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Are Free-Growing Stands Meeting Timber Productivity Expectations in the Lakes Timber Supply Area?

Alex Woods
Wendy Bergerud

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Management of forest and range resources is a complex process that often involves the balancing of ecological, social, and economic considerations. This evaluation report represents one facet of this process. Based on monitoring data and analysis, the author offers the following recommendations to those who develop and implement forest and range management policy, plans, and practices.

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Prepared by
Alex Woods, Regional Forest Pathologist, B.C. Ministry of Forests and Range Northern Interior Forest Region, Smithers, B.C.
Wendy Bergerud, Senior Biometrician, B.C. Ministry of Forests and Range, Research Branch, Victoria, B.C.
See Acknowledgements for complete list of contributors

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ABSTRACT

The current administrative milestone for ensuring effective reforestation is the free-growing declaration. When the free-growing milestone is achieved, it is assumed that the young managed stand is on a trajectory that will result in a productive mature stand. Currently, no monitoring procedures are in place to determine if free-growing stands are meeting these expectations. This study examines whether the reliance that has been placed on this policy is supported by stand performance from a timber yield perspective.

We examined 60 randomly selected free-growing stands in the Lakes Timber Supply Area (TSA) of central British Columbia. We used the silvicultural planning model TIPSY to estimate projected volume at a rotation age of 80 years. Based on declaration and 2005 stand attributes, the mean projected volumes for all stands was about 320 m^3/ha. Our values closely match the projected values from the most recent timber supply review for the Lakes TSA. The mean density of both well-spaced and free-growing stems has remained relatively stable since declaration with close to 1000 well-spaced stems per hectare.

In our 2005 assessment 18% of stands no longer contained the minimum of 700 free growing stems/ha based on the lower confidence decision rule, due mainly to the high incidence of hard pine rusts. Only one of our sample stands had been attacked by mountain pine beetle at that time. As of November 2007, mountain pine beetle had attacked 10 more sampled stands. Our analyses do not reflect these recent insect attacks because our field work took place prior to the mountain pine beetle attacking many of the young stands in the TSA.

Free-growing declarations may occur too early in the life of stands to provide an accurate projection of future stand productivity due to losses to pests and other natural disturbance agents. Our study demonstrates the importance of more intensive monitoring of free-growing stands. A mid-rotation assessment of stand productivity and forest health would provide more confidence in timber supply forecasts particularly in light of climate change.

Executive Summary

The current administrative milestone for ensuring effective reforestation is the free-growing declaration. When the free-growing milestone is achieved, it is assumed that the young managed stand is on a trajectory that will result in a productive mature stand. Currently, no monitoring procedures are in place to determine if free-growing stands are meeting these expectations. This study examines whether the reliance that has been placed on this policy is supported by stand performance from a timber yield perspective.

Sixty randomly sampled free-growing stands were evaluated in the Lakes Timber Supply Area (TSA) in central British Columbia. Sample stands were grouped into two classes based on the number of years since free-growing declaration: half were declared between 1987 and 1994 (early), and the other half were declared between 1995 and 2001 (late). All sampled stands were greater than 15 ha in size, and were surveyed using fifteen 3.99 m radius survey plots.

We used the silvicultural planning model TIPSY to estimate projected volume at a rotation age of 80 years. The mean projected volumes at rotation based on free-growing declaration values were not significantly different from volume projections based on 2005 stand attributes for either the early or late groups. Based on declaration and 2005 stand attributes, the mean projected volumes for all stands was about 320 m^3/ha. These projected values closely match the projected values from the most recent timber supply data package for the Lakes TSA. The mean density of both well-spaced and free-growing stems has remained relatively stable since declaration with both the early and late groups at or close to 1000 well-spaced stems per hectare.[1]

In our 2005 assessment 18% of stands no longer contained the minimum of 700 free growing stems/ha based on the lower confidence decision rule, due mainly to the high incidence of hard pine rusts. Over 27% of all declared free-growing, pine-leading stands had greater than 20% hard pine rust incidence. Pine-leading stands represent 90% of the sampled managed stands in the Lakes TSA. The majority (84%) of pest-affected trees in stands that no longer pass the minimum stocking level were in the 4 m+ height class.

In 2005, only one of our sample stands had been attacked by mountain pine beetle with 70 – 75% of the trees infested. As of November 2007, the insects had attacked 10 additional stands. The incidence of red-attack in these stands ranged from approximately 1% to close to 20%. Our analyses do not reflect these recent insect attacks because our ground-based field work took place prior to the mountain pine beetle attacking many of the young stands in the TSA.

This report on free-growing stands in the Lakes TSA is the first in a series of examinations throughout the province. The Lakes TSA presented a relatively simple managed forest scenario with much of the land base dominated by single species plantations in even-aged stands on similar biogeoclimatic zones. This lack of complexity allowed us to investigate the relationships between various measurements of stand density and TIPSY-projected volume at rotation.

Management of forest and range resources is a complex process that often involves the balancing of ecological, social, and economic considerations. Many FREP monitoring reports represent a single facet of this process. In this report we have focussed on the timber resource. From that perspective, our analyses suggest that free-growing declarations may be occurring too early in the life of stands to provide an accurate projection of future stand productivity. A mid-rotation assessment of stand productivity and forest health would provide more confidence. We are developing a survey protocol for post free-growing managed stands using lessons learned in this intensive study that will be used by Ministry of Forests and Range staff throughout the province under FREP (Forest and Range Practices Evaluation Program).

1. There are several different measures of density. We will use different units to distinguish between total density (stems per hectare), well-spaced density (well-spaced stems per hectare), and free-growing density (free-growing stems per hectare).

Acknowledgements

Hadrian Merler assisted with the initial design of this study. Carolyn Stevens of the Nadina Forest District assisted with the opening file searches. Brad Leroux and Silvicon Services Inc. carried out both the fieldwork and the TIPSY analyses. Erin Havard helped compile and organize data from TIPSY analyses into a format that we used in our statistical analyses and made the November 2007 aerial assessment of stands possible. Kathy Lewis, Dave Weaver, Dave Wilford, Dave Coates, Tim Ebata, Jim Goudie, Ralph Winter, Lorne Bedford, and others provided valuable feedback on earlier drafts of the report. This study was funded through the Forest and Range Evaluation Program (FREP) and the provincial Forest Health program. The support of Peter Bradford and Anthony Britneff throughout the project has been greatly appreciated.

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1.0 Introduction

The current administrative milestone for ensuring effective reforestation is the free-growing declaration.[2] This licensee obligation to create a free-growing stand is one of the few measurable results under the Forest and Range Practices Act. According to the Forest Practices Board (2003), "free-growing requirements ensure that reforested stands remain successfully reforested." That is the intent of the policy, but how can we be sure of success without monitoring programs in place? Once a stand is declared free-growing, the Crown not only assumes responsibility for the stand, but also assumes that the stand will remain healthy and productive until ready for harvest. Timber supply reviews throughout the province base predictions of managed stand productivity in large part on the stand conditions (species, density, and regeneration delay) observed when stands are declared free-growing. Under the Ministry of Forests and Range's stewardship mandate, it is essential to test these assumptions.

In the years since the inception of free-growing in 1987, few reviews of the policy have taken place even though over 2.5 million ha of Crown forest land[3] is designated as such. This is primarily because the majority of the stands created under the policy are only now being declared free-growing. Until this study, the Forest Practices Board (FPB) had conducted the most recent reviews in 2003 and 2006. For its 2006 review, the FPB assessed the free-growing status for all cutblocks required to achieve free-growing between 1987 and March 31, 2004 based solely on information in the RESULTS database[4] with no field checks (Forest Practices Board 2006). The 2003 FPB report was based on a comprehensive overview of free-growing stands in six forest districts located throughout the province. Because of its extensive nature, this FPB study primarily involved an office review of administrative milestones using the Ministry of Forests and Range's Integrated Silviculture Information System (ISIS). Most of the field examinations conducted during the FPB review consisted of low-level aerial assessments from helicopters (Forest Practices Board 2003).

In contrast, our study involves an intensive examination of stand conditions on the ground, and as such is the first detailed examination of the application and assumptions of free-growing policy at the field level.

In the 2003 study, with its focus on licensee obligations, the FPB examined stands that were established after the free-growing policy came into effect in 1987. Our study includes all stands declared free-growing from 1987 to 2001, within a single timber supply area—the Lakes TSA (Figure 1). The stands we examined were not created under FRPA legislation; therefore, we cannot state for certain how this key measurable result is currently being achieved. However, by including all stands classified as free-growing in RESULTS for the Lakes TSA, we were able to fully explore the "free-growing" concept. We were also able to examine a longer post-declaration period to determine whether these free-growing stands are still meeting timber productivity expectations.

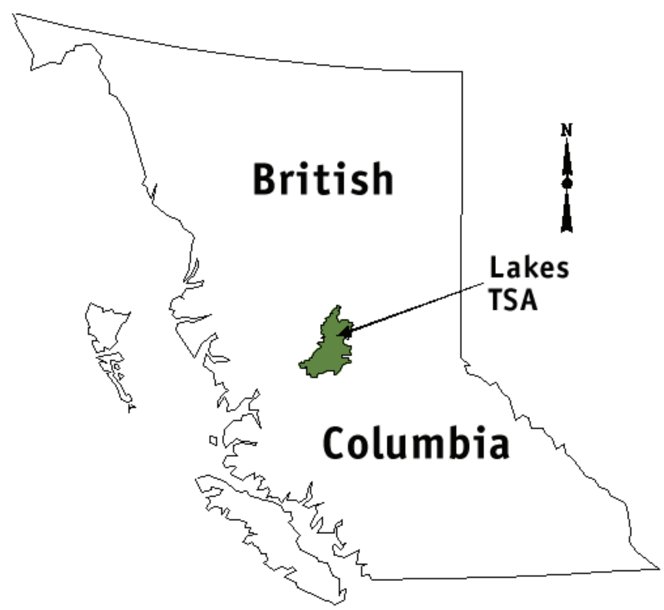

Figure 1. Location of the Lakes Timber Supply Area.

2 http://www.for.gov.bc.ca/tasb/legsregs/frpa/frpa/part3.htm
3 Including both basic obligation (post-1987) and non-basic (pre-1987) free-growing openings.
4 The RESULTS database is the successor to ISIS.

