Incorporating regeneration dynamics and reforestation treatment effects into growth and yield models

FOREST GROWTH
ORGANIZATION OF WESTERN CANADA

W. Richard Dempster

Growth and Yield Innovations Conference

Canmore, Alberta | June 18–21, 2023

Outline

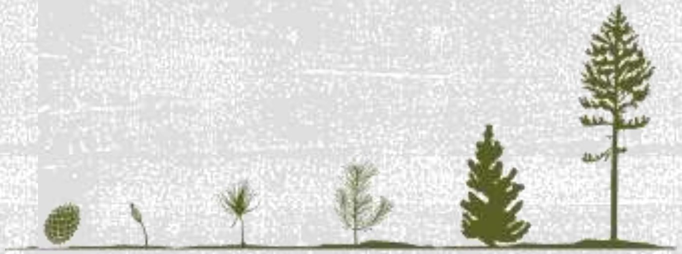
1. ***The road less travelled*** Challenges that arise in incorporating regeneration dynamics in growth and yield models, and from failing to do so
2. ***The right track?*** Local progress in meeting the challenge: the FGrOW Regenerated Lodgepole Pine Project
3. ***The way forward*** Opportunities for innovation to create better and more widely applied solutions

Terms and definitions

- **Tree:** a woody perennial plant, with a single stem or trunk capable of bearing lateral branches
- **Ingress**: the ingrowth of naturally regenerated trees into a specified minimum size class
- **Juvenile mortality**: density-independent death of trees occurring prior to crown closure and onset of self-thinning
- **Regeneration phase**: initial period of stand development following harvesting, during which ingress and / or juvenile mortality are occurring
- **Regeneration:** the production, survival, growth, and germination of seed; clonal reproduction; and the survival and growth of trees until the end of the regeneration phase

The road less travelled

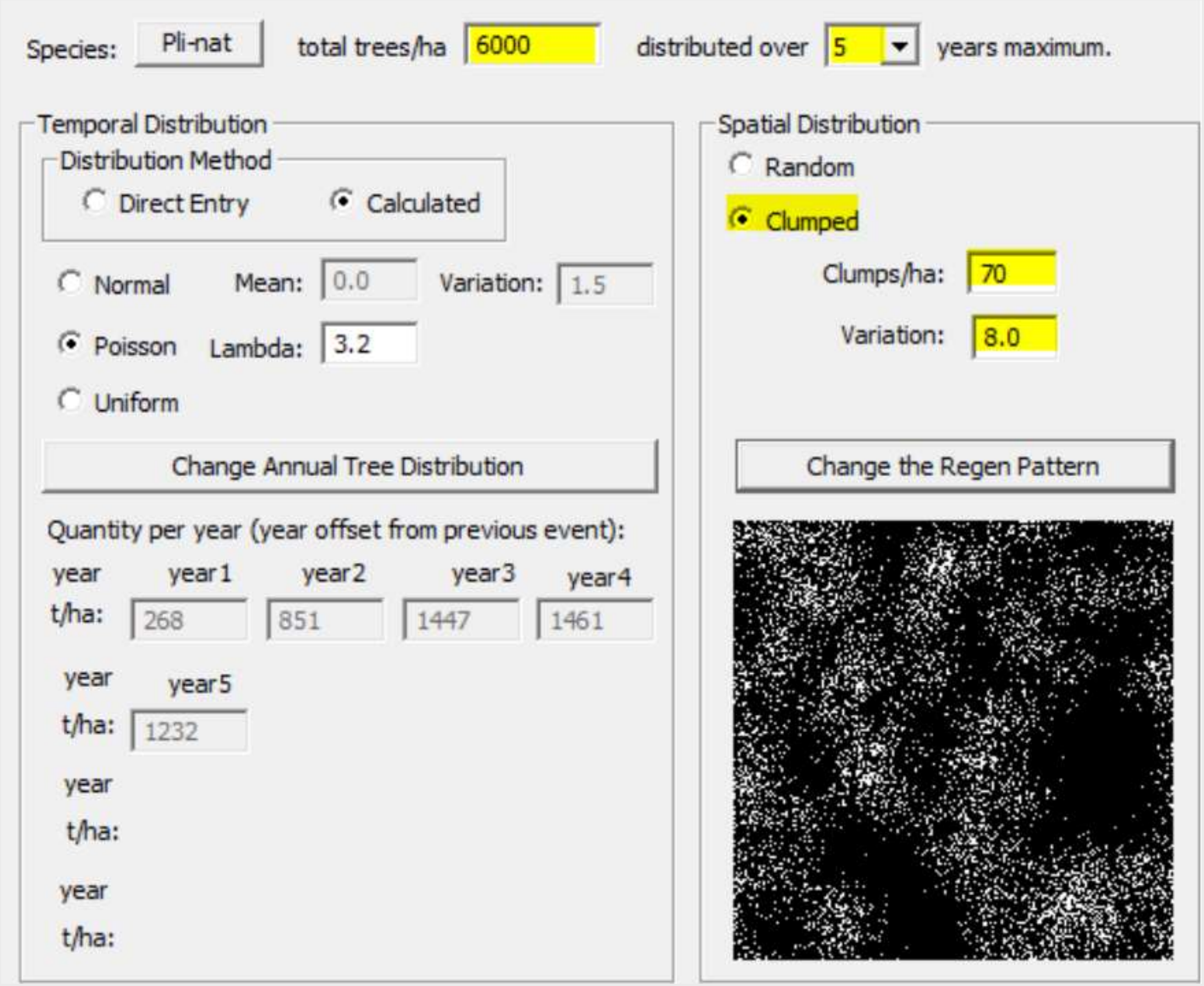
Representation of regeneration dynamics in growth and yield models



Regeneration modelling

North America

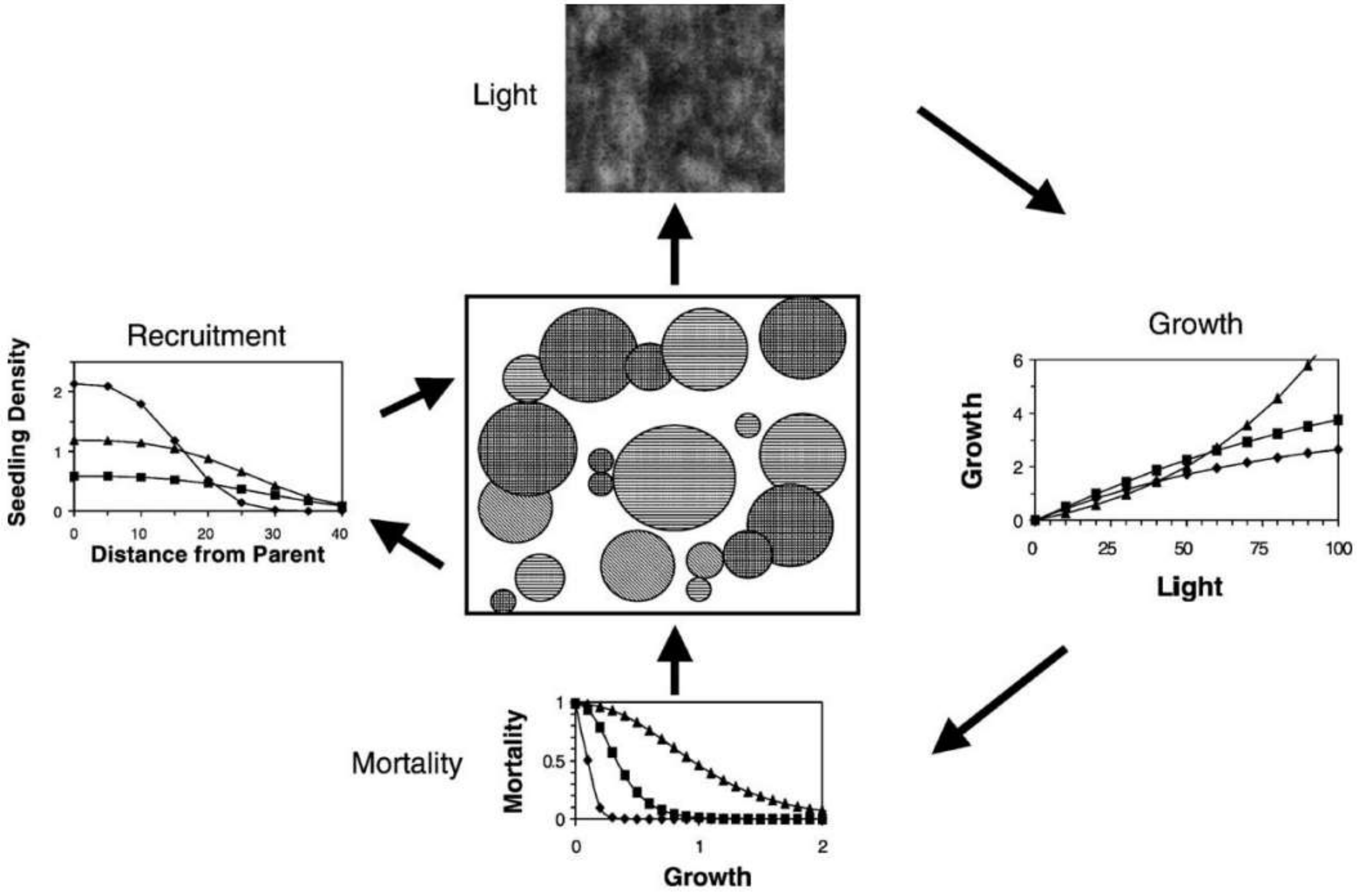
- Hanbury-Brown *et al.* (2022)
  - Forest regeneration processes poorly represented in Earth system models
- Burkhart and Tomé (2012)
  - *“Models of the juvenile phase of stand development are relatively rare, but there are some notable exceptions”*
  - Responses to vegetation management, initial spacing, site preparation and fertilization
  - Confined to growth and survival of plantations
- Ferguson *et al.*(1993)
  - FVS regeneration establishment models
  - Recognized two-state systems (e.g. stocking probability, stocked-plot attributes)
- Fortin and Deblois (2007), Li *et al.* (2011)
  - Combined probability distributions
- Worth *et al.* (2008)
  - Seed production and dispersal



