Growth & Yield Attributes of Three Lodgepole Pine Provenances in the BC Tree Improvement Program

Prepared for

Ed Collen, RPF
Weyerhaeuser Company Ltd.
Okanagan Falls Division

Project: WCF-032

March 31, 2003

J.S. Thrower & Associates Ltd. *Consulting Foresters*
Vancouver – Kamloops, BC

Executive Summary

Tree and branch attributes were measured in four lodgepole pine (Pl) progeny test sites planted with 30 families (10 from each of three provenances) selected for the BC Ministry of Forests Pl breeding program. The 1,697 measured trees were planted in 1986 at 4,444/ha and thinned to 2,222/ha at age 10-11 years. The analysis compared attributes among test sites, provenances, and families after 17 years of growth. The goal was to detect differences in key growth and yield attributes and model the potential impact on lumber grade recovery and value at rotation.

The growth and yield of Pl planted at 1200, 1600, and 2000/ha at site indices of 16, 19, and 22 m was modeled using TASS[1]. Branch size, log grade, lumber grade, and value were predicted using methods we developed for Weyerhaeuser in other projects. The results were compared using financial analysis to evaluate the differences in branch size and growth rate. The major results from these measurements and simulations are:

1. Site index differs up to 2-3 m among Pl provenances and families.
2. Tree diameter (standardized by tree height) is larger for some families and on lower sites.
3. High-grade lumber recovery and product value increase as establishment density increases and as branch size decreases.
4. Positive financial Site Value was shown only on the highest site with a 4% discount rate where trees had small branches (thus higher product value) and low planting costs.
5. Financial Site Value decreased with increasing branch size but losses could be offset by the increased yield achieved at higher site indices.

These results suggest there are potentially meaningful differences in tree and branch characteristics that should be included in Pl growth and yield models. The site index differences should be maintained to rotation; however, differences in other attributes such as tree form (taper), crown width, and rate of crown lift may not persist. Therefore, these trials should be periodically remeasured to compare differences and detect changes in these trends.

These results show the trade-off between volume and value gains as many Pl families with higher growth rates also have larger branches. For example, an increase of 1.0 m in site index can be accompanied by an increase of about 0.3 – 0.4 cm in average branch diameter without reducing financial Site Value (assuming average costs and 6% discount rate). Conversely, slower growing stands with smaller knots and higher lumber values can give higher financial Site Values than faster growing stands with larger knots.

[1] TASS (**T**ree **A**nd **S**tand **S**imulator) is an individual tree-based, spatially explicit computer simulation model developed by Ken Mitchell to model the growth of individual trees in three dimensions. TASS is the MOF standard to model the growth and yield of regenerated Pl and other tree species in BC.

This page is intentionally left blank.

Table of Contents

List of Tables

List of Figures

1. INTRODUCTION

1.1 TERMS OF REFERENCE

This project was completed by J.S. Thrower & Associates Ltd. (JST) under contract to Weyerhaeuser Company Ltd. (Weyco) (Ed Collen, RPF, Okanagan Falls Division) and was funded through the BC Government Forest Innovation Investment Program. The JST team included Jim Thrower, PhD, RPF (project manager), Gyula Gulyas, MScF (growth modeling and analysis), Guillaume Therien, PhD (statistical analysis), Eleanor McWilliams, MSc, RPF (financial analysis), and Dan Turner, RPF (assistant project manager).

This project was completed jointly with the BC Ministry of Forests (MOF), Research Branch. The MOF team was Mike Carlson, PhD, RPF (coordination and technical advice), John Murphy (field sampling coordination), and Greg O'Neill, PhD, RPF (analysis of genetic effects). The TASS simulations were completed by Ken Mitchell, PhD, RPF and Ken Polsson of the MOF Research Branch in Victoria.

1.2 BACKGROUND

Forest managers in British Columbia (BC) are becoming increasingly concerned that the quality of wood grown in regenerated lodgepole pine (Pl) stands may be lower than the current mill diet. Most mills rely on a steady diet of Pl trees from stands that have naturally regenerated after wildfire, often to stand densities of 100,000/ha and up to 1,000,000 trees/ha. These very high establishment densities result in height-growth repression, which is characterized by reduced height, diameter, and volume growth. However, these trees grown in very high-density stands have desirable wood quality characteristics such as small knots, low taper, narrow rings, and high mature wood content. Products from these trees are of high strength and visual appearance for valued dimension lumber and engineered wood products.

Recent studies in the BC interior suggest that knot size and tree taper in post-harvest regenerated (PHR) Pl stands may be substantially higher than the current mill diet of high quality trees. A preliminary study of Pl trees in PHR stands found that over 75% of trees had branches in the lower bole that were larger than the critical knot diameter of 2.5 cm (J.S. Thrower & Assoc., 1999). Subsequent studies in BC and Alberta (J.S. Thrower & Assoc., 2001a, 2001b) found that the average and largest branch diameter in the first 5-m log was about 2.3 cm and 3.1 cm, respectively for trees planted at 1,600 stems/ha. A study on stem taper in regenerated Pl stands found that the average taper of the first 5-m log was almost twice (1.95 cm/m) the taper of logs currently processed in interior mills (J.S. Thrower & Assoc., 2000).

The primary reason for this apparent decrease in log and wood quality is that trees in regenerated stands grow in much lower stand density conditions than those naturally regenerating after wildfire. However, there is also a genetic component to this issue. Anecdotal observation by researchers and practitioners in BC suggests that branching patterns of planted Pl trees in PHR stands, progeny trials, and provenance trials show differences in branching characteristics among provenances at the same age and stand density. Furthermore, there may also be differences in geographic and site effects on branching patterns for the same Pl genotypes. Current practice in BC is to plant genetically improved stock where seed is available, thus there is the additional concern that the potential wood quality problems associated with growing Pl in relatively low density stands may be exacerbated by using families that have large branches.

1.3 Goals & Objectives

The goal of this project was to provide new information to forest managers on the branching patterns of some Pl families in BC tree improvement program. The intent is that this information will help growth and yield researchers, tree breeders, and practitioners develop better silviculture regimes and identify areas were more work is needed to improve Pl management in BC.

The specific objectives to achieve this goal were to:

1. Measure trees of known provenance and family that contribute to seed orchard seedlots at four Pl progeny test sites in BC.
2. Compare key tree growth and yield attributes among test sites, provenances, and families.
3. Model observed differences to predict the growth and yield impacts over time.
4. Make recommendations for future Pl stand management in BC.

This project is reported in two papers presenting the results of: 1) analysis of progeny trial test site measurements for growth and yield attributes (this report); and 2) analysis of the progeny trial test site measurements for genetic effects (O'Neill et al., 2003).

1.4 Document Overview

The main sections in this document are:

1. **Introduction** – terms of reference, background, goals, and objectives (this section).
2. **Comparison of Attributes** – describes the Pl progeny test sites and the measurements of tree and branch attributes.
3. **Growth & Yield Modeling** – describes how the differences identified in the comparison of attributes were modeled to estimate the impacts at rotation.
4. **Financial Analysis** – describes the methods and results of comparing the growth and yield results using discounted costs and revenues under different assumptions.
5. **Conclusions** – gives a brief summary of the major results of the comparisons and analyses.
6. **Literature Cited** – references to documents cited in the report.
7. **Appendices** – contain supporting material for the main body of the report and the yield tables showing the impact of three different branch size scenarios.

2. METHODS

2.1 PROGENY TEST SITES

We measured tree and branch attributes from four field trial test sites established in the MOF 1986 Pl progeny test series. Two sites were located in the BC northern interior (Indian Point Creek and Moffat Lake) and two in the southern interior (Mission Creek and Pennask Lake) (Table 1). These were selected from among other sites in the test series because they contain a common set of 10 families from each of three provenances (Champion Lakes, Larch Hills, and Marl Creek). This provided the opportunity to measure trees from the same families over a geographic and site productivity gradient (Table 2).

Table 1. General description of the four field test sites (latitude and longitude are in degrees and minutes).

Field Test Site	Seed Planning Unit	General Location	Site Index	Latitude / Longitude	Elevation
Indian Point	Prince George	SE of Prince George	22.7 m	53 29 / 121 34	900 m
Moffat Lake	Prince George	SE of Williams Lake	19.5 m	52 10 / 121 20	1,065 m
Mission Creek	Thompson-Okanagan	E of Kelowna	22.9 m	49 54 / 119 05	1,325 m
Pennask Lake	Thompson-Okanagan	W of Kelowna	19. 6 m	50 01 / 120 16	1,275 m

These test sites were planted in 1986 with one-year old seedlings at 1.5 x 1.5 m spacing (4,444 stems/ha) in a randomized complete block design. The test site plantations were subsequently thinned to remove 50% of the trees (i.e., to 2,222/ha) at age 10 or 11 years. Trees that were damaged or had especially poor form were removed. The thinning did not favor larger trees or those with different crown form, thus we assume that this treatment will not bias the comparisons in this study. All sites were thinned by the same crew and were treated similarly. The thinning treatment should not affect the measurements in this study, as tree crowns had not started to lift significantly at the time of treatment. Thus, we assume that the branch and other measurements from these trees represent a stand established at 2,222/ha.

2.2 MEASUREMENTS

Measurements were taken from 10 families from each of three provenances at each of the four test sites. These 30 families were selected and tested for height and volume growth in the MOF long-term Pl progeny test series (EP770). Each wind-pollinated family represents a parent tree that was phenotypically selected from a wild stand. The long-term progeny test series included more than 300 different wind-pollinated families tested in each of the Prince George and Thompson-Okanagan seed planning units.

Measurements were taken for all trees in each family at the Mission Creek test site (August 2001) and Indian Point, Moffat Lake, and Pennask Lake test sites (September and October of 2002). About 75% of families had 12 to 17 trees at each site (Table 2). Tree measurements included age at breast height (1.3 m), total tree height, diameter at breast height (DBH), height to base of live crown, crown diameter, and wood density as indicated by Pilodyn[2] penetration. Branch measurements included diameter, live/dead status, and observation of branch galls in the primary whorls nearest to 1.0, 2.0, and 3.0 m above ground. Whorl measurements included whorl status (primary versus secondary), whorl height

[2] The Pilodyn is an instrument that measures the resistance of projecting a narrow steel pin into wood, which is directly related to wood relative density. The Pilodyn was developed for other purposes but has been adapted to measure relative density in forest research. See www.krsis.dk/pilodyn.htm for more information.

Table 2. Location description and number of trees measured at the four test sites.

Provenance	Family Attributes				Test Sites (number of trees measured)				
	Number	Elevation (m)	Latitude (degrees-minutes)	Longitude (degrees-minutes)	Indian Point	Mission Creek	Moffat Creek	Pennask Lake	Total
Champion Lakes	1645	1,350	49 14	117 58	10	15	8	19	52
	1647	1,350	49 14	117 58	16	17	7	14	54
	1648	1,200	49 18	117 56	15	18	7	21	61
	1649	1,200	49 18	117 56	16	17	12	16	61
	1654	1,350	49 15	118 02	15	15	4	16	50
	1655	1,350	49 15	118 02	12	13	4	15	44
	1656	1,200	49 18	117 56	12	15	8	13	48
	1657	1,200	49 18	117 56	14	14	12	17	57
	1658	1,000	49 18	117 54	11	16	11	17	55
	1659	1,200	49 18	117 56	16	18	11	13	58
	Total				*137*	*158*	*84*	*161*	*540*
Larch Hills	1767	960	50 41	119 12	12	17	10	14	53
	1769	960	50 42	119 12	15	18	12	15	60
	1770	960	50 42	119 12	12	19	12	16	59
	1772	850	50 41	119 13	9	16	9	16	50
	1773	850	50 41	119 13	13	16	4	13	46
	1774	960	50 41	119 13	16	16	17	15	64
	1775	960	50 41	119 13	14	16	8	17	55
	1776	960	50 41	119 13	16	17	5	15	53
	1778	650	50 42	119 13	13	19	14	16	62
	1779	650	50 42	119 13	2	17	12	13	44
	Total				*122*	*171*	*103*	*150*	*546*
Marl Creek	1661	975	51 33	117 11	12	19	11	17	59
	1662	975	51 33	117 11	16	14	13	19	62
	1664	975	51 33	117 11	16	15	10	21	62
	1665	925	51 32	117 13	15	16	9	17	57
	1666	925	51 32	117 13	12	15	14	17	58
	1667	925	51 32	117 13	14	17	16	16	63
	1668	925	51 32	117 13	16	20	18	16	70
	1670	925	51 33	117 12	17	15	12	16	60
	1673	925	51 33	117 12	15	16	14	19	64
	1679	925	51 34	117 14	14	14	11	17	56
	Total				*147*	*161*	*128*	*175*	*611*
Total					***406***	***490***	***315***	***486***	***1,697***

above ground, and the presence of stem galls, forks, and leader weevil damage. Branch measurements were only taken from the primary whorl nearest and below 1.0 m to the primary whorl nearest and above 3.0 m. Only the most important branch attributes are discussed in this report.

Trees at Mission Creek were measured one year earlier than the other test site locations, thus tree height and diameter were adjusted by adding one year of growth so that all measurements had 17 years of growth (18 years from seed). The additional year of height for the Mission Creek trees was added by estimating the height increment for the 17^{th} year using site index of the tree computed from the year 16 height and breast height age. The diameter was then adjusted to year 17 using the diameter/height ratio of each tree for year 16 and applying this to the predicted height at 17 years. Potential differences in measurements for the other attributes were not adjusted for this one-year difference.

2.3 Statistical Comparison

Statistical analyses showed highly significant differences for most tree and branch attributes among test sites, provenances, and families (Appendix I). These results did not provide any practical information for the growth and yield portion of this project because statistical differences do not imply practical importance. For example, a 0.1 mm differences in branch size can be statistically different but not have any practical importance to silviculture or growth and yield. Therefore, this project focused on the comparison of absolute differences and their practical importance to growth and yield and silviculture. A more detailed statistical analysis of these measurements is also presented in O'Neill et al. 2003.

2.4 Absolute Value Comparison

We compared the tree and branch attributes among test sites, provenances, and families using standardized and absolute variables to detect practical differences among provenances and families that could be meaningful to silviculture and growth and yield modeling. Observed differences in many tree and branch attributes are often related to tree size, thus standardization is needed to help isolate and detect practical differences related to genetic effects (Section 3). We standardized all variables where the tree effect should be removed to help identify differences related to seed source using tree height (Table 3). Other variables could be used for standardization such as diameter, basal area, etc.

Table 3. Tree and branch attributes compared in this study.

	Standardized with:	Computed as:	Variable Code	Units
Tree Attributes				
Site index			SI	m
Tree height			HT	m
DBH	Tree Height	DBH / Tree Height	D/H	cm/m
Years to breast height			YTBH	yrs
Live crown length	Tree Height	Crown length / Tree height (Live Crown Ratio)	LCR	m/m
Crown width	Tree Height	Crown Width / Tree Height (Relative Crown Radius)	RCW	m/m
Branch Attributes				
Number of Branches/Whorl			NBR	
Avg. Branch Diameter – Whorls 1-3	Tree Height	Avg. Branch Diameter / Tree height (Relative Average Branch Diameter)	RABD	cm/m
Max. Branch Diameter – Whorls 1-3	Tree Height	Avg. Maximum Branch Diameter / Tree height (Relative Maximum Branch Diameter)	RMBD	cm/m

3. COMPARISON OF ATTRIBUTES

3.1 OVERVIEW

The two main question addressed in this section are:

1) What are the actual differences in the measured attributes?

2) Are these differences practically meaningful to silviculture and growth and yield modeling?

The differences are presented in absolute values or ratios by test site, provenance, and family for each of the tree and branch attributes (Table 3). The practical significance of these differences is discussed for each attribute and summarized at the end of this section.

3.2 SITE INDEX

3.2.1 Standardization of Data

The site index data were not standardized for this comparison.

3.2.2 Test Site

The two high productivity test sites (Indian Point and Mission Creek) had site indices of 22–23 m and the two low productivity sites had site indices of 19-20 m (Moffat Lake and Pennask Lake) (Table 4). Thus, the average site index for the two northern test sites was the same as the two southern test sites (i.e., each had one high and one medium productivity site).

3.2.3 Provenance

The Larch Hills provenance showed the highest site index at three of the four test sites (and was close to the highest at the fourth test site) (Table 4, Figure 1). Overall, the site index of the Larch Hills trees was 1.2 m higher than Champion Lakes (the slowest growing provenance). Champion Lakes had the lowest site indices at all four test sites; however, the difference from Marl Creek trees was small in three of the four test sites (Figure 1).

Table 4. Site index (SI) (m) by test site and provenance. N=number of trees.

Test Site	Champ		Larch		Marl		Overall	
	SI	N	SI	N	SI	N	SI	N
Indian Pt	22.2	137	23.4	122	22.7	147	22.7	406
Mission Cr	22.3	158	23.7	171	22.7	161	22.9	490
Moffat Lk	18.2	84	19.8	103	20.2	128	19.5	315
Pennask Lk	19.3	161	20.1	150	19.5	175	19.6	486
Overall	*20.7*	*540*	*21.9*	*546*	*21.2*	*611*	*21.3*	*1,697*
MAI	5.2 m^3/ha/yr		5.8 m^3/ha/yr		5.5 m^3/ha/yr		5.5 m^3/ha/yr	
Vol. at 70 yrs	352 m^3/ha		385 m^3/ha		365 m^3/ha		367 m^3/ha	

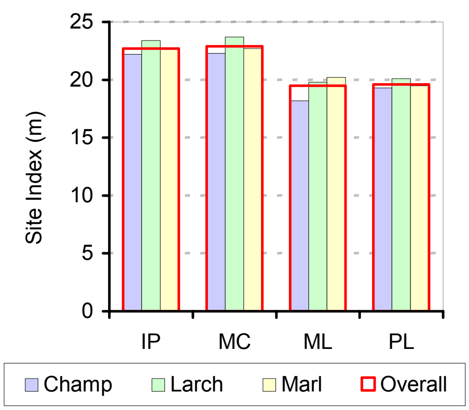

Figure 1. Average site index by test site and provenance. (IP= Indian Point, MC=Mission Creek, ML=Moffat Lake, PL=Pennask Lake).

The stand volume differences predicted using TIPSY[3,4] for these site indices show the maximum mean

[3] **TIPSY** (**T**able **I**nterpolation **P**rogram for **S**tand **Y**ield) is a computer program developed by the BC MOF to report on the yield tables produced by the **TASS** model.

[4] All yield estimates in this report were generated with TIPSY for Pl planted at 1600/ha, OAF1=15%, and OAF2=5%.

annual volume increment (MAI) for Larch Hills of 5.8 m^3/ha/yr compared to Champion Lakes at 5.2 m^3/ha/yr (Table 4). This difference of 0.6 m^3/ha/yr is about 12% more MAI and volume yield at rotation compared to the slower growing Champion Lakes provenance (assuming that site index and volume differences are maintained to rotation).

3.2.4 Family

Family differences in site index were larger than for provenances. The average site index of the top three families was 2.2 m higher on average than the lowest three families (Table 5). This is a substantial increase over the provenance average gains where overall Larch Hills was only 1.2 m greater than Champion Lakes. The MAI difference between the highest and lowest three families is about 1.1 m^3/ha/yr, which is a 22% increase for Larch Hills over Champion Lakes.

Table 5. Three families with the highest and lowest site indices (MAI is in m^3/ha/yr) by test site. N=number of trees.

Indian Point			Mission Creek			Moffat Lake			Pennask Lake			Overall		
No.	N	SI (m)	No.	N	SI (m)	No.	N	SI (m)	No.	N	SI (m)	No.	N	SI (m)
Highest Site Index														
1776	16	24.0	1769	18	24.3	1776	5	21.8	1775	17	20.8	1776	53	22.6
1778	13	23.8	1776	17	24.0	1772	9	21.6	1767	14	20.6	1772	50	22.2
1769	15	23.7	1775	16	24.0	1665	9	20.8	1772	16	20.4	1773	46	22.2
	44	*23.8*		*51*	*24.1*		*23*	*21.4*		*47*	*20.6*		*149*	*22.3*
MAI		*6.8*			*7.0*			*5.6*			*5.2*			*6.0*
Lowest Site Index														
1655	12	21.8	1645	15	21.5	1654	4	17.2	1656	13	18.7	1645	52	20.3
1647	16	21.7	1654	15	21.3	1655	4	16.7	1654	16	18.7	1654	50	20.2
1654	15	21.4	1655	13	20.6	1647	7	16.6	1655	15	18.3	1655	44	19.8
	43	*21.6*		*43*	*21.1*		*15*	*16.8*		*44*	*18.6*		*146*	*20.1*
MAI		*5.7*			*5.4*			*3.4*			*4.2*			*4.9*
SI Diff.		*2.2*			*2.9*			*4.5*			*2.0*			*2.2*
MAI Diff.		*1.1*			*1.6*			*2.2*			*1.0*			*1.1*

Family 1776 (Larch Hills) was in the top three high site index families at three of the four test sites (Table 5) and was near the top at the fourth site. Families 1655 and 1654 (Champion Lakes) were in the three lowest site index families at all sites. Overall, family 1776 had an average site index of 22.6 m compared to family 1655 at 19.8 m. These overall highest and lowest family average site indices give a predicted MAI of 6.0 compared to 4.9 m^3/ha/yr. This difference of 1.1 m^3/ha/yr (18%) is about 77 m^3/ha on a rotation of 70 years.

The difference in the average site index of the three top and bottom ranked site index families was 4.5 m at the Moffat Lake test site (Table 5). The top three site index families had similar values to the other test sites; however, the lowest site index families had site indices much lower than the other three test sites. This suggests that some of the lowest site index families may not be well suited to some sites.

3.2.5 Practical Significance

These results show that site index can vary by 10-25% by seed source and planting location. These differences in height growth rate could result in yield differences of 20-50% by seed source and planting location. These potentially large differences could be realized in operational plantations because current seed transfer guidelines allow for upward movement of up to 300 m in elevation.[5] These results can also be considered in the selection of families (within the studied provenances) for the next generation of Pl seed orchards.

These site index differences among provenances and families do not require modifications to BC growth and yield models. The TASS and TIPSY models (most commonly used for regenerated stands in BC) use site index to define growth rate, thus only accurate site index estimates are needed to predict the yield of different seed sources.[6] However, these site index differences clearly highlight the need to have accurate site indices to reflect the expected growth in regenerated stands when applied in forest level timber supply analysis.