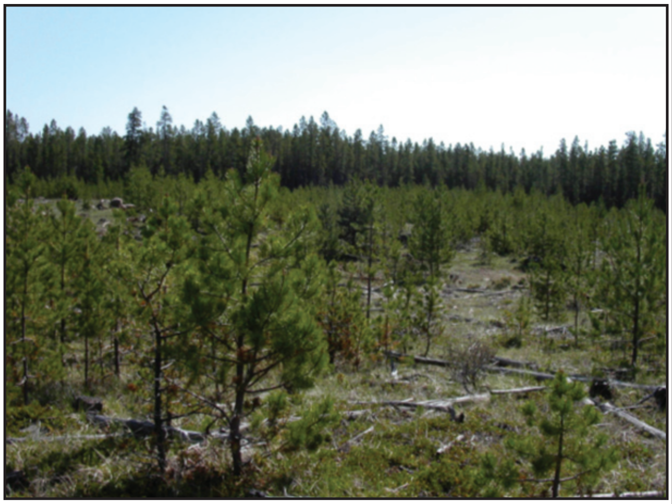

Figure 2. This photo illustrates what some may consider a "successful free-growing stand of trees" (Forest Practices Board 2003).

The example of a "successful free-growing stand of trees" (Figure 2; Forest Practices Board 2003) is representative of many lodgepole pine-leading stands in central British Columbia, including some of those surveyed in this study. The photograph illustrates several possible shortcomings associated with free-growing policy. If this is a free-growing stand, as stated in the FPB report, then is this stand really meeting our growth and yield expectations? Several sizeable voids already occur in this stand, and these will increase in size given the number of dead and dying lodgepole pine trees visible in the photo. This stand is also apparently quite young. Can we predict with confidence that this stand is on a healthy productive trajectory towards a final harvest that will meet our projected yield expectations?

In this study, we examine whether the free-growing declaration point-in-time assessment is an accurate predictor of future stand productivity and whether assumptions of stand performance are valid. The growth and yield model TASS (Mitchell 1975) and the associated computer application Table Interpolation Program for Stand Yields (TIPSY) form the basis of more than 95% of the growth and yield projections of managed stands in British Columbia, including those used in most timber supply reviews. It was for this reason that we focussed our study of free-growing stand performance using TIPSY as a basis for comparison. We designed our study so that we could compare several aspects of TIPSY projections of early stand growth to measurable current stand conditions. The degree of reliance that the Crown has placed on TASS/TIPSY mirrors the extent of trust placed on free-growing policy. We believe both of these fundamental components of the current forest management framework deserve a thorough review.

The specific objectives of this project were to answer the following questions:

1. Is there a significant discrepancy between TIPSY-projected volume at current age (based on values at the time of the free-growing declaration) and actual current volume?
2. Is there a significant discrepancy between TIPSY-projected merchantable volume at rotation age (80 years) based on values at the time of the free-growing declaration and current volumes projected to rotation by TIPSY?
3. Is the current species composition of leading species (the dominant species on-site in terms of both height and density) significantly different from that of the free-growing declaration?
4. Is there a significant discrepancy in site index estimate between the free-growing declaration estimate and the current estimate based on the growth intercept method?
5. Is there a significant discrepancy in well-spaced stocking of the dominant crop trees between free-growing declaration values and current stocking?
6. Is there a significant change in forest pest incidence from the time of the free-growing declaration to present conditions?

This report covers the initial pilot study of what will be a series of examinations of post–free-growing stands throughout the province. It is hoped that the results from this larger forest health and effectiveness evaluation project will lead to improvements in forest policy, management, and timber supply predictions.

2.0 Methods

2.1 *Stand Selection*

The B.C. Ministry of Forests and Range's RESULTS database was used to determine the population of all stands declared free-growing in the Lakes TSA. Sort procedures were then used to limit the sample population to stands with gross opening areas greater than 15 ha and disturbance dates later than 1960. Thirty stands were randomly selected from two groups: stands declared free-growing between 1987 and 1994 (early) and those declared free-growing between 1995 and 2001 (late). The free-growing stands were separated into two groups so we could compare results associated with current benchmark free-growing policy over the two time periods. Minimum height was added to the free-growing requirements in 1994, so the late group could have been influenced by this additional requirement. Note, however, that only areas harvested after 1994 would be directly affected by this policy change. Such stands would be at most 7 years old by 2001. For each stand (or opening), data from the original free-growing survey was compared with a follow-up free-growing survey conducted in 2005.

2.2 *Within Stand Sampling*

1. In each stand, fifteen 3.99 m radius plots were located in the largest strata on a systematic 100 x 100 m grid starting from a clearly marked and photo-identifiable point of commencement.
2. All trees, including hardwoods, greater than 130 cm high were tallied by species and placed in estimated height classes (i.e., < 2 m, 2–4 m, and > 4 m).
3. Well-spaced and free-growing trees were tallied in the field for both groups of stands. The M-value cap of 6 trees per plot (1200 well-spaced stems per hectare is the target stocking throughout the Lakes TSA) was used when determining free-growing status. Densities for the later group of stands were also calculated without capping the count with the M-value. Comparisons to the earlier group's declared values were made using an M-value cap of 6 trees per plot, since we assumed that the data from the early group had used the cap during calculations so that uncapped densities were not available.[5] Lower confidence limits for both well-spaced and free-growing stems were determined using the calculation card for silviculture survey confidence limits (FS 1138A).
4. In addition, all healthy well-spaced trees had their height recorded to the nearest 10 cm and diameter at breast height (dbh) recorded to the nearest 0.1 cm. Their species was recorded and their health determined using the current free-growing damage criteria.[6]
5. Pest incidence occurring on all trees by species, estimated height class, and the responsible damaging agent were recorded. All dead conifer trees were identified by species, cause of death (where discernible), and whether they were planted.
6. Strict adherence to the current free-growing damage criteria was applied, including the revised defoliation damage standard and the multiplier rules for all root diseases (i.e., stump-top assessments for Tomentosus root disease, etc.).
7. For each stand, 15 site index estimates per dominant species were made using the growth intercept method (i.e., in every plot, the tallest tree of each species was selected and the site index was determined).

5 Estimation of total well-spaced and free-growing density for a stand should be done without capping the counts by the M-value. But, when determining free-growing status of the stand, the M-value should be used during the calculations (Bergerud 2002). The M-value is the maximum number of well-spaced and (or) free-growing trees that can be tallied in a plot and is based on target density. A target density of 1200 stems per hectare corresponds with an M-value of 6 trees per plot. Use of the M-value ensures survey plots with a high number of well-spaced trees (representing more than target density) do not compensate for plots with insufficient stocking.

6 See the establishment to free-growing guidebook at: http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/guidetoc.htm.

3.0 ANALYSIS

This study could be considered either as a split-plot in time analysis or a repeated measures analysis. Two groups of stands were randomly selected from two time periods (early [1987–1994] and late [1995–2001]) during which they were declared free-growing. Just before declaration, these stands were sampled using the standard silviculture surveys procedures and the resulting summary statistics were available for analysis. In 2005, these stands were sampled again using standard sampling methodology. The analysis of variance (ANOVA) for this design was:

Source of Variation	Degrees of freedom	Effect:
Group	1	Fixed
Stand (Group)	58	Random
Survey Time	1	Fixed
Group x Time	1	Fixed
Time x Stand (Group)	58	Random

The following *a priori* questions (contrasts) were included in the analysis:

1. For the early group of stands, is there any difference in results for the two survey times?
2. For the late group of stands, is there any difference in results for the two survey times?
3. Is there a difference between the early and late groups of stands (averaged over survey time)?

All variables except the change in leading species were analyzed using this ANOVA. The required calculations were conducted using the mixed procedure within SAS (SAS Institute Inc. 1990). Residuals and influence statistics were examined to see whether the model described above adequately fit the data.

3.1 *Current Volume Calculations*

The current height and dbh of healthy well-spaced crop trees along with whole-stem volume equations (Watts 1983) for each species for the central Interior were used to determine current volume per hectare of crop trees in each stand. The volume equations we used were:

3.2 *Projected Volume Calculations (Using TIPSY)*

In our TIPSY analyses, we used total stocking, including deciduous from the original free-growing declarations, and compared the results of those TIPSY runs to TIPSY runs based on total trees in height classes of greater than 2 m from the 2005 assessment. The decision to include deciduous stocking was made to more realistically represent the degree of competition occurring in these stands and was based on advice from TASS developers (J. Goudie, pers. comm., May 2006). We chose to use only those trees greater than 2 m in the 2005 TIPSY runs as we believed this would provide a more accurate representation of the growing stand that had been declared. Had we included all 2005 conifer trees, even those less than 2 m in height, we would have included more natural ingress than TIPSY models (J. Goudie, pers. comm., May 2006). We did not assess the long-term implications of this decision; however, since nearly all timber supply reviews in this province are based on TASS/TIPSY projections we thought it most appropriate to try to approximate the conditions that TIPSY models.

We used the TIPSY feature “calculate from existing stand conditions” and the “natural stand” stem distribution option. We entered total stems from the free-growing declaration and current 2005 values at their respective age since denudation. Note that we did not include forest health or other free-growing criteria into our volume predictions because, aside from the Operational Adjustment Factors (OAFs), no means currently exist to do so. TASS/TIPSY volume projections are based on total tree density, not free-growing tree density. The base case scenario in the second Lakes TSA Timber Supply Review (TSR2) included an OAF1 of 20% rather than the provincial default of 15% to account for hard pine rusts in pine-leading stands (B.C. Ministry of Forests 2001). We used that same value in our TIPSY runs for pine-leading stands.

We assessed the effect of using a planted stand distribution in TIPSY for stands that had received spacing treatments following declaration. We were limited in our ability to assess this effect by the lack of post-spacing treatment target densities reported in RESULTS.

Lodgepole pine *log* Volume = −4.349504 + 1.822760 *log* dbh + 1.108120 *log* Height

Hybrid spruce *log* Volume = −4.294193 + 1.858590 *log* dbh + 1.007790 *log* Height

Subalpine fir *log* Volume = −4.291919 + 1.872930 *log* dbh + 0.998274 *log* Height

For those stands that had post-treatment densities, we found that the amount of ingress occurring after treatment suggested the natural stand stem distribution was still reasonable and the modelling of spacing treatments introduced unnecessary complication to our analyses.

Forecasted volume per hectare was projected using TIPSY to the current age (gross volume) and rotation age (merchantable volume at 80 years) for each stand. We used the 2005 site index value rather than the declaration site index value as we found significant increases in site index for the early-declared group.

