A Framework for Implementing Young Stand Monitoring In British Columbia

A Discussion Paper

Prepared for: Forest Analysis and Inventory Branch , Ministry of Forests, Lands, and Natural Resource Operations

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Updated November, 2013

EXECUTIVE SUMMARY

The primary focus of the young stand monitoring (YSM) program being developed by the British Columbia (BC) Ministry of Forests, Lands and Natural Resource Operations (MFNRO) Forest Analysis and Inventory Branch (FAIB) is to check the accuracy of growth and yield (GY) predictions of key timber attributes in young stands, to support management unit timber supply review (TSR). This monitoring program will provide feedback to timber supply analysts and GY modellers, to identify opportunities for improving timber supply forecasting. As well, information from this program can be used to meet other monitoring business needs, such as assessing silviculture investments and stand management practices. The monitoring initiative shall also incorporate forest health, current forest status information, and employ YSM data to inform current TSR exercises.

Data from all existing sampling programs were considered for monitoring, including inventory and research permanent sample plots (PSPs), vegetation resources inventory (VRI) ground samples, the Stand Development Monitoring (SDM) protocol, and the National Forest Inventory (NFI). However, these data were found to be inadequate because they did not target young stands, lacked re-measurements, were biased, or their sampling intensity was low.

The target population for monitoring is 15- to 50-year-old young stands that are likely to contribute to future timber supply in a management unit, e.g., forest management landbase. It will expand and contract over time as the mature stands that are disturbed regenerate and attain minimum age 15 years, and the young stands mature (> 50 years old).

The new monitoring method is similar to that currently used in the Change Monitoring Inventory (CMI) program. A minimum of 30 sample plots per monitoring unit will be established in the target population, using a uniform fixed grid with no pre-stratification, and remeasured every five years. An individual monitoring unit (IMU) is currently equivalent to a single management unit, but pilot tests are being conducted to evaluate amalgamating several management units into larger regional monitoring units (RMU).

The TSR assumptions to be checked include stand gross and net volume (gross volume net cruiser-called decay and waste), site index, total age, species composition and succession, pest and disease incidence and operational adjustment factors (OAF1). The GY estimates from the monitoring plots will be compared with GY predictions from GY models, to identify where large and significant differences occur. Plots may be added to the monitoring sample at remeasurement time as stands attain the minimum age of 15 years through the management unit grid, depending on budget and staff resources at the time. All the older plots (> 50 years)

may be retained for remeasurement over a limited period of two, 5-year re-measurements before being dropped.

The monitoring program plans to produce interim reports, including plot establishment reports each year new plots are established (every 5 years) depending on budget and staff resources. Monitoring plot establishment is estimated to cost, on average, about $1,540/plot. Access significantly impacts sampling cost; the unit cost for establishment of plots without helicopter is less, approximately $1,362/plot. Quality assurance cost was approximately $1,154/plot. These plot establishment and quality assurance cost estimates are based on experience from the YSM pilot projects conducted in 2013 in the Kootenay Lake and Morice TSAs. There is the on-going similar cost for remeasurement every five years, and additional estimated $15,000 per measurement year and monitoring unit, for sample planning, data analysis and reporting.

The proposed monitoring program has been pilot-tested in the Morice and Kootenay Lake Timber Supply Areas (TSAs) in 2012/13, to assess the sample design, and confirm cost estimates and Ministry staff time requirements (Omule, 2013; FAIB, 2013; Omule, 2013b).

Acknowledgements

This report was prepared by A.Y. Omule with input from a broad range of contributors. The author would like to thank the following people for their contributions to the revisions in this updated 2013 version of the report: Catherine Bealle Statland, Tamara Brierley, Rene De Jong, Mario Di Lucca, Jim Goudie, Graham Hawkins, Gary Johansen, Matt Makar, Chris Mulvihill, Gord Nigh, Peter Ott, Sam Otukol, Margaret Penner (Forest Analysis Ltd.) and Will Smith.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAC	Allowable Annual Cut
AU	Analysis Unit
BC	British Columbia
BGC	Biogeoclimatic Ecological Classification
CLT	Central Limit Theorem
CMI	Change Monitoring Inventory
GTG	Growth Type Group
FAIB	Forest Analysis and Inventory Branch
GY	Growth and Yield
GYMTF	Growth and Yield Monitoring Task Force
IFPA	Innovative Forest Practices Agreement
IMU	Individual Monitoring Unit
MAI	Mean Annual Increment
MFLNRO	Ministry of Forests, Lands and Natural Resource Operations
MU	Monitoring Unit
NFI	National Forest Inventory
OAF	Operational Adjustment Factor
PAI	Periodic Annual Increment
PSP	Permanent Sample Plot
PPSWR	probability Proportional to Size With Replacement
RMU	Regional Monitoring Unit
SABC	Sensitivity Analysis on the Base Case
SDM	Stand Development Monitoring
TEM	Terrestrial Ecosystem Mapping
TFL	Tree Farm License
THLB	Timber Harvesting Land Base
TSA	Timber Supply Area
TSR	Timber Supply Review
VRI	Vegetation resources Inventory
YSA	Yield Stand Audit
YSM	Young Stand Monitoring

1 Introduction

1.1 Background

The British Columbia (BC) Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) Forest Analysis and Inventory Branch (FAIB) has developed and pilot tested a new program for young stand monitoring (YSM). The YSM program is now starting to be implemented, especially in high risk forest management units (TSA and TFL). This initiative is intended to address the present information gap, which is monitoring data on the growth and yield (GY) of young stands (FAIB, 2011). The monitoring will compare the observed GY of the forest with the predicted GY of the forest (see Appendix D for a Glossary of Terms). It will also incorporate forest health and state-of-the forest information, and employ YSM data to support current timber supply review (TSR) exercises.

Data from all existing sampling programs were considered for monitoring, including inventory and research permanent sample plots (PSPs), vegetation resources inventory (VRI) ground samples, the Stand Development Monitoring (SDM) protocol, and the National Forest Inventory (NFI). However, these data were found to be inadequate because they did not target young stands, lacked re-measurements, were biased, or their sampling intensity was low.

The primary focus of FAIB's young stand monitoring program is to check the accuracy of the GY predictions (assumptions) of key timber attributes in young stands for timber supply review (TSR) in a management unit. Growth and yield estimates from an independent sample of plots that are remeasured over time will be compared with GY predictions from GY models or other sources (e.g., pest incidence from forest health surveys), to identify where large and significant differences occur. This will provide feedback to timber supply analysts (check yield and mean annual increment, MAI) and to growth modellers (check tree and stand growth curves). That is, the monitoring program will help to identify opportunities to improve the accuracy of timber supply forecasting for a management unit.

Information from this monitoring program, along with information from other sources, can also potentially be used to meet other monitoring business needs, including stand performance, silviculture investments, and stand management practices. These other business needs are described further in Appendix B; however, the application of the monitoring data for these needs is not discussed further in this report.

Much of the work of developing a monitoring program has already been investigated by the then Ministry of Forests' Resources Inventory Branch (RIB), in particular the Change Monitoring Inventory (CMI) and Young Stand Audit (YSA) that have been pilot tested in several management units.[1] The FAIB build upon this previous investment in knowledge and expertise to develop the new monitoring program.

1.2 YSM Pilot Projects

Two YSM pilot projects were conducted in 2012/2013 in the Kootenay Lake and Morice TSAs. The project objectives included assessing the proposed YSM sample design, identifying any technical issues, determining plot establishment costs and future plot recruitment estimates, and using the data to check GY model estimates. Plot establishment reports have been prepared for these projects (Omule, 2013; FAIB 2013). A summary of the salient findings from these reports are summarized in Appendix B. The Kootenay Lake establishment report was reviewed by FAIB staff, and several issues were raised. The issues addressed have been incorporated into this revised framework document; a summary of the remaining outstanding issues is given in Appendix C.

1.3 Document Objectives

This is an updated version of the discussion paper prepared in 2012 (FAIB, 2012), which outlined a framework for implementing a program for monitoring young stands in BC. The updates are highlighted in yellow. It provides recommendations for the YSM sampling design, program implementation, GY estimation and comparisons, and potential applications of the monitoring data. The sources of material for preparing this discussion paper included numerous reports from the previous work on monitoring by the former Resources Information Branch. A Glossary of Terms is provided in Appendix D.

2 Sample Design

2.1 Objective

The specific objective of the young stand monitoring is:

> *To check the accuracy of the GY predictions (assumptions) of key timber attributes of young stands used in TSR in a management unit, based on an independent random sample of monitoring plots. The TSR assumptions include stand gross and net volume (gross volume less cruiser-called decay and waste), site index, total age, and species composition and succession.*

[1] Much of this work was done under the guidance of the BC Ministry of Forests' Growth and Yield Monitoring Task Force (GYMTF) and the Ministry of Forests' Resources Inventory Branch.

The focus of YSM is on the longer term because some observed initial differences between the predictions and YSM plot values may diminish over time while others may persist.

In addition to TSR uses, the YSM data can also be used to meet other objectives, including:

- Characterizing young stand state and trends (e.g., current composition, structure, productivity, health, growth rates, and change).
- Assessing the accuracy of young stand attributes in the VRI file (e.g., stand age, height and site index).
- Providing a dataset for various special projects, e.g., test/refine site index estimates in the site productivity layer, and various other research needs.

2.2 Monitoring Unit

A monitoring unit is a defined geographic area of interest for the purposes of sample selection. It is defined prior to sample selection. A single TSA or TFL has so far been used to define the boundaries of an individual monitoring unit (IMU). The sampling plan, including sample size, is developed independently for each IMU, and the results applied directly to the specific management unit, particularly for TSR purposes. Experience from the YSM pilot projects (Section 1.2), however, suggests that the IMU sample sizes are generally small and limit the analysis and interpretation of the monitoring data.

The idea of amalgamating TSAs and/or TFLs into a larger regional monitoring unit (RMU), which would increase the sample size, is currently being considered and pilot-tested. More samples increase the precision (reduce standard error) of the RMU-level point estimates of change in attributes over time, and the sensitivity and power of the statistical comparisons, without affecting the unbiased nature of these estimates. If the RMU concept is implemented, it would provide broad change estimates that can be applied to all sampled management units within a given RMU, at reduced cost.

