ago. Although the Lakes and Vanderhoof sample polygons were geographically reasonably well distributed, unfortunately, most of the regenerated stands in the Morice were clumped in the south end of the district. Thus, the sample contains an unavoidable and unknowable bias that cannot be resolved until a representative distribution of cut blocks exists.

Most (92) stand edges were classified in the Sub-Boreal Spruce moist-cold sub zone - SBSmc2/01 (85) and SBSmc2/02 (7) BEC site series - and the remainder were distributed in the dry-cool zones - SBSdk/01 (8), SBSdk/02 (2), SBSdk/03 (1) and SBSdk/05 (7) series. Table 1 lists the overall mean, minimum, maximum and standard deviation of key stand and tree statistics for the managed and natural plots. The mean stand density of the natural plots was 1822/ha at 142 years breast height age. The managed stands averaged 3222/ha and were 10 years old at breast height. Although two types of site index (growth intercept and conventional height-age) were estimated on both natural and managed plots, the most reliable are the conventional estimate for natural stands (15.6 m) and the growth intercept estimate for managed stands (20.1 m), an average shift of 4.5 m. Table 2 presents the mean natural stand and managed stand site index by location and BEC subzone.

Figure 12 shows that the managed stand site index is not significantly affected by stand density. Although two of the 40 managed stand edges from the Morice District averaged greater than 10 000/ha and may be slightly affected by repression, they were retained in the sample. The managed stand densities averaged 2800, 3400 and 3700/ha for the Lakes, Vanderhoof and Morice Districts, respectively.

The relationship between managed stand site index (estimated by Nigh, 1995 growth intercept curves) and natural stand site index as determined by conventional means (Goudie 1984, Thrower et al. 1991) is presented in Figure 13. This analysis ignores the potential bias in stem analysis-derived site curves most recently pointed out by Magnussen and Penner (1996). We assume that (1) the top height trees currently alive in the natural stands were always the top height cohort and (2) the top height cohort in the managed stands will be so at breast height age 50 and may thus overestimate the difference between managed and natural stand productivity. Nonetheless, that all data points are above the 45-degree line is compelling evidence that natural stand site indexes are reduced by excessive, post-fire initial density. In addition, Figure 13 suggests an east-to-west progression since the average natural stand site index is 16.1 m, 15.4 m and 14.9 m for the Morice, Lakes and Vanderhoof Districts, respectively. This may support evidence of increasing cone serotiny from west to east (Illingworth 1970), resulting in greater post-fire levels of regeneration and repression.

Sampling of relocated temporary plots in the Lakes district shows very similar results when managed stands are measured and compared to the previous inventory plot at the same location (Figure 14). The average site index of natural stands is 1.1 m greater than the paired plots within the same ecological class but the managed stand site indices are nearly identical. Figures 13 and 14 also indicate that the estimates of site index in natural stands are largely unrelated to the production of subsequent managed stands.

Numerical results in the form of histograms for both types of site index estimates are displayed in Figure 15. Mean site index from growth intercept estimates are 1.0 and 0.2 m greater than the conventional estimate for the natural and managed stand, respectively (Table 1). The range for both stand types is slightly less for the growth intercept relationship.

Stand simulation results

No mechanistic or process models of repression in lodgepole pine exist. Hence, the average conditions in Table 1 were input into TASS to estimate the long-term growth and yield results. In the unrepressed stand, designed to mimic a managed regime, we planted 1600 simulated trees per ha on site 20.1 m. This approximates the recommended stocking standards for SBSmc2/01 of 1200/ha (Silviculture Interpretations Working Group 1993) if 400 trees would be either lost to early mortality or not free-growing at the time of a silviculture assessment. A repressed natural stand after fire was approximated by establishing 80 000 randomly-distributed stems per ha over five years and growing it on site 15.6 m for 120 years. Table 3 presents the growth and yield results of the two simulations.

Figure 16 illustrates the effect of average repression on merchantable volume (all trees greater than 12.5 cm DBH). Between reasonable rotation ages of 60 to 100 years, the regenerated stand produces 169–179 m^3 /ha (54–109%) more than the repressed stand of the same age. The culmination of mean annual increment is increased from 3.32 to 5.48 m^3/ha per year (+65%) and occurs 33 years earlier (Figure 17). Quadratic mean DBH is 8.0–10.8 (44–97%) cm greater for the managed stand between 60 and 100 years of age (Figure 18). The unrepressed stand meets an arbitrary 20 cm technical rotation 72 years earlier than the repressed stand. The repressed stand fails to reach a 25 cm average DBH in the 120 year simulation but the managed stand meets that criteria at 89 years.

Crown cover and dominant height growth are two potential measures of green-up that repression could affect. TASS predicts that the managed stand reaches an arbitrary 80% crown cover about six years later than the natural stand because the increased early height growth and branch extension does not compensate for the wide spacing (Figure 19). Figure 20 shows, however, that the managed stand reaches a 6 m dominant height about five years earlier. Visually, green-up is probably a combination of the two measures and is perhaps not affected appreciably by wider spacing.

Timber supply results

The Morice and Lakes TSAs have incorporated the effect of increased site index in managed stands into the timber supply analysis using the relationships in equation 1.

$$
\begin{aligned}
&\text{Lakes TSA, SBSmc2 sites:} && MSI = NSI + 20.157 - 1.007 \cdot NSI \quad (NSI\ 20.02) \\
&\text{Lakes TSA, SBSdk sites:} && MSI = NSI + 14.243 - 0.606 \cdot NSI \quad (NSI\ 20.00) \\
&\text{Morice TSA, SBSmc2 sites:} && MSI = NSI + 17.807 - 0.931 \cdot NSI \quad (NSI\ 19.12)
\end{aligned}
\qquad (1)
$$

where: MSI = managed stand site index,
NSI = natural stand site index.

Figure 21 shows that by adjusting regenerated stand volumes, the current cut levels in the Morice TSA can be maintained at 1.995 million cubic meters for an additional decade. The subsequent decline after the ninth decade is reduced and harvest stabilizes about 14 % higher than the unadjusted analysis (1.614 vs. 1.413 million cubic meters).

The Lakes TSA analysis is shown in Figure 22. The unadjusted base case maintains 1.5

million cubic meters per year for 70 years and then drops to 1.31 for 10 decades. The adjusted yields (applied to integrated resource management zones in lodgepole pine only) predicts an immediate increase to 1.77 million cubic meters (+18%) that can be maintained for 170 years. The harvest levels are thus 31–35% greater between the seventh and 17th decades for the adjusted projections. If adjustments are applied to all lodgepole pine zones (not shown), the increases are an additional 8% higher.

These TSA analyses are examples of how the results of the increased productivity of lodgepole pine stands will vary by management strategies, forecast assumptions and forest condition. The two most important reasons for the difference between the Morice and Lakes TSA projections are: (1) contrary to the Lakes, the Morice long-term harvest is lower than the current cut levels, thus the base case was conditioned to prevent any increase above the current cut levels and (2) only about 50% of the Morice TSA is expected to be managed for lodgepole pine stands compared to over 80% of the Lakes. In addition, the Lakes has a somewhat higher mature pine inventory than the Morice (35%) that may permit faster initial harvesting.

Comparison with other studies

Table 4 shows the comparison of these results to other studies and sampling strategies. Weyerhaeuser (1994) sampled the Merritt TSA with both paired plot techniques similar to our approach (25 stand edges) and a conventional sample of regenerated polygons where site index is compared to the previous inventory files (67 young stands). Weldwood Canada Corporation in Hinton, Alberta remeasured 16 continuous forest industry plots that had been logged and naturally regenerated to lodgepole pine (Udell and Dempster 1985). Finally, results of two unrelated studies conducted in the Prince Rupert Region with differing natural-stand selection criteria are compared. McLennan (1989) estimated the site index of SBSmc sites but "stand density was not used as a criterion for stand selection" while Wang *et al.* (1994) sampled similar BEC sites but avoided stands with "an identifiable history of height growth repression".

The increase in estimated site index of the Morice/Lakes/Vanderhoof study reported here is the most of any of the studies (4.5 m) but the range over all the studies is only 2.9 to 4.5 m (17.6–29.0%). These comparisons indicate that height growth repression in lodgepole pine stands is widespread and relatively consistent. A 3 m shift in site index is a conservative yet reasonable guide for sensitivity analysis for regenerated pine sites in other regions, but further sampling should be performed to confirm these findings.

CONCLUSIONS

Fire-origin lodgepole pine stands are not growing at the potential of interior BC sites. The average shift in site index after logging in the Morice and Lakes timber supply areas is 4.5 m (29%) and varies from 2.9 to 3.4 m in comparable studies. This increase in height growth due to reduced density after harvesting (naturally or through management) translates into approximately 170 extra cubic meters per hectare at reasonable rotation ages and 65% higher culmination of MAI (5.48 vs 3.32 m^3/ha/yr) on average sites. This in turn allows current levels of cut to either be maintained longer (Morice) or immediately increased (Lakes), depending on analytical constraints, percentage of lodgepole pine management polygons in the TSA and the amount of standing inventory available for earlier harvest. These results can be used as guides for sensitivity analysis in other regions of the Province but should be supported with additional localized studies.

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Table 1. Stand summary statistics for 110 lines of paired plots sampled in the Morice, Lakes and Vanderhoof districts.

Variable	Natural stand statistics				Managed stand statistics			
	Min.	Max.	Mean	Standard dev.[3]	Min.	Max.	Mean	Standard dev.[3]
Density (stems/ha)[1]	467	5620	1822	883	633	11 060	3222	1846
Mean DBH (cm)[2]	17.8	41.4	31.2	3.6	-	-	-	-
Age @ breast height	47	236	142	28.5	5.2	15.2	9.9	2.5
Top height. (m)	14.4	29.7	24.5	2.3	3.6	8.9	5.6	1.1
Growth intercept (cm)	19.8	50.1	31.9	4.9	35.4	68.7	47.7	5.5
Conventional site index (m)	11.5	20.2	15.6	1.8	16.1	25.5	19.9	1.6
GI site index (m)	13.0	20.8	16.6	1.3	16.9	24.5	20.1	1.3

[1]All trees above 1.3 m height
[2]Top height trees only
[3]Standard deviation of edge means.

Table 2. Mean site indexes for managed and natural stands by ecological classification and forest district.

Forest District	BEC site series[1]	Number of stand edges[2]	Natural stand site index[3] (m)		Managed stand site index[4] (m)		Site index shift (m)
			Mean	Standard deviation[5]	Mean	Standard deviation[5]	
Morice	SBSmc2/01	39	16.17	1.63	19.82	1.07	+3.65
	SBSmc2/02	1	12.90	-	18.20	-	+5.40
	SBSdk/05	2	17.05	0.78	21.80	0.57	+4.75
	All	42	16.14	1.66	19.88	1.15	+3.74
Lakes	SBSmc2/01	41	15.25	1.57	20.05	1.21	+4.80
	SBSdk/01	8	16.20	2.23	20.80	1.34	+4.60
	SBSdk/02	2	11.90	0.56	18.25	0.49	+6.35
	SBSdk/05	5	16.40	2.45	20.30	0.80	+3.90
	All	56	15.37	1.87	20.12	1.25	+4.75
Vanderhoof	SBSmc2/01	5	15.08	1.12	21.76	1.86	+6.68
	SBSmc2/02	6	14.43	1.67	20.43	1.36	+6.00
	SBSdk/03	1	17.20	-	21.20	-	+4.00
	All	12	14.93	1.53	21.05	1.59	+6.12
All Combined	SBSmc2/01	85	15.66	1.63	20.04	1.26	+4.38
	SBSmc2/02	7	14.21	1.63	20.11	1.50	+5.90
	SBSdk/01	8	16.20	2.23	20.80	1.34	+4.60
	SBSdk/02	2	11.90	0.56	18.25	0.49	+6.35
	SBSdk/03	1	17.20	-	21.20	-	+4.00
	SBSdk/05	7	16.58	2.05	20.73	1.01	+4.15
	All	110	15.61	1.80	20.12	1.28	+4.51

[1]Biogeoclimatic ecological classification site series (Pojar *et al.* 1987)
[2]Number of three- or five-plot pairs along stand boundaries.
[3]Natural stand site index determined by Goudie (1984) site curves.
[4]Managed stand site index determined by Nigh (1995) growth intercepts.
[5]Standard deviation of edge means.

