The Forestry Corp.

Mountain Pine Beetle Decision Support Tool Application Development

Prepared for: Foothills Growth and Yield Association

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EXECUTIVE SUMMARY

This report describes the detailed procedures of the Mountain Pine Beetle (MPB) Environment Decision Support Tool (DST) application development.

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1. Project Objectives

The Foothills Growth and Yield Association (FGYA) is implementing an important project to develop Decision Support Tools for forest management in a mountain pine beetle (MPB) environment. The project is sponsored by the Forest Resource Improvement Association of Alberta (FRIAA), the Foothills Research Institute and Alberta Sustainable Resource Development (SRD).

The objective of the FGYA MPB project is to identify the most common pine dominated stand structures across Alberta ecosites' range, modify their characteristics to emulate an MPB attack and potential subsequent management interventions, and project them forward in time using growth and yield models such as GYPSY and MGM.

2. Data and Input Matrix

2.1 Data Description

2.1.1 Surveyed PSPs in 2008

Based on a set of comprehensive criteria, a total number of 240 PSPs were selected for this project. From the total number of PSPs selected, 149 plots from 8 companies were surveyed in 2008. The number of plots surveyed for each company is presented in Table 1.

Table 1. Number and percent frequency of plots surveyed in 2008 by company.

Company	N Plots	Frequency %
BRL	5	3.4
CAN	4	2.7
HWP	13	8.7
MWF	4	2.7
SDA	4	2.7
SFP	5	3.4
SLS	3	2.0
SRD	111	74.5
Total	149	100.0

2.1.2 Variables Collected

Both quantitative and qualitative variables were collected during the 2008 field season. The collected data included measurements for trees (DBH $\geq$ 9.1 cm), saplings (trees < 9.1 cm in DBH and > 1.3 m in height), regeneration (trees < 1.3 m and $\geq$ 0.1 m in height), ecosite, non-tree vegetation, quantification of mountain pine beetle attack, arboreal lichens, and cone serotiny.

The tree information was obtained from the last re-measurement of the PSP. The plot size was represented by the actual PSP size. Age data by species were also obtained from previous PSP re-measurements. All other information was collected during the 2008 field season.

Sapling information was collected from a circular sub-plot centered on the PSP center with a radius of 5.64 m (100 m^2). Species, DBH, height, as well as the condition codes were recorded for each sapling.

Regeneration information as well as non-tree vegetation were collected from four circular 1.78 m radius plots (10 m^2) located in the four PSP quadrants. The count by five height classes was recorded for each species present in the plots.

All dead trees were recorded. The trees attacked by MPB were recorded in the entire PSP as well as the stage of the attack (green/red). The numbers of pitch tubes below and above 1.3 m were recorded.

In each quadrant, four trees closest to the center were used to assess the arboreal lichens and cone serotiny. One or two additional trees were added in some cases in order to include trees with evidence of MPB attack.

For non-tree vegetation, modal height, species, and percent cover were collected in the 4 regeneration plots.

2.2 Stand Classification

2.2.1 Strata Assignment

Stratum was determined as a function of ecosite and natural subregion (Table 2). The ecosite used in the stratification was the ecosite assessed in the field. Eight strata were defined in this project based on the ecosite and the natural subregion. Each of the sampled PSPs was assigned to one of the eight strata.

Table 2. Stratum summary.

Ecosite (and Edatopic) Type	Ecosite[1]	NSR[2]	Stratum Number
1. Bearberry / lichen/hairy wild rye (submesic / subxeric, medium - low)	b, c	Any	1
2. Labrador tea - mesic	d (c)	UF	2
(mesic - poor)	d (c)	LF	3
3. Billberry / cranberry / sarsaparilla / rhododendron	e (d)	SA/UF	4
(mesic - medium)	e (d)	LF	5
4. Honeysuckle / fern	f (e)	UF	6
(subhygric rich)	f (e)	LF	7
5. Labrador tea - hygric (hygric - poor)	h (f)	Any	8

1. Ecosites as classified by *Field guide to ecosites of west-central Alberta*, J.D. Beckinhham, I.G.W. Corns and J.H. Archibald, Can. For. Serv. Special Report 9, 1996. Equivalent classifications for southwestern Alberta are shown in brackets (*Field guide to ecosites of* southwestern *Alberta*, J.D. Beckinhham, G.D. Klappstein, and I.G.W. Corns, Can. For. Serv.)
2. Natural sub-regions (NSR): UF = Upper Foothills, LF = Lower Foothills, SA = Sub-alpine

2.2.2 Age Classification

Age class was determined based on the lodgepole pine total age from the PSPs data. Age class "1_50-100" was assigned to a plot if the pine total age was greater or equal to 50 years and smaller or equal to 100 years. If the pine total age was between 101 years and 140 years then age class "2_100-140" was assigned to the plot, while age class "3_140+" was assigned if the pine total age was greater than 140 years and smaller than 180 years.

2.2.3 Stand Structure

Based on the AVI field call, the sampled PSPs were grouped into single story (only overstory AVI field call) and two story stands (overstory and understory AVI field calls).

2.3 Input Matrix Framework

For each stratum, three age classes were defined as 50 to 100 year, 101 to 140 years and greater than 140 years. Growth model inputs were developed for the mid-point of each age class: 75 years, 120 years and 160 years.