There are, however, some issues with applying RMU to YSM that should be discussed and addressed as part of the RMU pilot projects. These issues include:

1. The TSR assumptions are generally made at the IMU level. A meaningful RMU analysis would require common assumptions across IMUs or explicit incorporation of the different assumptions.
2. The RMU sampling plans would need to include all IMUs, to identify meaningful post-sampling strata and ensure adequate post-strata sample sizes.
3. The currency and origin of the phase 1 inventory varies among IMUs, and it depends on the age of photography, whether an inventory originated as an older FIP format roll-

over to VRI or is a more recent re-inventory to the VRI standard, complexity of the forest types and the amount of depletion and update. Thus, combining inventories of different currency and origin might be problematic and could lead to misleading monitoring conclusions.

Combining TSAs or TFLs may be appropriate for analysis of some attributes, such as site index estimates from the provincial site productivity layer. It may also be appropriate for investigating regional patterns such as a consistent underestimation of the volume of a particular species. An RMU analysis of VRI-based estimates will be most appropriate when the VRIs of the component IMUs are of similar vintage and origin/format.

2.3 Target Population

The target population defines the sub-set of a monitoring unit from which the monitoring samples are chosen, and to which the sample-based estimates and conclusions apply. It is composed of 15- to 50-year-old young stands that are likely to contribute to future timber supply in a management unit, e.g., forest management landbase. This age range is generally consistent with the range that could be applied back to timber supply analysis, where young stands are put on a managed stand yield curve at the 50-year age cut-off.

Most of the target population is expected to be part of the timber harvesting land base (THLB).[2] It will evolve over time as the mature stands are disturbed (due to, e.g., harvesting, fire, blow down, epidemic infestation) subsequently regenerated, and attain age 15 years, and as the previously younger stands mature (> 50 years). The stand age will be determined from the VRI inventory files.

2.4 Monitoring Method Overview

The monitoring method is similar to that currently used in the CMI program. A minimum of 30 plots are established in the target population per monitoring unit, using a systematic (grid) sampling design and without pre-stratification. Measurements will be taken for tree attributes only. Plots are installed only in 15-50-year-old stands in a given monitoring unit. Sample plots

[2] This approximated THLB should ideally be based on the criteria that are normally used in TSR, e.g., criteria used to define the forest management landbase. However, restricting the target population to this landbase only may not achieve other YSM objectives. Currently, e.g., in the YSM of the Morice and Kootenay Lake TSAs, the target population is defined as all the VRI polygons, excluding private land, parks and Indian Reserve lands, polygons less that 0.1 ha, polygons less than 15 years old, and polygons older than 50 years.

shall be re-measured every five years. The most recent timber supply review schedule shall guide the schedule for the establishment and remeasurement of the monitoring plots. The TSR assumptions to check include stand gross and net volume (gross volume net cruiser-called decay and waste), site index, total age, and species composition and succession.

2.5 Stratification

There is no pre-stratification of the monitoring unit prior to sample selection. The intent is to monitor the entire YSM target population with similar precision, and to provide flexibility in handling anticipated future changes in the target population. Further rationale for this approach is given in Appendix E. Plots can, however, be post-stratified during analysis if the sample is large enough to provide meaningful results for the desired post-strata. Potential post-strata include Biogeoclimatic Ecological Classification (BGC) zone and leading tree species.

2.6 Sample Size

An adequate sample size, relative to the monitoring objective and available budget, should be set for the target population in the monitoring unit at the initial plot establishment.[3] It should be big enough such that practical differences between observed and predicted growth relevant to TSR can be detected with reasonable degree of certainty (at least at the first plot remeasurement).

Statistical power analysis (see, e.g., Nemec, 1991 and Lenth, 2001) may be used to determine sample size.[4] This approach is commonly used in planning designed experiments and is relevant to the monitoring program. Statistical power is the chance of detecting a statistically significant result using a statistical test (such a paired *t*-test); its value ranges from 0 to 100%. A powerful test is one that has a high chance in detecting even small differences. As power increases, however, the required sample size increases rapidly. The power analysis approach is recommended mainly because it incorporates the desired difference to be detected, and the chance of detecting it, directly in the sample size determination.

Power analysis for sample size determination involves (1) specifying a target difference between the observed and predicted GY values to be detected and the statistical power to detect that

[3] Note that sample size is only one of several design factors that affect the quality of a monitoring program, and the variables of interest may change over time.

[4] Another option is to use the available budget to set the sample size (instead of power analysis), but the managers will always ask the question “How many plots do we really need and why?”, and we still need to determine the desired minimum sample size, so management can know the price of their decisions (e.g., inability to detect practically important small differences).

difference, and (2) determining the minimum sample size that achieves those goals, given the variability of the variable of interest. That is, it requires the following elements:

- The significance level of the statistical comparison (α).
- Anticipated difference between actual and predicted GY values to be detected (Δ).
- Statistical power of the comparisons, which is the desired probability that the difference Δ will be significant ($1-\beta$).
- The variability (or standard deviation) of the differences between observed and predicted GY values (σ).

With these elements sample size can be calculated using a computer program such as SAS (e.g., Nemec, 1991, p. 8), or a stand-alone sample-size software package (e.g., Lenth, 2000). A minimum sample size of 30 plots is recommended. This minimum sample size is based on the Central Limit Theorem (CLT), one of the most important theorems in probability. The CLT states roughly that the average of a sufficiently large number of independent observations from the same distribution has an approximately normal distribution.[5] Larger samples will be required in most cases to permit post-stratification of the data, e.g., by BEC.

One problem with using power analysis to determine sample size is how to set the values of α, σ, $(1-\beta)$ and Δ. For the young stand monitoring program, the following preliminary values are suggested: α = 0.05 (a commonly used level in forestry), $(1-\beta)$ at least 60% (which is more than a 50-50% chance) and Δ less than ± 40% (depending on the sensitivity of the TSR assumptions on timber supply. Values for σ should be estimated from the already established and remeasured CMI projects. The differences between the observed and predicted GY values should be compared using a two-sided paired *t*-test.

Example

The following example is based on CMI data and power analysis done in the Meritt TSA (Omule, 2012). Statistical power (1-β) is the probability of detecting a statistically significant difference between the observed and predicted growth; its value ranges from 0 to 1.0.

Sample size was determined as follows:

[5] Thirty plots is "a sufficiently large number of observations", according to several statistical textbooks; a sample size of 30 is called a large sample and less than 30 is called a small sample. The CLT theorem permits us to conduct the usual normal-distribution statistical inferences or tests, e.g., comparing two means as in the monitoring program, even if the original distribution of the population is not normal.

1. Specify a target difference for volume periodic annual increment (PAI) between the observed and predicted growth to be detected. Set the target to detect a difference of Δ = 1.5 m^3/ha/yr at α = 0.05. This target is chosen because experience from analyzed CMI data so far, the differences between observed and predicted volume PAI are in the range of about 1 to 2 m^3/ha/yr.
2. Specify the expected standard deviation of the differences between observed and predicted PAI. Assume an estimated standard deviation of the difference to be σ = 5.2 m^3/ha/yr. This was the best available information; it was obtained from the CMI analysis of n = 14 plots (without catastrophic mortality) in the neighbouring Kamloops TSA (Penner and Omule, 2012, Table 5). This value is close to that observed in TFL 35 (Timberline Natural Resources Group, 2007) (σ = 4.1; n=48, Table 3).
3. Set the statistical power. The recommended minimum (1- β) is 0.6.
4. Determine the minimum sample size that achieves the above goals in Step 1, given the variability of the variable of interest in Step 2. Calculate the statistical power (assuming a two-sided paired *t*-test) corresponding to various sample sizes using the SAS software package. Plot a graph of statistical power versus sample size (Figure 1). From this graph, we see that the minimum number of plots required to detect a difference of Δ = 1.5 m^3/ha/yr at α = 0.05, and (1- β) = 0.6 is 60 plots.

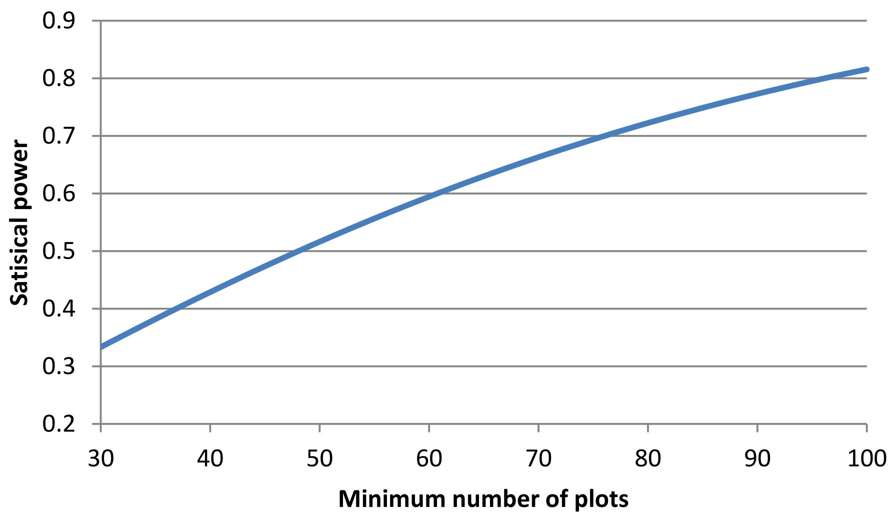

Figure 1. Increasing statistical power as sample size increases (Δ = 1.5 m^3/ha/yr; σ = 5.2 m^3/ha/yr; α = 0.05; and minimum (1- β) = 0.6). The minimum sample size based on the statistical power analysis is 60 plots.

2.7 Sample Selection

The method for selecting monitoring plots is a systematic (grid) sampling design with a random start from within the NFI 20 km x 20 km grid. The grid will be such that the grid intersections uniformly cover the management unit. The grid size (spacing) will depend on the chosen sample size for a given monitoring unit (see Section 2.6). Each monitoring grid will be used for the initial plot establishment and for adding new (young) plots. The monitoring grid shall be nested within the NFI grid, and will not change over time.

2.8 Plot Recruitment

As stated earlier, the monitoring target population will evolve over time. Depending on available budget and staff, plots may be added to the monitoring sample at remeasurement as stands attain the minimum age of 15 years (i.e., all the grid intersections falling in the stands attaining the minimum age). This number will increase over time.