Table 3. Simulated yields for natural established with 80 000 trees per hectare and grown on site index 15.6 m compared with a managed stand planted with 1600 trees per hectare on site 20.1 m.

Total age	Whole-stand statistics												Prime tree statistics (largest 250/ha)					
	Merch volume (12.5 cm+) (m^3/ha)		Mean annual increment (m^3ha^{-1}/yr)		Basal area (m^2/ha)		Quadratic mean DBH (cm)		Live trees per hectare		Crown cover (%)		Merch. volume (12.5 cm+) (m^3/ha)		Quadratic mean DBH (cm)		% live crown	
	N[1]	M[2]	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M
20	0	6	0.00	0.28	10.3	11.5	1.7	10.0	43903	1463	100	97	0	6	0.0	13.8	0	91
25	0	38	0.00	1.52	16.4	20.4	2.3	13.4	38100	1437	100	99	0	17	0.0	17.3	0	80
30	1	84	0.05	2.79	21.7	27.9	3.1	15.8	29257	1421	100	100	1	30	13.0	20.2	63	66
35	13	130	0.37	3.70	26.4	34.1	4.1	17.5	20328	1413	100	100	12	45	13.7	22.3	56	57
40	36	173	0.90	4.33	30.5	39.1	5.3	18.8	13583	1410	100	100	19	59	15.5	24.1	52	52
45	68	214	1.52	4.76	33.7	43.3	6.8	19.8	9378	1409	100	100	27	74	17.0	25.5	50	48
50	98	253	1.95	5.07	36.3	46.8	8.3	20.6	6732	1409	100	100	35	89	18.4	26.7	48	45
55	127	290	2.31	5.27	38.3	49.8	9.8	21.2	5062	1408	100	100	44	103	19.6	27.7	46	43
60	155	324	2.58	5.40	39.8	52.3	11.1	21.9	4087	1392	100	100	53	116	20.7	28.6	45	42
65	182	355	2.80	5.46	41.1	54.6	12.3	22.4	3457	1383	100	100	62	129	21.6	29.5	44	41
70	207	384	2.96	†5.48	42.2	56.4	13.4	23.0	3008	1358	100	100	71	142	22.5	30.2	42	40
75	232	410	3.09	5.47	43.1	57.8	14.3	23.6	2676	1326	100	100	80	154	23.3	30.9	41	39
80	254	433	3.18	5.42	44.1	58.9	15.1	24.1	2464	1287	100	100	88	166	24.0	31.6	40	39
85	276	455	3.24	5.35	44.9	59.8	15.9	24.7	2268	1251	100	100	96	177	24.6	32.1	40	38
90	295	474	3.28	5.27	45.6	60.4	16.6	25.2	2106	1212	100	100	104	187	25.2	32.7	39	38
95	314	492	3.31	5.18	46.0	61.1	17.4	25.6	1935	1184	100	100	111	197	25.7	33.1	39	38
100	332	510	†3.32	5.10	46.4	61.9	18.1	26.1	1796	1159	100	100	119	206	26.2	33.6	38	37
105	348	522	†3.32	4.97	46.9	61.9	18.7	26.5	1703	1119	100	100	126	215	26.7	34.0	38	37
110	364	532	3.31	4.84	47.3	61.7	19.3	27.1	1620	1073	100	100	133	224	27.1	34.4	38	37
115	379	537	3.29	4.67	48.0	60.7	19.7	27.7	1575	1009	100	100	139	232	27.5	34.8	37	36
120	391	544	3.26	4.53	48.2	60.2	20.2	28.2	1509	965	100	100	145	239	27.9	35.1	37	36

[1]N = 15.6 m site index, natural stand, 80 000 randomly established trees per hectare.
[2]M= 20.1m site index, planted stand, 1 600 systematically established trees per hectare.
† = culmination of MAI.

Table 4. Comparison of mean results for different sampling strategies and sampling areas

Location	Sampling approach	Sample size[1]	Natural stand site index (m)[2]	Managed stand site index (m)[3]	Increase (m)	Increase (%)
Morice/ Lakes/ Vanderhoof	Paired Plot	110	15.6	20.1	4.5	29.0
Lakes	Relocated TSPs[5]	14	16.6	20.0	3.4	20.5
Merritt	Paired Plot	25	16.5	19.4	2.9	17.6
Merritt	Classic Sampling	67	16.0	19.2	3.2	20.0
Weldwood	Relocated CFI plots[5]	16	13.1	16.2	3.1	23.7
Prince Rupert Region[4]	Subjective	78&18	15.8	18.9	3.1	19.6

[1]Sample size is the number of lines, number of openings, and the number of plots for the paired plot, classic sampling and relocated TSP approaches, respectively.

[2]Natural stand site index determined by field measurements in the paired plot approaches, by map call in the classic approach and by previous stand measurements in the relocated CFI approach.

[3]Managed stand site index is determined by conventional site index in the subjective sampling approach and by growth intercept relationships in the other methods.

[4]The Prince Rupert results are from two unrelated studies with different subjective plot selection criteria (with and without repression) (McLennan 1989 and Wang *et al.* 1994).

[5]TSP=temporary sample plot, CFI = continuous forest inventory plot

Figure 1. Repression effects in an 18-year-old lodgepole pine stand near Prince George, B.C.

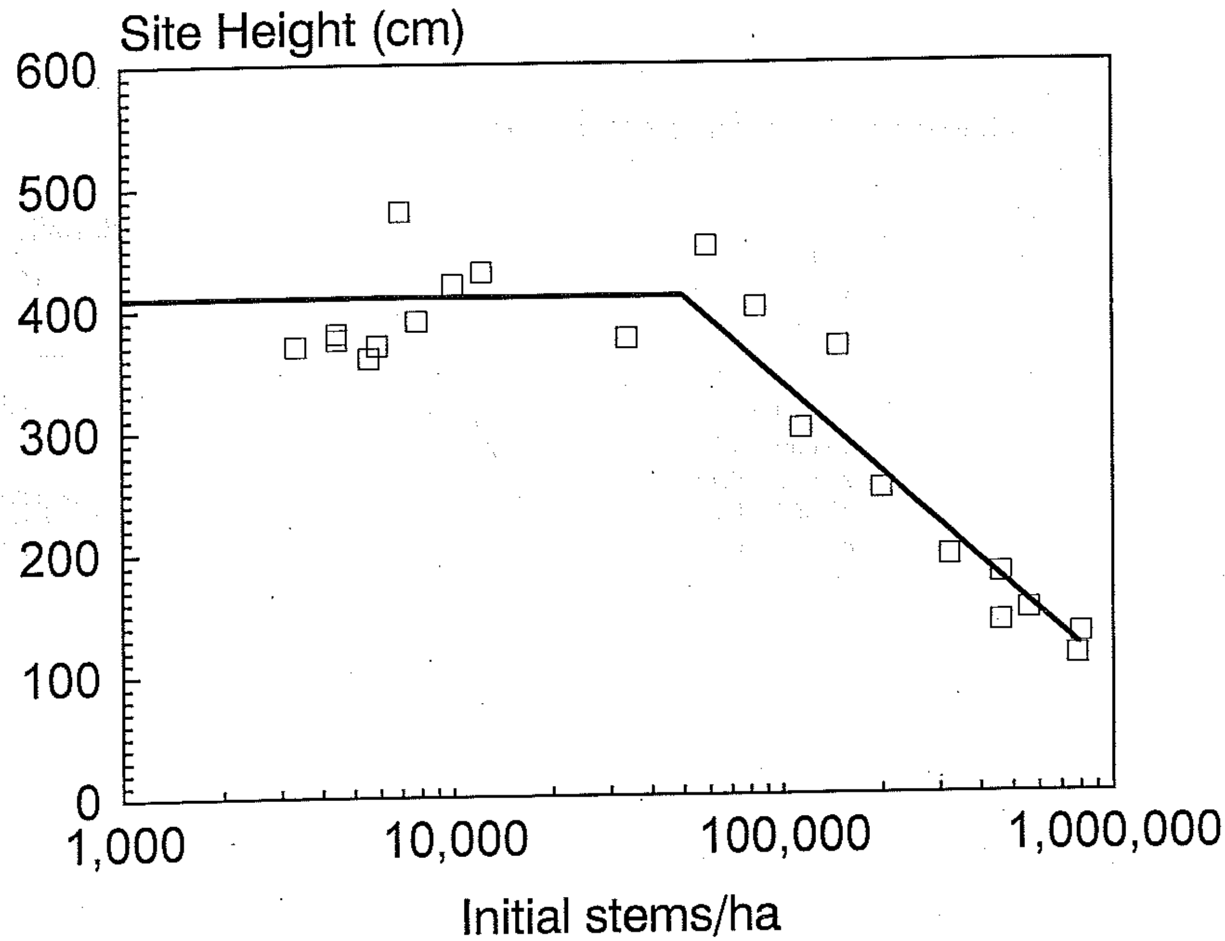

Figure 2. Repression in 18-year-old lodgepole pine near Williams Lake, B.C. (from Mitchell and Goudie,1980)

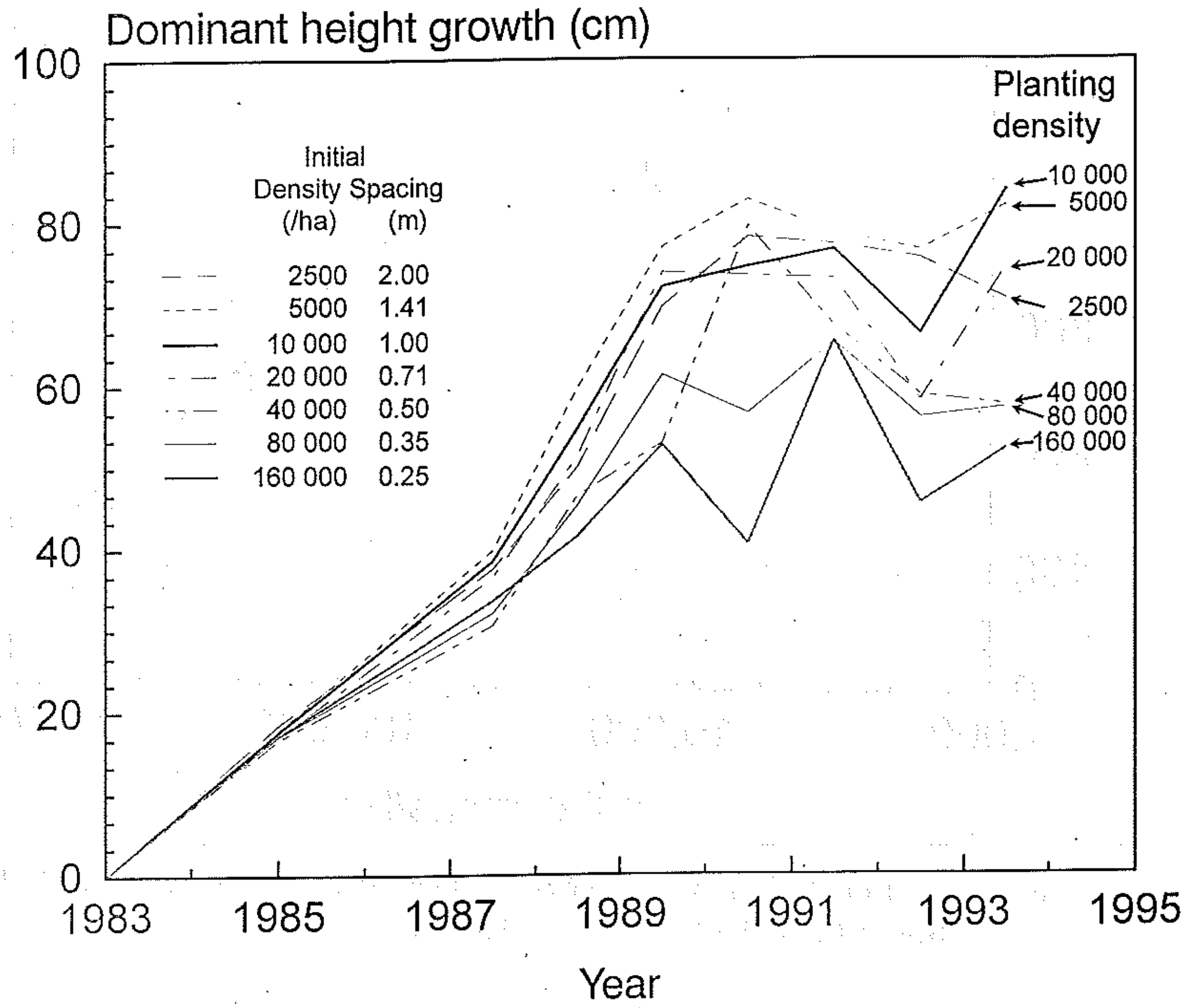

Figure 3. Average annual height growth of the tallest 5 trees/plot versus year for the Barnes Creek espacement trial