There were 149 permanent sample plots sampled in 2008 across all the 8 strata and all three age classes. The sampled data were not evenly distributed across the 8 strata and did not represent a random sample of what the stands susceptible to mountain pine beetle attack might look like. Table 3 presents the distribution of the plots by strata, age class, and stand type (single or two story stands).

Table 3. Number of plots by stratum, age class, and stand type (single or two storey).

Stratum Soil	Age Class	Layers	N Plots	Percent
1	1_50-100	1	5	71
		2	2	29
	2_100-140	1	1	7
		2	13	93
	3_140+	1	5	83
		2	1	17
2	2_100-140	1	14	82
		2	3	18
	3_140+	1	5	100
3	1_50-100	1	2	100
	2_100-140	1	9	82
		2	2	18
	3_140+	1	1	100
4	1_50-100	1	10	100
	2_100-140	1	6	67
		2	3	33
	3_140+	1	1	33
		2	2	67
5	1_50-100	1	2	40
		2	3	60
	2_100-140	1	21	53
		2	19	48
6	2_100-140	1	2	50
		2	2	50
7	2_100-140	1	5	100
8	2_100-140	2	1	100
*Age classes not listed had no PSPs in the sample.				

Since the actual sampled data were deemed insufficient to characterize the strata – age class combinations, the following approach was taken to develop the range of inputs required by the project. A Conceptual Framework and a Data Based Framework were both developed and were used to create the growth model input matrix.

2.3.1 Conceptual Framework

The process of defining stand types was based on the 'Field Guide to Ecosites of West-central Alberta'. The guide was used to determine, by frequency of occurrence, the most common stand types in each of the 8 strata, and whether the stands in the 8 strata were single story or two story stands. Table 4 presents the developed matrix describing the most probable stand types in each stratum.

Table 4. Matrix summarizing the most probable stand types and stand structures by stratum.

Stratum	Age_Class	Stand Structure	Overstory	Understory	Stand Type
1	1, 2, 3	1 Layer	Pl		1
	1, 2, 3	1 Layer	Pl+Aw		2
	1, 2, 3	2 Layers	Pl	Sb	3
	1, 2, 3	2 Layers	Pl+Aw	Sb	4
2	1, 2, 3	1 Layer	Pl		5
	1, 2, 3	2 Layers	Pl	Sb	6
3	1, 2, 3	1 Layer	Pl		7
	1, 2, 3	2 Layers	Pl	Sb	8
4	1, 2, 3	1 Layer	Pl		9
	1, 2, 3	1 Layer	Aw+Pl		10
	1, 2, 3	1 Layer	Sw+Pl		11
5	1, 2, 3	1 Layer	Pl		12
	1, 2, 3	1 Layer	Aw+Sw+Pl		13
6	1, 2, 3	1 Layer	Pl		14
	1, 2, 3	1 Layer	Pl+Aw+Sw		15
7	1, 2, 3	1 Layer	Pl		16
	1, 2, 3	1 Layer	Aw+Sw+Pl		17
8	1, 2, 3	1 Layer	Sb+Pl		18

18 unique 'Stand Types' across the 8 Strata were determined and represent the most common 'typical' stand types and species compositions found in the 8 project strata.

An input matrix was developed to characterize the species composition in each stratum*age class*stand_structure combination. The matrix presents the species associations most likely to be found in any of these combinations, as well as the vertical distribution of the trees (single layer or two layers). The matrix was based on both the actual plot data and the 'Field Guide to Ecosites of West-Central Alberta'. When the data conflicted with the guide and the sample size was too small (1-4 plots) the species association described in the guide prevailed in the matrix building.

The actual data were compiled and summarized as a 'Data Based Framework' and used in generating the pre-attack inputs.

2.3.2 Data Based Framework

1. PSP Compilations

➢ Breast Height or Stump Height Age by Species

The breast height age or stump height age was recorded differently for each company according to the particular protocol used. The age measurements (breast or stump height) were taken within the plot or in the PSP's buffer at plot establishment. There are cases where age was measured at plot establishment and at re-measurements. Because of multiple age measurements, in each plot and for each species, the latest age measurements were used to calculate the mean breast height or mean stump height age.

Not all measured ages were used in the mean age calculations. The range of ages was restricted by species and plot as follows: if the individual age was smaller than the maximum age minus 20 years, that age was not used for the mean age calculations.

There were no conversions between breast height and stump height ages. For some plots, both mean stump age and mean breast height age were calculated where data were available. However, in the site index calculations, the mean stump age was used with one exception, plot 101-1, black spruce.

The mean age (stump or breast height) was grown from the year of age measurement to the year of the last PSP re-measurement to match the year of the calculated top height. The same method was applied for the FRIAA GYPSY validation project when the mean age of the PSP was compiled.

➢ Top Height

Only live trees (DBH ≥ 9.1 cm) were included in the top height calculation. The largest 100 trees by DBH per species and per hectare were used to calculate the top height. The exact number of trees in each plot is dependent on the PSP size.

➢ Site Index

Site index was calculated using GYPSY 2006 plot based equations. The mean breast height or mean stump height age together with the top height by species were used to calculate the site index. The mean age (breast or stump height) was grown forward in time until the last re-measurement when height was recorded. Where available, mean stump age was used to calculate site index. Where mean stump age was not available, breast height age was used to calculate the site index.

➢ Density

Based on the AVI field call, the sampled PSPs were grouped into single story (only overstory AVI field call) and two story stands (overstory and understory AVI field calls). The individual species were grouped into four species groups, similar to GYPSY groupings (Aw, Pl, Sb, and Sw).