At each remeasurement time, the plots in stands over 50 years of age may be dropped from remeasurement, since they are no longer in the target population. However, dropping all the older plots means no monitoring information is available on older stands. Yet, information on older stands is needed for stand modelling. Thus, all the plots in the older stands should be retained for remeasurement over a limited period of two, 5-year re-measurements. Thus, the total number of possible plot re-measurements will range from 2 to 9. Note that the cut-off age for plot establishment is 50 years, but the cut-off age for remeasurement is 60 years. The dropped monitoring plots can be evaluated for retention for other purposes, such as inventory PSPs, since the plot locations will be available. Note that the YSM focus is young stands; growth trajectories beyond 50 years can be tracked using data from other PSPs.

Examples

Two examples are provided for adding/dropping samples; these are Kootenay Lake TSA (Omule, 2013) and the Morice TSA (FAIB, 2013).

<u>Kootenay Lake</u>

The number of existing young (< 15 yrs) grid points at establishment in 2012 was 20, and the number of existing older (> 50 yrs) grid points at establishment in 2012 was 80. The harvest rate (area) in the TSA was assumed to be approximately 684 ha/yr (or approximately 0.5%),[6] assuming the mature (51+ yrs) potential timber harvesting landbase (THLB) in Kootenay Lake is

[6] Note that this estimate of the harvest rate may be a bit low. As well, disturbance rates of other disturbance agents, such as forest fires, were not included.

about 138,000 ha. This means that approximately 0.4 sample grid points are harvested per year, or approximately two older grid points every 5-year period.

Based on the simulation, the number of grid points available for plot establishment and re-measurement increased over time, from 50 in 2012 to 69 in 2022, or a 28% increase (Table 1). This increase in sample size over time is expected to be counter-balanced by dropping of the plots > 60 years old. However, in this simulation, no plots were dropped over this period, as no plots had yet attained the age 60 years cut-off threshold. Thus, the increase in sample size over time appears to be modest, and is manageable at the present maintained staff levels.

Table 1. YSM plots to be established, re-measured and dropped over time 2012 – 2022 in Kootenay Lake TSA.

Year	Establish				Drop	Re-measure	Total (establish + re-measure)
	YSM population in 2012	Young grid points (< 15 yrs in 2012)	Harvested/ regenerated grid points	Total to establish			
2012	50			50			50
2017		8	0	8	0	50	58
2022		11	0	11	0	58	69

Morice TSA

The original YSM population was polygons 15-50 years old but plots only get dropped from the YSM population when they are older than 60 years, so it is not surprising the number of plots to measure increases over time. In particular, no plots are dropped in the first 10 years but 22 plots are added (Table 2). Essentially, the population age range goes from 15-50 to 15-60, and increase by 29%, so the number of plots to re-measure can be expected to increase by that amount, on average.

Table 2. YSM pots to establish, re-measure and drop over time 2012 – 2027 in Morice TSA.

Age class	Year			
	2012	2017	2022	2027
0-4	5	31	30	28
5-9	17	5	31	30
10-14	5	17	5	31

Age class	Year			
	2012	2017	2022	2027
15-20	4	5	17	5
21-25	22	4	5	17
26-30	7	22	4	5
31-35	7	7	22	4
36-40	6	7	7	22
41-45	1	6	7	7
46-50	3	1	6	7
51-55	0	3	1	6
56-60	0	0	3	1
61+	609	579	549	523
Total	687	687	687	687
Establish	50	5	17	5
Remeasure	0	50	55	72
Drop	0	0	0	3
Total	50	55	72	74

2.9 Data Collection

2.9.1 Variables to Measure & Report

The list of core attributes to be collected is given in Table 3, including pest and disease incidence and tree status (live or dead), as is done in the CMI.[7] Other attributes, such as coarse woody debris (CWD), may be included.

Table 3. List of attributes and the data collection method.

Attribute	*Method*
Site Height (m)	Measured
Breast-Height Age of Site Height Tree (yr)	Measured
Total height of all trees at least 1.3m tall (m)	Measured
DBH of all trees at least 1.3m tall (cm)	Measured
Pest and disease incidence	Observed on the plots.

[7] http://archive.ilmb.gov.bc.ca/risc/pubs/teveg/nficmp2012/CMI%20Procedures_ver1_2012_Final.pdf

Attribute	*Method*
Tree mortality	Observed on the trees.

Suggested additional information to collect includes tree crown length and upper stem diameters, and general stand attributes and stand history. The minimum stand attributes to report on are given in Table 4.

Table 4. List of minimum key stand attributes to be reported (current values and changes in these attributes over time).

Stand Attribute	*Comment*
Site Index	This is a critical attribute in TIPSY, for which the differences will not diminish over time. Its values should be obtained from the site productivity layer.
Gross and net volume	These volumes should use the lowest utilization possible to avoid zero volumes. These are derived attributes and any biases young ages may persist, diminish or increase over time, and could also be artefacts of the volume estimation.
Stand density	This is a critical attribute in TIPSY.
Site height	The TIPSY model is height driven, and requires accurate heights.
Site Age	This attribute is important at young ages (for years to green up), but the effect is expected to diminish over time.

2.9.2 Plot Design & Establishment

The plot design will follow the CMI protocol. The CMI plot consists of three nested plots: a 400 m^2 (11.28-m radius) plot for measuring all trees at least 9.0 cm diameter at breast height (DBH); a 100 m^2 (5.64-m radius) for trees between 4.0 and 9.0 cm; and a 19.6 m^2 (2.50-m radius) plot for all trees at least 30 cm tall and less than 4.0 cm DBH. The sample plots are centered at the grid intersection points. The plots will be established only within the target population (as defined by the most current VRI inventory data) as follows:

1. Plots that fall in netted-out areas such as double line roads, mapped rock, ice, and roads (as indicated in the inventory /forest management land base), are dropped; they are outside the target population.

2. Plots that straddle a monitoring-unit boundary or the target population boundary shall potentially be sampled using the "walkthrough" method (Ducey, *et al.* (2004). The "walkthrough" method was being field tested by FAIB at the time of writing this report.
3. Inaccessible plot locations or plots that have been disturbed (e.g., harvested) will be replaced by plot locations selected from a randomized list of alternate sample locations.

2.9.3 Incorporating Existing Plots

Existing potential data to incorporate into the monitoring program include NFI, CMI, young stand audit (YSA) and SDM.[8] Existing monitoring samples from the CMI and YSA will be used as they are, possibly with an upgrade at remeasurement if more variables are needed for the new monitoring program. Existing NFI plots closest to the selected monitoring plot locations shall be incorporated as young stand monitoring plots. Data from the SDM will be used to provide general stand characteristics for the monitoring plot which falls in the sampled SDM polygon.

These potential sources of data are briefly described further as follows:

1. **The CMI** has been established in ten management units in the province: TFL 5, TFL 30, TFL 33, TFL 35, TFL 37, TFL 52, Fort. St. John TSA, Merritt IFPA, Quesnel TSA and Hope IFPA. These projects were implemented with funding from the FRBC/FIA Landbase Program. There is no need to re-establish monitoring plots in these units.
2. **The NFI** is a network of permanent photo and ground plots located on a national 20-km x 20-km grid. Sampling covers the entire landbase regardless of land use or ownership. In 2006, the province established a baseline of 268 ground plots. This level of ground sampling intensity is expected to contribute a limited number of plots to be incorporated into young stand monitoring.
3. **The Stand Development Monitoring (SDM)** protocol has been developed as a check of stand attributes assigned at free-growing, a check of forest health, and a process to provide yield estimates to assist in refining yield projections. One of the strengths of SDM is that it offers forest health (FH) agent extent and severity identification. The SDM data in projects that measured all the trees can be used provide general stand characteristics for the monitoring plots that happen to fall in the SDM sample polygons. The potential to integrate the SDM data into the young stand growth monitoring will be investigated further in the future.

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[8] It might also be possible to integrate the existing 0.04-ha plots from the PSP program, provided they meet the monitoring plot establishment and maintenance guidelines (section 2.8.2).

4. **The YSA (young stand audit**) samples are the result of the streamlining of the VRI ground sampling process. They are intended to be used as an additional data source for conducting forest inventory sensitivity analyses in the TSR process. These samples are selected using a pre-stratified (by leading species) probability proportional to size with replacement (PPSWR) methodology, but use the same plot design as the CMI. The YSA samples have been established in Mackenzie TSA, TFL 18 and TFL 53 in the 2011 field season. There is no need to re-establish monitoring plots in these units.

3 Growth and Yield Analysis

3.1 Overview

Growth and yield data analysis procedures are described for continuous variables (stand volume, site index, site age, site height, and stand density) and categorical variables (leading species). Detailed compilation and estimation procedures have been prepared (FAIB 2013b), along with an example of the analysis using the TFL 35 CMI data in a Microsoft Excel Spreadsheet. These procedures outline weighting procedures for average attributes such as age, or stand density that may use data from more than one of the nested plots.

3.2 Ground Data Compilation

Compilation of the ground plot raw data involves aggregating (scaling-up) the individual-tree attributes measurements into plot averages and per-hectare values. The key plot-level attributes of interest are shown in Table 5. The compilation is done as follows:

1. Error checking (data edits). Check individual tree measurements between Time t and Time t-1 ($t \geq 2$) for errors such as abnormal changes in diameter, height, status (live/dead), and species labels. This is usually done in the field using the electronic data recorder TIMVEG developed by the MFRNO. The data are also screened using appropriate criteria to detect any departures from the intended YSM population. In particular, the data are screened for large, old trees as well as any identified as residuals. Residuals are trees classified as veterans and those that exceed specified tree DBH, age or crown class thresholds. These thresholds are set on a project-specific basis. This screening is important in the comparison of the data with the TIPSY estimates. Trees should be identified as veterans in the field, and further identification of other residuals should be done during analysis on a project-specific basis. Plots with high volumes are also examined in more detail.

2. Compilation. The edited individual tree data are compiled for key attributes for both Time *t* and Time *t-1* measurements using an updated version of the VRI/CMI compiler of the MFRNO.

