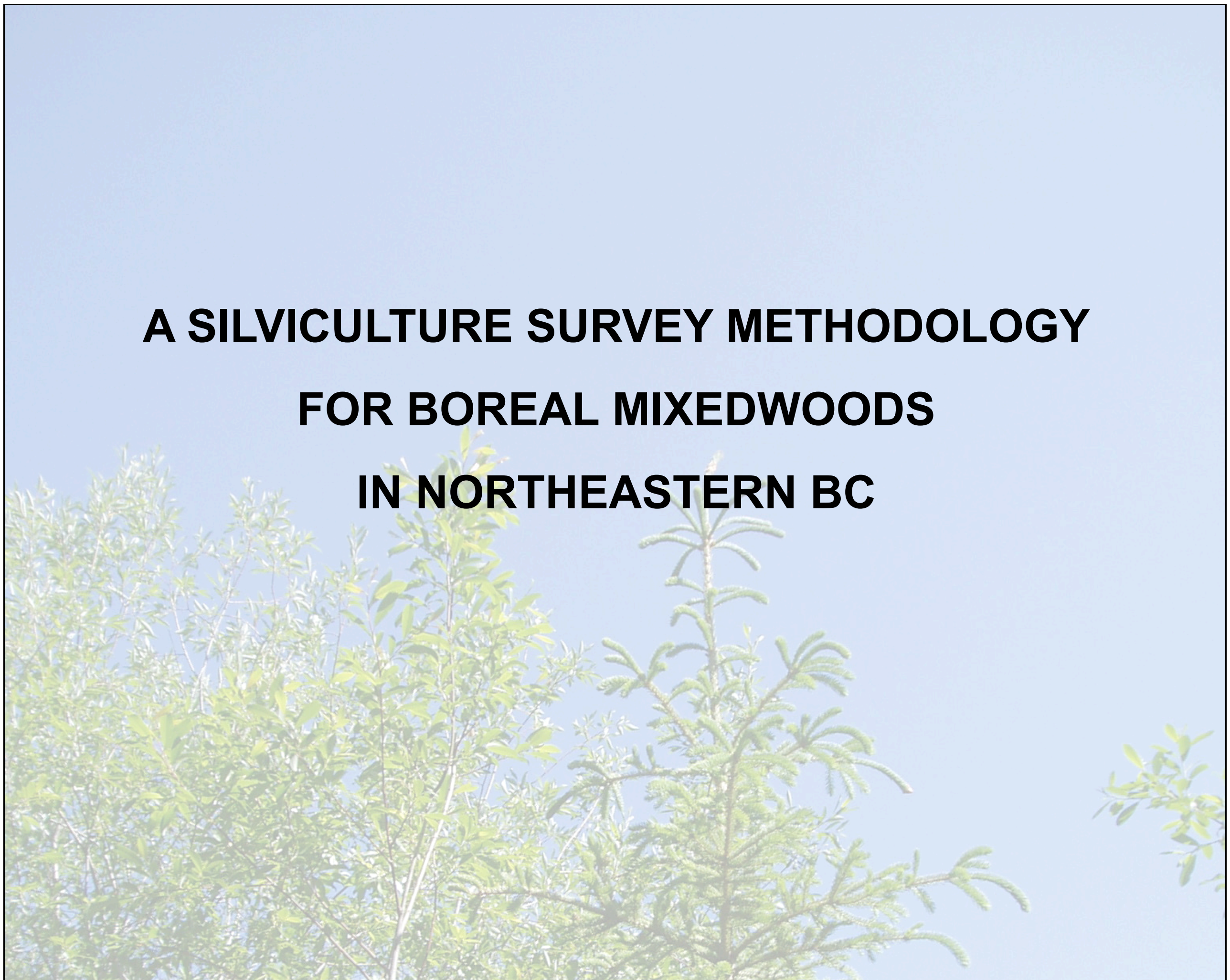

A SILVICULTURE SURVEY METHODOLOGY FOR BOREAL MIXEDWOODS IN NORTHEASTERN BC

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The layout of this document follows closely that of an earlier document produced by J.S. Thrower and Assoc. Ltd. that describes a similar survey procedure. Some portions of the surveys are identical, and in such cases text describing field procedures has been copied verbatim. Even where text has not been copied, it should be recognized that the current survey procedure builds upon the work of these and other authors. Their precedents are appreciated.