TIPSY inputs included species, site index, and total stocking. For the 2005 TIPSY runs, total stocking was the number of trees greater than 2 m in height.

Statistical tests were then run on the following comparisons:

- the current volume estimates using whole-stem volume equations (Watts [editor] 1983) versus TIPSY-projected volumes to 2005 based on declaration values;
- the measured quadratic mean dbh of all well-spaced trees per stand and the maximum measured dbh of the largest 15 trees per stand in 2005 (200 stems per hectare) and TIPSY projections of quadratic mean dbh and maximum dbh of the top 250 stems per hectare based on declaration values projected to the year 2005; and
- TIPSY merchantable harvest volume projections to age 80 based on declaration values versus those based on 2005 attributes.

The relationships between projected volume and both free-growing and total tree density were examined. Projected volumes were adjusted to a site index of 20 m based on an empirical linear relationship developed using the ANOVA model, but adding site index as a covariate.

3.3 *Species Composition*

Free-growing declaration values for leading species proportions (inventory labels) were compared to current leading species proportions on a per stand basis to determine whether species compositions had changed significantly since declaration.

3.4 *Site Index*

Free-growing declaration site index estimates were compared to current site index estimates as determined using the growth intercept method (B.C. Ministry of Forests 1995).

3.5 *Stocking Estimates*

Stand densities based on free-growing declaration values for total stocking, well-spaced, and free-growing trees were compared to current stocking densities of the same three stand-density values. For analysis comparisons to declaration values, an M-value of 6 trees per plot (based on a target stocking density of 1200 well-spaced stems per hectare) was applied on the assumption that this M-value was used in the earlier estimates.

3.6 *Forest Pest Incidence*

Unacceptable levels of damage to trees based on the current provincial free-growing damage criteria were recorded in 2005.[7] Comparisons were made between estimates of forest pest incidence at the time of the free-growing declaration and current estimates of pest incidence.

4.0 Results and Discussion

4.1 *Representation of the Free-Growing Stand Population*

We limited our sample population to stands with disturbance dates later than 1960. Our stand-selection criteria captured 73% of the population of stands declared free-growing between 1995 and 2001 and 45% of the earlier age group (Table 1). By sampling 30 stands in each declaration period, our sampling intensity was 12.9% for the period 1987–1994 and 5.8% for the period 1995–2001. Over 73% of all stands declared free-growing in the Lakes TSA have gross opening areas greater than 15 ha.

Table 1. Sample population criteria relationship with total population of stands declared free-growing in the Lakes TSA in the period 1987–2001.

Period Declared Free-Growing	Total Popu-lation	Disturbed after 1960	>15 ha	Disturbed after 1960 and >15 ha	Sampling Intensity (%)
1987-1994 (early)	523	309	397	233	12.9
1995-2001 (late)	714	699	527	521	5.8

The greatest number of stands declared free-growing in a single year during the period examined occurred in 2001 (Figure 3). This is an expected result. Stands created under

7 See the establishment to free-growing guidebooks at: http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/guidetoc.htm

free-growing policy would have been at most 14 years old in that year. We were somewhat surprised to see the spike in free-growing declarations in 1993. A concerted effort was waged in the early 1990s to clear-up old backlog blocks listed as not free-growing. The increase in free-growing declarations in 1993 may be an artefact of available funding and ministry policy to reduce that backlog. Forest Resources Development Agreement (FRDA) backlog treatments occurred from the early to late 1980s, so these treated stands may have reached a point where they could have been classed as free-growing around 1993.

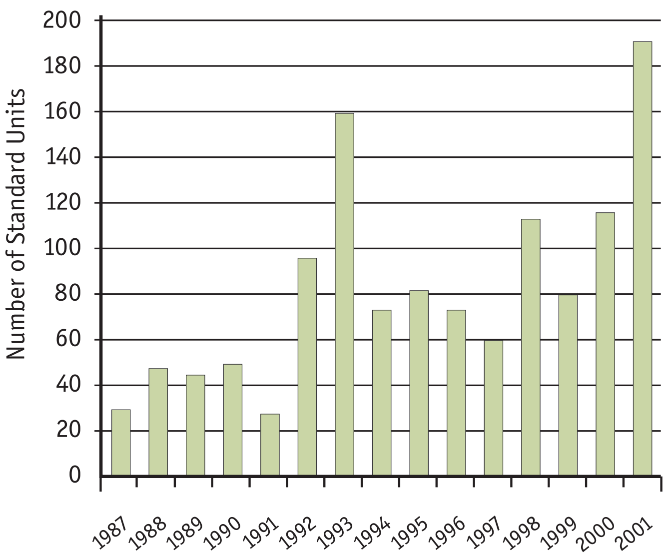

Figure 3. *Number of standard units declared free-growing in the Lakes TSA during the period 1987–2001.*

4.2 Stand Age Since Disturbance

The number of years elapsed since disturbance for the early group ranged from 18 to 44 years, with a mean of 27.3±1.9 years (95% CI), while the late group ranged from 15 to 25 years, with a mean of 20.8±1.1 years.

4.3 Comparison of TIPSY Projections to Current Stand Conditions

We found no significant difference between the 2005 measured volume of well-spaced trees and the TIPSY-estimated volume projected to 2005 for the late-declared group (Table 2). We did, however, find a significant difference between the two volume estimates for the early-declared group (Table 2). TIPSY volume projections for the early-declared group of stands were 35% greater than the measured volume of well-spaced trees in those stands. Part of the difference is undoubtedly due to our approach to volume estimation (i.e., TIPSY volumes projections are based on total trees and we measured only the well-spaced tree volume); however, given that the volume estimates of the late-declared group were not significantly different, it is difficult to explain the magnitude of the difference for the early group.

Table 2. *Comparison between TIPSY-estimated current gross volume, quadratic mean dbh and maximum dbh of the largest 250 trees per hectare based on declared stand attributes projected to 2005 and measured 2005 stand attributes of well-spaced trees in 60 free-growing stands in the Lakes TSA. Values appearing in bold type are significant at $\alpha = 0.05$.*

Contrasts	Contrast Means		Difference	SE of Difference	*p*-value
Two Measures of Volume					
	Measured*	**TIPSY**			
Early	40.4	54.7	-14.3	3.3	**<0.0001**
Late	19.9	21.0	-1.2	3.3	0.73
	Early	**Late**			
Averaged over group	47.5	20.5	-27.1	4.7	**<0.0001**
Average Quadratic Diameter					
	Measured	**TIPSY**			
Early	11.2	8.0	-3.2	0.30	**<0.0001**
Late	8.6	5.2	-3.4	0.30	**<0.0001**
	Early	**Late**			
Averaged over group	9.9	6.6	-3.3	0.21	**<0.0001**
Max DBH					
	Measured	**TIPSY**			
Early	14.9	15.4	-0.4	0.65	0.52
Late	11.9	13.1	-1.2	0.65	0.074
	Early	**Late**			
Averaged over group	13.4	14.2	-0.8	0.46	0.085

* Using whole-stem volume equations from Watts (1983).

We would have expected a greater difference in volume estimates between the two estimation approaches for the late-declared group, as the relative difference in size between the trees that were included in the volume estimates was least. The relative difference in size between the average free-growing and well-spaced crop tree and the average total tree should intuitively be less for the late group because the trees in those stands would have had less time to demonstrate differences in dominance, so stocking (i.e., 1200 well-spaced stems per hectare vs. 3500 total stems per hectare) should have had a greater influence on volume. We only measured the well-spaced tree volume, whereas TIPSY volume projections would include all trees. Conversely, the older the stand was, the closer one would expect the measured volume of the apparent crop trees (i.e., the free-growing and well-spaced trees) should be to TIPSY projections as the relative volume contribution of total trees, including co-dominant and understorey trees, diminished and proportionately more volume accrued in the dominant trees. We did not find this.

Comparing both quadratic mean and maximum measured dbh from our 2005 survey to TIPSY projections for the same attributes provided an easily determined field verification of the TASS/TIPSY model. We found that TIPSY consistently, significantly underestimated current dbh in terms of the quadratic mean (Table 2). This result is understandable since our quadratic mean dbh was based on well-spaced trees and the TIPSY value is based on all trees. Another possible explanation for this difference is that we used natural stand stem distributions in TIPSY rather than planted, yet most of the stands we surveyed were planted. While the TIPSY values for current maximum dbh of the largest 250 stems per hectare were higher than the measured data the results were not statistically significant.

We recognize that comparing current stand volumes based on a given set of volume equations to TIPSY projections, is not without question. TASS and TIPSY volume projections are based on the volumes of all trees; our estimates were based on the volume of the healthy well-spaced trees. Nevertheless, it did seem appropriate to attempt to compare TIPSY projections to some estimate of current volume that practising foresters could easily measure and visualize. The use of whole-stem volume equations to estimate the volume of well-spaced trees should provide a conservative estimate of current volumes compared to TIPSY. Determining the volume of the well-spaced trees in fifteen 3.99 m radius plots per stand was feasible from a fieldwork production viewpoint. Attempting to determine the volume of total trees in the same plots would have been prohibitively time-consuming.

These differences in approach to volume estimation do limit our ability to draw conclusions about stand growth trajectories. However, it is difficult to explain the incongruity between TIPSY projecting 35% greater volume than our measured volume for the early group when TIPSY's quadratic mean dbh was 29% smaller than our measured quadratic mean dbh. This result suggests that perhaps the mortality functions in TIPSY/TASS could be reviewed. Our maximum dbh estimates did not differ significantly from TIPSY. It appears that all of those trees that were not well-spaced are making up the difference in volume.

These results suggest the need for a standardized approach to verify TIPSY projections mid-rotation for use in the field. If TASS/TIPSY was able to project the volume of the largest well-spaced trees throughout a rotation, then field verification of the model would be much easier. Procedures similar to those developed in this project could be used. We believe mid-rotation field verification of TASS/TIPSY would improve the level of confidence in timber supply projections and, by extension, the entire current forest management framework in the province. Our results also emphasize the need for a follow-up examination of the same stands used in our study after 10 or more years to see whether a trend towards greater divergence between the measured volume of well-spaced crop trees and TIPSY projections is evident.