3.3 HEIGHT

3.3.1 Standardization of Data
The tree height data were not standardized for this comparison.

3.3.2 Test Site
These stands are all the same age thus height is closely related to site index. Consequently, the results for height were almost identical to site index. The two test sites with the highest site indices (Indian Point and Mission Creek) were the tallest in height and the two with the lowest site indices (Moffat Lake and Pennask Lake) were the shortest (Table 6).

3.3.3 Provenance
The Larch Hills provenance showing the highest site indices also had the tallest trees, and was about 0.4 m higher than the Marl Creek and 0.7 m higher than the Champion Lakes provenances (Table 6, Figure 2). The Champion Lakes provenance had the shortest trees at all four test sites.

Table 6. Average tree height (HT) (m) by test site and provenance. N=number of trees.

Test Site	Champ		Larch		Marl		Overall	
	HT	N	HT	N	HT	N	HT	N
Indian Pt	8.2	137	9.1	122	8.7	147	8.7	406
Mission Cr	8.0	158	8.8	171	8.2	161	8.3	490
Moffat Lk	5.1	84	6.2	103	6.2	128	5.9	315
Pennask Lk	5.5	161	6.1	150	5.9	175	5.8	486
Overall	*6.9*	*540*	*7.6*	*546*	*7.2*	*611*	*7.2*	*1,697*

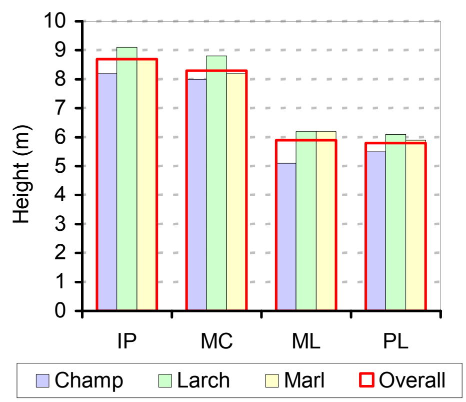

Figure 2. Average tree height by test site and provenance. (IP= Indian Point, MC=Mission Creek, ML=Moffat Lake, PL=Pennask Lake).

3.3.4 Family
The family results for height were also the same as site index. Larch Hills families 1769 and 1776 had the tallest

[5] We did not measure trees from random wild seed in this study; however, further work could compare these results with height and genetic gain estimates from random wild seedlots used in the Prince George and Thompson-Okanagan progeny test series.

[6] This assumes that all other growth relationships are constant among different genotypes, which may not be true.

trees at all test sites (Table 7). Champion Lakes families 1655, 1654, and 1645 were the shortest at all test sites. The average difference between tallest and shortest families was about 1.5 m.

3.3.5 Practical Significance

The results of these comparisons are the same as for site index as are the practical implications.

Table 7. The three families with the tallest and shortest heights (HT) (m) by test site. N=number of trees.

Indian Point			Mission Creek			Moffat Lake			Pennask Lake			Overall		
No.	N	Ht	No.	N	Ht	No.	N	Ht	No.	N	Ht	No.	N	Ht
Tallest Height														
1769	15	9.3	1769	18	9.1	1776	5	6.5	1769	15	6.4	1776	53	8.0
1776	16	9.2	1776	17	9.0	1775	8	6.5	1776	15	6.3	1769	60	8.0
1772	9	9.2	1772	16	8.9	1769	12	6.4	1772	16	6.2	1773	46	7.8
	40	*9.3*		*51*	*9.0*		*25*	*6.4*		*46*	*6.3*		*159*	*7.9*
Shortest Height														
1645	10	8.0	1645	15	7.8	1645	8	4.8	1645	19	5.3	1654	50	6.6
1654	15	7.8	1654	15	7.6	1655	4	4.4	1654	16	5.1	1645	52	6.5
1655	12	7.6	1655	13	7.2	1654	4	4.4	1655	15	4.9	1655	44	6.3
	37	*7.8*		*43*	*7.5*		*16*	*4.6*		*50*	*5.1*		*146*	*6.4*
Difference :		*1.5*			*1.5*			*1.8*			*1.2*			*1.5*

3.4 Diameter at Breast Height

3.4.1 Standardization of Data

DBH was larger on the higher productivity sites, but this is expected since DBH is strongly correlated with height. Consequently, the effect of tree size (in this case height) was removed from the diameter measurements to help detect genetic effects. Thus we compared DBH using the ratio of diameter to height (D/H) for individual trees. This D/H ratio changes as height increases; however, these data were within a relatively narrow range of height and this potential bias should not impact the comparison.

3.4.2 Test Site

The D/H ratios differed among the four test sites with the largest ratios at Pennask and the smallest at Mission Creek (Table 8). This difference of 0.08 cm/m suggests that the average DBH of 10 m tall trees[7] at Mission Creek would be 11.9 cm and 12.7 cm at Pennask. This difference in diameter could be over 1.0 cm when these stand reach rotation size (e.g., about 22 m of height).

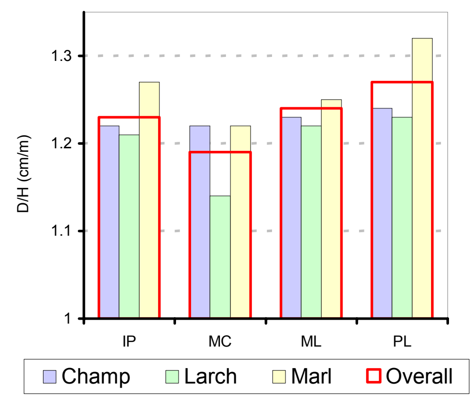

Figure 3. Average D/H ratio by test site and provenance. (IP= Indian Point, MC=Mission Creek, ML=Moffat Lake, PL=Pennask Lake).

3.4.3 Provenance

The provenance effect for the D/H ratio was about the same as for the test sites, with differences of approximately 0.07 cm/m (Table 8). Larch Hills had the smallest overall D/H at all sites, and Marl Creek had the highest ratios at all sites (Figure 3).

[7] A common height of 10 m is used throughout this section to illustrate relative differences at a common stage of stand development. The tallest trees in these test sites were about 8-9 m on average for the two high sites and about 6 m on average for the lower sites (Table 6).

Table 8. Average diameter (DBH) (cm) and diameter-height ratio (D/H) (cm/m) by test site and provenance. N=number of trees.

Test Site	Champ			Larch			Marl			Overall		
	DBH	D/H	N	DBH	D/H	N	DBH	D/H	N	DBH	D/H	N
Indian Pt	10.1	1.22	137	10.9	1.21	122	11.0	1.27	147	10.7	1.23	406
Mission Cr	9.7	1.22	158	10.0	1.14	171	10.0	1.22	161	9.9	1.19	490
Moffat Lk	6.3	1.23	84	7.6	1.22	103	7.7	1.25	128	7.3	1.24	315
Pennask Lk	6.9	1.24	161	7.5	1.23	150	7.8	1.32	175	7.4	1.27	486
Overall	*8.4*	*1.23*	*540*	*9.1*	*1.20*	*546*	*9.1*	*1.27*	*611*	*8.9*	*1.23*	*1,697*

These differences in tree form result in a 10-15% difference in volume at rotation at the same site index. Larch Hills showed the smallest diameters for the same height, but also showed the highest site indices; thus potential volume gains from the increase in site index from Larch Hills provenances may be lost in the lower D/H ratio (i.e, smaller diameters for the same height).

3.4.4 Family

Difference in the D/H ratio among families was over double that of provenances. The three families with highest ratios were from Marl Creek and the three lowest were from Larch Hills and Champion Lake (Table 9). The overall difference between these family groups was 0.17 cm/m (15% difference from the low family group). This potential difference in D/H ratio could result in large volume increases if these differences persist to rotation and apply to all trees in a stand.

Table 9. The three families with the largest and smallest D/H ratios (cm/m) by test site. N=number of trees.

Indian Point			Mission Creek			Moffat Lake			Pennask Lake			Overall		
No.	N	D/H	No.	N	D/H	No.	N	D/H	No.	N	D/H	No.	N	D/H
Largest D/H Ratios														
1668	16	1.35	1645	15	1.32	1673	14	1.34	1679	17	1.37	1673	64	1.32
1774	16	1.34	1661	19	1.31	1661	11	1.31	1670	16	1.35	1661	59	1.32
1673	15	1.33	1649	17	1.28	1648	7	1.30	1673	19	1.35	1670	60	1.29
D/H	47	1.34		51	1.30		32	1.32		52	1.36		183	1.31
Smallest D/H Ratios														
1770	12	1.14	1772	16	1.10	1659	11	1.17	1772	16	1.18	1658	55	1.15
1772	9	1.12	1773	16	1.08	1658	11	1.15	1658	17	1.18	1767	53	1.15
1658	11	1.09	1767	17	1.06	1772	9	1.10	1775	17	1.17	1772	50	1.13
D/H	32	1.12		49	1.08		31	1.14		50	1.18		158	1.14
Difference :		*0.22*			*0.22*			*0.18*			*0.18*			*0.17*

3.4.5 Practical Significance

If these differences persist to later stages of stand development, these differences in tree form (as shown in the D/H ratio) could have large practical impacts on silviculture and growth and yield. The result could be large differences in stand volume, taper, and possibly product recovery among different seed sources. These tree form differences are very important to growth and yield modeling because many prediction systems include the fundamental relationship between height and diameter. These tree form differences are also likely important to the tree-breeding program to help select breeding parents with desirable traits for future seed orchards.

These results are from relatively young trees and we do not know if they will persist to rotation and to which cohorts of trees they will apply. Consequently, the main practical significance of these results is to raise the issue of potentially significant differences in Pl tree form among provenances, families, and planting sites. The differences in the D/H ratio in this analysis are highly statistically different (*p=0.0000*); however, the practical significance of potential differences depends on if they persist over time, to which trees they apply, and if and how these traits are related to other characteristics that may impact growth and yield. Consequently, more work is needed to study these potential differences.

3.5 Years To Breast Height

3.5.1 Standardization of Data

The data for years to breast height (BH) were not standardized for this comparison.

3.5.2 Test Site

Trees reached BH in year seven (from seed) except at Indian Point where they reached BH in year five (Table 10). We expect trees with similar site index and other conditions to reach BH about the same time; however, this trend was not shown at Indian Point and Mission Creek (the two high sites). This could be because Mission Creek is at a higher elevation than Indian Point (Table 1) and so the growth may be slowed. Conversely, trees at Indian Point may have grown faster in early years because the site was broadcast burned before planting and had reduced vegetative competition.

3.5.3 Provenance

The time to reach BH differed by only one year among the three provenances. On average, trees from Champion Lakes took marginally more time to reach BH at all test sites (Table 10, Figure 4), but these small differences are probably not practically meaningful.

3.5.4 Family

The family results were similar with average differences of about 1.0 to 1.5 years to reach BH between the three highest and lowest ranking families (Table 11).

3.5.5 Practical Significance

These results do not suggest any practical difference in the number of years to reach BH for consideration in silviculture or growth and yield modeling.

Table 10. Average years to breast height (YTBH) by test site and provenance. Overall average is with (w) and without (wo) Indian Point (IP). N=number of trees.

Test Site	Champ		Larch		Marl		Overall	
	YTBH	N	YTBH	N	YTBH	N	YTBH	N
Indian Pt	4.4	134	4.1	122	4.1	146	4.2	402
Mission Cr	6.4	158	6.2	171	6.3	161	6.3	490
Moffat Lk	7.1	80	6.1	101	6.5	123	6.6	304
Pennask Lk	7.2	161	6.6	150	6.5	174	6.8	485
Overall (w IP)	*6.3*	*533*	*5.8*	*544*	*5.9*	*604*	*6.0*	*1,681*
Overall (wo IP)	*6.9*		*6.3*		*6.4*		*6.6*	

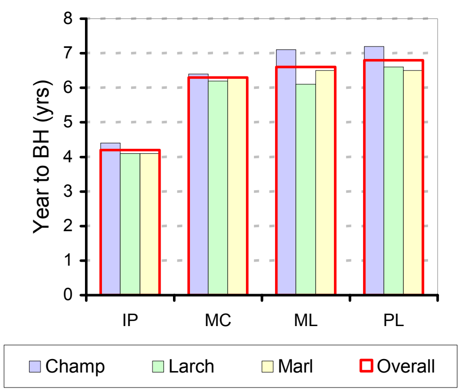

Figure 4. Average years to breast height (YTBH) by test site and provenance. (IP= Indian Point, MC=Mission Creek, ML=Moffat Lake, PL=Pennask Lake).

Table 11. Three families with largest and smallest years to breast height (YTBH) by provenance. N=number of trees.

Indian Point			Mission Creek			Moffat Lake			Pennask Lake			Overall		
No.	N	YTBH	No.	N	YTBH	No.	N	YTBH	No.	N	YTBH	No.	N	YTBH
Most YTBH														
1655	12	4.9	1655	13	6.8	1649	11	7.5	1655	15	7.6	1645	50	6.7
1645	9	4.7	1649	17	6.7	1645	7	7.5	1645	19	7.5	1655	44	6.6
1649	16	4.7	1645	15	6.6	1655	4	7.4	1649	16	7.5	1658	53	6.6
	37	4.8		45	6.7		22	7.5		50	7.5		147	6.6
Least YTBH														
1662	16	3.9	1774	16	6.0	1778	14	6.1	1668	16	6.4	1774	64	5.6
1774	16	3.8	1662	14	6.0	1775	8	6.0	1662	19	6.3	1662	62	5.6
1769	15	3.8	1769	18	5.9	1769	12	5.7	1769	15	6.2	1769	60	5.4
	47	3.8		48	6.0		34	5.9		50	6.3		186	5.5
Difference :		*1.0*			*0.7*			*1.6*			*1.2*			*1.1*

3.6 LIVE CROWN RATIO

3.6.1 Standardization of Data

The height to the live crown (HLC) is also related to tree height at the same density, thus we standardized this measurement to height by using the live crown ratio (LCR).

3.6.2 Test Site

The LCR was about 75-80% at all sites except Indian Point where it was about 60% (Table 12). The most plausible explanation for the difference at Indian Point is the area has experienced more needle blight (*Dothistroma spp.*) and needle cast (*Lophodermella spp.*) than the other test site areas.[8] These diseases could have resulted in a higher rate of needle mortality in the lower crown and thus a faster rate of crown lift. Given the difficulty of accurately measuring this attribute in the field, this difference of about 5% in LCR is probably not of practical importance at these four sites.

Table 12. Average height to live crown (HLC) (m) live crown ratio (LCR) by test site and provenance. N=number of trees.

Test Site	Champ			Larch			Marl			Overall		
	HLC	LCR	N	HLC	LCR	N	HLC	LCR	N	HLC	LCR	N
Indian Pt	3.4	0.59	137	3.5	0.62	122	3.1	0.64	147	3.3	0.61	406
Mission Cr	1.5	0.81	158	1.6	0.82	171	1.4	0.82	161	1.5	0.82	490
Moffat Lk	1.4	0.71	84	1.3	0.79	103	1.5	0.75	128	1.4	0.75	315
Pennask Lk	1.1	0.81	161	1.2	0.80	150	1.1	0.81	175	1.1	0.81	486
Overall (w IP)	*1.8*	*0.74*	*540*	*1.9*	*0.76*	*546*	*1.7*	*0.76*	*611*	*1.8*	*0.75*	*1,697*
Overall (wo IP)	*1.3*	*0.79*	*403*	*1.4*	*0.80*	*424*	*1.3*	*0.80*	*464*	*1.3*	*0.80*	*1,291*

3.6.3 Provenance

There was also no meaningful difference in the provenance average LCR when the Indian Point measurements were removed from the comparison (Table 12). There were no trends in LCR by provenance or interactions with site (Figure 5).

8 Personal communication with Mike Carlson, MOF Research Branch, Kalamalka Research Station. March 2003.

3.6.4 Family

There was little difference overall between families with the highest and lowest LCRs (Table 13). However, at Moffat Lake the top three families had a LCR that was 21% higher than the three families with the lowest LCR. We cannot explain the trend at this site; however, we note that Moffat Lake contained the greatest difference in site index between the families with the three highest and three lowest site indices.

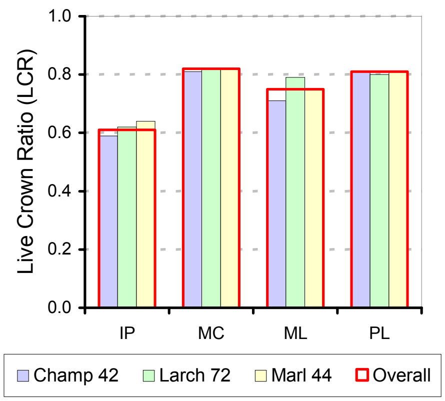

Figure 5. Average live crown ratio by test site and provenance. (IP= Indian Point, MC=Mission Creek, ML=Moffat Lake, PL=Pennask Lake).

3.6.5 Practical Significance

These results do not suggest any practical difference for silviculture or growth and yield modeling in the LCR and associated rate of crown lift among sites, provenances, or families. However, possible family-site interactions may show larger differences in future and be practically significant in the rate of crown lift among different seed sources and sites.

Table 13. The three families with the largest and smallest live crown ratio (LCR) by provenance. N=number of trees.

Indian Point			Mission Creek			Moffat Lake			Pennask Lake			Overall		
No.	N	LCR	No.	N	LCR	No.	N	LCR	No.	N	LCR	No.	N	LCR
Largest LCR														
1673	15	0.67	1649	17	0.86	1775	8	0.85	1662	19	0.83	1772	50	0.79
1668	16	0.66	1679	14	0.85	1774	17	0.84	1772	16	0.83	1673	64	0.78
1666	12	0.66	1666	15	0.84	1772	9	0.83	1657	17	0.83	1774	64	0.77
	43	0.67		46	0.85		34	0.84		52	0.83		178	0.78
Smallest LCR														
1779	2	0.55	1648	18	0.79	1654	4	0.64	1665	17	0.78	1658	55	0.72
1658	11	0.54	1654	15	0.79	1658	11	0.63	1770	16	0.78	1654	50	0.72
1655	12	0.54	1655	13	0.78	1655	4	0.60	1779	13	0.76	1655	44	0.71
	25	0.55		46	0.79		19	0.63		46	0.77		149	0.72
Difference:		*0.12*			*0.06*			*0.21*			*0.06*			*0.07*

3.7 Crown Width

3.7.1 Standardizaton of Data

Crown width is related to tree size and so we standardized these measurements to tree height. This relative crown width (RCW) ratio stabilizes over time as trees grow correspondingly less in crown width than in height. These measured trees were within a relatively narrow range of height and thus this potential source of bias should not negatively impact these comparisons.

3.7.2 Test Site

The RCW varied from 22–27% (of tree height) among the four test sites. The highest RCW was at Marl Creek (27%) and lowest was at Indian Point at (22%) (Table 14). Thus, at a common height of 10 m, trees at Marl Creek would have crown widths of 2.7 m compared to 2.2 m at Indian Point.

Table 14. Average crown width (CW) and relative crown width (RCW) by test site and provenance. N=number of trees.

Test Site	Champ			Larch			Marl			Overall		
	CW	RCW	N	CW	RCW	N	CW	RCW	N	CW	RCW	N
Indian Pt	1.7	0.21	137	2.0	0.22	122	2.0	0.23	147	1.9	0.22	406
Mission Cr	1.8	0.23	158	2.1	0.24	171	2.0	0.25	161	2.0	0.24	490
Moffat Lk	1.3	0.25	84	1.7	0.27	103	1.6	0.27	128	1.6	0.27	315
Pennask Lk	1.2	0.22	161	1.4	0.23	150	1.4	0.23	175	1.3	0.23	486
Overall	*1.5*	*0.22*	*540*	*1.8*	*0.24*	*546*	*1.8*	*0.24*	*611*	*1.7*	*0.24*	*1,697*

3.7.3 Provenance

The RCW showed less difference by provenance where it varied by only 2%. Champion Lakes contained the narrower crowns at 22%, and Larch Hills and Marl Creek were larger at 24% of tree height. There was no strong trend for provenances by test site (Figure 6).

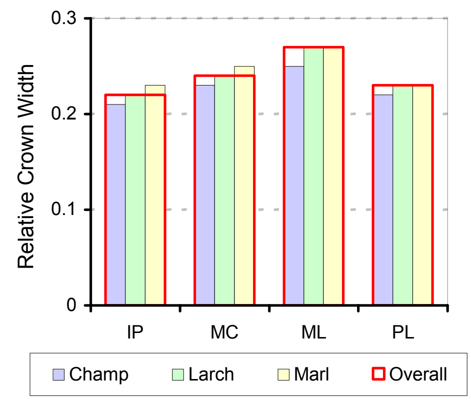

Figure 6. Average relative crown width by test site and provenance. (IP= Indian Point, MC=Mission Creek, ML=Moffat Lake, PL=Pennask Lake).

3.7.4 Family

Comparison of the RCW in the top and bottom three families by test site did not show strong trends. The range of the RCW was similar when compared by test site or provenance (Table 15).

3.7.5 Practical Difference

These results do not suggest there is any practical difference in the RCW in these measured trees. However, subsequent growth and competition among trees could show meaningful differences in future. The RCW will decrease over time as trees grow in height; however, a 0.5 m difference in crown width at rotation (e.g., 22 m of height) could significantly impact on tree mortality and volume to that point of stand development.

Table 15. The three families with the largest and smallest crown width (RCW). N=number of trees.

Indian Point			Mission Creek			Moffat Lake			Pennask Lake			Overall		
No.	N	RCW	No.	N	RCW	No.	N	RCW	No.	N	RCW	No.	N	RCW
Largest RCW														
1774	16	0.25	1774	16	0.25	1769	12	0.31	1779	13	0.26	1779	44	0.27
1667	14	0.24	1667	17	0.24	1679	11	0.29	1666	17	0.25	1673	64	0.26
1668	16	0.24	1668	20	0.25	1673	14	0.28	1679	17	0.25	1679	56	0.25
	46	0.24		53	0.25		37	0.29		47	0.26		164	0.26
Smallest RCW														
1655	12	0.19	1655	13	0.21	1657	12	0.25	1658	17	0.21	1772	50	0.22
1649	16	0.19	1649	17	0.24	1649	12	0.23	1775	17	0.20	1654	50	0.21
1658	11	0.18	1658	16	0.21	1658	11	0.23	1654	16	0.20	1658	55	0.21
	39	0.19		46	0.22		35	0.27		50	0.21		155	0.21
Difference:		*0.05*			*0.02*			*0.05*			*0.05*			*0.04*

3.8 Number of Branches

3.8.1 Standardization of Data

The number of branches (NBR) in the measured whorls was not standardized for this comparison.