Representation of regeneration dynamics in growth and yield models

British Columbia

TASS III ver. 4.0.9
September 2017



Representation of regeneration dynamics in growth and yield models

British Columbia

SORTIE

Coates *et al*. 2003

Representation of regeneration dynamics in growth and yield models

Alberta

Huang *et al.* 2009

Growth and Yield Projection System

- Stand-level model developed and supported by Alberta government
- Validated against permanent sample plots in post-harvest regenerated stands
- Initialized from regeneration performance surveys 12-14 years after cut

GYPSY©

FORESEEING THE GROWING FUTURE

Mixedwood Growth Model (MGM)

- Individual tree-based stand growth model for the boreal forest
- Recently validated against large dataset from fire-origin and post-harvest untreated permanent sample plots age >12 years
- Initialized by tree list

Representation of regeneration dynamics in growth and yield models

Alberta

Bokalo *et al.* 2013

Comeau *et al.* 2021

Why regeneration modelling has received little attention

Factor	Against	For
Phase	short	long
Planting	yes	no
Prediction	hard	easy
Profession	silviculture	mensuration
Principles	evolving	established
Practice	art	science
Policy	implicit	explicit

Why regeneration models are needed in Alberta

Reforestation practices

- Expensive and intrusive
- Variable need and justification
- Increasingly opposed
- Increasingly high investment risk

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Natural regeneration

- Major component of stand dynamics and ecosystem maintenance
- Prolific for some species and sites
- But variable in abundance, composition and timing

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Linking Regeneration Standards to Growth and Yield and Forest Management Objectives

Prepared by
Alberta Reforestation Standards
Science Council

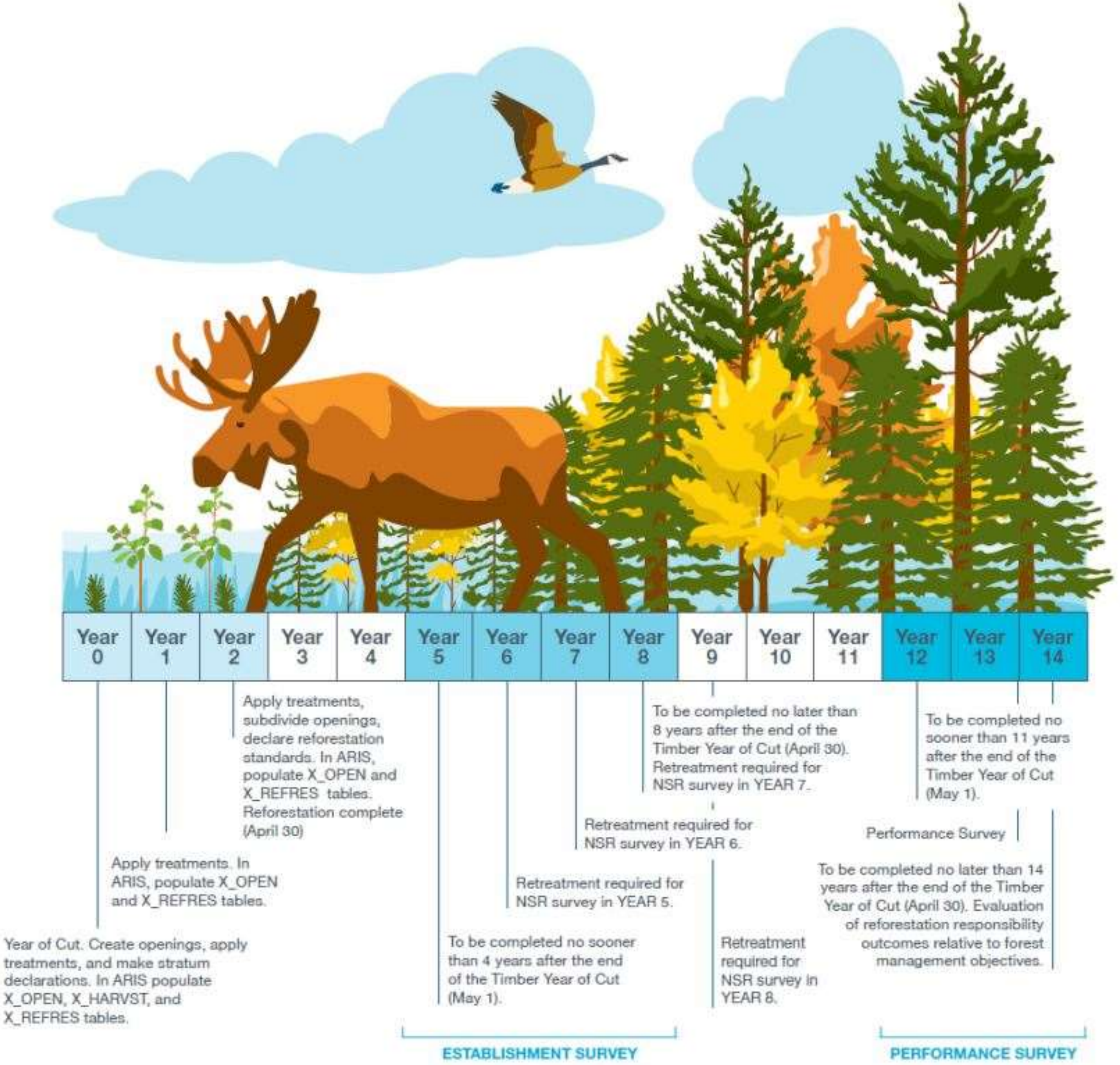
For
Alberta's Minister of Sustainable Resource Development

