FRIPSY

Foothills Reforestation Interactive Planning System

User Guide

FRIPSY version 2022_v220803

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Introduction

FRIPSY (Foothills Reforestation Interactive Planning System) is a tool to assist silvicultural and forest management planning in the Alberta Foothills Forest Region. It is designed to:

- Facilitate and encourage application of results from the FGrOW Regenerated Lodgepole Pine (RLP) trial and project;
- Assist silviculturists in selecting which treatments best meet objectives for reforestation of lodgepole pine following harvesting;
- Support timber supply planning by linking regeneration performance to predictions of long-term growth and yield.

It consists of a regeneration model linked directly to the Alberta government's Growth and Yield Projection System (GYPSY)[1]. FRIPSY's regeneration model uses site and treatment information to forecast crop performance at 12 to 14 years following cut (consistent with the Reforestation Standard of Alberta[2]), and at 18 years (considered to better represent the end of the regeneration phase). Treatments recognized are site preparation, planting, chemical weeding, and pre-commercial thinning. The regeneration forecasts are "handed-over" to GYPSY at 18 years to project subsequent growth and yield to rotation age.

This Guide consists of three sections:

1. *Instructions for use*: includes a quick-start overview, followed by more detailed instructions for creating and interpreting regeneration forecasts and growth and yield projections;

2. *System design and structure*: describes the project background, approaches taken to regeneration modelling, data on which the system is based, and the various types of sub-models;

3. *Appendices*: contains detailed information on (1) new features of the 2021 version, (2) regeneration sub-models, and (3) installing the GYPSY dynamic link library (required for making growth and yield projections).

The overview in Section 1 will suffice to get most users started. The remaining instructions and following sections are for reference as needed. They also provide interested readers with a more in-depth understanding of the how FRIPSY works, and the juvenile stand dynamics that it simulates.

[1] Huang, S., Meng, S., & Yang, Y. (2009). *A growth and yield projection system (GYPSY) for natural and post-harvest stands.* Alberta Sustainable Resource Development Tech. Report Pub. No. T/216.
[2] Alberta Environment and Sustainable Resource Development. (2022). *Reforestation standard of Alberta*. Alberta Agriculture, Forestry, and Rural Economic Development, Edmonton, Alberta.

1 Instructions for use

1.1 Quick-start overview

FRIPSY is run in Microsoft Excel. In order to project yields to rotation-age you also will need the GYPSY dynamic link library (DLL) provided by the Government of Alberta (GoA). If you do not have the DLL already registered on your computer, follow this link to the GoA growth and yield projection system web page: https://www.alberta.ca/growth-and-yield-projection-system.aspx; and follow the instructions for downloading and installing the *GYPSY 2009 COM DLL* file. Currently, the DLL runs only on the 32-bit version of Excel. Without the DLL, and if you are using the 64-bit version of Excel, you will be unable to produce yield projections by GYPSY; but all other FRIPSY regeneration forecasts will be available.

You may run the model in either of two processing modes: single-stand or batch. The single-stand module is accessed by clicking on the *Input* tab located at the bottom left corner of the screen (see Figure 1). You enter data manually, and generate reports for one stratum or opening at a time. The batch processing module enables you to load and process data for multiple openings in the *Batch_Setup* sheet. You will need to provide the following information in either mode:

- *Stand site and establishment factors*. Stand identifier, soil nutrient and moisture classes, natural sub-region, elevation and latitude are mandatory inputs. You are also encouraged to enter optional information on soil depth, slope, ground cone density, and % stocking of secondary species if available.
- *Projection options.* These allow you to include or exclude from projections pine natural regeneration, and trees girdled by Western Gall Rust. In batch mode you will also be given the choice of whether to report detailed GYPSY output, which in single-stand mode will always be reported if the GYPSY DLL is registered on your computer.
- *Events*. These are silvicultural operations or milestones: cut, site preparation, plant, weed, thin, and performance assessment. For each event you are prompted to enter the year of operation. In addition, you will need to enter the type of site preparation, number of trees planted per ha, and target number of crop trees per ha after thinning.

Figure 1. Tabs for accessing FRIPSY worksheets

In single-stand mode, having entered the above information in the *Input* worksheet (see Figure 2), click on the *Generate Report* button. The result will be shown in the *Report* worksheet, with yield projections summarized in the *Report* sheet and detailed in the GYPSY worksheets. In batch mode, having entered the input information in the *Batch_Setup* sheet, use the *Validate* and *Batch* buttons to process the runs. The results will be displayed in the *Batch_Output* sheet, and you will be prompted to identify a folder location to which they will be downloaded.

For more detailed information on inputs, processing and outputs, refer to sections 1.2 to 1.6 below.

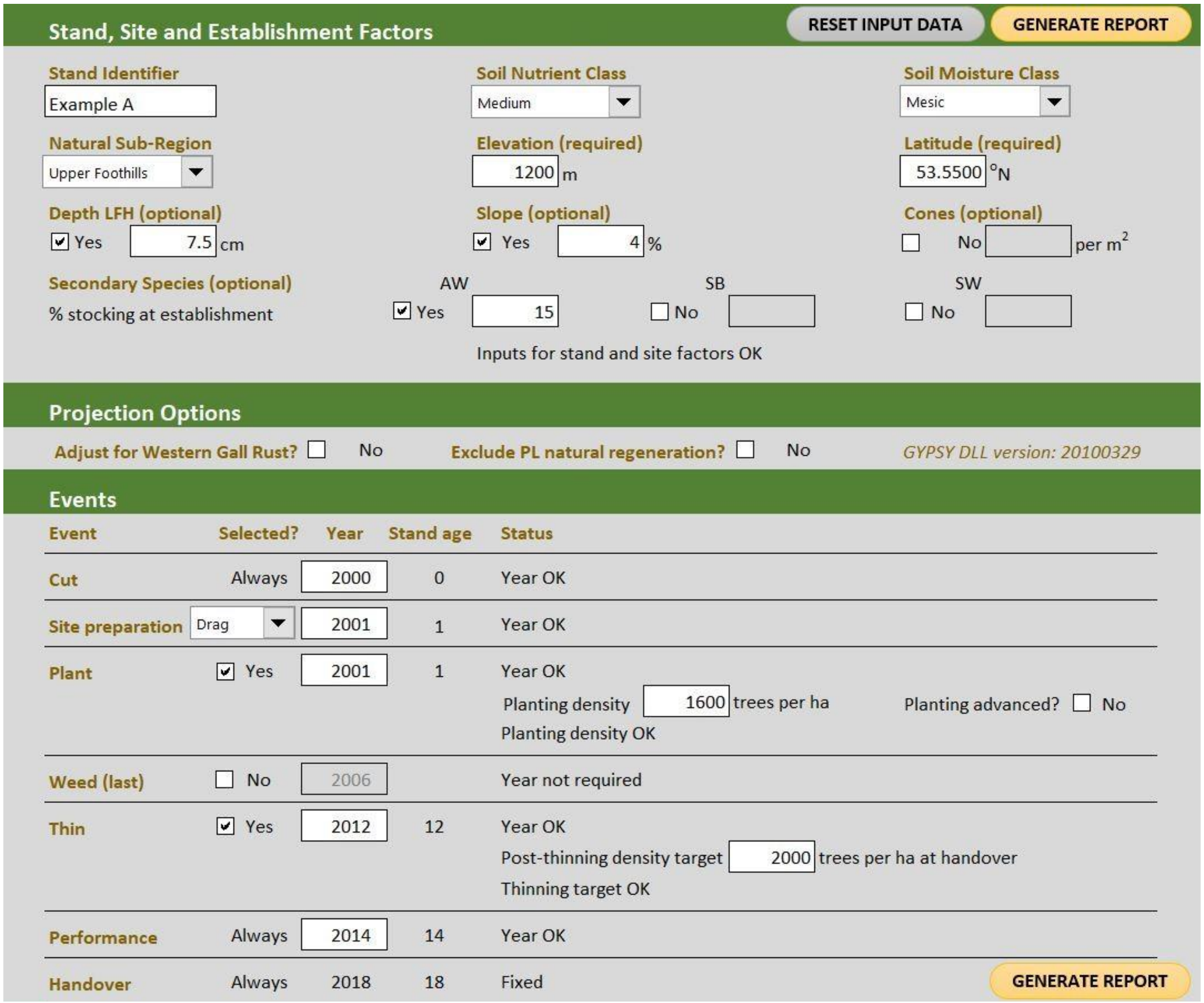

Figure 2. *Input* worksheet for single-stand processing

1.2 Inputs

1.2.1 Stand, site and establishment factors

Stand identifier (*StandId*)

- ✓ Must be a unique alphanumeric value.
- ✓ Mandatory.

Soil nutrient class (*SNC*)

- ✓ 1 = Poor, 2 = Medium, 3 = Rich.
- ✓ Mandatory.

Soil moisture class (S*MC*)

- ✓ 1 = Dry (sub-mesic and sub-xeric), 2 = Mesic, 3 = Moist (sub-hygric and hygric).
- ✓ Mandatory.

Natural sub-region (*NSR*)

- ✓ UF = Upper Foothills, LF = Lower Foothills.
- ✓ Mandatory.

Elevation (*Elev*)

- ✓ Numeric value between 840 and 1621m above sea level (range covered by the RLP trial).
- ✓ Mandatory (if not known, values in Table 1 may suffice for broad planning purposes).

Latitude (*Lat*)

- ✓ Numeric value between 51.5 and 54.8 decimal degrees N (range covered by the RLP trial).
- ✓ Mandatory (if not known, values in Table 1 may suffice for broad planning purposes).

Table 1. Average elevations and latitudes of RLP trial installations by forest management area

Forest Management Area	Elevation (m)	Latitude (^{o}N)
ANC Timber	1163	54.00
Blue Ridge Lumber	1187	54.74
Canadian Forest Products	949	54.45
Millar Western	1083	54.08
Spray Lake Sawmills	1565	51.51
Sundre Forest Products	1215	52.18
West Fraser (Edson)	1341	52.90
West Fraser (Hinton)	1199	53.32
Weyerhaeuser (Drayton Valley)	1209	53.05
Weyerhaeuser (Edson)	864	53.37
Weyerhaeuser (Grande Prairie)	1061	54.55
Total study area	1163	53.48

Depth of organic soil (*LFH*)

- ✓ Combined depth of Litter, Fungal and Humus layers.
- ✓ Numeric value between 2 and 57cm (range covered by the RLP trial).
- ✓ Optional. If left blank, default of 8.7 cm is used (average value observed in the RLP trial).

Slope percent (*Slope*)

- ✓ Numeric value between 0 and 23.
- ✓ Optional. If left blank, default of 4% is used (modal value observed in the RLP trial).

Ground cone density (*Cones*)

- ✓ Number of cones per m^2 on ground after site preparation.
- ✓ Numeric value between 0 and 30.
- ✓ Optional. If left blank, default of 3 is used (modal value observed in the RLP trial).

Secondary species % stocking at establishment

- ✓ Numeric value between 0 and 100.
- ✓ Obtained from establishment survey (normally 5 to 8 years after cut).
- ✓ **Must have been assessed AFTER ANY WEEDING and BEFORE ANY THINNING**.[3]

[3] Be sure to follow this instruction! For example, do not input pre-weeding aspen stocking values when simulating weeding effects. When a run is setup to include a weeding treatment, the model assumes the input stocking to have been assessed after weeding. If after-weeding stocking information is not available for this run, allow the model to forecast the response based on the other site and stand variables that have been entered.

- ✓ Optional for aspen / balsam poplar (PsAW), black spruce (PsSB), and white spruce (PsSW).
- ✓ Inputs for these species are desirable because secondary species are irregular in occurrence. An indication of aspen stocking at establishment can result in improved forecasts of both aspen itself and lodgepole pine, because aspen is highly variable on mid to low elevation sites, and affects pine regeneration, mortality and growth.

For detailed descriptions of ecological strata (*SNC, SMC, NSR*) see field guides to ecosites of west-central and southwestern Alberta.[4]

1.2.2 Projection options

Adjust for western gall rust? (*WGR*)

- ✓ Logical (*Yes* / *No*).
- ✓ If *Yes* selected, the regeneration model will simulate the RSA practice of excluding girdled trees from GYPSY inputs. (The resulting densities and diameters are reported for the handover stage; densities reported at earlier stages are unadjusted.)
- ✓ Default is *No*.

Exclude lodgepole pine natural regeneration? (*ExPLnat*)

- ✓ Logical (*Yes* / *No*).
- ✓ If *Yes* is selected, the regeneration model will simulate the development of planted pine without any ingress of pine from seed. (This allows forecasting plantation development without the complications and uncertainties introduced by pine ingress, which is highly variable. Note however that on most sites some level of ingress is likely, and can affect growth of the planted stock.)
- ✓ Default is *Yes*.

1.2.3 Events

Timber year of cut (*YrCut*)

- ✓ Mandatory.
- ✓ Used to compute years since cut (YSC) for subsequent events.

Mechanical site preparation

- ✓ Method (*Prep*) must be 1 = None, 2 = Drag, or 3 = Mound (see Table 2).
- ✓ If MSP undertaken, but none of methods listed in Table 2 apply, assign to Group 2 if the method was adopted to encourage natural regeneration, or Group 3 if intended to provide microsites for planting.
- ✓ Timber year of site preparation (*YrPrep)* required if MSP undertaken. (Must be greater or equal to *YrCut.*)

Planting (lodgepole pine only)

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[4] Archibald, J. H., Klappstein, G. D., & Corns, I. G. (1996). *Field guide to ecosites of southwestern Alberta.* Special Report 8, Canadian Forest Service, Northwest Region, Northern Forestry Centre, Edmonton, Alberta.
- Beckingham, J. D., Corns, I. G., & Archibald, J. H. (1996). *Field guide to ecosites of west-central Alberta.* Special Report 9. Canadian Forest Service, Northwest Region, Northern Forestry Centre, Edmonton, Alberta.
- Corns, I. G., Downing, D. J., & Little, T.I. (2005). *Field guide to ecosites of west-central Alberta: supplement for managed forest stands up to 40 years of age.* Special Report 15, Canadian Forest Service, Northwest Region, Northern Forestry Centre, Edmonton, Alberta.

