Growth & Yield Monitoring Plan for the Fort St. John Timber Supply Area

Version 2.0

Prepared for

Don Rosen
Canadian Forest Products Ltd.
Chetwynd, BC

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

Table of Contents

List of Tables

List of Figures

1. INTRODUCTION

1.1 BACKGROUND

The Fort St. John Timber Supply Area (TSA) licencees are developing a sustainable forest management (SFM) plan that links TSA forest management activities to Canadian Standards Association (CSA) standards. Most activities supporting the SFM plan include setting forest management goals and objectives (through public consultation), developing targets for these objectives, and developing indicators to measure progress toward meeting the targets. One component of this SFM plan is to ensure that the productive capability of the landbase is maintained; this can be done by tracking growth & yield (G&Y) through a G&Y monitoring[1] program.

1.2 PROJECT GOAL & OBJECTIVES

The primary goal of this project is to develop a G&Y monitoring program for the Fort St. John TSA. This program will be designed to monitor the critical G&Y indicators and as many other indicators as possible to track progress towards meeting the SFM plan targets.

The specific objectives of this project are to:

1) Identify the business needs for a G&Y monitoring program in the TSA.
2) Define specific objectives for the G&Y monitoring program.
3) Identify where the G&Y monitoring program can provide data on other SFM indicators.
4) Develop a sampling design to meet the business needs and objectives.

1.3 TERMS OF REFERENCE

This project was completed by J.S. Thrower & Associates Ltd. (JST) for Don Rosen of Canadian Forest Products Ltd. (Canfor) of Fort St. John, BC. The JST project team was Eleanor McWilliams, *MSc RPF* (project manager), Jim Thrower, *PhD RPF* (technical support), Ron Zayac, *B.Comm* (GIS manager) and Wendy Creighton, *Dipl. Tech. GIS* (GIS technician).

Additional contributors to the G&Y monitoring options were Greg Taylor, *RPF* (Canfor), Jeff Beale, *RPF* (Slocan- Louisiana Pacific OSB Corp), Roger St. Jean, *RPF* (BC Timber Sales), Dave Menzies *RPF* (Canfor), Rod Brooks *RPF* (Louisiana Pacific Ltd.), Doug Russel (Louisiana Pacific Ltd.), Winn Hays-Byl, *RPF* (Ministry of Sustainable Resource Management [MSRM]), and Rod Kronlachner (Ministry of Forests [MOF]).

[1] General information on monitoring is provided in Appendix I.

2. BUSINESS NEEDS & OBJECTIVES FOR G&Y MONITORING

2.1 BACKGROUND

Clearly defined business needs and program objectives are critical components of a well-designed monitoring program. Business needs should focus on information requirements to support forest management decisions and processes (e.g., SFM planning, allowable annual cut determinations). One example of a business need is to periodically measure the actual G&Y of post-harvest and regenerated (PHR) stands to check against the corresponding projections used in timber supply analysis.

Business needs should be defined with a clear understanding of the importance of how different information impacts forest management decisions. Understanding the risk of using incorrect information in decision-making processes is important in determining the key variables (indicators) to be monitored. For example, large errors in some estimates may have very little impact on management decisions, but small errors in others may have large consequences. A sensitivity analysis of managed stand volumes done for the Fort St. John timber supply analysis[2] showed that if managed stands yields were increased by 10%, the initial conifer harvest would increase by 4.1%. Conversely, if these yields are reduced by 10%, the initial conifer harvest is reduced by 9.5%.

2.2 THE PROCESS

The Fort St. John TSA G&Y monitoring business needs were identified through discussions with licencee, MOF, and MSRM staff. Different monitoring needs for the TSA were considered including monitoring all stands, only PHR stands, and subsets of PHR stands (e.g., mixedwood, conifer and deciduous). The need to monitor timber and non-timber forest attributes was also discussed. Many potential uses and needs for information derived from a monitoring program were evaluated and included analysis of their costs, benefits, uncertainty in management processes, and potential future changes.

2.3 PRIMARY BUSINESS NEEDS

The primary business needs identified for G&Y monitoring on the Fort St. John TSA are to:

1) Periodically measure actual G&Y of managed stands to check projections used in timber supply analysis.
2) Provide data on indicators to support SFM requirements.
3) Provide data for inventory and G&Y model development.

2.4 SECONDARY BUSINESS NEEDS

The secondary business need is to monitor G&Y and stand dynamics in mature stands (particularly mixedwood stands) to check corresponding projections used in timber supply analysis. Monitoring mixedwood stands could become a key component of a mixedwood strategy that tests assumptions of how mixedwood stands change over time.

2.5 G&Y MONITORING OBJECTIVES

Based on these business needs, the specific objectives of the G&Y monitoring program for the Fort St. John TSA are to:

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[2] Ministry of Forests. 2002. Timber supply review, Fort St. John Timber Supply Area analysis report. June 2002. 142p.

1) Monitor change in volume, species composition, top height, and site index in managed stands beginning 15 years post-harvest. This data will be compared with predicted values of the same attributes used in timber supply analysis to provide a level-of-comfort that the projections used in timber supply analysis are accurate and precise. This data can also be used to track SFM indicators should the harvest level change in future.
2) Provide data on snags, coarse woody debris, and shrubs to address SFM objectives.
3) Provide data on stand growth that can be used as a subset of the data required to develop new G&Y models.
4) Develop a sample design that can be modified in future to incorporate plot establishment in mature stands and link with Vegetation Resources Inventory (VRI) Phase II ground sampling.[3]
5) Link the G&Y monitoring plots with silviculture surveys designed to monitor the first 15 years post-harvest.

[3] If all or a randomly chosen subset of the G&Y monitoring plots are re-measured at the same time as the temporary sample plots are established for VRI ground sampling, then the two data sources can be combined to give a better estimate of current yield.

3. SAMPLE DESIGN

3.1 OVERVIEW

The key features of the proposed sample design are:

1) Potential sample points are located on a systematic grid across the TSA.
2) Samples are 400 m^2 circular plots centered at these grid points.
3) Plots are installed in managed stands established 15 years post-harvest.
4) All sample plots will be installed over more than one year.
5) Sample plots will be re-measured every 10 years (funding permitting).