4.4 *Stocking Densities: Well-Spaced, and Free-Growing Stems*

In comparing the stocking densities between declaration and 2005, we assumed an M-value of six had been applied in the original free-growing surveys. We were not able to confirm whether an M-value was used, but believe this was standard practice in the TSA. We found a statistically significant reduction in well-spaced density between the declared values and the 2005 survey for stands declared between 1987 and 1994 when the M-value was applied. In real terms, the relatively small changes in mean stocking levels for both well-spaced and free-growing stems suggest little cause for concern. Mean stocking levels[8] of both well-spaced and free-growing stems are still close to or above 1000 well-spaced stems per hectare, regardless of whether the M-value rule is applied (Table 4).

8 We are using a biased estimator for well-spaced and free-growing stocking here because we had to use values capped by the M-value. Of course, the M-value caps are appropriate when making the decision of whether the stand should be declared free-growing.

Throughout the Lakes TSA (and much of the province) the minimum stocking standard is 700 free-growing stems per hectare. Decisions as to whether a stand meets this standard are generally made using the 90% lower confidence limit (LCL) although the mean can be used in some circumstances.[9] The LCL rule significantly reduces the liability of the Crown when accepting understocked stands as free-growing (Bergerud 2002).

Seven stands in the early-declared group and four stands in the late-declared group no longer have LCLs exceeding the minimum of 700 free-growing stems per hectare. Although mean stocking levels of free-growing stems for both early and late groups combined are close to or above 1000 free-growing stems per hectare, over 18% of the stands we sampled, which had been declared as free-growing, no longer meet the LCL test.

No significant differences were evident in the number of total stems between the time of declaration and 2005 for either the early or late groups of stands (Table 3). For example, in the case of the early stands, the average number of total stems had not changed significantly over the 11–17 years since declaration. This illustrates the amount of natural ingress that is occurring in these stands. TASS and TIPSY assume that stands tend to lose stems to competition over time and do not currently model the degree of natural ingress that we encountered. For this reason, we modelled stands with TIPSY using only trees greater than 2 m in height (as of 2005) as "total trees" (Table 4).

Table 3. *Comparison of total trees in 2005 (minimum height of 1.3 m) and total trees greater than 2 m in height in 2005 illustrating the degree of natural ingress occurring in the early- and late-declared groups of stands in the Lakes TSA.*

Contrasts	Contrast Means		Difference	SE of Difference	*p*-value
	Early	**Late**			
Total trees (2005)	3715	3627	88	380	0.82
Total trees > 2m	2539	2766	-227	326	0.49
Ingress	1176	861	315	215	0.15
Difference from declaration (total trees)	-38	292	330	393	0.39

9 See the Silviculture Manual, page 75 ff at http://www.for.gov.bc.ca/hfp/publications/00099/surveys/SurveysProcManual3.pdf

Table 4. *Means and estimates of the mean differences, including p-values, for well-spaced density (with and without the M-cap), free-growing density (with and without the M-cap), total stems, site index and forest pest damage incidence for the early (1987–1994) and late (1995–2001) groups of free-growing stands, as well as the differences between the early and late groups. Values appearing in bold type are significant at α = 0.05.*

Contrasts	Contrast Means		Difference	SE of Difference	*p*-value
Well-Spaced (stems/ha)					
	Declaration	**2005**			
Early		1114.3			
Late		1159.1			
Well-Spaced (stems/ha) (M-cap)					
	Declaration	**2005**			
Early	1114.8	1019.0	-95.8	24.5	**0.0003**
Late	1088.1	1054.7	-33.4	24.5	0.18
	Early	**Late**			
Averaged over survey time	1066.9	1071.4	4.5	24.5	0.86
Free-Growing (stems/ha)					
	Declaration	**2005**			
Early		1051.1			
Late		1105.3			
Free-Growing (stems/ha) (M-cap)					
	Declaration	**2005**			
Early	1020.8	972.9	-47.9	34.5	0.17
Late	975.0	1010.7	35.6	34.5	0.31
	Early	**Late**			
Averaged over survey time	996.9	992.8	4.1	27.8	0.89
Total Trees (stems/ha)					
	Declaration	**2005[a]**			
Early	3753	3715	-38	270	0.89
Late	3335	3627	292	270	0.29
	Early	**Late**			
Averaged over survey time	3734	3481	252	363	0.49
Site Index (m)					
	Declaration	**2005**			
Early	18.4	20.2	1.8	0.38	**<0.0001**
Late	19.8	19.9	0.11	0.38	0.77
	Early	**Late**			
Averaged over survey time	19.3	19.8	-0.54	0.27	**0.052**
Forest Health (% incidence)					
	Declaration	**2005**			
Early	6.9	16.1	-9.2	1.7	**0.0001**
Late	7.6	15.3	-7.7	2.2	**0.0008**
	Early	**Late**			
Averaged over survey time	11.5	11.4	0.12	1.5	0.94
	Declaration	**2005**			
Averaged over group	7.2	15.7	-8.5	1.4	**<0.0001**

a Total trees reported in 2005 include all trees with a minimum height of 1.3 m.

4.5 Site Index

The accuracy of site index estimates appears to have improved over time likely due to the development of standardized estimation methods such as the growth intercept method (B.C. Ministry of Forests 1995). Of the 30 stands assessed in the early-declared group, 24 had site index estimates of 18 m in their free-growing declaration documentation. The preponderance of this single value suggests that past surveyors used conversion tables based on "Good," "Medium," and "Poor" site designations that related to specified site index values. Although no significant difference was evident between mean site index estimates in the late-declared group and 2005 values (Table 4), there was a significant difference for the early group.

Despite the overall improvements in estimate accuracy, our review of unusual site index values suggests a systematic bias in estimates for interior spruce. Three of the seven unusual site index values identified in our analysis were spruce-leading stands, yet spruce-leading stands represented only 8.3% of our sample (Table 5). Two of the three unusual spruce site index values involved overestimates at the time of declaration during the period 1995–2001.

Table 5. *Unusual site index values and likely explanations for seven sampled free-growing stands declared by group (1987–1994 and 1995–2001) from a sample of 60 stands in the Lakes TSA. Predicted values were obtained from the analysis of variance.*

Group	Opening Number	Leading Species	Observed Values	Predicted Values	Residual	Studentized Residual	Explanation
Early 87–94	93F043-028	Pine	21.8	18.4	3.4	2.2	Valid measure in 1994
Early 87–94	93F043-020	Pine	17.0	20.2	–3.2	–2.2	Valid low SI
Early 87–94	93F052-014	Pine	17.2	20.2	–3.0	–2.1	Valid low SI, DMP[a]
Late 95–01	93E099- 502	Pine	24.0	19.8	4.2	2.9	Overestimate in 1998, now 20.1
Late 95–01	93F042-003	Spruce	24.6	19.8	4.8	3.3	Overestimate, wide variation in spruce SI height
Late 95–01	93F051-001	Spruce	23.6	19.8	3.8	2.6	Overestimate, wide variation in spruce SI height
Late 95–01	93F061-803	Spruce	16.7	19.9	–3.2	–2.2	Valid low SI, wide variation in spruce SI height

a DMP = lodgepole pine dwarf mistletoe.

Site index values ranged from 16.7 to 22.1 and 17 to 22.3 for the late- and early-declared groups, respectively.

4.6 TIPSY-Projected Merchantable Volume at Age 80, Based on Declared and 2005 Attributes

We found no significant difference in TIPSY-projected merchantable volume at age 80 between declared values and 2005 values for stands in the late group (Table 6). A statistically significant drop was apparent in projected volume between projections based on free-growing declaration attributes and those of 2005 for the early group, but this difference was less than 1% and was not of practical concern.

Table 6. *Comparison between TIPSY-projected volume at age 80 for stands declared in the period 1987–1994 and 1995–2001 based on declaration and 2005 stand attributes. Values appearing in bold type are significant at $\alpha = 0.05$.*

Contrasts	Contrast Means		Difference	SE of Difference	*p*-value
Projected Volume at 80 yrs					
	Declaration	**2005**			
Early	327	324	3.2	1.4	**0.032**
Late	316	314	2.5	1.4	0.091
	Early	**Late**			
Averaged over survey time	325	315	10.2	10.1	0.32

As 90% of the stands we sampled in the Lakes TSA were lodgepole pine-leading, we focussed further analyses on this species.

4.7 TIPSY-Projected Merchantable Volume at Age 80 and Free-Growing Density (For Lodgepole Pine-Leading Stands Only)

The merchantable volume at age 80 depends on site index and does so in a straightforward linear fashion (Figure 4); therefore, an empirical relationship was developed between the projected volume and site index as recorded in 2005. This allowed us to adjust the projected volumes to a common site index and simplify the study of the relationship between projected volume and free-growing density. The original volumes were adjusted to a site index of 20 by subtracting 27.9 x (SI at 2005 – 20) from the TIPSY-projected merchantable volume.

Interestingly, forest health factor incidence was evenly distributed over the range of site indices (Figure 4). Also, note how at the time of declaration none of the stands in either age group had a high incidence of forest health factors (top row Figure 4).