- ✓ Timber year of planting (*YrPlant*): required if *PSph* is greater than 0; must be greater than or equal to *YrCut*.
- ✓ Planting density (*PSph*): must be between 800 and 4500 trees per ha if planting undertaken.
- ✓ Planting advanced (*Pearly*): logical (*Yes* / *No*); Select *Yes* only if you are confident that either early planting or use of 2-year stock will advance growth by one full growing season; default is *No*.

Table 2. Site preparation methods

Group	Name	Site Preparation Methods
1	None	No mechanical site preparation performed
		Hand scalped
2	Drag	Drag
		Drag - heavy
		Drag - shark fin barrels
		Disk - passive trencher
		Blade - shear
3	Mound	Mounder - Donaren mounder
		Mounder - excavator hoe bucket
		C&S plough

Timber year of weeding (*YrWeed*)
- ✓ Required if chemical weeding undertaken.
- ✓ Refers to last year of treatment.
- ✓ Must be greater than or equal to *YrCut*.

Pre-commercial thinning and hardwood brushing
- ✓ Timber year of thinning (*YrThin*): required if thinning undertaken or planned; must be greater than or equal to *YrCut*.
- ✓ Post-thinning target density for lodgepole pine (*ThinSph*): if thinning undertaken or planned, must be between 500 and 5000 trees per ha. (Note that the target is the number of crop trees per ha (1.3m+ in height) desired at handover i.e. stand age 18 years.)

Year for regeneration performance forecast (*YrPerf*)
- ✓ Year at which regeneration forecast is required

1.2.4 Errors and warnings

In single stand mode, errors and warnings are displayed interactively as you attempt to enter data in the *Input* sheet, and additional warnings may be included in the *Report* worksheet. *Errors* include any data issues that would result in an invalid run that cannot be processed by the base model. Examples are:

- Missing input data errors;
- Infeasible or missing thinning target (note that the run is aborted if the thinning target exceeds the number of trees predicted to be available at handover);

Warnings in single stand mode are possible data problems that will not result in an invalid run, but may have been unintended by the user or reflect limitations of the input data. Examples are:

- Site variable warnings (for elevation, latitude, depth LFH, slope percent, and cone density) indicate where the input values are outside the range of data used to develop FRIPSY (see Section 1.2.1 above);
- Treatment warnings indicate where timing of site preparation, planting, weeding or thinning treatment is illogical or outside the age range modelled by FRIPSY (see Section 1.2.3 above);
- SB and SW projection warnings indicate where the species density or age is too low at handover for GYPSY to project.

In batch mode, errors and warnings are defined and handled a little differently than in single stand mode. Data are checked for errors and possible issues by clicking the Validate button in the *Batch_Setup* sheet (see Section 1.4 below). Input values for site and treatment variables are constrained to be within modelled ranges, and any data entry outside the specified allowable values will result in an error. This feature was introduced (a) because irrational forecasts are less likely to be noticed in batch than in single stand mode, and (b) to avoid crashing the model during batch operations.

1.3 Single stand processing and outputs

Input information is processed by clicking on the *Generate Report* button in the completed *Input* worksheet. The resulting *Stand Regeneration Report* will be shown in the *Report* worksheet (see Figure 3). Further details of the yield projections are reported in three GYPSY worksheets (see Section 1.5). The *Stand Regeneration Report* contains: a summary of the input data (stand, site and establishment factors, selected projection options, and events); a *Regeneration Forecast*, and a *Yield Projection* summary. The *Regeneration Forecast* reports stand conditions by event and species group. The *Yield Projection* summary reports mean annual increment and other stand conditions projected to the age of pine MAI (mean annual increment) culmination.

1.3.1 Regeneration forecast

Reported events are:

- *Thin* (with conditions reported immediately before and after treatment in the stated year since cut, if a thinning has been specified);
- *Performance* (i.e. regeneration performance assessment in the stated year since cut);
- *Handover* (always at 18 years since cut).

Recognized species groups are:

- *AW*: trembling aspen (includes balsam poplar);
- *PL*: lodgepole pine
- *SB*: black spruce
- *SW*: whites spruce (includes balsam fir).

SB and SW are reported only at the handover stage, and only for non-thinned stands.

Stand conditions, reported by event and species, are:

- *Age (years)*: germination age of top height trees
- *Top height (m)*: top height – average height of the 100 largest diameter trees per ha
- *% stocked*: percentage of 10m^2 regeneration sub-plots containing at least one tree meeting minimum height requirements (see note below)
- *Trees per ha*: number of trees per ha meeting minimum height requirement (see note below)
- *DBH (cm)*: quadratic mean diameter at breast height (1.3m)
- *Basal area (m^2/ha)*: total basal area measured at breast height (1.3m)

Stand, Site and Establishment Factors

Natural sub-region:	UF	Elevation (m):	1200	Latitude (deg.):	53.5500
Soil moisture class:	mesic	Soil nutrient class:	medium	Depth LFH (cm):	7.50
Cone density (per m^2):	unknown	Slope %:	4.0		
Secondary species % stocking	AW: 15		SB: unknown		SW: unknown

Selected Projection Options

No adjustment for Western Gall Rust — PL ingress included in all projections

Events	Year	Details
Cut (timber year of cut)	2000	
Site preparation	2001	Drag scarification
Plant	2001	Density: 1600 trees per ha
Weed (last chemical)	Never	
Thin (manual)	2012	Target density: 2000 trees per ha at handover
Performance assessment	2014	
Handover	2018	

Regeneration Forecast (PL ingress included)

Event	Years since cut	Species	Age (years)	Top ht (m)	% * stocked	Trees * per ha	DBH (cm)	Basal area (m^2/ha)
Thin	12	AW	10.3	2.89	19.1	479		
(before)		PL	12.0	4.10	96.6	15535		
Thin	12	AW	2.9	1.17	0.6	12		
(after)		PL	12.0	4.10	92.1	2477		
Performance	14	AW	4.6	1.43	1.7	32		
		PL	14.0	5.02	91.9	2458		
Handover	18	AW	7.9	2.17	11.4	209	0.43	0.00
		PL	18.0	6.86	92.0	2000	8.66	11.78
		SB						
		SW						

Yield Projection to age of PL MAI culmination at 72 years after cut — BACK

Species	Site index (m @ 50 yrs)	MAI (m^3/ha/yr)	Volume (m^3/ha)	Age (years)	Top ht (m)	Trees (per ha)	DBH (cm)	Basal area (m^2/ha)
AW	14.8	0.20	14.3	61.9	16.1	188	16.5	4.0
PL	19.8	3.91	281.4	72.0	22.7	883	21.4	31.7
SB								
SW								
Con		3.91	281.4			883	21.4	31.7

** Based on minimum tree height 0.3m for conifers at thinning and performance, and 1.3m for AW (always) and conifers at handover.*

Figure 3. Stand regeneration report

DBH and basal area are reported only for PL and AW at the handover stage. They are not reliable indicators of stand condition at younger ages or in SB and SW because of varying proportions of trees being less than 1.3m in height.

The minimum tree heights used to define % stocking and trees per ha differ between events and species. Both stocking and trees per ha are based on a minimum tree height of 0.3m for conifers at thinning and performance, and 1.3m for AW (all ages) and conifers at handover. The 0.3m standard is used for conifers during the performance phase for consistency with the RSA. The 1.3m standard is used for all species at handover, because it is required by GYPSY for growth projection.

1.3.2 Yield projection

The variables itemized below are tabulated by species group. SB and SW are not included for thinned stands. All values except site index are projected to a rotation age calculated as the years since cut of lodgepole pine merchantable mean annual volume culmination.

- *Site index (m @ 50 years)*: top height (average height of the 100 largest diameter trees per ha) at 50 years' breast-height age;
- *MAI (m^3/ha/year)*: gross merchantable mean annual increment;
- *Volume (m^3/ha)*: gross merchantable volume per ha;
- *Age (years)*: total age (since germination);
- *Top height (m)*: average height of the 100 largest diameter trees per ha
- *Trees per ha*: number of trees per ha (minimum height 1.3m);
- *DBH (cm)*: quadratic mean diameter at breast-height (1.3m);
- *Basal area (m^2/ha)*: basal area per ha at breast-height (1.3m).

Merchantable MAI and volume are based on the following utilization limits:

- 15cm stump diameter over-bark;
- 10cm top diameter inside-bark;
- 0.3m stump height;
- 3.66m minimum merchantable length.

No deductions are made for defect, decay or breakage.

Any species group with 50 trees per ha or less is considered to be a minor species component. Minor components are reported in the regeneration forecast, but are not counted by GYPSY in subsequent yield projection.

1.4 Batch processing and outputs

The batch input data variables are the same as those required for single-stand processing. The batch processor input screen can be accessed by clicking on the *Batch_Setup* worksheet tab (see Figure 1). You can input data for multiple openings under the appropriate headings as shown in Figure 4, either directly on screen or by pasting external data already compiled to this format. Each row of data represents one opening/stand with a unique identifier (*StandID*). Stands should be entered continuously with no blank rows between data records. A short descriptor of the expected data, acceptable values, type (text, numeric or logical), and the default values assumed if missing is embedded in each header row. The input descriptor is triggered by clicking on a heading.

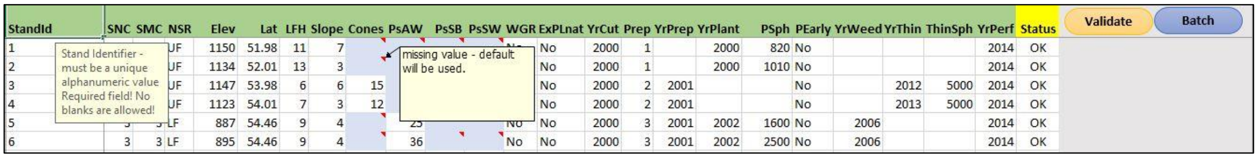

Figure 4. Batch processor input screen

Data are validated for errors and warnings by clicking the *Validate* button in the upper right corner of the data range.

- Errors are identified by a light red cell color and an embedded cell comment that explains the nature of the error. Any data entry that is outside the allowable values for the data column will result in an error.
- Warnings are identified by a light blue cell color and an embedded cell comment that explains the nature of the data issue.

For each stand, the validation records the status of the run by placing OK for stands with valid input or !! for stands with invalid input in the *Status* column. An explanation of any error or warning can be viewed by hovering the cursor over, or clicking on, the cell in question.

Once the input data are entered and validated, the batch process can be run by clicking the *Batch* button. You will be presented with the batch module interface (see Figure 5). Clicking the *Batch* button will always trigger a re-validation of the input. This ensures that the input data are checked for errors even if you forget to validate.

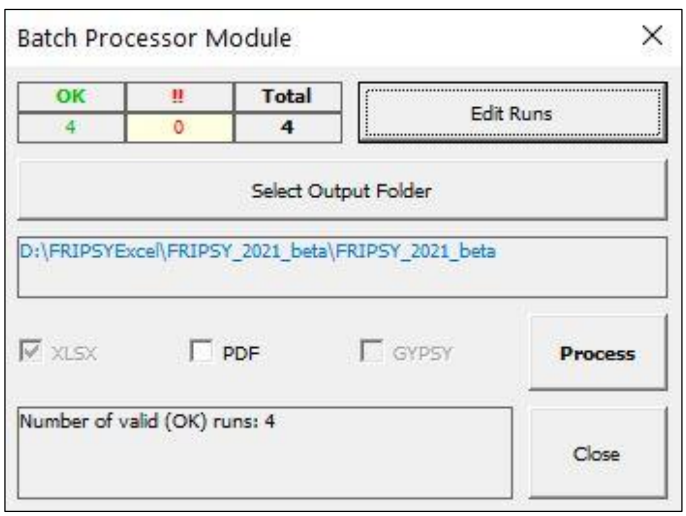

Figure 5. Batch processing interface

The interface, as shown in Figure 5, includes the following:

- Information about the number of valid (OK) and invalid (!!) runs;
- An opportunity to correct inputs before processing by clicking the *Edit Runs* button;
- A *Select Output Folder* button enabling you to select a folder for the batch output (the default location is the folder from where the main FRIPSY program is launched);
- Check boxes for selecting output options, including PDF files and detailed GYPSY reports;
- A *Process* button for completing the runs;
- Miscellaneous messages for the batch process;

- A *Close* button for closing the batch interface window.

Batch output, located in the *Batch_Output* worksheet and the output file specified as above, includes the same output information as that described for single-stand processing in Section 1.3 above; and is divided into the following groups of columns:

- *Input Data*: see 1.2 above;
- *Before Thinning*: regeneration forecast of conditions immediately before thinning in the year specified in the input data (see 1.3.1 above)'
- *After Thinning*: regeneration forecast of conditions immediately after treatment in the year specified in the input data (see 1.3.1 above)
- *Performance Assessment*: regeneration forecast of conditions in the year of performance assessment specified in the input data (see 1.3.1 above);
- *Handover*: regeneration forecast of conditions 18 years after cut (see 1.3.1 above);
- *GYPSY Projection @ PL Culmination Age*: yield projection summary (see 1.3.2. above);
- *Errors and Warnings*: see 1.2.4 above.