The two story stands were split using the midpoint height between the overstory and understory AVI heights as taken from the AVI field call. For the two story stands, trees and saplings above the midpoint height were used to calculate overstory density, while trees and saplings below the midpoint height were used to calculate the understory density.

Mean densities were calculated by stratum and age class. For the two story stands, they were calculated for both the overstory and the understory layers.

Total age and site index were also compiled for each plot and species group with available data, and they were averaged by stratum and age class.

Due to missing age or stratum information, only 140 PSPs were used to compile the Data Based Framework.

2. Pre-Attack Stand Conditions

To avoid dealing with multiple growth trajectories within the same matrix row, that might potentially lead to completely different stand types for the same matrix row, the following approach was taken to create pre-attack inputs (Table 5):

➢ From the Data Based Framework the matrix row mean inputs (density, site index, total age) for the age class with the most plots measured was selected.

➢ Site index from the actual data was checked against the Ecosite Guide's site index and adjusted to match the range of productivities described by the guide (modified values are highlighted in Table 5)

➢ Densities were checked against Phase 3 Pl density tables and in some cases adjusted to match the Phase 3 densities (modified values are highlighted in Table 5)

➢ The density projections were compared with actual plot data to ensure that they were reasonable.

Table 5. Modified GYPSY inputs used to create the pre-attack stand conditions.

Stratum	Age Class	Stand Structure	Overstory	Understory	N Plots	Species	Data Based Inputs Density	SI	Total Age	Modified Inputs for GYPSY Density	SI	Total Age
1	1_50-100	1 Layer	Pl		5	PL	1,107	14.9	80.5	1,800	14.9	80.5
1	1_50-100	1 Layer	Pl+Aw		5	AW		13.9	65.5	540	13.9	65.5
						PL	1,107	14.9	80.5	1,260	14.9	80.5
1	2_100-140	2 Layers	Pl	Sb	13	PL	663	19.7	120.2	663	14.9	120.2
						SB	274	14.3	110.5	274	14.3	40.0
1	2_100-140	2 Layers	Pl+Aw	Sb	13	AW	64	19.3	132.3	64	19.0	132.3
						PL	663	19.7	120.2	663	14.9	120.2
						SB	274	14.3	110.5	274	14.3	40.0
2	2_100-140	1 Layer	Pl		14	PL	1,085	14.9	113.6	1,200	14.9	113.6
2	2_100-140	2 Layers	Pl	Sb	3	PL	983	14.9	113.6	983	14.9	113.6
						SB	100	7.4	98.0	100	7.4	98.0
3	2_100-140	1 Layer	Pl		9	PL	996	15.4	115.8	1,200	15.4	115.8
3	2_100-140	2 Layers	Pl	Sb	2	PL	100	15.4	115.8	1,000	15.4	115.8
						SB	70	14.9	118.5	70	14.9	118.5
4	1_50-100	1 Layer	Pl		10	PL	1,312	19.0	78.7	1,800	15.0	78.7
4	1_50-100	1 Layer	Aw+Pl		10	AW				600	18.0	78.7
						PL	1,312	19.0	78.7	1,000	15.0	78.7
4	1_50-100	1 Layer	Sw+Pl		10	PL	1,312	19.0	78.7	1,000	15.0	78.7
						SW	346	10.7	79.0	650	10.7	79.0
5	2_100-140	1 Layer	Pl		21	PL	1,022	18.2	113.3	1,022	18.2	113.3
5	2_100-140	1 Layer	Aw+Sw+Pl		21	AW	468	20.6	106.6	468	18.0	106.6
						PL	1,022	18.2	113.3	700	18.2	113.3
						SW	600	9.8	112.0	600	15.0	112.0
6	2_100-140	1 Layer	Pl		2	PL	1,186	17.9	110.7	1,186	17.9	110.7
6	2_100-140	1 Layer	Pl+Aw+Sw		6	AW				600	17.0	110.0
						PL	1,186	17.9	110.7	800	17.9	110.7
						SW	200			200	16.0	110.0
7	2_100-140	1 Layer	Pl		5	PL	494	16.3	118.5	700	18.0	118.5
7	2_100-140	1 Layer	Aw+Sw+Pl		5	AW	488	15.6	106.0	488	18.0	106.0
						PL	494	16.3	118.5	494	18.0	118.5
						SW	178	11.8	114.0	178	18.0	114.0
8	2_100-140	1 Layer	Sb+Pl		1	PL		15.2	107.7	1,200	15.2	107.7
						SB				1,200	11.0	107.0

The modified inputs in Table 5 were projected forwards and backwards using GYPSY and localized at 3 ages: 75 years, 120 years, and 160 years. These localized projection outputs (such as site index, density, BA, and top height) represent the pre-attack stand conditions at each age (midpoint of the age class). The pre-attack stand conditions were used to obtained Post Attack Stand inputs for both GYPSY and MGM projections through modifications appropriate for various combinations of MPB attack, salvage treatments and regeneration options as defined in the following section.

3. Post Attack Stand Inputs

This section describes the methods used to obtain the input matrix by stratum, age class, MPB attack levels, and treatment combinations to be used as starting conditions in a suite of growth and yield models (GYPSY and MGM). The inputs were built to describe a range of possible treatments following different levels of mountain pine beetle attack.