3.8.2 Test Site

The NBR was between five and six at all sites (Table 16). Trees at Indian Point had about 0.5 branches/whorl more than the other sites on average; however, this is probably not a practically significant difference.

3.8.3 Provenance

There was no practical difference in the NBR among the three provenances (Table 16, Figure 7).

Table 16. Average number of branches per whorl (NBR) by test site and provenance. N=number of trees.

Test Site	Champ		Larch		Marl		Overall	
	NBR	N	NBR	N	NBR	N	NBR	N
Indian Pt	5.7	137	5.6	122	5.3	147	5.5	406
Mission Cr	4.9	158	5.0	171	4.9	161	4.9	490
Moffat Lk	4.9	84	4.9	103	4.6	128	4.8	315
Pennask Lk	5.2	161	5.0	150	4.9	175	5.0	486
Overall	*5.2*	*540*	*5.1*	*546*	*4.9*	*611*	*5.1*	*1,697*

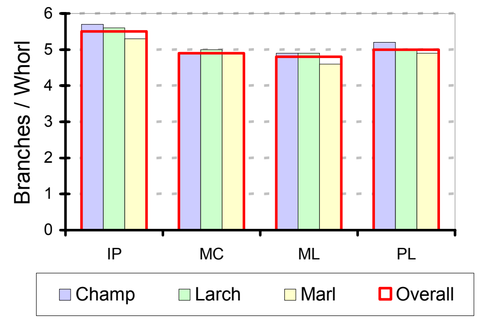

Figure 7. Average number of branches per whorl by test site and provenance. (IP= Indian Point, MC=Mission Creek, ML=Moffat Lake, PL=Pennask Lake).

3.8.4 Family

The highest and lowest NBR families differed by about one branch on average, which is probably not a practically significant difference (Table 17).

3.8.5 Practical Significance

The results do not suggest any practical difference in the NBR at the different test sites or among provenances and families. This is important because the NBR (also called the number of knots in a cluster) is a key factor in the recovery of high quality lumber. This comparison does not address the additional (but small) degrade that may result from false branch whorls on some sites.

Table 17. The three families with the largest and smallest number of branches per whorl (NBR) by test site. N=number of trees.

Indian Point			Mission Creek			Moffat Lake			Pennask Lake			Overall		
No.	N	NBR	No.	N	NBR	No.	N	NBR	No.	N	NBR	No.	N	NBR
Largest NBR														
1658	11	6.1	1767	17	5.3	1657	12	5.2	1657	17	5.5	1657	57	5.5
1657	14	6.0	1661	19	5.2	1658	11	5.2	1658	17	5.5	1658	55	5.5
1648	15	5.9	1657	14	5.2	1767	10	5.2	1648	21	5.4	1767	53	5.4
	40	6.0		50	5.3		33	5.2		55	5.5		165	5.5
Smallest NBR														
1670	17	5.2	1775	16	4.5	1654	4	4.4	1775	17	4.6	1775	55	4.7
1666	12	5.0	1666	15	4.5	1666	14	4.1	1666	17	4.5	1666	58	4.5
1664	16	4.9	1664	15	4.4	1664	10	4.0	1664	21	4.5	1664	62	4.5
	45	5.0		46	4.5		28	4.1		55	4.5		175	4.6
Difference :		*1.0*			*0.8*			*1.1*			*1.0*			*0.9*

3.9 Average Branch Diameter

3.9.1 Standardization of Data

Branch diameter is strongly related to tree height and diameter, thus we removed the tree size effect by using relative average branch diameter (RABD) computed as branch diameter divided by tree height. This ratio becomes smaller over time as trees grow less in branch size than in height, thus this cannot be used to predict branch size at later stages of stand development. We analyzed the differences in branch size among the three whorls measured in these trees. Generally, branch size increases as height to the whorl increases, but differences were small among provenances and families and so we combined the measurements from the 1, 2, and 3 m whorls into an overall average branch diameter.

3.9.2 Test Site

The RABD was 38% larger at the two medium productivity sites (Moffat Lake and Pennask Lake) than the high productivity sites (Table 18). This suggests that (all else being equal) trees on lower productivity sites may have larger branches than on more productive sites when trees are at the same height. For example, these results suggest that 10 m tall trees growing on high sites may have an average branch size of 1.6 cm compared to 2.2 cm for 10 m tall trees on a medium site. This is a large difference when compared to the overall average branch diameter and could be very significant if these size differences continue to rotation.

Table 18. Average branch diameter (ABD) (cm) and relative average branch diameter (RABD) (cm/m) by test site and provenance. N=number of trees.

Test Site	Champ			Larch			Marl			Overall		
	ABD	RABD	N	ABD	RABD	N	ABD	RABD	N	ABD	RABD	N
Indian Pt	1.3	0.16	137	1.5	0.16	122	1.4	0.17	147	1.4	0.16	406
Mission Cr	1.2	0.16	158	1.3	0.15	171	1.3	0.16	161	1.3	0.16	490
Moffat Lk	1.2	0.23	84	1.5	0.24	103	1.4	0.22	128	1.4	0.23	315
Pennask Lk	1.0	0.19	161	1.2	0.20	150	1.3	0.22	175	1.2	0.20	486
Overall	*1.2*	*0.18*	*540*	*1.4*	*0.19*	*546*	*1.3*	*0.19*	*611*	*1.3*	*0.19*	*1,697*

3.9.3 Provenance

There was no practical difference in the RABD among the three provenances (Table 18) and no apparent interaction with the test site (Figure 8). However, branches at Moffat Lake were larger for all provenances than at the other sites.

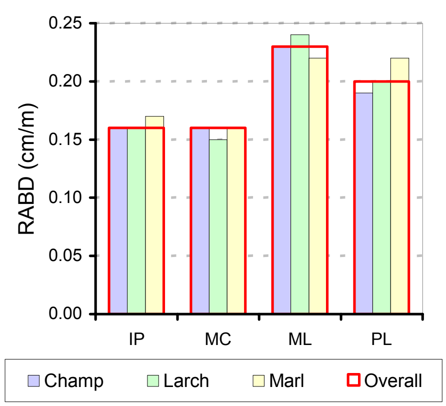

Figure 8. Relative average branch diameter by test site and provenance. (IP= Indian Point, MC=Mission Creek, ML=Moffat Lake, PL=Pennask Lake).

3.9.4 Family

There was about 24% difference in RABD between the three highest and lowest ranking families (Table 19). The two medium productivity sites showed RABD differences of 0.06 and 0.07 cm/m (30% and 41%) compared to 0.04 (29% and 31%) at the high productivity sites. In absolute terms, these differences are about the same as between the high and medium productivity sites (i.e., about 0.6 cm for 10 m tall trees). There was no strong trend between site index and RABD (Figure 9); however, this relationship shows that three Larch Hills families (1772, 1773, and 1775) have the highest site indices and smallest relative branches.

3.9.5 Practical Significance

These comparisons show relatively large differences in branch size among families, and these differences could significantly impact the grade recovery of solid wood products at rotation if they increase over time. Most branches in the 2 and 3 m whorls are still alive and will increase in diameter until the crown lifts past these heights. Consequently, these branches will likely be larger at rotation than shown in these measurements. Branch size in high-density stands should remain small even for families with relatively large branches, as crowns lift quickly and branches do not live long enough to reach the large sizes. However, some families may develop proportionately larger branches when grown in lower density stands. These family-density interactions should be evaluated in larger area-based trials (e.g., realized genetic gain trials) designed to observe branch growth and crown lift over time.

Table 19. The three families with the highest and lowest ranking of relative average branch diameter (RABD) (cm/m) by test site. N=number of trees.

Indian Point			Mission Creek			Moffat Lake			Pennask Lake			Overall		
No.	N	RABD	No.	N	RABD	No.	N	RABD	No.	N	RABD	No.	N	RABD
Largest RABD														
1666	12	0.18	1645	15	0.18	1775	8	0.26	1673	19	0.26	673	64	0.21
1668	16	0.18	1673	16	0.18	1779	12	0.26	1667	16	0.23	779	44	0.20
1774	16	0.18	1649	17	0.17	1659	11	0.26	1769	15	0.23	666	58	0.20
	44	0.18		48	0.18		31	0.26		50	0.24		166	0.21
Smallest RABD														
1773	13	0.15	1665	16	0.14	1665	9	0.21	1654	16	0.18	767	53	0.17
1664	16	0.14	1773	16	0.13	1664	10	0.21	1658	17	0.17	648	61	0.17
1658	11	0.14	1767	17	0.13	1670	12	0.20	1648	21	0.17	658	55	0.17
	40	0.14		49	0.13		31	0.20		54	0.17		169	0.17
Difference:		*0.04*			*0.04*			*0.06*			*0.07*			*0.04*

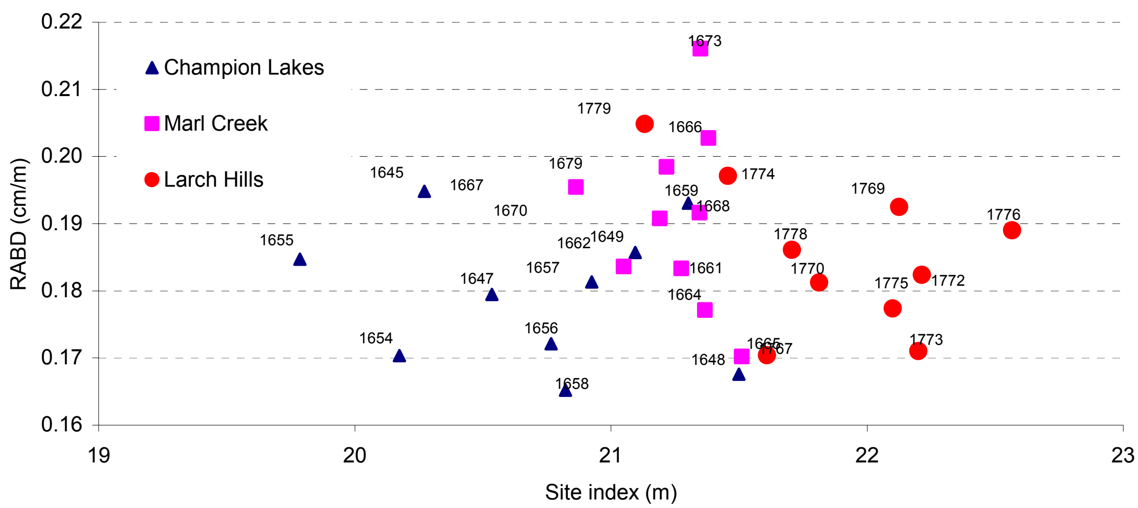

Figure 9. Relationship between the relative average branch diameter and site index for the 30 families. Family numbers are given for each graph point. The family site index values are averaged across the four sites.

3.10 Largest Branch Diameter

3.10.1 Standardization of Data

Measurements for largest branch size were standardized to height and comparisons made using the average relative maximum branch diameter (RMBD) (cm/m). As with RABD, this ratio decreases as trees grow in height and less in branch size, thus this ratio cannot be used to predict branch size at later points in stand development.

3.10.2 Test Site

The overall trends for the largest branch were the same as for the average branch size. The RMBD was also highest on the two low productivity test sites than on the high sites (Table 20); however, these ratios are larger than those reflecting the average branch size. The lower productivity sites showed the same 38% increase in branch size as was shown when comparing average branch size.

Table 20. Average relative maximum branch diameter (RMBD) (cm/m) by test site and provenance. N=number of trees.

Test Site	Champ			Larch			Marl			Overall		
	MBD	RMBD	N	MBD	MXBD	N	MBD	MXBD	N	MBD	MXBD	N
Indian Pt	2.0	0.25	137	2.3	0.26	122	2.2	0.25	147	2.2	0.25	406
Mission Cr	1.9	0.24	158	2.1	0.23	171	2.1	0.25	161	2.0	0.24	490
Moffat Lk	1.9	0.37	84	2.4	0.40	103	2.1	0.34	128	2.1	0.37	315
Pennask Lk	1.6	0.29	161	2.0	0.32	150	1.9	0.33	175	1.8	0.31	486
Overall	*1.8*	*0.28*	*540*	*2.2*	*0.29*	*546*	*2.1*	*0.29*	*611*	*2.0*	*0.29*	*1,697*

3.10.3 Provenance

There was no meaningful difference in the RMBD among provenance (Table 20, Figure 10). The largest branch size was only marginally smaller on the lower sites than the higher sites, even though the trees are much smaller. Consequently, the lower sites would have larger branches when they reach the same height as trees now have in the higher productivity test sites (assuming the branches grow at the same overall rate for the next few years).

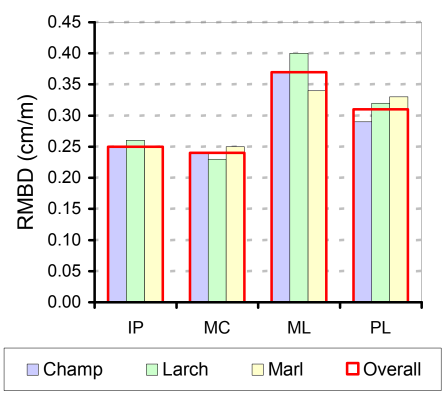

Figure 10. Relative average maximum branch diameter (RMBD) by test site and provenance. (IP= Indian Point, MC=Mission Creek, ML=Moffat Lake, PL=Pennask Lake).

3.10.4 Family

Family differences in the largest branch diameter were greater than for provenances (Table 21, Figure 10). The largest branch size for the three highest ranking families was 0.21 compared to 0.17 cm/m for the three lowest ranking families (24% difference). The difference between the highest and lowest family groups by test site was 30-40%, suggesting that some families may produce larger branches when growing on certain sites.

3.10.5 Practical Significance

The practical significance of these differences is the same as for average diameter. This information suggests there may be large differences between families in the largest branch size attained on different sites. Again, the important question is whether these differences persist to rotation or dissipate with time.

Table 21. The three families with the largest and smallest relative maximum branch diameter (RMBD) (cm/m) by test site. N=number of trees.

Indian Point			Mission Creek			Moffat Lake			Pennask Lake			Overall		
No.	N	MXBD	No.	N	MXBD	No.	N	MXBD	No.	N	MXBD	No.	N	1XBD
Largest RMBD														
1774	16	0.29	1776	17	0.27	1779	12	0.46	1673	19	0.37	1779	44	0.33
1778	13	0.29	1659	18	0.27	1769	12	0.43	1769	15	0.35	1774	64	0.33
1666	12	0.28	1649	17	0.27	1655	4	0.41	1774	15	0.35	1673	64	0.32
	41	0.29		52	0.27		28	.043		49	0.36		172	0.32
Smallest RMBD														
1658	11	0.22	1656	15	0.21	1664	10	0.31	1656	13	0.27	1665	57	0.26
1664	16	0.22	1772	16	0.21	1665	9	0.31	1658	17	0.27	1656	48	0.26
1779	2	0.21	1767	17	0.21	1670	12	0.30	1648	21	0.26	1648	61	0.25
	29	0.22		48	0.21		31	0.31		51	0.27		166	0.26
Difference :		*0.07*			*0.06*			*0.12*			*0.09*			*0.07*

3.11 Summary

Tree and branch attributes were compared for 30 Pl families (10 in each of three provenances) at 17 years of age planted at four tests sites in north and south central BC. These measurements are for relatively young trees, thus differences may increase over time and be larger at rotation than shown in this study. Conversely, observed differences could dissipate over time and not be important when trees reach rotation. These trends may also differ for trees planted in other areas, growing on different sites, planted at other densities, or in stands not having the same early thinning as was done in these progeny trials. However, given the limitations of these measurements and the possibility that they may not differ in other areas, the major conclusions from these comparisons are:

1. **Site Index & Height:** Larch Hills families consistently showed the highest site indices (up to 2 m higher) at all test sites. The best Larch Hills families were generally 2-3 m higher than the poorest performers (Champion Lakes) at all sites, and up to 4.5 m higher at one site. Height growth patterns are relatively stable over time, thus we expect these site index differences to remain constant over time. This is key information to consider with other project results to help design the next generation of seed orchards. Growth and yield models in BC already have the ability to include these site index differences; however, these results show the extreme importance of having accurate site indices when forecasting the yield of regenerated Pl stands in forest-level timber supply analysis.

2. **Diameter & Tree Form:** These results show large differences in DBH among test sites, provenances, and families when standardized to the same height. These differences suggest that some of the potential volume gain from high site index families may be offset by smaller diameters when compared to trees that grow less in height but more in diameter. More work is needed to assess this trend because we do not know if these differences will persist through time. These differences will be critical to Pl growth and yield modeling and tree breeding programs if they persist.

3. **Crown Lift & Width:** These results show potential differences in the rate of crown lift and in crown width. However, more work is needed to specifically study these trends because we do not know if these potential differences at early ages will persist over time.

4. **Number & Size of Branches:** There was no difference in the number of branches among test sites, provenances, or families; however, the results showed potentially large differences in average and

maximum branch diameter. Furthermore, there was a strong trend showing that trees on higher productivity sites may have larger branches than trees of the same height on lower productivity sites. Three Larch Hills families showed the desirable combination of among the highest overall site indices and smallest relative branch sizes. More work is also needed to study and monitor these trends over time to determine if they increase, decrease, or remain the same in magnitude.

4. GROWTH & YIELD MODELING

4.1 OVERVIEW

We used the results described in the previous section to develop three branch size scenarios. The growth and yield impacts of these scenarios were then modeled using TASS. The growth and yield results were then compared (this section) and the financial implications are described in Section 0.

4.2 YIELD TABLES

4.2.1 TASS Simulations

We used TASS[9] to model the growth and yield impact of three branch size scenarios for different initial stand densities and site indices. This was done in six steps using processes previously developed for Weyco (J.S. Thrower and Assoc. 2002). The simulations included site indices of 16, 19, and 22 m for Pl planted at 1,200, 1,600, and 2,000/ha with large, medium, and small branches. Each simulation was done for a 1.0 ha block (100 x 100 m). Predicted volume was reduced to approximate the 15% OAF1 applied in TIPSY by reducing log volumes. The impact of OAF2 was also included by reducing tree and log volumes using the same processes as used in TIPSY.

4.2.2 Bucking

The merchantable portion of each simulated tree was bucked into 5 m logs from a 30 cm stump to 10 cm top. Top logs shorter than 5.0 m were bucked into 2.5 m sawlogs and smaller logs contributed only to chip volume. Each log was then assigned to a conceptual bin (i.e., grade) based on position of the log in the tree (butt, second logs, and top logs), top end diameter, and average knot size (Table 22).

Table 22. Grade attributes for Pl logs.

Log Position	Average	Top End	Log
Butt & 2nd Logs	≤ 3/4" (1.9 cm)	≤ 6" (15 cm)	Medium
		> 6" (15 cm)	High
	> 3/4" (1.9 cm)	≤ 8" (20 cm)	Low
		> 8" (20 cm)	Medium
Top logs		≤ 8" (20 cm)	Low
		> 8" (20 cm)	Medium

4.2.3 Knot/Branch Size

4.2.3.1 The Base Model

We predicted knot (branch) size using a model previously developed for Weyco (J.S. Thrower and Assoc. 2002). This model (called *Model 1* in the original report) predicts branch size (average and maximum) at each whorl along the bole of individual trees using DBH, tree height, crown length, and distance from tree top. The model predicted well the branch sizes measured in this study (Appendix II). The model was then modified to reflect differences in the average and maximum branch size observed.

4.2.3.2 Modifications for Genetic Differences

We developed three branch size scenarios to represent reasonable expectations of branch size differences at rotation. Differences of 0.4 to 0.6 cm in the average diameter branches of 17 year-old trees were observed among families and test sites (Table 6, Table 18, Table 19). Given that these branches will likely increase in size before the crowns lift, the size at rotation will be greater than we currently observe. Thus, we added 0.4 cm and 0.8 cm to the average branch size and 0.6 cm and 0.9 cm to the

[9] TASS (**T**ree **A**nd **S**tand **S**imulator) is an individual tree, spatially explicit computer simulation model developed by Ken Mitchell to model the growth of individual trees in three dimensions. TASS and TIPSY are the MOF standard programs to model growth and yield in BC.

maximum branch size predicted with Model 1 to represent small, medium, and large branch sizes, respectively (Appendix II, Table 23).

Table 23. Branch sizes for the three modeled scenarios.

Branch Size	Average Diameter	Maximum Diameter
Small	0.0 cm	0.0 cm
Medium	+ 0.4 cm	+ 0.6 cm
Large	+ 0.8 cm	+ 0.9 cm

4.2.4 Lumber Recovery & Grade

The board-foot (FBM) lumber recovery of each sawlog was estimated using top-end diameter and taper (cm/m). This was done using empirical average lumber recovery factors (LRF) developed from thousands of logs scanned in the primary breakdown laser scanners in two of Weyco's BC interior mills (Figure 11).

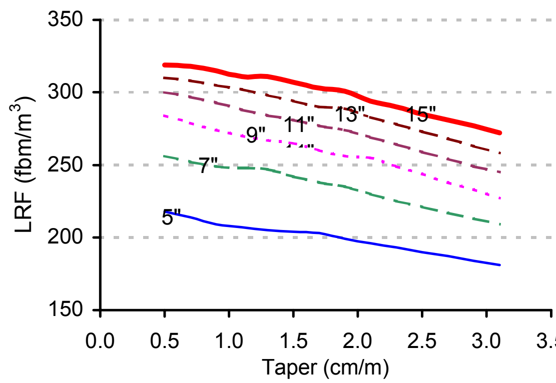

Figure 11. Lumber recovery factors for 5 m logs. These LRFs have been reduced in this graph to protect proprietary Weyco information.