1.5 Detailed GYPSY reports

Details of FRIPSY projections are output in single-stand mode and, if requested, in batch mode. They are organized in three worksheets:

1. *GYPSY_Observed*: includes the GYPSY stand attributes at the time of handover (18 years since cut) as generated by the FRIPSY regeneration model. Additional stand attributes such as site index, percent stocking index (PSI) and breast height (BH) age are also generated.
2. *GYPSY_Projected*: includes GYPSY model projections from handover to 250 years in 1-year increments.
3. *GYPSY_Report*: provides all relevant GYPSY model outputs in a concise report which shows observed and projected stand attributes in graphical and tabular format, including a yield table.

Variables reported in the detailed GYPSY outputs are listed and described in Appendix 3.3.

1.6 Limitations and cautions

Although FRIPSY 2021 takes into account more site, stand and treatment variables than did previous versions, much unexplained variation remains, particularly in natural regeneration of pine and secondary species.

Adjustments have been made to the regeneration model in an attempt to reconcile predictions with other experimental and operational data (see Appendix Section 3.1). However, the model does not fully take into account differences between research and operational data that can arise from:

- Natural and man-made voids in stands, typically not encountered or permitted in research plots;
- Lower levels of treatment effectiveness achieved operationally, when compared to research trials;
- Limitations in the detail and accuracy of operational data.

Comparisons of FRIPSY simulations with empirical post-harvest (EPH) operational data suggest that such factors may reduce projected mean annual increment by 25 to 35 percent.

Densities of both planted and naturally regenerated lodgepole pine, observed in the latest measurements of the RLP trial, declined between 18 and 20 years since cut in the majority of sample plots.[5] This

[5] Dempster, W.R. 2021. *Final crop performance report for the regeneration phase of the Regenerated Lodgepole Pine Trial*. FGrOW internal technical report.

observation supported the choice of stand age 18 years, used in FRIPSY for defining the transition between regeneration and growth phases. However, densities of spruce and fir continued to increase between 18 and 20 years in the RLP trial, as did the density of aspen in thinned plots. FRIPSY projections of growth and yield beyond stand age 18 may therefore underestimate the density and significance of secondary species.

FRIPSY and the RLP trial indicate much higher effectiveness of chemical weeding in controlling aspen than do operational empirical post-harvest (EPH) data. We were unable to determine to what extent this was the result of (a) experimental ground applications really being more effective than operational (mostly aerial) treatments, or (b) lack of experimental control in the operational data, (e.g. operational treatments being concentrated on highly competitive stands, few of which are left untreated). The extent to which responses to weeding treatments predicted by FRIPSY are operationally achievable is therefore uncertain. Validation requires controlled monitoring following operational treatments e.g. installing and measuring sample plots both in aerially sprayed openings and in unsprayed areas left as controls on the same site type. Until such validation is available, FRIPSY forecasts should be interpreted as indicating potential, but not necessarily achievable, treatment responses.

Another discrepancy observed between RLP / FRIPSY results and EPH data was generally lower pine densities recorded by the latter in regeneration performance surveys. This may be partially explained by voids reducing stocking in operational openings relative to research installations. However, we suspect capping and underestimation of tree counts in stocked plots to have occurred in operational surveys. In FRIPSY, predicted densities are not adjusted on this basis, because ignoring higher tree counts would compromise analysis of treatment responses, particularly thinning.

Aspen stocking is highly variable on some site types. We therefore advocate improving FRIPSY regeneration forecasts wherever possible by inputting percent stocking estimates obtained from establishment surveys. Predictions for black and white spruce are weak because of the species' low incidence, high variability, and slow rates of ingress, and should be interpreted with caution. You may find them helpful in identifying which sites are most likely to support each of the species and, as for aspen, forecasts can be improved by inputting stocking data.

Forecasts made by FRIPSY for the regeneration phase of the rotation are based on responses to actual reforestation treatments under experimentally controlled conditions. Projections for the growth phase are made by GYPSY, which is based on data from both fire origin stands and post-harvest stands, without control of reforestation treatments. There are currently insufficient data in Alberta to validate these projections over the whole rotation, because none of the stands which have received the treatments being simulated have reached rotation age. Therefore, long-term projections made by FRIPSY and GYPSY should be interpreted with caution, and periodically reviewed by ongoing monitoring of the RLP trial.

2 System design and structure

2.1 Background and approach

Reforestation of public lands in Alberta represents a substantial cost and liability, and is exposed to critical scrutiny; but it also offers opportunities for sustaining and increasing timber supplies. The quantitative relationships between silvicultural treatments, regeneration success and the subsequent growth and yield of Alberta's foothills forests should be primary considerations in forest planning. This was not always the case, but is now mandated by the Reforestation Standard of Alberta (RSA)[2], whereby reforestation success is defined in terms of mean annual timber volume increment at rotation, predicted from regeneration performance assessed in the second decade after harvest.

A distinction is made in the RSA between the regeneration and growth phases of the forest rotation. The regeneration phase typically applies to seedlings below breast-height (1.3m), and is characterized by increasing stocking and density where natural regeneration occurs, with irregular mortality related to climate, pathogens, or inter-specific competition. The growth phase typically applies to trees above breast-height, and is characterized by stand density decreasing as a result of regular mortality dominated by inter-tree competition. Most silvicultural operations in Alberta are undertaken before or during the regeneration phase, with little active management during the growth phase until harvest. Forest stands in Alberta have been extensively studied and modeled during the growth phase to produce projection systems like GYPSY, but much less attention has been paid to stand dynamics during the regeneration phase. The resulting gap in our ability to forecast stand development following reforestation was the main stimulus for the development of FRIPSY, with emphasis on modelling stand dynamics during the regeneration phase, and linking them to conventional growth models for projection during the growth phase (see Figure 6).

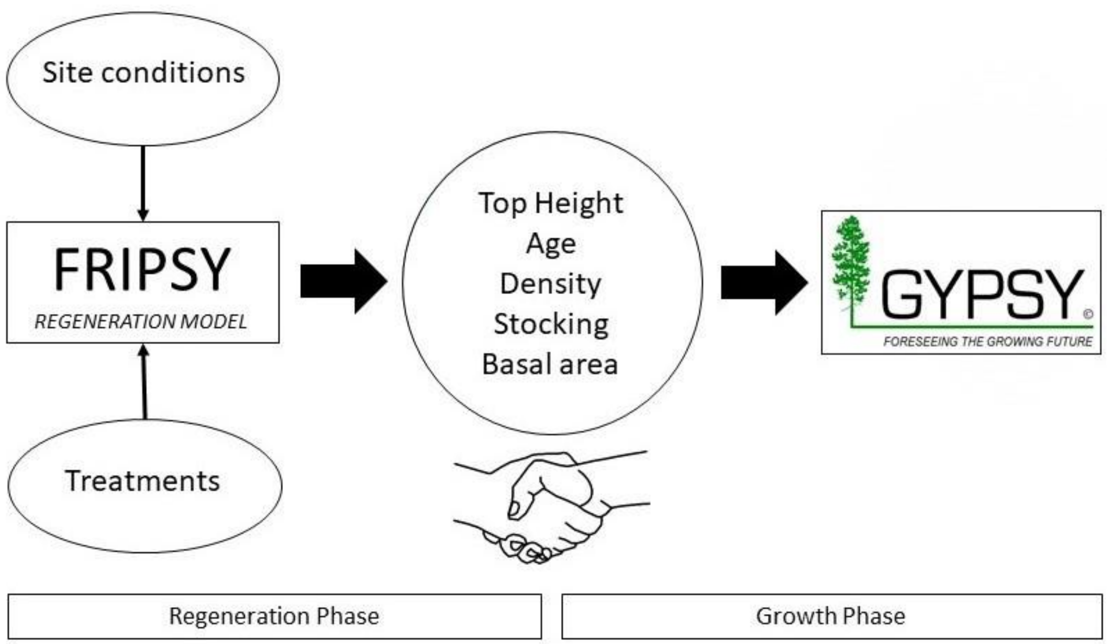

Figure 6. Linkage between the FRIPSY regeneration model and the Alberta growth and yield projection system (GYPSY)

A limitation in pre-existing growth and yield models is illustrated in Figure 7. Stand density is assumed to decline only (line AB). In lodgepole pine and most other Alberta forest types, natural regeneration occurs, resulting in density increasing during the regeneration phase (line DC), culminating (at C), and then declining throughout the growth phase of the rotation (CB). Conventional growth models can project density (and associated variables like basal area) correctly for planted stock once trees have reached breast-height at time D; but where natural regeneration occurs they are applicable only during the growth phase after point C. A different approach is required for simulating increasing densities during the regeneration phase.

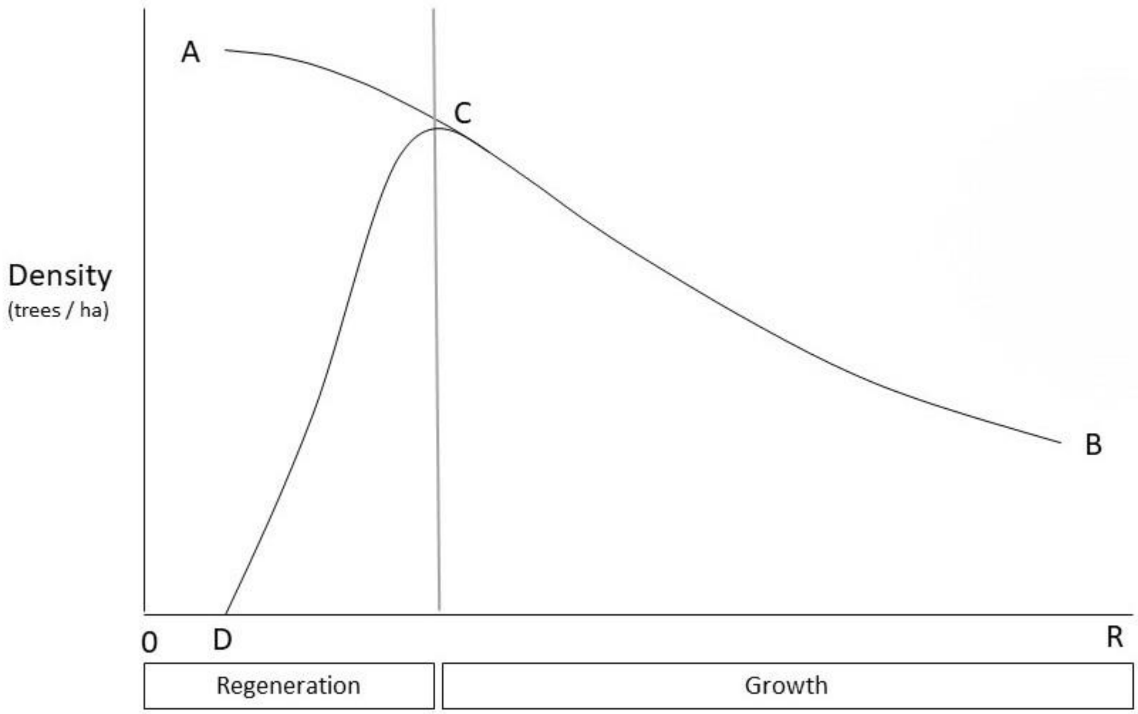

Figure 7. Density trends forecast by conventional growth and yield model (line ACB) and in combination with a regeneration model (line DCB)

The latest results of the RLP trial[4] suggest that densities of lodgepole pine may continue to increase after RSA performance surveys conducted at 12 to 14 years after cut, but culminate by 18 years. We therefore extended the FRIPSY regeneration model to 18 years (previous versions were to 14 years, consistent with the RSA). As noted previously (Section 1.6), densities of secondary species may not culminate within 18 years of cut.

The RSA recognizes two minimum tree height standards for defining stocking and density: N03 (0.3m), and N13 (1.3m). The N03 standard is applied to conifers, and the N13 standard to hardwoods, for surveys assessing regeneration establishment and performance. The GYPSY growth model is based entirely on the N13 standard; but the RSA permits coniferous projections to be made from performance survey data collected according to the N03 standard. We observed that GYPSY projections of the RLP trial data, made 16 to 18 years after cut using the N13 standard, were more stable than were projections made using

N03.[6] We therefore concluded that the N13 standard should be used for densities and stocking of all species "handed-over" from the FRIPSY regeneration model to GYPSY at age 18 years.

An important consideration in the linkage between FRIPSY, RSA and GYPSY is the exclusion by RSA of lodgepole pine trees with more than 50% encirclement of the main stem by western gall rust (WGR). The assumption of the GYPSY development team, and the resulting RSA rule, is that the density curves in GYPSY represent regular self-thinning, and not the pathogenic mortality from WGR observed in young post-harvest stands. This argument has two weaknesses. Firstly, it is based largely on a single study of two pre-commercially thinned stands (Wolken et al. 2006[7]), in which a decline in survival was observed only in stems with over 80% gall encirclement in one stand and 90% in the other. Secondly, as a precautionary measure (i.e. reducing yield forecasts in response to presence of the pathogen) the rule is questionable, because in higher density stands application of the rule can result in GYPSY projecting yield increase in response to the density reduction. As a result of this dilemma we have modelled the effect of WGR on pine density and diameter growth, and provided FRIPSY users the choice of either retaining or excluding girdled trees in the GYPSY projections.

In model development, three distinct stages were recognized within the regeneration phase of stand development:

1. Establishment (stand age 4 to 8 years);
2. Performance (stand age 12 to 14 years);
3. Handover (stand age 16 to 18 years).

Forecasts are not reported for the establishment stage; but users are encouraged to input stocking values for secondary species observed at this stage if available, since these improve forecasts for the subsequent stages. Stocking and density at the performance stage are modelled and reported at the N03 density standard for conifers, and the N13 standard for hardwoods, consistent with the RSA. Only the N13 standard is used for modelling and reporting at the handover stage.