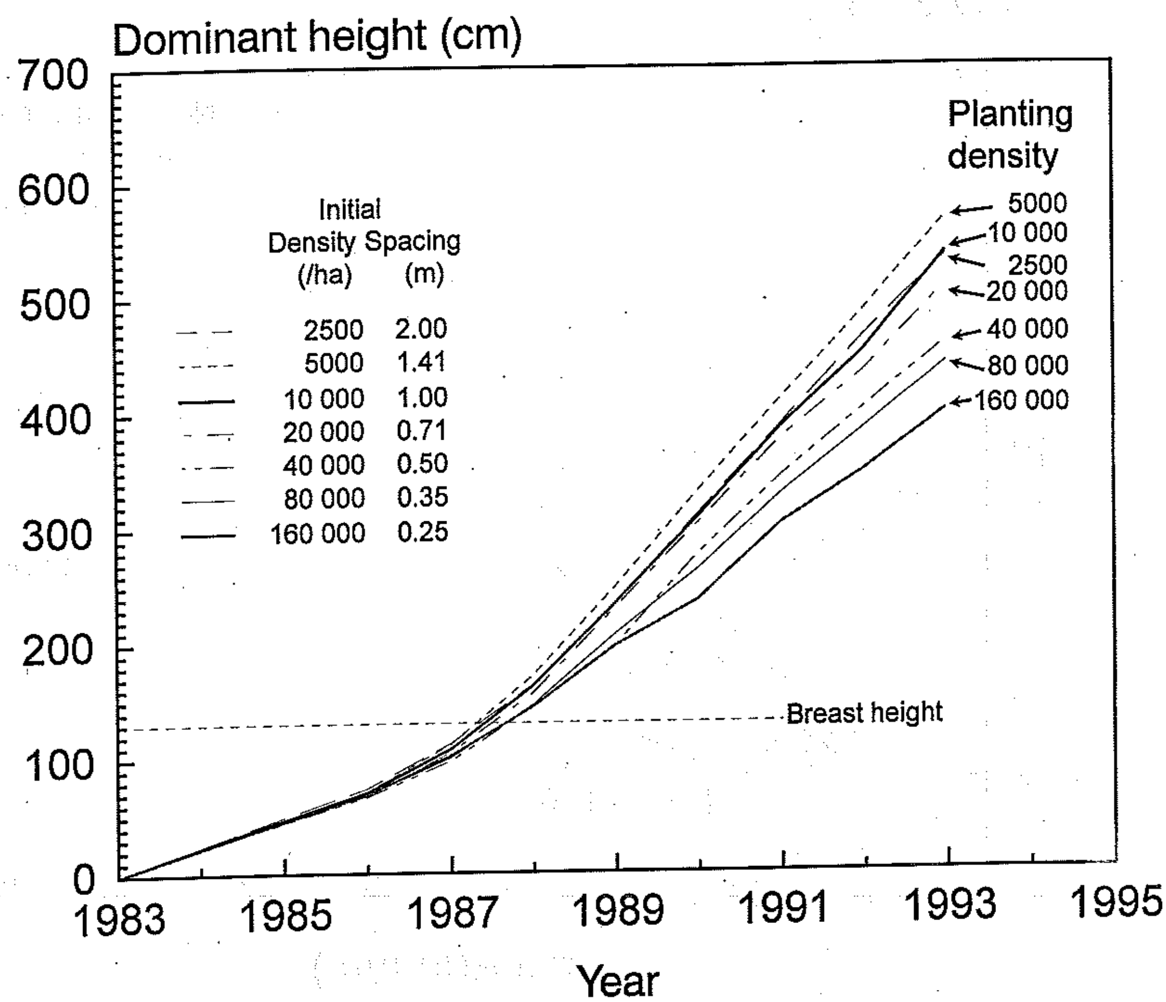

Figure 4. Average cumulative height of the tallest 5 trees/plot versus year for the Barnes Creek espacement trial

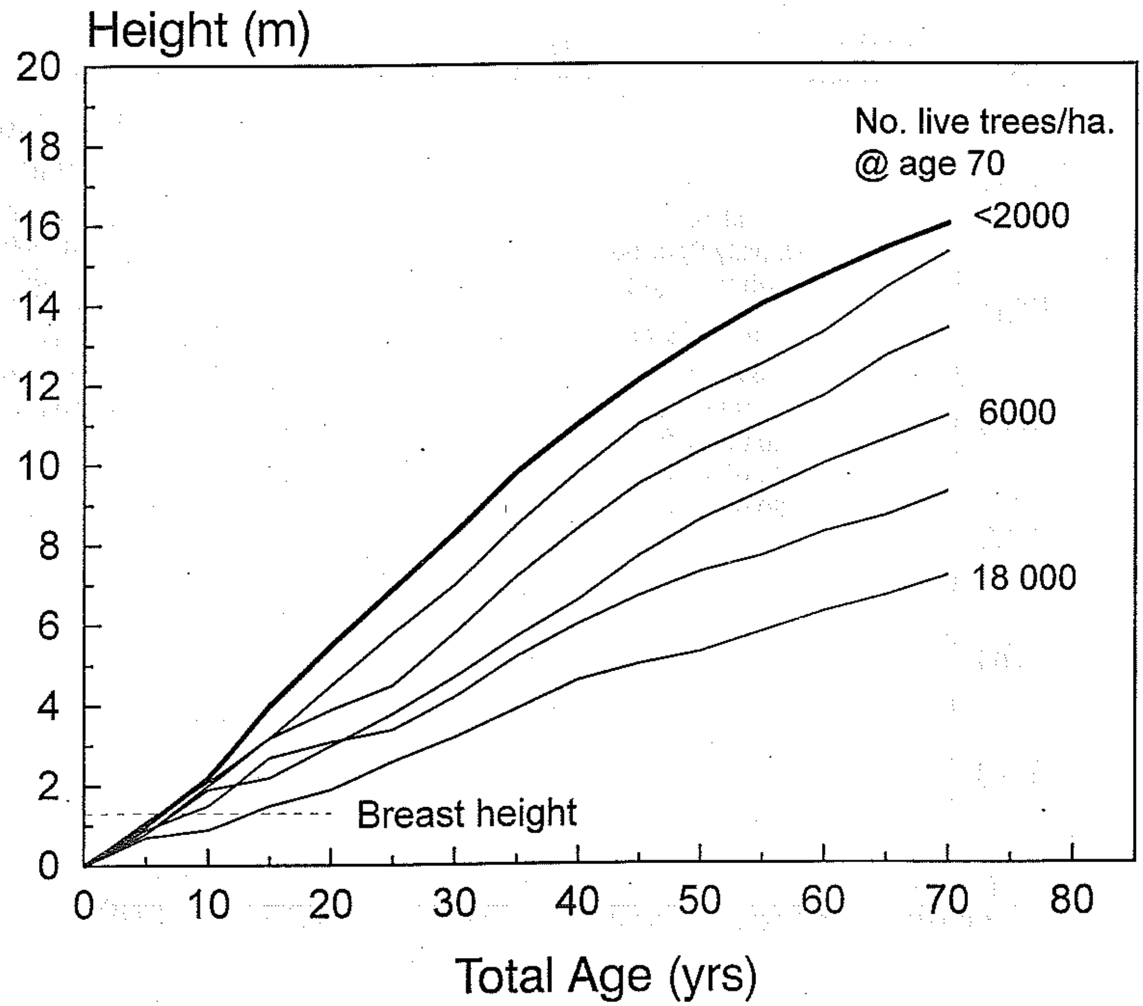

Figure 5. Height growth in relation to density in 70-year-old lodgepole pine near Williams Lake, B.C.

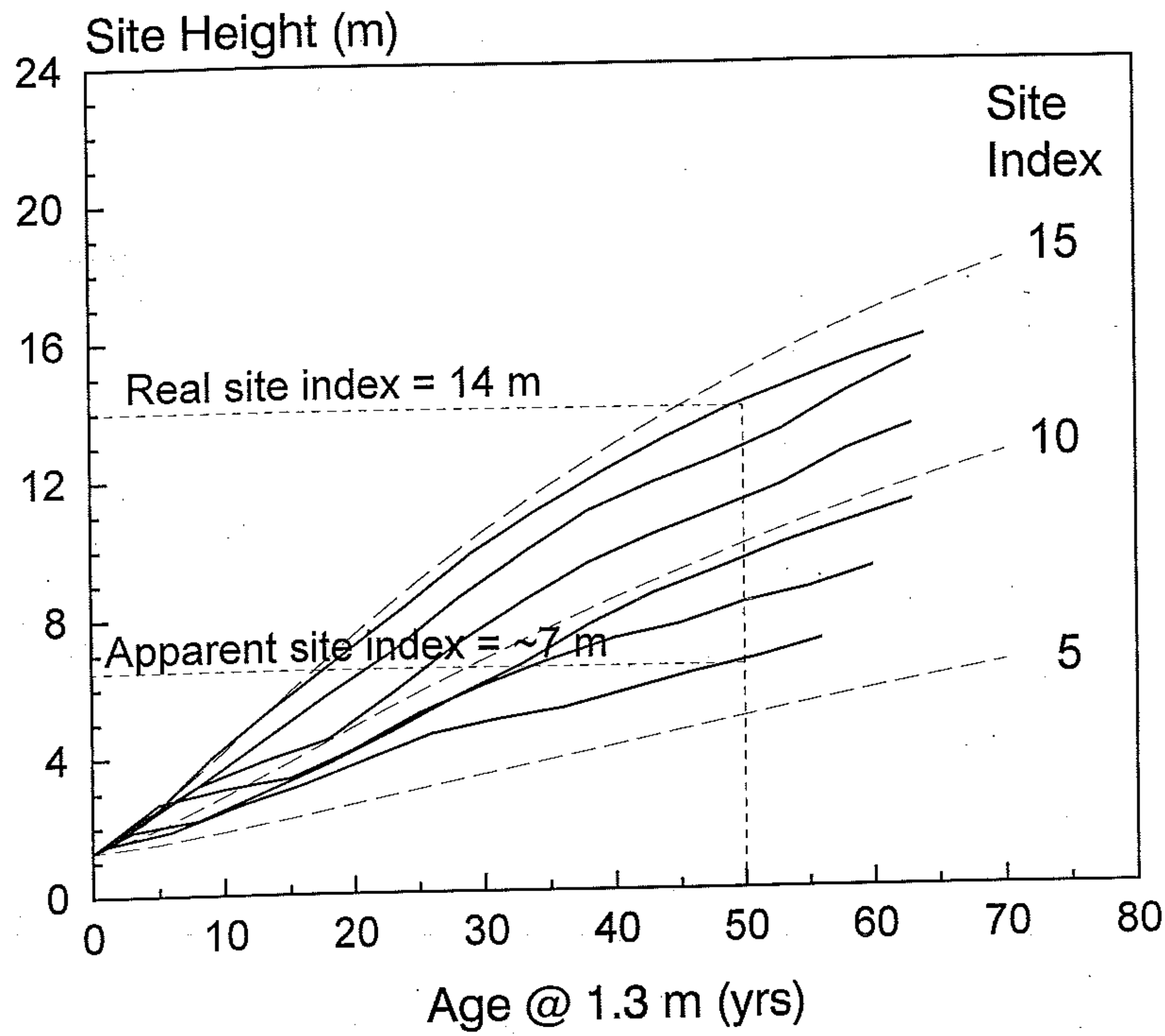

Figure 6. Height versus breast height age in 70-year-old lodgepole pine of varying densities near Williams Lake, B.C.