3.3 Predictions

The source of the GY predictions needs to be clearly described in the analysis. In general, the predictions will start with Analysis Unit (AU) assumptions including species composition, site index and establishment density. Then, TIPSY is used to generate managed stand yield tables (MSYT) for each analysis unit. Each ground plot is then assigned to an AU and the GY predictions associated with that plot are taken from the MSYT at the appropriate age. These predictions are appropriate for testing the TSR AU assumptions and MSYTs.

An alternative source of GY estimates is the use of TIPSY to project each plot using the "existing stand" option. TIPSY was developed to predict growth of managed, even-aged, pure species stands. Many of the YSM plots contain a mix of species and ages and some are not managed. The use of TIPSY to predict growth for these plots is not simple and the predictions should be considered an extrapolation. These predictions should not be used to test the TSR AU assumptions but rather to test the appropriateness of TIPSY for the YSM conditions.

3.4 Species Matching

Species matching is used to select data pairs to be used to analyze age, height and site index. The method developed for VRI (FAIB, 2011) is to be followed. The YSM ground data are matched with the corresponding Phase I inventory data for the parent polygon. The YSM ground plot heights and ages are based on the average values for suitable height trees for the leading species. The objective is to match the Phase II ground leading species to the Phase I inventory leading or secondary species and compare the ages and heights. The five possible matching cases are as follows:

- Case 1: Phase I inventory leading Sp0 matches the YSM ground leading Sp0.
- Case 2: Phase I inventory second Sp0 matches the YSM ground leading Sp0.
- Case 3: Phase I inventory leading species and the YSM ground leading species are both coniferous or are both deciduous.
- Case 4: Phase I inventory second species and the YSM ground leading species are both coniferous or are both deciduous.
- Case 5: No match.

The species matching rules are also used for site index, but only the plots in Case 1 and Case 2 are considered satisfactory matches. Site index comparisons could be expanded to more observations since ground site tree data are collected from all species in the YSM ground plots. The site index comparison could be made based on predictions from the provincial site productivity tile (where available and permitted). This way the site index comparison can be made for almost all species where ground site tree data are collected and not just the leading species.

3.5 Estimation of Bias

The ground plot attributes are considered to be "actual", "measured" or "truth" while the VRI or TSR-derived predictions are considered "estimates". If there is a difference between the ground attributes and the VRI or TSR estimates, the VRI or TSR estimates are considered to be biased.

Plot bias, which is the difference between the observed (ground - x) attribute yield (or change or growth over time) and the predicted (estimate - $\hat{x}$) yield (or change in value over time), for a given attribute, is calculated follows:[9]

$$d_i = x - \hat{x} \qquad [1]$$

where d_i is the bias of attribute *x* (e.g., current volume, 5-year volume increment, or site index).

These derived plot values are used to make graphical and statistical comparisons for the monitoring unit as described in Section 3.8. Note that the VRI predicted values are polygon-based and the actual (YSM) values are based on a 0.04-ha plot within the polygon. Some of the differences between the VRI and YSM values may arise because the YSM plot is a subsample of the polygon and may not fully capture some of the within polygon variation considered by photo interpreters when assigning a VRI label to reflect the overall polygon.

An estimate of the average bias for the target population (or post-stratum) at Time *t* is obtained by scaling-up the plot-level data, assuming that:

[9] There will be proper weighting to account for per-hectare variables that use combined nested plots or the average variables such as stand age.

1. The monitoring plots, which are laid out on the grid, are a simple random sample.
2. Plot growth or change is estimated only from the remeasured plots at Time *t* and Time *t*-1.
3. The monitoring unit grid spacing does not change over time.

The scaling-up is achieved simply as the average plot bias as follows:

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n} \qquad [2]$$

where *n* is the total number of monitoring plots in the target population and *d* is as defined earlier (Eq. 1).

The estimated variance and the standard error (StdErr%) of $\bar{d}$ are, respectively:

$$\hat{\mathrm{var}}(\bar{d}) = \frac{1}{n} \times \frac{\sum_{i=1}^{n} \left(d_i - \bar{d}\right)^2}{(n-1)} \qquad [3]$$

and

$$StdErr\%(\bar{d}) = \frac{\sqrt{\hat{\mathrm{var}}(\bar{d})}}{\bar{d}} \times 100 \qquad [4]$$

3.6 Partitioning Volume Total Bias

There is a need to partition the total bias of gross or merchantable volume into components, including model-related bias and VRI attribute-related bias. This partitioning provides useful feedback to GY modelling, VRI estimation, and TSR modelling.

The volume total bias is divided into two components (model bias and attribute bias), which are calculated as follows:

Total Bias = VOL1 – VOL3
Model Bias = VOL1 – VOL2
Attribute Bias = VOL2 – VOL3

where:

VOL1: Ground-based whole stem plot volume. The data are screened and residual trees removed. VOL1 is identical to the ground compiled volume except for the removal of veteran trees. The compiled ground plot volumes must match as closely as possible the predicted volumes generated from yield curves (e.g., may include a minimum DBH limit, close utilization specs, and or inclusion of decay, waste, and breakage factors).

VOL2: TIPSY-predicted volumes for each YSM ground sample, using ground plot inputs together with MP-based analysis unit assumptions. The ground-based input attributes include site index and species composition. The predicted volume assigned to each ground sample will be at the location on the MSYT where the height of the ground-based site trees match the top height predicted from the TIPSY MSYT.

VOL3: These are the volumes from Section 3.3 – usually the predicted volumes from the TSR yield curves.

This approach, which is similar to the Inventory Audit volume bias partitioning, was developed and applied to the Morice TSA YSM pilot project data (FIAB 2013).

3.7 Forest Status Reporting

Data from the YSM plots can be used to describe current stand structure of young stands in a monitoring unit. Data from the YSM plots are used to describe current stand structure of young stands in a monitoring unit. This ground information can be used, possibly along with other existing information (e.g., VRI Phase I), to report on the current status of young stands in a monitoring unit.

Overall monitoring unit YSM descriptive statistics are calculated for selected attributes, including basal area/ha, stems/ha, gross volume/ha, net merchantable volume/ha and dead volume/ha. The diameter distribution of number of stems and volume per hectare of the YSM population can also be produced. The YSM plots also provide data on damage agents and severity on individual trees, to get an assessment of forest health. Damage agent types include abiotic, disease, insects, treatment injuries, and animal damage.

3.8 Graphical and Statistical GY Comparisons

3.8.1 Continuous variables

Growth could be checked in form of graphs by comparing the predicted growth over a period to the actual GY from the plots. Yield can also be checked by comparing the actual yield at a given time to the yield projected by the growth models such as TIPSY or VDYP, or existing inventory. There are several simple and proven ways data can be plotted to provide a graphical comparison of actual and predicted values:

1. *Plot measured values versus age against a yield curve.*
   For example, plot the aggregate volume/ha versus age yield curve and overlay

individual plot volume curves. In this case, measured values will likely show considerable variation around the aggregate curve.

2. *Plot measured versus predicted values.*
   If predicted values are accurate, most points should fall equally above and below the 1:1 line. If the predictions are precise, the points should show a linear trend. Outliers can be flagged and examined to determine if any potential problems in prediction are indicated.
3. *Plot the difference (actual – predicted) versus age.*
   This may indicate trends of over- or under-prediction for different age ranges. The same absolute differences at younger and older ages have different implications. Expressing differences as a percent of the predicted value can provide a better view of the differences over time and age.

Simple statistical tests, such as paired *t*-tests, are used in conjunction with graphical analyses of continuous attributes. In many cases, post-stratification the data (e.g., by BGC zone) may reveal important differences.

3.8.2 Leading Tree Species

Two leading species comparisons are of interest are:

1. Has the ground leading species changed over time?
2. Are there differences between the ground and inventory leading species?

These comparisons use an error matrix approach (see, e.g., Congalton and Mead (1983) and the Kappa (*K*) statistic, as was done in the Inventory Audit program of the 1990's. The Kappa statistic tests the null hypothesis that the leading species is not changing over time or that there is good agreement between the ground and inventory leading species. The error matrix tabulates the ground plot leading species frequencies at Time t and T-1 or ground versus inventory.

Table 5. Sample error matrix of YSM plot and VRI polygon leading species in the Kootenay Lake TSA YSM. Plot counts are in the matrix cells; cells where there is agreement (60%) are shaded gray.

VRI polygon leading species	YSM plot leading species								Total	
	S	Hw	Pl	Fd	Cw	Bl	Lw	Ep	Count	%
S	15	1	1		1	3			21	42%
Hw		2			1				3	6%
Pl	1		6	1	1			1	10	20%

Fd		1		4	2				7	14%
Cw	1		1		0				2	4%
Bl		1		1	1	2			5	10%
Lw	1						1		2	4%
Ep								0	0	0%
Count	18	5	8	6	6	5	1	1	50	
%	36%	10%	16%	12%	12%	10%	2%	2%		100%

Note that the conclusions from the leading species analysis that compares YSM ground plot and VRI polygon species compositions should be interpreted with caution since the YSM plot is typically a very small portion of the parent VRI polygon, and the comparison is not very precise since only one plot is established per sampled polygon. In addition, for young stands with small diameters, the leading species is sensitive to the utilization level. Note also that currently this analysis does not rank the importance of differences in ground plot and VRI polygon leading species between Time t and t-1; e.g., some changes in leading species may not be an issue.

3.8.3 Pest and Disease Incidence

Pest and disease is only measured on the ground plots so there is no comparison to the VRI inventory. The analysis is the same as that of the leading species comparison. The objective is to determine if there have been changes in pest and disease incidence between Time *t* and Time *t-1*. These comparisons are also based on the confusion matrix approach, which involves the Kappa (*K*) statistic, as discussed in Section 3.8.2.

3.9 Reporting Analysis Results

The analysis report should provide complete documentation of the compilation and estimation procedures and the results of the GY comparisons; see examples of the Morice and Kootenay Lake YSM (FAIB, 2013; Omule, 2013). Information should be provided to allow the replication of the process, if required. All assumptions and non-standard procedures must be carefully noted. A list of the samples and sample weights should also be provided. Most importantly, the monitoring analysis report should provide a tabulation of the differences between the observed and predicted GY for all the variables and by post-strata (if any). The intent is that the timber supply analysts can then use this information in a management unit TSR, e.g., Sensitivity Analysis of the Base Case (SABC) (see Table 6). Note that the monitoring information is not used to adjust the inventory.