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1.0 INTRODUCTION

The purpose of this document is to outline a survey and compilation procedure for the assessment of post-harvest spruce-aspen mixedwood stands where the spruce component consists primarily of planted trees. The procedure is based on extensive modeling of mixedwood stand development, and uses survey outcomes to predict future yields and the partitioning of that yield into conifer and broadleaved components. The procedure is initially targeted at satisfying the management criteria for intimate mixtures of spruce and aspen as identified in the Sustainable Forest Management Plan for the Fort St. John Pilot Project. However, it should be generally applicable to any post-harvest juvenile, even-aged mixture of white spruce and trembling aspen across the boreal forest of BC and nearby regions of other jurisdictions.

2.0 MIXEDWOOD SURVEY

2.1 Mixedwood Survey Objectives

The goals of the survey are to:

1. Describe stand characteristics in sufficient detail to estimate the Predicted Mean Volume (PMV) at age 80 along with the volume breakdown (composition) by species group (conifer versus broadleaved).
2. Contrast PMV to a threshold percentage of the theoretical maximum achievable volume – the target mean volume (TMV) for a stand of the same species composition.
3. Produce inventory labels
4. Identify areas that would potentially benefit from silvicultural treatments.

2.2 Mixedwood Survey Overview

The key components of the mixedwood survey are:

1. The survey in its current form can be applied to even-aged mixtures of white spruce and trembling aspen, with aspen also being an analogue for cottonwood. Minor components of other species such as lodgepole pine and paper birch can be tolerated.
2. Stands are surveyed approximately 15 years after harvest to estimate the predicted mean volume (PMV) at age 80, and the percentage of that volume produced by conifer species (mainly spruce).
3. Sample plots for stocking (quadrats) are located at 25 m intervals on strip lines spaced 100 m apart, based on UTM coordinates (NAD 83). Quadrats are 10 m^2 in area (1.78 m radius).
4. Quadrat plots are classified based on the presence or absence of trees by species class and (for conifers) free growing status *relative to non-tree competing vegetation*:
    a) Null - plot is outside the net area to be reforested (NAR)

   b) NP
   c) Unstocked, stockable
   d) Conifer, well growing
   e) Conifer, impeded
   f) Broadleaved tree
   g) Both conifer and broadleaved; conifer well growing
   h) Both conifer and broadleaved; conifer impeded

5. Enhanced plots are located on a 200 m grid (every eighth sample point on alternating strip lines). Enhanced plots are 100 m^2 (5.64 m radius) in size and are sampled in addition to the quadrat on the same point.
6. Measurements in enhanced plots include:
   a) Site Series
   b) % Cover of the tree layer and composition of the understorey
   c) Height and age of the dominant and co-dominant trees
   d) Site index

2.3 Target Population

The target population to sample in a given year is the NAR created from harvesting 15 years previously, where the intention was to reforest with intimate or micro-scale mixtures of spruce and aspen. While the intent is to always survey stands at age 15, the predictive models are not significantly affected by assessment ages that deviate by at least up to 5 years.

2.4 Office Procedures

2.4.1 Map & Previous Data

A Silviculture Prescription (SP) map (or equivalent) should be used to develop the plot locations of the stand survey and should be updated following each survey. This map should show block boundaries, NP areas, non-commercial cover (NCC), wildlife tree patches (WTP's), riparian management areas (RMA's), permanent access structures and temporary roads. The surveyor should be familiar with the block history.

2.4.2 Office Stratification

Prior to field sampling, the following information should be transferred to the survey map:

1. NAR boundary
2. Standards unit boundaries from the SP (or equivalent) map

Standards units can be combined if they have the same site index and the same preferred and acceptable (p+a) species.

2.4.3 Plot Locations

Strip lines are located at 100 m intervals. Under most conditions, strip lines can be positioned on a UTM grid (NAD 83) at even 100 m intervals (last two digits of either the northing or easting are 00, depending on whether the strips are oriented E-W or N-S respectively). Quadrats are spaced at 25 m intervals on the strip lines, with enhanced plots at 200 m intervals on alternating strips (Fig 1). In keeping with conventions for other surveys, enhanced plots should be placed where both the northing and easting coordinates are even multiples of 200 m (000, 200, 400, 600 or 800). For both quadrat and full measure plots, allowance should be made at the office stage for the possibility of grid points that appear to be outside the NAR according to mapped boundaries, but are found to be within the NAR in the field.