Grade was then assigned to the lumber from each log using a log-lumber grade (LLG) matrix we developed with Weyco sawmill product production managers[10] (Appendix III). This matrix estimates the proportion of lumber in High, Std+Btr, and Economy[11] grade classes from each log type (bin). The LLG factors inherently include sawing method, wane, sweep, knot clusters, juvenile wood, product mix, and sawing pattern.

4.2.5 Lumber & Stand Value

Lumber value was then estimated by assigning values of $260, $350, and $440/mfbm for Economy, Standard and Better (Std+Btr), and High grade lumber, respectively (Section 0). The high-grade class includes MSR grades; Std+Btr class includes Std/No. 2+Btr; and the Economy grade includes No. 3, Utility, and Economy grade lumber. Weyco provided lumber and chip values based on current and historical trends. Chip volume was approximated using a function[12] of the empirical average LRFs and from the volume of top logs shorter than 2.5 m. Stand value was then calculated as the total of all lumber and chips ($70/BDU).

4.2.6 Output

The resulting yield tables included attributes related to stand, log, and lumber yield for the three different knot size scenarios (Appendix IV). We also used these yield tables to compare the financial impacts of the different knot size scenarios (Section 0).

4.3 STAND & LOG VOLUME

The branch size scenarios did not impact growth and yield results for stand and log volume. The TASS simulations showed the expected trends for volume where better sites grow faster, have more volume, and reach culmination of MAI sooner (Table 24). The simulations indicated that lower sites (<20 m site index) had the best overall growth at 1,600/ha establishment density.

---

[10] Mill product supply managers are Bob Sidhu at the OK Falls mill and Ben Demarni at the Kamloops sawmill.

[11] The *high grade* includes various MSR grades; *Std+Btr* includes Std/#2+Btr; and *Economy grade* includes No. 3 and Utility grades.

[12] CHIP yield (all logs) BDU/m^3 = (426–LRF) x 0.00087 (Interior Appraisal Manual, November 1, 2002).

Table 24. Summary of main growth and yield attributes at culmination age from the TASS simulations.

Establishment density	1,200/ha			1,600/ha			2,000/ha		
Site index	16 m	19 m	22 m	16 m	19 m	22 m	16 m	19 m	22 m
Merch. Volume (m^3/ha) - all trees	276	339	390	279	341	385	273	330	376
Merch. Volume (m^3/ha) - prime 500	177	219	257	159	201	231	149	188	223
Culmination age (yrs)	80	70	60	80	70	60	80	70	60
Max. MAI (m^3/ha/yr)	3.4	4.8	6.5	3.5	4.9	6.4	3.4	4.7	6.3
Stand height (m)	19.6	21.7	23.1	19.6	21.6	23	19.7	21.6	23.1
Quadratic mean DBH (cm)	22.8	24	24.9	20.4	21.5	22.3	18.6	19.8	20.9
Number of logs (no/ha)	3,161	3,560	3,694	3,798	4,116	4,291	4,164	4,431	4,500
Butt log top DIB (cm)	17.5	18.8	19.7	15.8	16.9	17.7	14.8	15.8	16.7
Butt log size (m^3)	0.16	0.18	0.19	0.13	0.14	0.16	0.11	0.12	0.14
Butt log taper (cm/m)	1.49	1.50	1.49	1.31	1.31	1.31	1.21	1.21	1.20
Lumber volume (MFBM/ha)	73	93	109	72	91	105	70	87	102
Chip volume (BDU/ha)	39	45	50	41	47	51	41	46	51
LRF (fbm/m^3)	265	273	279	259	268	273	255	264	271
Chip yield (BDU/m^3)	0.14	0.13	0.13	0.15	0.14	0.13	0.15	0.14	0.13

Note: merchantability limit was 12.5 cm DBH, 10 cm top, and 30 cm stump.

The lower densities stands have more merchantable volume in fewer and larger logs. The largest average log size (m^3) was produced at the lowest density (1,200/ha) for all site indices and the smallest logs were produced at the highest density (2,000/ha). The largest average log size from the 1,200/ha stands was about 0.16 – 0.19 m^3 at culmination of stand MAI for all site indices, and the smallest logs from the highest density regimes were about 0.11– 0.14 m^3. The larger logs also have greater taper that offsets lumber recovery gains achieved in larger logs. Lumber and chip volumes were relatively consistent across densities; high sites (site index=22m) contained 30% more lumber recovered than lower sites (site index=16 m).

Average tree and log size is important because stands with smaller pieces have marginally higher harvesting costs (i.e., more pieces to handle). The increases are from slightly higher felling and forwarding costs, which have been greatly reduced in recent years with modern multi-grip harvesters. The results indicate that high-density stands with smaller logs have more lineal length to process affecting mill productivity, as more throughout is needed to process the same amount of volume.

4.4 LUMBER GRADE RECOVERY & PRODUCT VALUE

The differences in branch size impact lumber value by changing log grades through the LLG matrix. The simulation results showed that most high-grade lumber volume is in the higher density stands for all site indices (Figure 12). The amount of high-grade lumber decreased steadily with increasing branch size (Figure 13). This trend is expected since the grade recovery is affected by increasing knot size in the LLG matrix (Appendix III). Lower density stands produce larger logs, but also produce larger knots that result in lower recovery of the higher lumber grades.

The results showed a clear trend that small knots increase stand values (Figure 14). The differences in stand value among knot size classes increases with the differential price between high- and low-grade lumber. On average, there was a $3,000/ha difference between the small and large branching scenarios.
The highest stand value was generally achieved at 1,600/ha establishment density for all site indices.

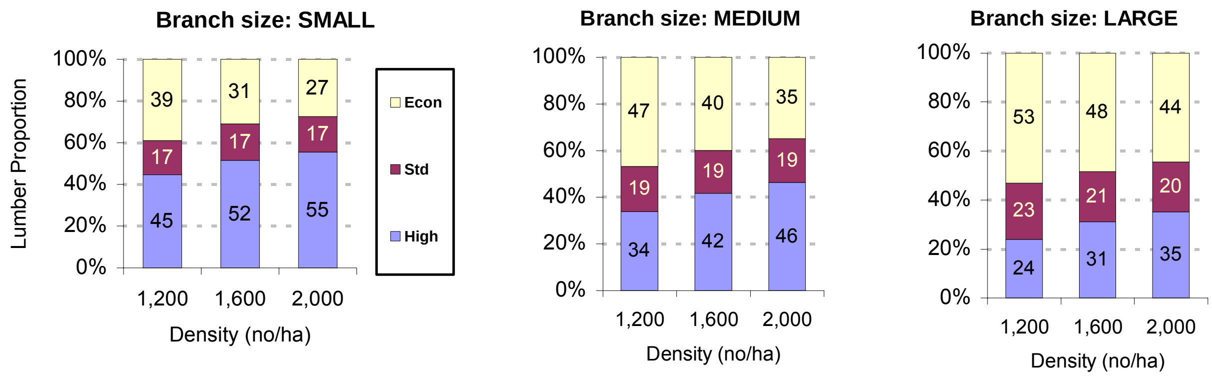

Figure 12. Lumber grade distribution by stand establishment density and branch size class (site index 19 m).

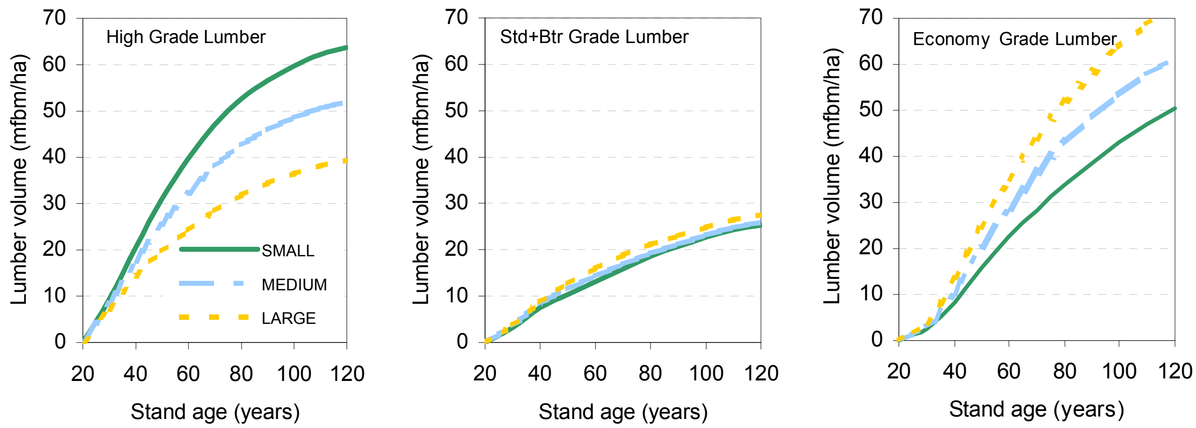

Figure 13. Volume (mfbm/ha) of high, Std+Btr and economy lumber grade by branching pattern for 1,600/ha planting density and 19 m site index.

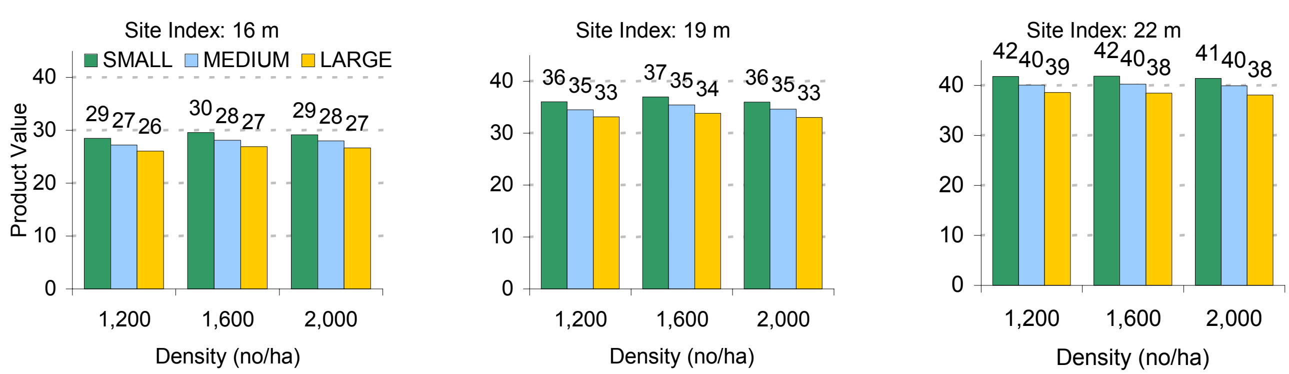

Figure 14. Product value ($ '000) by density and branching scenario at culmination age.

4.5 SUMMARY

The general conclusions from these TASS simulations are:

1. The proportion of high-grade lumber recovery increases as planting density increases, and decreases as branch size increases.
2. Most of the reduction in high-grade lumber volume from larger knots is shifted to low grade, and the proportion of Std+Btr lumber volume is largely unaffected.

5. FINANCIAL ANALYSIS

5.1 OVERVIEW

The financial analysis included 27 combinations of establishment density, site index, and branch size (Table 25). The analyses focused on the financial trade-off between volume and value. Families with high growth rates with small branches give the highest value.

Table 25. Three factors and three levels in the financial analysis.

Factor	Levels
Planting density	1200, 1600, and 2000/ha
Site index	16, 19, and 22 m
Branch size	small, medium, large

5.2 ANALYSIS

5.2.1 Site Value

The site value (SV) [13] was computed for a range of harvest ages (including financial and biological rotations), costs, and value assumptions for each scenario. The analyses were done from the perspective of a private landowner where silviculture treatments should be done to maximize financial return.

$$SV = \frac{\sum_{y=0}^{H}\left(R_y - C_y\right)(1+i)^{(H-y)}}{(1+i)^H - 1}$$

Where: R_y = revenue received in year y
C_y = cost incurred in year y
i = discount rate
H = final harvest age
and the present is time 0.

5.2.2 Costs & Values

An average (base case), low, and high value was used for each cost and value[14] (Table 26). Survey costs were also included but were not varied (Table 27).

Table 26. Costs and values for the stand level financial analyses.

	Base	Low	High
Costs			
Planting (1200, 1600, 2000)	\$0.58, \$0.54, \$0.50/tree	\$0.44, \$0.42, \$0.40/tree	\$0.68, \$0.62, \$0.56/tree
Harvesting	\$45.52/m^3	\$44.27/m^3	\$49.27/m^3
Milling	\$38.50/m^3	\$34.70/m^3	\$41.00/m^3
Values			
High (MSR grades)	\$440/MFBM	\$400/ MFBM	\$480/ MFBM
Std+Btr (Std/#2 and better)	\$350/ MFBM	\$310/ MFBM	\$380/ MFBM
Economy (#3 and utility grades)	\$260/ MFBM	\$180/ MFBM	\$290/ MFBM
Chips	\$70/BDU	\$50/BDU	\$100/BDU

13 SV is the present value of all cash flows produced by an infinite series of identically managed rotations and includes the benefits from future rotations and the cost of foregoing revenues from future rotations. Using SV (instead of net present value (NPV) of a single rotation) allows comparison of silviculture regimes with different rotation lengths.

14 Costs and values were set after discussions with Weyco to reflect a range of current average operating conditions.

5.2.3 Discount Rate

We used 4% to represent a social discount rate for BC forestry investments (Heaps and Pratt, 1989), 6% for the base case, and 8% to represent a common cost of capital for BC forestry companies.

Table 27. Silviculture survey costs and times (years after harvest).

Survey	Cost ($/ha)	Site Index		
		16 m	19 m	22 m
Regen	20	2	2	2
Stocking	15	5	5	5
Stocking	15	8	---	---
Free-growing	20	11	7	7

5.3 Results

5.3.1 Product Value

Discounted product value[15] increased with site index and decreasing branch size (Figure 15). Maximum discounted value was always reached about 40 – 50 years of age, which is about 20 – 40 years earlier than the culmination of MAI (Table 24).

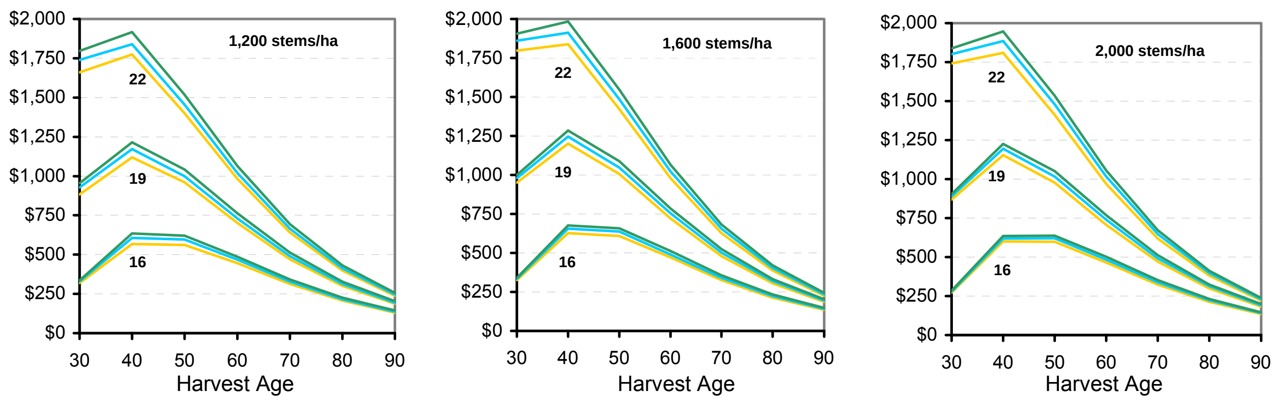

Figure 15. Discounted product value (lumber and chips) ($/ha) by harvest age, site index, and branch size (small —, medium —, large —). Discounted stand values were calculated using base case values and 6% discount rate.

The change in discounted product value was much larger for the 3 m differences in site index than for these differences in branch size. The 3 m increase in site index from 16 to 19 m increased maximum discounted product value by about $550/ha for all planting densities, and about $775/ha when increased from 19 to 22 m. The increase in discounted product value was about $90/ha between stands grown with small and large branches. The larger differences between site indices are the result of the extra volume produced on higher sites. The change in discounted product value per m^3 is almost identical for the difference between small and large branches and the 3 m difference in site index.

5.3.2 Site Value

5.3.2.1 Overall

The analyses showed that all SVs were negative under base case costs and revenues (Table 28). The only positive SVs were for a 4% discount rate with base case costs and revenues when Pl trees had small branches planted at 1200 and 1600/ha on the highest site (22 m). The negative SVs result from the discounted net profit at harvest not covering the planting costs. The maximum SV for a given site index was always with small branches and the lowest establishment density (Figure 16). This is because the

[15] Product value is the sum of lumber and chip revenues. Discounted product value = (product value)/$(1+ i)^H$

Table 28. Maximum site values using the base case cost and revenue assumptions.

SI (m)	Planting Density	Branch size Large	Medium	Small
16	1200	-$724	-$703	-$683
	1600	-$885	-$864	-$843
	2000	-$1,020	-$1,001	-$983
19	1200	-$662	-$620	-$575
	1600	-$815	-$770	-$728
	2000	-$957	-$915	-$879
22	1200	-$575	-$506	-$423
	1600	-$726	-$645	-$567
	2000	-$863	-$791	-$724

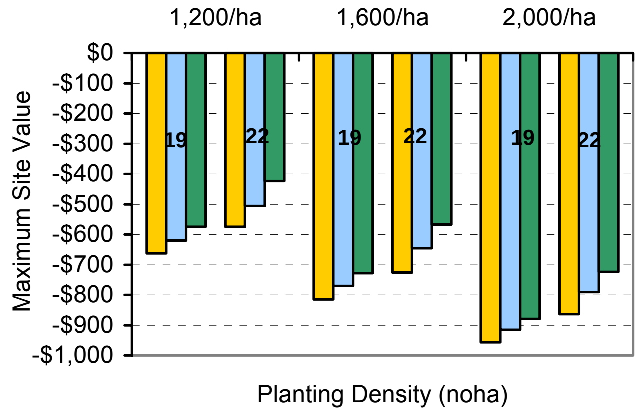

Figure 16. Maximum site value by planting density, site index (19 and 22 m) and branch size (small —, medium —, large —).

up-front planting costs are lowest at 1200/ha and the return at harvest is the highest with small branches. Absolute values change with cost and revenue assumptions but the SV relative ranking did not change.

5.3.2.2 Volume – Value Trade-Off

We compared the volume and value trade-off between Pl with small branches planted at 1200/ha for site index 19 m against site index 22 m with all branch sizes. The site index 19 m stand had only 70-80% of the volume of the 22 m stand between about 50-80 years of age; however, the lower site index stand (with small branches) had more high-grade lumber than the higher site index stand (with large branches) (Figure 17). The lower site index (and smaller branch) stand also showed more high-grade lumber after about 60 years of age than the higher site index stand with medium sized branches. However, these analyses also show that the increase in stand value from more high-grade lumber can be offset by large increases in low-grade lumber in faster growing stands.

Differences in SV between the four combinations of site index and branch size (Figure 18) varied with the lumber grades price and harvest and milling costs. Site index 22 m had higher SVs with medium and small branches than with large branches, and higher SVs than site index 19 m with small branches. The relative ranking of the site index 22 m large branch stand and the site index 19 m small branches stand

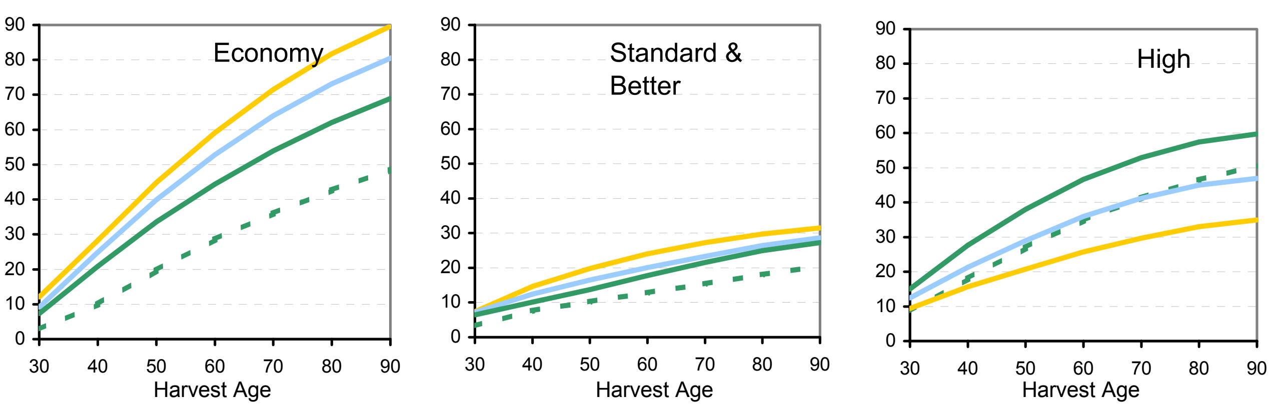

Figure 17. Lumber volumes (MFMB/ha) by grade, harvest age, and branch size (small —, medium —, large —). For site index 22 m (solid lines) and site index 19 m (dashed line) planting at 1,200/ha.