4 Program Implementation

4.1 Costs

The monitoring plot establishment is estimated to cost, on average, about $1,540/plot. Access significantly impacts sampling cost; the unit cost for establishment of plots without helicopter is less, approximately $1,362/plot. Quality assurance cost is approximately $1,154/plot. These plot establishment and quality assurance cost estimates are based on experience from the YSM pilot projects conducted in 2013 in the Kootenay Lake and Morice TSAs.) There is also the on-going similar cost for remeasurement every five years, and additional $15,000/measurement year/monitoring unit for sample planning, data analysis and reporting.

4.2 Scheduling

An establishment schedule and budget for implementing the monitoring program shall be prepared for priority management units. The high priority management units (TSAs) currently include: Prince George, Quesnel, Williams Lake, 100 Mile House, Cranbrook, Mackenzie and Lakes. This list should be confirmed based on the latest TSR schedule. As well, a decision to pool samples across multiple management units should be made, based on findings from the regional Caribou sampling being conducted in the 2013 field season. An establishment schedule is needed to ensure that longer-term planning with regard to funding can be done.

5 Applications of the Monitoring Results

5.1 Overview

The monitoring results include estimates (and statistical comparisons) of the differences between actual and predicted GY estimates for various timber attributes investigated. These statistics will not be used to adjust existing GY predictions. Instead, the monitoring statistics can be used to provide feedback to timber supply analysts and GY modellers, to identify opportunities for improving timber supply forecasting. The YSM data can also be used to better inform TSR scenarios as has been done for the Morice TSA.

5.2 Timber Supply Analysis

The monitoring information can be used to check the accuracy of timber supply analysis assumptions, including operational (OAF-adjusted) merchantable volume (MV), MV growth, potential site index, stand density, and species composition and succession, as well as, by management unit. This would be achieved by examining the results of the GY analyses and comparisons.

The GY comparisons may show good agreement or poor agreement between the observed and predicted GY. If the agreement is poor, the source of the discrepancy must be identified. The disagreement could, for example, be included in the Chief Forester's TSR rationale statements as impetus for further investigation, if the disagreement has a significant impact on timber supply or management decisions. The YSM results should be included in AAC determination meetings.

As stated earlier, the monitoring analysis should provide a table of the biases by post-strata (e.g., Table 6). The timber supply analysts can then use this information in a management unit SABC. Note, however, that these values are not used to adjust the inventory. These differences are based on actual significant differences between the CMI data and the assumed timber supply values that were extracted from a CMI analysis report of a management unit. Other attributes such as basal area and stems per hectare should be included in Table 6.

Table 6. Example List of Bias based on Actual Monitoring (CMI) Data. The mean difference is followed in brackets by the standard error expressed as a percent of the mean.

Population	Attribute	Bias
Managed stands	Net merchantable volume periodic annual increment (PAI) (m^3/ha/yr)	-1.9 (70%)
Managed stands (Spruce, Sxi)	Potential site index (PSI) (m)	2.8 (13%)
Managed stands	Leading species correct ID: yield table assignment assumptions (%)	36
Managed stands	Pests & disease (MPB) volume loss (m^3/ha/yr)	-0.3
All young stands	Stand inventory age (yrs)	3.4 (11%)
All young stands	Leading species correct ID: inventory label (%)	46

5.3 GY models

The monitoring growth comparisons are useful for GY modellers to check the level and shapes of the yields curves. This could be achieved, for example, by examining the differences between the monitoring data and the predicted GY values based on the actual plot data inputs to TIPSY. The monitoring data on tree mortality extent and causes could also be used to check the GY model mortality functions.

The monitoring information may not be adequate to help modellers identify possible causes of model prediction biases on an individual management unit basis. However, the observed differences between the actual and predicted values would alert the GY modellers of potential problems with the GY models. As well, accumulated monitoring data from several management units could be used, with proper weighting of the data, to check the accuracy of how adjustments (OAFs) are applied to potential yield to obtain operational yields from TIPSY.

5.4 Policy Decision-Making

The monitoring information can be used to provide feedback on the impact of past policies, and to support policy decision-making on topical issues such as climate change and carbon sequestration, as well as other emerging issues. This is achieved by examining the long-term trends in the differences between observed and predicted growth and yield of timber attributes and pest and disease incidence. The process to incorporate the monitoring data to policy decision-making will be developed further.

6 Reporting

The monitoring program reports to be produced include:

1. Initial plot establishment report (one time). This report shall include a check on the timber inventory and an analysis of past tree basal area and height growth.
2. GY comparison analysis reports following each plot remeasurement (every 5 years), including cost and recruitment of any new plots.

The monitoring program results shall also be communicated to stakeholders through a website.

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Appendix A – Monitoring Business Needs

FAIB undertook a monitoring business case analysis in 2010 and excerpts from Section 2 of the resulting business case report *Why We Need to Monitor Change in Our Managed Forests*, October, 2010, are provided in this appendix. The business case outlines 11 objectives for YSM monitoring provided below. Obtaining YSM data and analyzing trends to meet some of these objectives, such as providing trend information to support AAC determinations and checking site productivity estimates, could realistically be addressed over the short- to mid-term. This work is currently underway through YSM plot establishment and preliminary analysis for Morice and Kootenay Lake TSAs and initiation of other YSM sampling in Merritt, Quesnel and Williams Lake TSAs. However, providing meaningful trend data for some of the other objectives, e.g., impact of climate change and carbon accounting will require a longer term commitment to YSM monitoring and trend analysis.

Excerpts from the FAIB business case report *Why We Need to Monitor Change in Our Managed Forests*, October, 2010, Section 2, are outlined as follows.

To Demonstrate Sustainability

Each year in BC thousands of hectares are harvested and reforested. The social license that allows us to harvest is based on the assumption that we will "put back" what was harvested. We do this by spending approximately 200 million dollars annually on basic silviculture. We ensure that regenerated stands are "free-growing", but past this point there are no requirements to check stand growth. Presently this situation leads to a significant gap in our knowledge between free growing declaration and the point at which younger stands enter the inventory database as part of the inventory update or re-inventory processes. What proof can we provide the public that post free-growing stands are growing as assumed? We continue to base AAC determinations, silviculture investments, carbon sequestration estimates, watershed stability, biodiversity and habitat distributions, anything that requires an estimate of future forest conditions on our assumptions and predictions about how regenerated forests are growing and will grow in the future.

We claim to be world leaders in forest management, yet we do not have a single, easily accessible source of information on how our managed forests are actually growing. As professionals, we are accountable to the public to ensure that we are managing our forests sustainably.

Fulfilling Responsibilities

To successfully fulfill each of the Forest and Range Resource Stewardship core responsibilities[10] requires accurate, defensible information on the change in our managed forests. We cannot ensure that forest management policies and practices are resulting in a sustainable resource without the information to demonstrate sustainability. In order to recommend practices and procedures to mitigate climate change impacts, ensure forest health and guide tree improvement, we need continuous feedback on the results of past and current practices. The mountain pine beetle (MPB) has accelerated our reliance on managed forests. The “state of our forests” is increasingly becoming “the state of our young managed forests”, forests that change at a much faster rate than mature forests and therefore require more frequent measurement to assess their state and change. How can we confidently state to the public that we know the state of our young managed forests when the last required check of regenerated stands is free-growing? Furthermore, how can we have confidence in our AAC determinations when they are becoming increasingly sensitive to projections of managed stand yields, yields that we have very little information to rigorously verify?

To Provide Critical Information for AAC Determinations

In management units with significant mature timber, AAC determinations are typically not that sensitive to changes in projected regenerated stand growth. However, as the proportion of regenerated stands increases so does the sensitivity of the AAC determination to regenerated stand projections. Post MPB, the significance of regenerated stand growth projections to AAC determinations has increased dramatically. The current uncertainty in actual regenerated stand growth causes a considerable risk that inappropriate AAC determinations will be made. This results in the need to confirm or modify current timber supply review (TSR) assumptions.

In the Prince George TSA the mid-term timber supply is highly sensitive to assumptions of managed stand growth.[11] Two recently completed sensitivity analyses clearly demonstrate this. Lowering the managed stand site indices from SIBEC estimates to the original inventory estimates results in the managed stand volume remaining unavailable until much later in the forecast and contributing significantly less to the long term harvest level. Forty years from now the future timber supply drops by 40% due to this change in managed stand growth assumptions (Figure 1). Removing the genetic gain assumed in the base case results in many managed stands not reaching the minimum harvest threshold by age 60 and therefore not

[10] Ministry of Forests and Range. 2010. The objectives and tasks of functional change to realize our business response. February 1, 2010. (page 14).

[11] Barry Snowdon, personal communication, September 14, 2010.

contributing to the available harvest volume in the mid-term. This is particularly applicable 40-50 years out when there may be up to 18% less managed stand volume available for harvest. In the long term, uncertainty regarding genetic gain may represent a downward pressure up to 5% (Figure 2).