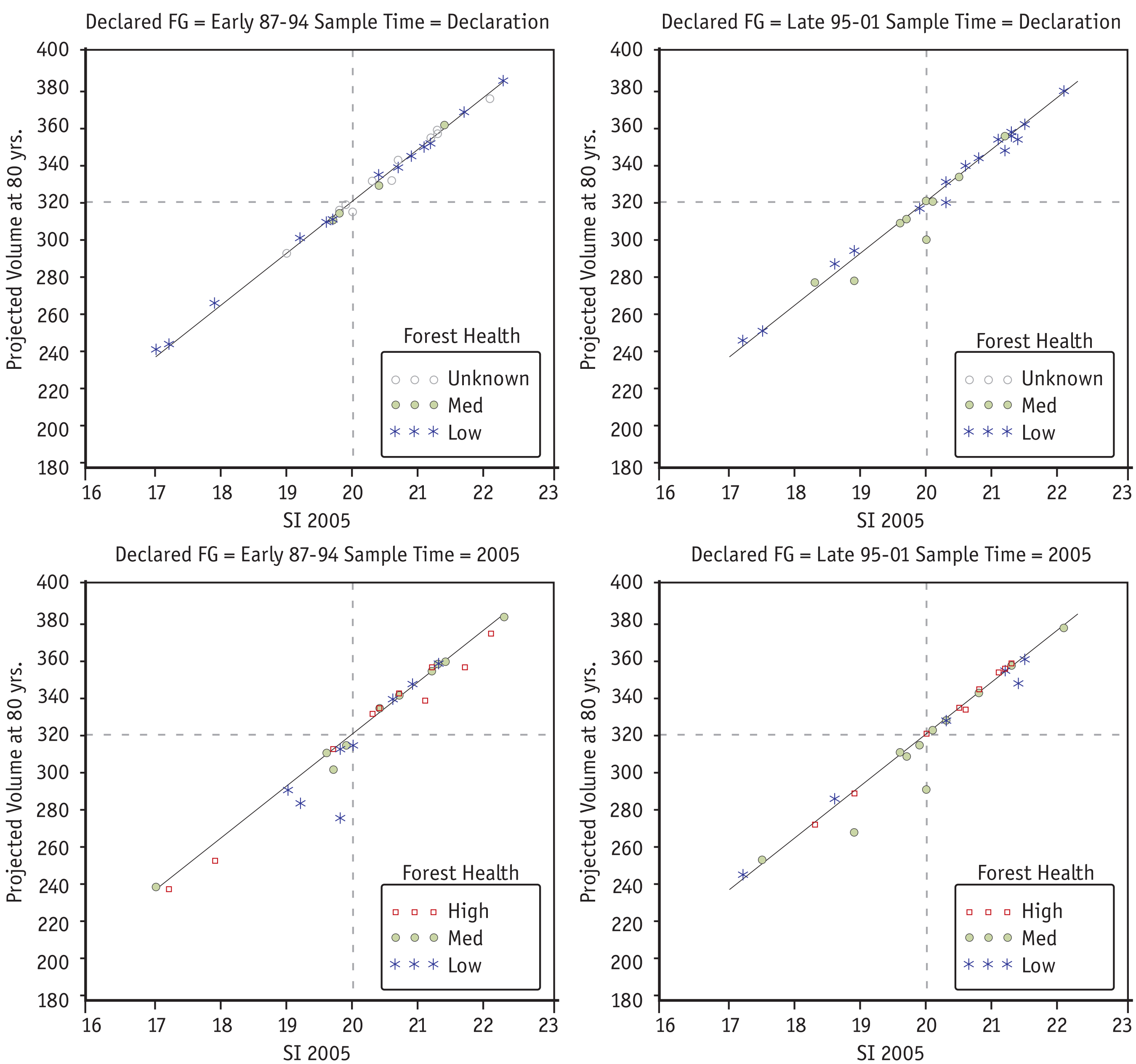

Figure 4. *Plots of projected volume against site index for the early- and late-declared groups using just the 2005 site index values. Sites with low levels of forest health problems in 2005 (< 10%) are shown with blue stars, with medium levels (10–20%) with green dots and high levels (> 20%) with red squares. The lines shown are volume = 321.0 + 27.9 (SI at 2005 – 20). Only lodgepole pine leading stands are shown.*

We plotted the adjusted projected volumes, based on declaration attributes (upper panels) and 2005 attributes (lower panels), against the density of trees greater than 2 m in height in 2005 (Figure 5). The adjusted projected volume is reasonably steady at about 321 m^3/ha for densities greater than 2000 stems per hectare. A decline is evident in projected volume for densities below 1500 stems per hectare. This pattern (using actual stand data) closely matches the theoretical relationship between these two factors described in Land Management Handbook No. 50 (Bergerud 2002).

The projected volumes based on declaration total density (Figure 5 upper left panel) are relatively constant for the early-declared group. For the late-declared group, five stands had densities less than 1600 stems per hectare and showed reduced projected volume (Figure 5, upper right panel). Two of these five stands have experienced substantial ingress after declaration, which brings their projected volume into line with the projected volume of the majority of stands. The other three stands experienced further declines in total stocking, which dropped their projected volume still further.

Six stands in the early-declared group have less than 1600 total trees greater than 2 m in 2005 and have undergone considerable change since declaration. Those six stands are largely responsible for the differences between projected volumes using declaration attributes and volume projections based on 2005 attributes. Five of those six stands have suffered from high forest health factor incidence that has reduced their total stocking; three have both high forest health factor incidence and a history of silvicultural treatments.

Despite declines in total stocking between declaration and 2005 for the early group, the magnitude of the drop in projected volume is still only about 12% in the worst case (lower left panel, Figure 5). This stand (93F072-004) had been spaced from 3224 stems per hectare at declaration to 825 stems per hectare in 1993. This stand has subsequently been severely attacked by mountain pine beetle (> 75% mortality) in the summer of 2005. We modelled this stand without taking the beetle attack into account; therefore, the reduced projected volume portrayed in the lower left panel is grossly optimistic. The second greatest drop in projected volume between declaration and 2005 occurred in stand 93F082-45 and was less than 4%. Despite an incidence of hard pine rusts of 46% in stand 93L090-009 and a current stocking of 1293 stems per hectare in 2005, the reduction in projected volume was also less than 4% (Figure 5).

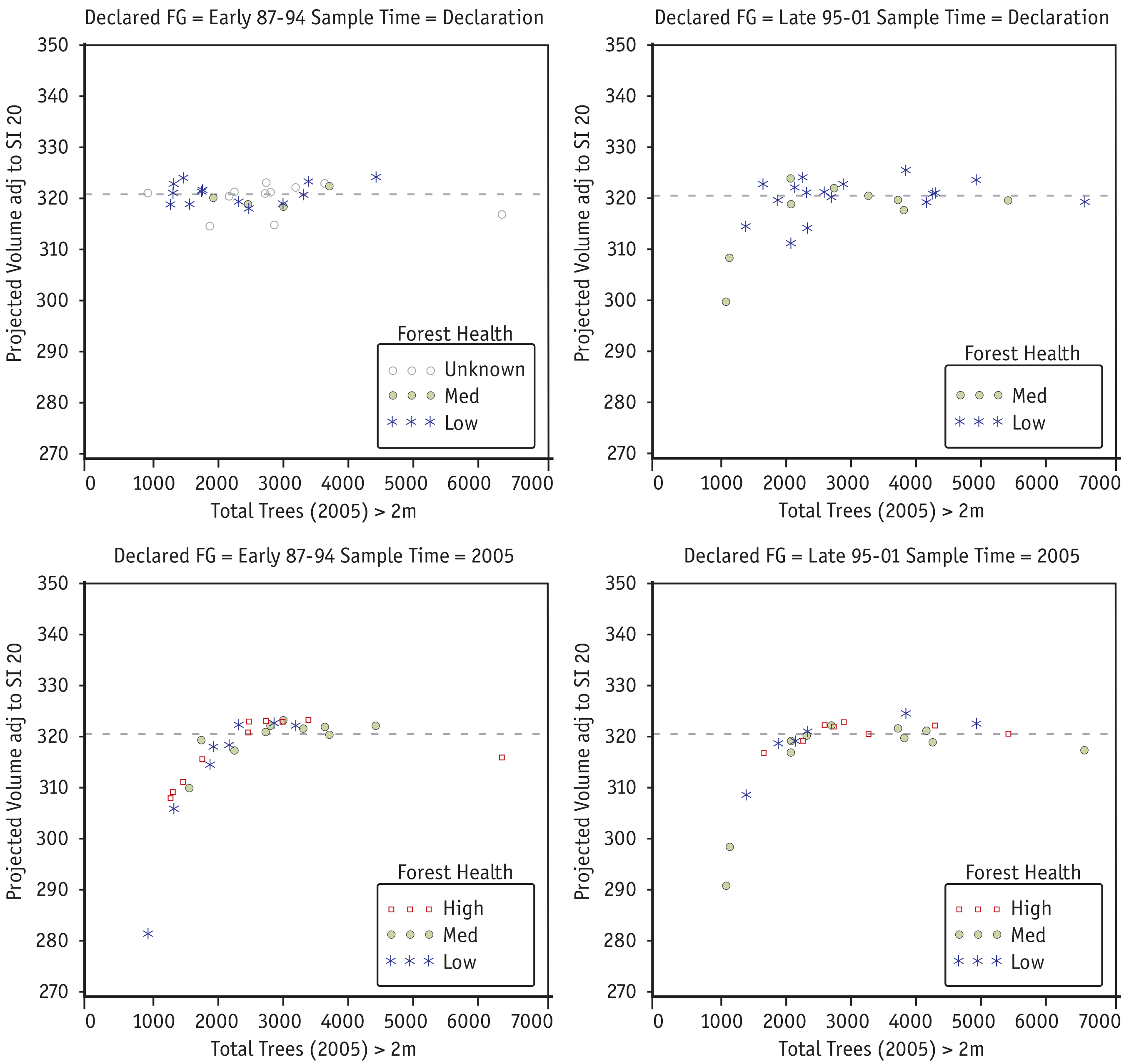

Figure 5. *Plots of the TIPSY-projected volume at age 80 years adjusted to a site index of 20 m (by subtracting 27.9 x [SI at 2005 – 20] from the original projected volume), against density of total trees greater than 2 m in 2005. Sites with low levels of forest health problems in 2005 (< 10%) are shown with blue stars, medium levels (10–20%) with green dots, and high levels (> 20%) with red squares. The horizontal line is at a projected volume of 321.0 m^3/ha. Only lodgepole pine leading stands are shown.*

If a strong relationship existed between free-growing density and total density, then we would expect a similar tight trend between TIPSY-projected volume and free-growing density (Figure 6). In general, the scatter of data points is greater than that found when plotting projected volume against total trees, but this is not surprising since TIPSY-projected volume is based on total trees not free-growing trees. A trend towards reduced projected volume is evident once free-growing density (as assessed in 2005, not declaration) drops below 900 free-growing stems per hectare (lower panels, Figure 6). Again, the greatest decline in projected volume, not surprisingly, occurs in stand 92F072-004. The second most significant decline between the declaration volume projection and the 2005 volume projection occurred in stand 93F082-45, a drop of 5.5%. The two stands with the lowest projected volumes in the late group (Figure 6, right panels), based both on declaration (top) and 2005 attributes (bottom), had low stocking.