3.1 Projection Scenarios

3.1.1 Defining Levels of MPB Attack

Four levels of MPB attack were defined (0%, 25%, 50%, and 100% kill), and were assumed to occur in one unique kill-event.

3.1.2 Defining Salvage Treatment

Two levels of salvage treatment were defined:

> ➢ No: No removal of trees, no matter the degree of attack.

> ➢ Yes: Removal of all attacked trees, no matter the degree of attack.

3.1.3 Defining Regeneration Assumptions

The following assumptions were defined for regeneration:

> ➢ There is no pre-existing lodgepole pine natural regeneration in the stand prior to the attack

> ➢ All new regeneration of lodgepole pine following MPB attack is limited to those cases where some level of salvage is undertaken. The disturbed areas recruit natural Pine at rates observed in the FGYA RLP study; recruitment rates vary by stratum.

> ➢ In areas undisturbed by salvage, pre-existing regeneration (if present) continues to grow, but no new regeneration is recruited into the stand.

> ➢ Optional supplemental planting of pine is done where the MPB attack is followed by salvage operations.

3.1.4 Defining Silviculture Treatments

Optional scarification and site preparation to promote additional natural regeneration are available only after salvage in 100% MPB attack.

3.1.5 Projection Scenario

Based on combinations of 4 levels of MPB attack, 2 levels of salvage, 2 levels of planting, and two levels of site preparation, 11 scenarios were created for each stand type, age class and stratum combination selected for modeling (Table 6).

Table 6. Projection Scenarios.

Scenario Number	MPB Kill	Salvage	Natural Regen	Fill Plant	Site Prep	Scenario Type
1	0	No	No	No	No	1
2	25	No	No	No	No	2
3	25	Yes	Yes	No	No	3
4	25	Yes	Yes	Yes	No	3
5	50	No	No	No	No	2
6	50	Yes	Yes	No	No	3
7	50	Yes	Yes	Yes	No	3
8	100	No	No	No	No	2
9	100	Yes	Yes	No	No	3
10	100	Yes	Yes	Yes	No	3
11	100	Yes	Yes	Yes	Yes	3

* See section 3.2.2 for definition of Scenario Type.

The existing matrix with 18 stand types localized at three ages 75, 120, and 160 years representing three age classes: 50-100 years, 101-140 years, and over 140 years was considered appropriate as the basis for the projections. This generated 594 (=18 Stand Types X 3 Age Classes X 11 Scenarios) unique stands available for model projections.

3.2 Starting Conditions

3.2.1 Starting Conditions

The pre-attack stand inputs obtained from GYPSY projections and from the compiled regeneration data were modified using the intensity of the MPB attack and presence/absence of salvage operations to obtain the post-attack stand conditions.

1. Overstory and Understory

For Overstory and Understory, the pre-attack stand conditions were used to obtain Post Attack Stand inputs for both GYPSY and MGM projections after modifications account for the MPB attack levels and salvage operations.

2. Regeneration

➢ Existing Regeneration

The Regeneration densities for Aw, Sb and Sw were estimated based on the PSP data, Ecosite Guide, single or two story type of stand, and stand age. The density of black spruce natural regeneration was considered to increase with the age of the stand. The black spruce density in a two layers 75 years old stand was estimated at 1500 stems per hectare (spha) and at 4000 spha in a 120 and 160 years old stand. The white spruce and aspen densities were considered 3000 spha for all three age classes.

➢ New Natural Pine Regeneration

The natural Pine regeneration recruitments were determined at the rates observed in FGYA RLP study. Natural regeneration densities post-salvage were calculated to reflect site preparation and no site preparation, and are stratum specific.

➢ New Pine Planting

Planted Pine density was estimated at 2000 spha 10 years after the MPB attack and the salvage operations.

3.2.2 Input Modifications and Area Reductions

The 11 scenarios in Table 6 can be grouped into three types. Each type involves a series of assumptions and model projections. The three types of scenarios identified are presented below:

1. Type 1 – no kill, no salvage, no planting, no new natural regeneration (1 scenario)

2. Type 2 – MPB kill (25%, 50%, 100%), no salvage, no planting, no new natural regeneration (3 scenarios)

3.   Type 3 – MPB kill (25%, 50%, 100%), salvage, site preparation or no site preparation, planting or no planting, and new natural regeneration (7 scenarios)

The post-attack stand inputs were calculated differently for each combination.

1.   Type 1 Scenarios

Type 1 scenarios represent stands with no kill, no salvage, no planting, no new PL natural regeneration. The pre-attack inputs were used for the post-attack stand inputs.

2.   Type 2 Scenarios

Type 2 scenarios represent stands that were attacked by MPB (25%, 50%, 100%), but there was no salvage, no planting, and therefore no new regeneration.

Only pre-attack overstory Pl density and BA were reduced to reflect the MPB kill levels and used as post-attack stand inputs.

➢ N_PLpost-attack = (1-%MPB kill)*N_PLpre-attack

➢ BA_PLpost-attack = (1-%MPB kill)* BA_PLpre-attack

No adjustments were made for post-attack density or BA for non-pine overstory species, or any understory or regeneration layer species.

3.   Type 3 Scenarios

Type 3 scenarios are represented by stands affected by MPB kill (25%, 50%, 100%), salvage, site preparation or no site preparation, planting or no planting, and new natural regeneration. The area of these stands is split into the remnant stand area and the salvaged stand area.