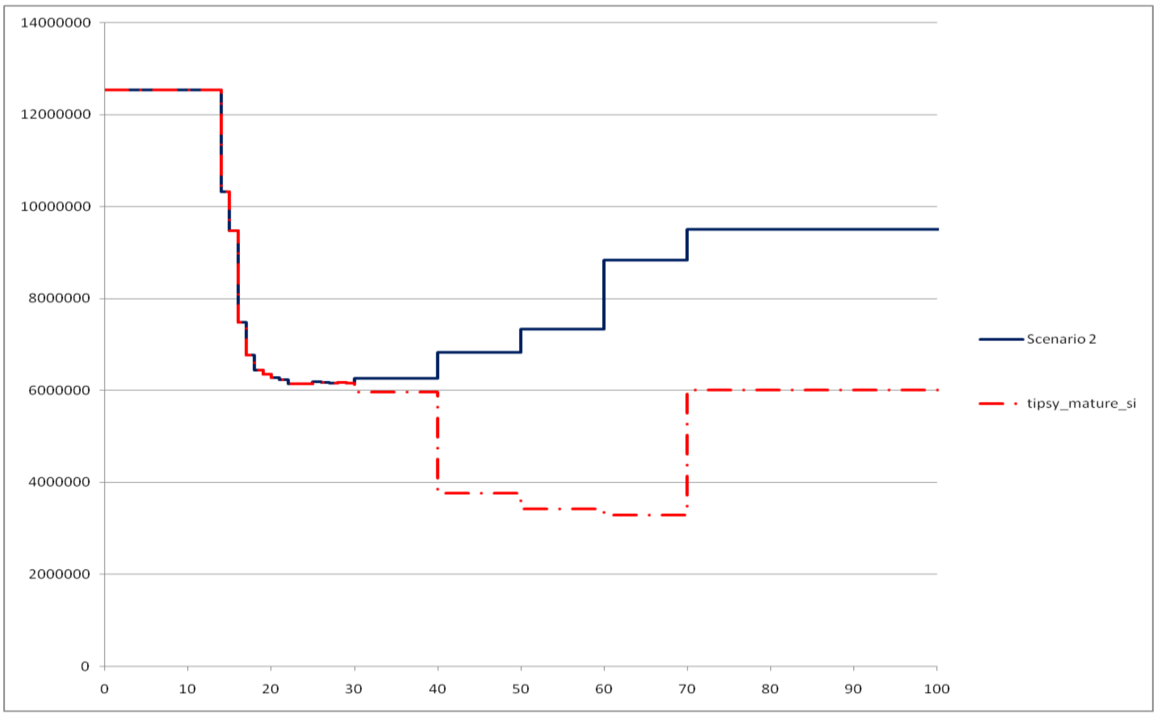

Figure 1. Prince George TSA. The blue line represents the projected future timber supply assuming SIBEC site index estimates for managed stands. The red line represents the projected future timber supply with the original inventory site index estimates.

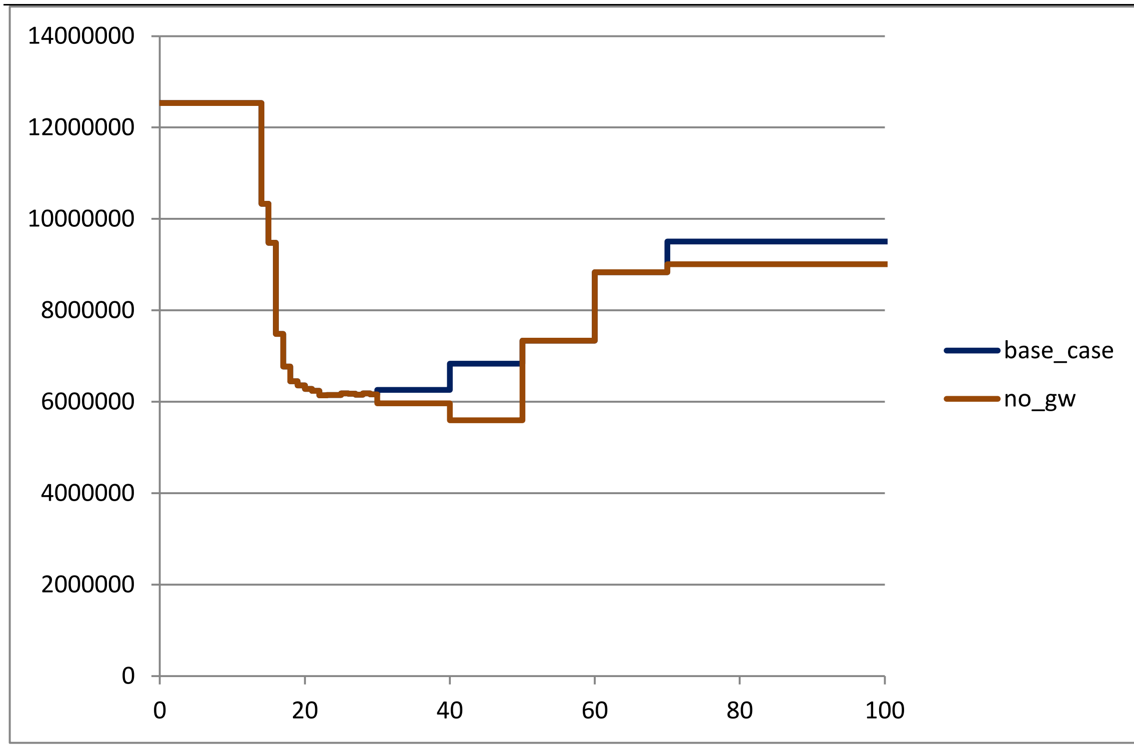

Figure 2. Prince George TSA. Future timber supply with and without genetic gain in managed stands.

In the Quesnel TSA managed stands make an increasingly significant contribution to the mid-term timber supply once MPB salvage is complete.[12] When existing and future managed stand yields were dropped by 20%[13], there is a 10% drop in harvest volume available between 2029 and 2038 and the average long-term harvest level drops (compare Figure 3 and Figure 4).

Several AAC rationales have included requests from the Chief Forester to monitor growth in regenerated stands to assess site productivity estimates and ensure yield projections are accurate (Appendix I).

[12] Gordon Nienaber, personal communication, September 15, 2010.

[13] 20% could be argued to be conservative given that surveys of age class 2 stands showed a 39% mortality rate. (Forest Analysis and Inventory Branch. 2010. Quesnel TSA timber supply review data package. April 2009.)

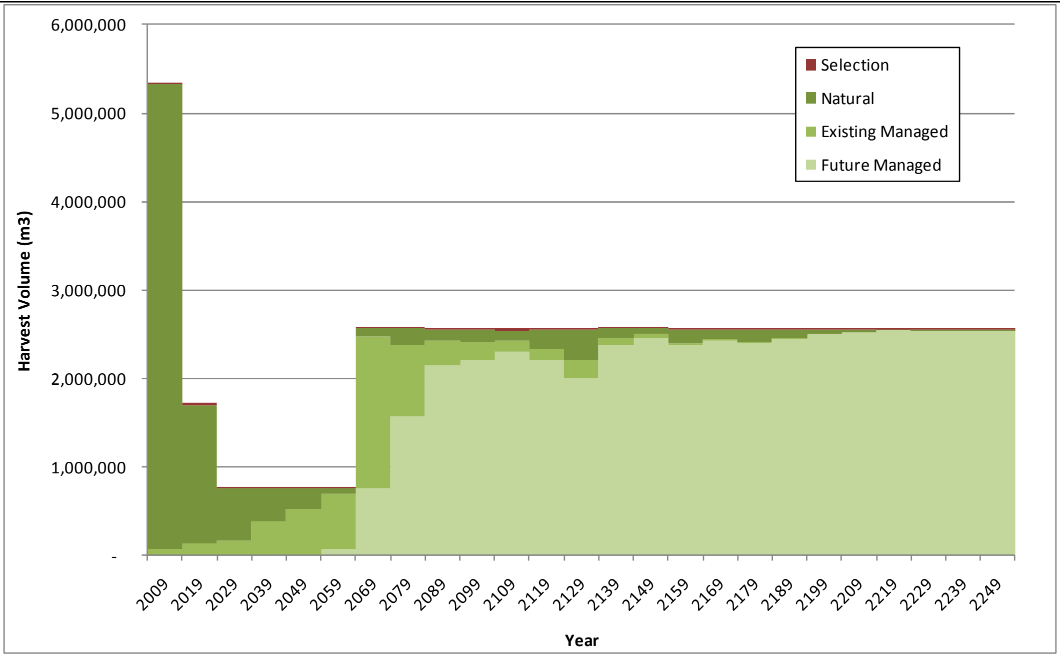

Figure 3. Quesnel TSA base case timber supply.

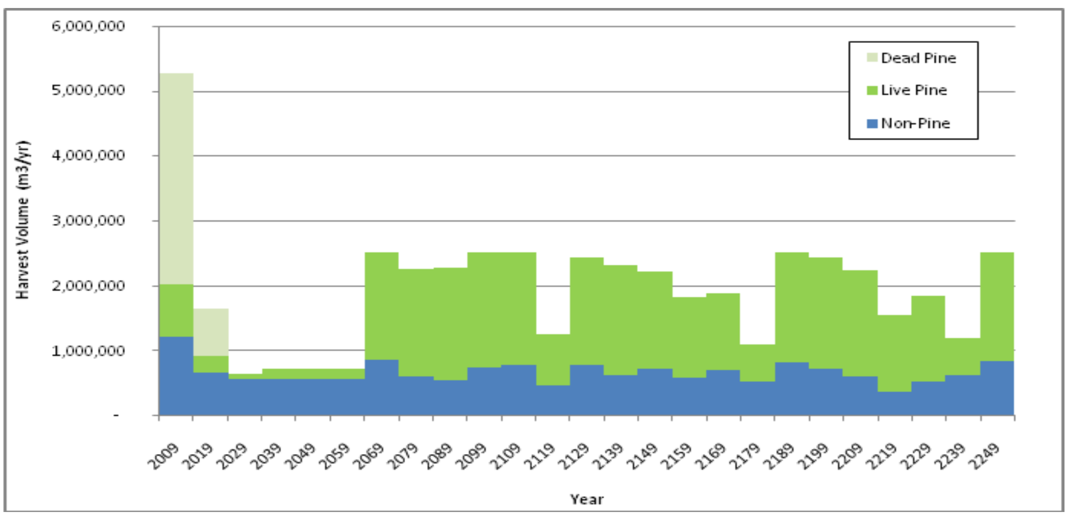

Figure 4. Quesnel TSA timber supply with a 20% reduction in existing and future managed stand yields.

To Check Site Productivity Estimates

Site productivity is primarily indicated by site index, which is a key driver in most growth and yield models. Changes in site index inputs for managed stand projections have significant impacts on future yield projections. In addition, a given site index estimate has an associated assumed height growth trajectory for top height trees which is implicitly used in growth and yield models such as TASS. Checking the actual growth of top height trees over time is a critical component in validating the operational application of our growth and yield models that are used for timber supply analysis and silviculture decision-making.