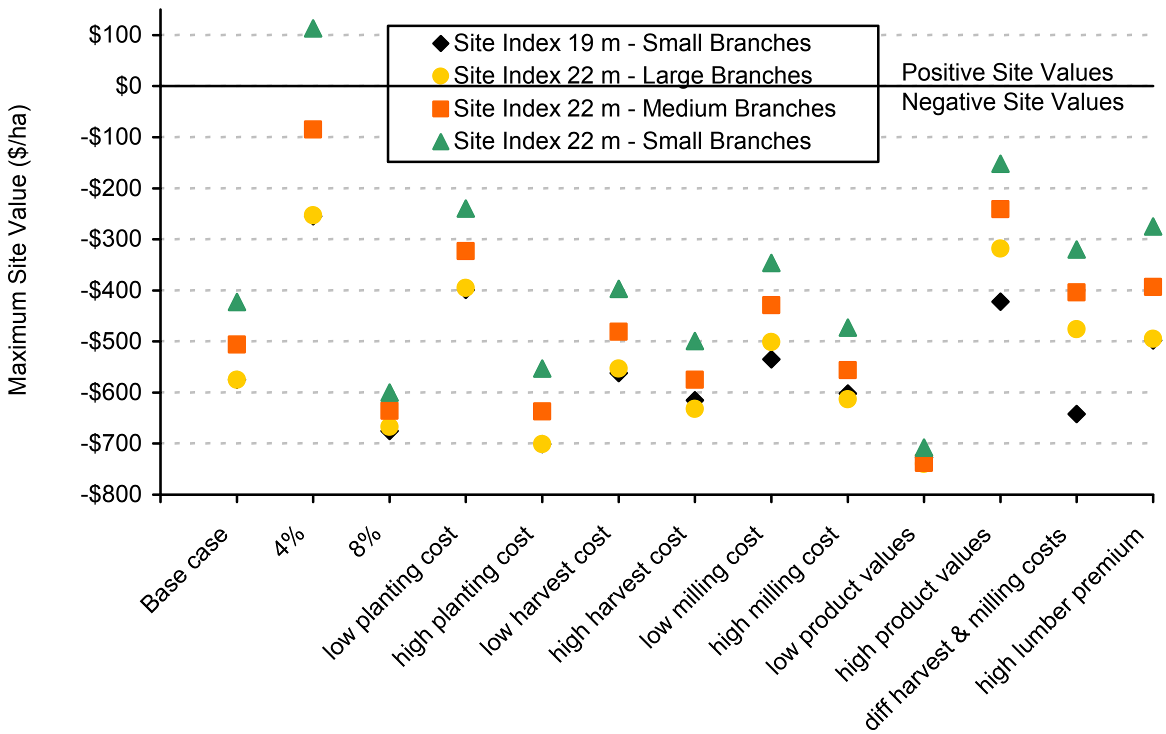

Figure 18. Sensitivity of site value calculations to changes in costs and values. In the “diff harvest & milling costs” scenario, the site index 19 stand is assigned high harvest and milling costs and the site index 22 stands are assigned low harvest and milling costs. In the “high lumber premium” scenario, the base case revenues are used except the value of high lumber is raised to $500/MFBM.

changes with cost and revenue assumptions (Figure 18). In most cases, SVs are similar indicating that the higher volume of high-grade lumber for site index 19 m is offset by the increased volume of Economy and Std+Btr lumber at site index 22 m. The largest difference in SV for these two combinations is caused by lowering the cost of harvest and milling at site index 22 m and with the highest lumber values (Figure 18).

The maximum SV for a site index 19 m stand with small branch trees planted at 1200/ha (point A in Figure 19) shows the same SV as a site index 20.2 m stand with medium branches (point B) and a site index 22 m stand with large branches (point C) (Table 29). Likewise, a site index 16 m stand with small branches shows a higher SV than a site index 18 m stand with large branches. These trends are the same for the higher density stand planted at the 2000/ha (Figure 19), but the differences in site index are slightly less than at the lower density stands.

This graph also shows the loss in SV from larger branches between stands with the same site index. For example, Pl planted at 1200/ha on site index 21 shows SVs of -$475, -$545, and -$605 for small, medium and large branches, respectively (indicated by solid circles at site index 21 m in Figure 19). This is a loss of $70/ha when moving from small to medium branches and $130/ha when compared to large branches.

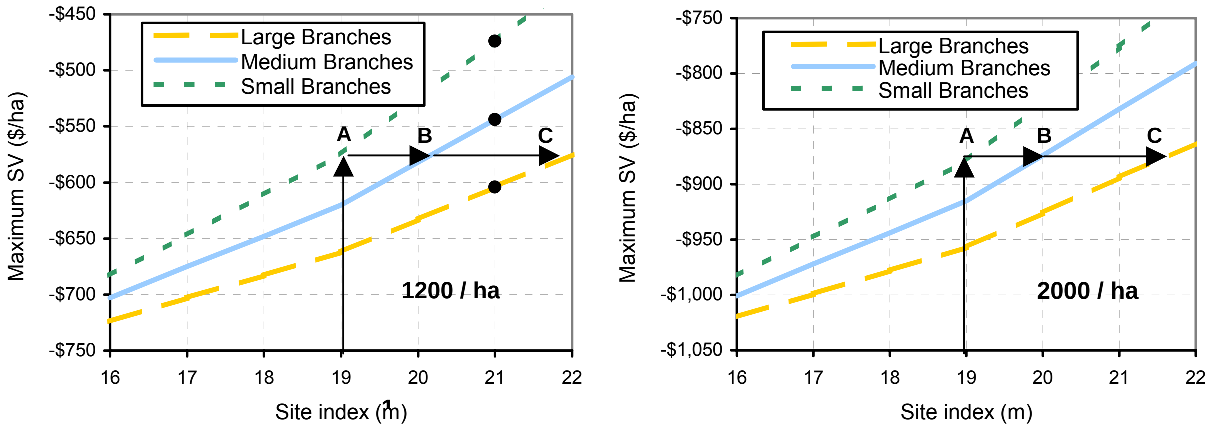

Figure 19. Maximum SV by site index for different branch sizes for Pl planted at 1200 and 2000/ha. Base case costs and values, 6% discount rate. Note the two graphs have different SV axes.

Table 29. Interpolated maximum SV for site indices 17, 18, 20 and 21 using base case costs, values, and 6% discount rate.

Site Index (m)	Branch size								
	Large	Medium	Small	Large	Medium	Small	Large	Medium	Small
	1200 / ha			*1600 / ha*			*2000 / ha*		
16	-$724	-$703	-$683	-$885	-$864	-$843	-$1,020	-$1,001	-$983
17	-$703	-$675	-$647	-$862	-$833	-$805	-$999	-$972	-$948
18	-$683	-$648	-$611	-$838	-$801	-$766	-$978	-$944	-$914
19	-$662	-$620	-$575	-$815	-$770	-$728	-$957	-$915	-$879
20	-$633	-$582	-$524	-$785	-$728	-$674	-$926	-$874	-$827
21	-$604	-$544	-$474	-$756	-$687	-$621	-$894	-$832	-$776
22	-$575	-$506	-$423	-$726	-$645	-$567	-$863	-$791	-$724

5.4 Summary

These results show that the best financial return is from the fastest growing Pl stands with the smallest branches. These results also show that slower growing stands with less volume can make up the difference in stand value through higher quality lumber. However, stands with significantly higher growth (by 2-3 m of site index) may show more value because the much larger volume of low-grade lumber offsets the loss of high value lumber compared to the slower growing stand.

Using the base case cost and revenue assumptions in a 1200/ha stand, an increase in site index of 1 m can be accompanied by a average branch size increase of approximately 0.3 – 0.4 cm without a decrease in SV. This also results in

If branch size increases more than this, the SV will be decreased. Conversely, if the volume gain is accompanied by a smaller increase in branch size the SV will be increased.

6. CONCLUSIONS

6.1 PROGENY TEST SITE MEASUREMENTS:

The major conclusions from measuring tree and branch attributes for the 30 Pl families across four test site locations are:

1. There are large differences in **site index** among provenances and families. The Larch Hills families consistently showed the highest site index at all test sites and was generally 2-3 m higher than the poorest performing families (Champion Lakes). Height growth patterns are relatively stable over time, thus these differences should be maintained for the life of these stands. These differences may be of concern to practical silviculture in selecting seedlots for planting. Growth and yield models used in BC (e.g., TASS and TIPSY) can incorporate these growth differences if accurate estimates of site index are available for stands of different genetic origin. These differences highlight the extreme importance of having accurate site indices for Pl stands when including growth and yield projections in forest level timber supply analysis.
2. There are large relative differences in **tree diameter** among families when measurements are standardized to the same tree height. These differences in tree form could result in a 10-15% increase in stand volume at rotation (assuming all else is equal). These potentially different tree forms can dramatically alter stand dynamics and yield, and thus is of keen interest to growth and yield modeling; however, we don’t know if these trends for young stands will persist to rotation.
3. There may be significant meaningful differences in **crown width** and the rate of **crown lift**; however, again we don’t know if these differences will persist to rotation. These differences could result in different stand dynamics and yield, thus will be of interest to all aspects of Pl management if they persist to later stages of stand development.

6.2 GROWTH AND YIELD IMPACTS

The major conclusions from modeling three different branch size scenarios developed from the Pl measurements are:

1. The recovery of **high-grade lumber** increases as establishment density increases, and decreases as branch size increases. These simulation results confirm the anecdotal observations and expectations that higher density stands produce more high value lumber.
2. **Stand value** increases as site index increases and branch size decreases. Stands with higher site indices yield substantially more lumber volume than lower sites. In these simulations, the 22 m site index stands with large branches had a higher stand value than a 19 m site index stand with small branches. This suggests that a large increase in site index (3 m in this example) can offset the loss of higher grade lumber from having large branches.

6.3 FINANCIAL IMPACTS

The major conclusions from using the simulated product recovery from the growth and yield simulations of three site indices (16, 19, 22 m), three branch sizes (small, medium, large) and three planting densities (1200, 1600, 2000 stems/ha) are:

1. **Site Values** are negative using discount rates of 6 and 8% because the discounted net harvest profit does not cover planting cost.

2. Positive **Site Values** were obtained for site index 22 m, small branches, and 1200 or 1600/ha using average cost and revenue assumptions with a 4% discount rate. The maximum SV for all site indices was with the small branches and the lowest establishment density.
3. The loss in **product value** from larger branches can be offset with higher growth rates. In addition, faster growth rates give shorter rotations that improve financial return as planting costs are carried for a shorter period. Increasing branch size from small to medium and medium to large requires about 1.0 m and 1.5 m increases in site index respectively to maintain **Site Values**.

7. LITERATURE CITED

Ballard, L.A. and Long, J.N. 1988. Influence of stand density on log quality of lodgepole pine. Can. J. For. Res. 18:911-916.

Heaps, T. and Pratt, B. 1989. The social discount rate for silviculture investments. B.C. Ministry of Forests, Forestry Canada, Forest Resources Development Agreement. FRDA Rep. 071.

J.S. Thrower and Associates Ltd. 1999. A pilot study of branch size in post-harvest regenerated lodgepole pine stands in the Merritt and Kamloops areas. Contract report to Weyerhaeuser Canada Ltd., BC. 17 pp. JST Project WCK-048.

J.S. Thrower and Associates Ltd. 2000. Lodgepole pine log taper in trees from low-density fire-origin SBS stands. Contract report to Weyerhaeuser Canada Ltd., Merritt, BC. 10 pp. JST Project WCK-058.

J.S. Thrower and Associates Ltd. 2001a. Branch and taper measurements in the EP671 lodgepole pine espacement trial. Contract report to Weyerhaeuser Canada Ltd., Merritt, BC. 7 pp. JST Project WCM-013.

J.S. Thrower and Associates Ltd. 2001b. Branch and taper measurements in the Gregg Burn lodgepole pine spacing trial. Contract report to Weyerhaeuser Canada Ltd., Merritt, BC. 7 pp. JST Project WCM-014.

J.S. Thrower and Associates Ltd. 2002. A prototype model to predict lumber grade and value from TASS simulated lodgepole pine stands. Contract report to Weyerhaeuser Company Ltd., Kamloops BC. March 31, 2002. 28 pp. JST project WCK-084.

Maguire, D.A., Johnston, S.R., and Cahill, J. 1999. Predicting branch diameters on second-growth Douglas-fir from tree-level descriptors. Can. J. For. Res. 29:1829-1840.

Mäkinen, H. and Colin, F. 1999. Predicting the number, death, and self-pruning of branches in Scots pine. Can. J. For. Res. 29:1225-1236.

O'Neill, G., Carlson, M., Murphy, J., and Berger, V. 2003. Growth and form in lodgepole pine. Contract report submitted to FII as part of this project.6 pp. + figures and tables.

Roeh, R. and Maguire, D.A. 1997. Crown profile models based on branch attributes in coastal Douglas-fir. For. Ecol. Manag. 96:77-100.

APPENDIX I – STATISTICAL COMPARISON

Overview

The main question addressed in the statistical analysis of the growth and yield attributes is:

Are there statistical differences in tree and branch attributes among provenances or families?

The analysis followed a sequence of testing for effects of test site, provenance, families, and interactions. The large number of trees measured in these trials resulted in small standard errors, thus even small differences in these attributes were statistically significant.[16] For example, significant differences were detected for test sites, provenances, and families for many tree and branch attributes.

Methods

Statistical differences between tree and branch attributes among test sites, provenances, and families were tested using analysis of variance (ANOVA) (Table 30). The experimental design of the test series was a randomized complete block (RCB) replicated at four locations.[17] At each location, there were eight blocks, three provenances, and 10 families per provenance (240 experimental units). The number of surviving families in each provenance varied from 5 to 10. There were one to four trees measured in each experimental unit for a total of 1,697 trees (1.9 trees/experimental unit). The statistical model for the experimental design is:

Table 30. Attributes compared using statistics analysis.

Tree Attribute
Tree Attributes
1. Site index
2. Tree height
3. DBH
4. Years to breast height
5. Height to live crown
6. Crown width
Branch Attributes
1. Number of Branches/Whorl
2. Avg. Branch Diameter – Whorls 1-3
3. Max. Branch Diameter – Whorls 1-3

$$Y_{ijklm} = S_i + B(S)_{ij} + P_k + F(P)_{kl} + SP_{ik} + SF(P)_{ikl} + \text{Exper. Error} + \text{Sampling Error}$$

where *Y* = attribute of interest; *S* = site effect (i=1,…,4); *B* is the block effect (j=1,…,8); *P* = provenance effect (k=1,…,3); *F* = family effect (l=1,…,10). The provenance and test site effects are cross-classified (all provenances appear at all locations). The family effect is nested within the provenance effect, and the block effect is nested within the test site effect.

The experimental error must first be tested against the sampling error, and pooled if not significantly different. The interaction between test site and family, *SF(P)* is then tested against the experimental error, and test site effects (*S*) tested against the *B(S)* term. If there is no interaction between test site and family (i.e., the *SF(P)* term is not significant), the family effect *F(P)* can be tested against the experimental error, and the interaction between test site and provenance *(SP)* can be tested against the *SF(P)* term. If the *F(P)* term is not significant, then the provenance effect can be tested against the *F(P)* term.

Table 31. Model effect tests with corresponding error terms and situation when the test is meaningful.

When	Source	Error
Always	Exper. error	Sampl. error
Always	S	B(S)
Always	SF(P)	Exper. error
If SF(P) is not significant	F(P)	Exper. error
If SF(P) is not significant	SP	SF(P)
If F(P) is not significant	P	F(P)

[16] A 95% significance level was used for all statistical tests in this report.

[17] This design is also called split-plot in space in the statistical literature.

ANOVA Results

Tree Attributes

The experimental and sampling errors were not pooled because the ANOVA showed they were always significantly different (Table 32). The test site effect was also significant for all attributes meaning environmental condition impacted the attributes. Tree attributes were not uniquely influenced by the genotype, which is expected because these test sites were purposively selected to test different environmental conditions.

Table 32. ANOVA significance (*p*) values of the model effects for the tree attributes.

Source	Exp. Error	S	SF(P)	F(P)	SP	P
Site Index (m)	0.027	0.000	0.006			
Total Height (m)	0.000	0.000	**0.264**	0.000	0.000	
DBH (cm)	0.000	0.000	**0.691**	0.000	0.002	
Years to BH	0.000	0.000	**0.478**	0.001	**0.060**	
Height to Live Crown (m)	0.000	0.000	0.024			
Crown Width (m)	0.000	0.000	**0.145**	0.000	**0.130**	

Note: Non-significant effects are in bold. Highlight indicates effects where no meaningful test could be performed.

There was no significant interaction between test site and family for height, DBH, years to breast height, and crown radius; however, the interaction was significant for site index and height to live crown. This means there was less variability in site index than in height and age. Once height is standardized to a common reference age (i.e., site index), variability decreases and the interaction between family and test sites becomes significant. DBH and crown radius responded similarly, which was expected since these two attributes are strongly correlated. Families also responded similarly across all sites for these two attributes.

There were significant differences among families for all attributes. There was no interaction between test site and provenance for years to breast height and crown radius, but there was a significant interaction for height and DBH. No conclusion can be drawn about the provenance for any of the tree attributes.

Branch Attributes

The experimental error was not significantly different from the sampling error for the maximum branch size and the number of branches, thus the two errors were pooled into one experimental error for these attributes (Table 33). The test sites effect was significant for all attributes while the interaction between family and test site was not significant. This means that while environmental conditions had an impact on branch attributes, families responded similarly across test sites.

Table 33. ANOVA significance (*p*) values of the model effects for the branch attributes.

Source	Exper. Error	S	SF(P)	F(P)	SP	P
Number of Branches - All Whorls (cm)	**0.370**	0.000	**0.278**	0.000	**0.523**	
Average Branch Size - Whorls 1-3 (cm)	0.009	0.000	**0.464**	0.000	0.001	
Maximum Branch Size - Whorls 1-3 (cm)	**0.100**	0.000	**0.822**	0.000	0.000	

The family within provenance effect was significant for all branch attributes suggesting there are families with larger or more numerous branches. The interaction between provenance and test site was significant for average and maximum branch size. This means that at least one provenance showed different results at the different test sites. There was less variation when the data were analyzed by provenance than by family. This means that a family-test site interaction could not be detected but the provenance-test site was significant. No conclusion can be drawn about the provenance for any of the branch attributes.

Spearman Correlation Results

The next step was to examine the relationship in the response of families among attributes. The relative response was considered more important than the absolute response. Therefore, rather than measuring the correlation between attributes, the correlation between the ranking of the families for two attributes was measured. This analysis showed that if the best family for one given attribute is also the best family for another attribute.

We ranked the attributes for each family within provenances from the largest (rank=1) to smallest (rank=10) and computed a Spearman correlation matrix to measure the similarity between ranks. High correlation means that the same families tend to be above average for both compared attributes, and low correlations mean that good families for one attribute tend to be below average for the other attribute.

Correlation Among Tree Attributes

As expected, site index and height ranks were strongly correlated among all provenances (Table 34). Height and DBH were correlated for the Champion Lakes and Larch Hills provenances, but not for the Marl Creek provenance. Normally taller trees also have the largest diameters, but families in Marl Creek with large diameter were shorter compared to the average. Height and years to breast height were generally negatively correlated. This means that taller trees reached breast height faster than shorter trees. This indicates that taller trees today were also taller when trees reached breast height.

Height to live crown was not correlated to any attribute for the Champion Lakes and Marl Creek provenances. For Larch Hills, however, height to live crown was strongly correlated to site index and height. The tallest trees for these provenances also had a more pronounced crown lift. Crown radius was strongly correlated to DBH for Champion Lakes and Larch Hills, but not for Marl Creek. This could be the result of the poor correlation between height and DBH in Marl Creek.

Correlation Branch Attributes

Branch size measures were also strongly correlated among families (Table 34). The number of branches was poorly correlated with average and maximum branch size for Champion Lakes and Larch Hills. This means that families with a higher number of branches were not necessarily the families with the smallest branches. This counter-intuitive result is probably due to variability in the number of branches and branch size.

Correlation Between Tree & Branch Attributes

DBH and height were positively correlated with average and maximum branch diameter in all provenances. This means that families of larger trees also have larger branches. This is expected as families with the widest and longest crowns have the largest branches.

Table 34. Spearman correlation matrix for tree and branch attributes with significant family within provenance effect.

Provenance	Attribute	Tree Height	DBH	Years to Breast Height	Crown Radius	Height to Live Crown	Average Branch Diameter	Maximum Branch Diameter	Number of Branches
Champion Lakes	Site index	**83%**	**65%**	-26%	**76%**	4%	**53%**	**59%**	20%
	Height		**87%**	**-71%**	**87%**	21%	41%	47%	-2%
	DBH			**-72%**	**87%**	4%	45%	48%	21%
	Years to BH				**-54%**	-14%	-33%	-37%	37%
	Crown Width					-9%	**58%**	**58%**	13%
	Height to Live Crown						**-50%**	-42%	-1%
	Avg. branch							**98%**	-10%
	Max. branch								-5%
Larch Hills	Site index	**90%**	25%	-12%	-4%	**59%**	12%	-14%	-3%
	Height		**55%**	-42%	21%	**79%**	27%	16%	1%
	DBH			**-83%**	**72%**	48%	72%	**85%**	9%
	Years to BH				**-50%**	-41%	**-56%**	**-76%**	-12%
	Crown Width					20%	**81%**	**81%**	**58%**
	Height to Live Crown						-8%	4%	18%
	Avg. branch							**87%**	25%
	Max. branch								12%
Marl Creek	Site index	**71%**	24%	10%	-5%	18%	-4%	8%	-20%
	Height		21%	-49%	22%	44%	4%	5%	2%
	DBH			-5%	26%	2%	18%	16%	36%
	Years to BH				-32%	-44%	-14%	-4%	-1%
	Crown Width					-36%	**89%**	**82%**	12%
	Height to Live Crown						**-54%**	**-52%**	-7%
	Avg. branch							**92%**	-18%
	Max. branch								1%

Note: Correlations greater (smaller) than 50% (-50%) are in bold.

APPENDIX II – BRANCH & KNOT MODELING

Overview

We modeled the differences in branch size among seed sources using a model we previously developed for Weyco (J.S. Thrower and Assoc., 2002). We compared our two models to determine which would be the most appropriate method for this study. Model 1 predicts the branch diameter of each whorl in the live crown using tree attributes only. Model 2 predicts branch diameter in the first 5 m log using only initial stand density. We subsequently modified Model 1 to incorporate the different branch sizes related to seed source.

Model 1: Predicting Branch Diameter Profile within the Live Crown

Model Review

A quadratic function without intercept predicted well the branch diameter profile in the previous studies (Figure 20). This is confirmed by other researchers who generally used segmented polynomial functions to predict branch diameters at each whorl (Roeh and Maguire, 1997; Maguire et al., 1999; Mäkinen and Colin, 1999). Our model predicts the height where the largest branch occurs. Knowing this "peak" of the function (i.e., largest branch size) and its location (height from ground) allows for an analytical solution of the quadratic function.

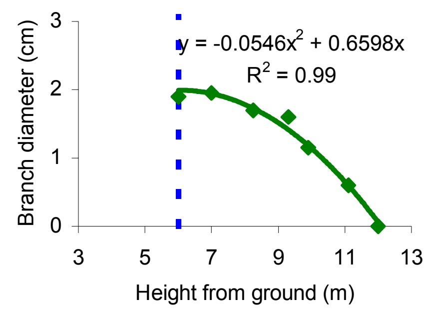

Figure 20. Branch diameter profile in the live crown. Dashed line indicates crown base.