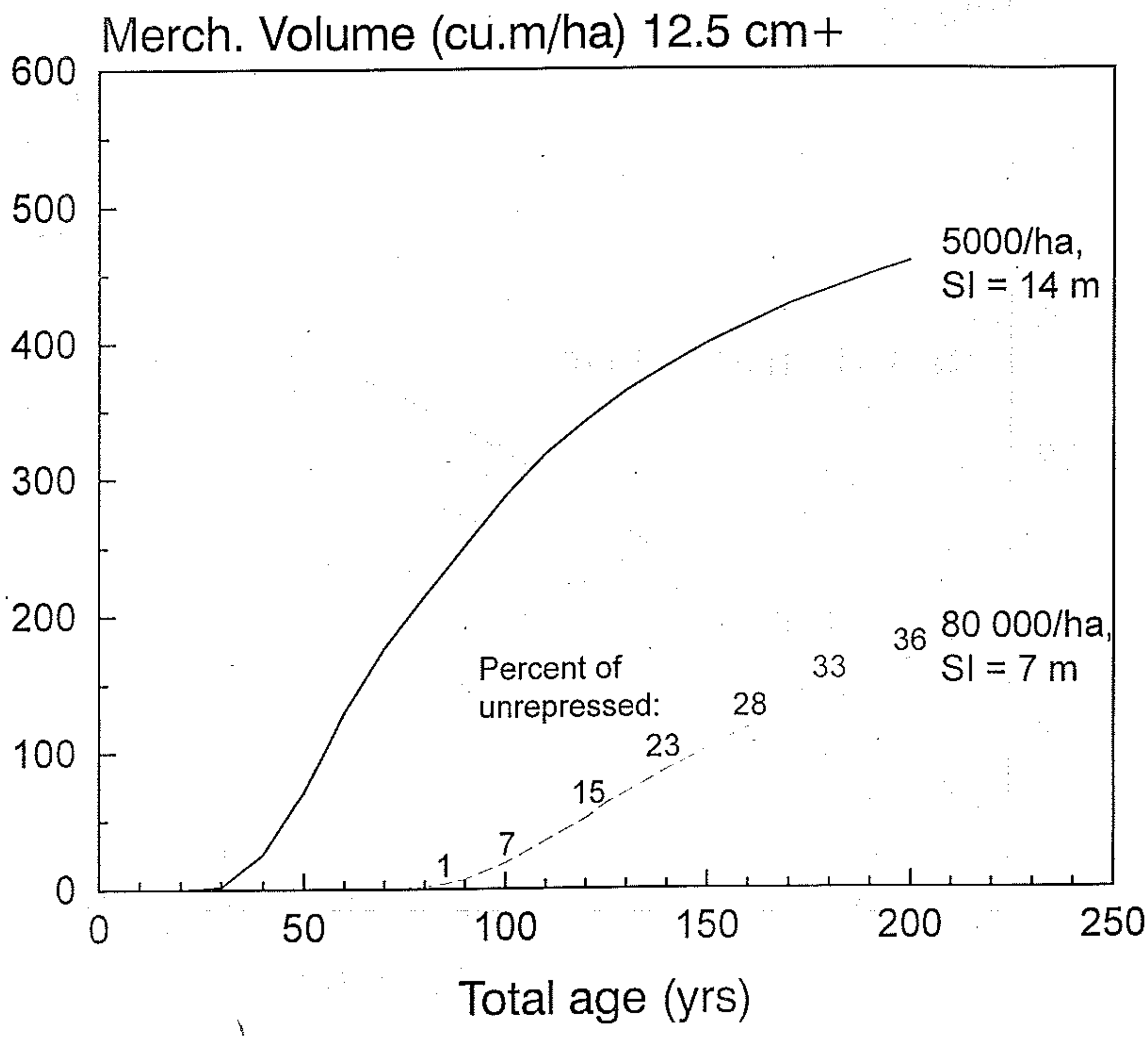

Figure 7 Effect of repression on merchantable volume of naturally regenerated lodgepole pine as simulated by TASS.

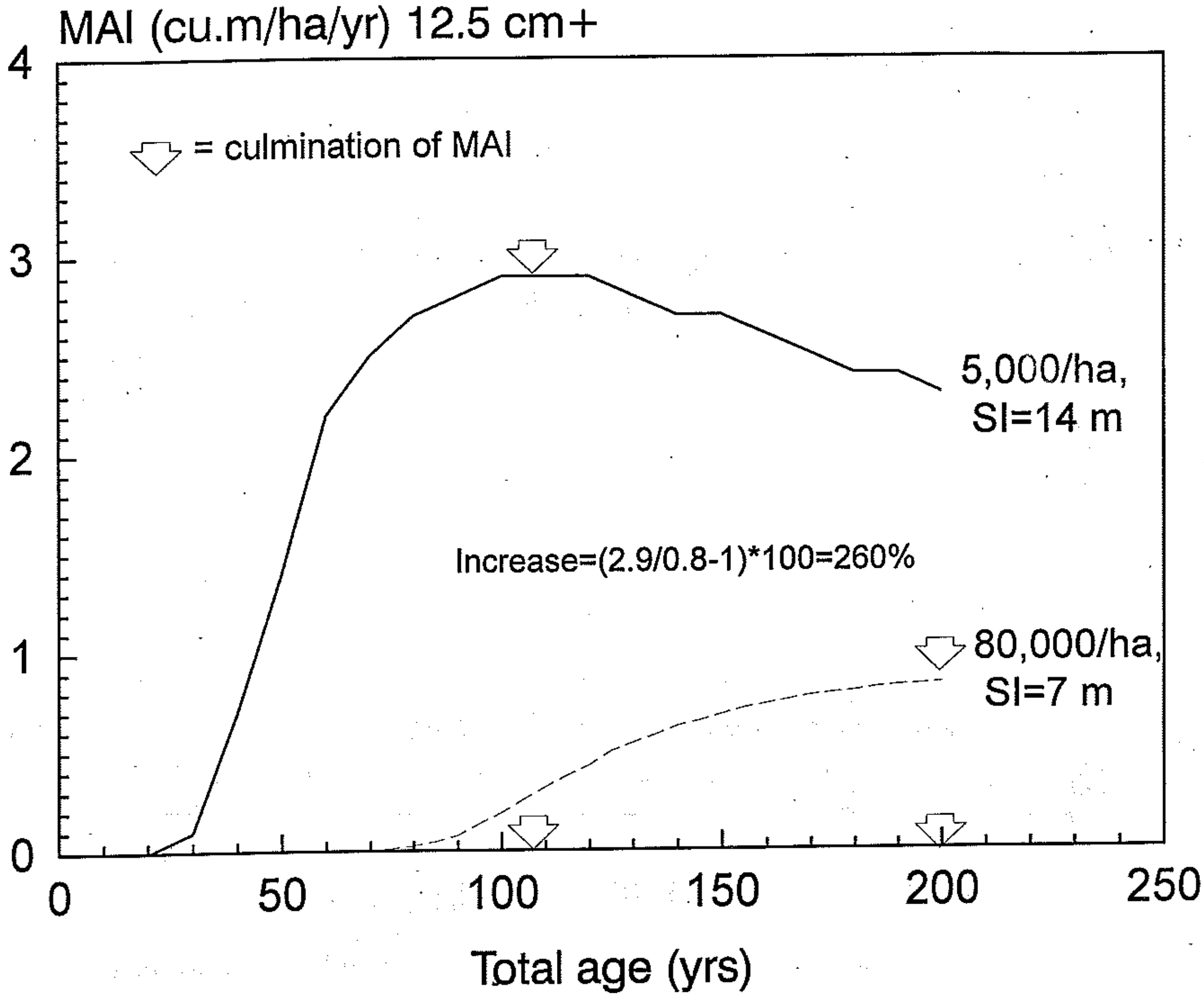

Figure 8. Simulated effects of repression on merchantable volume mean annual increment of naturally regenerated lodgepole pine

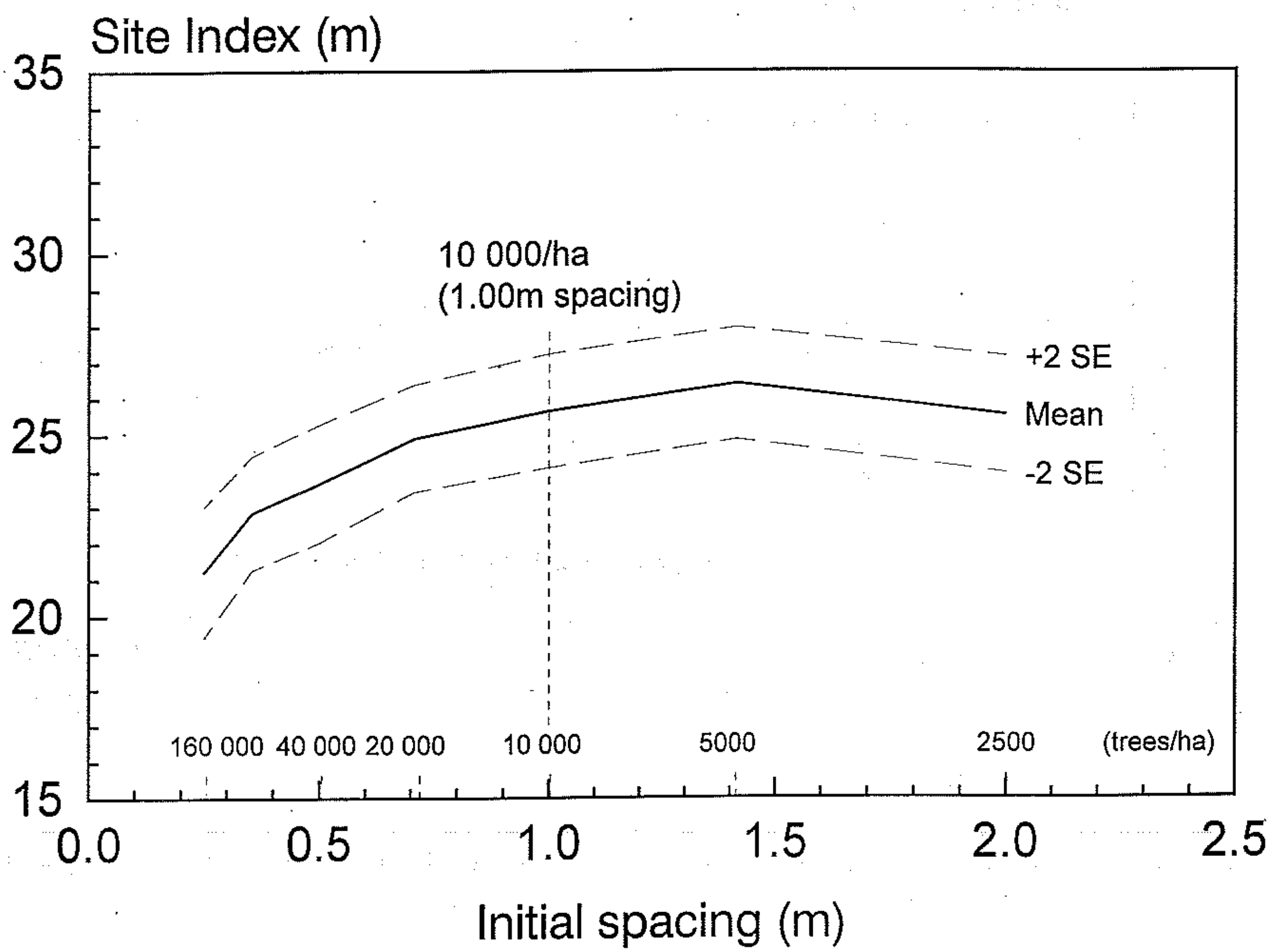

Figure 9. Mean site index (tallest 5 trees/plot) and 2 standard errors (SE) predicted by Nigh (1995) growth intercept equations across initial densities of the Barnes Creek espacement trials.