3.2 PURPOSE

The purpose of this sample design is to provide tree-level and non-timber data from a representative sample of managed stands on the TSA. This design is intended to provide data to address the program objectives (Section 2.5), be compatible with the MOF Change Monitoring Inventory (CMI) protocol[4], and to provide this information in a cost-effective manner.

G&Y monitoring is *the process of comparing the actual G&Y of a forest or stand to the predicted or expected G&Y for that forest or stand.* This program is intended to check existing G&Y predictions for managed stands and not to estimate stand response from silviculture treatments.

3.3 TARGET POPULATION

The target population is all managed stands at least 15 years post-harvest in the timber harvesting land base (THLB) of the TSA.[5] The target population will expand as stands are harvested and regenerated. This definition may change in future if natural stands are included in the G&Y monitoring program.

Pre-stratifying the target population is not recommended because it is extremely difficult to maintain the stratification over time. The system should be designed to be simple and flexible in order to ensure its longevity. Changes in species composition and silviculture treatments can affect stratification schemes when stands “jump” between strata.

3.4 SAMPLE LOCATION

We recommend locating monitoring plots in managed stands on a systematic grid across the TSA. Plots can be randomly or systematically located without compromising the statistical validity of the design. Plots located systematically on a grid will cover as many conditions as random plots, and have added convenience since plot locations are known once the grid size is defined.

The intent is that these plots provide a statistically valid sample of the target population. Thus, all stand types should be sampled, plot locations are not moved to “representative conditions of the stand”, nor are plots protected or buffered. If plots are buffered or treated differently than the rest of the target population, they cease to be a valid sample.

[4] Ministry of Sustainable Resource Management. 2002. Change monitoring inventory ground sampling procedures for the provincial change monitoring inventory program, *version 1.2*. http://srmwww.gov.bc.ca/tib/publications.htm.

[5] The THLB is approximately 23% of the total TSA area according to the Fort St. John timber supply area analysis report.

3.5 PLOT NUMBERING

We recommend using a plot numbering system based on Universal Transverse Mercator (UTM) coordinates. These numbers can be used to uniquely identify plots and their locations and limit the possibility for numbering errors as plots are added over time.

3.6 SAMPLE SIZE

Several grid sizes (1, 2, 3, 4, and 5 km) were superimposed on the TSA inventory and all points in the THLB were identified. Preliminary analyses, which balanced sample size and cost, suggests a grid size between 3 and 4 km to sample the managed stand population. A 3 km grid provides one plot every 900 ha, while a 4 km grid provides one plot every 1,600 ha.

Table 1. Distribution of 3 km grid points in managed stands by major species.

	Post-harvest (yrs)		
Species Group	0-14	15 +	Total
Sw > 80%	21	10	31
Mixedwood SxAt	3	16	19
Mixedwood AtSx	5	13	18
At > 80%		10	10
Sw leading conifer	2	8	10
Pl > 80%	6	2	8
Pl leading conifer	1	4	5
Mixedwood AtPl	2	2	4
Mixedwood PlAt	2		2
Total	*42*	*65*	*107*

Prior to further analyses, the inventory data for the 3 km grid points was checked to ensure that it was correct. This included ensuring harvest updates were complete and reconciling stand ages and harvest history data. This information was used to produce a summary of the distribution of 3 km grid points in managed stands by major species (Table 1).[6]

Table 2. Forecasted harvest levels for the Fort St. John TSA.

	Harvest (ha/year)	
Year	Conifer	Deciduous
2003	3,000	200
2004	3,000	200
2005	3,600	1,500
2006	3,600	3,000
2007	3,800	3,500
2008	3,800	4,200
⋮	⋮	⋮
2052	3,800	4,200

The 3 km grid data was used to proportionately estimate the distribution of grid points (by major species and years since harvest) in managed stands on 3.2, 3.4, 3.6, 3.8, and 4 km grids. Inventory records were used to estimate the number of plots to be established in the next 14 years. Forecasted harvest levels (Table 2) provided by Canfor were used to estimate the number of plots to be established 15 years and later. The distribution of these future plots was projected by major species group and assumed that current species distribution will be maintained as coniferous- or deciduous-leading. This distribution was obtained from the Fort St. John TSA analysis report (June 2002) (Table 3) and was applied to the projected number of G&Y monitoring plots to be established on areas not yet harvested.

Table 3. Species distribution within deciduous and coniferous leading stands.[7]

Species Group	%
Deciduous	65
Mixedwood At-Pl	16
Mixedwood At-Sx	19
Deciduous Total	*100*
Mixedwood Sx-At	11
Mixedwood Pl-At	11
Pl > 80%	24
Pl-leading conifer	19
Sw > 80%	19
Sw-leading conifer	16
Conifer Total	*100*

3.6.1 Post-stratification

The choice of grid sizes is partly a function of the ability to post-stratify the plots into large enough[8] groups to check the G&Y projections for those groups (Section 3.11). Species groups are usually categorized by conifer, deciduous, conifer mixedwood, and deciduous mixedwood. However,

[6] Lodgepole pine (Pl), white spruce (Sw), and trembling aspen (At).

[7] Data is compiled from the June 2002 Fort St. John TSA analysis report (Tables A3 and A16).

[8] A minimum sample size of 30 plots is recommended for G&Y estimates. Estimates of growth have less variability than estimates of yield and therefore require smaller sample sizes to obtain the same precision.

since the objective of checking G&Y projections, mixedwoods should be divided into Pl-At[9] mixtures and Sw-At mixtures.

G&Y models for Pl-At and Sw-At mixtures will be different because Pl and Sw have different shade tolerances; thus, the models will be developed separately. Further, Pl-At mixtures are easier to model and new models will likely be developed for this mixture before models are developed for a Sw-At mixture. Thus, given the objective of checking G&Y projections, we recommend splitting the mixedwood stands by conifer species.

Table 5. Estimated distribution of plots by general species composition, grid size and year.