Thus, modeling branch diameter profile in the crown depends on our ability to predict the largest branch size and the height where it occurs. Based on graphical and statistical analyses we found that Equation [1] using RECL and DBH as predictor variables provided consistent, stable, and significant parameter estimates for the average and maximum branch diameters. Equation [1] is a variation of the combined exponential and power function.

$$[1] \quad BD_{peak} = b_0 * DBH^{b_1} * e^{b_2 * RELCL}$$

Where

BD_{peak}	=	Largest average or maximum branch diameter (cm) within the live crown.
DBH	=	Diameter at breast height (cm).
RELCL	=	Relative crown length (%).
b_0-b_2	=	Model parameters.

The root mean squared error (RMSE) for Model 1 was 3 mm when predicting the average and maximum branch diameters.[18]

Model Performance

Overall

Model 1 predicts branch size within the live crown, thus could only be tested against live branch whorls in this study. More than 2/3 of the trees measured in this project met this requirement. Comparison of actual and predicted knot sizes shows that Model 1 predicted the average and maximum branch size within 0.1 cm (Table 35).

---

[18] Model 1 was developed from branch data collected in untreated PHR Pl stands in the Merritt and Kamloops areas.

The difference between observed and predicted branch size was significantly different in all whorls;[19] however, as shown in previous sections, statistical significance does not imply practical importance. Therefore, we tested the absolute difference between actual and predicted diameter for being greater than 10% of actual value.[20] None of these differences were significant, indicating that Model 1 predicts branch diameter within 10% of the observed averages in the first three whorls.

Provenance

Comparisons of actual and predicted branch sizes showed similar results as the overall comparison. The model mostly over-predicted branch size, but differences were generally within 0.1 cm (Table 36, Table 37, and Table 38).

Table 35. Actual and predicted branch sizes using Model 1 for the average and maximum branch diameters.

Crown base below:	Whorl Near 1.0 m			Whorl Near 2.0 m			Whorl Near 3.0 m		
	Actual	Pred.	Diff.	Actual	Pred.	Diff.	Actual	Pred.	Diff.
Average Branch Size (cm)									
Whorl 1	1.2	1.3	0.1	1.4	1.5	0.1	1.5	1.5	0.0
Whorl 2	1.0			1.3	1.4	0.1	1.4	1.4	0.0
Whorl 3	1.2			1.4			1.8	1.8	0.0
Maximum Branch Size (cm)									
Whorl 1	1.6	1.5	-0.1	1.8	1.8	0.0	1.8	1.8	0.0
Whorl 2	1.3			1.6	1.7	0.1	1.8	1.7	-0.1
Whorl 3	1.5			1.7			2.2	2.2	0.0

Table 36. Actual and predicted branch sizes using Model 1 for the Champion Lakes trees.

Crown base below:	Whorl Near 1.0 m			Whorl Near 2.0 m			Whorl Near 3.0 m		
	Actual	Pred.	Diff.	Actual	Pred.	Diff.	Actual	Pred.	Diff.
Average Branch Size (cm)									
Whorl 1	1.0	1.2	0.2	1.2	1.4	0.2	1.2	1.3	0.1
Whorl 2	0.9			1.1	1.2	0.1	1.1	1.2	0.1
Whorl 3	1.1			1.3			1.7	1.7	0.0
Maximum Branch Size (cm)									
Whorl 1	1.3	1.4	0.1	1.5	1.6	0.1	1.5	1.5	0.0
Whorl 2	1.2			1.5	1.5	0.0	1.4	1.4	0.0
Whorl 3	1.4			1.6			2.1	2.0	-0.1

Table 37. Actual and predicted branch sizes using Model 1 for the Larch Hills trees.

Crown base below:	Whorl Near 1.0 m			Whorl Near 2.0 m			Whorl Near 3.0 m		
	Actual	Pred.	Diff.	Actual	Pred.	Diff.	Actual	Pred.	Diff.
Average Branch Size (cm)									
Whorl 1	1.4	1.3	-0.1	1.5	1.6	0.1	1.6	1.6	0.0
Whorl 2	1.1			1.3	1.5	0.2	1.5	1.5	0.0
Whorl 3	1.3			1.5			2.0	1.9	-0.1
Maximum Branch Size (cm)									
Whorl 1	1.8	1.5	-0.3	2.0	1.8	-0.2	2.0	1.9	-0.1
Whorl 2	1.4			1.7	1.7	0.0	1.7	1.8	0.1
Whorl 3	1.7			1.9			2.4	2.3	-0.1

[19] We used t-tests to assess the significance of prediction bias (actual minus predicted branch diameter).

[20] We used 10% as the benchmark for practical considerations and measurement precision of branch and knot size.

Table 38. Actual and predicted branch sizes using Model 1 for the Marl Creek trees.

Crown base below:	Whorl Near 1.0 m			Whorl Near 2.0 m			Whorl Near 3.0 m		
	Actual	Pred.	Diff.	Actual	Pred.	Diff.	Actual	Pred.	Diff.
Average Branch Size (cm)									
Whorl 1	1.3	1.4	0.1	1.5	1.6	0.1	1.6	1.6	0.0
Whorl 2	1.0			1.4	1.5	0.1	1.5	1.5	0.0
Whorl 3	1.2			1.4			1.8	1.9	0.1
Maximum Branch Size (cm)									
Whorl 1	1.6	1.6	0.0	1.9	1.9	0.0	2.0	1.9	-0.1
Whorl 2	1.3			1.7	1.8	0.1	1.9	1.8	-0.1
Whorl 3	1.5			1.7			2.2	2.2	0.0

All statistical tests were significant. Testing whether the absolute difference was greater than 10% showed that average branch diameter for the Champion Lakes provenance was slightly over-predicted in Whorls 1 and 2 (1.7 and 1.5 mm, respectively). Maximum branch diameter was under-predicted for the Larch Hills provenance in Whorl 1 (0.3 cm). The latter difference was large and not expected and more detailed examination of the data did not reveal any anomalies that might explain this deviation.

Generally, there was good agreement between Model 1 predictions and actual averages by provenance, thus the residual error would not be reduced by calibrating the model by provenance. The observed absolute differences in branch size between the Champion Lakes and Larch Hill provenances are explained well by the model. This is because the model accounts for tree size differences between these provenances.

Family

There was more variability in branch size by family (Table 39), thus calibrating the branch model by family should reduce residual error. However, these data did not include full crown measurements and thus the model could not be calibrated to these data.

Table 39. Examples of the largest differences between actual and predicted branch sizes using Model 1 for selected families.

Crown base below:	Whorl Near 1.0 m			Whorl Near 2.0 m			Whorl Near 3.0 m		
	Actual	Pred.	Diff.	Actual	Pred.	Diff.	Actual	Pred.	Diff.
Family 1657 – Over-Prediction of Average Branch Size									
Whorl 1	1.2	1.3	0.1	1.4	1.6	0.2	1.3	1.5	0.2
Whorl 2	1.0			1.1	1.4	0.3	1.2	1.3	0.1
Whorl 3	1.0			1.2			1.4	1.7	0.3
Family 1648 – Over-Prediction of Maximum Branch Size									
Whorl 1	1.4	1.6	0.2	1.7	1.9	0.2	1.8	1.9	0.1
Whorl 2	1.0			1.3	1.6	0.3	1.4	1.6	0.2
Whorl 3	1.4			1.6			2.1	2.2	0.1
Family 1776 – Under-Prediction of Average Branch Size									
Whorl 1	1.5	1.3	-0.2	1.6	1.6	0.0	1.9	1.6	-0.3
Whorl 2	1.0			1.4	1.4	0.0	1.4	1.4	0
Whorl 3	1.5			1.6			2.1	1.9	-0.2
Family 1774 – Under-Prediction of Maximum Branch Size									
Whorl 1	2.2	1.7	-0.5	2.0	2.0	0.0	2.3	2.0	-0.3
Whorl 2	1.4			2.0	1.9	-0.1	2.0	1.9	-0.1
Whorl 3	1.6			1.8			2.6	2.4	-0.2

Discussion

Model 1 predicts branch diameters well overall and for provenances. The model predicts branch size using tree size attributes, thus accounts for the observed differences in tree size among provenances and families. The source of prediction error cannot be assessed with these data as only partial crown measurements were taken. Calibrating Model 1 would require full crown measurements to assess the size and location of the largest branch diameters within tree crowns. Some families may have different crown profiles, thus our assumptions about the location of the largest branch and about using the quadratic function to describe the profile might have to be adjusted for these differences. Previous studies have shown that the location of the largest branch is related to crown length (Table 40). The location of the maximum branch diameter varies among trees because of differences in how crowns interact, genetics, and chance events; however, it is generally close to the base of the live crown (Mäkinen and Colin, 1998; Maguire *et al*., 1999).

Table 40. Location of the peak diameter.

Relative Crown Length Class	Relative Distance from Apex
0.0 - 0.4	1.00
0.4 - 0.6	0.89
0.6 - 0.8	0.80
0.8 - 1.0	0.73

We checked the agreement between predicted largest branch size and location of the widest point in the crown based on the partial crown measurements of this study. There was good agreement between the findings of previous studies and the current study (Table 41). We also confirmed that the location of the largest branch is practically the same for the average and maximum diameters and there is no apparent trend by provenance.

Table 41. Location of the largest average (Avg) and maximum (Max) branch in the crown.

RCL Class	Champ		Larch		Marl		Overall	
	Avg	Max	Avg	Max	Avg	Max	Avg	Max
0.4-0.6	0.86	0.88	0.93	0.93	0.89	0.85	0.88	0.88
0.6-0.8	0.77	0.77	0.81	0.81	0.82	0.81	0.80	0.80
0.8-1.0	0.63	0.62	0.67	0.68	0.68	0.67	0.66	0.66

Model 2: Predicting Branch Diameter in the Butt Log

Model Review

Model 2 predicts branch diameter in the first 5 m (butt) log using only stand establishment density. The first log is important because it contains a high proportion of stem volume and value. Separate models were originally developed for three data sources (EP-671 espacement trial, Gregg Burn spacing trial, and Merritt branch study). The non-linear power function provided the best model form to describe the relationship between branch diameter and establishment density. This was consistent with findings by Ballard and Long (1988). Other researchers found the relationship between tree spacing and branch diameter is approximately linear. Since density is expressed as the number of trees per unit area, assuming square spacing will result in consistent estimates with regards to the linear relationship between initial spacing and branch diameter.

The early spacing from 4,444 to 2,222/ha at age 10 and 11 years should not affect these branch measurements as tree crowns had not started to lift significantly. For testing model performance, the initial stand density was therefore set at 2,222/ha. We used the branch models previously developed for the EP-671 espacement trial (Figure 21) where provenance 28 (Red Rock, BC) was planted. The EP-671 may relate better to our study as the Gregg Burn spacing trial and Merritt branch study areas were from naturally regenerated stands.

Two limitations of the study data are that Model 2 describes the average and maximum branch diameter of the 5 m butt log and these data only include measurements in the first three whorls (up to 3 m). Furthermore, the branches in this study are alive and are still growing thus may increase in size. However, some Pl branches may stop growing and thus may not increase in size for several years before they die (J.S. Thrower & Assoc., 1999).

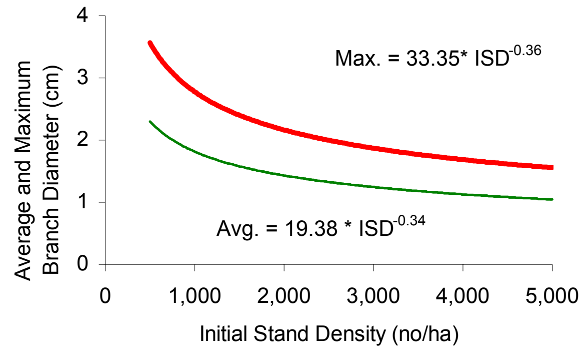

Figure 21. Model 2 for EP-671 for average (Avg) and maximum (Max) branch diameter. ISD= initial stand density.

Model Performance

Overall

There is a statistically significant difference between the actual (1.30 cm) and predicted (1.38 cm) average branch diameter (p=0.000). Results were the same for actual and predicted maximum branch diameter (2.02 and 2.08 cm, respectively). Testing whether these differences were greater than 10% suggests that, overall Model 2 predicts average and maximum branch diameters well (Table 42).

Table 42. Model 2 performance by provenance.

Provenance	Avg. Branch Diam. (cm)	Max. Branch Diam. (cm)	N
Champ	**1.19**	**1.84**	540
Larch	1.36	2.15	546
Marl	1.34	2.05	611
Overall	*1.30*	*2.02*	*1,697*
Prediction	*1.38*	*2.08*	

Provenance

Model 2 predicted well the Marl Creek and Larch Hills provenances, but under-predicted the average and maximum branch diameters for Champion Lakes (Table 42). Tables 11 and 12 show that the Champion Lakes provenance is smaller in height and diameter and most the lowest whorls in these trees are still alive and growing. These factors are not incorporated into Model 2 predictions.

Family

The average branch diameter for the Champion Lakes provenance was statistically significantly smaller than predicted with Model 2 (with the exception of family 1659). Only two families (1767, 1773) of the Larch Hills provenance were statistically significant. All families but 1666, 1668, 1670 and 1679 of the Marl Creek provenance were significantly larger than predicted. Statistical tests for the maximum branch diameter followed a similar trend.

The difference between the three highest and lowest ranking families was about 0.4 cm in average branch diameter (Table 43). This is a +7% difference (largest) and –21% difference (smallest) than predicted with Model 2. The average difference between families with the largest and smallest maximum branch diameter was 0.6 cm (+12% and –17% difference) (Table 44).

Table 43. The three families with the largest and smallest average branch diameter (AVBD) (cm) by provenance.

Champ			Larch			Marl			Overall		
No.	N	AVBD	No.	N	AVBD	No.	N	AVBD	No.	N	AVBD
Largest AVBD											
1659	58	1.34	1776	53	1.48	1673	64	1.48	1673	64	1.48
1649	61	1.24	1769	60	1.45	1666	58	1.44	1776	53	1.48
1657	57	1.23	1774	64	1.43	1668	70	1.38	1769	60	1.45
	176	1.27		177	1.45		192	1.43		177	1.47
Smallest AVBD											
1655	44	1.11	1775	55	1.33	1661	59	1.27	1655	44	1.11
1654	50	1.10	1773	46	1.26	1664	62	1.26	1654	50	1.10
1658	55	1.07	1767	53	1.22	1665	57	1.23	1658	55	1.07
	149	1.09		154	1.27		178	1.25		149	1.09
Difference :		*0.18*			*0.18*			*0.18*			*0.38*

Table 44. The three families with the largest and smallest maximum branch diameter (MXBD) (cm) by provenance.

Champ			Larch			Marl			Overall		
No.	N	MXBD	No.	N	MXBD	No.	N	MXBD	No.	N	MXBD
Largest MXBD											
1659	58	2.07	1774	64	2.36	1666	58	2.23	1774	64	2.36
1649	61	1.93	1769	60	2.30	1673	64	2.19	1769	60	2.30
1657	57	1.90	1776	53	2.29	1679	56	2.14	1776	53	2.29
	176	1.96		177	2.32		178	2.19		177	2.32
Smallest MXBD											
1655	44	1.75	1773	46	1.98	1667	63	2.00	1655	44	1.75
1658	55	1.72	1772	50	1.97	1665	57	1.89	1658	55	1.72
1654	50	1.70	1767	53	1.95	1664	62	1.89	1654	50	1.70
	149	1.72		149	1.97		182	1.93		149	1.72
Difference :		*0.24*			*0.35*			*0.26*			*0.60*

The absolute differences by provenance are comparable (0.18 cm) for average branch diameter. However, the families with the largest branches for Champion Lakes are still smaller than the families with the smallest branches of the Larch Hills provenance. The same trend applies to maximum branch diameters. Combining this information with findings related to tree size reveals that there are great differences in absolute branch size between provenances, but most of the differences can be attributed to growth and tree size differences.

Discussion

Model 2 performs well overall and there is no practical difference between observed and predicted branch diameters. The results also show that differences between actual and predicted diameters increase when compared by provenance and family. As shown earlier in this report, most of these differences can be attributed to differences in tree size that result from differences in site quality (as measured by site index). Model 2 does not account for tree size differences; rather it provides average conditions at various initial densities. Moreover, the initial stand density is intended to cover the range of densities that might occur from the start of competition among stems until the live crown lifts above the first 5 m log. Incorporating average stand diameter into Model 2 would likely improve model predictions.

Summary

The two branch size prediction models generally performed well when compared with these data, and thus could be used to predict Pl branch size with reasonable confidence. Model 2, however, is limited to predicting branch size in the first 5 m log for average stand conditions. Model 1 accounted for most of the observed differences in branch size, indicating that most of the genotype effect on branch size is mainly through the indirect effect on growth (tree size). There are, however, genetic differences by families (Table 43, Table 44) that should be modeled. These differences may not be practically meaningful if the absolute differences are maintained over time; however, relative differences can significantly impact wood quality and ultimately the grade recovery of solid wood products.

Given that these measurements are from relatively young stands where branches in the first log may grow for another 10 years, and that we do not know if the observed differences will continue to rotation, we modeled the range of observed differences in branch diameter as a "genetic modifier" in Model 1 (Equation 2). The genetic modifier (G) is implemented as an intercept and therefore the absolute difference in branch size is maintained over time.[21]

[2] $$BD_{peak} = G + b_0 * DBH^{b_1} * e^{b_2 * RELCL}$$

where the value of G is based on the observed differences in average and maximum branch size.

[21] We tested the provenance effect on branch size using DBH as a covariate. This showed that the slope of the relationship was not significantly different among provenances but the intercept was different. This suggests there is a genetic effect but it is likely not related to tree size.

APPENDIX III – LOG-LUMBER GRADE MATRIX

Log-lumber grade conversion matrix showing lumber recovery as a proportion of the total by log size, knot class, and log position in tree.

Log Diameter (small end)	Knot Class (average size)	Butt & Second Logs			Top Logs		
		High Grade	Medium Grade	Low Grade	High Grade	Medium Grade	Low Grade
4-6"	0.00-0.50"	70	15	15	50	25	25
	0.51-0.75"	60	25	15	40	30	30
	0.76-1.00"	50	25	25	30	30	40
	1.01-1.25"	25	25	50	10	10	80
	1.26-1.50"	0	10	90	0	0	100
	1.50-1.75"	0	0	100	0	0	100
	1.76" +	0	0	100	0	0	100
6-8"	0.00-0.50"	80	10	10	60	20	20
	0.51-0.75"	70	15	15	50	25	25
	0.76-1.00"	50	25	25	35	30	35
	1.01-1.25"	25	40	35	10	20	70
	1.26-1.50"	0	10	90	0	0	100
	1.50-1.75"	0	0	100	0	0	100
	1.76" +	0	0	100	0	0	100
8-10"	0.00-0.50"	90	5	5	65	20	15
	0.51-0.75"	80	10	10	55	25	20
	0.76-1.00"	60	20	20	40	30	30
	1.01-1.25"	30	40	30	15	15	70
	1.26-1.50"	10	40	50	5	5	90
	1.50-1.75"	0	40	60	0	0	100
	1.76" +	0	20	80	0	0	100
10-12"	0.00-0.50"	90	5	5	65	20	15
	0.51-0.75"	80	10	10	55	25	20
	0.76-1.00"	60	20	20	40	30	30
	1.01-1.25"	40	30	30	15	15	70
	1.26-1.50"	25	25	50	5	5	90
	1.50-1.75"	10	40	50	0	0	100
	1.76" +	0	40	60	0	0	100
12-14"	0.00-0.50"	90	5	5	65	20	15
	0.51-0.75"	80	10	10	55	25	20
	0.76-1.00"	60	20	20	40	30	30
	1.01-1.25"	40	30	30	15	15	70
	1.26-1.50"	25	25	50	5	5	90
	1.50-1.75"	10	40	50	0	0	100
	1.76" +	0	40	60	0	0	100
14" +	0.00-0.50"	90	5	5	65	20	15
	0.51-0.75"	80	10	10	55	25	20
	0.76-1.00"	60	20	20	40	30	30
	1.01-1.25"	40	30	30	15	15	70
	1.26-1.50"	25	25	50	5	5	90
	1.50-1.75"	10	40	50	0	0	100
	1.76" +	0	40	60	0	0	100

APPENDIX IV – YIELD TABLES

These tables give the predicted yield/ha for stand, log, and lumber attributes for Pl planted at 1200, 1600, and 2000/ha for site indices 16, 19, and 22 m. These yield tables were generated using TASS and the post-processing models described in this report. The yield table variables are described below. The stand and log attributes apply to all planted Pl stands in BC. The lumber attributes for medium sized branches should be used if there is no information on the seed source to determine relative branch size.

Stand Attributes	
Age	Stand age from seed (years).
Height	Stand top height (largest diameter 100 trees/ha).
HLC	Height to the live crown (m).
QMD	Quadratic mean diameter (all trees).
BA	Total basal area (m^2) of all trees.
Trees	Total number of trees/ha (all trees).
Tr. Vol	Average merchantable volume of individual trees (m^3).
Vol	Total merchantable stand volume (m^3/ha).
MAI	Mean annual merchantable volume increment (m^3/ha/yr).
Lumber	Total board of lumber/ha (MFBM).
LRF	Average lumber recovery factor for all trees and logs (FBM/m^3).
Chips	Total volume of chips (bone dry units (BDU)).
Logs	Total number of logs/ha (sum of butt, second, and top logs).
Log Attributes (for Butt, Second, and Top Logs)	
Vol.	Average volume (m^3) of logs.
SED	Average small end diameter (SED) (cm).
N	Total number of logs/ha.
Lumber Attributes (for Small, Medium, & Large Branches)	
High Lumber	Total volume (MFBM) of high-grade lumber.
Std Lumber	Total volume (MFBM) of medium-grade lumber (Standard + Better).
Econ Lumber	Total volume (MFBM) of low-grade (Economy) lumber.
Value	Total value ($) of all lumber in the stand.