The following assumptions were made:

➢ For the remnant stand portion (i.e. not attacked by MPB), the overstory pine input basal area and density were reduced with a percentage equal to the percent kill, with no further adjustments from MPB attack for any other species or layers. The projected Remnant Stand volumes were applied to the remnant portion of the stand.

➢ The Salvaged Stand Area was calculated based on the Post-Attack Densities. This is the area that is grown as a clear cut and it is represented by the area formerly occupied by the MPB killed and salvaged pine.

The percentages of Salvage Stand Area and Remnant Stand Area are calculated based on the overstory species specific densities as below:

➢ %Salvage Stand Area = N_PLpre-attack* %MPB_kill/SUM (N_PLpre-attack, N_SBpre-attack, N_SWpre-attack, N_AWpre-attack)

> ➢ %Remnant Stand Area = 1 – %Salvage Area

An additional 15% mortality was assumed for all species and all the layers as a result of salvage operation impacts in the Remnant Stand Area.

The area and the salvage adjustment were applied only to the Type 3 scenarios. Figure 1 shows an example of how the Remnant and Salvage Area were calculated in a hypothetical two story stand affected by 25% MPB kill.

Stand 1 – PL and SW Overstory
SB Uderstory

Pre-Attack Conditions

700 PL + 300 SW
600 SB2

25% MPB Kill

Post Attack Conditions

0.75*700 PL + 300 SW =
600 SB2
525 PL+ 300 SW
600 SB2

% Salvage Area = $\frac{700*0.25}{700+300}$ = 17.5%

% Remnant Area = 1 – % Salvage Area =
1 – 0.175 = 0.875 = 82.5%

Salvage Area=
17.5 %

Remnant Area =
82.5%

Clearcut+
New PL
Regen

0.85*(525 PL + 300 SW)
0.85*(600 SB2)

15% of stems are lost as a result
of the salvage operations

Figure 1. Example of Remnant and Salvage Areas calculations for the DST reporting.

3.2.3 Post Attack Stand Inputs

The 11 projection scenarios for each of 18 stand types at each of 3 ages produced 594 unique scenarios for stand projections using the Growth Models.

The Excel workbook provided with this document details the variables used as inputs as well as the pre-attack/post-attack values for each of the 594 unique scenarios used to create growth projections with both GYPSY and MGM.

4. Stand Projections

Projections from the growth and yield models describe future stand conditions post mountain pine beetle attack. Two growth and yield models - GYPSY and MGM were used in this project.

4.1 GYPSY Projections

GYPSY (short for Growth and Yield Projection System) is a forest growth model composed of a number of sub-models or functions.

4.1.1 GYPSY_Layers3

Shongming Huang at SRD provided The Forestry Corp with a new version of GYPSY - GYPSY_Layers3, capable of handling data from 4 species groups located in three layers: layer1 – overstory, layer2 – understory, and layer3 – regeneration.

The following species groups can now be included in the input dataset to be projected with the model: AW, SB, SW, PL representing the overstory, AW2, SB2, SW2, PL2 to represent the understory, and AW3, SB3, SW3, PL3 to represent the regeneration layer. The stand density factor (SDF) functions for each of the twelve components have been modified to accommodate the interactions between the 12 components.

The SDFs for AW, AW2, AW3, SB, SB2, and SB3 are independent of each other and of any other species. The other six SDFs are dependent on other species' SDFs as follows:

$SDFSW = f(SDFAW)$

$SDFSW2 = f(SDFAW, SDFAW2)$

$SDFSW3 = f(SDFAW, SDFAW2, SDFAW3)$

SDFPL = *f*(SDFAW, SDFSB, SDFSW)

SDFPL2 = *f*(SDFAW, SDFAW2, SDFSB, SDFSB2, SDFSW, SDFSW2)

SDFPL3 = *f*(SDFAW, SDFAW2, SDFAW3, SDFSB, SDFSB2, SDFSB3, SDFSW, SDFSW2, SDFSW3)

The species composition for the overstory layer is calculated as the ratio between the species overstory density and the sum of the species in the overstory (Example 1).

Example 1 – Layer1 (Overstory, AW)

SC_AW = den_AW/sum(den_SB, den_AW, den_PL, den_SW)

The species composition for the understory layer is calculated as the ratio between the species understory density and the sum of densities from the overstory and understory (Example 2).

Example 2 – Layer2 (Understory, AW)

SC_AW2 = den_AW2/sum(den_SB2, den_AW2, den_PL2, den_SW2, den_SB, den_AW, den_SW, den_PL)

The species composition from the regeneration layer is calculated as the ratio between the species regeneration density and the sum of densities from all three layers: overstory, understory, and regeneration (Example 3).

Example 3 – Layer3 (Regeneration, AW)

SC_AW3 = den_AW3/sum(den_SB3, den_AW3, den_PL3, den_SW3, den_SB2, den_AW2, den_PL2, den_SW2, den_SB, den_AW, den_SW, den_PL)

4.1.2 GYPSY Inputs

For each projected species, GYPSY requires the following variables as inputs: density (N), BA (optional), site index (SI), total age.

4.1.3 GYPSY Projections

A detailed description of the GYPSY runs is presented below.

1. Type 1 Scenarios

The post-attack inputs (N, BA, SI, Total Age) for all the stand type components (all layers and species groups) were used to do the stand projections using GYPSY_Layers3. The post-attack inputs are equal to the pre-attack inputs. The outputs represent the baseline scenario, no attack and no salvage operations and they were applied to 100% of the stand area.