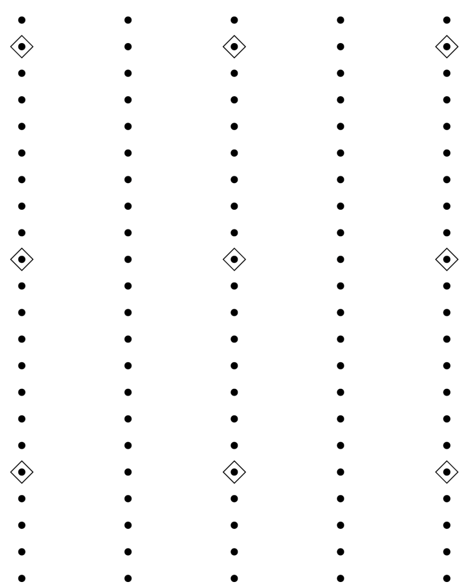

Figure 1. Strips and Plots.

Quadrat plots are located at 25 m intervals on strips lines spaced 100 m apart. Full measure plots are located at 200 m x 200 m grid points, corresponding to every eighth quadrat on alternating strip lines.

In some cases, it will be inappropriate to run strip lines on a N-S or E-W bearing. The classic case is where linear features affecting stocking have been created through management actions. Such cases can lead to significant bias in survey outcomes, as the probability of any one plot falling within a particular stocking condition are affected by the pattern. There are two options in such cases, depending on the nature of the pattern:

1. If the striped pattern has irregular stripe widths or the stripes do not follow straight lines, strip lines can be run in either the N-S or E-W direction, depending which is closest to being perpendicular to the stripes. Plots are placed at the standard intervals.

2. If the striped pattern has regular stripe widths and stripes follow straight lines, strip lines can be run as in option 1 above, but plots must be spaced at irregular intervals. This can be achieved either by
    a. plotting each successive quadrat interval as a random distance between 4 and 46 m (a range from 0 to 50 would allow for overlapping plots which is less than desirable), or
    b. starting with a regular 25 m interval, and adding a random distance along the strip line ranging from –23 to +23 m.

    In both of these cases, enhanced plots should be placed not on regular grid points but at every eighth quadrat on alternating strips.

2.5 Field Sampling

2.5.1 Quadrats versus Quadrants

An unfortunate source of potential confusion in this field procedure arises from the similar spelling and sound of two technical terms used in this versus other similar survey methods (e.g. Mean Stocked Quadrant or MSQ surveys):

> **Quadrat**: a fixed area plot, typically quite small, used as a measure of habitat in which individuals in a population are tallied to assess local distribution. The word quadrat originally referred to a rigid square frame used to define the limits of the plot, which in turn is derived from the squarish shape of the quadrate bone in the skulls of birds or reptiles. In practice quadrats may be any shape but are most commonly square or circular (Oxford University Press 2005).
>
> **Quadrant**: one fourth of a circular plot that is subdivided by two diameters passing through the plot center and oriented to each other at right angles. In practice, each quadrant of a circular plot is considered as roughly equivalent to a quadrat (as in MSQ surveys). One important difference is that quadrant data is usually summarized at the plot level first before calculating stand level statistics. In such cases, the number of samples, n, is based on the number of plots rather than the number of quadrants. If quadrant level statistics are treated as discrete samples, problems are encountered with hypothesis tests because the quadrants are spatially correlated and are not independent (independence is a key assumption of many statistical tests).

2.5.2 Stratification

Prior to the survey, a walkthrough is required to complete the following:

1. Review block in the field and update the map. This may require identification and GPS location of unmapped natural features or new developments such as well sites and seismic lines.
2. Preliminary identification or confirmation of strata. Strata are areas greater than 2 ha with the same forest cover, site type, stocking class and treatment opportunity.