The approach taken to regeneration modelling for FRIPSY recognizes juvenile stand attributes as being influenced by reforestation treatments, site and stand variables, and interactions between attributes. Figure 8 illustrates the complexity and multiplicity of these relationships. Sub-models predicting top height, age, stocking, and density were developed for all species groups. Quadratic mean diameter and basal area per ha were also modeled for aspen and pine. Planted stock and natural regeneration of lodgepole pine were modelled separately (because they demonstrate different development trends), or in combination where appropriate (e.g. for top height and age in planted stands). Sub-models were developed either separately for performance and handover stages, or by combining both stages and incorporating years since cut (YSC).

Sub-models are of two broad types:

1. Nominal logistic regression (NLR): used for predicting stocking probabilities;
2. Standard least squares (SLS): multiple linear regression and analysis of variance / covariance, with variables transformed as appropriate.

Two-state combinations of NLR and SLS are used for density estimation of aspen and spruce i.e. density is calculated as a product of stocking probability (estimated by NLR) and trees per stocked plot (estimated by SLS analysis). All other sub-models are single-state.

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[6] *Effects of minimum height standards on growth and yield projections.* Addendum to Regenerated Lodgepole Pine Trial Crop Performance Report (18-year Results).

[7] Can. J. For. Res. Vol. 36: 878-885.

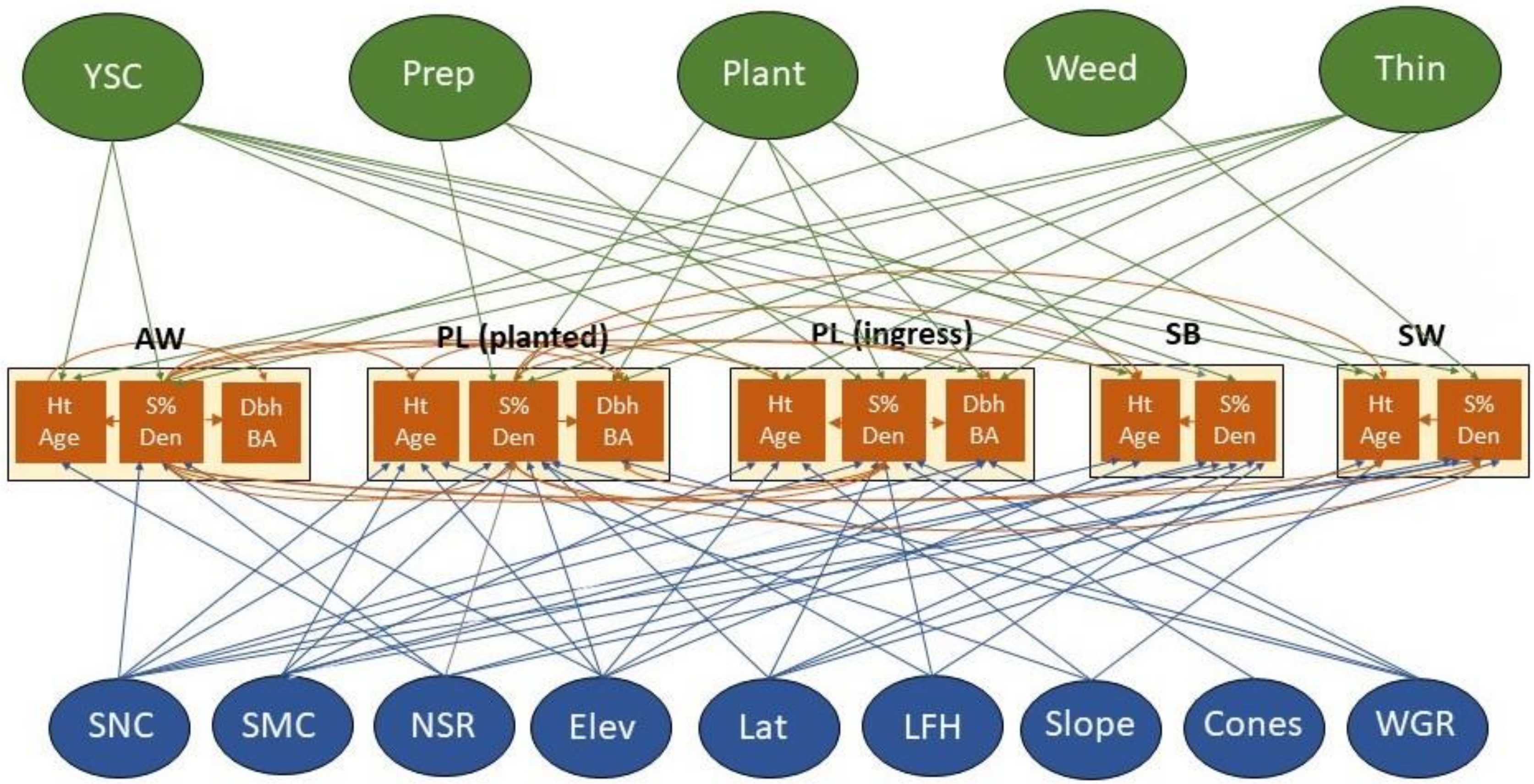

Figure 8. Treatment, site and stand variables used to predict stand attributes

Reforestation treatments are shown in green, and site and stand factors in blue (see Section 1.2 for variable definitions). Predicted attributes are shown in brown (*Ht Age* = top height and total age, *S% Den* = stocking % and density, *Dbh BA* = diameter breast-height and basal area). Species groups are AW (aspen / balsam poplar), PL (lodgepole pine), SB (black spruce) and SW (white spruce). The PL group is subdivided into planted and naturally regenerated (ingress) cohorts. Modeled linkages between treatments and attributes are indicated by green arrows, between other factors and attributes by blue arrows, and between attributes by brown arrows. Each line-arrow represents an independent (X) variable used in a sub-model.

Treatment, site and stand variables were selected for predicting stand attributes according to the following criteria. (Selections are represented by the colored arrows in Figure 8).

- *Statistical significance*. Potential predictive independent (X) variables were screened for the statistical significance of their effects on dependent (Y) variables; and the AIC (Akaike information criterion) was applied in preliminary analyses to judge which and how many parameters to use within a sub-model. Significance was explored using a mixed (fixed and random) effect model appropriate for the split-plot design of the RLP trial. X-variables were normally retained only if they had very high significance levels (i.e. probability of chance occurrence <0.0001). The Tukey HSD criterion was used to test for differences between levels of categorical variables (levels not significantly different were normally combined).
- *Goodness of fit and contribution to explained variation.*
    - Effect tests: F-ratios for SLS, likelihood-ratio and Wald tests for NLR;
    - R-square: for SLS (minimum 0.25);
    - R-square (U): for NLR (minimum 0.25; lower values permitted providing equivalent least-squares analyses met the SLS minimum criterion);
    - Leverage and residual plots: visualizations of distributions, trends, linearity and residuals; assisted selection of variables and transformations.
- *Independence*. Where possible, if two X-variables were found to interact, either the model was split into 2-submodels, or one of the variables was rejected.
- *Biological rationality*. Models were retained only where the relationship between X and Y variables, and the combination of X variables, was explainable and reasonable in terms pf biological process.
- *Data availability (user inputs)*. Variables selected as mandatory inputs are generally known by users or required under RSA protocols; additional optional inputs were selected where valuable for prediction and sometimes known by users.

2.2 Data

The main source of data for FRIPSY was the Regenerated Lodgepole Pine (RLP) trial. The trial was established in 2000 to monitor, under experimentally controlled conditions, the effects of planting, weeding and pre-commercial thinning on the growth and yield of lodgepole pine regenerated after harvesting. During the 20 years since establishment of the trial, the project focused on quantifying relationships between treatments, site and regeneration performance during the regeneration phase of stand development.[4]

Figure 9 illustrates the RLP design as applied from establishment of the trial in 2000 to the latest measurements taken in 2020. Each installation was planted at one of 6 densities, and divided into 4 treatment plots. The 6 planting densities were replicated 17 times, resulting in a total of 102 installations. A 1000m^2 measurement plot was placed centrally in each treatment plot, and sub-sampled with 16 circular 10m^2 sub-plots. All planted lodgepole pine within the measurement plot were tagged and assessed bi-annually for health and mortality. Natural regeneration in the 16 subplots was monitored by species for % stocking, density and height class. In addition, since 2015, all saplings and trees within the 16 sub-plots, plus sample planted trees previously designated outside the sub-plots, were assessed individually for species, height, diameter and health. Top height and age were measured by species on 4 sub-plots, each 100m^2.

Two additional datasets were used to supplement the RLP data.

1. *The Sundance site preparation trial*. The trial was established in 2001 to evaluate under controlled experimental conditions the effects of alternative harvesting and site preparation

methods on lodgepole pine stand development. Following harvest in 2000, the trial was site-prepared in 2001, planted at 2000 trees per ha in 2002, and re-measured in 2017.[8] The results were used to calibrate effects of site preparation as modeled from the RLP data. (Site preparation was not experimentally controlled in the RLP trial, and was suspected of being confounded with site effects.)

2. *The Empirical Post-harvest (EPH) database*. This includes data from operational performance surveys conducted according to RSA standards, and silvicultural records for the surveyed openings. The data facilitated comparison of FRIPSY projections, based entirely on experimental data, with results of operational regeneration performance surveys. The lack of experimental control severely curtailed the utility of EPH data for operational calibration of FRIPSY, but nevertheless provided some useful insights.

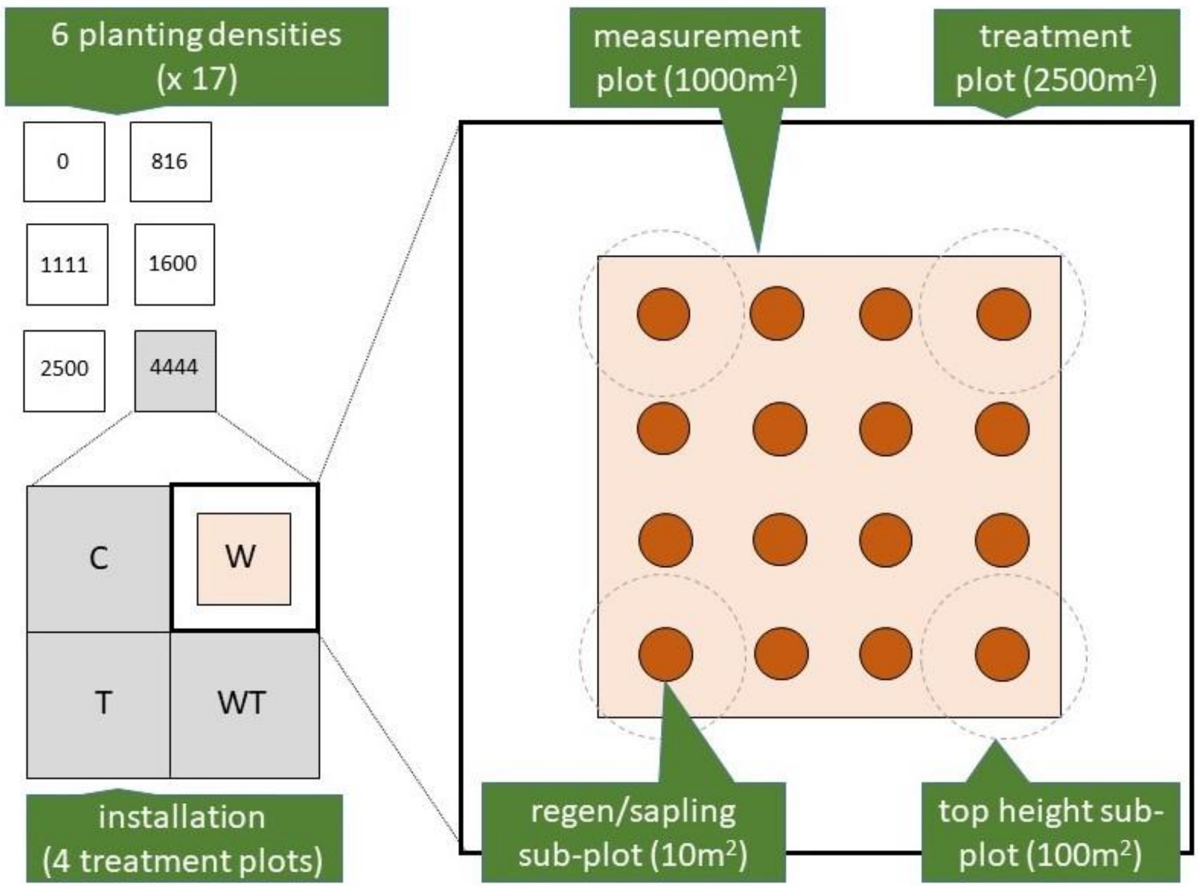

Figure 9. Design of the FGrOW Regenerated Lodgepole Pine Trial

[8] Dempster, W.R., S.M. Landhäusser, T. Ramsfield, S. Meredith. *Effects of harvesting and site preparation methods on juvenile stand development of lodgepole pine*. Sundance Site Preparation Trial, Final Technical Report prepared for Edson and Hinton Woodlands, West Fraser Mills Ltd., February 2020.

2.3 *Regeneration sub-models*

The FRIPSY regeneration model consists of over 40 linked sub-models, falling into 7 categories, which are overviewed in Sections 2.3.1 to 2.3.7 below. They are described in more detail in Appendix sections 3.2.1 (complete list of sub-models), 3.2.2 (list and definitions of variables), and 3.2.3 (statistical summaries of each sub-model).

2.3.1 Mortality and density of lodgepole pine planted stock

Mean annual mortality percent is estimated from Equation 1, separately for thinned and non-thinned planted stock.