	Grid Size (km)					
Species Group	3.0	3.2	3.4	3.6	3.8	4.0
			2005			
Deciduous	10	9	8	7	6	6
Mixedwood (Pl-At)	2	2	2	2	1	1
Mixedwood (Sw-At)	31	27	24	22	19	17
Conifer	30	26	23	21	19	17
Total	*73*	*64*	*57*	*51*	*45*	*41*
			2015			
Deciduous	10	9	8	7	6	6
Mixedwood (Pl-At)	6	5	5	4	4	3
Mixedwood (Sw-At)	36	32	28	25	22	20
Conifer	51	45	40	35	32	29
Total	*103*	*91*	*80*	*72*	*64*	*58*
			2025			
Deciduous	25	22	20	17	16	14
Mixedwood (Pl-At)	13	12	10	9	8	7
Mixedwood (Sw-At)	45	39	35	31	28	25
Conifer	79	69	61	55	49	44
Total	*162*	*142*	*126*	*112*	*101*	*91*
			2035			
Deciduous	56	49	43	39	35	31
Mixedwood (Pl-At)	25	22	20	18	16	14
Mixedwood (Sw-At)	58	51	45	41	36	33
Conifer	112	98	87	77	70	63
Total	*251*	*220*	*195*	*174*	*156*	*141*
			2045			
Deciduous	86	75	67	60	53	48
Mixedwood (Pl-At)	37	33	29	26	23	21
Mixedwood (Sw-At)	72	63	56	50	45	40
Conifer	144	127	112	100	90	81
Total	*340*	*299*	*264*	*236*	*212*	*191*

The projected plot distribution by species groups over time (Table 5) shows that by 2005 a 3 km grid would contain enough plots to check conifer and mixedwood Sw-At stands as individual groups (30 and 31 plots, respectively), but insufficient plots to check either deciduous or mixedwood Pl-At stands separately. The latter would be checked as part of the overall average of managed stand performance. By 2015, the 3 km grid would produce enough plots to extract pure Sw stands from the conifer group and analyze them separately (Table 6, Appendix II). In contrast, a 4 km grid would not provide enough plots to analyze conifer stands as a group unit 2015 and mixedwood Sw-At stands until approximately 2030 (Table 5). The estimated difference in average annual costs between a 3 and 4 km is $11,500 per year over the first three decades (Table 4).

Table 4. Estimated average annual cost for plot establishment and re-measurement by decade and grid size. Assuming $2,500 per plot for establishment and $1,000 per plot for re-measurement.

	Grid size (km)					
Decade	3.0	3.2	3.4	3.6	3.8	4.0
2003-2012	$23,300	$20,400	$18,100	$16,100	$14,500	$13,100
2013-2022	$19,900	$17,500	$15,500	$13,800	$12,400	$11,200
2023-2032	$35,700	$31,400	$27,800	$24,800	$22,300	$20,100
2033-2042	$44,600	$39,200	$34,700	$31,000	$27,800	$25,100
2043-2052	$53,500	$47,000	$41,700	$37,200	$33,400	$30,100

The ability to post-stratify the data to provide information on coarse woody debris, snags and shrubs, and range species to meet SFM information requirements has not yet been fully considered. It is not clear how potential strata would be defined besides using the major species groups. A summary of the data available to meet SFM requirements is provided in Appendix III.

[9] Pl-At mixtures include the full range of mixtures from 21 – 79% of either species, with Pl being the leading conifer. In contrast the symbols Pl-Aand At-l are used to refer to Pl leading and At leading stands respectively.

The choice of grid size is a function of available funding. It is important to recognize that establishing a monitoring program is an ongoing commitment that will require annual funding. Details of estimated costs and the quantity of G&Y data supplied by the different grid sizes are provided in Appendix II (Table 7, Table 8)

3.7 Plot Design

We recommend using a slightly modified version of the standard MSRM CMI plot (Figure 1). Tree measurements taken from the Main plot and Small-tree plot would be consistent with CMI standards. The Main Plot is 400 m^2 (11.28 m radius) where all trees greater than 9 cm diameter at breast-height (DBH) are measured and tagged. Trees between 4 and 9 cm are measured and tagged in the Small-tree plot (100 m^2, 5.64 m radius). The proposed modification is to the increase the radius of the Regeneration plot from 2.5 m to 3.99 m.[10] In this plot, all trees taller than 30 cm but less than 4 cm DBH are measured and tagged (50 m^2, 3.99 m radius). This will make the Regeneration plot the same size as the proposed full-measure silviculture survey plots (Section 4) that have previously been established at the same plot center and re-measured over the first 15 years post-harvest.

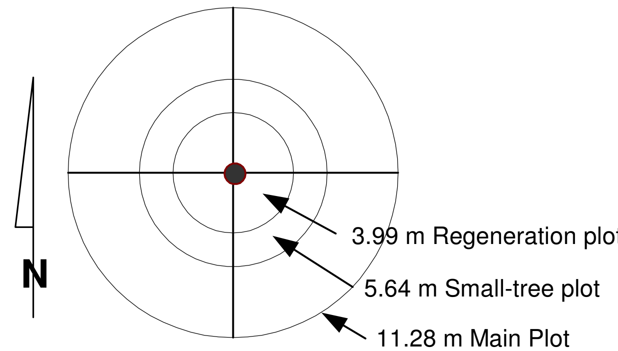

Figure 1. Monitoring plot design for tree measurements.

Coarse woody debris, ecological, vegetation and range data will be collected to CMI standards.

~~3.7~~3.8 Re-measurement Period

We recommend a ten-year re-measurement period to coincide with every second five-year Management Plan cycle. In other management units, five-year re-measurement schedules have been recommended but the growth rates in the Fort St. John TSA do not warrant re-measurement every five years.

3.9 Plot Measurements

3.9.1 Overview

We propose that most MSRM CMI standard field procedures be used; however, stem-map information should not be collected and a modified selection of site trees is proposed. A summary of procedures is provided in Appendix IV.

~~3.8.3~~3.9.2 Tree Tags

Brown tree tags should be affixed at breast-height rather than at stump height as recommended in the CMI protocol. This simplifies the work without making the plot unduly visible.

~~3.8.6~~3.9.3 Top Height & Site Trees

Top height trees should be selected as per CMI guidelines from the Small-tree plot. We recommend that leading and second species not be determined prior to site trees selection.

[10] If required, a 2.5 m radius could be used and trees within this plot recorded to maintain consistency with other CMI projects.