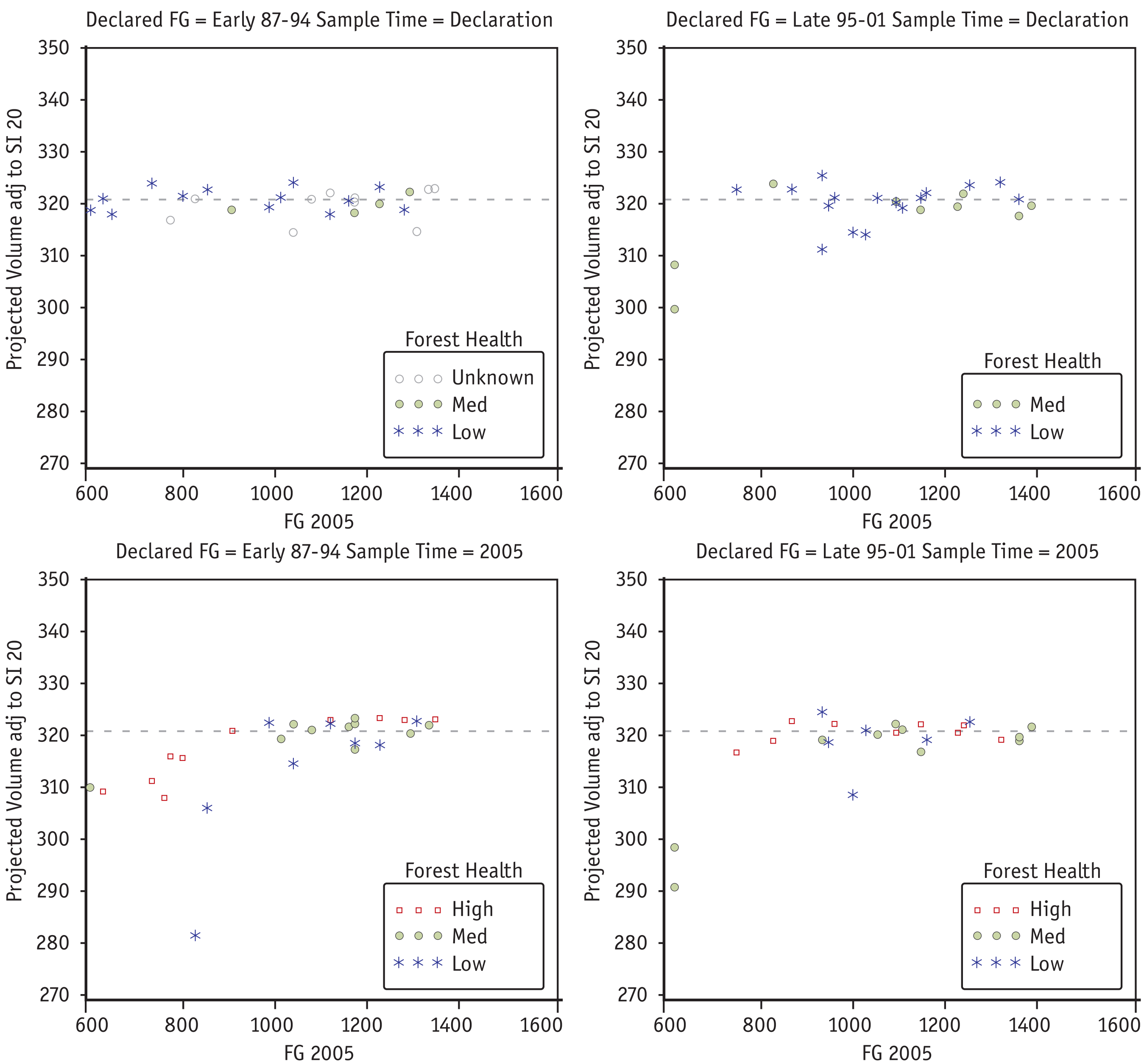

Figure 6. Plots of the TIPSY-projected volume at age 80 years adjusted to a site index of 20 m (by subtracting 27.9 x [SI at 2005 – 20] from the original projected volume), against the sampled free-growing density in 2005. Sites with low levels of forest health problems in 2005 (< 10%) are shown with blue stars, medium levels (10–20%) with green dots, and high levels (> 20%) with red squares. The horizontal line is at a projected volume of 321.0 m3/ha. Only lodgepole pine leading stands are shown.

We then looked at the relationship between the density of free-growing trees in 2005 and the number of total trees greater than 2 m at that time (Figure 7). The relationship between these factors is stronger for the early group except for one unusual point with very high total trees. The larger scatter for the late-declared stands suggests that more of those stands have a clumpy distribution. This may be because fewer of these stands have been thinned either deliberately or by natural mortality.

Our predictions of future stand productivity for the younger stands are less accurate as the influence of forest health agents and other natural events are yet to be realized. The one particularly unusual point in the early group (Figure 7) emphasizes this. At the time of declaration, stand 93K003-043 contained over 10 000 total trees per hectare, yet in 2005 the minimum threshold of 700 free-growing stems per hectare could no longer be met. The same stand in 2005 had a 39% incidence of hard pine rusts, yet no pests or pathogens had been recorded at declaration. It is highly unlikely that this stand was rust-free at the time of declaration, but it is almost certain that the incidence of rusts has increased since it was declared free-growing.

The high initial density in stand 93K003-043, coupled with a high incidence of hard pine rusts, was likely responsible for another affront to this unfortunate stand. In late October 2006, the Bulkley Valley and Lakes area of central British Columbia experienced an extreme snowfall event with over 100 cm of heavy, wet snow falling in a 2-day period. This event led to severe snowpress in several locations including in stand 93K003-043 (Figure 8).

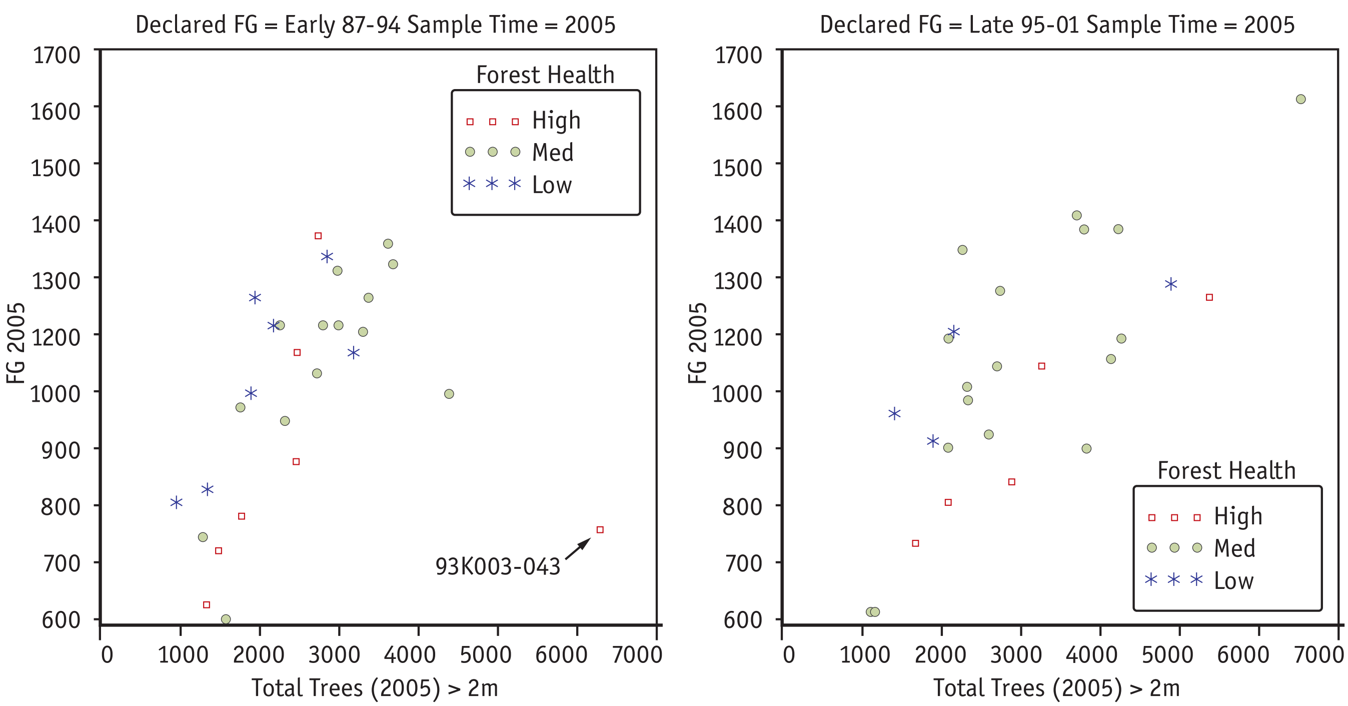

Figure 7. Plot of the free-growing density in 2005 and density of total trees greater than 2 m in 2005 for stands declared free growing in the period 1987–1994 and 1995–2001. Sites with low levels of forest health problems (< 10%) are shown with blue stars, with medium levels (10–25%) with green dots, and high levels (> 25%) with red squares. Only lodgepole pine leading stands are shown.

Figure 8. Severe snowpress in stand 93K003-043, the result of an extreme snowfall event October 2006 in the Lakes TSA (photo: Erin Havard, November 2007).

In general, any decline in harvest volume projections based on 2005 attributes as compared to declaration attributes were not large and occurred only in those stands with total densities lower than 1600 stems per hectare (free-growing densities lower than 900 stems per hectare). Provided stand densities are not allowed to drop below these levels, free-growing stands in the Lakes TSA appear to be meeting expectations. To improve the accuracy of timber supply forecasts, projections of managed stand productivity should be updated after declaration to account for changes in stocking that occur due to silvicultural treatments, natural events, and forest health agents.

4.8 Species Composition

Of the 60 free-growing stands we surveyed, only six (10%) were dominated by a species other than lodgepole pine, both at the time of free-growing declaration and in 2005. Five stands were spruce-leading and the sixth was dominated by subalpine fir. This result suggests that the species composition of managed stands may be even more concentrated on a single species than the operable timber harvesting area. In the Lakes TSA, 77% of that operable timber harvesting area is dominated by pine (B.C. Ministry of Forests 2001).

Changes to species composition in free-growing stands since declaration have been subtle, but have tended towards a loss of diversity, which is supported by a recent report covering managed stands throughout the province (Ralph Winter, pers. comm., July 2007). At the time of free-growing declaration, eight stands had inventory labels that consisted of three species, which included trembling aspen. In 2005, none of the surveyed stands contained trembling aspen in their inventory labels. Similarly, the number of stands with three conifer species in their inventory labels has dropped from 10 at the time of free-growing declaration to six in 2005. Changes to species composition have largely been due to silvicultural treatments (i.e., brushing and juvenile spacing). The late-declared group of stands has not received silvicultural treatments to the same extent as the early group. Only 30% (9 out of 30) of the late-declared group had been either spaced or brushed compared to 63% (19 out of 30) for the early-declared group. The timing and availability of funding sources for silviculture programs, such as Forest Resource Development Agreements (FRDA 1 and 2) and Forest Renewal BC (FRBC), largely explain this difference.