By the completion of the survey, the cutblock must be divided into confirmed strata (polygons), based on common local and Provincial criteria and subject to the following requirements:

1. Inventory labels for the polygon must accurately specify species composition and site index, as per section 4.7.1 of the *Surveys Manual*[1]
2. Areas with different TMV (if any) due to differences in moisture regime or other rationale must be delineated.
3. Areas with different stocking classes (NSR, SR and WG) must be delineated.
4. Areas with different mixedwood stand type classes (D, DC, CD and C) must be delineated
5. Areas with treatment opportunities must be delineated. If, during the survey, the surveyor identifies and stratifies an area 2 ha or larger that would benefit from further treatment (i.e. fill planting, control of non-crop vegetation), then the boundaries of the area must be transferred to the map. A description and rationale for the treatment must be provided.

Note: post-stratification based on grouping like plots on a map is not an acceptable practice and will not be tolerated under any circumstances.

2.5.3 Quadrats

Quadrats are milhectare (10 m^2 or 1.78 m radius) plots that are classified based on the presence of certain combinations of trees, productive capability and competitive environment. The classes are:

Null

Plot is outside the NAR; plot is not included in any subsequent summaries

Unstockable

No acceptable trees are present; plot is non-productive ground

Unstocked, stockable

No acceptable trees are present but plot is potentially stockable. Comments are required regarding potential reasons for no acceptable trees being present and feasibility of adding trees.

Conifer, well growing

The only acceptable trees present are conifers. At least one conifer is of an acceptable species, an acceptable size and condition, and is free from overtopping non-crop vegetation (see well growing definition below).

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[1] The Surveys Manual is available at: http://www.for.gov.bc.ca/hfp/publications/00099/Surveys/Silviculture%20Survey%20Procedures%20Manual-April%201%202009.pdf

Conifer, impeded

The only acceptable trees present are conifers. At least one conifer is of an acceptable species and is of acceptable size and condition, but all such trees are impeded by competition from non-crop vegetation (see well growing definition below).

Broadleaved tree

The only acceptable trees present are broadleaved.

Mixed; conifer well growing

Both acceptable conifers and acceptable broadleaved trees are present, and at least one conifer is free from overtopping tall shrubs (see free growing definition below).

Mixed; conifer impeded

Both acceptable conifers and acceptable broadleaved trees are present; all acceptable conifers are impeded by tall shrubs (see free growing definition below).

In addition to classifying the plot, record:

1. pest codes for any pests present, along with the number of live and dead trees affected.
2. an *ocular estimate* of the total number of trees by species (Sx, Pl, Bl, Sb, Lt, At, Ac and Ep).

<u>Conifer Tree Acceptability</u> – trees must be at least 30 cm tall to be tallied (unless otherwise defined in an SP or equivalent document), and must be free of insect or disease conditions that will prevent them from becoming merchantable-sized trees (minor growth limiting pests and deformities do not limit acceptability) - see FS 660.

<u>Broadleaved Tree Acceptability</u> – trees must be at least 150 cm tall and

a) the tree pith must not be laterally displaced more than 30 cm from the root crown pith, and
b) the tree must not originated from a cut stump (aspen and cottonwood), and
c) the tree must have at east one live leader, and
d) the tree must not have a wound that is greater than 10% of the stem circumference or greater than 10% of the stem length, and
e) the tree must not have any fungal or insect infection affecting tissues below the bark surface (visible without destructive sampling), and
f) the tree must not be browsed so as to limit its ability to become a crop tree.

Damage to trees where the tree is likely to overcome the damage and continue growing as a dominant or co-dominant tree should not limit the tree from being tallied.

Conifer well growing assessments –conifer trees are well growing if:

a) they meet the acceptability criteria above, and
b) they are at least 100% of the height of all herbaceous and grass competition within a 1 m radius cylinder, and
c) they are taller than shrub competition in three of four quadrants of a 1 m radius cylinder

It is important to recognize that broadleaved crop trees (aspen, cottonwood and birch) are ignored in well growing assessments for conifers – the competitive effects of these species are accounted for in a different fashion.

2.5.4 Enhanced Plots

In addition to the quadrat, enhanced sample points include a 100 m^2 (5.64 m radius) plot to collect BEC , site index and additional inventory label data:

- assess and record site series, complete with zone, subzone and variant
- estimate percent cover of the tree layer
- record percent cover and average height of non-crop vegetation by species; include any species that might compete with crop trees
- record mean height and age of dominant and co-dominant crop trees by species
- for each of the dominant conifer and broadleaved crop tree species in the stratum *for which growth intercept equations are available*, locate the fattest tree in the plot for potential use as a growth intercept sample tree. If a selected tree meets the acceptability criteria listed below, record the height and breast height age. If the fattest tree does not meet the acceptability criteria, use the second fattest tree. If the second fattest tree is also unsuitable, attempt to find a suitable site tree in a 100 m^2 plot centered on each successive quadrat until a suitable replacement is found.