The age of the largest diameter, dominant or co-dominant tree of each species in each quadrant should be measured. This ensures that the age of the leading and second species are recorded. If the largest diameter tree of a given species (coded as “S” tree) is not suitable for height and age measurement, the next largest diameter tree suitable for height and age will be selected (and coded as “O” tree). If site trees between 4 and 9 cm DBH are outside the Small-tree plot (but inside the Main plot) they should not be tagged during plot establishment. In this case, site trees should be tagged and the height and age recorded in the site tree section on Card 10.

3.10 Data Management

Data will be entered into the most recent version of the VRI Data Entry (VIDE) software, suitable for both VRI and CMI data. JST can compile the data using the MSRM CMI data compiler.

3.11 Data Analysis & Interpretation

Data from the first measurement provides yield estimates only. These can be used to audit the projected yield of managed stands in timber supply analysis. Change is estimated when two or more measurements are available and then is it possible to determine differences between measured and predicted G&Y for the main attributes of interest. Graphical analysis includes plotting actual versus predicted values and plotting differences (actual-predicted) versus stand age or any other chosen variable to examine trends. The statistical analysis includes the average differences and associated confidence intervals.[11]

When the sample is large enough, it is possible to post-stratify the data to examine issues on subsets of managed stands. A minimum sample size in a stratum is approximately 30 plots.

The graphical and statistical analysis is intended to examine overall trends of over- or under-prediction in the data. If the analyses suggest over- or under-prediction, then possible sources of the differences should be identified. For example, when considering volume estimates, potential factors to consider as sources of error are the differences between the inventory inputs into the model and the actual stand attributes. Potential inventory attributes to examine include stocking, site index, treatment, species composition, stand structure, and pest or disease incidence.

The monitoring plot data could be used to adjust yields, but we recommend the data not be used to adjust growth projections (yield curves) based on observed growth. Both activities address the symptom of a problem rather its actual cause. Adjusting current yields for the sampled population is acceptable if data are representative of current yields. Adjusting yield curves to reflect observed growth in one time period is risky because this trend may not continue over time. The more prudent approach is to determine why differences occur. Often they result from incorrect inputs to the models.

The main objective of the monitoring program is to detect differences in growth. This program is limited in its ability to determine the causes of the differences. Consequently, additional samples or studies may be needed to identify possible sources of differences, should they occur.

[11] J.S. Thrower & Associates Ltd. 2000. Graphical and statistical analysis for monitoring estimates of change at the management-unit level. Version 2.0. Contract report to B.C. Ministry of Forests, Resources Inventory Branch, Victoria, B.C. Project MFI-055.

3.12 FUTURE MODIFICATIONS

Future modifications to the G&Y monitoring program could include:

1) **Decreasing sample intensity –** Sampling intensity can be decreased in future as more plots are located in managed stands. The number of plots will increase as natural stands are harvested, regenerated, and brought to the minimum 15 years from disturbance. If the program becomes too costly, randomly selected plots can be dropped from older managed stands where the comfort of predicting stand yield is higher. As well, costs can be reduced by increasing the re-measurement period of some plots.

2) **Expanding the monitoring program to natural stands –** The G&Y monitoring program could be expanded to include natural stands. This would form a separate target population and a separate analysis would be needed to determine potential sample sizes. One possibility is using a grid size that is a multiple of that chosen for the managed stands so that once plots in the natural stand grid are harvested, the same plot centers could be used for silviculture surveys and PHR monitoring program. Initial analyses suggest that a 7.2 km grid size (twice 3.6 km) would provide approximately 50 plots in natural mixedwood stands. Expanding the grid into natural stands should be coordinated with VRI ground sampling to minimize sampling costs.

3) **Re-measure the G&Y monitoring plots as part of the VRI ground sample –** If all or a randomly chosen subset of the G&Y monitoring plots are re-measured with the VRI Phase II ground sampling, then the two data sources can be combined to give a better estimate of current yield.

4. LINK TO SILVICULTURE SURVEYS

4.1 OVERVIEW

The proposed monitoring plots will track the G&Y of managed stands beginning at 15 years post-harvest. "Full-measure" silviculture survey plots will be established at permanent points on a 200 m grid at the time of the first survey and re-measured in subsequent surveys over the next 15 years. A subset of these 200 m grid points will form part of the G&Y monitoring plot sample.[12]

4.2 FULL-MEASURE SILVICULTURE SURVEY PLOTS

Each full-measure plot includes a 50 m^2 (3.99 m radius) plot (Main plot) divided into quadrants along cardinal directions to measure tree attributes, and a 100 m^2 (5.64 m radius) plot (Site Index plot) to collect height and age data from site trees (located at the same plot center) (Figure 2). Suitable site trees have three or more years height growth above breast-height. Site tree data should be collected from one tree of each species located in the Site Index Plot with a suitable site tree.

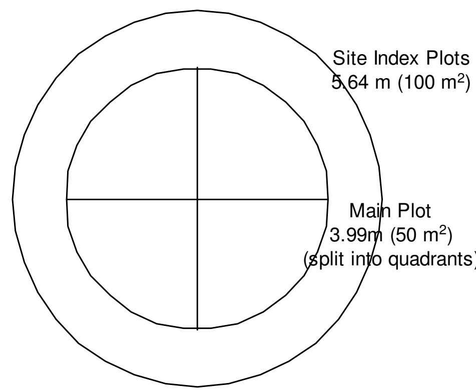

Figure 2. Full-measure plot design.

4.2.1 Plot Location

Full-measure plots are established on the 200 m grid. Plot centers should be permanently marked with a steel pin[13] and global positioning system (GPS) coordinates recorded. Plot locations should be geo-referenced in the geographic information system (GIS). These sample points should not be visible in order to avoid treating the plot area differently than other portions of the stand (which may bias the information from the sample point at subsequent measurements). The same center point will be used for the subset of full-measure plot locations chosen for the G&Y monitoring program.

4.2.2 Main Plot – 50 m^2

Quadrant Information – Each quadrant is recorded as stocked if it contains at least one healthy tree of an acceptable species that is free of brush competition (according to current free growing regulations). If a non-stocked quadrant could support tree growth, comment on why there are no trees (e.g., type of non-productive (NP) ground, missed plantable spots, brush competition, or health problems).