August 29, 2001

Why regeneration models are needed in Alberta

Policy

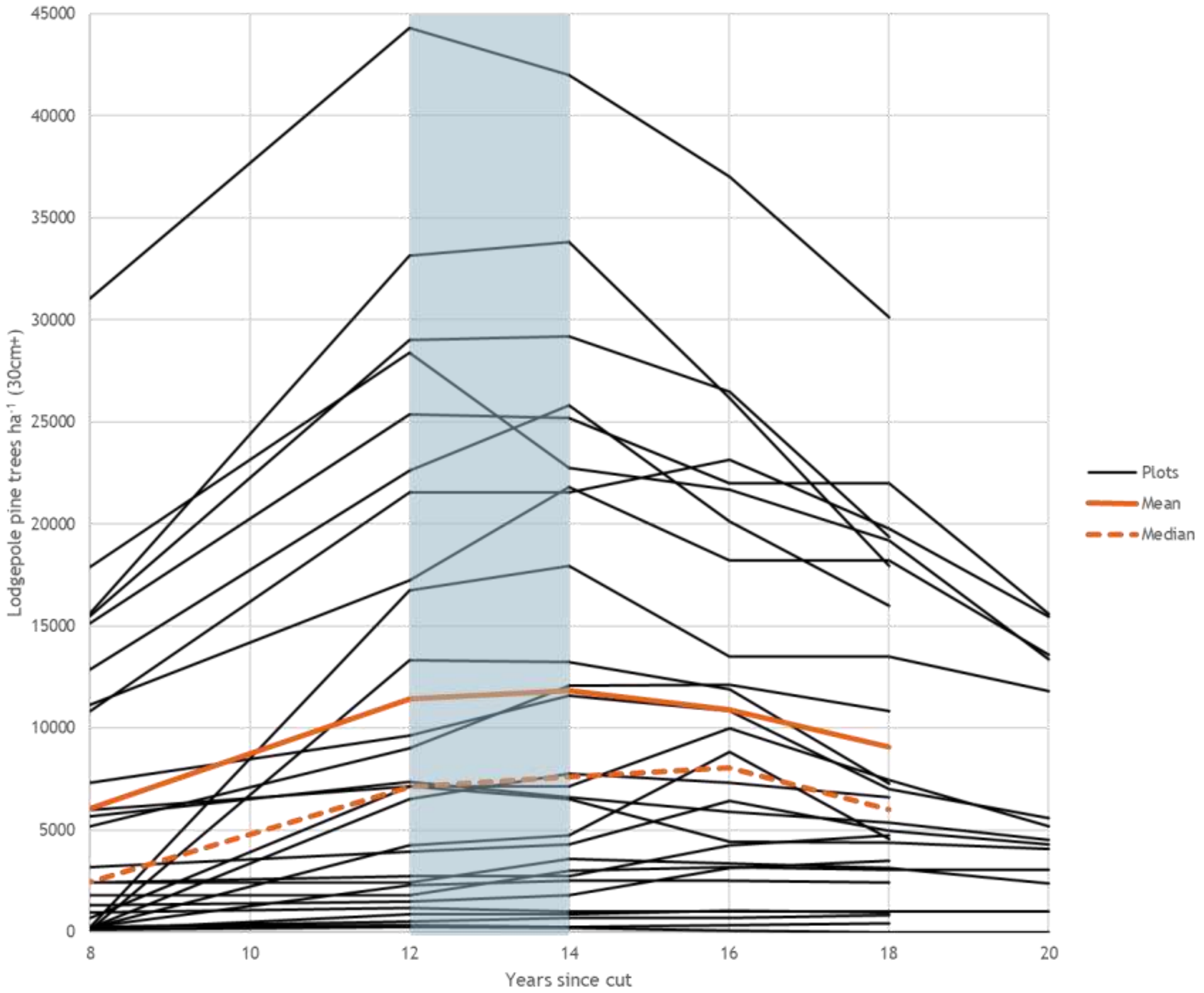
- Forest management on a sustained yield basis required by law
- Reforestation standards linked to growth and yield



Why regeneration models are needed in Alberta

Policy

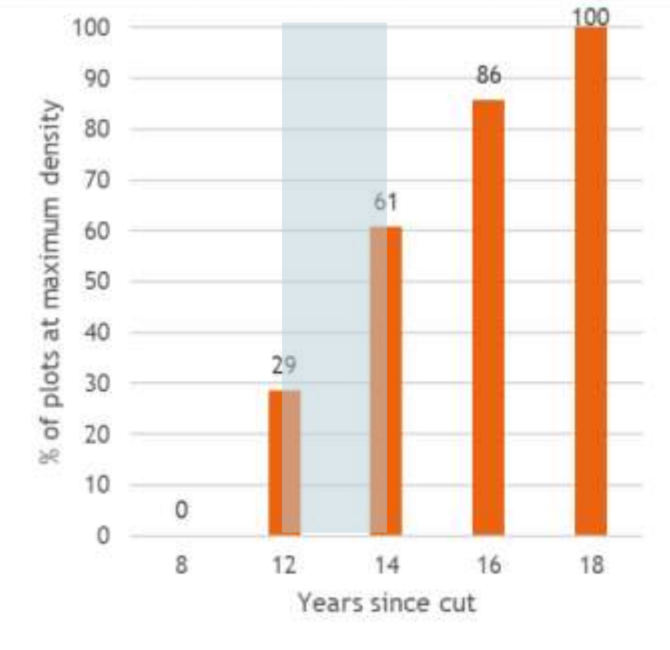
- Reforestation Standard of Alberta (RSA)requires performance surveys
- Conducted 12 – 14 years after cut
- Linked to long-term growth and yield



Why regeneration models are needed in Alberta

RLP ingress trends – pine

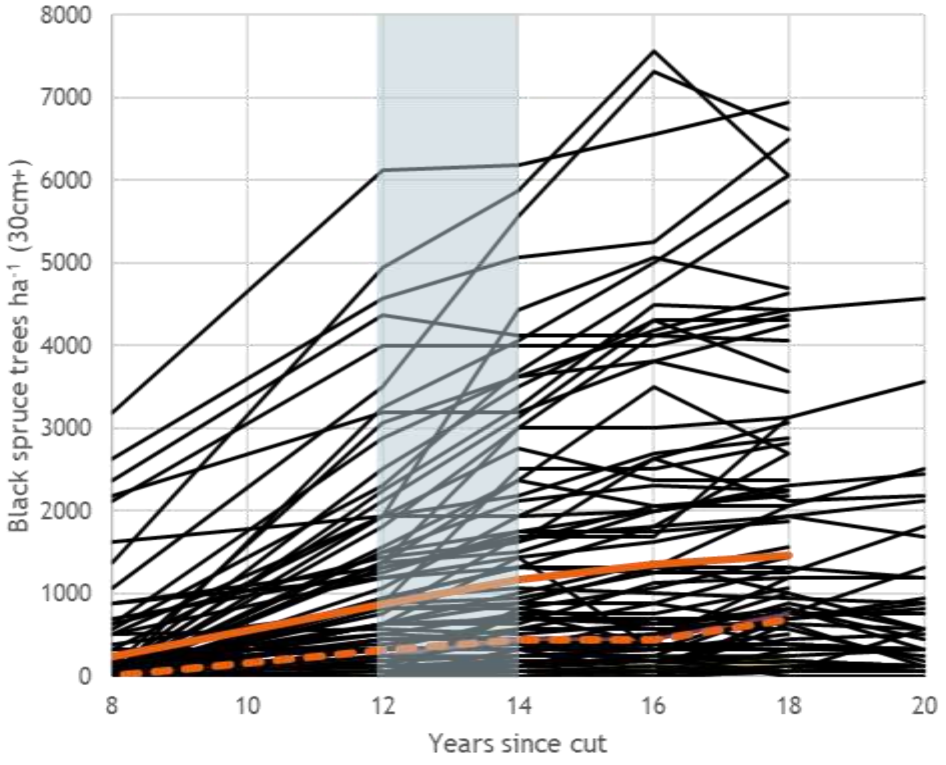
- Non-planted non-thinned sample plots in FGrOW RLP trial
- Shaded area indicates RSA performance assessment period