To be suitable for growth intercept evaluations of site index, a tree must:

- have three or more years height growth above breast height, and
- have an undamaged stem with vigorous, relatively uniform height growth above breast height, and
- have vigorous and uniform ring width at breast height, and
- must not be directly overtopped by other trees or brush, and
- must be in a dominant or co-dominant position

3.0 SURVEY OUTCOMES – YIELD AND STAND TYPE

3.1 Overview

This free growing assessment procedure for intimate and micro-scale boreal mixedwoods is based on an analysis framework described by Farnden (2009a). This framework uses a combination of simulated surveys and projections of yield from existing growth models to build new simplified models using input parameters derived from silviculture survey data. Model outcomes include Predicted Mean Volume (PMV), Target Mean Volume (TMV) and Species Composition (Conifer Percentage of PMV). PMV is the predicted total yield at age 80, and TMV is a threshold percentage of the maximum potential yield for a stand of similar species composition.

3.2 Objectives

There are two primary objectives for predicting yields for mixedwood stands using silviculture survey data as predictive parameters:

1. Assessing compliance with statutory or contractual reforestation obligations
2. Assessing stand level contributions to landscape level management objectives

If the TMV exceeds the PMV for a stand or an area weighted collection of stands, the reforestation obligations are deemed to have been met. Compliance with landscape level species composition objectives are tracked by classifying each stand into a Mixedwood Stand Type class[2], and tracking the area reforested into each class in a ledger system (see Martin et al. 2002).

3.3 Model Development

Details on the generation and functioning of the models for calculating TMV and projected species composition are provided here for reference. While an understanding of the system is useful, in most cases field staff will rely on spreadsheets or custom programs to compile survey results and calculate the required outcomes.

Separate prediction models were developed for each 1 m increment of white spruce site index, covering a productivity range from SI_{50} = 13 to SI_{50} = 27. For each model, a set of 113 mixedwood stands (9 ha each) was generated using the following criteria:

- 9 levels of area coverage by aspen clones from 10 to 90% in 10% increments, where the aspen density varied randomly fro 10,000 to 16,000 trees/ha
- 4 levels of aspen density between clonal patches at 0, 50, 200 and 800 trees/ha
- spruce planted at 1400 trees/ha and three levels of survival: 30, 60 and 90%
- aspen site index was calculated from the spruce site index using a conversion equation provided by Nigh(2002):

$$SI_{At} = -4.768 + 1.253 \times SI_{Sw}$$

For each stand, yields were predicted using the Mixedwood Growth Model[3] (MGM), and surveys were simulated using the Silviculture Survey Simulator developed as part of the PhD work Farnden (2009b,c) at the University of BC.

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[2] Stand Type Classes: D = 0 to 20% conifer volume, DC = 20 to 50% conifer volume, CD = 50 to 80% conifer volume and C = 80 to 100% conifer volume.

[3] Mixedwood Growth Model (MGM): an individual tree, distance independent growth model developed at the University of Alberta for use in boreal mixedwoods. Information on the model can be accessed at http://www.ales2.ualberta.ca/rr/mgm/mgm.htm (as accessed April 2, 2009).

3.3.1 MGM Simulations

For each simulated 9 ha stand, a set of 36 sampled treelists was generated using randomly located 100 m^2 plots and used to generate a discrete yield curve. The 36 yield curves were then combined to generate a composite yield curve for the stand. Each sample treelist was assumed to represent local growing conditions, such that variation in competitive conditions throughout the stand would be appropriately represented in the predicted yields.

Stands were grown from the initial age of 12 years to a projected age of 80 years using BC site curves and merchantability limits set at a 12.5 cm dbh limit, 30 cm stump height and 10 cm minimum top diameter. No yield deductions were made for waste or decay.