To Continually Improve Basic Silviculture

Each year approximately 200 million dollars are spent on basic silviculture. The choice of regeneration treatment is based in large part on meeting prescribed stocking standards to achieve free-growing. What information do we have to assess that the stocking standards are promoting basic silviculture practices that result in acceptable stands at rotation, not just at free growing? The process of setting stand level objectives, and in particular early stand objectives (stocking standards), fundamentally relies on our ability to predict the development of regenerating stands. It is imperative that we recognize the uncertainty around existing predictions of stand development and therefore the need to continually check the actual growth and development of our regenerated stands. In a review of the effects of stocking standards on stewardship for the ABCFP[14] our failure to track the actual growth, health and composition of regenerated stands beyond free-growing was identified by most foresters interviewed as one of the major problems in our current system.

The linkage between stocking standards and timber supply now defined in the Forest Planning and Practices Regulation (FPPR) must also be considered. The FPPR has the requirement that stocking standards be consistent with timber supply assumptions. FPPR Section 26(3):

"*The minister must approve the regeneration date, free growing height and stocking standards… if … (a) the regeneration date and the standards… (ii) is consistent with the timber supply analysis & forest management assumptions that apply to the area …*"

How can we ensure consistency between stocking standards and timber supply assumptions when we have limited information on how regenerated stands are performing post free-

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[14] McWilliams, J. and McWilliams, E. 2009. A Review and Analysis of the effect of BC's Current Stocking Standards on Forest Stewardship. Prepared for the ABCFP stewardship committee. http://www.abcfp.ca/publications_forms/publications/documents/Stocking_Standards.pdf

growing? Are the stocking standards resulting in reforestation practices that produce stands that are consistent with timber supply assumptions?

Additionally, what statistically sound information do we have to provide feedback to the silviculturists to improve their practices or to evaluate if the economic efficiency of reforestation investments is the highest possible? They need data to confirm that the anticipated returns on investment are being met. To a large extent we simply operate on the assumption that passing the free-growing milestone will result in the desired stand at rotation. We need to confirm assumptions are valid or change management directions accordingly.

Post Free-Growing Stands are the Responsibility of the Crown

Once regenerated stands are declared free-growing they become the responsibility of the Crown. There is a significant gap in our knowledge of regenerated stands and the assumptions we have made about them need to be verified on a number of business fronts. If these stands fail to meet expectations, and the decision is made to apply remedial treatments, these treatments will have to be funded by the Crown. The present lack of information on regenerated stand performance results in an unknown potential future liability to the Crown. The understory reports[15,16], various CMI and SDM work done to date all indicate that we should be monitoring to determine the extent of any such liability to the Crown.

To Ensure Wise Investments in Incremental Silviculture

Incremental silviculture investment decisions are based on return on investment and impacts on timber supply. How much extra wood will be gained, or how much wood will be available sooner because of the treatment? Currently approximately 50 million dollars is spent in the province annually on incremental silviculture, including backlog reforestation and MPB rehabilitation, yet we cannot answer this question.

The responses to treatment are predicted with models available in Ministry software such as Tree and Stand Simulator (TASS) and the distributed software Table Interpolation Program for Stand Yield (TIPSY). The TASS / TIPSY models predict the response to various treatments after verifying results against the best available research data. These tests are best done when the

[15] Churlish Consulting Ltd., Jahraus & Associates Consulting Inc. 2010. 100 Mile House TSA understory sampling. Unpublished contract report.

[16] Churlish Consulting Ltd., Jahraus & Associates Consulting Inc. 2009. Quesnel TSA pine understory sampling pilot project. Unpublished contract report.

stand conditions prior to treatment are correctly specified. For example, fertilizer responses in TIPSY, for a given species, site index and age, are a constant percentage of the unfertilized volume. So if for example TIPSY assumes a 10% fertilizer response, if the starting volume is 350 m^3, the absolute response will be 35 m^3, however if the starting volume is only 300 m^3, then the absolute response will be 30 m^3. Clearly, it is critical to have accurate estimates of the stand conditions prior to treatment. Operational analyses typically include information on pre-treatment stand condition from pre-treatment assessments. Provincial strategic analyses however, with no better data available, must simply assume the yield projections for managed stands are accurate. How can we strategically plan and state to the public that we are investing their tax dollars wisely in large incremental silviculture programs in our regenerated stands when we have very little information on how those stands are currently growing?

Recent Concerns Regarding Regenerated Lodgepole Pine

Three recent reports have stated serious concerns over the health of regenerated lodgepole pine stands and the need for monitoring of their performance.

1. Forest and Range Evaluation Program. 2009. Forest stewardship plan stocking standards evaluation. FREP Report #19.

"…there is significant concern for the future development of pine-leading stands established according to the stocking standards in the area represented by the inspections of the FSPs in the Northern Interior Region. The concerns relate to the impacts of the high incidence of hard pine stem rusts and/or the poor quality attributes of pine stands on medium to good sites grown to the densities targeted in the stocking standards. There should be considerable concern about this situation given the:

- *Widespread use of pine established at similar densities in the interior,*
- *Widespread range and incidence of forest health agents which affect pine and the uncertainty about the impacts of these health issues on future stand development, and*
- *The importance of existing managed and future stands to the mid-term timber supply in MPB impacted forest management units."*

"There is a need for extensive and long-term monitoring of free growing stands throughout BC to ensure they are meeting timber supply projections and quality expectations. "

2. Heineman, J.L., Sachs, D.L., Mather, W.J., Simard, S.W. 2010. Investigating the influence of climate, site, location, and treatment factors on damage to young lodgepole pine in southern British Columbia. Can. J. For. Res. 40: 1109-1127.
   "It is assumed that stands considered acceptable at this stage [free-growing] will remain productive through to maturity: however, there is no formal process to monitor their

ongoing condition. Anecdotal evidence that lodgepole pine is sustaining high levels of disease, insect, and abiotic damage beyond age 15, coupled with apprehension about the potential effects of climate change, has raised the profile of this issue."

"We quantified the presence of 14 damaging agents in sixty-six 15- to 30-year old pine stands. Hard pine stem rusts, primarily western gall rust, were present on every site."

"…our results suggest the need to consider potential increases in damage from disease and insects during silviculture planning and timber supply prediction."

3. Mather, W.J., Simard, S.W., Heineman, J.L., Sachs, D.L. 2010, Decline of planted lodgepole pine in the southern interior of British Columbia. For. Chron. 86(4):484-497. *"Lodgepole pine is extensively planted across western Canada but little is known about development of these stands beyond the juvenile stage."*

   "Our finding that over one-quarter of lodgepole pine plantations have substandard stocking levels soon after being declared free-growing as a result of insect, disease and abiotic damage is cause for concern because of the potential for broad-scale reductions in forest yield relative to projections."

   "The need for a new emphasis in the approach to monitoring and managing juvenile lodgepole pine stands in interior British Columbia is obvious from this study. Consideration should be given to establishing an effective permanent plot system for monitoring post free-growing stands to ensure that performance is maintained beyond the free-growing declaration and track mortality, damage and forest development."

Tree Improvement

The province invests approximately 8 million dollars annually in tree improvement programs and the expectations of increased growth and improved pest and disease resistance have been incorporated into timber supply analyses for the past ten years. Tree improvement continues to be strongly supported through the Land Base Investment Strategy. What information do we have to ensure that we are accurately projecting the operational gains from tree improvement? Monitoring is required to determine if genetic gain assumptions (growth, pest & disease resistance) are realized in the field. Without testing these assumptions, we cannot fully justify our investments in these programs nor the assumed timber supply gains.

Furthermore, genetic gain estimates could increase or decrease as a result of climate change depending on species and geographic location. This increases the uncertainty and therefore increases the need for monitoring, especially when select seed use is expected to increase as a climate change adaptation strategy. This adds an additional requirement to monitor to evaluate the effectiveness of current and new climate based seed use policies. Monitoring is required to determine the magnitude, rate, and direction of genetic mal-adaptation due to negative climate change and associated forest health impacts.

Climate Change

The purpose of the Future Forest Ecosystems Initiative (FFEI) is to adapt BC's forest and range management framework to a changing climate. Work conducted under this initiative includes research, modeling, policy analysis, policy change, communication, and monitoring. Sixteen indicators have been recommended for monitoring.[17] A network of systematically located permanent sample plots, such as those provided by the National Forest Inventory (NFI) or CMI programs have been identified as data sources for three indicators (ecosystem distribution and composition, ecosystem productivity, and species diversity). In addition, a network of independent plots that are representative of the land base provides a valuable dataset to check predictions of climate change impacts.

Forest management has become more challenging because of climate change. Woods *et al* (2010)[18] cite the impacts of climate change on forest health with MPB and *Dothistroma* needle blight outbreaks being prime examples. Furthermore, they state, "*The task for the next decade is to understand better how climate affects biotic and abiotic disturbances and how forests respond to them. Improved monitoring programs and analytical tools are needed to develop this understanding."*

Carbon Accounting

The inventory-based Carbon Budget Model (CBM-CFS3) developed by the Canadian Forest Service is the preferred model to account for total carbon stocks over time. CBM-CFS3 projections of carbon are sensitive to the merchantable volume equations input into the model, not only for projections of carbon accumulation in live biomass over time, but also for the initiation of dead organic matter pools. Key to ensuring accurate projections of carbon is utilizing accurate merchantable volume equations as model inputs. This requires monitoring of

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[17] Forest and Range Evaluation Program. 2009. Monitoring forest and rangeland species and ecological processes to anticipate and respond to climate change in British Columbia. FREP Report #20.

[18] Woods, A.J., Heppner, D., Kope, H.H., Burleigh, J., MacLauchlan, L. 2010. Forest health and climate change: A British Columbia perspective. For. Chron. 86(4):412-422.

regenerated stands to ensure that they are growing as predicted. For example, select seed use is an eligible activity under the Pacific Carbon Trust, BC Forest Offset protocol. Do we have the correct merchantable volume curves for these genetically improved stands to input into the carbon model? This information is critical to ensure we are not over- or under-stating the case for BC forests being effective agents for carbon sequestration.

Appendix B – Summary of YSM Pilot Projects Results

Two YSM pilot projects were conducted in the Kootenay Lake and Morice TSAs in 2012/13. Results from these two pilots are summarized below (source: Omule, 20013; FAIB, 2013).

Kootenay Lake TSA

The YSM target population consisted of 15- to 50-year-old stands in the TSA (total area 56,658 ha), vegetated and non-vegetated, excluding parks, private land, and Indian Reserves, but including community forests and woodlots. Fifty YSM plots, selected systematically from a 2 km x 2km fixed grid, were established in the target population using the Change Monitoring Inventory (CMI) protocols. The data were used to describe the current status of the young stands.