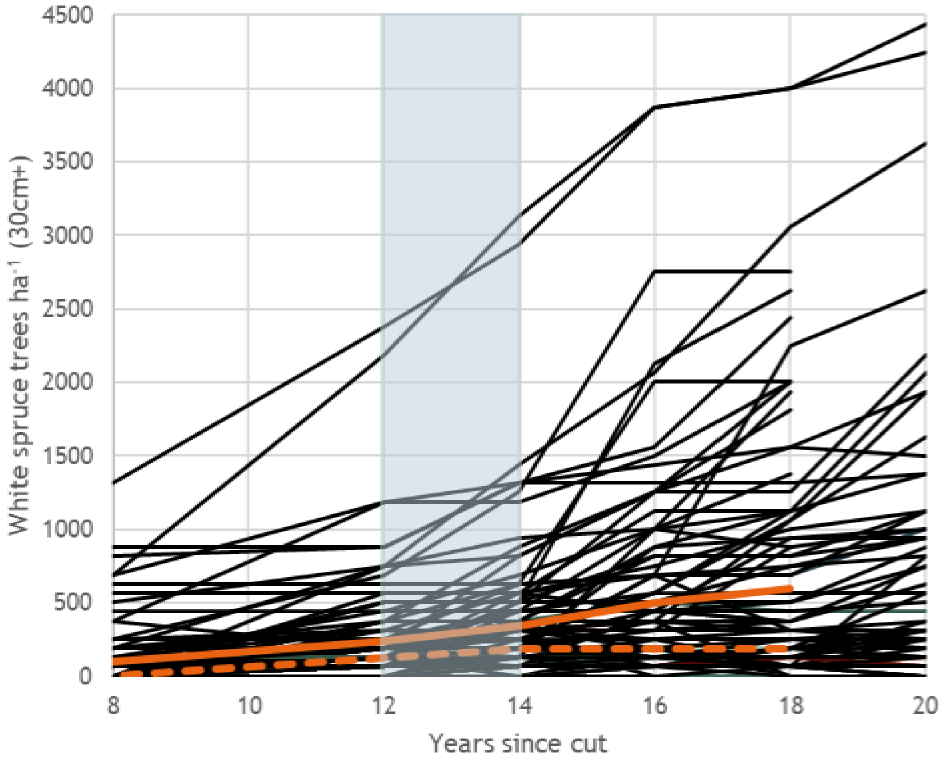
Why regeneration models are needed in Alberta