2. Type 2 Scenarios

In this Scenario, the modified overstory PL density and basal area, plus the pre-attack stand conditions for all other species and layers, were used to do the stand projections using GYPSY_Layers3. The outputs represent the results for these scenarios and were applied to 100% of the stand area.

3. Type 3 Scenarios

Step 1. Project the Remnant Stand

The modified overstory PL density and basal area, plus the pre-attack stand conditions for all other species and layers, were used to do the stand projections using GYPSY_Layers3. The GYPSY projections (volumes, density, and BA) were adjusted downwards with 15% to account for the salvage damage. The reduction was applied to all species and all the layers as a result of salvage operations in Remnant Stand Area.

Step 2. Project the Salvage Area (New Regeneration and Planting)

The New Natural Regeneration and the New Planted Regeneration were used to do the stand projections using GYPSY_Layers3. In the Salvage Area there is only pine growing similar to the pine in a clear cut. Pine densities in the Salvage Area reflect natural pine recruitment, variable by stratum, plus supplemental planting if specified.

Step 3. Summarize Volumes for Type 3 Projections

On an area-weighted basis, the Remnant Stand volume gets applied to the %Remnant Stand Area, while the volume grown in the Salvage Area gets applied to the %Salvage Stand Area.

Basal Area (BA) was used as an input into GYPSY projections, however, the BAs reported in DST are the GYPSY BA projections without any adjustment.

4.2 MGM Projections

The Mixedwood Growth Model (MGM) is a deterministic, distance-independent, individual tree-based stand growth model for the boreal forest. It is capable of summarizing both tree and stand characteristics. Summaries are provided as yield tables and charts portraying averages and totals for the conifer and hardwood components. Growth may be simulated for stands provided as a tree list or stand table, including juvenile trees < 1.3m height, or trees may be simulated based on an assumed tree diameter distribution. Pure or mixed stands of white spruce, aspen, lodgepole pine and black spruce may be simulated.

The following presents the steps taken to create the inputs for MGM runs. The PSP data collected in 2008 and the GYPSY input matrix were both used to create the inputs.

4.2.1 MGM Input Requirements

For each projected species, MGM requires the following variables as inputs: density (N), site index (SI), mean height (HT), mean DBH (DBH), standard deviation of the height (STD_HT), standard deviation of the DBH (STD_DBH).

In MGM it is possible to establish the same species group in several different cohorts (e.g. a regenerating pine cohort under a mature pine cohort). However, each cohort requires its own set of inputs.

The same stand ages as for GYPSY inputs were used to create MGM inputs. A combination of GYPSY inputs and 2008 PSP dataset compilation were used to create the MGM inputs. The following steps were taken in order to compile the MGM inputs for MPB scenario projections. As for GYPSY, the MGM inputs were required for three layers:

➢ Layer 1 – overstory

➢ Layer 2 – understory

➢ Layer 3 – regeneration

1. Layer 1 - Overstory

Step 1 - Stand age, density, site index and top height came from the GYPSY input matrix. The method of how to obtain these inputs was described in Section 2.3.2.

Step 2 – Mean height and mean DBH compilation

Mean height and mean DBH are not outputs from GYPSY projections, therefore these variables were calculated. In order to keep some degree of consistency between the inputs used in both models, the GYPSY projected top height was used to calculate the mean height and mean DBH for MGM projections.

The linear relationship by species group between mean height and top height from the actual PSP dataset as well as the projected GYPSY top height were used to calculate the mean height for the MGM inputs.

The linear relationship between the mean DBH and top height from the actual PSP dataset as well as the projected GYPSY top height were used to calculate the mean DBH for MGM inputs.

Both relationships, Mean_HT = f(TopHT) and Mean_DBH = f(TopHT), were developed using only singled layered stands, however the results were applied to both single and two layer stands.

Step 3 – Standard deviation of the height and standard deviation of the DBH

The height and DBH standard deviations were calculated for all the one layered stands within the PSP database by species group. The species groups within the PSPs were grouped in three

height classes based on the mean height: 0-10 m, 10.1-20 m and greater than 20 m. The median standard deviation of the height and the median standard deviation of the DBH were calculated for all three age classes by species group. The height and the DBH standard deviations were appended by species group for each set of inputs based on the calculated mean height.

2. Layer 2 – Understory

The density, site index, and total age of the understory species for each scenario came from the GYPSY inputs. The post-attack densities for each scenario also came from the GYPSY inputs. The mean height, mean DBH, standard deviation of the height and standard deviation of the DBH were calculated in the same manner as for Layer 1.

3. Layer 3 - Regeneration

The density, site index, and total age of the regeneration species for each scenario came from the GYPSY inputs. The mean height, mean DBH, standard deviation of the height, and standard deviation of the DBH came from the FGYA RLP study data summarizing the information on natural regeneration and planting post-salvage.

4.2.2 Scenarios Inputs

1. Layer 1 & Layer 2

➢ Use the pre-attack densities and compiled information (mean height and DBH, standard deviation of the height and DBH) to create the tree lists in MGM for both layers.

➢ Allow MGM to remove the MPB affected trees from the tree lists based on the percent attack in the scenario. In the MGM Crop Plan, the pine density removal was done proportionally across the entire tree list. In this way, a 25 % reduction of Pine density equates a 25% reduction in basal area.

3. Layer 3

➢ Use the post-attack GYPSY densities and the other compiled variables in an 'Establishment' event in MGM to create the post-attack scenario based tree lists for the regeneration species.