Tree Information – Data for each tree in the plot includes:

i) Quadrant number (1-4).
ii) Tree species.
iii) Height (measure some for reference and visually estimate others).
iv) Forest health codes (use the same codes used in other silviculture surveys).

Brush Information – Record percent cover and average height of brush by species in each quadrant.

NP Area Information – Record the type of NP area (e.g., rock, water) and percent cover in each quadrant.

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[12] All proposed grid sizes for the G&Y monitoring plots are multiples of 200 m.

[13] Any pin type could be used as long as it does not degrade and can be detected with a metal detector.

4.2.3 Site Index Plots – 100 m^2

Record site index information for one site tree of each species from the Site Index Plot located at each plot center. Site trees are:

i) The tallest tree in the 100 m^2 plot for that species.[14]
ii) Undamaged (stem damage resulting in less than 5% reduction in height growth).
iii) Not overtopped by other trees or competing vegetation where height growth may be affected.

The second tallest tree can be measured for site index if the tallest is not suitable. This must be noted on the field card. Information collected for each tree should include:

i) Total height.
ii) Age at breast-height.
iii) Total age.
iv) Rank in height relative to other trees in the plot of that species (e.g., tallest, 2nd tallest, etc.).

4.3 INFORMATION PROVIDED

If full-measure plots are repeatedly revisited as part of regular surveys during the first fifteen years post-harvest, they will provide a large observational database that can be linked to silviculture history and ecological data to determine trends in stand development. The same plot size (3.99 m radius) must be used and the same measurements (species, quadrant, estimated heights, damage codes, percent brush cover, and brush height[15]) must be taken during each survey. The data collected will provide information on:

1) **Early height growth** – This data can be used to check assumed years to breast-height and years to green-up. Other data can be used to check juvenile height growth curves or the juvenile height assumed with site index curves.
2) **Ingress patterns** – This data can be used to assess planting requirements and expected species composition.
3) **Growth following different silviculture treatments** – This data will not provide information on treatment response[16], but will provide feedback and demonstrate growth trends following various treatments.
4) **Stand-level details required to assign yield curves for timber supply** – The full-measure plots can be post-stratified and summarized by analysis units to provide statistically-defensible information to generate yield curves for timber supply analysis.
5) **Data on SFM indicators** – This includes data to check site productivity (early height growth), presence of snags and shrubs. A summary of the data provided on SFM indicators is presented in Appendix III.

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[14] Where site trees are less than 1.3 m in height they must be selected by height as opposed to DBH. Generally, it is more efficient to select site trees in young stands based on height and in older stands based on DBH. The VRI procedure is to choose trees based on DBH (Section 3.9.3). Site trees could be tagged on all or a subset of plots and the tagged trees could be re-measured in subsequent surveys to examine how site trees changes over time and how this influences site index estimates.

[15] If brush is a significant management issue, then surveys should be done at the same time of the year to ensure consistent % cover estimates.

[16] Treatment response is defined as the incremental gain (or loss) due to the treatment. It is the growth in the treated stands minus the growth that would have occurred if the stand had not been treated.

5. RECOMMENDATIONS

As a result of this analysis and discussions with the licensees and MOF and MSRM stakeholders, we recommend:

1) A 3 to 4 km monitoring grid size be used. The final choice of grid size will depend on funding and the level of detailed data needed. If possible, we recommend choosing a 3.6 km (or smaller) grid size to allow for sufficient plots for post-stratification into major species groups.
2) If the G&Y monitoring program is expanded into mature stands, it should be coordinated with VRI Phase II ground sampling.
3) Early stand establishment and stand dynamics be monitored with full-measure silviculture survey plots. This will provide a large database that can link silviculture history and ecological data to examine trends in stand development. This can be complimented with well-designed trials to determine cause and effect relationships.
4) G&Y monitoring plots provide some of the data necessary to calibrate G&Y models. However, calibrating the models requires a collaborative effort needed to develop a mixedwood growth model. One of the first strategic decisions the licensees need to consider is whether the work already completed to calibrate TASS should be used or whether a new model should be developed. It is also important to determine the appropriate scope for collaborative work to ensure that local issues are adequately addressed. The proposed G&Y monitoring plots could provide a portion of the data required for model calibration. Additional data from designed experiments (i.e., WESBOGY trials) and natural stands will be required.

APPENDIX I – GENERAL INFORMATION ON MONITORING

WHAT IS MONITORING?

The term “monitoring” is widely used and is very ambiguous. The term “monitoring” is generally used to describe the process of checking or regulating some defined activity. It is also used interchangeably with the word “measuring”. The literature is filled with numerous kinds of “monitoring”, for example: adaptive monitoring, biodiversity monitoring, change monitoring inventory, compliance monitoring, ecosystem monitoring, effectiveness monitoring, environmental monitoring, fertilizer application monitoring, fertilizer response monitoring, forest health monitoring, forest monitoring, growth and yield monitoring, habitat monitoring, herbicide application monitoring, implementation monitoring, silviculture monitoring, trend monitoring, validation monitoring, etc. So the bottom line is, don’t worry what a monitoring program is called, focus on what is being done and why. What are the objectives? Where can the results be applied? How can the results be used?

Under the principles of SFM, monitoring is defined as the periodic measurement and assessment of change of an indicator, where an indicator is a variable used to report progress towards achieving a goal. Goals are broad, general statements that describe a desired state or condition related to one or more forest values.[17] In this context, two broad categories of monitoring can be recognized. The first, which may be referred to as “administrative monitoring”, checks that planned SFM activities are implemented (i.e., did we do what we said we were going to do?). An example is monitoring to ensure conformance with established visual quality objectives. Most administrative monitoring can be carried out internally by individual licensees.

The second category of monitoring may be referred to as monitoring the state of the forest, which includes activities that measure timber and non-timber variables over time. **G&Y monitoring**, which is the process of checking G&Y estimates for a defined population, is in this broad category. Monitoring the state of the forest requires a long-term commitment to establishing and re-measuring plots over time. To be cost-effective, it is best addressed as a joint venture among licensees.

Some of the variables a program designed to monitor the state of the forest could track include volume, wood quality, species composition, site productivity, and coarse woody debris.