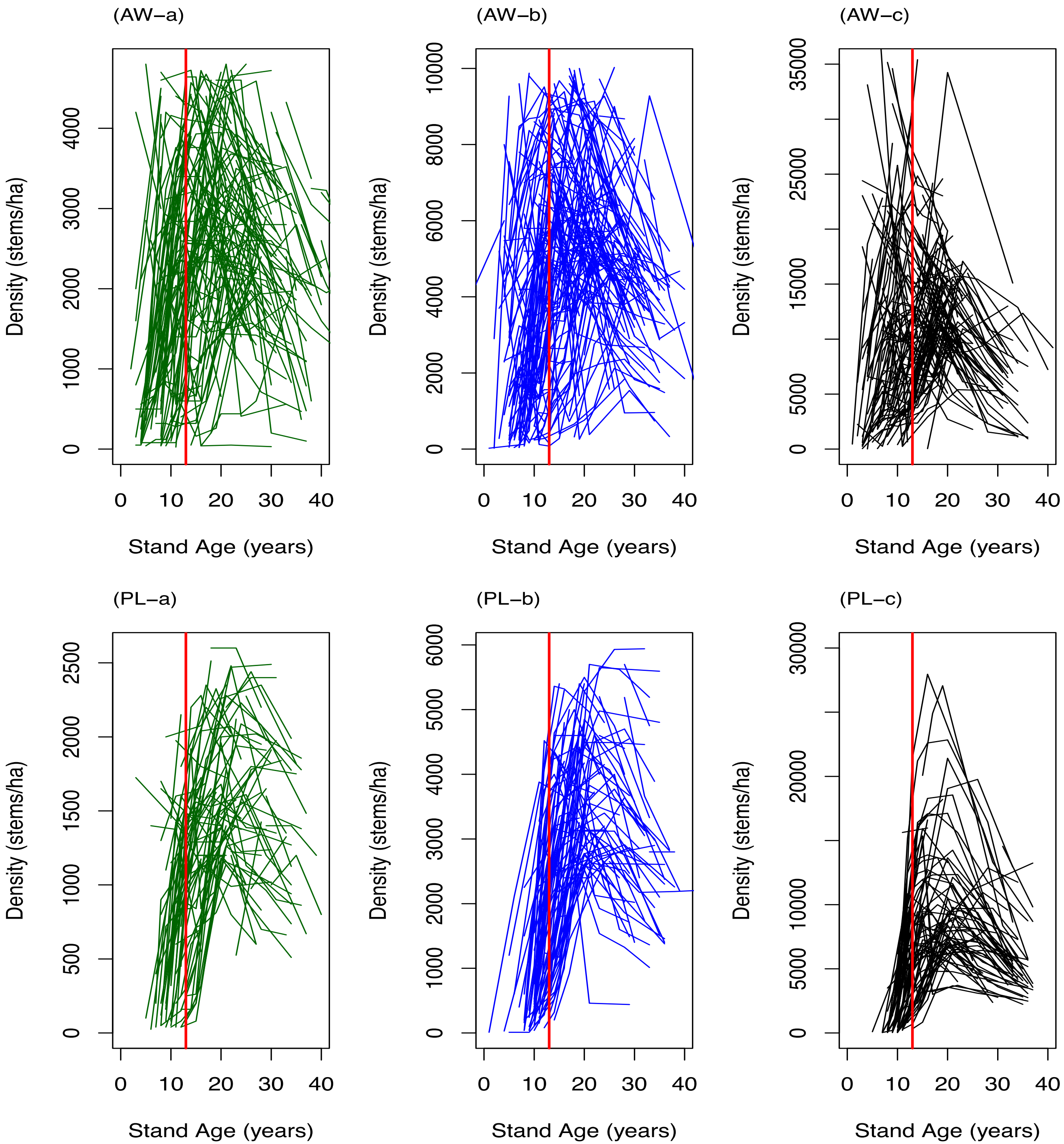
RLP ingress trends

Black spruce



White spruce

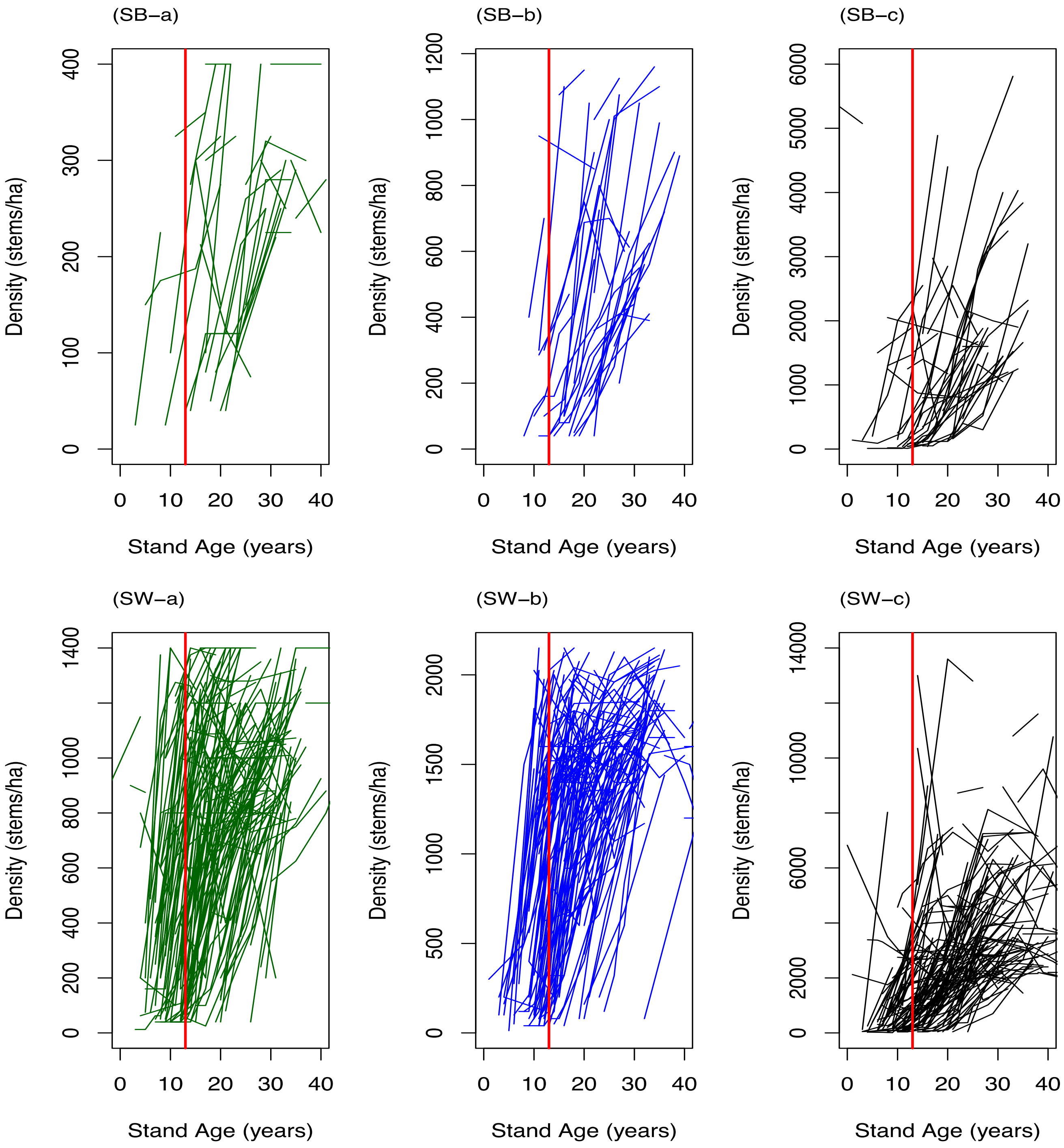




Why regeneration models are needed in Alberta

EPH ingress trends - aspen and pine

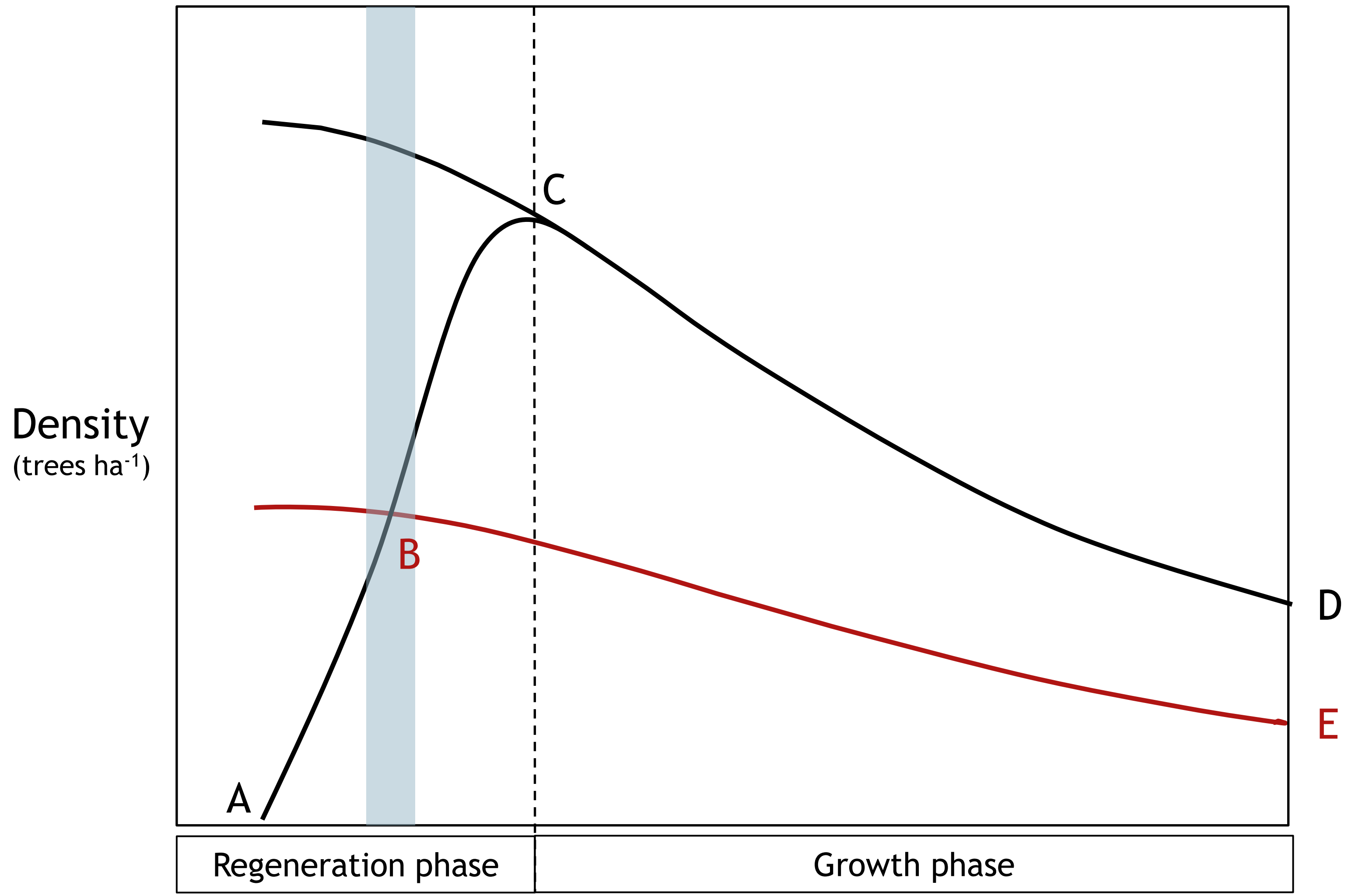
- Empirical post-harvest dataset
- Stand density trajectories for aspen (AW) and lodgepole pine (PL) at the PSP level by max density quartile, for the 2nd, 3rd, and 4th quartiles (panels a, b, and c, respectively)
- The vertical red line indicates age 13
-