Establishment Density: 1200 /ha
Site Index: 16 m

	STAND												BUTT LOG			SECOND LOG			TOP LOGS		
Age	Height	HLC	QMD	BA	Trees	Tr. Vol	Vol	MAI	Lumber	LRF	Chips	Logs	Vol	SED	N	Vol	SED	N	Vol	SED	N
(yr)	(m)	(m)	(cm)	(m^2)	(no/ha)	(m^3)	(m^3)	(m^3/ha/yr)	(mfbm)	(fbm/m^3)	(bdu)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)
10	2.2	0.2	1.0	0.1	1,166	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
20	5.6	0.4	7.4	4.9	1,118	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
30	9.2	1.6	13.5	15.4	1,085	0.03	26	0.88	5	187	5	1,021	0.03	11.7	686	0.01	10.8	322	0.01	10.4	13
40	12.3	4.4	17.0	24.2	1,071	0.08	83	2.09	18	211	16	1,914	0.07	12.1	1,047	0.01	11.2	660	0.01	10.4	207
50	14.7	6.8	19.2	30.9	1,066	0.13	139	2.78	33	235	23	2,334	0.11	13.5	1,076	0.02	11.4	908	0.01	10.6	350
60	16.7	8.8	20.8	36.1	1,066	0.18	191	3.18	48	249	29	2,731	0.13	15.2	1,083	0.04	11.6	1,041	0.01	10.9	607
70	18.3	10.3	21.9	40.2	1,066	0.22	236	3.37	61	257	35	3,003	0.14	16.5	1,085	0.06	12.0	1,066	0.01	10.9	852
80	*19.6*	*11.5*	*22.8*	*43.5*	*1,066*	*0.26*	*276*	*3.44*	*73*	*265*	*39*	*3,161*	*0.16*	*17.5*	*1,087*	*0.08*	*12.6*	*1,077*	*0.02*	*11.0*	*997*
90	20.8	12.4	23.5	46.2	1,066	0.29	309	3.44	83	270	42	3,396	0.17	18.2	1,087	0.09	13.4	1,077	0.02	11.1	1,232
100	21.7	13.2	24.1	48.5	1,066	0.31	339	3.39	93	274	45	3,558	0.18	18.8	1,087	0.10	14.1	1,080	0.03	11.2	1,391
110	22.5	13.9	24.6	50.5	1,064	0.34	365	3.32	101	277	47	3,658	0.18	19.3	1,085	0.11	14.7	1,080	0.03	11.2	1,493
120	23.3	14.5	25.0	52.0	1,057	0.36	387	3.22	108	279	49	3,751	0.19	19.8	1,078	0.12	15.2	1,075	0.04	11.3	1,598

	SMALL BRANCHES							MEDIUM BRANCHES							LARGE BRANCHES						
Age	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value
(yr)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)
10	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
20	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
30	2.9	60	1.2	25	0.8	16	2,300	2.7	54	1.2	25	1.0	21	2,256	2.3	46	1.2	25	1.4	29	2,184
40	9.5	54	4.1	23	4.0	23	7,762	7.6	43	4.4	25	5.6	32	7,440	5.1	29	4.0	23	8.5	48	6,958
50	15.4	47	7.7	24	9.5	29	13,601	12.2	37	8.5	26	12.0	37	13,087	8.3	25	8.0	24	16.4	50	12,339
60	21.0	44	10.5	22	16.1	34	19,131	16.2	34	11.8	25	19.6	41	18,377	10.9	23	12.5	26	24.2	51	17,492
70	26.3	43	12.4	20	22.0	36	24,058	19.5	32	14.4	24	26.9	44	23,012	13.2	22	16.1	26	31.5	52	22,029
80	*31.1*	*43*	*14.2*	*19*	*27.6*	*38*	*28,532*	*22.5*	*31*	*16.8*	*23*	*33.6*	*46*	*27,214*	*15.2*	*21*	*19.0*	*26*	*38.7*	*53*	*26,099*
90	35.2	42	15.9	19	32.3	39	32,411	25.3	30	18.8	23	39.3	47	30,893	16.9	20	21.5	26	45.1	54	29,607
100	38.7	42	17.6	19	36.5	39	35,849	28.0	30	20.5	22	44.3	48	34,181	18.4	20	23.7	25	50.8	55	32,725
110	41.6	41	19.2	19	40.2	40	38,784	30.3	30	21.9	22	48.7	48	37,004	19.7	19	25.5	25	55.9	55	35,402
120	44.0	41	20.7	19	43.4	40	41,308	32.4	30	23.2	21	52.5	49	39,441	20.9	19	26.9	25	60.2	56	37,714

Notes: Utilization: 12.5 cm minimum DBH, 10 cm top DIB, 30 cm stump.
Product value: $440/mfbm for high, $350/mfbm for Std+Btr, $260/mfbm for economy grade lumber and $70/bdu for chips.
Culmination age is in italic.

Establishment Density: 1200 /ha
Site Index: 19 m

	STAND												BUTT LOG			SECOND LOG			TOP LOGS		
Age	Height	HLC	QMD	BA	Trees	Tr. Vol	Vol	MAI	Lumber	LRF	Chips	Logs	Vol	SED	N	Vol	SED	N	Vol	SED	N
(yr)	(m)	(m)	(cm)	(m^2)	(no/ha)	(m^3)	(m^3)	(m^3/ha/yr)	(mfbm)	(fbm/m^3)	(bdu)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)
10	2.7	0.2	1.8	0.3	1,157	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
20	7.2	0.5	10.3	9.1	1,102	0.01	2	0.12	0	46	1	172	0.02	12.1	106	0.01	10.4	66	0.00	0.0	-
30	11.5	3.3	16.3	22.3	1,074	0.07	70	2.32	15	208	13	1,778	0.06	11.9	1,017	0.01	11.2	598	0.01	10.4	163
40	15.0	6.7	19.5	31.9	1,066	0.14	150	3.74	36	238	24	2,459	0.11	13.8	1,080	0.03	11.4	956	0.01	10.7	423
50	17.8	9.4	21.6	38.9	1,066	0.21	223	4.46	57	255	33	2,898	0.14	16.1	1,085	0.06	11.8	1,060	0.01	10.9	753
60	19.9	11.4	22.9	44.1	1,066	0.26	286	4.76	76	266	40	3,183	0.16	17.7	1,087	0.09	12.8	1,076	0.02	11.0	1,020
70	*21.7*	*12.9*	*24.0*	*48.2*	*1,065*	*0.31*	*339*	*4.85*	*93*	*273*	*45*	*3,560*	*0.18*	*18.8*	*1,086*	*0.10*	*13.9*	*1,081*	*0.03*	*11.2*	*1,393*
80	23.1	14.0	24.8	51.5	1,062	0.36	385	4.81	107	278	50	3,720	0.19	19.6	1,083	0.12	14.9	1,080	0.03	11.3	1,557
90	24.2	15.0	25.6	54.1	1,049	0.40	423	4.71	119	282	53	3,882	0.20	20.3	1,070	0.13	15.8	1,068	0.04	11.5	1,744
100	25.2	15.8	26.3	56.0	1,033	0.43	455	4.55	130	286	56	4,021	0.21	21.0	1,054	0.14	16.5	1,054	0.05	11.7	1,913
110	26.0	16.4	26.9	57.7	1,016	0.47	481	4.37	139	289	57	4,064	0.22	21.6	1,037	0.15	17.1	1,037	0.05	12.0	1,990
120	26.7	17.0	27.3	59.1	1,006	0.49	504	4.20	147	291	59	4,124	0.23	22.0	1,027	0.15	17.6	1,027	0.05	12.2	2,070

	SMALL BRANCHES							MEDIUM BRANCHES							LARGE BRANCHES						
Age	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value
(yr)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)
10	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
20	0.1	60	0.0	25	0.0	15	99	0.1	55	0.0	25	0.0	20	98	0.1	50	0.0	25	0.0	25	97
30	8.5	59	3.2	22	2.8	19	6,526	7.3	50	3.6	25	3.6	25	6,339	5.7	39	3.5	24	5.3	36	6,046
40	18.0	50	7.6	21	10.0	28	14,879	14.6	41	8.4	24	12.6	35	14,346	10.8	30	9.1	26	15.7	44	13,716
50	27.0	47	10.2	18	19.7	35	22,868	20.8	37	12.1	21	23.9	42	21,937	15.0	26	14.0	25	27.9	49	21,053
60	34.7	46	12.8	17	28.5	38	29,954	26.5	35	15.1	20	34.5	45	28,672	18.8	25	18.0	24	39.3	52	27,552
70	*41.3*	*45*	*15.4*	*17*	*36.0*	*39*	*36,059*	*31.5*	*34*	*17.8*	*19*	*43.4*	*47*	*34,503*	*22.2*	*24*	*21.2*	*23*	*49.2*	*53*	*33,151*
80	46.5	43	18.0	17	42.6	40	41,307	35.5	33	20.3	19	51.3	48	39,539	25.2	24	23.8	22	58.1	54	38,001
90	50.6	42	20.5	17	48.4	41	45,715	38.9	33	22.6	19	58.0	49	43,798	27.8	23	26.0	22	65.7	55	42,105
100	53.9	41	22.6	17	53.5	41	49,402	41.6	32	24.5	19	63.8	49	47,375	30.0	23	27.7	21	72.3	56	45,563
110	56.6	41	24.6	18	57.9	42	52,545	43.9	32	26.5	19	68.6	49	50,432	31.8	23	29.4	21	77.8	56	48,528
120	58.6	40	26.1	18	62.0	42	55,184	45.6	31	28.0	19	73.2	50	53,005	33.4	23	30.7	21	82.7	56	51,044

Notes: Utilization: 12.5 cm minimum DBH, 10 cm top DIB, 30 cm stump.
Product value: $440/mfbm for high, $350/mfbm for Std+Btr, $260/mfbm for economy grade lumber and $70/bdu for chips.
Culmination age is in italic.

Establishment Density: 1200 /ha
Site Index: 22 m

Age	STAND												BUTT LOG			SECOND LOG			TOP LOGS		
Age	Height	HLC	QMD	BA	Trees	Tr. Vol	Vol	MAI	Lumber	LRF	Chips	Logs	Vol	SED	N	Vol	SED	N	Vol	SED	N
(yr)	(m)	(m)	(cm)	(m^2)	(no/ha)	(m^3)	(m^3)	(m^3/ha/yr)	(mfbm)	(fbm/m^3)	(bdu)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)
10	3.4	0.2	2.9	0.8	1,146	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
20	9.0	0.9	13.1	14.6	1,087	0.03	22	1.12	4	186	5	893	0.03	11.6	611	0.01	10.7	276	0.01	10.3	6
30	13.9	5.3	18.6	29.0	1,066	0.12	125	4.18	29	230	21	2,171	0.10	13.0	1,070	0.02	11.2	852	0.01	10.5	249
40	17.8	9.1	21.6	39.1	1,065	0.21	228	5.71	59	257	34	2,911	0.14	16.3	1,083	0.06	11.9	1,060	0.01	10.9	768
50	20.8	11.9	23.5	46.1	1,064	0.29	316	6.32	85	270	43	3,394	0.17	18.3	1,084	0.10	13.4	1,078	0.02	11.1	1,232
60	*23.1*	*13.8*	*24.9*	*51.4*	*1,059*	*0.36*	*390*	*6.50*	*109*	*279*	*50*	*3,694*	*0.19*	*19.7*	*1,079*	*0.12*	*15.0*	*1,076*	*0.04*	*11.3*	*1,539*
70	25.0	15.3	26.0	55.3	1,042	0.43	450	6.43	129	285	55	3,933	0.21	20.7	1,063	0.14	16.2	1,061	0.05	11.7	1,809
80	26.4	16.4	27.0	58.1	1,013	0.48	498	6.23	145	290	59	4,102	0.23	21.7	1,034	0.15	17.3	1,033	0.05	12.1	2,035
90	27.7	17.4	28.2	58.7	938	0.55	528	5.87	156	295	60	4,017	0.25	22.9	958	0.17	18.5	958	0.06	12.5	2,101
100	28.6	18.1	29.2	58.9	878	0.62	549	5.49	164	299	61	3,966	0.26	23.8	896	0.18	19.6	896	0.07	12.9	2,174
110	29.4	18.8	30.1	58.7	827	0.67	564	5.13	170	302	61	3,866	0.28	24.6	844	0.20	20.5	844	0.07	13.2	2,178
120	30.1	19.2	30.9	58.0	776	0.72	570	4.75	174	305	60	3,754	0.29	25.3	792	0.21	21.3	792	0.08	13.5	2,170

Age	SMALL BRANCHES							MEDIUM BRANCHES							LARGE BRANCHES						
Age	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value
(yr)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)
10	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
20	2.8	67	0.7	17	0.6	15	1,986	2.5	59	1.0	24	0.7	17	1,947	2.3	56	1.0	25	0.8	20	1,926
30	15.0	52	6.5	22	7.4	25	12,285	12.5	43	7.2	25	9.2	32	11,893	9.4	33	7.3	25	12.1	42	11,354
40	27.6	47	10.1	17	20.8	36	23,478	21.3	36	12.4	21	24.9	42	22,540	15.6	27	14.7	25	28.3	48	21,728
50	38.0	45	13.7	16	33.6	39	33,287	28.9	34	16.5	19	39.9	47	31,900	20.7	24	19.8	23	44.8	52	30,723
60	*46.7*	*43*	*17.8*	*16*	*44.4*	*41*	*41,802*	*36.0*	*33*	*20.1*	*18*	*52.8*	*49*	*40,077*	*25.7*	*24*	*24.1*	*22*	*59.1*	*54*	*38,586*
70	53.0	41	21.6	17	54.0	42	48,746	41.2	32	23.3	18	64.0	50	46,789	29.7	23	27.3	21	71.5	56	45,075
80	57.5	40	25.0	17	62.1	43	54,307	45.0	31	26.4	18	73.1	51	52,190	33.0	23	29.8	21	81.8	57	50,337
90	59.8	38	27.3	18	69.0	44	57,991	46.9	30	28.6	18	80.5	52	55,799	34.9	22	31.5	20	89.6	57	53,902
100	60.7	37	28.8	18	74.7	45	60,472	47.8	29	30.1	18	86.4	53	58,258	36.1	22	32.5	20	95.7	58	56,363
110	61.1	36	29.8	17	79.4	47	62,209	48.1	28	31.0	18	91.1	53	59,993	36.8	22	33.0	19	100.5	59	58,134
120	60.6	35	30.3	17	82.8	48	63,034	47.8	28	31.5	18	94.4	54	60,837	37.0	21	33.2	19	103.6	60	59,035

Notes: Utilization: 12.5 cm minimum DBH, 10 cm top DIB, 30 cm stump.
Product value: $440/mfbm for high, $350/mfbm for Std+Btr, $260/mfbm for economy grade lumber and $70/bdu for chips.
Culmination age is in italic.

Establishment Density: 1600 /ha
Site Index: 16 m

	STAND												BUTT LOG			SECOND LOG			TOP LOGS		
Age	Height	HLC	QMD	BA	Trees	Tr. Vol	Vol	MAI	Lumber	LRF	Chips	Logs	Vol	SED	N	Vol	SED	N	Vol	SED	N
(yr)	(m)	(m)	(cm)	(m^2)	(no/ha)	(m^3)	(m^3)	(m^3/ha/yr)	(mfbm)	(fbm/m^3)	(bdu)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)
10	2.2	0.2	1.0	0.1	1,551	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
20	5.6	0.4	7.3	6.3	1,485	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
30	9.2	2.6	12.6	18.0	1,441	0.02	25	0.84	5	200	5	986	0.03	11.4	693	0.01	10.7	282	0.01	10.5	11
40	12.2	5.5	15.6	27.1	1,419	0.07	87	2.17	18	213	16	2,228	0.06	11.8	1,238	0.01	11.1	764	0.01	10.3	226
50	14.7	7.8	17.5	33.8	1,413	0.11	145	2.91	34	231	25	2,827	0.09	12.8	1,349	0.02	11.2	1,099	0.01	10.5	379
60	16.7	9.5	18.7	39.0	1,412	0.14	197	3.28	48	244	31	3,313	0.11	14.1	1,372	0.04	11.4	1,246	0.01	10.8	695
70	18.3	10.9	19.7	43.0	1,410	0.17	241	3.44	61	252	36	3,592	0.12	15.1	1,379	0.05	11.7	1,298	0.01	10.8	915
80	*19.6*	*11.9*	*20.4*	*46.2*	*1,406*	*0.20*	*279*	*3.49*	*72*	*259*	*41*	*3,798*	*0.13*	*15.8*	*1,378*	*0.07*	*12.2*	*1,317*	*0.02*	*10.9*	*1,103*
90	20.7	12.7	21.1	48.8	1,401	0.23	311	3.46	82	264	44	4,000	0.14	16.4	1,379	0.07	12.7	1,329	0.02	11.0	1,292
100	21.7	13.4	21.6	50.8	1,386	0.25	340	3.40	91	268	47	4,128	0.14	17.0	1,368	0.08	13.2	1,322	0.02	11.0	1,438
110	22.4	14.0	22.1	52.5	1,368	0.27	363	3.30	99	271	49	4,263	0.15	17.4	1,354	0.09	13.7	1,314	0.03	11.1	1,595
120	23.1	14.5	22.6	53.7	1,338	0.29	383	3.19	105	274	51	4,307	0.16	17.9	1,330	0.10	14.1	1,298	0.03	11.2	1,679

	SMALL BRANCHES							MEDIUM BRANCHES							LARGE BRANCHES						
Age	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value
(yr)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)
10	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
20	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
30	3.2	64	1.0	21	0.8	16	2,331	2.9	57	1.3	25	0.9	18	2,293	2.6	51	1.3	25	1.2	24	2,234
40	11.0	60	4.1	22	3.3	18	8,279	9.4	51	4.6	25	4.4	24	8,036	7.4	40	4.6	25	6.4	35	7,677
50	18.3	55	7.8	23	7.5	22	14,447	15.4	46	8.2	24	10.0	30	13,967	12.0	36	8.6	26	13.0	39	13,392
60	25.4	53	10.2	21	12.4	26	20,130	20.3	42	11.2	23	16.4	34	19,305	15.4	32	12.1	25	20.5	43	18,502
70	31.7	52	12.0	20	16.9	28	25,143	24.6	40	13.7	23	22.5	37	23,998	18.3	30	14.9	25	27.5	45	22,986
80	*37.3*	*52*	*13.8*	*19*	*21.0*	*29*	*29,567*	*28.6*	*40*	*15.8*	*22*	*27.8*	*39*	*28,168*	*20.8*	*29*	*17.4*	*24*	*34.0*	*47*	*26,911*
90	42.1	51	15.6	19	24.6	30	33,452	32.2	39	17.7	21	32.4	39	31,856	23.0	28	19.6	24	39.7	48	30,375
100	45.8	50	17.3	19	28.1	31	36,747	35.2	39	19.2	21	36.8	40	35,012	25.0	27	21.3	23	44.8	49	33,370
110	48.8	49	18.8	19	31.0	31	39,535	37.7	38	20.6	21	40.4	41	37,691	26.7	27	22.9	23	49.0	50	35,921
120	51.3	49	20.1	19	33.7	32	41,913	39.7	38	21.8	21	43.6	42	39,979	28.2	27	24.1	23	52.9	50	38,117

Notes: Utilization: 12.5 cm minimum DBH, 10 cm top DIB, 30 cm stump.
Product value: $440/mfbm for high, $350/mfbm for Std+Btr, $260/mfbm for economy grade lumber and $70/bdu for chips.
Culmination age is in italic.

Establishment Density: 1600 /ha
Site Index: 19 m

Age	STAND											Logs	BUTT LOG			SECOND LOG			TOP LOGS		
Age	Height	HLC	QMD	BA	Trees	Tr. Vol	Vol	MAI	Lumber	LRF	Chips	Logs	Vol	SED	N	Vol	SED	N	Vol	SED	N
(yr)	(m)	(m)	(cm)	(m^2)	(no/ha)	(m^3)	(m^3)	(m^3/ha/yr)	(mfbm)	(fbm/m^3)	(bdu)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)
10	2.7	0.2	1.8	0.4	1,540	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
20	7.2	0.7	9.9	11.3	1,463	0.01	2	0.10	0	82	1	132	0.02	11.8	79	0.01	10.5	53	0.00	0.0	-
30	11.4	4.4	15.0	25.1	1,423	0.06	72	2.40	15	209	14	2,049	0.05	11.7	1,165	0.01	11.1	693	0.01	10.4	191
40	14.9	7.7	17.7	34.8	1,412	0.11	157	3.91	37	234	26	2,970	0.09	13.1	1,356	0.02	11.3	1,143	0.01	10.6	471
50	17.7	10.1	19.4	41.7	1,411	0.16	229	4.58	57	250	35	3,464	0.12	14.8	1,376	0.05	11.6	1,284	0.01	10.8	804
60	19.9	11.8	20.6	46.8	1,408	0.21	290	4.83	75	261	42	3,807	0.13	16.0	1,380	0.07	12.3	1,318	0.02	10.9	1,109
70	*21.6*	*13.1*	*21.5*	*50.6*	*1,390*	*0.25*	*341*	*4.87*	*91*	*268*	*47*	*4,116*	*0.14*	*16.9*	*1,372*	*0.08*	*13.1*	*1,323*	*0.02*	*11.1*	*1,421*
80	23.0	14.2	22.4	53.3	1,352	0.29	383	4.79	105	274	51	4,277	0.16	17.7	1,340	0.09	14.0	1,307	0.03	11.2	1,630
90	24.1	15.0	23.3	54.6	1,277	0.33	416	4.62	116	278	53	4,332	0.17	18.6	1,273	0.11	14.7	1,256	0.04	11.4	1,803
100	25.1	15.7	24.1	55.8	1,225	0.36	444	4.44	125	282	55	4,388	0.18	19.3	1,221	0.12	15.4	1,211	0.04	11.6	1,956
110	25.9	16.4	24.8	56.7	1,173	0.40	465	4.23	133	286	57	4,316	0.19	20.0	1,172	0.13	16.1	1,167	0.05	11.9	1,977
120	26.6	16.9	25.4	57.1	1,126	0.43	482	4.02	139	289	57	4,356	0.20	20.5	1,126	0.13	16.7	1,122	0.05	12.1	2,108

Age	SMALL BRANCHES							MEDIUM BRANCHES							LARGE BRANCHES						
Age	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value
(yr)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)
10	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
20	0.1	63	0.0	22	0.0	15	107	0.1	58	0.0	24	0.0	18	106	0.1	53	0.0	25	0.0	22	105
30	9.4	62	3.3	22	2.4	16	6,847	8.4	56	3.7	25	2.9	20	6,714	7.2	48	3.8	25	4.0	27	6,510
40	20.7	57	7.5	21	8.4	23	15,748	17.6	48	8.4	23	10.6	29	15,271	14.4	39	8.8	24	13.4	37	14,727
50	31.1	54	10.4	18	15.8	28	23,878	25.6	45	11.5	20	20.2	35	22,987	19.8	35	12.7	22	24.8	43	22,060
60	39.8	53	13.2	17	22.5	30	30,879	32.2	43	14.3	19	28.9	38	29,621	24.3	32	16.0	21	35.1	47	28,341
70	*47.1*	*52*	*16.0*	*17*	*28.3*	*31*	*36,954*	*38.1*	*42*	*16.9*	*19*	*36.4*	*40*	*35,415*	*28.4*	*31*	*18.8*	*21*	*44.1*	*48*	*33,851*
80	52.6	50	18.6	18	33.8	32	42,011	42.7	41	19.2	18	43.1	41	40,272	31.8	30	21.2	20	52.1	50	38,488
90	56.6	49	20.7	18	38.5	33	45,909	46.0	40	21.2	18	48.7	42	44,039	34.4	30	23.0	20	58.5	50	42,119
100	59.7	48	22.7	18	42.8	34	49,222	48.5	39	23.1	18	53.5	43	47,255	36.5	29	24.9	20	63.9	51	45,242
110	62.2	47	24.3	18	46.8	35	51,979	50.6	38	24.8	19	57.8	43	49,937	38.2	29	26.5	20	68.6	51	47,861
120	63.8	46	25.3	18	50.3	36	53,997	51.9	37	25.9	19	61.5	44	51,919	39.3	28	27.6	20	72.4	52	49,803

Notes: Utilization: 12.5 cm minimum DBH, 10 cm top DIB, 30 cm stump.
Product value: $440/mfbm for high, $350/mfbm for Std+Btr, $260/mfbm for economy grade lumber and $70/bdu for chips.
Culmination age is in italic.