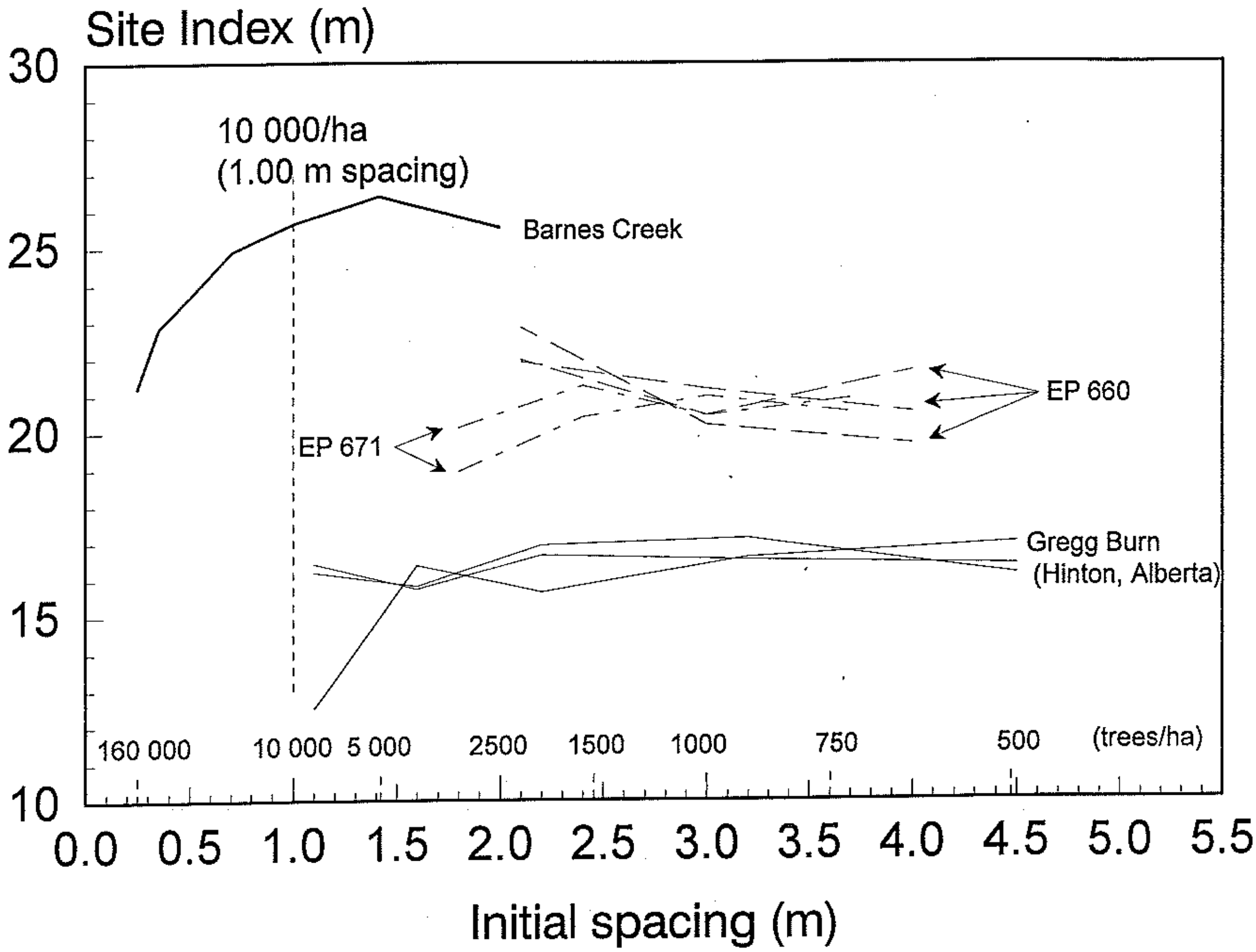

Figure 10. A comparison of predicted site index of the Barnes Creek trial with three other density trials in B.C. and Alberta.

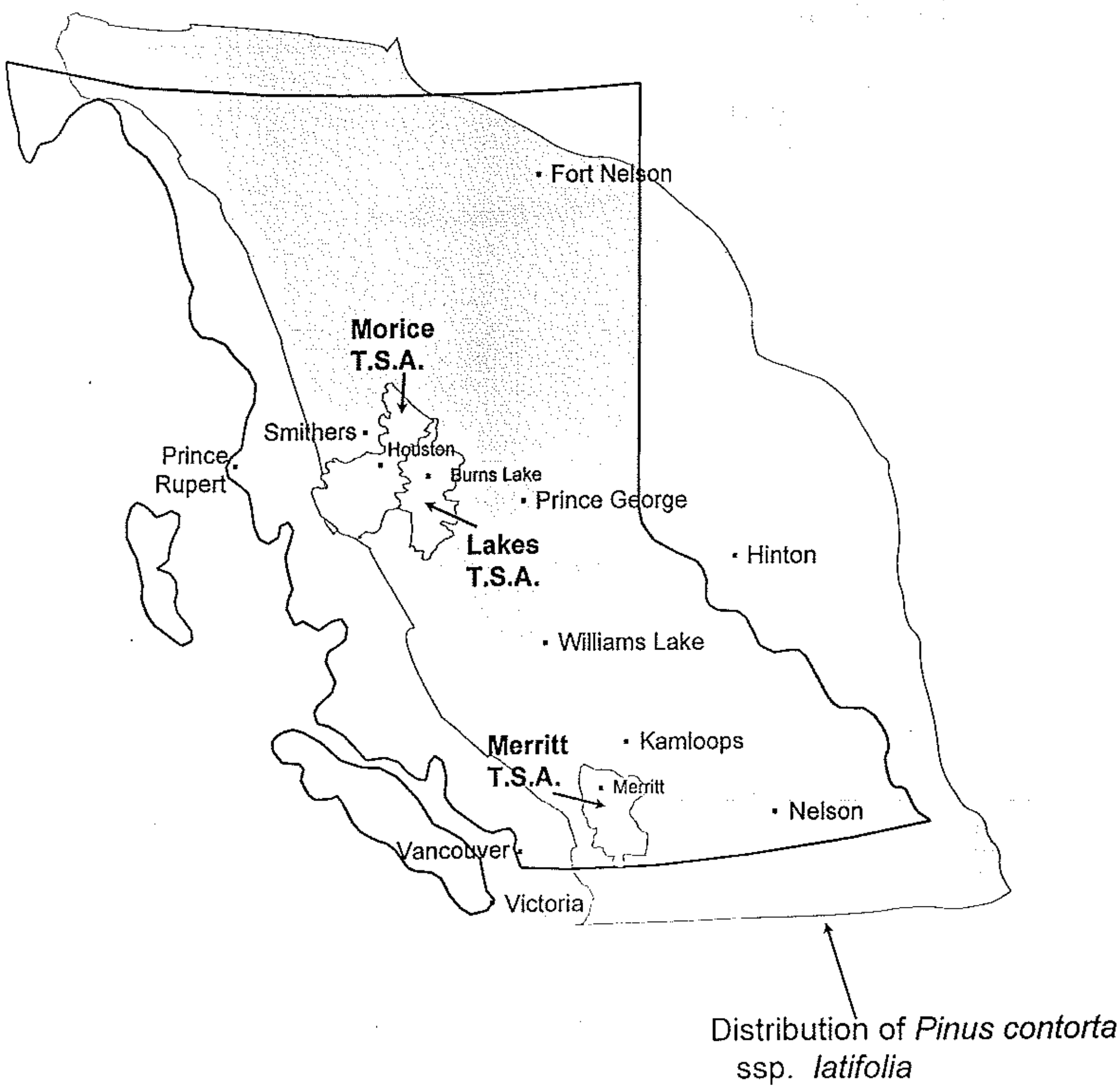

Figure 11. Location of the Morice, Lakes and Merritt TSAs in British Columbia and the potential geographic range of lodgepole pine.

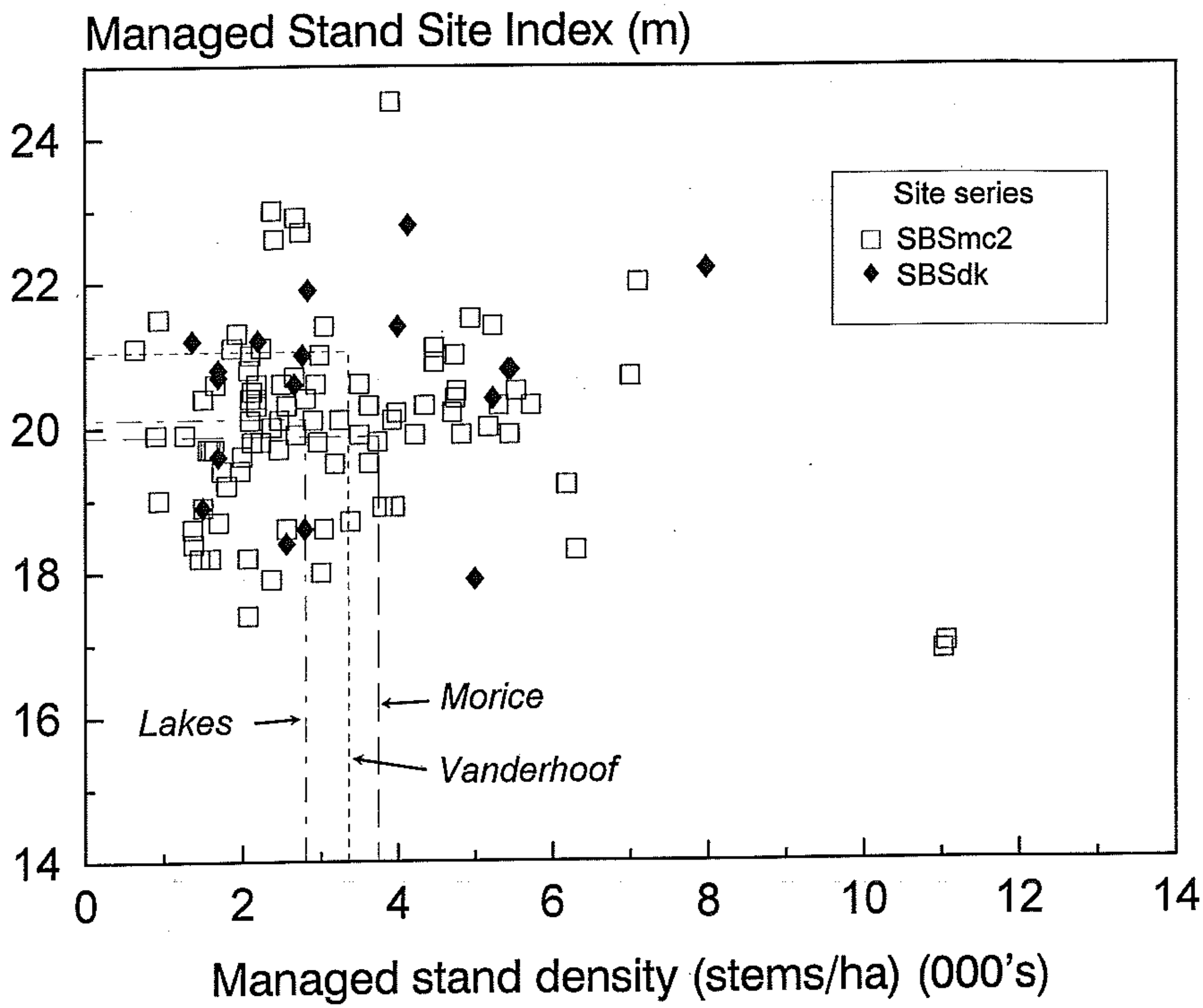

Figure 12. Relationship between managed stand site index and number of live stems per ha greater than 1.3 m tall.