Monitoring is a key process in adaptive management. It is the feedback loop that provides information for continuous improvement. The level of success in achieving objectives can be evaluated, and planning and management activities can be improved accordingly.

LINKS BETWEEN G&Y MONITORING AND OTHER DATA COLLECTION PROGRAMS

Monitoring the state of the forest requires permanent sample plots (PSPs) and associated establishment and re-measurement costs. Field costs[18] for plot establishment on other G&Y monitoring projects have ranged between $1,500 - $2,000/plot. Plot establishment costs are a function of access and the number of variables to be measured. Costs increase significantly if a single plot cannot be established in one

[17] These are the Canadian Standards Association CAN/CSA-Z808/809-96 definitions.

[18] Field costs include planning (hiring crews, arranging transportation, equipment, etc.), crew time, helicopter time where necessary, training and quality assurance, and data entry.

day. In addition to field costs, there are costs for sample plan development, data analysis, and reporting. Given the expense of plot establishment, it is prudent that the data collection is closely linked to the business needs, and that the data collected be used for as many purposes as possible. The following outlines potential linkages between a monitoring program and other data collection programs.

VRI Phase II Ground Plots

PSPs established for G&Y monitoring purposes could be used as a portion of the plots established for VRI Phase II ground sampling. Data from fixed area PSPs and variable radius temporary sample plots (TSPs) currently established for VRI Phase II can be combined. Single fixed area PSPs are less efficient[19] for estimating current volume than the VRI Phase II prism plot cluster, but if the plots are already established, they could be used to reduce the number of Phase II plots needed to be established. Theoretically, inventory and G&Y monitoring plots should be kept separate so that the G&Y monitoring plots provide an independent check of the inventory and inventory projections. Practically, the implications of using plots for both inventory and G&Y monitoring should be minimal if the monitoring plots make up a small portion of the inventory plots and the cost savings offsets these minimal implications.

For the Fort St. John TSA, the G&Y monitoring plots will make up all of the VRI Phase II ground plots in managed stands. This means the G&Y monitoring data can be used to check growth projections, but cannot be used to conduct an independent check of future yields. There will be a small chance that the G&Y monitoring plots will give an estimate of yield significantly removed from the true value for the area, and this situation will persist over time. For example, if the G&Y monitoring plots happen to under-estimate the true yield at time 1, they will likely under-estimate the true yield at time 2 while the observed growth rates will likely be representative of the area. An independent check of yields can be carried out at any time in the future with a set of temporary plots randomly or systematically established to represent the population of interest.

Developing Growth Models

BC has a long history of establishing and re-measuring PSPs[20] to develop and maintain G&Y models. Most of these PSPs were subjectively[21] located in natural and treated stands, or established as part of designed experiments. G&Y monitoring plots could be used to augment the data sets used for model development. There is risk to doing this as it could result in incorrect conclusions from monitoring. This risk is a function of the degree to which the monitoring data have influenced the model. For example, the risk would be highest where most of the same data used to develop a model (e.g., VDYP) were also used to the check the estimates from the model. Ideally, completely independent PSPs would be used to develop and check models, however, the costs of maintaining two independent sets of plots is likely prohibitively expensive and unnecessary.

[19] Empirical evidence from TFL 37 suggests that the single CMI plot is approximately 30% less efficient for estimating current volume than the VRI Phase II prism plot cluster. That is, sampling for net volume using the single CMI plot would require 30% more plots than would the five-point VRI cluster, to attain the same target sampling error.

[20] For example, the Growth Natural Program.

[21] Plots purposely established in fully stocked portions of stands. Monitoring plots will be randomly or systematically located.

In the Fort St. John TSA, models need to be developed for mixedwood stands. Most provincial G&Y models (e.g., TASS, VDYP7, and PrognosisBC) are developed using data from a range of areas and stand conditions. Consequently, the risk of a model projection being largely influenced by the data from any given management unit is low. It should be noted that other types of modeling data (e.g., experimental plots to determine treatment responses) are still needed in addition to plots established for monitoring and model development.

Site Index Adjustment (SIA)

Many TFLs and most Innovative Forestry Practices Agreement (IFPA) areas in the province have chosen a statistical approach to provide unbiased estimates of potential site index (PSI) for yield projection in PHR stands in timber supply analysis. The data are collected from randomly selected plots across the management unit and used to adjust preliminary estimates attached to each polygon for the entire management unit. This approach has been widely used by industry (on more than 20 land bases) and is accepted for generating managed stand yield tables for application in timber supply projections.

A G&Y monitoring program does not provide enough samples in suitable stand types to complete an SIA project. However, data from G&Y monitoring plots can be used for this purpose. Using data from the monitoring plots to develop the SIA theoretically compromises the independence to monitor the site index estimates over time. However, this potential problem is probably not of practical significance if the proportion of G&Y monitoring plots in the overall sample used for SIA is low.

Site Index-Biogeoclimatic Ecosystem Classification (SIBEC).

Data from all suitable PSPs should be used to contribute to the provincial SIBEC database. Data from G&Y monitoring PSPs are probably more suitable for the SIBEC database as they will be from randomly or systematically located plots as opposed to the current policy of subjectively locating SIBEC plots.

Predictive Ecosystem Mapping (PEM)

G&Y monitoring plots could be used to provide point estimates of site series to check PEM estimates of site series. However, the observations from this program should be supplemented with many more samples to achieve the objective.