Equation 1: $$m\% = e^{(a + \sum(biXi))}$$

where:

m% = mean annual mortality percent;
e = the base of natural logarithms;
bi = vector of regression coefficients;
Xi = vector of independent variables.

Density of planted stock (denPLp)is calculated before (or without) thinning as the number of planted trees per ha (input by the user) less the number of trees forecast to have died since planting (estimated from age and the mean annual mortality rate). After thinning it is calculated retroactively from the user-specified post-thinning target density at handover, the number of growing seasons since thinning, and the mean annual mortality rate.

2.3.2 Density of lodgepole pine natural regeneration (ingress)

Density of non-thinned pine ingress at the handover stage is estimated from Equation 2.

Equation 2: $$denPLn = (a + \sum(b_iX_i))^2$$

where:

denPLn = density (stems per ha);
X_i is a vector of i independent variables;
a and b are coefficients.

In thinned stands at handover it is computed from the user-specified thinning target and density of planted stock. Density of pine ingress during the performance stage is retroactively estimated from density at handover.

2.3.3 Stocking of lodgepole pine

Stocking (the probability of $10m^2$ regeneration sub-plots having at least one live planted seedling) is estimated by Equation 3 from the number of live trees per ha calculated as described above.

Equation 3: $$sPL = (1 + e^X)^{-1}$$

where:

sPL = stocking probability of planted and naturally regenerated pine (combined);
e = the base of natural logarithms;
X = a + b * √denPLp + c* √denPLp;

a, b and c are coefficients.

2.3.4 Stocking and density of other species

The prediction of stocking and density for secondary species groups (aspen / balsam poplar, black spruce, white spruce / balsam fir) involves two-state models, whereby the probability of a regeneration plot being stocked, and the number of trees per stocked plot, are modeled separately, and then combined in order to predict density (trees per ha). Sub-models for stocking probability are of the general form shown in Equation 4.

Equation 4: $\mathbf{s = (1 + e^{(\sum biXi)})^{-1}}$

where:

s = stocking probability
e = the base of natural logarithms;
bi = vector of regression coefficients;
Xi = vector of independent variables.

Sub-models for prediction of stocking at performance and handover stages incorporate a stocking probability index (*spin*), defined as stocking % / 100 at 8 years after cut. Where this cannot be provided by the user from operational establishment surveys, it is predicted within the FRIPSY regeneration model from RLP trial data using Equation 4.

Sub-models for prediction of trees per stocked plot are of the general form shown in Equation 5.

Equation 5: $\mathbf{tpsp = e^{(a + \sum(biXi))}}$

where:

tpsp = number of trees per stocked plot;
e = the base of natural logarithms;
bi = vector of regression coefficients;
Xi = vector of independent variables.

2.3.5 Tree diameter

Quadratic mean diameters are estimated directly (for aspen and planted pine), or log transformed (for pine ingress), as linear functions of site and stand variables as shown in Equation 6.

Equation 6: **dbh *or* LN(dbh) = a + $\sum(b_i X_i)$**

where:

dbh = quadratic mean diameter at breast-height;
LN(dbh) = natural logarithm of dbh;
X_i is a vector of i independent variables;
a and b_i are coefficients.

The FRIPSY regeneration model uses quadratic mean diameter to predict basal area per ha (the product of basal area per tree and number of trees per ha).

2.3.6 Top height and age

Age of pine in planted stands is calculated from the planting year specified by the user. (Total age at planting is assumed to be one year after germination, unless the user specifies planting as being "advanced".) Ages of pine in unplanted stands, and of secondary species, are predicted as linear functions of site and stand variables, including years since cut (YSC).

Top heights are predicted directly (for coniferous species), or log transformed (for aspen), as linear functions of site and stand variables as shown in Equation 7.

Equation 7: $$\textbf{topht } \textbf{\textit{or}} \textbf{ LN(topht)} = a + \sum(b_i X_i)$$

where:

topht = top height (average height of 100 largest DBH trees per ha)
LN(topht) = natural logarithm of top height;
X_i is a vector of i independent variables, including age;
a and b_i are coefficients.

2.3.7 Western gall rust effects on lodgepole pine density and diameter

Pine densities and mean diameters, after excluding pine trees with stems more than 50% encircled by western gall rust (WGR), are predicted by simple linear regression as functions of unadjusted densities and diameters. No other stand or site variables were added as predictors, because they were found to be either statistically non-significant, not independent of density, or not to substantially improve explained variation.

3 Appendices

3.1 New features and enhancements

The following features and enhancements were included in FRIPSY 2021, and have been retained in the 2022 version.

Extension of the regeneration phase

- Handover from the regeneration model to GYPSY is extended to 18 years after harvest, instead of at 12 -14 years as in previous versions and the RSA;
- Regeneration performance is still reported at 12-14 years; but also at the “handover” stage (i.e. the extended end of the regeneration phase);
- Stocking and densities reported at the handover stage and used for input to GYPSY are based on a minimum tree height of 1.3m (as distinct from 0.3m at performance assessment in the RSA);
- Stocking and densities for performance assessment at 12 – 14 years, as in the existing version and RSA, are based on the 1.3m standard for aspen / poplar, but on a minimum tree height of 30cm for conifers, in order to maintain consistency with the RSA;
- GYPSY inputs include basal area (except for the spruce / fir regeneration which is generally insufficiently advanced by 18 years for inclusion of basal area to be useful).

Pre-commercial thinning

- Optional pre-commercial thinning of pine (with manual brushing of hardwood) is now added to site preparation, planting, and chemical weeding as a reforestation treatment;
- Users may specify a thinning year, plus a target post-thinning density for pine at the end of the regeneration phase;
- The model estimates the thinning density required at the specified thinning year, in order to meet the target density at handover;
- Thinning may be before, during, or after the year specified for RSA performance assessment.

Secondary species

- Forecasts for natural regeneration of white spruce / balsam fir (combined) and black spruce are given for non-thinned stands (insufficient data and experimental control were available for including spruces in the thinning treatment);
- Aspen forecasts (trembling aspen and black poplar combined) are provided with and without thinning;
- Users may optionally input establishment stocking of secondary species to improve / localize forecasts (this option has been discontinued for pine, the primary species, because it was found not to improve prediction).

Western gall rust

- An option is provided for simulating the RSA protocol for western gall rust, by adjusting pine densities and diameter growth to reflect exclusion of girdled trees from GYPSY inputs and other statistics reported for the handover stage.

Additional user inputs

- Latitude and elevation have been added to the existing mandatory site variables (natural sub-region, soil nutrient class, soil moisture class) because they substantially improve some of the sub-models and are easily available to most users;

- The following variables have also been found to improve some sub-models, and are added as optional inputs: pine ground cone density (following harvesting and / or site preparation), depth of organic soil, and slope percent.

Calibration and adjustments

- Following comparisons of FRIPSY predictions with data from the Sundance site preparation trial, empirical-post harvest database, and latest measurements of the RLP trial, the adjustments described below were made to sub-models within the FRIPSY regeneration model.
- Site preparation treatments *None* and *Mound* were merged in the prediction of pine natural regeneration densities. Data from the Sundance trial, where the effects of site preparation was experimentally controlled, did not show statistically significant differences between the two treatments. Difference observed in the RLP trial data were suspected to have resulted from site and treatment effects being confounded.
- Top height, density, and diameter predicted for pine at handover and for initializing GYPSY were constrained not to exceed the upper 97.5th percentile observed in the RLP trial data.
- Other cautionary downward adjustments were made for lodgepole pine in the prediction of top height on sites in the *Poor* soil nutrient class, top height and diameter in natural regeneration, and stocking percent.
- No such downward adjustments were made for aspen, because comparisons with the EPH data suggested that, in an operational environment, aspen competition may be more severe than predicted. Models predicting aspen stocking and density were adjusted upwards to include effects of extreme outlier RLP trial weeded plots, and to offset possible underestimation on non-weeded mid-elevation sites in the *Medium* soil nutrient class.

No new features were added in 2022. However, a number of minor bugs have been fixed since release of FRIPSY 2021. Also, the criterion for defining minor species has been raised from 30 to 50 trees per ha (see page 9).

In January 2023, minor revisions were made to the User Guide, sections 1.2.1, 1.2.4 and 1.4, in response to questions and comments raised during a FRIPSY workshop held on November 21, 2022. The revisions are purely for clarification, and did not require or involve any changes to FRIPSY itself.

3.2 Description of regeneration sub-models

3.2.1 List of sub-models

1A	Mean annual mortality of non-thinned lodgepole pine planted stock to handover age
1B	Mean annual mortality of thinned lodgepole pine planted stock to handover age
2A	Stems per ha of non-thinned lodgepole pine natural regeneration at handover stage
1A	Mean annual mortality of non-thinned lodgepole pine planted stock to handover age
1B	Mean annual mortality of thinned lodgepole pine planted stock to handover age
2A	Stems per ha of non-thinned lodgepole pine natural regeneration at handover stage
2B	Stems per ha of lodgepole pine natural regeneration during performance stage
3A	Percent stocking pine (1.3m+) in planted stands at handover stage
3B	Percent stocking pine (1.3m+) in unplanted stands at handover stage
3C	Percent stocking pine (30cm+) in planted stands during performance stage
3D	Percent stocking pine (30cm+) in unplanted (leave for natural) stands during performance stage
4A1	Stocking probability index for aspen/poplar (1.3m+) in non-weeded stands
4A2	Stocking probability index for aspen/poplar (1.3m+) in weeded stands
4A3	Stocking probability non-thinned non-weeded aspen/poplar(1.3m+) during performance and handover stages
4A3	Stocking probability non-thinned weeded aspen/poplar(1.3m+) during performance and handover stages
4A4	Stocking probability of thinned aspen / poplar(1.3m+) during performance and handover stages
4A5	Trees per stocked plot of non-weeded non-thinned aspen / poplar (1.3m+) during performance and handover stages
4A6	Trees per stocked plot of weeded non-thinned aspen / poplar (1.3m+) during performance and handover stages
4A7	Trees per stocked plot of thinned aspen / poplar (1.3m+) during performance and handover stages
4B1	Stocking probability index of black spruce (30cm+)
4B2	Stocking probability index of whie spruce / balsam fir (30cm+)
4B3	Stocking probability of black spruce (1.3m+) at handover (non-thinned stands only)
4B4	Stocking probability of black spruce (1.3m+) at handover (augmented, non-thinned stands only)
4B5	Stocking probability of white spruce / balsam fir (1.3m+) at handover (non-thinned stands only)
4B6	Trees per stocked plot (1.3m+) of black spruce at handover (non-thinned stands only)
4B7	Trees per stocked plot (1.3m+) of white spruce / balsam fir at handover (non-thinned stands only)
5A1	Quadratic mean diameter of planted non-thinned pine at handover
5A2	Quadratic mean diameter of planted thinned pine at handover
5A3	Quadratic mean diameter of non-thinned pine natural regeneration at handover
5A4	Quadratic mean diameter of thinned pine natural regeneration at handover
5B1	Quadratic mean diameter of non-thinned aspen / poplar at handover
5B2	Quadratic mean diameter of thinned aspen / poplar at handover
6A1	Total age of naturally regenerated pine in unplanted non-thinned stands
6A2	Total age of naturally regenerated pine in unplanted thinned stands
6A3	Top height of pine in unplanted stands
6A4	Top height of pine in planted stands
6B1a	Total age of thinned aspen / balsam poplar
6B1b	Total age of untreated aspen / balsam poplar (no weed, no thin)
6B1c	Total age of weeded non-thinned aspen / balsam poplar
6B2	Top height of aspen / balsam poplar after
6C1	Total age of black spruce at handover in non-thinned stands
6C2	Top height of black spruce at handover in non-thinned stands
6C3	Total age of white pruce / balsam fir at handover in non-thinned stands
6C4	Top height of white spruce / balsam fir at handover in non-thinned stands
7	Adjustments to pine handover density and DBH excluding trees with more than 50% stem girdling by western gall rust