Why regeneration models are needed in Alberta

EPH ingress trends – black and white spruce

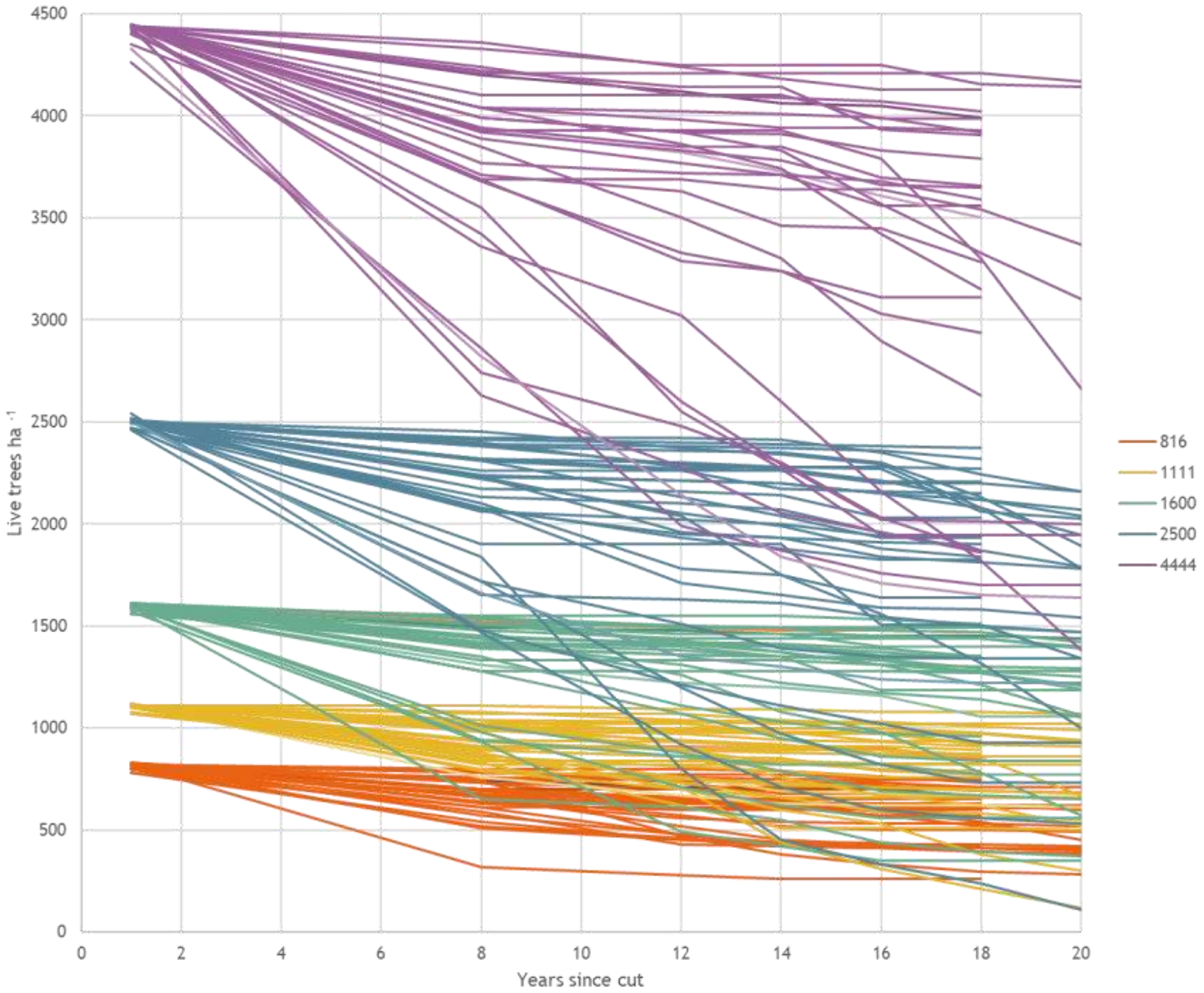
- Empirical post-harvest dataset
- Stand density trajectories for black spruce (SB) and white spruce (SW)at the PSP level by max density quartile, for the 2nd, 3rd, and 4th quartiles (panels a, b, and c, respectively)
- The vertical red line indicates age 13
-



Why regeneration models are needed in Alberta

Regeneration phase duration

- Actual density curve for ingress (ABCD) culminates at end of regeneration phase (point C)
- Density models for growth phase have negative slopes (CD, BE)
- Model initiated at C gives best estimate of curve CD
- Model initiated at earlier performance survey (point B) incorrectly predicts curve BE



Why regeneration models are needed in Alberta

Juvenile mortality

- Observed in regenerated lodgepole pine trial, non-thinned planted stock
- Independent of pine density
- Varies with natural sub-region, aspen density, soil moisture, latitude, evapo-transpiration, spring temperature, depth of organic soil, site preparation
- Mortality agents: Warren root collar weevil, *Armillaria* root disease, mammals, western gall rust etc.

Why regeneration models are needed in Alberta

Making research results useful to forest managers

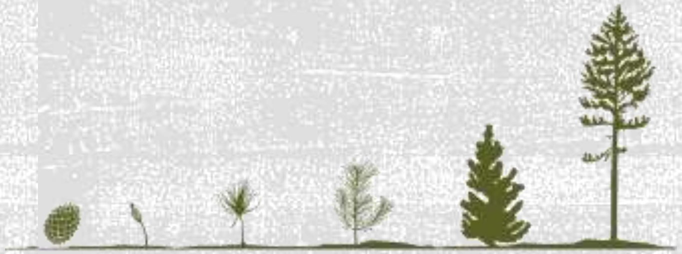
Why regeneration models are needed in Alberta

Summary

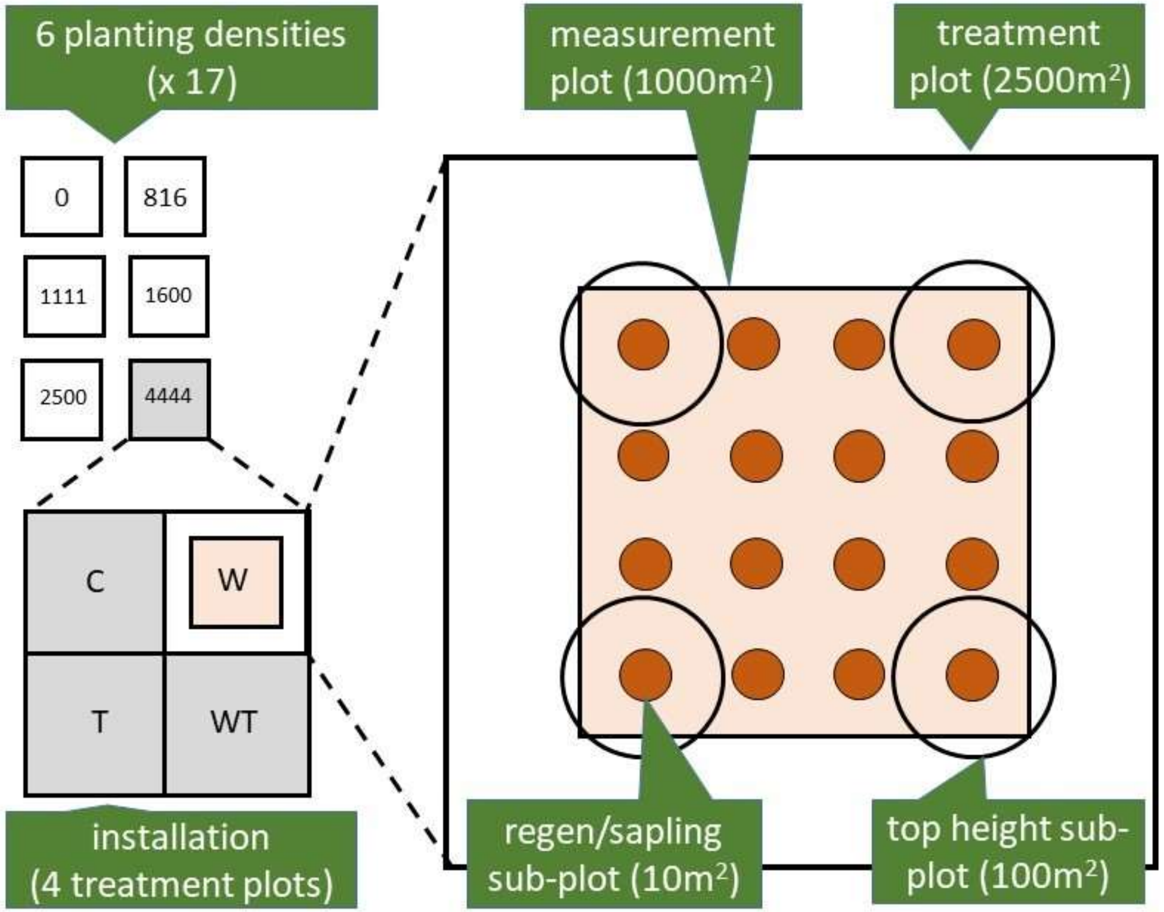
- Reforestation treatments and regeneration performance assessments take place before the regeneration phase of stand development is complete, therefore requiring growth and yield models predicting their outcomes to take into account regeneration dynamics.
- Existing growth and yield models fail to represent ingress of natural regeneration and variation in juvenile mortality, and therefore do not reliably predict future timber yield or species composition.
- Reforestation treatment decisions are increasingly being challenged, and increasingly subject to risk, therefore requiring stronger support and justification.
- Usefulness of regeneration research to practitioners is enhanced if results can be consolidated into quantitative decision support tools.