Reductions in the proportion of stands that received silvicultural treatments in the late group may be a positive development. Our analyses of projected volumes illustrate the potential negative effects of silvicultural treatments when they occur in stands already compromised by forest health agents. Improving the resiliency of managed stands has increasingly been lauded as a goal for forest management in British Columbia (Future Forest Ecosystems Initiative 2005). Increasing species diversity in managed stands would help to achieve this goal in the Lakes TSA. We recommend that the subtle trend towards greater concentration on lodgepole pine in our study area be reversed. In much of the Lakes TSA, a minimum of three tree species (i.e., lodgepole pine, interior spruce, and trembling aspen) could be managed. A greater emphasis should be placed on diversifying the species composition of managed stands. Forest Stewardship plans should consider the strategic use of all species and mixtures. The current Forests for Tomorrow silviculture/reforestation program considers this point when developing their project plans.

Throughout this report, we have focussed on forest management from a timber productivity perspective. Increasing tree species diversity would not only reduce the risks associated with losses to timber supply caused by forest pests, but would also benefit other forest resources, including wildlife habitat and biodiversity.

4.9 Forest Health

The greatest change in stand attributes between the time of free-growing declaration and the 2005 survey for both the early and late groups occurred with the incidence of forest pest damage. Hard pine rusts, including western gall rust and comandra blister rust (Figure 9), were the most prevalent damaging agents. In 2005, over 27% of pine-leading stands had a combined hard pine rust incidence greater than 20% and over 67% of the stands had greater than 10% combined incidence. These results are consistent with other surveys of hard pine rust incidence in the Lakes TSA (Woods et al. 2000). The incidence of hard pine rust was significantly higher in 2005 than at the time of free-growing declaration in both the early- and late-declared groups (Table 4).

Figure 9. A sporulating comandra blister rust canker (left) and multiple western gall rust infections on pole-sized lodgepole pine (right), both considered lethal in the current provincial free-growing damage criteria.

This increase in rust incidence is likely due to a combination of factors. Recognition of forest pests in young stands and their influence on forest management goals has generally improved over time. Thirteen of the free-growing stands in the early group either had no record or blank records of forest health agents in their declarations, and 12 of these stands were pine-leading. Given the abundance of hard pine rusts in the Lakes TSA, it is very unlikely that these stands were free of rusts at declaration. In the late group of declared stands, only five of the stands were pest-free at declaration and there were no blank records. More importantly, real increases in rust incidence have occurred after declaration. Typically free-growing declarations are made when stands are 10–15 years old. Other studies of lodgepole pine and hard pine rusts (van der Kamp and Spence 1987; Blenis and Duncan 1997) have found that rust incidence does not peak until age 18 or older. In another study of hard pine rusts in the Lakes TSA, marked increases in rust incidence were observed over a 7-year period in stands that were over 20 years old when first examined (Woods, unpublished data).

If stands are tested by comparing the mean to the minimum stocking threshold of 700 free-growing stems per hectare, then three stands are no longer free-growing in the early-declared group. When we use a decision rule based on the LCL of 700 free-growing stems per hectare, then seven stands are no longer free-growing in the early group (Table 7). The four additional stands have all experienced marked increases in hard pine rust incidence since free-growing declaration (e.g., increases from 5.1 to 29.3%, 3.1 to 24.1%, 0 to 38.3%, and 3.0 to 24.3%). In these stands, forest pest incidence is concentrated in the tallest trees where 91% of all pest-affected trees are greater than 4 m tall. Based on the mean decision rule, two stands no longer meet the minimum stocking requirement for free-growing in the late-declared group. Using the lower confidence decision rule, two additional stands are no longer free-growing. In both cases, the change in free-growing status is again due to hard pine rusts (e.g., increases from 19.6 to 24.3% and 5.0 to 28.6%). If all 60 sample stands are considered when applying the LCL decision rule, then 18.3% of the stands no longer meet the minimum stocking requirement primarily because of pests, or a combination of pests and silvicultural treatments. In these stands, 84% of all pest-affected trees are in the tallest tree class (i.e., > 4 m tall).

Table 7. Declared free-growing stands in the Lakes TSA that failed the minimum stocking rule of 700 free-growing stems per hectare based on either the mean or the LCL decision rules, including the change in pest incidence since declaration and the proportion of forest pest-affected trees by estimated height class in those stands.

Group	Opening Number	FG MSS Test Failed	Change in % Pest Incidence FG - 2005	% Pest Affected Trees by Height Class			Total # Pest Affected Trees Assessed in Stand
				<2m	2-4m	4+m	
Early 87–94	93F052-014	LCL	5.1 – 29.3	0.0	8.3	91.7	48
Early 87–94	93F062-021	LCL	3.1 - 24.1	3.0	0.0	97.0	33
Early 87–94	93F003-043	LCL	0.0 – 38.3	1.5	8.6	89.8	197
Early 87–94	93F025-013	LCL	3.0 – 24.3	0.0	11.5	88.5	26
Early 87–94	93F090-009	Mean	10.0 - 46.9	5.8	3.8	90.4	52
Early 87–94	93F021-008	Mean	1.0 - 17.2	24.1	24.1	51.7	29
Early 87–94	93F072-004	Mean	0.0 - 75.0[a]	0.0	0.0	75.0	55
Late 95–01	93F052-023	LCL	19.6 – 24.3	6.8	9.1	84.1	44
Late 95–01	93F063-022	LCL	5.0 – 28.6	5.5	5.5	89.0	54
Late 95–01	93F053-007	Mean	12.0 – 19.4	17.9	0.0	82.1	28
Late 95–01	93F063-021	Mean	16.3 – 18.1	39.5	9.3	51.2	43

a The incidence of individual trees attacked by mountain pine beetle was not recorded; this is an estimate.

To identify unusual values for the stocking of both well-spaced and free-growing stems, we conducted checks of residual and influence plots from the analyses of variance. In the case of well-spaced stems, six of the seven unusual values were due to low stocking numbers at the time of free-growing declaration, which subsequently decreased even further because of hard pine rusts (Table 8). Predictably, the same trends occurred in the numbers of free-growing stems, since many of the stands were represented in both groups of unusual values (Table 9).

Table 8. Unusual values for well-spaced stems (M-capped) from 60 sampled free-growing stands declared by group (early and late).

Group	Opening Number	Observed Dec / 2005 Values	Predicted Values	Residual	Studentized Residual	Explanation
Early 87–94	93E089-524	921 /	1115	–193.8	–1.70	Low stocking at declaration; now 1120 wsph[a] due to natural ingress
Early 87–94	93F062-021	/ 787	1019	–232.0	–2.03	Low stocking at declaration; now even lower due to DSG[b]
Early 87–94	93K003-043	/ 773	1019	–246.0	–2.15	41% of 4 m+ tall trees have DSG
Early 87–94	93K021-008	/ 680	1019	–339.0	–2.97	Low stocking at declaration; now even lower due to DSG and moose
Early 87–94	93K025-013	/ 800	1019	–219.0	–1.92	Increase in DSG since declaration
Early 87–94	93L090-009	/ 680	1019	–339.0	–2.97	Increase in DSG since declaration
Late 95–01	93F053-007	/ 707	1055	–347.7	–3.04	Low stocking at declaration; now even lower due to DSG

a wsph = well-stocked stems per hectare.

b DSG = western gall rust.

Table 9. Unusual values for free-growing-stems and likely causes from 60 sampled stands declared by group (early and late).

Group	Opening Number	Observed Values 2005	Predicted Values	Residual	Studentized Residual	Explanation
Early 87–94	93K021-008	600	973	–373	–2.65	Low stocking; now even lower due to DSG[a] and moose
Early 87–94	93L090-009	627	973	–346	–2.46	Increase in DSG
Late 95–01	93F053-007	613	1011	–398	–2.82	Low stocking; now even lower due to DSG
Late 95–01	93F062-021	613	1011	–398	–2.82	Low stocking; now even lower due to DSG (32% of 4 m+ trees infected)

a DSG = western gall rust.

Only two of the 60 openings surveyed contained evidence of lodgepole pine dwarf mistletoe in either their declaration reports (93F072-004) or the 2005 survey (93F052-014) (Table 5). This pathogen is usually associated with low productivity, low site index stands. Our survey results suggest that dwarf mistletoe is not a common forest pathogen in juvenile managed stands in the Lakes TSA. All of the stands we sampled were over 15 ha; therefore, the chances of dwarf mistletoe spreading from neighbouring infected mature trees along the stand perimeter would be less in our samples than in smaller stands where the edge-to-opening ratio is greater.

Although not prevalent in the stands we examined in the Lakes TSA, root diseases (e.g., Tomentosus) are particularly at odds with free-growing policy as they do not typically cause losses in managed stands until age 20 or older (Whitney 1993; Lewis and Hansen 1997). Our data supports the concern generally held by the forest health community that free-growing policy does not fit well with biological reality (Kathy Lewis, pers. comm., December 2005). Free-growing stands will continue to lose trees to forest health agents after declarations, and unless there are sufficient stems to cover these losses, timber productivity will suffer.

The greatest single loss due to forest health factors occurred in a spaced and pruned stand (93F072-004) where 70–75% of the lodgepole pine crop trees were attacked by mountain pine beetle (Brad Leroux, pers. comm., July 2005). Despite the obvious presence of pine beetles, the green-attacked trees were tallied as free-growing in the 2005 survey because free-growing damage criteria are currently not available for mountain pine beetle. In our analysis, we continued to treat these trees as healthy and free-growing in the absence of information on the incidence of beetle attack. Therefore, the results of our TIPSY analyses do not account for the losses that have occurred in this stand. As of March 2006, trees in this stand still had green crowns despite the loss of much of their bark due to woodpecker feeding activity over the winter (Figure 10).