3.2.2 List of variables

ageAW	Total age of aspen / poplar site trees (years)
agePL	Total age of pine site trees (years since germination)
ageSB	Total age of black spruce site trees (years since germination)
ageSW	Total age of white spruce / fir site trees (years since germination)
Cones	Ground cone density per m^2 (pine only)
dbhAW	Quadratic mean diameter breast-height aspen / poplar
dbhPL	Quadratic mean diameter breast-height pine
dbhPLn	Quadratic mean diameter breast-height pine ingress
dbhPLnX	dbhPLn adjusted for exclusion of trees with more than 50% girdling of main stem by western gall rust
dbhPLp	Quadratic mean diameter breast-height planted pine
dbhPLpX	dbhPLp adjusted for exclusion of trees with more than 50% girdling of main stem by western gall rust
denAW	Stems per ha aspen / poplar (1.3m+) = tpspAW*sAW *1000
denAW2000	denAW-2000 (transformation used when no response shown below 2000 stems per ha)
denPL	Stems per ha pine total (30cm+) - planted plus natural
denPL13	Stems per ha pine total (1.3m+) - planted plus natural
denPLn	Stems per ha pine ingress (30cm+)
denPLn13	Stems per ha pine ingress (1.3m+) at handover
denPLn13X	denPLn13 adjusted for exclusion of trees with more than 50% girdling of main stem by western gall rust
denPLp	Stems per ha planted pine (30cm+) during performance stage; non-thinned = nP*(1-(mP/100*GSP)); thinned = nTp*1/(1-(mT/100*GST))
denPLp13	Stems per ha planted pine (1.3m+) at handover; non-thinned = (1-(Mp/100*GSP))*nP; if thinned =nTp
denPLp13X	denPLp13 adjusted for exclusion of trees with more than 50% girdling of main stem by western gall rust
denSB13	Stems per ha black spruce (1.3m+) = tpspSB*sSB13*1000
denSW13	Stems per ha white spruce (1.3m+) = tpspSW*sSW13*1000
Elev	Elevation (m) above sea level
GSG	Growing seasons since germination (PL planted stock)
GSP	Growing seasons since planting (PL planted stock)
GST	Growing seasons since thinning
Lat	Decimal degrees north
LFH	Depth of organic soil (litter, fungi, humus)
LN1Cones	Natural logarithm of (Cones+1)
LN1denPL	Natural logarithm of (denPL+1)
LN1mP	Natural logarithm of (mP+1)
LN1mT	Natural logarithm of (mT+1)
LNnP	Natural logarithm of nP
LNpsSB13	Natural logarithm of psSB13
LNpsSW13	Natural logarithm of psSW13
LNtophtAW	Natural logarithm of AW top height
LNtophtPL	Natural logarithm of pine top height
mP	Mean annual mortality percent of lodgepole pine planted stock since planting: cumulative mortality/GSP.
mT	Periodic annual mortality rate of lodgepole pine planted stock after thinning
nP	Number of lodgepole pinetrees planted per ha
nP1600	nP-1600 (transformation used when no response shown below 1600 stems per ha)
nP750	nP-750 (transformation used when no response shown below 750 stems per ha)
NSR	Natural sub-region: Upper or Lower Foothills
nT	Target post-thinning density of lodegpole pine at handover (trees per ha 1.3m+)
nTn	Target post-thinning density of natural lodegpole pine at handover (trees per ha 1.3m+) = nT -nTp
nTp	Target post-thinning density of planted lodegpole pine at handover (trees per ha 1.3m+)
Prep	Mechanical site preparation: none, drag, mound
PrepB	Broad mechanical site prep (2 levels): drag, other
PrepC	Broad mechanical site prep (2 levels): none, MSP

ps....	(Prefacing species name e.g. psAW) Percent stocking (equals stocking probability * 100)
sAW	Stocking probability aspen / poplar (1.3m+)
Slope	Slope percent
SMC	Soil moisture class: dry, mesic, moist
SMCb	Broad soil moisture class (2 levels): MesicDry, Moist (used when no significanr response difference between mesic and dry levels)
SMCc	Broad soil moisture class (2 levels): Dry, MesicMoist (used when no significant difference between mesic and moist levels)
SNC	Soil nutrient class: rich (D), medium (C), poor (B)
SNCb	Broad soil nutrient class (2 levels): B, CD (used when significant difference between C and D)
SNCd	Broad soil nutrient class (2 levels): D, BC (used when no significant difference between B and C)
spinAW	Stocking probability index aspen / poplar (1.3m+): probability of $10m^2$ regeneration sub-plot having at least one live naturally regenerated seedling by 8 years after cut
spinAW125	spinAW-0.125 (transformation used when no response shown below 0.125)
spinAW8125	spinAW-0.8125 (transformation used when no response shown below 0.8125)
spinSB	Stocking probability index black spruce (30cm+): probability of $10m^2$ regeneration sub-plot having at least one live naturally regenerated seedling by 8 years after cut
spinSW	Stocking probability index white spruce / fir (30cm+): probability of $10m^2$ regeneration sub-plot having at least one live naturally regenerated seedling by 8 years after cut
sPL	Stocking probability of pine (30cm+)
sPL13	Stocking probability of pine (1.3m+)
SQRTdenPLn	Square root of denPLn
SQRTdenPLn13	Square root of denPLn13
SQRTdenPLp	Square root of denPLp
SQRTdenPLp13	Square root of denPLp13
sSB13	Stocking probability of black spruce (1.3m+)
sSW13	Stocking probability of white spruce (1.3m+)
Thin	Thinning to target density, plus removal of hardwood competition: thinned (Yes),non-thinned (No)
tophtAW	Top height of aspen / poplar (cm)
tophtPL	Top height of pine (cm)
tophtSB	Top height of black spruce (cm)
tophtSW	Top height of white spruce / fir (cm)
tpspAW	Number of live naturally regenerated aspen / poplar trees (1.3m+) per stocked regeneration plot
tpspSB	Number of live naturally regenerated black spruce trees (1.3m+) per stocked regeneration plot
tpspSW	Number of live naturally regenerated white spruce / balsam fir trees (1.3m+) per stocked regeneration plot
Weed	Chemical weed control during establishment stage (completed before YSD 8): weeded (Yes), non-weeded (No)
YSC	Years since cut (based on Timber Year of Cut)

3.2.3 Statistical summaries

1A Mean annual mortality of non-thinned pine planted stock to handover age

Response LN1mP Transformation: mP = exp(LN1mP)-1

Summary of Fit

RSquare	0.61752
RSquare Adj	0.601909
Root Mean Square Error	0.24225
Mean of Response	0.894557
Observations (or Sum Wgts)	154

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.2803319	1.158147	6.29	<.0001
PrepB[MSP]	-0.149253	0.023447	-6.37	<.0001
NSR[LF]	0.1233784	0.024855	4.96	<.0001
SMCb[MesicDry]	0.1024504	0.024038	4.26	<.0001
Lat	-0.122209	0.021656	-5.64	<.0001
denAW	0.0000397	0.000007	5.66	<.0001
LFH	0.01463	0.002635	5.55	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
PrepB	1	1	2.3778813	40.5193	<.0001
NSR	1	1	1.4460715	24.6412	<.0001
SMCb	1	1	1.0660341	18.1653	<.0001
Lat	1	1	1.8687964	31.8445	<.0001
denAW	1	1	1.8794078	32.0253	<.0001
LFH	1	1	1.8086536	30.8196	<.0001

1B Mean annual mortality of thinned pine planted stock to handover age

Response LN1mT   Transformation: mT = exp(LN1mT)-1

Summary of Fit

RSquare	0.304361
RSquare Adj	0.277606
Root Mean Square Error	0.381028
Mean of Response	0.479042
Observations (or Sum Wgts)	109

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.9218365	0.233457	3.95	0.0001
SNCb[B]	-0.171878	0.045595	-3.77	0.0003
spinAW	0.3248999	0.146695	2.21	0.029
Elev	-0.000624	0.000191	-3.26	0.0015
nP	0.0000688	0.000029	2.34	0.0211

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
SNCb	1	1	2.0630678	14.2102	0.0003
spinAW	1	1	0.7121728	4.9054	0.029
Elev	1	1	1.5453427	10.6441	0.0015
nP	1	1	0.7957114	5.4808	0.0211

2A Stems per ha (1.3m+) of non-thinned pine natural regeneration at handover stage

Response SQRTdenPLn13 Transformation: denPLn13 = (SQRTdenPLn13)^2

Summary of Fit

RSquare	0.745986
RSquare Adj	0.733364
Root Mean Square Error	21.75784
Mean of Response	66.01618
Observations (or Sum Wgts)	170

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	318.45901	121.9524	2.61	0.0099
PrepC[Drag]	15.816305	2.055525	7.69	<.0001
SNC[B]	-8.415743	3.195118	-2.63	0.0093
SNC[C]	13.193607	2.639102	5	<.0001
Lat	-5.170499	2.233949	-2.31	0.0219
denAW	-0.00319	0.000601	-5.31	<.0001
nP1600	-0.008248	0.001634	-5.05	<.0001
LN1Cones	22.081144	3.385722	6.52	<.0001
LFH	-1.044781	0.206294	-5.06	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
PrepC	1	1	28028.283	59.2059	<.0001
SNC	2	2	12336.182	13.0292	<.0001
Lat	1	1	2536.005	5.357	0.0219
denAW	1	1	13328.337	28.1543	<.0001
nP1600	1	1	12067.225	25.4903	<.0001
LN1Cones	1	1	20135.953	42.5344	<.0001
LFH	1	1	12142.492	25.6493	<.0001

2B Stems per ha (30cm+) of pine natural regeneration during performance stage

Response SQRTdenPLn — Transformation: denPLn = (SQRTdenPLn)^2

Summary of Fit

RSquare	0.94129
RSquare Adj	0.940914
Root Mean Square Error	12.39191
Mean of Response	65.16165
Observations (or Sum Wgts)	315

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.5594531	1.200216	2.97	0.0033
SQRTdenPLn13	1.2230386	0.020825	58.73	<.0001
Thin[No]	2.1547925	0.833097	2.59	0.0101

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
SQRTdenPLn13	1	1	529666.79	3449.262	<.0001
Thin	1	1	1027.3	6.6899	0.0101

3A Percent stocking of pine (1.3m+) in planted stands at handover stage

Nominal logistic response Y — Transformation: sPL13 = $((1 + e^{Y})^{-1})$

RSquare (U)	0.2579
Observations (or Sum Wgts)	5056

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	2.63935273	0.2010829	172.28	<.0001
Thin[No]	0.40137704	0.0569774	49.62	<.0001
SQRTdenPLn13	-0.044647	0.0030649	212.2	<.0001
SQRTdenPLp13	-0.1093307	0.0060728	324.12	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
Thin	1	1	49.6248536	0
SQRTdenPLn13	1	1	212.204186	0
SQRTdenPLp13	1	1	324.121431	0

3B Percent stocking of pine (1.3m+) in unplanted stands at handover stage

Nominal logistic response Y	Transformation: sPL13 = $((1 + e^{Y})^{-1})$
RSquare (U)	0.4419
Observations (or Sum Wgts)	896

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	3.41114208	0.3292332	107.35	<.0001
Thin[No]	0.31759737	0.1144261	7.7	0.0055
SQRTdenPLn13	-0.0902168	0.0066034	186.65	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
Thin	1	1	7.70377105	0.0055
SQRTdenPLn13	1	1	186.653757	0

3C Percent stocking of pine (30cm+) in planted stands during performance stage

Nominal logistic response Y	Transformation: sPL = $((1 + e^{Y})^{-1})$
RSquare (U)	0.2548
Observations (or Sum Wgts)	5056

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	2.56435842	0.2364389	117.63	<.0001
Thin[No]	0.2825084	0.0639761	19.5	<.0001
SQRTdenPLn	-0.0347872	0.0025428	187.16	<.0001
SQRTdenPLpRP	-0.1090304	0.0071554	232.18	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
Thin	1	1	19.4996593	0
SQRTdenPLn	1	1	187.16271	0
SQRTdenPLp	1	1	232.179841	0

3D Percent stocking of pine (30cm+) in unplanted stands during performance stage

Nominal logistic response Y — Transformation: $sPL = ((1 + e^{Y})^{-1})$

RSquare (U)	0.4232
Observations (or Sum Wgts)	896

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	2.68121574	0.2605757	105.88	<.0001
Thin[No]	0.24992337	0.1064955	5.51	0.0189
SQRTdenPLn	-0.0643641	0.0047985	179.92	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
Thin	1	1	5.50746278	0.0189
SQRTdenPLn	1	1	179.921608	0

4A1 Stocking probability index of aspen/poplar (1.3m+) in non-weeded stands

Nominal logistic response Y — Transformation: $spinAW = ((1 + e^{Y})^{-1})$

RSquare (U)	0.5116
Observations (or Sum Wgts)	2896

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-9.8674522	0.5693905	300.32	<.0001
SNC[B]	2.9547378	0.2035317	210.75	<.0001
SNC[C]	-0.4395933	0.1203763	13.34	0.0003
Elev	0.01052609	0.0005178	413.25	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
SNC	2	2	404.203024	0
Elev	1	1	413.250659	0

4A2 Stocking probability index of aspen/poplar (1.3m+) in weeded stands

No statistically significant sub-model found; RLP trial averages by soil nutrient class used instead.

SNC	Average
B	0.008929
C	0.023897
D	0.027439

4A3a Stocking probability of untreated aspen/poplar (1.3m+) during performance and handover stages (no weeding or thinning)

Nominal logistic response Y Transformation: sAW = $((1 + e^{Y})^{-1})$

RSquare (U) 0.5176
Observations (or Sum Wgts) 5568

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	1.06231657	0.4168329	6.5	0.0108
spinAw	-5.2519521	0.1917775	749.97	<.0001
SNC[B]	0.74389368	0.104567	50.61	<.0001
SNC[C]	-0.473438	0.0696211	46.24	<.0001
Elev	0.00136858	0.0003479	15.47	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
spinAw	1	1	749.973724	0
SNC	2	2	63.7704588	0
Elev	1	1	15.4719492	0.0001

4A3b Stocking probability of weeded aspen/poplar (1.3m+) during performance and handover stages (no thinning)

Nominal logistic response Y Transformation: sAW = $((1 + e^{Y})^{-1})$

RSquare (U) 0.0995
Observations (or Sum Wgts) 2816

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	1.17969636	0.7333381	2.59	0.1077
spinAw	-14.710444	1.3599161	117.01	<.0001
Elev	0.00225166	0.0007201	9.78	0.0018

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
spinAw	1	1	117.01118	0
Elev	1	1	9.77604463	0.0018

4A4 Stocking probability of thinned aspen / poplar (1.3m+) during performance and handover stages

Nominal logistic response Y — Transformation: $sAW = ((1 + e^{Y})^{-1})$

RSquare (U)	0.3259
Observations (or Sum Wgts)	7936

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	5.62534165	0.1761748	1019.6	<.0001
spinAW	-3.9612752	0.1286976	947.39	<.0001
GST	-0.4963176	0.0355299	195.13	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
spinAW	1	1	947.391186	0
GST	1	1	195.133251	0

4A5 Trees per stocked plot of untreated aspen / poplar (1.3m+) during performance and handover stages (no weeding or thinning)

Response LNtpspAW — Transformation: tpspAW = EXP(LNtpspAW)

Summary of Fit

RSquare	0.735424
RSquare Adj	0.731943
Root Mean Square Error	0.521045
Mean of Response	1.243884
Observations (or Sum Wgts)	232