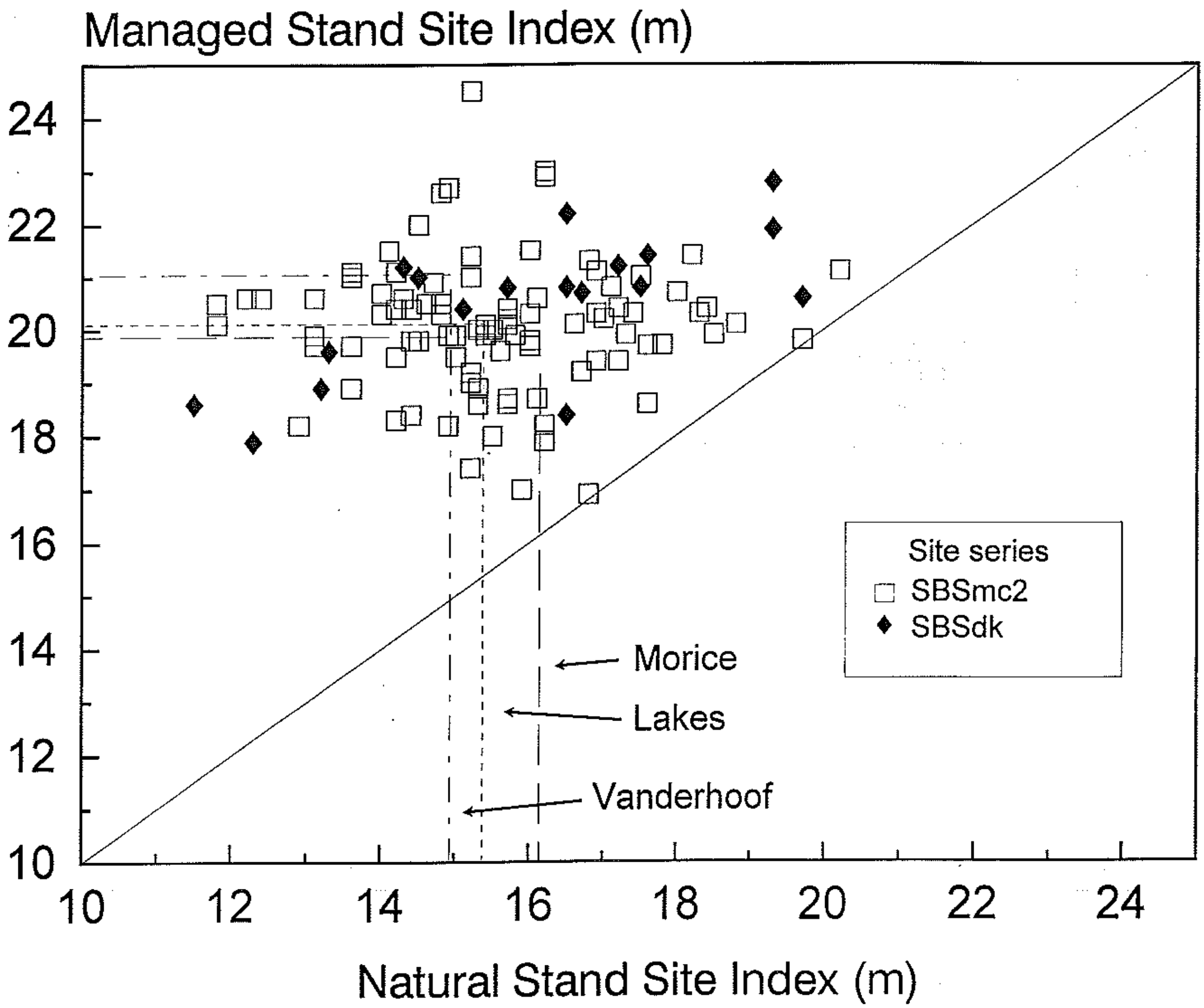

Figure 13. Relationship between managed stand site index estimated by growth intercept relationship and natural stand site index determined by conventional means.

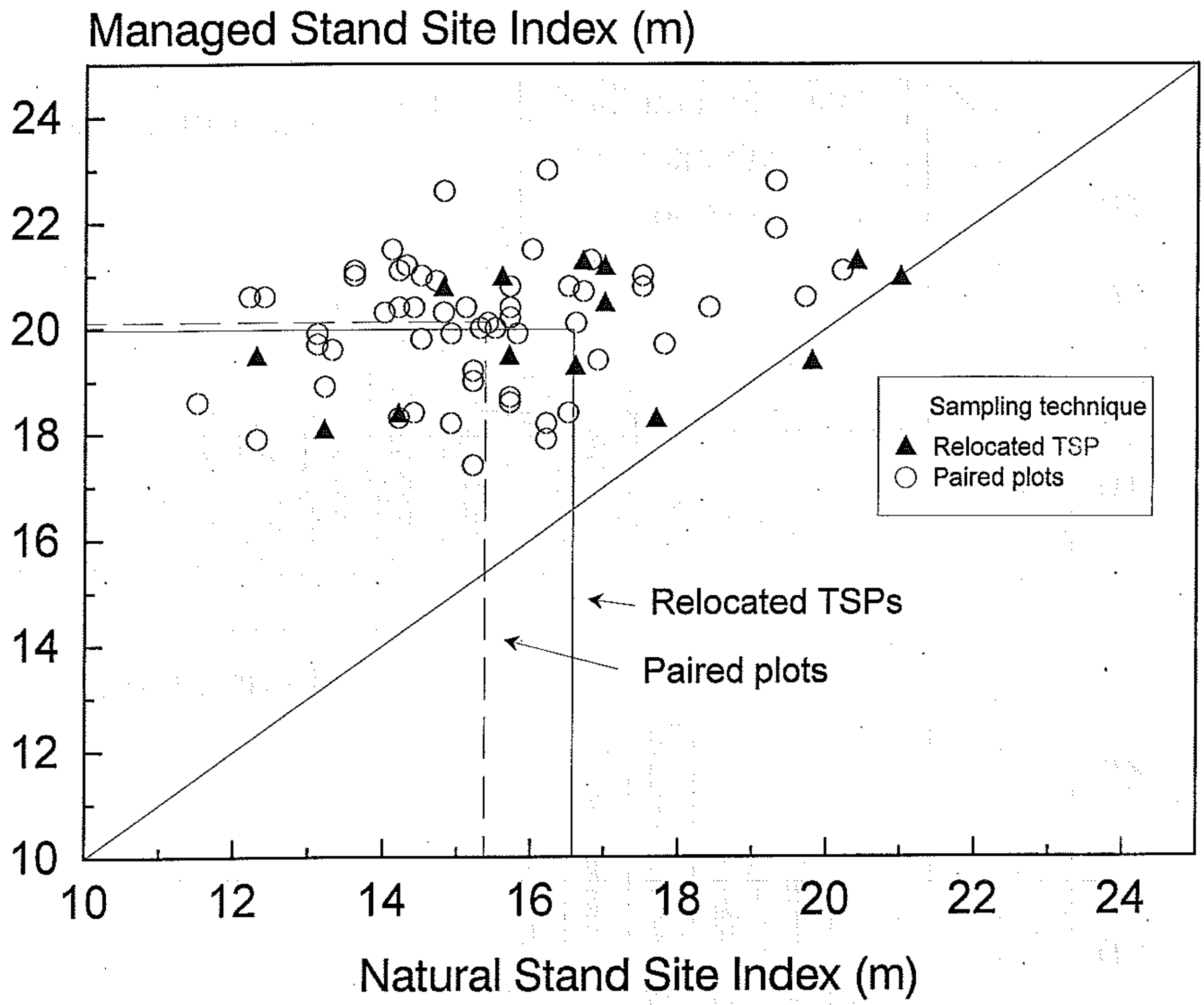

Figure 14. A comparison of sampling techniques (relocated temporary sample plots vs. paired plots) on the relationship between managed stand site index estimated by growth intercept relationship and natural stand site index determined by conventional means.

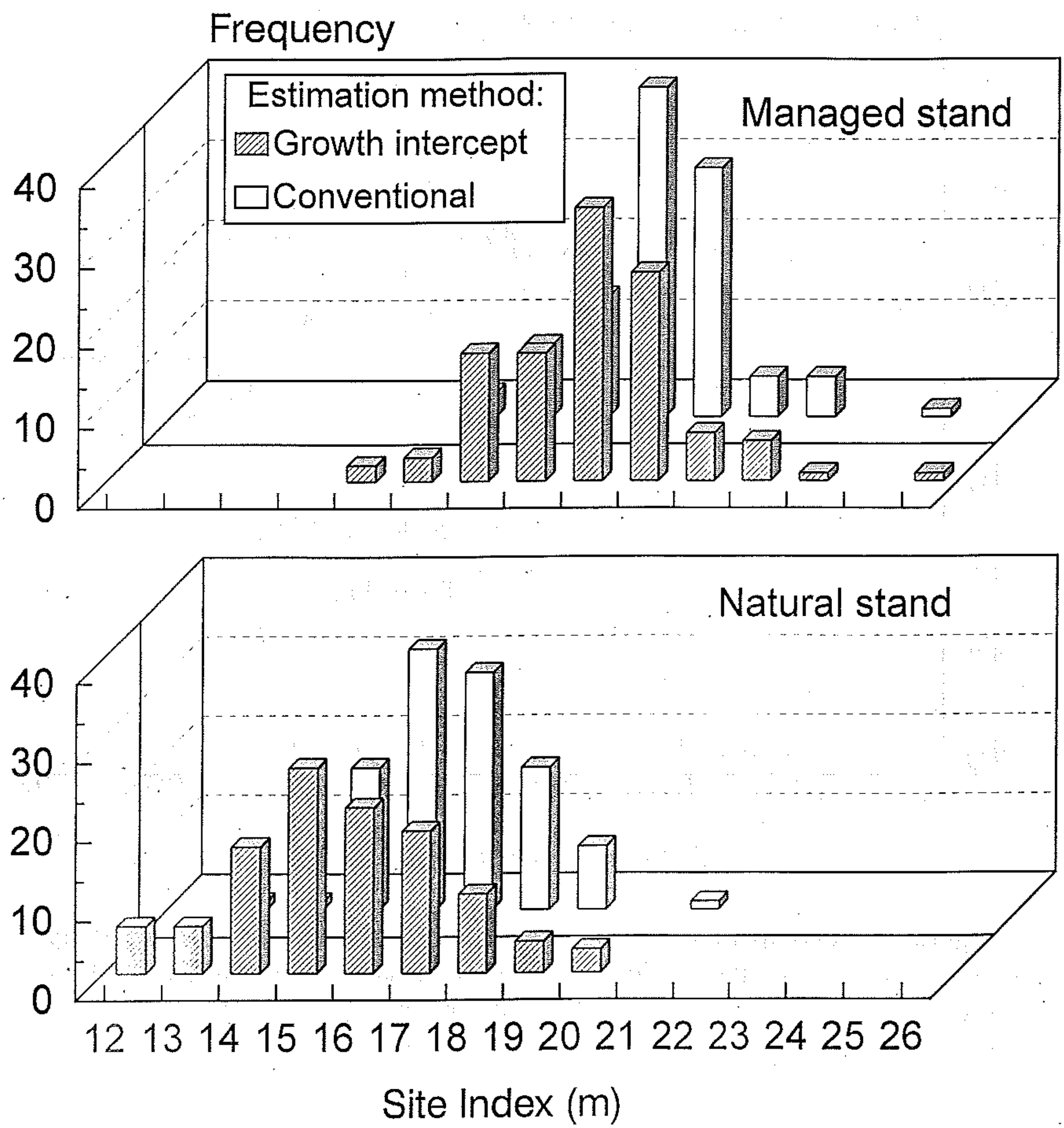

Figure 15. Distribution of site classes for two adjacent stand types and two methods of site index determination on 110 stand edges in the Morice, Lakes and Vanderhoof TSAs