3.3.2 Simulated Surveys

Surveys were simulated using survey algorithms built into the Silviculture Survey Simulator. For each stand, survey statistics were compiled from a set of 144 randomly located 10 m^2 quadrats, each of which was classified as:

1. Unstocked: no trees present
2. Aspen: at least 1 broadleaved tree present; no conifers
3. Spruce: at least one conifer tree present; no broadleaves
4. Mixed: at least one broadleaved tree and at least one conifer present

Survey summary statistics are simply the percentages of plots in each class (C_0, C_1, C_2 and C_3 respectively).

3.3.3 Model Fitting

Models for PMV and species composition (% spruce) are based on either on multiple linear regression using ordinary least squares (OLS), a complex variant of a Weibull function or a complex variant of a logarithmic function (Farnden 2009c):

PMV $= b_0 + b_1C_0 + b_2C_1 + b_3C_2$ for SI = 13 to 21

$= b_6 * \left(1 - e^{-b_4(b_0 + b_1C_0 + b_2C_1 + b_3C_2)^{b_5}}\right)$ for SI = 22 to 27

% Spruce $= 1 - e^{-b_4(b_0 + b_1C_0 + b_2C_1 + b_3C_2)^{b_5}}$ for SI = 13 to 18

$= b_4 + b_5 \log(b_0 + b_1C_0 + b_2C_1 + b_3C_2)$ for SI = 19 to 22

$= b_0 + b_1C_0 + b_2C_1 + b_3C_2$ for SI = 23 to 27

Where b_0 through b_6 are separate sets of coefficients for each model. C_3 is not utilized as it is redundant information. All models were fit using JMP version 8.0.1. Model parameters and fit statistics are provided in Tables 1 and 2.

Table 1. Coefficients and fit statistics for the models used to calculate PMV assuming discrete site index values. Separate models have been generated for different levels of site productivity based on 1 m increments of white spruce site index.

Sw SI_{50}	Y_{80}								
	b_0	b_1	b_2	b_3	b_4	b_5	b_6	R^2/I^2	RMSE
13	89.38	-74.63	-68.79	9.52				0.961	3.80
14	109.47	-90.22	-72.35	12.52				0.957	4.45
15	135.28	-110.34	-77.09	12.77				0.953	5.28
16	168.83	-136.33	-84.62	8.94*				0.946	6.49
17	212.86	-170.26	-94.54	-0.48*				0.9348	8.31
18	270.41	-214.11	-113.56	-17.50				0.928	10.51
19	338.82	-265.93	-136.47	-40.43				0.925	13.04
20	415.78	-323.60	-161.10	-68.23				0.9224	15.85
21	496.45	-382.77	-178.63	-97.47				0.9187	18.84
22	36.53	-15.413	-9.318	-7.419	1.772e-7	4.734	533.84	0.913	21.77
23	26.61	-10.244	-5.861	-5.0277	1.076e-7	5.372	589.8	0.909	23.58
24	8.544	-0.1417	-0.07340	-0.07096	1.336e-151	162.8	647.5	0.905	28.43
25	5.750	-1.0310	-0.4970	-0.5597	1.357e-10	14.08	702.6	0.892	27.24
26	2.829	-0.3355	-0.1802	-0.1834	2.516e-11	25.74	742.4	0.877	29.5
27	1.518	-0.001953	-0.001184	-0.001104	1.1953e-106	1741.7	787.56	0.875	30.47

Table 2. Coefficients and fit statistics for the models used to calculate yield-based species composition (% Spruce) assuming discrete site index values. Separate models have been generated for different levels of site productivity based on 1 m increments of white spruce site index.

Sw SI_{50}	Y_c							
	b_0	b_1	b_2	b_3	b_4	b_5	R^2/I^2	RMSE
13	1.1240	-0.6415	-1.1225	-0.2422	8.868	1.814	0.955	0.0349
14	0.8877	-0.5186	-0.9103	0.0938	6.024	1.360	0.945	0.0421
15	0.9351	-0.4746	-0.9621	0.4181	3.567	1.194	0.931	0.0498
16	1.1150	-0.4773	-1.1511	0.8132	2.059	1.087	0.914	0.0568
17	0.6057	-0.1881	-0.6284	0.6201	2.829	1.027	0.898	0.0628
18	0.5691	-0.0594	-0.5955	0.7979	2.101	1.040	0.888	0.0650
19	0.6052	0.0906	-0.4225	0.4346	0.9468	0.6249	0.888	0.0647
20	0.5753	0.1180	-0.3072	0.3447	1.020	0.8275	0.887	0.0650
21	0.5567	0.0724	-0.1515	0.1588	1.514	1.702	0.887	0.0645
22	0.7754	0.0124	-0.0264	0.0241	4.207	14.57	0.898	0.0618
23	0.5011	0.2052	-0.5115	0.4461			0.908	0.0580
24	0.5147	0.1647	-0.5400	0.4301			0.9181	0.0550
25	0.5399	0.1074	-0.5778	0.4021			0.9271	0.0520
26	0.5757	0.0587	-0.6158	0.3618			0.9324	0.0500
27	0.6273*	0.0268	-0.6551	0.3016			0.9320	0.0496