4.2.3 MGM Projections

The scenario types that were used to create projections in MGM were the same as the GYPSY scenarios described in Section 4.1.3. For Type 1 and Type 2 scenarios all the inputs for Layers 1, 2, and 3 were projected using a single Crop Plan. In this way all species from all layers are interacting throughout the projection and the results represent dynamics of a single or multi-layered stand.

Two separate Crop Plans were used to create the projections for all stands in Type 3 scenarios. One Crop Plan was used to project all the layers in the Remnant Stand (overstory, understory and

pre-existing regeneration), while a second Crop Plan was used to project the Pine natural regeneration accompanied or not by additional planting in the Salvaged Area. The separation into two Crop Plans allowed for the species in the multi-layered Remnant Stand to interact throughout the projection, as well as allowing the Pine in the Salvaged Area to grow similar to a pure pine stand after a clear cut. Projections for the Remnant Stand and for the Salvage Area were combined by area-weighting as per the method used for GYPSY projections.

All MGM projections used a Gap Area Loss of 30%.

5. Wood Quality Parameter

5.1 Parameter Lists

The following four wood quality parameters (Non-Mensurational Response Variables) were required for the first 10 years of projection in DST Application.

1. MPB Killed Trees Standing;

2. MPB Killed trees with checks;

3. MPB Killed trees with saprot;

4. MPB Killed trees with woodborer damage.

For each Stratum X Species/Stand Structure X Age Class combination, there are 11 projection scenarios (see section 3.1.5) as follows:

1. No MPB Kill

2. 25% MPB Kill, no salvage

3. 25% MPB Kill + Salvage

4. 25% MPB Kill, + Salvage + Planting

5. 50% MPB Kill, no salvage

6. 50% MPB Kill + Salvage

7. 50% MPB Kill, + Salvage + Planting

8. 100% MPB Kill, no salvage

9. 100% MPB Kill + Salvage

10. 100% MPB Kill, + Salvage + Planting

11. 100% MPB Kill, + Salvage + Planting + Site Prep

Wood quality parameters were required for Projection Scenario Numbers 2, 5, and 8 (MPB Kill in the absence of salvage). Wherever there is salvage, it is assumed that all MPB Killed trees are salvaged and harvested, therefore no MPB killed trees are left for which to report wood quality parameters.

5.2 Parameter Calculations

5.2.1 Fall Down Rate

All trends are based on Lewis and Thompson, 2009 (Change in wood quality and fall rate of trees up to ten years after death from mountain pine beetle. 2009. Lewis, K.J.; Thompson, D. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-30).

It is assumed that there is 0 fall-down of MPB killed trees for years 1 to 5. Fall-down begins in year 6, and is equal annually for years 6 to 10, with final fall-down proportions by year 10 that are Stratum-specific as follows:

Stratum 1 (dry): 50% of MPB killed stems are down by year 10

Strata 2, 3, 4, 5 (mesic): 25% of MPB killed stems are down by year 10

Strata 6, 7, 8 (wet): 18% of MPB killed stems are down by year 10

Fall-down applies only to the MPB killed portion of the PL density, and not to any other species.

5.2.2 MPB Killed Trees Standing

For years 1 to 5, because of 0 fall-down of MPB killed trees, the number of MPB Killed Trees Standing is equal to MPB killed stems.

For years 6 to 10, the number of MPB Killed Trees Standing is calculated using the equation below:

# of MPB Killed Trees Standing = MPB killed stems*(1- Fall Down Rate*(Year-5)/5).

For Example:

Assume Stratum 1 (dry), pre-attack PL density = 2000, 50% kill, therefore post-attack live PL density = 1000 and post-attack standing dead PL density = 1000.

Years 1 to 5: Standing Dead PL density = 1000

Year 6: Standing Dead PL density = 900

Year 7: Standing Dead PL density = 800

Year 8: Standing Dead PL density = 700

Year 9: Standing Dead PL density = 600

Year 10: Standing Dead PL density = 500

That is, for year 6 to 10, the annual fall-down is equal, and such that the year 5 standing dead PL density is reduced by 50%.

5.2.3 MPB Killed Trees with Checks

The proportion of standing MPB killed trees with checks increases by year, and the rate of increase is the same for all projections (no difference by stratum, age class or stand structure) as follows:

Year	% trees with checks
0	0
1	30
2	70
3	70
4	70
5	70
6	80
7	90
8	90
9	100
10	100

The number of Standing MPB Killed trees with checks is calculated as:

# of Standing MPB Killed trees with checks = # of MPB Killed Trees Standing*Check Rate

5.2.4 MPB Killed Trees with Saprot

The proportion of standing MPB killed trees with saprot increases by year, and the rate of increase is the same for all projections (no difference by stratum, age class or stand structure) as follows:

Year	% trees with saprot
0	0
1	30
2	50
3	50
4	80
5	80
6	80
7	90
8	100
9	100
10	100

The number of Standing MPB Killed trees with saprot is calculated as:

# of Standing MPB Killed trees with saprot = # of MPB Killed Trees Standing* Saprot Rate

5.2.5 MPB Killed Trees with Woodborer Damage

The proportion of standing MPB killed trees with woodborer damage increases by year, and the rate of increase is the same for all projections (no difference by stratum, age class or stand structure) as follows:

Year	% trees with woodborer
0	0

1	30
2	60
3	60
4	60
5	60
6	60
7	60
8	60
9	90
10	90

The number of Standing MPB Killed trees with woodborer is calculated as:

# of Standing MPB Killed trees with woodborer = # of MPB Killed Trees Standing* Woodborer Rate

6. Decision Support Tool Application

6.1 Decision Support Tool Description

Mountain Pine Beetle (MPB) Decision Support Tool (DST) is a Web-based application. The DST is designed to help users assess the impacts of different levels of MPB infestation, and various silviculture interventions, on post-attack stand development.