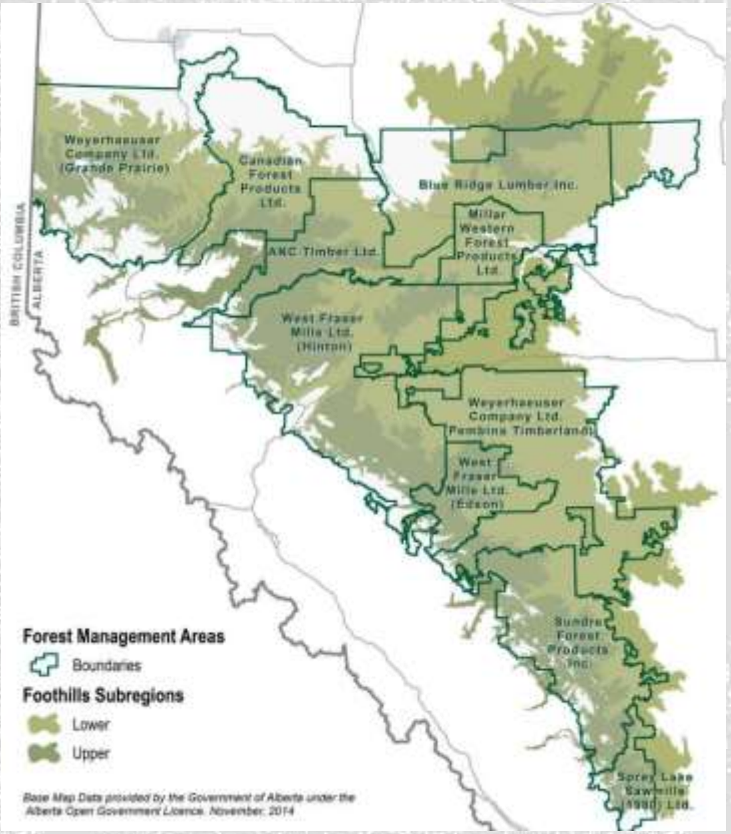
The right track?

FGrOW Regenerated Lodgepole Pine Project



Regenerated Lodgepole Pine (RLP) Trial





Analytical methods

Standard least squares (SLS)

$$y = a + \sum(b_i X_i)$$

where:

y = predicted stand-level attribute

b_i = vector of regression coefficients

X_i = vector of independent variables

a and b_i are coefficients

- Applied to predict top height, age, density, trees per stocked sub-plot, quadratic mean diameter
- Multiple linear regression
- Analysis of variance / covariance
- Linear and categorical variables
- Linear variables transformed as appropriate

Analytical methods

Logistic regression

$$s = (1 + e^{-(\sum ßiXi)})^{-1}$$

where:

s = stocking probability

e = the base of natural logarithms

$ß_i$ = vector of regression coefficients

X_i = vector of independent variables

- Applied to predict stocking probabilities and % stocking
- Used in combination with SLS to estimate density of secondary species i.e. density = stocking probability x trees per stocked sub-plot

Analytical methods

Cumulative density functions

$$\mathrm{F}(x) = 1 - \exp[-(x/B)^C]$$

where:

$\mathrm{F}(x)$ = cumulative density

x = dependent variable (number of trees per stocked plot or size class)

B = Weibull scale parameter

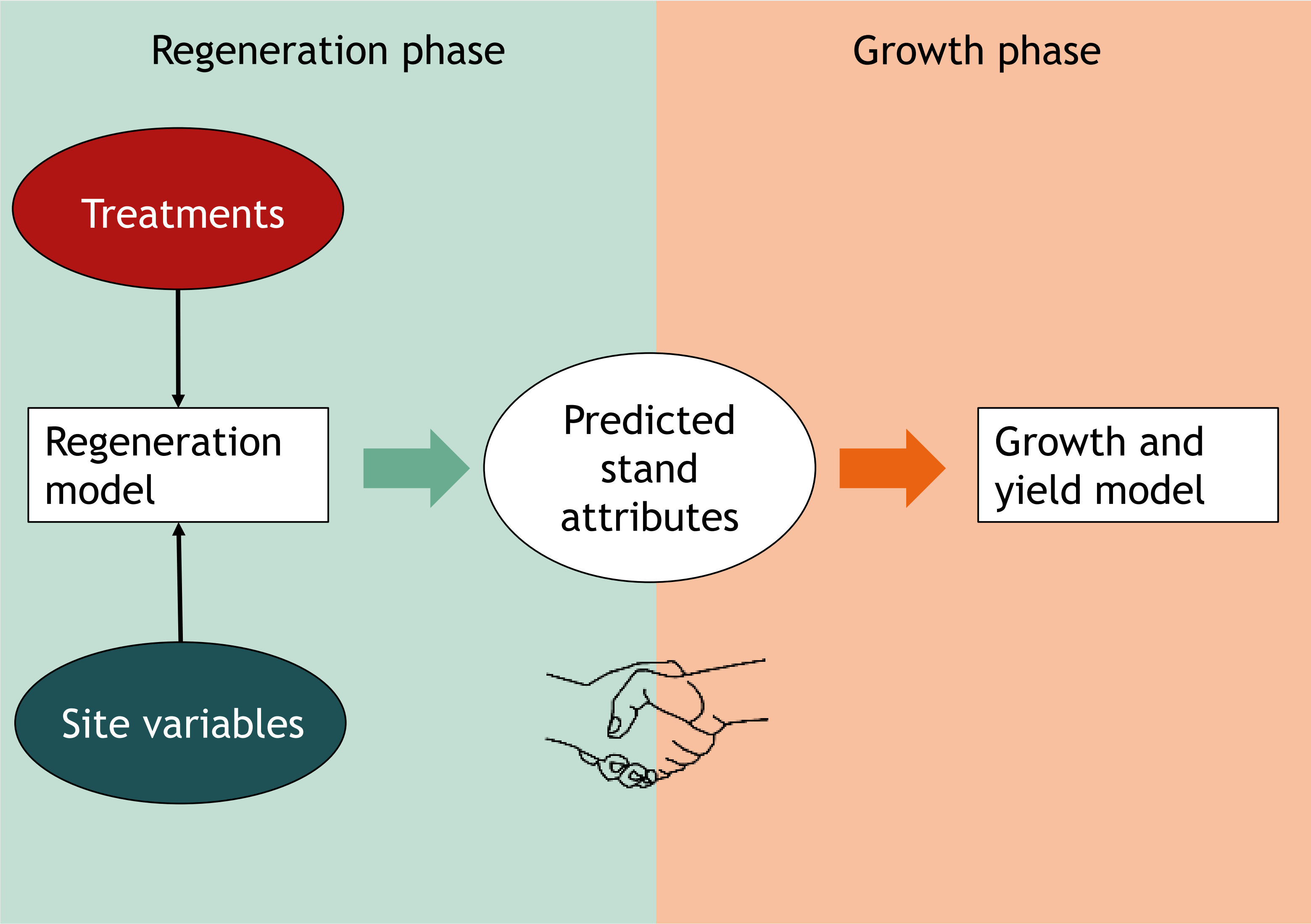
C = Weibull shape parameter

- Weibull scale and shape parameters estimated as SLS functions of treatment and site variables
- Solved for dependent variable by $x = B[-\ln(1 - F(x))]1/^C$
- Applicable to estimate number of trees per stocked sub-plot, diameter class, or height class
- Could be used with pseudo-random number generator to simulate tree lists for input into individual tree growth models

Analytical methods

Criteria for selecting predictive variables

- Statistical significance
- Goodness of fit and contribution to explained variation
- Independence
- Biological rationality
- Data availability for user inputs



Consolidation

- Regeneration model predicts juvenile stand attributes from treatment and site inputs
- Output at 18 years used to initialize growth and yield model

Regeneration model elements

Treatments

Prep.