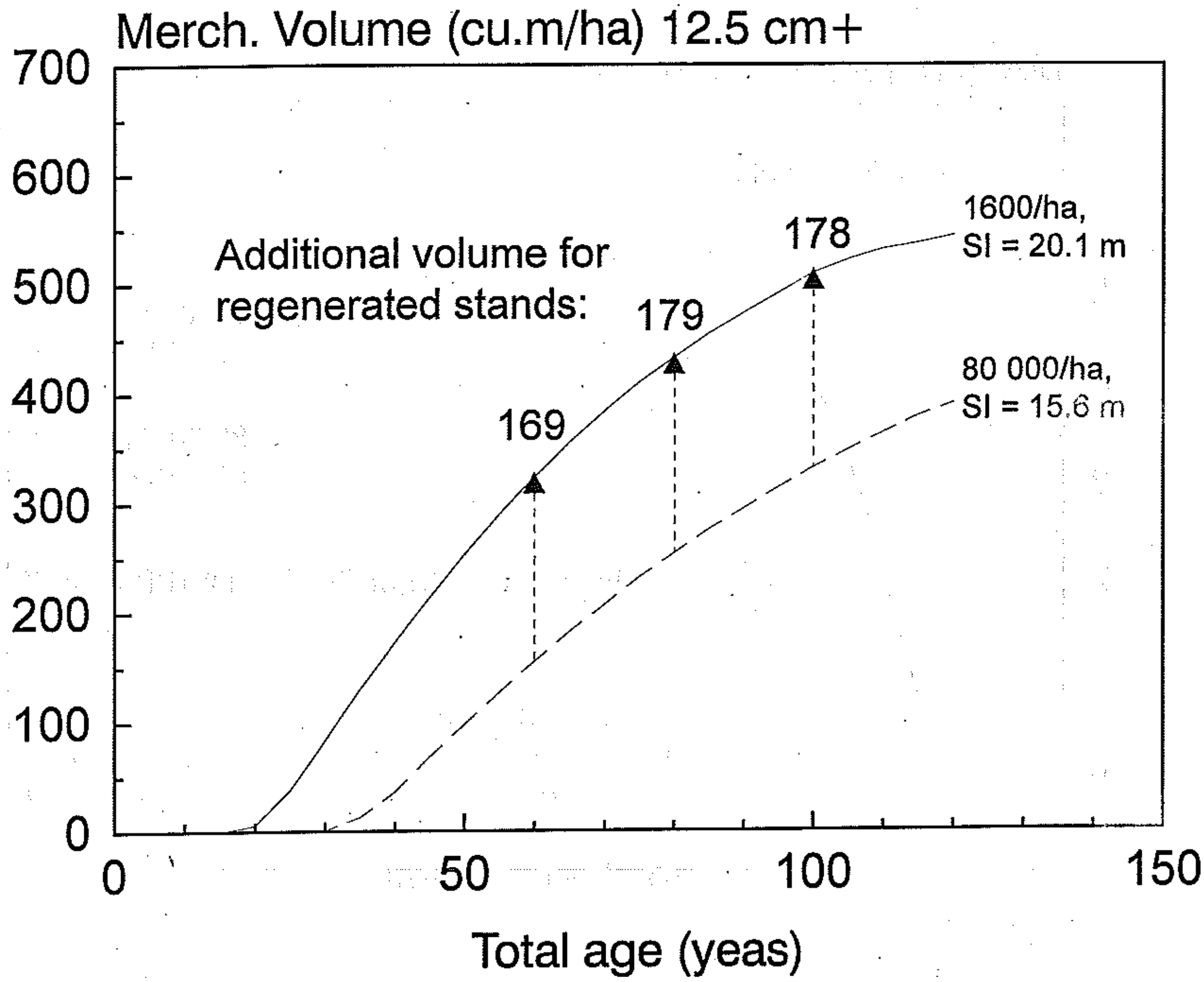

Figure 16. Simulated effects of repression on merchantable volume of lodgepole pine on average repressed and managed stand conditions in the Morice, Lakes and Vanderhoof TSAs.

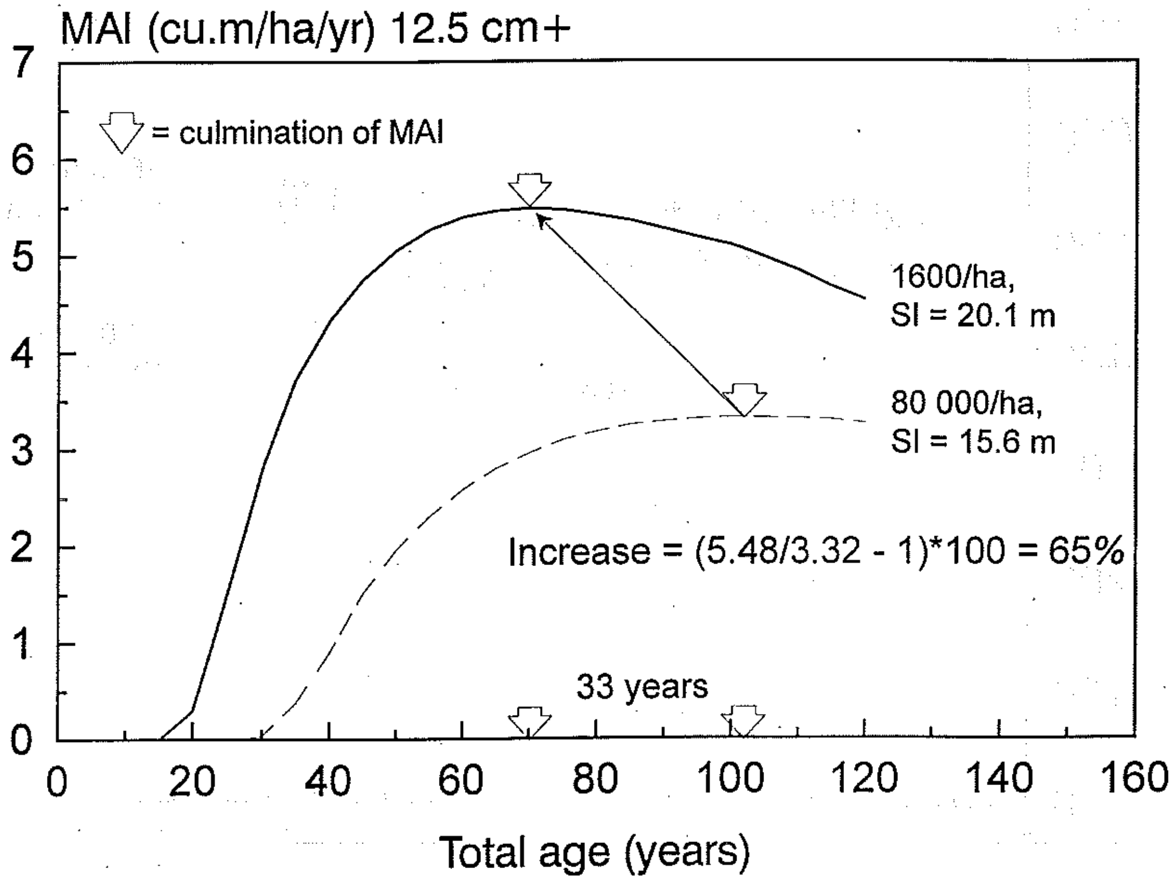

Figure 17. Simulated effects of repression on mean annual increment of lodgepole pine growing on average repressed and managed stand conditions in the Morice, Lakes and Vanderhoof TSAs.

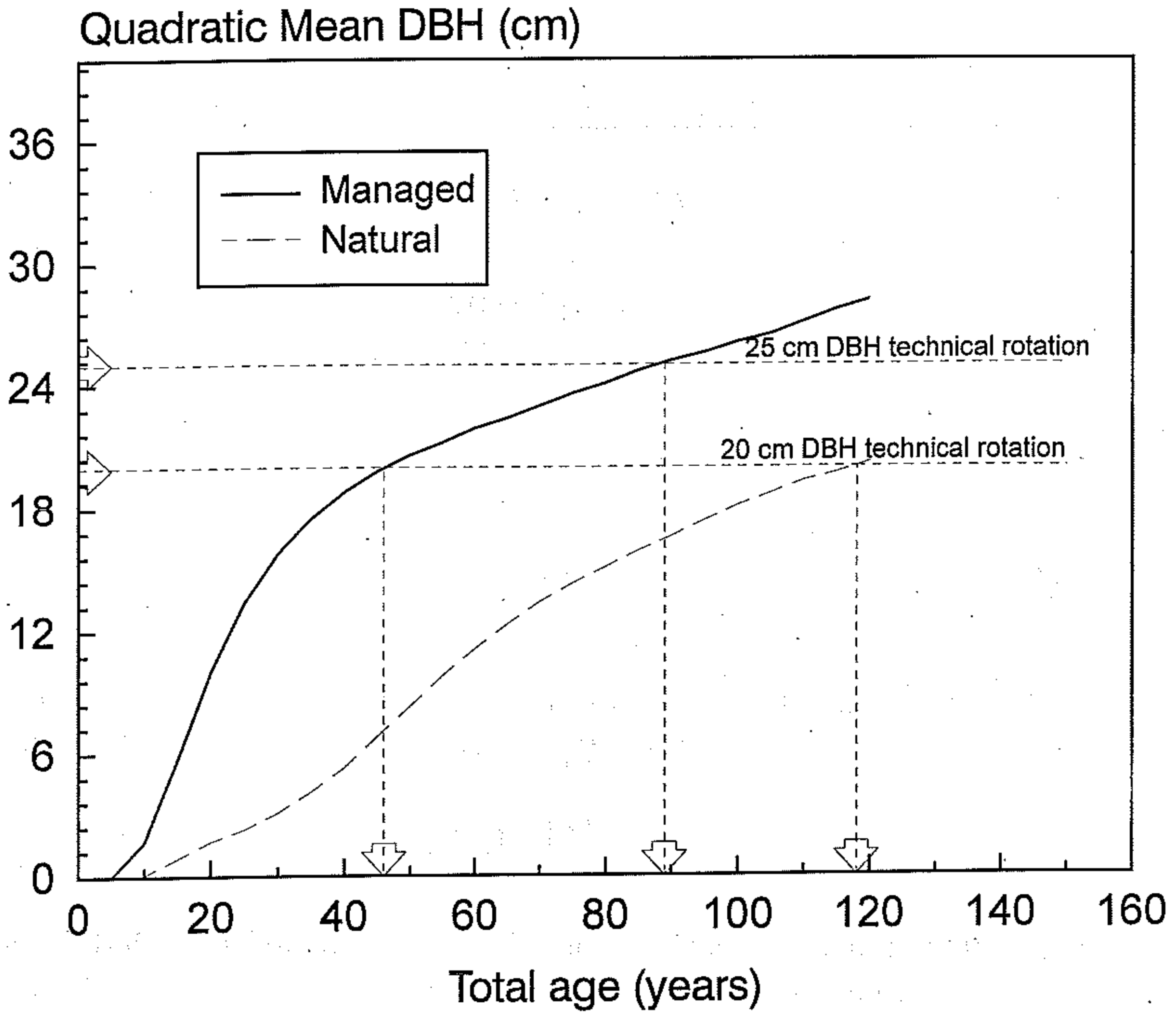

Figure 18. Simulated effects of repression on diameter growth and technical rotation of lodgepole pine growing on average repressed and managed stand conditions in the Morice, Lakes and Vanderhoof TSAs.

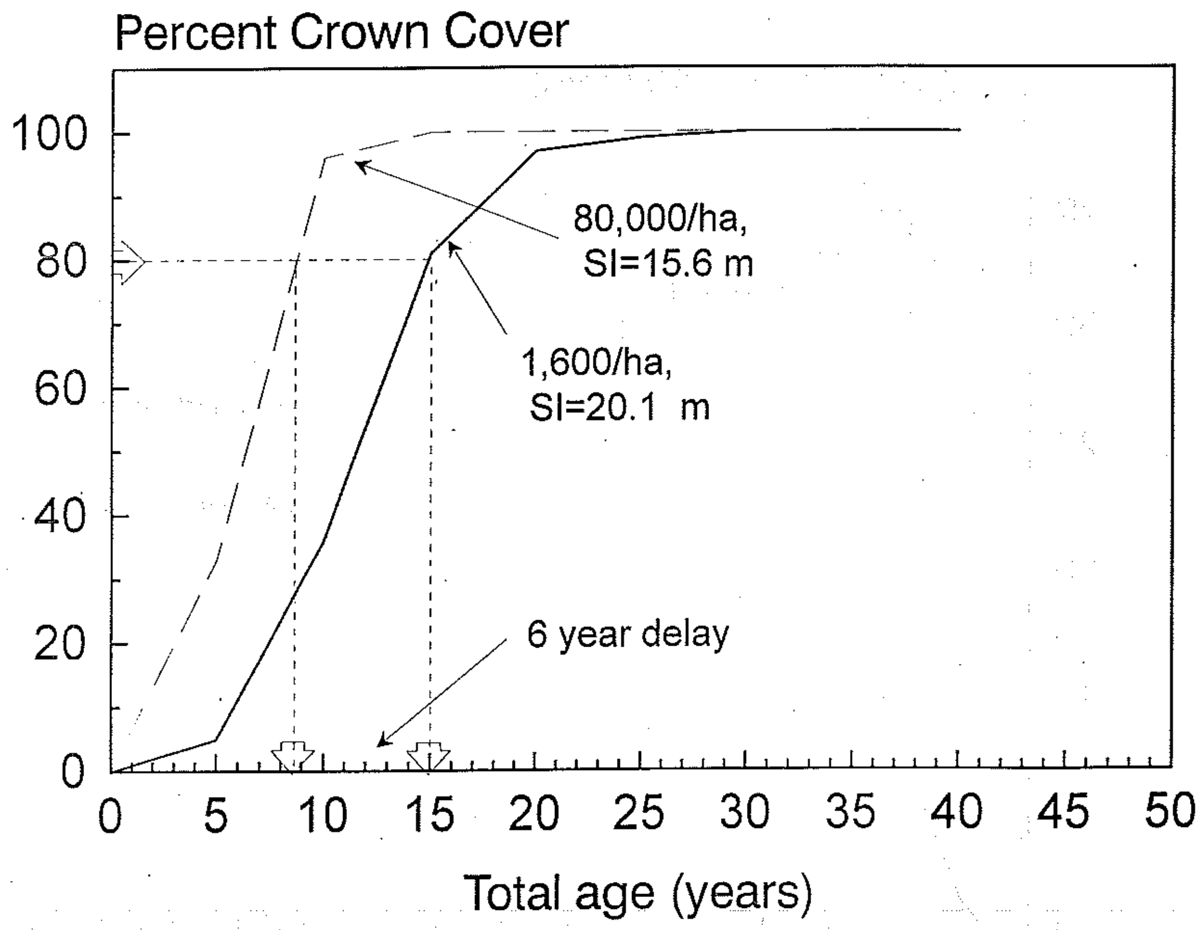

Figure 19. Simulated effects of repression on crown closure of lodgepole pine growing on average repressed and managed stand conditions in the Morice, Lakes and Vanderhoof TSAs.