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.0045586	0.226616	8.85	<.0001
spinAw	1.5858104	0.09523	16.65	<.0001
YSC	-0.085171	0.014694	-5.8	<.0001
NSR[LF]	0.3412056	0.039373	8.67	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
spinAw	1	1	75.283773	277.3006	<.0001
YSC	1	1	9.121249	33.5972	<.0001
NSR	1	1	20.388748	75.1	<.0001

4A6 Trees per stocked plot of weeded non-thinned aspen / poplar (1.3m+) during performance and handover stages

Response LNtpspAW Transformation: tpspAW = EXP(LNtpspAWc)

Summary of Fit

RSquare	0.517309
RSquare Adj	0.504771
Root Mean Square Error	0.351915
Mean of Response	0.356764
Observations (or Sum Wgts)	80

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.9378484	0.241916	3.88	0.0002
spinAW	5.5998424	0.655809	8.54	<.0001
YSC	-0.058229	0.016285	-3.58	0.0006

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
spinAW	1	1	9.0296756	72.9117	<.0001
YSC	1	1	1.5834301	12.7857	0.0006

4A7 Trees per stocked plot of thinned aspen / poplar (1.3m+) during performance and handover stages

Response LNtpspAW Transformation: tpspAW = EXP(LNtpspAW)

Summary of Fit

RSquare	0.6928
RSquare Adj	0.681629
Root Mean Square Error	0.448291
Mean of Response	0.753587
Observations (or Sum Wgts)	58

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.3209677	0.074846	4.29	<.0001
spinAW	1.5184861	0.172737	8.79	<.0001
NSR[LF]	0.1990344	0.063422	3.14	0.0027

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
spinAW	1	1	15.530058	77.2775	<.0001
NSR	1	1	1.97925	9.8487	0.0027

4B1 Stocking probability index of black spruce (30cm+)

Nominal logistic response Y	Transformation: spinSB = $((1 + e^{Y})^{-1})$
RSquare (U)	0.2518
Observations (or Sum Wgts)	5952

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	4.28226793	0.3622919	139.71	<.0001
NSR[LF]	0.97900427	0.1420271	47.51	<.0001
SMC[Dry]	1.98632197	0.6754164	8.65	0.0033
SMC[Mesic]	-1.0862344	0.3497897	9.64	0.0019
SNCb[B]	-0.9220635	0.0724315	162.06	<.0001
LFH	-0.0365635	0.0065178	31.47	<.0001
Slope	0.19538885	0.0320322	37.21	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
NSR	1	1	47.5145596	0
SMC	2	2	9.71253799	0.0078
SNCb	1	1	162.056733	0
LFH	1	1	31.4695986	0
Slope	1	1	37.2071709	0

4B2 Stocking probability index of white spruce / balsam fir (30cm+)

Nominal logistic response Y	Transformation: spinSW = $((1 + e^{Y})^{-1})$
RSquare (U)	0.1698 (standard least squares equivalent 0.2792)
Observations (or Sum Wgts)	5920

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	54.4311615	5.1119222	113.38	<.0001
SNCd[BC]	0.67746408	0.0716775	89.33	<.0001
NSR[LF]	-0.4656527	0.0606377	58.97	<.0001
SMCb[MesicDry]	0.53133369	0.0676463	61.69	<.0001
spinAW	1.36298775	0.2370594	33.06	<.0001
Lat	-0.9666471	0.0944292	104.79	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
SNCd	1	1	89.3318586	0
NSR	1	1	58.9711459	0
SMCb	1	1	61.6944816	0
spinAW	1	1	33.0574671	0
Lat	1	1	104.790729	0

4B3 Stocking probability of black spruce (1.3m+) at handover (non-thinned stands only)

Nominal logistic response Y	Transformation: sSB = $((1 + e^{Y})^{-1})$
RSquare (U)	0.2948
Observations (or Sum Wgts)	5872

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	50.807021	5.7745682	77.41	<.0001
SNCb[B]	-0.7637103	0.0772837	97.65	<.0001
PrepB[MSP]	-0.7115784	0.0805626	78.02	<.0001
Lat	-0.8090853	0.105278	59.06	<.0001
YSC	-0.234843	0.0530396	19.6	<.0001
LFH	-0.0419577	0.0046706	80.7	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
SNCb	1	1	97.6520587	0
PrepB	1	1	78.0150451	0
Lat	1	1	59.0626874	0
YSC	1	1	19.6044827	0
LFH	1	1	80.6995895	0

4B4 Stocking probability of black spruce (1.3m+) at handover (augmented, non-thinned stands only)

Nominal logistic response Y	Transformation: sSB = $((1 + e^{Y})^{-1})$
RSquare (U)	0.3164
Observations (or Sum Wgts)	5872

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	58.9748775	6.2463008	89.14	<.0001
SNCb[B]	-0.5109321	0.0841783	36.84	<.0001
PrepB[MSP]	-0.6494864	0.0846043	58.93	<.0001
Lat	-0.9529354	0.1137765	70.15	<.0001
YSC	-0.257228	0.0544669	22.3	<.0001
LFH	-0.0235817	0.0056339	17.52	<.0001
spinSB	-2.9717776	0.344158	74.56	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
SNCb	1	1	36.8405131	0
PrepB	1	1	58.9325081	0
Lat	1	1	70.1490683	0
YSC	1	1	22.3033718	0
LFH	1	1	17.5196236	0
spinSB	1	1	74.5618884	0

4B5 Stocking probability of white spruce / balsam fir (1.3m+) at handover (non-thinned stands)

Nominal logistic response Y — Transformation: $sSW = ((1 + e^{Y})^{-1})$

RSquare (U)	0.2504
Observations (or Sum Wgts)	5952

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	6.18655461	1.2446639	24.71	<.0001
YSC	-0.1550561	0.0720514	4.63	0.0314
denPLp13	0.00024224	0.0000819	8.75	0.0031
Weed[No]	0.29578886	0.0764944	14.95	0.0001
SNCd[BC]	0.43848945	0.0773578	32.13	<.0001
spinSW	-6.6540913	0.3857778	297.51	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
YSC	1	1	4.6311922	0.0314
denPLp13	1	1	8.7524501	0.0031
Weed	1	1	14.9521783	0.0001
SNCd	1	1	32.1299537	0
spinSW	1	1	297.510973	0

4B6 Trees per stocked plot (1.3m+) of black spruce at handover (non-thinned stands only)

Response LNtpspSB — Transformation: tpspSB = EXP(LNtpspSB)

Summary of Fit

RSquare	0.452998
RSquare Adj	0.448854
Root Mean Square Error	0.321435
Mean of Response	0.461932
Observations (or Sum Wgts)	134

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.5705	0.102576	-5.56	<.0001
LNpsSB13	0.3504881	0.033522	10.46	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LNpsSB13	1	1	11.294561	109.3155	<.0001

4B7 Trees per stocked plot of white spruce / balsam fir (1.3m+) at handover (non-thinned stands only)

Response LNtpspSW Transformation: tpspSW = EXP(LNtpspSW)

Summary of Fit

RSquare	0.424219
RSquare Adj	0.417445
Root Mean Square Error	0.251358
Mean of Response	0.251055
Observations (or Sum Wgts)	87

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.395858	0.086074	-4.6	<.0001
LNpsSW13	0.257441	0.032531	7.91	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LNpsSW13	1	1	3.9567347	62.6257	<.0001

5A1 Quadratic mean diameter of non-thinned planted pine at handover

Response dbhPLp

Summary of Fit

RSquare	0.75425
RSquare Adj	0.751068
Root Mean Square Error	1.029371
Mean of Response	8.206877
Observations (or Sum Wgts)	314

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-29.69763	2.162025	-13.74	<.0001
LNtophtPL	7.62577	0.315068	24.2	<.0001
LNnP	-1.411253	0.099625	-14.17	<.0001
denPLn	-0.000077	0.000009	-8.15	<.0001
spinAw125	-4.297986	0.252015	-17.05	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LNtophtPL	1	1	620.72999	585.8125	<.0001
LNnP	1	1	212.62708	200.6663	<.0001
denPLn	1	1	70.45625	66.4929	<.0001
spinAw125	1	1	308.19255	290.856	<.0001

5A2 Quadratic mean diameter of thinned planted pine at handover

Model dbhPLpT Quadratic mean diameter of thinned planted pine at handover
Response dbhPLp

Summary of Fit

RSquare	0.780971
RSquare Adj	0.778837
Root Mean Square Error	1.041413
Mean of Response	9.112415
Observations (or Sum Wgts)	312

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.307736	0.812136	15.15	<.0001
tophtPL	0.013717	0.000491	27.93	<.0001
LNnP	-1.626548	0.100672	-16.16	<.0001
spinAw8125	-12.11799	1.602801	-7.56	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
tophtPL	1	1	846.16559	780.2058	<.0001
LNnP	1	1	283.11723	261.0478	<.0001
spinAw8125	1	1	61.99374	57.1612	<.0001

5A3 Quadratic mean diameter of non-thinned pine natural regeneration at handover

Response LNdbhPLn Transformation: dbhPLn = EXP(LNtdbhPLn)

Summary of Fit

RSquare	0.668406
RSquare Adj	0.660487
Root Mean Square Error	0.177117
Mean of Response	1.255145
Observations (or Sum Wgts)	344

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.3711533	0.153781	2.41	0.0163
SNC[B]	-0.232183	0.015809	-14.69	<.0001
SNC[C]	0.0439257	0.01516	2.9	0.004
SMCb[MesicDry]	0.0567753	0.011084	5.12	<.0001
denPLn13	-0.000019	0.000002	-10.44	<.0001
denAW	-0.000051	0.000005	-9.36	<.0001
nP	-0.000091	0.000007	-12.78	<.0001
YSC	0.0812169	0.007983	10.17	<.0001
Elev	-0.000167	0.000062	-2.68	0.0078

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
SNC	2	2	6.9178492	110.2607	<.0001
SMCb	1	1	0.8230807	26.2375	<.0001
denPLn13	1	1	3.420608	109.0393	<.0001
denAW	1	1	2.7466828	87.5564	<.0001
nP	1	1	5.1237986	163.3321	<.0001
YSC	1	1	3.2468118	103.4991	<.0001
Elev	1	1	0.2248623	7.168	0.0078

5A4 Quadratic mean diameter of thinned pine natural regeneration at handover

Response LNdbhPLn Transformation: dbhPLn = EXP(LNtdbhPLn)

Summary of Fit

RSquare	0.658645
RSquare Adj	0.651131
Root Mean Square Error	0.214874
Mean of Response	1.670004
Observations (or Sum Wgts)	326

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.5474708	0.046813	33.06	<.0001
SNC[B]	-0.208621	0.019555	-10.67	<.0001
SNC[C]	0.0903515	0.017267	5.23	<.0001
SMCb[MesicDry]	0.0726288	0.014168	5.13	<.0001
denPLn13	-0.000033	0.000009	-3.66	0.0003
denAW2000	-0.000166	0.000015	-10.81	<.0001
nP750	-0.000133	0.000009	-13.99	<.0001
GST	0.0760591	0.009815	7.75	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
SNC	2	2	5.4283369	58.7854	<.0001
SMCb	1	1	1.2133403	26.2794	<.0001
denPLn13	1	1	0.6194382	13.4162	0.0003
denAW2000	1	1	5.3934056	116.8143	<.0001
nP750	1	1	9.0301368	195.5812	<.0001
GST	1	1	2.772486	60.0485	<.0001

5B1 Quadratic mean diameter of non-thinned aspen / poplar at handover

Response dbhAW

Summary of Fit

RSquare	0.797645
RSquare Adj	0.794053
Root Mean Square Error	0.945525
Mean of Response	2.739452
Observations (or Sum Wgts)	173

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-8.201299	0.907652	-9.04	<.0001
spinAw	3.5640757	0.397432	8.97	<.0001
denAW	-0.000161	0.000031	-5.24	<.0001
LNtophtAW	1.7022924	0.15779	10.79	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
spinAw	1	1	71.89771	80.4209	<.0001
denAW	1	1	24.5335	27.4418	<.0001
LNtophtAW	1	1	104.05379	116.389	<.0001

5B2 Quadratic mean diameter of thinned aspen / poplar at handover

Response dbhAW

Summary of Fit

RSquare	0.77328
RSquare Adj	0.770217
Root Mean Square Error	0.231655
Mean of Response	0.423139
Observations (or Sum Wgts)	76

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-6.444942	0.433126	-14.88	<.0001
LNtophtAW	1.277585	0.080417	15.89	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LNtophtAW	1	1	13.544471	252.3943	<.0001

6A1 Total age of naturally regenerated pine in unplanted non-thinned stands

Response agePL

Summary of Fit

RSquare	0.837044
RSquare Adj	0.832251
Root Mean Square Error	1.055665
Mean of Response	13.0922
Observations (or Sum Wgts)	141

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-5.244988	0.77367	-6.78	<.0001
YSC	0.9523723	0.038253	24.9	<.0001
LN1denPL	0.4831352	0.059592	8.11	<.0001
SMC[Dry]	-0.431802	0.165687	-2.61	0.0102
SMC[Mesic]	0.6318302	0.122746	5.15	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
YSC	1	1	690.7784	619.8494	<.0001
LN1denPL	1	1	73.25144	65.73	<.0001
SMC	2	2	29.74704	13.3463	<.0001

6A2 Total age of naturally regenerated pine in unplanted thinned stands

Response agePL

Summary of Fit

RSquare	0.798346
RSquare Adj	0.786656
Root Mean Square Error	0.977421
Mean of Response	15.09797
Observations (or Sum Wgts)	74

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-7.290003	1.379889	-5.28	<.0001
YSC	0.9181594	0.06997	13.12	<.0001
LN1denPL	0.8733965	0.121323	7.2	<.0001
SMC[Dry]	-0.96614	0.256285	-3.77	0.0003
SMC[Mesic]	0.6907664	0.172312	4.01	0.0002