Establishment Density: 1600 /ha
Site Index: 22 m

Age	STAND												BUTT LOG			SECOND LOG			TOP LOGS		
Age	Height	HLC	QMD	BA	Trees	Tr. Vol	Vol	MAI	Lumber	LRF	Chips	Logs	Vol	SED	N	Vol	SED	N	Vol	SED	N
(yr)	(m)	(m)	(cm)	(m^2)	(no/ha)	(m^3)	(m^3)	(m^3/ha/yr)	(mfbm)	(fbm/m^3)	(bdu)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)
10	3.4	0.2	2.9	1.0	1,525	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
20	9.0	1.6	12.3	17.1	1,442	0.02	21	1.06	4	203	4	816	0.03	11.3	590	0.01	10.8	214	0.01	10.4	12
30	14.0	6.3	17.0	32.0	1,413	0.10	132	4.40	30	226	23	2,670	0.08	12.5	1,327	0.02	11.1	1,028	0.01	10.4	315
40	17.8	9.8	19.4	41.8	1,410	0.17	233	5.83	59	251	35	3,482	0.12	14.9	1,379	0.05	11.6	1,295	0.01	10.8	808
50	20.7	12.2	21.0	48.6	1,402	0.23	317	6.33	84	265	44	3,961	0.14	16.5	1,381	0.08	12.6	1,336	0.02	11.0	1,244
60	*23.0*	*13.9*	*22.3*	*53.0*	*1,351*	*0.29*	*385*	*6.41*	*105*	*273*	*51*	*4,291*	*0.16*	*17.7*	*1,338*	*0.09*	*13.9*	*1,310*	*0.03*	*11.2*	*1,643*
70	24.9	15.2	23.7	55.2	1,249	0.35	436	6.22	122	281	55	4,371	0.18	19.0	1,246	0.11	15.1	1,232	0.04	11.5	1,893
80	26.3	16.3	24.8	56.9	1,176	0.41	477	5.96	137	286	58	4,401	0.19	20.0	1,175	0.13	16.1	1,169	0.05	11.9	2,057
90	27.5	17.2	26.3	54.9	1,009	0.49	490	5.45	144	293	57	4,089	0.22	21.5	1,009	0.15	17.6	1,008	0.06	12.3	2,072
100	28.5	17.9	27.5	53.9	908	0.56	503	5.03	149	297	56	3,917	0.24	22.6	908	0.17	18.8	908	0.06	12.7	2,101
110	29.3	18.4	28.5	53.3	836	0.62	513	4.67	154	301	56	3,799	0.25	23.5	836	0.18	19.8	836	0.07	13.0	2,127
120	30.0	18.8	29.3	52.2	773	0.67	517	4.30	157	304	55	3,618	0.27	24.3	773	0.20	20.7	773	0.08	13.4	2,072

Age	SMALL BRANCHES							MEDIUM BRANCHES							LARGE BRANCHES						
Age	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value
(yr)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)
10	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
20	3.0	69	0.7	16	0.7	15	1,997	2.6	60	1.0	24	0.7	16	1,960	2.5	57	1.1	25	0.8	18	1,942
30	17.3	58	6.3	21	6.3	21	13,048	15.2	51	7.0	23	7.7	26	12,731	12.6	42	7.3	24	10.0	33	12,293
40	31.6	54	10.0	17	17.0	29	24,307	26.0	44	11.6	20	21.0	36	23,437	20.3	35	12.8	22	25.5	44	22,523
50	43.4	52	13.7	16	26.7	32	33,937	35.2	42	15.3	18	33.2	40	32,604	26.6	32	17.2	21	40.0	48	31,220
60	*52.4*	*50*	*17.3*	*16*	*35.4*	*34*	*41,880*	*42.6*	*41*	*18.6*	*18*	*43.9*	*42*	*40,237*	*31.7*	*30*	*20.9*	*20*	*52.5*	*50*	*38,483*
70	58.5	48	21.0	17	42.7	35	48,037	47.7	39	21.8	18	52.6	43	46,181	35.8	29	23.9	20	62.5	51	44,215
80	63.0	46	23.7	17	49.9	37	53,030	51.5	38	24.5	18	60.6	44	51,034	38.9	28	26.4	19	71.2	52	48,945
90	63.3	44	25.1	17	55.1	38	54,965	51.8	36	25.9	18	65.9	46	52,961	39.4	27	27.7	19	76.5	53	50,894
100	63.6	43	25.9	17	59.9	40	56,571	52.1	35	26.9	18	70.4	47	54,592	40.1	27	28.5	19	80.9	54	52,569
110	63.7	41	26.5	17	64.1	42	57,881	52.2	34	27.7	18	74.4	48	55,925	40.5	26	29.3	19	84.6	55	53,953
120	62.9	40	26.7	17	67.5	43	58,396	51.6	33	28.1	18	77.3	49	56,497	40.3	26	29.6	19	87.2	56	54,588

Notes: Utilization: 12.5 cm minimum DBH, 10 cm top DIB, 30 cm stump.
Product value: $440/mfbm for high, $350/mfbm for Std+Btr, $260/mfbm for economy grade lumber and $70/bdu for chips.
Culmination age is in italic.

Establishment Density: 2000 /ha
Site Index: 16 m

Age	STAND											Logs	BUTT LOG			SECOND LOG			TOP LOGS		
Age	Height	HLC	QMD	BA	Trees	Tr. Vol	Vol	MAI	Lumber	LRF	Chips	Logs	Vol	SED	N	Vol	SED	N	Vol	SED	N
(yr)	(m)	(m)	(cm)	(m^2)	(no/ha)	(m^3)	(m^3)	(m^3/ha/yr)	(mfbm)	(fbm/m^3)	(bdu)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)
10	2.2	0.2	1.0	0.2	1,937	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
20	5.7	0.5	7.2	7.5	1,849	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
30	9.2	3.2	11.8	19.6	1,792	0.02	20	0.68	4	209	4	784	0.03	11.3	567	0.01	10.8	206	0.01	10.2	11
40	12.3	6.0	14.4	28.6	1,764	0.05	81	2.03	17	210	15	2,337	0.05	11.6	1,301	0.01	11.0	820	0.01	10.3	216
50	14.7	8.1	16.0	35.1	1,756	0.08	141	2.82	32	227	24	3,138	0.08	12.4	1,531	0.02	11.1	1,192	0.01	10.5	415
60	16.8	9.7	17.1	40.1	1,755	0.11	192	3.20	46	240	31	3,641	0.09	13.3	1,584	0.03	11.3	1,353	0.01	10.7	704
70	18.4	10.8	17.9	43.9	1,739	0.14	236	3.37	58	248	37	3,954	0.10	14.2	1,597	0.04	11.5	1,443	0.01	10.8	914
80	*19.7*	*11.7*	*18.6*	*46.9*	*1,716*	*0.16*	*273*	*3.42*	*70*	*255*	*41*	*4,164*	*0.11*	*14.8*	*1,604*	*0.06*	*11.9*	*1,465*	*0.01*	*10.9*	*1,095*
90	20.8	12.5	19.3	49.1	1,680	0.18	305	3.39	80	261	44	4,330	0.12	15.4	1,594	0.07	12.4	1,463	0.02	11.0	1,273
100	21.8	13.1	20.0	50.5	1,614	0.21	331	3.31	88	265	46	4,382	0.12	15.9	1,552	0.07	12.9	1,437	0.02	11.0	1,393
110	22.6	13.7	20.5	51.7	1,564	0.23	354	3.22	95	269	48	4,480	0.13	16.4	1,521	0.08	13.3	1,420	0.03	11.1	1,539
120	23.2	14.2	21.1	52.3	1,491	0.25	373	3.11	101	272	50	4,570	0.14	16.8	1,475	0.09	13.7	1,396	0.03	11.2	1,699

Age	SMALL BRANCHES							MEDIUM BRANCHES							LARGE BRANCHES						
Age	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value
(yr)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)
10	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
20	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
30	2.8	67	0.8	18	0.6	15	1,944	2.5	59	1.1	25	0.7	16	1,912	2.3	54	1.1	25	0.9	21	1,870
40	10.6	62	3.7	22	2.8	16	7,767	9.4	55	4.2	24	3.6	21	7,582	8.0	47	4.3	25	4.8	28	7,345
50	18.5	58	7.1	22	6.3	20	13,985	16.2	51	7.7	24	8.0	25	13,614	13.2	41	8.0	25	10.6	33	13,113
60	26.2	57	9.4	20	10.4	23	19,695	21.7	47	10.7	23	13.6	30	19,009	17.4	38	11.3	24	17.4	38	18,272
70	32.9	56	11.3	19	14.3	24	24,700	26.7	46	13.0	22	18.8	32	23,745	20.6	35	13.8	24	24.1	41	22,721
80	*38.9*	*56*	*13.1*	*19*	*17.8*	*26*	*29,187*	*31.4*	*45*	*15.0*	*22*	*23.4*	*34*	*28,006*	*23.6*	*34*	*16.2*	*23*	*30.1*	*43*	*26,705*
90	43.8	55	14.9	19	21.0	26	32,992	35.4	44	16.7	21	27.5	35	31,646	26.2	33	18.2	23	35.2	44	30,133
100	47.6	54	16.6	19	23.8	27	36,168	38.5	44	18.3	21	31.1	35	34,693	28.5	32	19.9	23	39.6	45	33,026
110	50.8	53	18.0	19	26.3	28	38,888	41.1	43	19.8	21	34.2	36	37,311	30.5	32	21.3	22	43.3	46	35,533
120	53.3	53	19.3	19	28.7	28	41,175	43.2	43	21.1	21	37.0	36	39,522	32.2	32	22.5	22	46.6	46	37,662

Notes: Utilization: 12.5 cm minimum DBH, 10 cm top DIB, 30 cm stump.
Product value: $440/mfbm for high, $350/mfbm for Std+Btr, $260/mfbm for economy grade lumber and $70/bdu for chips.
Culmination age is in italic.

Establishment Density: **2000 /ha**
Site Index: **19 m**

	STAND												BUTT LOG			SECOND LOG			TOP LOGS		
Age	Height	HLC	QMD	BA	Trees	Tr. Vol	Vol	MAI	Lumber	LRF	Chips	Logs	Vol	SED	N	Vol	SED	N	Vol	SED	N
(yr)	(m)	(m)	(cm)	(m^2)	(no/ha)	(m^3)	(m^3)	(m^3/ha/yr)	(mfbm)	(fbm/m^3)	(bdu)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)
10	2.7	0.2	1.7	0.5	1,922	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
20	7.2	1.1	9.4	12.7	1,820	0.00	1	0.06	0	57	0	88	0.02	11.9	49	0.01	10.5	39	0.00	0.0	-
30	11.5	5.0	13.8	26.4	1,769	0.04	65	2.18	13	205	13	2,120	0.05	11.6	1,177	0.01	10.9	749	0.01	10.3	194
40	15.0	8.0	16.1	35.8	1,755	0.09	150	3.74	34	229	26	3,245	0.08	12.5	1,537	0.02	11.1	1,246	0.01	10.6	462
50	17.7	10.1	17.6	42.4	1,745	0.13	221	4.42	54	245	35	3,855	0.10	13.9	1,591	0.04	11.4	1,413	0.01	10.7	851
60	19.9	11.6	18.7	47.1	1,715	0.17	281	4.69	72	257	41	4,202	0.11	14.9	1,603	0.06	12.0	1,470	0.02	10.9	1,129
70	*21.6*	*12.8*	*19.8*	*50.1*	*1,631*	*0.20*	*330*	*4.72*	*87*	*264*	*46*	*4,431*	*0.12*	*15.8*	*1,561*	*0.07*	*12.8*	*1,445*	*0.02*	*11.0*	*1,425*
80	23.0	13.8	20.8	51.7	1,516	0.24	370	4.62	100	271	50	4,490	0.14	16.7	1,487	0.09	13.5	1,400	0.03	11.1	1,603
90	24.2	14.6	22.0	52.3	1,381	0.29	400	4.44	110	276	52	4,506	0.15	17.6	1,377	0.10	14.3	1,337	0.03	11.4	1,792
100	25.2	15.4	23.0	52.7	1,272	0.33	424	4.24	119	281	53	4,401	0.16	18.5	1,281	0.11	15.0	1,265	0.04	11.6	1,855
110	26.0	16.0	23.7	53.2	1,206	0.37	445	4.05	127	285	55	4,414	0.17	19.2	1,217	0.12	15.7	1,208	0.05	11.8	1,989
120	26.6	16.5	24.4	53.7	1,152	0.40	462	3.85	133	288	55	4,363	0.18	19.8	1,164	0.13	16.3	1,158	0.05	12.0	2,041

	SMALL BRANCHES							MEDIUM BRANCHES							LARGE BRANCHES						
Age	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value
(yr)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)
10	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
20	0.0	66	0.0	19	0.0	15	54	0.0	59	0.0	23	0.0	18	54	0.0	56	0.0	25	0.0	19	54
30	8.6	64	2.7	20	2.1	15	6,181	7.9	59	3.2	24	2.4	18	6,085	7.0	52	3.4	25	3.1	23	5,940
40	20.6	60	6.7	19	7.0	20	15,002	17.9	52	7.9	23	8.4	25	14,624	15.1	44	8.0	23	11.2	33	14,130
50	31.4	58	9.5	18	13.2	24	23,036	26.5	49	11.1	21	16.5	30	22,295	21.3	39	11.8	22	21.1	39	21,411
60	41.0	57	12.3	17	18.8	26	30,151	34.2	47	13.9	19	24.0	33	29,073	26.3	37	15.0	21	30.8	43	27,750
70	*48.4*	*55*	*15.0*	*17*	*23.8*	*27*	*35,978*	*40.3*	*46*	*16.4*	*19*	*30.5*	*35*	*34,650*	*30.7*	*35*	*17.8*	*20*	*38.8*	*44*	*33,036*
80	54.0	54	17.6	18	28.5	28	40,832	45.0	45	18.9	19	36.2	36	39,326	34.3	34	20.2	20	45.6	46	37,513
90	58.0	53	19.7	18	32.8	30	44,574	48.3	44	21.0	19	41.1	37	42,954	36.9	33	22.2	20	51.3	46	41,009
100	61.2	51	21.2	18	37.0	31	47,687	50.9	43	22.7	19	45.7	38	45,979	39.0	33	23.9	20	56.4	47	43,944
110	63.6	50	22.3	18	40.8	32	50,238	53.0	42	24.1	19	49.7	39	48,481	40.7	32	25.2	20	60.8	48	46,378
120	65.4	49	23.2	17	44.3	33	52,297	54.5	41	25.3	19	53.1	40	50,509	42.0	32	26.4	20	64.5	49	48,363

Notes: Utilization: 12.5 cm minimum DBH, 10 cm top DIB, 30 cm stump.
Product value: $440/mfbm for high, $350/mfbm for Std+Btr, $260/mfbm for economy grade lumber and $70/bdu for chips.
Culmination age is in italic.

Establishment Density: 2000 /ha
Site Index: 22 m

Age	STAND												BUTT LOG			SECOND LOG			TOP LOGS		
Age	Height	HLC	QMD	BA	Trees	Tr. Vol	Vol	MAI	Lumber	LRF	Chips	Logs	Vol	SED	N	Vol	SED	N	Vol	SED	N
(yr)	(m)	(m)	(cm)	(m^2)	(no/ha)	(m^3)	(m^3)	(m^3/ha/yr)	(mfbm)	(fbm/m^3)	(bdu)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)	(m^3)	(cm)	(no/ha)
10	3.4	0.2	2.8	1.2	1,901	0.00	0	0.00	0	0	0	-	0.00	0.0	-	0.00	0.0	-	0.00	0.0	-
20	9.0	2.2	11.5	18.6	1,794	0.02	17	0.84	4	208	3	660	0.03	11.2	480	0.01	10.8	175	0.01	10.4	5
30	14.0	6.8	15.5	33.4	1,757	0.08	127	4.24	28	223	22	2,938	0.07	12.2	1,470	0.02	11.0	1,121	0.01	10.4	347
40	17.8	9.9	17.7	42.9	1,746	0.13	229	5.72	56	246	36	3,902	0.10	14.0	1,590	0.04	11.5	1,419	0.01	10.8	893
50	20.8	12.0	19.3	48.9	1,679	0.19	311	6.23	81	262	45	4,294	0.12	15.4	1,591	0.07	12.4	1,461	0.02	10.9	1,242
60	*23.1*	*13.6*	*20.9*	*51.9*	*1,519*	*0.25*	*376*	*6.27*	*102*	*271*	*51*	*4,500*	*0.14*	*16.7*	*1,493*	*0.09*	*13.5*	*1,413*	*0.03*	*11.2*	*1,594*
70	25.0	14.9	22.6	52.8	1,317	0.32	423	6.05	118	280	54	4,435	0.16	18.2	1,326	0.11	14.7	1,298	0.04	11.5	1,811
80	26.5	16.0	23.9	53.6	1,191	0.38	460	5.75	132	286	56	4,356	0.18	19.4	1,205	0.12	15.8	1,193	0.05	11.9	1,958
90	27.7	16.9	25.6	51.4	999	0.47	473	5.26	139	293	55	4,062	0.21	21.1	1,011	0.15	17.4	1,011	0.06	12.3	2,040
100	28.6	17.5	26.8	50.2	887	0.54	484	4.84	144	298	54	3,825	0.23	22.2	898	0.17	18.7	898	0.06	12.7	2,029
110	29.5	18.0	27.9	49.6	813	0.60	494	4.49	149	301	54	3,685	0.24	23.2	823	0.18	19.7	823	0.07	13.1	2,039
120	30.1	18.5	28.7	49.2	762	0.65	502	4.19	153	304	53	3,620	0.26	23.9	771	0.19	20.6	771	0.08	13.3	2,078

Age	SMALL BRANCHES							MEDIUM BRANCHES							LARGE BRANCHES						
Age	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value	High Lumber		Std Lumber		Econ Lumber		Value
(yr)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)	(mfbm)	(%)	(mfbm)	(%)	(mfbm)	(%)	($)
10	0.0		0.0		0.0		-	0.0		0.0		0.0		-	0.0		0.0		0.0		-
20	2.4	70	0.5	15	0.5	15	1,627	2.1	60	0.9	25	0.5	15	1,595	2.0	58	0.9	25	0.6	17	1,584
30	17.4	61	5.5	19	5.4	19	12,568	15.5	55	6.5	23	6.4	22	12,313	13.1	46	6.8	24	8.4	30	11,914
40	32.5	58	9.3	17	14.5	26	23,834	27.4	49	11.1	20	17.8	32	23,078	21.8	39	12.0	21	22.4	40	22,158
50	45.3	56	13.3	16	22.9	28	33,644	37.8	46	14.8	18	28.8	35	32,439	28.8	35	16.5	20	36.2	44	30,956
60	*54.5*	*53*	*17.3*	*17*	*30.1*	*30*	*41,414*	*45.6*	*45*	*18.4*	*18*	*38.0*	*37*	*39,908*	*34.5*	*34*	*20.1*	*20*	*47.4*	*46*	*38,066*
70	60.3	51	20.6	17	37.5	32	47,283	50.5	43	21.5	18	46.4	39	45,592	38.3	32	23.1	19	57.1	48	43,541
80	64.6	49	23.0	17	44.3	34	51,892	54.1	41	24.1	18	53.7	41	50,096	41.3	31	25.5	19	65.0	49	47,931
90	65.1	47	23.8	17	49.7	36	53,719	54.4	39	25.1	18	59.1	43	51,906	41.8	30	26.4	19	70.3	51	49,763
100	65.1	45	24.4	17	54.4	38	55,127	54.3	38	26.0	18	63.7	44	53,320	42.2	29	27.3	19	74.5	52	51,251
110	65.5	44	24.7	17	58.6	39	56,476	54.5	37	26.6	18	67.8	46	54,665	42.6	29	28.0	19	78.2	53	52,652
120	65.7	43	25.0	16	62.1	41	57,521	54.6	36	27.1	18	71.1	47	55,719	42.8	28	28.6	19	81.3	53	53,737

Notes: Utilization: 12.5 cm minimum DBH, 10 cm top DIB, 30 cm stump.
Product value: $440/mfbm for high, $350/mfbm for Std+Btr, $260/mfbm for economy grade lumber and $70/bdu for chips.
Culmination age is in italic.