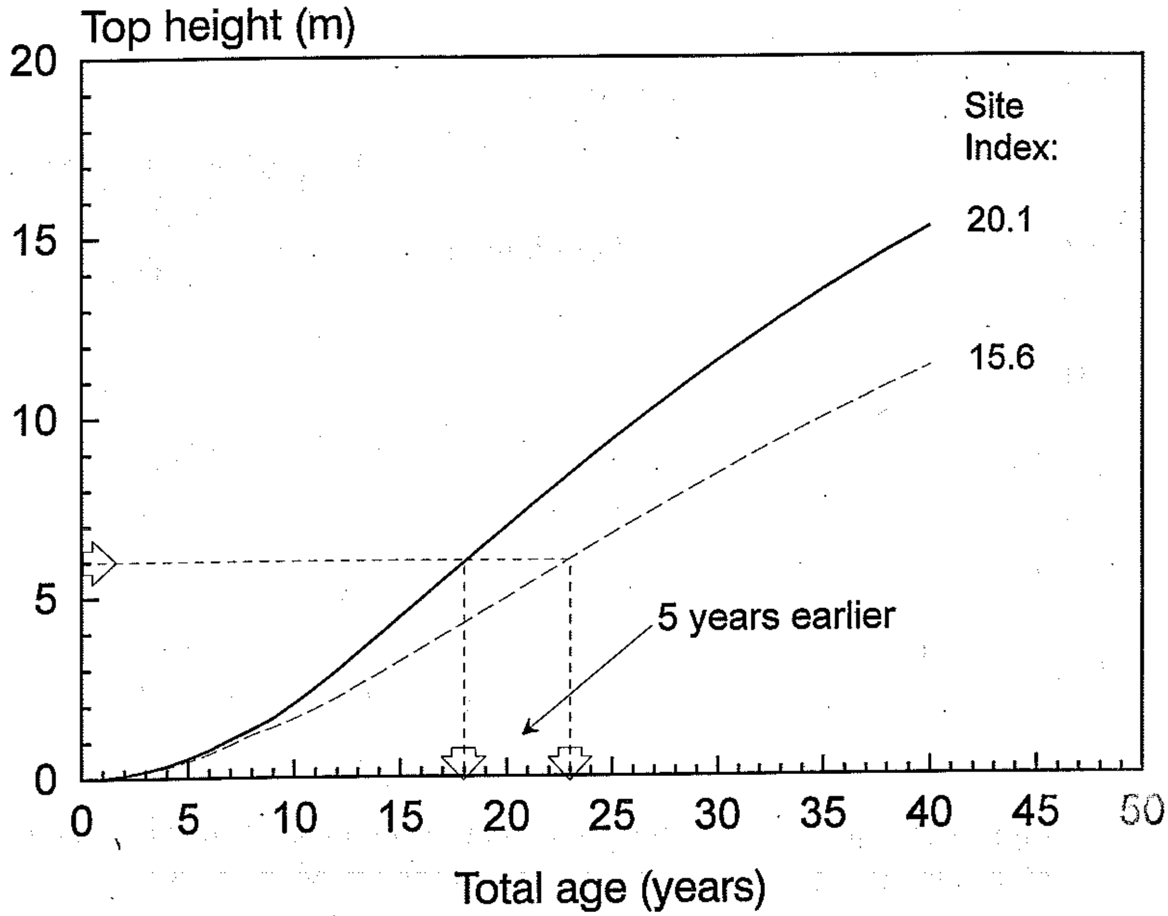

Figure 20. Simulated effects of repression on early top height growth and green-up of lodgepole pine growing on average repressed and managed stand conditions in the Morice, Lakes and Vanderhoof TSAs.

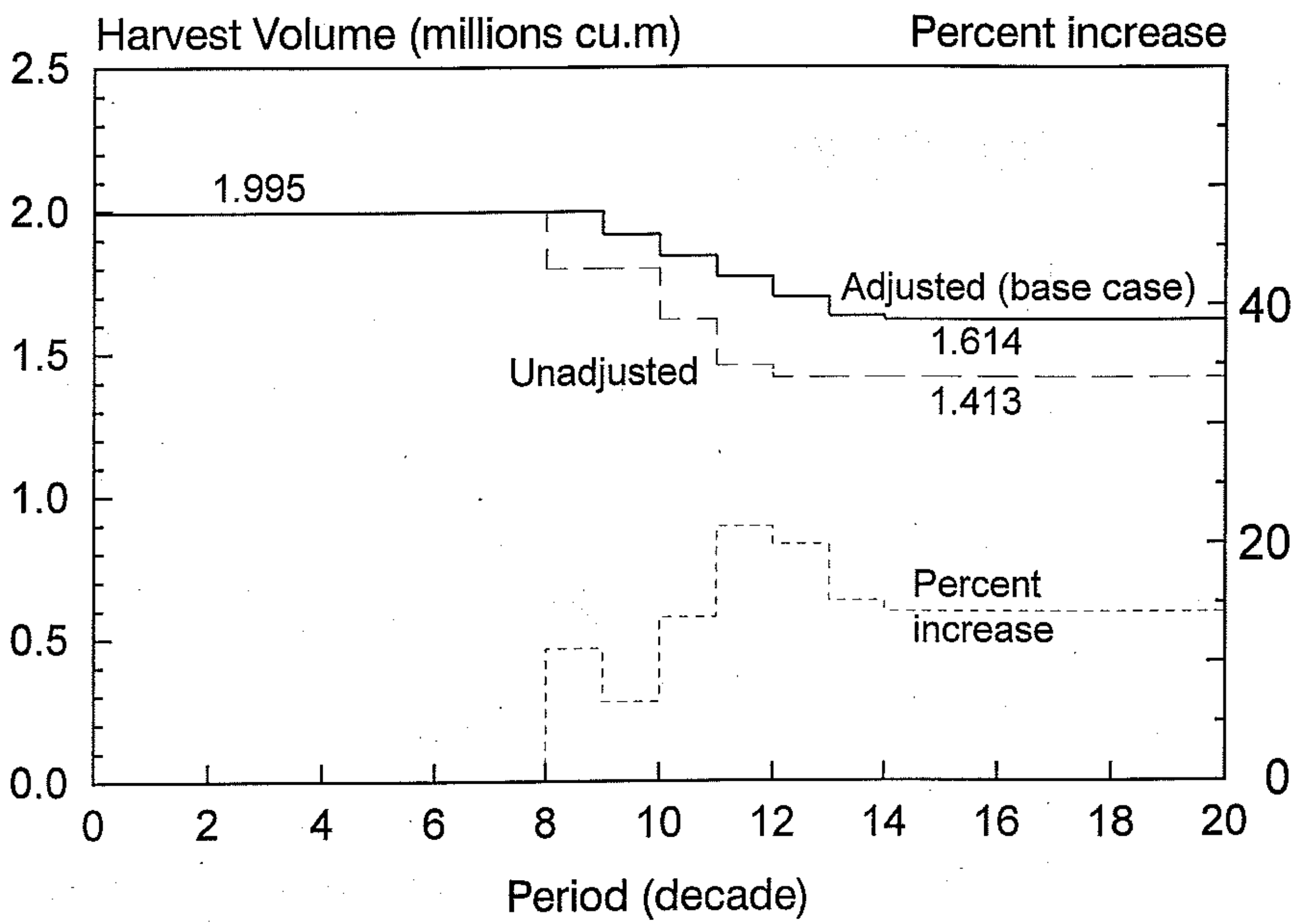

Figure 21. Simulated effects of increased site index of managed lodgepole pine stands on long range sustained yield in the Morice TSA.

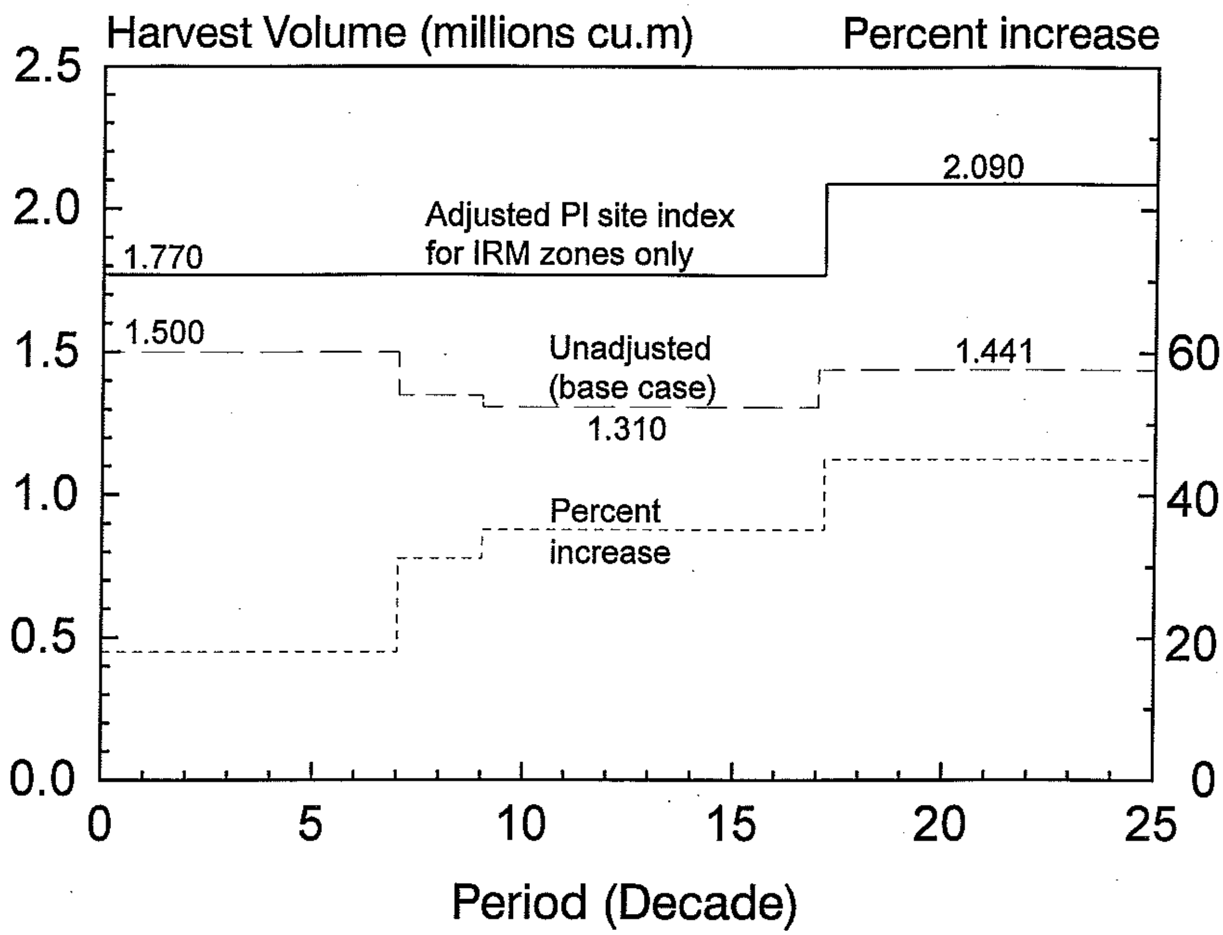

Figure 22. Simulated effects of increased site index of managed lodgepole pine stands on long range sustained yield in the Lakes TSA.