DST can provide stand level projections of pre- and post-attack conditions, by assimilating growth model outputs, monitoring assessments and domain knowledge expertise such that forest planners can incorporate appropriate management strategies to mitigate the medium and long term impacts on timber supply.

The user may undertake the following using DST:

➢ Quantify the impacts of different levels of lodgepole pine mortality that leave varying residual structures of live trees following MPB attack

➢ Quantify the impact of different regeneration assumptions following varying degrees of MPB attack

➢ Identify and project differences in secondary structure and regeneration observed or hypothesized in different stand types (ecosites)

Intended users are forest planners at the compartment, operating area or FMA level. Users are given User ID's and Passwords by the System Administrator. The archived 'Answer Database' contains the results from all MGM and GYPSY projections.

6.2 Method to Use

Users can define simulation scenarios by specifying growth model, ecosite, stand structure, species composition, stand age, MPB severity, and silviculture intervention. For each defined scenario, the application searches the pre-populated 'Answer Database' and reports stand growth projections.

Users can specify:

> ➢ Model preference (MGM vs GYPSY)

> ➢ Stratum (one of 8 possible)

> ➢ Stand Structure (pre-defined for each Stratum)

> ➢ Current Age Class (75, 120, 160)

> ➢ MPB Mortality Level (0, 25, 50, 100%)

> ➢ Intervention (determined by MPB %)

> ➢ No Salvage (Base Run)

> ➢ Salvage (implies Natural Pl Regen)

> ➢ Salvage + Supplemental Planting

> ➢ Salvage + Supplemental Planting + Vegetation Management (only for 100% Kill and Salvage)

The application queries the 'Answer Database' for Scenarios specified by the user.

6.3 Simulation Results

The results are reported from the run that projects the Scenario specified by the user.

Simulation results include tabular and graphical reports of standard mensurational stand growth attributes, and post-MPB wood quality metrics, for 100 years and 10 years post-attack, respectively.

Tabular and graphic outputs include:

1. Mensurational stand growth parameters for 100 year projection period:

➢ Overstory merchantable volume (15/10, stump ht=30 cm) by species.

➢ Understory SB merchantable volume (15/10, stump ht=30 cm).

➢ Regen merchantable volume (15/10, stump ht=30 cm) by species.

➢ Overstory total density by species.

➢ Understory SB total density.

➢ Regen total density by species.

➢ Overstory total BA by species.

➢ Understory SB total BA.

➢ Regen total BA by species.

➢ Overstory average height by species.

➢ Understory SB average height.

➢ Regen average height by species.

2. Wood quality parameters for first 10 years of projection:

➢ MPB Killed Trees Standing.

➢ MPB Killed trees with checks.

➢ MPB Killed trees with saprot.

➢ MPB Killed trees with woodborer damage.

Table 7 lists the species reported in the DST's outputs for mensurational stand growth parameters and wood quality parameters for each stand type.

Table 7. Species reporting specification.

Stand Types	Stratum	Stand Struct.	Over Sp. Comp	Under Sp. Comp	Pre-Existing Overstory				Pre-Existing Understory	Pre-Existing Regen			New Regen
					PL	AW	SB	SW	SB	AW	SB	SW	PL
1	1	1 layer	Pl		X								X
2	1	1 layer	Pl+Aw		X	X							X
3	1	2 Layers	Pl	Sb	X				X		X		X
4	1	2 Layers	Pl+Aw	Sb	X	X			X		X		X
5	2	1 layer	Pl		X								X
6	2	2 Layers	Pl	Sb	X				X		X		X
7	3	1 layer	Pl		X								X
8	3	2 Layers	Pl	Sb	X				X		X		X
9	4	1 layer	Pl		X								X
10	4	1 layer	Aw+Pl		X	X				X			X
11	4	1 layer	Sw+Pl		X			X				X	X
12	5	1 layer	Pl		X								X
13	5	1 layer	Aw+Sw+Pl		X	X		X				X	X
14	6	1 layer	Pl		X								X
15	6	1 layer	Pl+Aw+Sw		X	X		X					X
16	7	1 layer	Pl		X								X
17	7	1 layer	Aw+Sw+Pl		X	X		X					X
18	8	1 layer	Sb+Pl		X		X						X

X: denotes attributes for that species need to be reported

Users can:

1. View results (tabular)

2. Report results (tabular + graphic)

3. Save Scenario specifications

4. Export results to Excel

5. Print results report to PDF

7. References

The Forestry Corp. 2006. Proposal to support implementation of FRIAA MPB Project.

MacDonald, Ellen. 2008. Development of sampling protocol to quantify/document forest vegetation responses to mountain pine beetle attack.

Lewis, K.J.; Thompson, D. 2009. Change in wood quality and fall rate of trees up to ten years after death from mountain pine beetle. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC.

Appendix I   Post Attack Stand Inputs Tables

1. Post Attack Stand Inputs Table for GYPSY

2. Post Attack Stand Inputs Table for MGM

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