APPENDIX II – DETAILED PROJECTIONS OF FUTURE PLOT DISTRIBUTIONS

Table 6. Estimated distribution of plots by detailed species composition, grid size and year

	Grid Size (km)					
	3	3.2	3.4	3.6	3.8	4
			2005			
Deciduous	10	9	8	7	6	6
Mixedwood AtPl	2	2	2	1	1	1
Mixedwood PlAt	0	0	0	0	0	0
Mixedwood AtSx	15	13	12	10	9	8
Mixedwood SxAt	16	14	12	11	10	9
Pl > 80%	3	3	2	2	2	2
Pl leading conifer	4	4	3	3	2	2
Sw > 80%	15	13	12	10	9	8
Sw leading conifer	8	7	6	6	5	5
Total	*73*	*64*	*57*	*51*	*45*	*41*
			2015			
Deciduous	10	9	8	7	6	6
Mixedwood AtPl	4	4	3	3	2	2
Mixedwood PlAt	2	2	2	1	1	1
Mixedwood AtSx	18	16	14	13	11	10
Mixedwood SxAt	18	16	14	13	11	10
Pl > 80%	8	7	6	6	5	5
Pl leading conifer	4	4	3	3	2	2
Sw > 80%	29	25	23	20	18	16
Sw leading conifer	10	9	8	7	6	6
Total	*103*	*91*	*80*	*72*	*64*	*58*
			2025			
Deciduous	25	22	20	17	16	14
Mixedwood AtPl	8	7	6	5	5	4
Mixedwood PlAt	5	5	4	4	3	3
Mixedwood AtSx	22	20	17	16	14	13
Mixedwood SxAt	22	20	17	16	14	13
Pl > 80%	16	14	12	11	10	9
Pl leading conifer	11	10	9	8	7	6
Sw > 80%	37	33	29	26	23	21
Sw leading conifer	15	13	12	10	9	8
Total	*162*	*142*	*126*	*112*	*101*	*91*
			2035			
Deciduous	56	49	43	39	35	31
Mixedwood AtPl	15	13	12	11	9	9
Mixedwood PlAt	10	9	8	7	6	6
Mixedwood AtSx	31	28	24	22	20	18
Mixedwood SxAt	27	24	21	19	17	15
Pl > 80%	26	23	20	18	16	14
Pl leading conifer	19	17	15	13	12	11
Sw > 80%	45	40	35	31	28	25
Sw leading conifer	22	19	17	15	14	12
Total	*251*	*220*	*195*	*174*	*156*	*141*
			2045			
Deciduous	86	75	67	60	53	48
Mixedwood AtPl	23	20	18	16	14	13
Mixedwood PlAt	15	13	11	10	9	8
Mixedwood AtSx	40	35	31	28	25	23
Mixedwood SxAt	32	28	25	22	20	18
Pl > 80%	36	32	28	25	22	20
Pl leading conifer	27	24	21	19	17	15
Sw > 80%	53	47	41	37	33	30
Sw leading conifer	29	25	22	20	18	16
Total	*340*	*299*	*264*	*236*	*212*	*191*

Table 7. Estimated number of plots to establish and re-measure by year on a 3 km grid. Total cost is based on $2,500 for establishment and $1,000 for re-measurement.

		Re-measurement				Total
Year	Establish	1st	2nd	3rd	4th	Cost
2003	25					$62,500
2004	24					$60,000
2005	24					$60,000
2006	2					$5,000
2007	1					$2,500
2008	3					$7,500
2009	0					$0
2010	2					$5,000
2011	8					$20,000
2012	4					$10,000
2013	2	25				$30,000
2014	8	24				$44,000
2015	0	24				$24,000
2016	0	2				$2,000
2017	4	1				$11,000
2018	4	3				$13,000
2019	4					$10,000
2020	6	2				$17,000
2021	7	8				$25,500
2022	8	4				$24,000
2023	9	2	25			$49,500
2024	9	8	24			$54,500
2025	9		24			$46,500
2026	9		2			$24,500
2027	9	4	1			$27,500
2028	9	4	3			$29,500
2029	9	4				$26,500
2030	9	6	2			$30,500
2031	9	7	8			$37,500
2032	9	8	4			$34,500
2033	9	9	2	25		$58,500
2034	9	9	8	24		$63,500
2035	9	9		24		$55,500
2036	9	9		2		$33,500
2037	9	9	4	1		$36,500
2038	9	9	4	3		$38,500
2039	9	9	4			$35,500
2040	9	9	6	2		$39,500
2041	9	9	7	8		$46,500
2042	9	9	8	4		$43,500
2043	9	9	9	2	25	$67,500
2044	9	9	9	8	24	$72,500
2045	9	9	9		24	$64,500
2046	9	9	9		2	$42,500
2047	9	9	9	4	1	$45,500
2048	9	9	9	4	3	$47,500
2049	9	9	9	4		$44,500
2050	9	9	9	6	2	$48,500
2051	9	9	9	7	8	$55,500
2052	9	9	9	8	4	$52,500

Table 8. Estimated numbers of plots with yield data (one measurement) or growth data (multiple measurements) over time.

Grid Size (km)	Plots with data to compare:				
	Yield	Growth for:			
		10 yrs	20 yrs	30 yrs	40 yrs
			2005		
3.0	73				
3.2	64				
3.4	57				
3.6	51				
3.8	45				
4.0	41				
			2015		
3.0	103	73			
3.2	91	64			
3.4	80	57			
3.6	72	51			
3.8	64	45			
4.0	58	41			
			2025		
3.0	162	103	73		
3.2	142	91	64		
3.4	126	80	57		
3.6	112	72	51		
3.8	101	64	45		
4.0	91	58	41		
			2035		
3.0	251	162	103	73	
3.2	220	142	91	64	
3.4	195	126	80	57	
3.6	174	112	72	51	
3.8	156	101	64	45	
4.0	141	91	58	41	
			2045		
3.0	340	251	162	103	73
3.2	299	220	142	91	64
3.4	264	195	126	80	57
3.6	236	174	112	72	51
3.8	212	156	101	64	45
4.0	191	141	91	58	41

APPENDIX III – PROVIDING DATA ON SFM INDICATORS

Table 9. Data for SFM indicators developed for the Fort St. John TSA provided by a network of systematically established G&Y monitoring plots.