3.3.4 Spruce Site Index

Spruce site index is required for model selection. Several sources of site index are available, listed in order of preference:

1. growth intercept estimate for spruce using data from surveyed block
2. 2nd or later generation SIBEC estimate[4]
3. growth intercept estimate for spruce using data from nearby block on same site series and soil type
4. 1st generation SIBEC estimate
5. Pre-harvest inventory estimate

3.3.5 Brush Impacts

The growth model used to predict yields (MGM) is unable to explicitly model the effects of non-tree brush competition. The effects of these competitors must therefore be added in after the generation of the fitted models. Adjustments are based on the assumption that tall shrubs overtopping spruce will have a temporary effect on spruce growth, thus reducing spruce yields. This is handled within the survey system by:

a) Subdividing the classes of plots where conifers are present (C_2 and C_3) into those where at least one conifer is free of impeding competition from tall shrubs (mainly alder and willow) versus those where all conifers are impeded
b) Assuming that the impeding vegetation will, on average, result in a *10*% reduction of yield for the affected trees

For the impeded spruce plots, 10% are then transferred to the unstocked (C_0) category, and the remainder to the unimpeded spruce (C_2) category For the impeded mixed plots, *10*% are transferred to the aspen (C_1) category, and the remainder to the mixed (C_3) category.

3.3.6 Non-Productive Quadrats

Non-productive (NP) and null (plot center is outside of NAR) quadrats are treated as exclusive to the sampled population and are not included in the calculation of the percentage of plots in each stocking category.

3.3.7 TMV's

TMV is not fit as a model on its own, but is calculated using the PMV model. For TMV, the number of unstocked plots in excess of 5% are redistributed proportionately to the stocked classes (where 95% stocked plots is a theoretical upper ceiling) to determine a theoretical maximum yield. The threshold volume for acceptable regeneration performance is then set as some proportion of the theoretical maximum yield. For

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[4] Second generation and later estimates are recognized in the SIBEC tables by the inclusion of a standard error value.

example, the value set in the 2003 Sustainable Forest Management Plan for the Fort St. John Pilot Project is 0.95.

Example:

A stand has survey outcomes with C_0=8.1%, C_1=21.4%, C_2=15.4% and C_3=55.1%. In this case, there is 3.1% excess in the unstocked (C_0) class that must be redistributed to the other classes:

$C_{0(new)} = 0.05$

$C_{1(new)} = C_1 + C_1 * 0.031 \div (1-0.081) = 0.221$

$C_{2(new)} = C_2 + C_2 * 0.031 \div (1-0.081) = 0.159$

$C_{3(new)} = C_3 + C_3 * 0.031 \div (1-0.081) = 0.570$

To determine TMV using the 0.95 threshold from the Fort St. John SFMP, the calculation becomes

0.95 x PMV(0.05, 0.221, 0.159)

4.0 SURVEY OUTCOMES – INENTORY LABELS

Elements of the inventory label for reporting to the BC Ministry of Forests' Results database are determined as follows:

Species Composition: based on the total tally of trees by species in all quadrats:

$$Species\%_i = \frac{\sum Species_i}{\sum All\ \ Trees}$$

Height and Age: based on the estimates of the mean height and age of the dominant and co-dominant trees of the 1st and 2nd leading species from the enhanced plots.

Site Index: based on growth intercept estimates of the dominant species where available, otherwise using the best available alternate method.

Crown Closure: based on mean crown closure as estimated for each of the enhanced plots

Total Trees: based on the tally of trees within the quadrats

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