The average tree size was 19.7 cm (quadratic mean DBH). Most of the live trees were in the 0-10 cm DBH class (63%) (mainly Sx and Cw), and 11-20 cm DBH class (30%) (mainly Sx and Pl). Gross volume per hectare was concentrated in the 11-20 cm DBH class (29%) (mainly Pl and Sx), 21-30 cm DBH class (16%) (mainly Bl and Sx), and > 70 cm DBH class (20%) (mainly Cw). The amount of dead pine was negligible (0.6 $\pm$ 82% m^3/ha, or approximately 9% of the total pine volume). There was relatively high volume of dead western red cedar (12.3 $\pm$ 57% m^3/ha, or approximately 52% of total cedar volume). Approximately 58% of all the sampled trees showed no damage, 26% showed damage of known causes and 16% showed damage of unknown causes. The most common known primary damage agents were abiotic (scarring, rubbing, snow or ice).

Mean total biases of the predicted yield estimates used in the last TSR, defined as the difference between YSM plot values and the predicted yields, were calculated along with their standard errors (SE), for NMV, stand age, height and site index. Predicted volumes for plots less than 27 years old were based on TIPSY yield tables, and those of the older plots were based on the VRI VDYP7 volumes projected to 2012. The utilization levels were 12.5 cm+ DBH for Pl and 17.5 cm+ DBH for all other species. The age cu-off of 27 years and the two utilization levels were those that were used in the last TSR. Tests of total biases indicated that the VDYP7 NMV predictions, height and site index were significantly under-estimated (95% probability level), and that the total bias of the TIPSY volume predictions and age were not statistically significant (i.e., were accurate). The VDYP7volume, height and site index biases were 26.4 m^3, 2.2 m and 2.8 m, respectively.

The results of the leading species comparisons indicated that there was a 60% agreement between the YSM plot leading species and VRI polygon leading species. The Kappa statistic – a measure of agreement – was 0.47 and statistically significant ($p < 0.0001$), indicating that the observed agreement between the two is closer than what would be observed by chance. This conclusion should be interpreted with caution since the YSM plot is typically a very small portion of the parent VRI polygon.

This pilot project has successfully demonstrated YSM plot establishment, description of current stand structure of young stands in the KL TSA, and provided feedback to TSR analysts on the accuracy of the predicted yields used in the last KL TSR. It has also provided baseline data for monitoring, i.e., estimating change to compare with growth projections in the future. These KL YSM plots should be re-measured in 2017.

Morice TSA

Fifty ground plots were established in the Morice TSA to monitor young stands. The YSM target population was 15- to 50-year-old stands which represent approximately 72,000 ha within a vegetated land base of approximately 1,000,000 ha.

The YSM ground plot age, height and site index (SI) were compared to the VRI Phase I inventory polygon estimates. For young stands, the VRI Phase I polygon attributes often come from silvicultural records and, for this TSA, SI was taken from the provincial site productivity layer. The inventory ages were unbiased but the inventory height was 2.7 m (or 23%) less than the ground height, a statistically significant difference. The inventory SI from the site productivity layer was 8% lower than the YSM ground plot SI. The ground plot leading species and the inventory leading species were the same for 39 of the 50 plots.

The YSM ground plot basal area, trees per hectare and volume were compared to VRI Phase I inventory estimates generated by TIPSY using the analysis unit assumptions, the Phase I inventory species composition and SI from the provincial site productivity layer. The Phase I inventory basal area was significantly lower than the YSM ground basal area while the Phase I inventory trees per hectare (TPH) were slightly higher than the YSM ground TPH. The Phase I TIPSY-generated volumes were significantly lower than the YSM ground volumes and the total bias was dominated by attribute bias (rather than model bias). The population is young and the stands are growing rapidly. Although some of the differences are large, they are comparable to the growth from age 30 – 35. As a consequence, the results should be viewed with caution.

These are monitoring plots and the results reported here are based on one measurement. Re-measurements will be used to quantify trends in the differences – whether they increase, decrease or stay the same over time. A key question not addressed here is how differences in young stands will translate to differences at maturity and the effect on wood supply.

Appendix C – Outstanding YSM Issues to be Addressed

A draft Kootenay Lake establishment report (7 May 2013 version 1.2) was reviewed by FAIB staff, and several issues were identified. Most of the feedback has been reflected in this revised Framework or in the Kootenay Lake YSM pilot project and establishment reports. Some issues are, however, still being resolved in an ongoing manner and are listed in Table 7 below.

Table 7: YSM monitoring issues

Issue raised by Reviewers	*Author Comments*
3. **Boundary plots** that straddle more than one vegetation type should use the "walkthrough method", but this could have issues too (namely identifying the population boundary from the ground). Moving to half- or quarter- plots as per the VRI will not help matters.	This procedure is currently being field tested
4**. Adding/dropping plots**: identifying future samples is a nice idea, but it may be difficult to implement over time (given the current resources), and we should not expect to allow sample size to keep growing over time.	The grid sample intersections are to be checked at re-measurement for recruitment into the YSM sample, and should not be a problem (assuming there is adequate staff at FAIB). If the sample size becomes unmanageable, then ways to reduce the sample size, e.g., sub-sampling, may be considered.
5. **Replacement of missing plots**, i.e., plots that cannot be established due to difficult or dangerous access of the plot locations.	Replacement of missing plots can be considered. However, the current method of plot replacement may not be appropriate. It involves random selection of replacement samples from a list, which implies that the unavailable sample locations occur at random. This will not be the case in almost all situations. Selecting replacements by matching as is done in the VRI is a better alternative.
6. **Make best use of the data** – Merchantable volume has a 12.5 or 17.5 cm utilization, so few YSM plots have merchantable volume. Analysts should be consulted to ensure YSM monitoring provides useful feedback.	Ongoing discussion is underway with TSR analysts as to the best use of YSM information. Potentially ask analysts to provide, as part of the TSR yield curves, whole stem volume at a lower utilization level (e.g., 7.5cm or 4.0cm).
9. **Tree diameter limit of 12.5 cm dbh in the large tree plot** – Have we	This is an issue for FAIB to consider.

Issue raised by Reviewers	*Author Comments*
considered changing dbh breakpoints from 9 cm to 12.5 cm for the large tree plot? A 9-cm tree seems pretty small for a large tree plot. Not sure how much $/effort this change would save or what the implications would be on our databases and software.	
13. **Not sure of the logic of dropping plots older than 60 years**. Keep all, if not most, of the plots when they reach age 50, for other purposes, e.g., GY model validation and calibration.	The plot locations will be available, in case the older plots need to be remeasured for other purposes. The YSM focus is in young stands; growth trajectories beyond 50 years can be tracked using data from other PSPs.

Appendix D – Glossary of Terms

Audit is a one-time check on the accuracy of the inventory.

Growth (or Change) is the difference in the level of the resource (e.g., stand volume) between two time points, Time *t* and Time *t-1*.

Monitoring is the process of observing the growth and yield (GY) in a forest and comparing this with the predicted GY of that forest.

Monitoring Unit is a geographical grouping of the target population from which the samples are chosen, for the purposes of, and prior to, sample selection. For the proposed monitoring of young stands, the monitoring unit may be an individual management unit or multiple management units.

Post-Stratification involves the division of a monitoring unit into mutually exclusive sub-populations (strata) *after* ground sampling has been completed. Samples that fall in each post-stratum are analyzed separately and the results are applied to the corresponding population post-strata to improve the precision of the inventory's overall averages and totals.

Pre-Stratification involves the division of a monitoring unit into mutually exclusive sub-populations (strata) *before* ground sampling to provide estimates for specific areas, or to increase the confidence in the overall estimates by considering the special characteristics of each stratum.

Sample Size for monitoring is the minimum number of sample plots to be established in a management unit to meet specified goals (such as statistical power and differences to be detected).

Statistical power is the chance of detecting a statistically significant result using a statistical test (such a paired *t*-test); its value ranges from 0 to 100%.

Sub-unit describes sub-division of the target population in a management unit. A sub-unit may be defined by a specific geographic area (e.g., operable landbase) or stand type (e.g., problem forest types) within the individual management unit.

Target Population is the population from which the monitoring samples are chosen and the sample-based estimates and conclusions apply.

Appendix E – Rationale for no Pre-stratification

It is proposed in Section 2.3 that there be no pre-stratification of the YSM target population prior to sample selection. The intent is to monitor the entire YSM target population with similar precision (at least at plot establishment, for a given attribute), to achieve multiple YSM objectives. The intent is also to provide flexibility in handling anticipated future changes in the target population. This is achieved with the current method of sample selection using a uniform fixed grid. This rationale leads to including the entire vegetated land base that meets the age criteria, and not restricting the target population to vegetated treed polygons with a minimum crown closure.

Pre-stratification is one statistical tool normally used to reduce cost and to focus sampling effort in particular domains. Thus, due to limitations funding and staff resources, there has been some consideration given to targeting future YSM ground sampling more in the THLB rather than the entire VT landbase. Note that low sampling intensity and high standard errors have been observed during analysis of the YSM projects in MacKenzie, Morice, and Kootenay Lake TSAs, for TSR purposes. However, the rationale for not using pre-stratification to control sample size in YSM is as follows:

1. The YSM target population changes over time. For example, Balsam stands on marginally productive sites might not be attractive economically now but that scenario could change in the future if there are AAC reductions, etc.
2. Sampling intensity could be increased in domains of particular interest (not rare) at remeasurement. However, the monitoring has a time lag. For example, the Balsam stratum mentioned in Item 1 above may only get a handful of YSM plots at the beginning. However, if in 5 years, Balsam gets included in the AAC, additional samples can be allocated but they will only have a single measurement and monitoring results will only be available for the handful of plots originally sampled.
3. The YSM monitoring has several objectives, in addition to checking current TSR assumptions (see Section 2.1). Thus, if pre-stratification was done, the criteria for stratification would not be optimal for all these objectives.
4. Strata boundaries would change over time, and the sample selection weights (and thus, analysis) may become intractable over time.

The decision to pre-stratify should be based on consideration of the advantages and disadvantages of pre-stratification, achieving YSM multiple objectives, and available funding and staff resources.