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
YSC	1	1	164.50356	172.1914	<.0001
LN1denPL	1	1	49.51079	51.8246	<.0001
SMC	2	2	17.15341	8.9775	0.0003

6A3 Top height of pine in unplanted stands

Response tophtPL

Summary of Fit

RSquare	0.848093
RSquare Adj	0.843513
Root Mean Square Error	56.85188
Mean of Response	491.1022
Observations (or Sum Wgts)	206

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	146.86931	37.08664	3.96	0.0001
agePL	44.885832	1.596208	28.12	<.0001
SMCb[MesicDry]	32.604725	5.261769	6.2	<.0001
Elev	-0.230866	0.026096	-8.85	<.0001
SNC[B]	-55.25247	8.55099	-6.46	<.0001
SNC[C]	3.5358922	6.285559	0.56	0.5744
spinAW	-108.1649	20.44249	-5.29	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
agePL	1	1	2555813.2	790.7505	<.0001
SMCb	1	1	124104.4	38.397	<.0001
Elev	1	1	252972.7	78.268	<.0001
SNC	2	2	140478.4	21.7315	<.0001
spinAW	1	1	90488.8	27.9966	<.0001

6A4 Top height of pine in planted stands

Response tophtPL

Summary of Fit

RSquare	0.816427
RSquare Adj	0.81536
Root Mean Square Error	62.71118
Mean of Response	568.1407
Observations (or Sum Wgts)	1212

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-5.177674	18.19531	-0.28	0.776
GSG	46.488787	0.799771	58.13	0
SNC[B]	-92.62518	2.969992	-31.19	<.0001
SNC[C]	-4.20248	2.652356	-1.58	0.1134
SMCb[MesicDry]	6.1123601	2.052867	2.98	0.003
Elev	-0.093075	0.011836	-7.86	<.0001
Slope	-5.310468	0.480089	-11.06	<.0001
spinAW	-49.82341	7.690871	-6.48	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
GSG	1	1	13287867	3378.822	0
SNC	2	2	4578434	582.0992	<.0001
SMCb	1	1	34865	8.8654	0.003
Elev	1	1	243205	61.842	<.0001
Slope	1	1	481184	122.355	<.0001
spinAW	1	1	165046	41.9678	<.0001

6B1a Total age of thinned aspen / balsam poplar

Response ageAW

Summary of Fit

RSquare	0.407611
RSquare Adj	0.391156
Root Mean Square Error	1.730557
Mean of Response	5.423333
Observations (or Sum Wgts)	75

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.1983782	0.564262	5.67	<.0001
GST	0.8396399	0.126178	6.65	<.0001
spinAW	-1.949435	0.579935	-3.36	0.0012

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
GST	1	1	132.61505	44.2814	<.0001
spinAW	1	1	33.84008	11.2995	0.0012

6B1b Total age of untreated aspen / balsam poplar (no weed, no thin)

Response ageAW

Summary of Fit

RSquare	0.613563
RSquare Adj	0.608305
Root Mean Square Error	1.791501
Mean of Response	14.13667
Observations (or Sum Wgts)	150

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1917619	1.003549	0.19	0.8487
YSC	0.8025411	0.06528	12.29	<.0001
spinAW	3.1375083	0.3948	7.95	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
YSC	1	1	485.07518	151.1385	<.0001
spinAW	1	1	202.69774	63.1561	<.0001

6B1c Total age of weeded non-thinned aspen / balsam poplar

Response ageAW

Summary of Fit

RSquare	0.676754
RSquare Adj	0.663824
Root Mean Square Error	1.487784
Mean of Response	12.50617
Observations (or Sum Wgts)	27

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-2.33981	2.071939	-1.13	0.2695
YSC	0.945381	0.130674	7.23	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
YSC	1	1	115.85585	52.3405	<.0001

6B2 Top height of aspen / balsam poplar

Response LNtophtAW Transformation: tophtAW = EXP(LNtophtAW)

Summary of Fit

RSquare	0.824854
RSquare Adj	0.823165
Root Mean Square Error	0.277804
Mean of Response	6.046654
Observations (or Sum Wgts)	315

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.4492004	0.04507	98.72	<.0001
ageAW	0.1230439	0.003698	33.27	<.0001
spinAW	0.412883	0.047416	8.71	<.0001
NSR[LF]	0.1106833	0.017448	6.34	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
ageAW	1	1	85.447299	1107.191	<.0001
spinAW	1	1	5.851675	75.8236	<.0001
NSR	1	1	3.105538	40.2403	<.0001

6C1 Total age of black spruce at handover (non-thinned stands only)

Response ageSB

Summary of Fit

RSquare	0.31178
RSquare Adj	0.295848
Root Mean Square Error	2.301136
Mean of Response	12.50601
Observations (or Sum Wgts)	222

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.1659664	3.021985	3.03	0.0027
YSC	0.5784216	0.158457	3.65	0.0003
Elev	-0.007022	0.001071	-6.55	<.0001
psSB13	0.0232625	0.008242	2.82	0.0052
spinAW	-3.374588	0.895874	-3.77	0.0002
SMCc[Dry]	-1.444265	0.457954	-3.15	0.0018

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
YSC	1	1	70.5584	13.3249	0.0003
Elev	1	1	227.4409	42.9521	<.0001
psSB13	1	1	42.17998	7.9657	0.0052
spinAW	1	1	75.1332	14.1889	0.0002
SMCc	1	1	52.6665	9.946	0.0018

6C2 Top height of black spruce at handover (non-thinned stands only)

Response tophtSB

Summary of Fit

RSquare	0.735529
RSquare Adj	0.730586
Root Mean Square Error	55.12849
Mean of Response	214.1717
Observations (or Sum Wgts)	219

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-169.3953	19.97521	-8.48	<.0001
ageSB	29.176516	1.4511	20.11	<.0001
nP	-0.01241	0.002649	-4.68	<.0001
psSB13	0.748401	0.199153	3.76	0.0002
SMCc[Dry]	-30.37269	10.76843	-2.82	0.0052

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
ageSB	1	1	1228638.6	404.2704	<.0001
nP	1	1	66687.4	21.9428	<.0001
psSB13	1	1	42918.6	14.1219	0.0002
SMCc	1	1	24177.6	7.9554	0.0052

6C3 Total age of white spruce / balsam fir at handover (non-thinned stands only)

Response ageSW

Summary of Fit

RSquare	0.314622
RSquare Adj	0.303005
Root Mean Square Error	2.461577
Mean of Response	11.71225
Observations (or Sum Wgts)	181

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-54.61418	11.50179	-4.75	<.0001
YSC	0.4609748	0.155796	2.96	0.0035
Lat	1.0795372	0.217064	4.97	<.0001
spinSW	6.7102639	1.466731	4.57	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
YSC	1	1	53.0477	8.7547	0.0035
Lat	1	1	149.87436	24.7344	<.0001
spinSW	1	1	126.82501	20.9304	<.0001

6C4 Top height of white spruce / balsam fir at handover (non-thinned stands only)

Response tophtSW

Summary of Fit

RSquare	0.661472
RSquare Adj	0.652323
Root Mean Square Error	88.41773
Mean of Response	215.2323
Observations (or Sum Wgts)	191

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1041.9899	414.5013	2.51	0.0128
ageSW	36.185261	2.183862	16.57	<.0001
Slope	-5.632823	1.543323	-3.65	0.0003
nP	-0.016124	0.004923	-3.28	0.0013
psSW13	1.1284182	0.450754	2.5	0.0132
Lat	-22.60792	7.886909	-2.87	0.0046

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
ageSW	1	1	2146306.7	274.5447	<.0001
Slope	1	1	104140	13.3211	0.0003
nP	1	1	83863.6	10.7274	0.0013
psSW13	1	1	48993.7	6.267	0.0132
Lat	1	1	64237.2	8.2169	0.0046

7 Pine handover density and DBH excluding trees with more than 50% girdling of main stem by western gall rust

Model	Y-variable	X-variable	Rsquare	Notes / equations
7A	denPLp13X	denPLp13	0.9619	Intercept ns
Density planted PL				Y=0.839283*X (zero intercept)
7B	denPLn13X	denPLn13	0.9403	Intercept ns
Density PL ingress				Y=0.733511*X (zero intercept)
7C	dbhPLpX	dbhPLp	0.9898	
DBH planted PL				Y= 0.197571+0.987841*X
7D	dbhPLnX	dbhPLn	0.9697	Intercept ns
DBH PL ingress				Y=1.016237*X (zero intercept)

3.3 GYPSY variable names and descriptions

GYPSY_Observed Worksheet

Variable	Description
gypsy_model_id	GYPSY model identifier
stand_id	Stand description
standtype	Stand type (natural/regen)
standage	Stand age
spatial	Spatial flag
ba_known	Basal area adjustment flag
sdob_aw	Stump DOB in cm - AW
tdib_aw	Top DIB in cm - AW
stht_aw	Stump height in m - AW
sdob_sb	Stump DOB in cm - SB
tdib_sb	Top DIB in cm - SB
stht_sb	Stump height in m - SB
sdob_sw	Stump DOB in cm - SW
tdib_sw	Top DIB in cm - SW
stht_sw	Stump height in m - SW
sdob_pl	Stump DOB in cm - PL
tdib_pl	Top DIB in cm - PL
stht_pl	Stump height in m - PL
tage_aw	Total age - AW
bage_aw	BH age - AW
topht_aw	Top height in m - AW
den13_aw	Density >= 1.3 m - AW
ps_aw	Percent stocking - AW
ba_aw	Basal area - AW
tage_sb	Total age - SB
bage_sb	BH age - SB
topht_sb	Top height in m - SB
den03_sb	Density >= 0.3 m - SB
ps_sb	Percent stocking - SB
ba_sb	Basal area - SB
tage_sw	Total age - SW
bage_sw	BH age - SW
topht_sw	Top height in m - SW

Variable	Description
den03_sw	Density >= 0.3 m - SW
ps_sw	Percent stocking - SW
ba_sw	Basal area - SW
tage_pl	Total age - PL
bage_pl	BH age - PL
topht_pl	Top height in m - PL
den03_pl	Density >= 0.3 m - PL
ps_pl	Percent stocking - PL
ba_pl	Basal area - PL
SI_bh_aw	Site index BH - AW
SI_t_aw	Site index Total Age - AW
y2bh_aw	Years to BH - AW
SDF_aw	Stand density factor - AW
N0_aw	Initial density - AW
PSI_aw	Percent stocking index - AW
SI_bh_sb	Site index BH - SB
SI_t_sb	Site index Total Age - SB
y2bh_sb	Years to BH - SB
SDF_sb	Stand density factor - SB
N0_sb	Initial density - SB
PSI_sb	Percent stocking index - SB
SI_bh_sw	Site index BH - SW
SI_t_sw	Site index Total Age - SW
y2bh_sw	Years to BH - SW
SDF_sw	Stand density factor - SW
N0_sw	Initial density - SW
PSI_sw	Percent stocking index - SW
SI_bh_pl	Site index BH - PL
SI_t_pl	Site index Total Age - PL
y2bh_pl	Years to BH - PL
SDF_pl	Stand density factor - PL
N0_pl	Initial density - PL
PSI_pl	Percent stocking index - PL

GYPSY_Projected worksheet

Variable	Description
gypsy_model_id	GYPSY model identifier
stand_id	Stand description
standage_p	Projected stand age
tage_aw	Total age - AW
bage_aw	BH age - AW
ba_aw	Basal area - AW
ps_aw	Percent stocking - AW
den13_aw	Density > 1.3 m - AW
mden13_aw	Merchantable density - AW
sc_aw	Species composition - AW
topht_aw	Top height - AW
qmd_aw	Quadratic mean DBH - AW
tage_sb	Total age - SB
bage_sb	BH age - SB
ba_sb	Basal area - SB
ps_sb	Percent stocking - SB
den03_sb	Density > 0.3 m - SB
mden03_sb	Merchantable density - SB
sc_sb	Species composition - SB
topht_sb	Top height - SB
qmd_sb	Quadratic mean DBH - SB
tage_sw	Total age - SW
bage_sw	BH age - SW
ba_sw	Basal area - SW
ps_sw	Percent stocking - SW
den03_sw	Density > 0.3 m - SW
mden03_sw	Merchantable density - SW
sc_sw	Species composition - SW
topht_sw	Top height - SW
qmd_sw	Quadratic mean DBH - SW

Variable	Description
tage_pl	Total age - PL
bage_pl	BH age - PL
ba_pl	Basal area - PL
ps_pl	Percent stocking - PL
den03_pl	Density > 0.3 m - PL
mden03_pl	Merchantable density - PL
sc_pl	Species composition - PL
topht_pl	Top height - PL
qmd_pl	Quadratic mean DBH - PL
tv_aw	Total volume - AW
mv_aw	Merchantable volume - AW
mai_aw	MAI - AW – species tage based
tv_sb	Total volume - SB
mv_sb	Merchantable volume - SB
mai_sb	MAI - SB – species tage based
tv_sw	Total volume - SW
mv_sw	Merchantable volume - SW
mai_sw	MAI - SW – species tage based
tv_pl	Total volume - PL
mv_pl	Merchantable volume - PL
mai_pl	MAI - PL – species tage based
tv_con	Total volume - Conifer
mv_con	Merchantable volume - Conifer
mai_con	MAI - Conifer - stand age based
tv_dec	Total volume - Deciduous
mv_dec	Merchantable volume - Deciduous
mai_dec	MAI - Deciduous - stand age based
tv_tot	Total volume - Total
mv_tot	Merchantable volume - Total
mai_tot	MAI - Total - stand age based