Figure 10. *A 38-year-old lodgepole pine stand in the Lakes TSA that was declared free-growing in 1992, subsequently spaced (1993) and pruned (1994), and now attacked by mountain pine beetle. (photo: Dave Weaver, March 2006)*

This single example graphically illustrates the "snapshot in time" aspect of the free-growing declaration. Much of the British Columbia interior is in the midst of the largest mountain pine beetle infestation ever recorded; in addition, mortality in 30-year-old lodgepole pine stands was hitherto unheard of. Nevertheless, "free-growing" is a temporary condition. During the final preparation of this evaluation report, we aerially surveyed 55 of the 60 sampled stands to determine whether the incidence of mountain pine beetle attack had changed since our initial assessment in 2005. As of November 2007, an additional 10 pine-leading stands in the early-declared group had suffered beetle attack, although attack incidence was 5% or less in all but one of these 10 stands. As we could detect only red-attacked trees in our aerial survey, it is quite possible that our incidence estimate was conservative. Eight of the additional 10 beetle-attacked stands had passed the LCL minimum stocking rule tests in 2005. Whether these stands would still pass the tests is not known.

If this unprecedented mountain pine beetle infestation is related to climate change as suggested by Carroll et al. (2004), can we maintain a high level of confidence in free-growing policy? Will managed stands be subjected to other unexpected threats associated with climate change (e.g., see Woods et al. 2005)? Is the observed increase in hard pine rust incidence a reflection of the increased frequency of warm rain events documented by Woods et al. (2005)? Are the decisions made by licensees to achieve free-growing stands the same decisions that would be made if the goal was to ensure that stands reached maturity?

4.10 *Utility of Free-Growing Survey Data*

Since the inception of free-growing policy, collected data has been used primarily as an administrative check of licensee performance in meeting their obligations. Despite the vast quantities of detailed tree and stand data, free-growing declarations contribute little specific information to forest estate models. The inventory labels recorded in free-growing declarations are one of the few values that are used in higher-level models. These labels, however, are based on ocular estimates of species composition applied to total tree tallies at a portion of the survey plots. Actual tallies of well-spaced or free-growing trees are only used to confirm that the stocking standards have been achieved. Site index estimates from free-growing declarations are used to update vegetation files in the Vegetation Re-Inventory Management System (VRIMS). These estimates subsequently inform managed stand assumptions for timber supply reviews. Timber supply analysts, however, often lump these values into analysis units so that it is virtually impossible to link the performance of a given stand to predicted productivity estimates in timber supply projections (Doug Beckett, pers. comm., June 2005).

We could obviously improve our ability to model managed stand productivity by making better use of free-growing data. In the future, stocking standards, and free-growing declarations recorded in RESULTS, will be tied directly into timber supply reviews (Brian Raymer, pers. comm., March 2004). VRIMS will be in production in the fall of 2007[10] (Ralph Winter, pers. comm., June 2007).

5.0 LAKES TIMBER SUPPLY AREA: TIMBER SUPPLY REVIEW FOREST MANAGEMENT ASSUMPTIONS

Our primary goal in this evaluation project was to determine whether the timber productivity expectations placed on free-growing stands in the Lakes TSA are being met. We conclude with a brief comparison (see Table 10) of our results and the forest management assumptions contained in a recent timber supply review conducted on the Lakes TSA (B.C. Ministry of Forests 2001). Over 91% of the timber harvesting land base in this TSA is dominated by two biogeoclimatic ecosystem classification variants—the Sub-Boreal Spruce Moist Cold Babine variant (SBSmc2; 42.1%) and the SBS Dry Cool variant (SBSdk; 49.1%) (B.C. Ministry of Forests 2001). To simplify this comparison, we focussed on

10 See http://www.for.gov.bc.ca/hts/vcu/vrims/index.htm

these two BEC variants. As 90% of our sample stands were lodgepole pine-dominated, we compared our results to the TSR analysis units that were pure pine rather than mixed pine and spruce (B.C. Ministry of Forests 2001:121).

Table 10. Comparison of TIPSY-projected merchantable volume at age 80 years, site index, and total conifer stocking between the mean determined from 60 randomly selected, free-growing stands in the Lakes TSA by early-declared (1987–1994) and late-declared (1995–2001) groups versus the same attributes according to the Lakes TSA Timber Supply Report (B.C. Ministry of Forests 2001).

	Early-declared group[a]	Late-declared group[a]	TSR pure pine (SBSmc2; all sites)	TSR pure pine (SBSdk; all sites weighted evenly)
Projected volume (m^3/ha) at age 80	325	315	323	330
Site Index (m)	20.2	19.9	20.0	21.8
Conifer stocking (total stems per hectare) (2005)	3565	3326	2800	2800

a Averaged over declaration and 2005.

The results from our evaluation generally mirror the forest management assumptions presented in the Lakes TSA TSR2 report (B.C. Ministry of Forests 2001). For example, our mean site index values are very similar to the TSR2's adjusted site index values. The projected volume estimates also differ little. Given the strong relationship between site index and TIPSY volume projections, and the fact that our site index estimates matched those of the TSR, it is not surprising that our volume estimates were similar. Both the TSR projections and our TIPSY projections came from the same model, using virtually identical input variables. The largest differences involve total conifer stocking, which again indicates that the extent of natural ingress occurring in managed stands of the Lakes TSA may be underestimated by TIPSY.

The Lakes TSR2 base case scenario included an OAF1 of 20% rather than the provincial default of 15%. This increase in the OAF1 value is used to account for the effect of hard pine rusts in lodgepole pine-dominated stands of the Lakes TSA (Woods et al. 2000). Our assessment of free-growing stands in the Lakes TSA supports the revised OAF1 factor in the TSR2 (B.C. Ministry of Forests 2001). However, the Lakes TSR2 base case scenario did not account for mountain pine beetle attack in managed stands.

6.0 Conclusions

We introduced this report with a photograph of a declared free-growing stand that did not appear to be meeting expectations of productivity. Our results suggest that the situation in the Lakes TSA is more positive even with a high incidence of hard pine rusts. We found that, on average, free-growing stands in the Lakes TSA are currently meeting expectations. Mean values for well-spaced and free-growing densities remain relatively stable after the free-growing declaration despite the incidence of hard pine rusts. All field surveys for this study took place outside the rust sporulation window when rust infections are most visible (i.e., mid-May to mid-July). As a result, we likely underestimated current rust incidence. It is quite possible that the original free-growing declarations were also conducted outside the peak visibility window for hard pine rusts.

In 2005, one stand showed evidence of mountain pine beetle attack. If we consider this stand as not satisfactorily stocked, then 11 of the 60 (or 18.3%) declared free-growing stands in the Lakes TSA no longer meet the minimum stocking threshold of 700 free-growing stems per hectare based on the LCL rule. The majority of pest-affected trees in these failing stands are in the tallest height class (> 4 m). However, further uncertainty surrounds the future health of age class 2 and 3 lodgepole pine stands in the central Interior due to the current beetle infestation (MacLauchlan 2006). Our November 2007 aerial survey of the stands we first sampled in 2005 identified 10 additional beetle-attacked stands. We do not know whether these recent beetle attacks are severe enough to reduce stocking below the 700 free-growing stems per hectare threshold. In 2005, in the early-declared group, 23.3% of the free-growing stands no longer met minimum stocking requirements. Although only 13% of the late group were in the same condition, it may be a matter of time before they too are considered at higher risk.

No formal procedures are in place to monitor free-growing stands after declaration and, therefore, no set stocking thresholds exist for stands at this stage of development. In our analysis, we used a minimum acceptable stocking threshold of 700 free-growing stems per hectare, a threshold designed for stand ages of 10–15 years. Our early-declared group had an average age since disturbance of 27 years, and so this threshold may be inappropriate for stands of this age.

We return to the question of "does the free-growing assessment provide an accurate estimate of future stand productivity?" Our analyses suggest that free-growing declarations may occur too early in the life of stands to provide an accurate projection of future stand productivity. The likelihood of making overly optimistic projections of stand productivity increases the earlier stands are declared free-growing, as the influence of forest health factors is not yet realized.

Our study involved an intensive examination of stand conditions on the ground. In contrast, the Forest Practices Board's extensive examination primarily involved an office review of administrative milestones (Forest Practices Board 2003). Our study demonstrates the importance of more intensive on-the-ground monitoring of free-growing stands. We intend to conduct similar assessments in other timber supply areas.

7.0 Recommendations

Management of forest and range resources is a complex process that often involves the balancing of ecological, social, and economic considerations. Many FREP monitoring reports represent a single facet of this process. Based on monitoring data and analysis, we offer the following recommendations for consideration to those who develop and implement forest and range management policy, plans, and practices.

1. Although the majority of free-growing stands in the Lakes TSA are currently meeting timber productivity expectations, those that are not are dominated by lodgepole pine and have low initial densities, which are further compromised by forest health agents. In areas where species options are limited to lodgepole pine, increasing initial planting densities should be considered.[11] In areas where species options are not limited, we recommend increased species diversity.
2. Silviculture survey training and accreditation should include a mandatory update of forest health agent field identification training to ensure that free-growing surveys accurately capture the incidence of forest pests. We also recommend closer field inspections of contract survey work to ensure forest health agents are properly identified.
3. Mid-rotation field assessments of stand productivity and comparison of current volume with TASS/TIPSY projections would improve the level of confidence in timber supply projections and help refine the TASS/TIPSY models. Methods specifically designed to accomplish this need to be developed. This would include developing a field protocol for the collection of data suitable for input into TASS/TIPSY as well as possible modifications to TASS/TIPSY to facilitate these assessments.
4. For a stand to be declared free-growing, the 90% lower confidence limit (LCL) associated with the estimate of the mean should be greater than the minimum acceptable stocking level. Using the LCL decision rule would significantly reduce the liability of the Crown when accepting understocked stands as free-growing.
5. TSA performance measures could include a requirement for an acceptable minimum proportion of stands to remain free-growing. To accomplish this, a minimum stocking threshold for post–free-growing stands should be established that better represents stands at this stage of development (i.e., a minimum of 700 free-growing stems per hectare may not be appropriate for a 35-year-old stand).
6. Our analyses suggest that free-growing declarations may be occuring too early in the life of stands to provide an accurate projection of future stand productivity. A mid-rotation assessment of stand productivity and forest health would provide more confidence. A program to survey post-free growing stands should be developed. Survey results should populate a new inventory of managed stands in the province.
7. Policy-makers should consider how well free-growing policy will continue to uphold the B.C. Ministry of Forest and Range's stewardship mandate, given the uncertainty associated with the direct and indirect effects of climate change. A free-growing designation presupposes that young trees will continue to grow and thrive in a relatively stable environment.

11 In lodgepole pine dominated stands where hard pine rust incidence is high, initial planting densities of 1600 sph too often lead to insufficiently stocked stands post free-growing, based on local experience the Regional Forest Pathologist recommends 2500 sph.

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