Indicator	Target	Data Provided	VRI/CMI Cards
4. Snags/Cavity Sites	4.1 Establish a minimum of 6 snags and/or merchantable live trees (i.e., potential cavity sites) per hectare, as averaged over the total are harvested annually.	Number of snags and merchantable live trees per hectare. The issue here is the high variability resulting in low precision (wide confidence interval). Most of the plots will have 0 snags and a few will have 1 or 2.	Tree Details (TD)
5. Coarse Woody Debris Volume (relative %)	5.1 Maintain 50%+ of pre-harvest levels as measured in representative monitoring plots.	Gross volume of coarse woody debris by decay class. The issue will be whether there are sufficient plots to post-stratify into the strata developed for CWD target retention ranges. If the sample size is insufficient, the plots could still be used as part of the total sample required.	Coarse Woody Debris (EW) Coarse Woody Debris (EC)
7. Shrubs	7.1 Evaluate and determine baseline shrub levels (species diversity, distribution, and abundance) across seral stages and forest types.	Biogeoclimatic site series, successional stage, % cover and heights for trees, shrubs, herbs and mosses. Re-measurements will provide data on the changes over time. The issue will be whether the sample size is sufficient to allow for the required post-stratification.	Ecological Description 1 (EP) Ecological Description 2 (ED) Tree and Shrub Layer (ET) Herb and Moss Layer (EH) Succession Interpretations (EO)
15. Long term harvest level measured in m^3/yr	15.1 Harvest at a rate that does not adversely affect the long-term harvest level.	Growth & yield data for managed stands that can be used to check the accuracy of yield curves used to project managed stands in timber supply.	Tree Details (TD) Tree Loss Indicators (TL) Small Tree, Stump, and Site Tree Data (TS)
16. Site index	16.1 Post-harvest site index will not be less than pre-harvest.	Estimates of site index from monitoring plots can be used to check current inventory site indices and compare to pre-harvest site indices. The sample size should be sufficient to determine across the population of regenerated stands if the site indices are the same, lower or higher than pre-harvest site indices. Data on site tree height growth can be compared to height growth curves (site index curves) to check that the site index curves accurately reflect site tree height growth.	Small Tree, Stump, and Site Tree Data (TS)
21. Mean annual increment	21.1 Maintain or increase MAI for the TSA over time.	Growth & yield data for managed stands that can be used to provide a representative sample of the MAI in managed stands (15 years post-harvest) over time.	Tree Details (TD) Tree Loss Indicators (TL) Small Tree, Stump, and Site Tree Data (TS)
22. Total growing stock	22.1 Analyze and determine target range for growing stock (THLB and NHLB)	Growth & yield data for managed stands that can be used to check the accuracy of yield curves used to project growing stock in managed stands in the THLB.	Tree Details (TD) Tree Loss Indicators (TL) Small Tree, Stump, and Site Tree Data (TS)

Table 10. Data for SFM indicators provided by a network of systematically established and re-measured silviculture survey plots.

Indicator	Target	Data Provided
4. Snags/Cavity Sites	4.1 Establish a minimum of 6 snags and/or merchantable live trees (i.e., potential cavity sites) per hectare, as averaged over the total are harvested annually.	Number of snags and merchantable live trees per hectare could be determined if snags and merchantable live trees were recorded on the plots. The issue here is the high variability resulting in low precision (wide confidence interval). Most of the plots will have 0 snags and a few will have 1 or 2.
7. Shrubs	7.1 Evaluate and determine baseline shrub levels (species diversity, distribution, and abundance) across seral stages and forest types.	Percent cover of shrub species could be recorded and summarized by forest type.
16. Site index	16.1 Post-harvest site index will not be less than pre-harvest.	The plots will provide a large observational database on early height growth that can be compared to juvenile height growth curves or assumed early height growth patterns from site index curves used in timber supply.
15. Long term harvest level measured in m^3/yr	15.1 Harvest at a rate that does not adversely affect the long-term harvest level.	Plot data can be post-stratified by analysis units and used to assign appropriate yield curves for timber supply analysis.

APPENDIX IV – FIELD SAMPLING METHODS

OVERVIEW

For the most part, Ministry of Sustainable Resource Management Monitoring procedures should be followed to establish the plots. This appendix outlines proposed changes to these procedures (by VRI/CMI card number) for review and consideration for use in the Fort St. John TSA. It should be noted that any changes require modification of the standard compilation procedures.

1 Header Card (CH)

Plot number – There are four spaces to enter a plot number on this card. It is recommended that plot numbers incorporate the UTM coordinates of the plot to ensure unique plot numbers over time. This also allows for easy location of the plot. A plot number based on UTM coordinates could be recorded in the notes section. A sequential plot number (for plots established in any given year) could be entered in the plot sample # field. This information along with the date of establishment will be stored in the database, allowing plot XXXX-XXXX to be cross-referenced as the Yth plot established in year Z.

2 Compass Card (CP)

Complete following CMI procedures.

3 Cluster Layout (CL) (Version 99/3)

Complete following CMI procedures.

4 Range Sampling (RS) Shrub Transect #1

Complete following CMI procedures.

5 Range Sampling (RS) Shrub Transect #2

Complete following CMI procedures.

6 Coarse Woody Debris (EW) Transect #1

Complete following CMI procedures.

7 Coarse Woody Debris (EW) Transect #2

Complete following CMI procedures.

8 Tree Details (TD)

Regeneration plot radius – The regeneration plot radius is changed from 2.5 m to 3.99 m to be compatible with full-measure silviculture survey plots previously established at the same center point.
Height to live crown

CMI procedures specify recording height to live crown to the nearest m. For this project, since we are measuring small trees, record to the nearest decimeter. For example, 0.4 m is entered as 04 in columns 21 and 22.

Call Grading is not completed.

9 Tree Loss Indicators (TL)

Complete and enter following CMI procedures with the exception of stem mapping.

10 Small Tree, Stump and Site Tree Data (TS)

Top height tree (T) – Measured as per CMI standards.

Leading (L) and second (S) species – Do not determine prior to selecting site trees. The age of the largest diameter, dominant or co-dominant, tree of each species in each quadrant is measured. If the largest diameter tree of a given species (coded as "S" tree) is not suitable for height and age, the next largest diameter tree suitable for height and age will be selected (and coded as "O" tree). If a site tree is between 4 and 9 cm DBH, outside the Small-tree plot but inside the Main plot, this site tree will be tagged and the height will be recorded in the site tree section on Card 10.

11 Auxiliary Plot Card (TA)

Not used.

12 Ecological Description 1 (EP)

Complete following CMI procedures.

13 Ecological Description 2 (ED)

Complete following CMI procedures.

14 Tree and Shrub Layers (ET)

Complete following CMI procedures except use the 11.28 m radius plot was instead of a 10.0 m radius plot.

15 Herb and Moss Layers (EH)

Complete following CMI procedures.

16 Succession Interpretations (EO)

Complete following CMI procedures.