Plant

Weed

Thin

Regeneration model elements

Treatments Prep. Plant Weed Thin

Cohorts AW PLp PLn SB SW

Regeneration model elements

Treatments

- Prep.
- Plant
- Weed
- Thin

Cohorts

Attributes

AW	PLp	PLn	SB	SW
Ht, S%, Dbh Age, Den, BA	Ht, S%, Dbh Age, Den, BA	Ht, S%, Dbh Age, Den, BA	Ht, S% Age, Den	Ht, S% Age, Den

Regeneration model elements

Treatments

Prep. | Plant | Weed | Thin

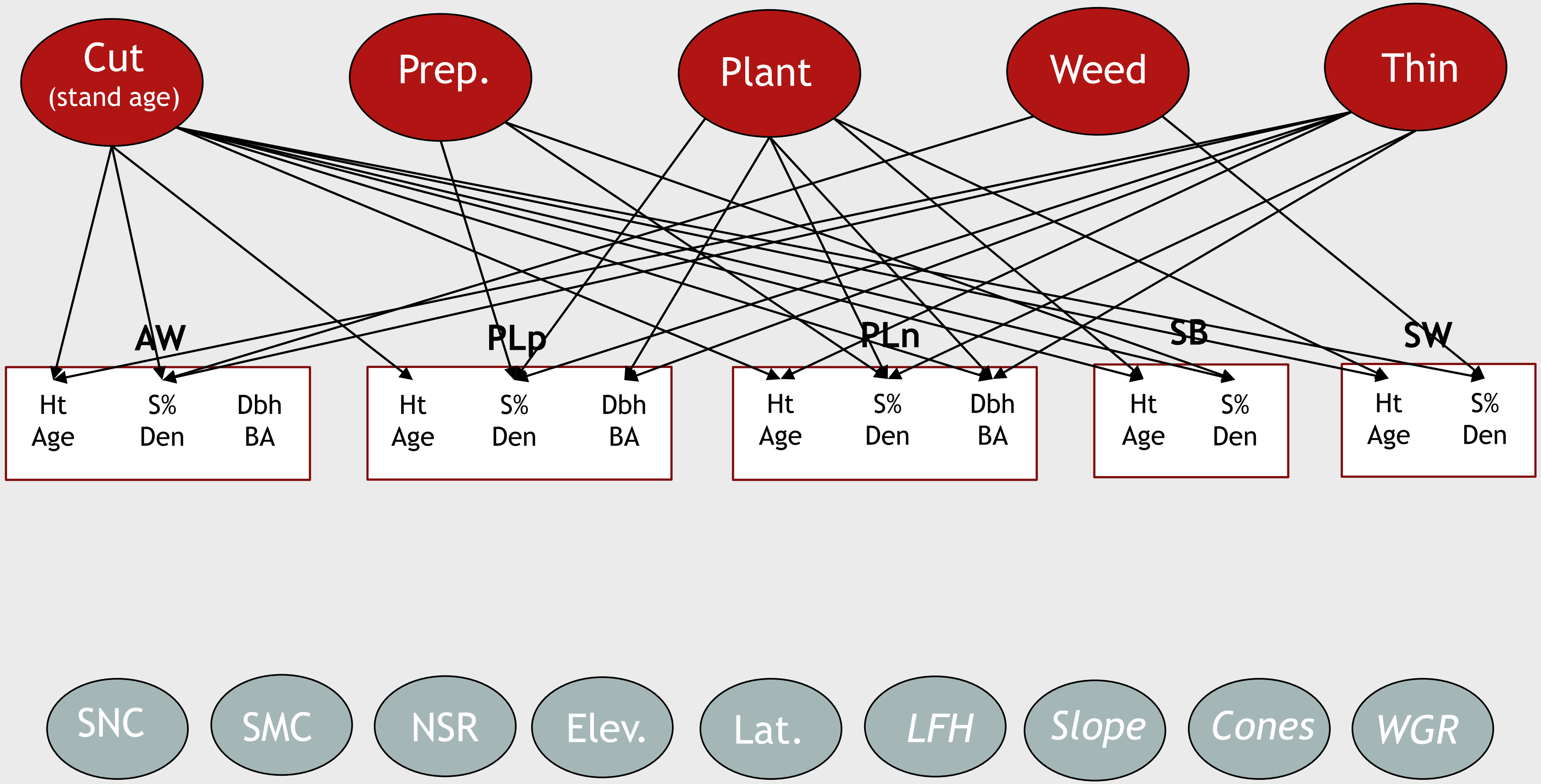
Cohorts / Attributes

AW	PLp	PLn	SB	SW
Ht, S%, Dbh Age, Den, BA	Ht, S%, Dbh Age, Den, BA	Ht, S%, Dbh Age, Den, BA	Ht, S% Age, Den	Ht, S% Age, Den

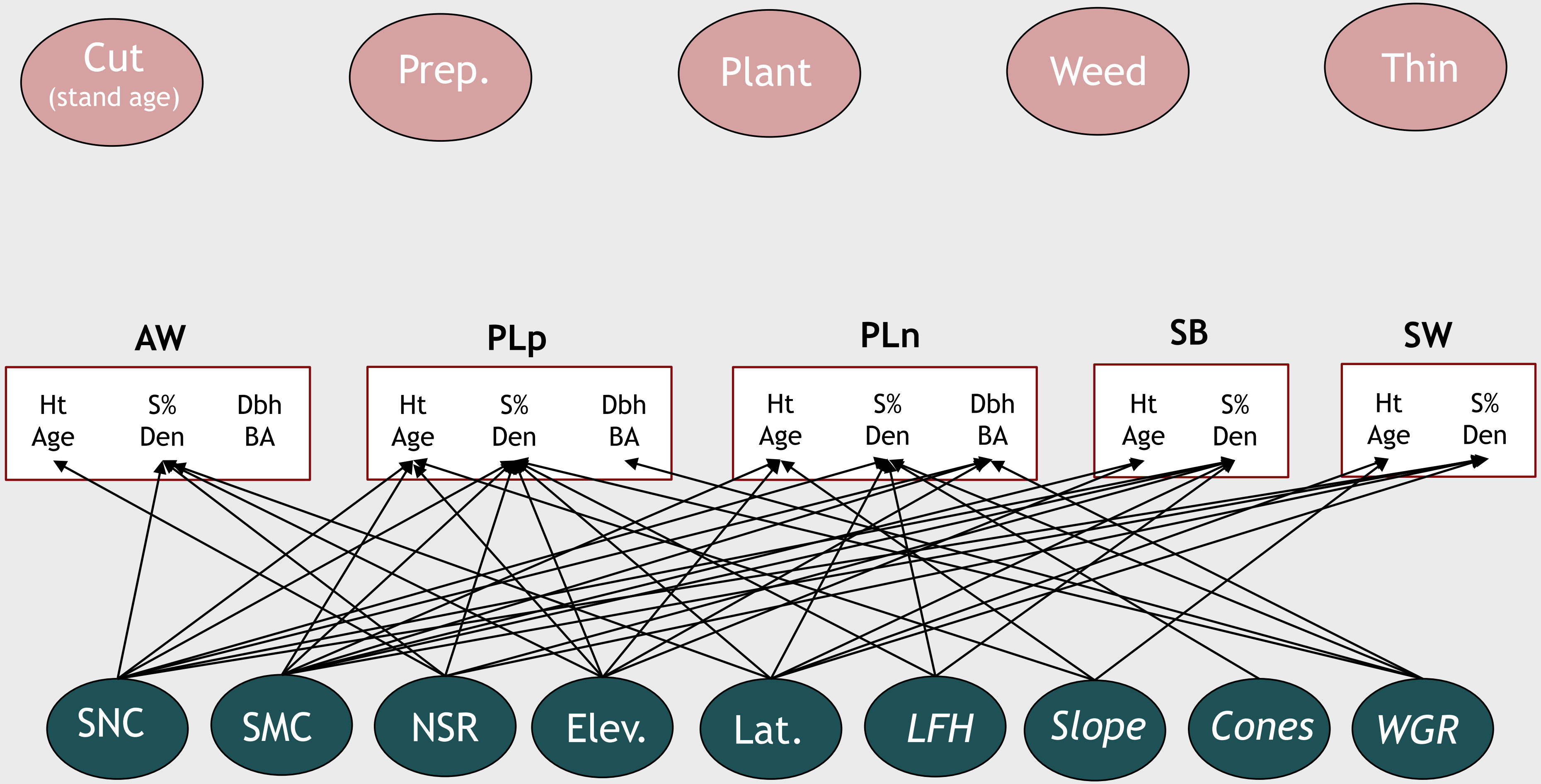
Site variables

SNC | SMC | NSR | Elev. | Lat. | *LFH* | *Slope* | *Cones* | *WGR*

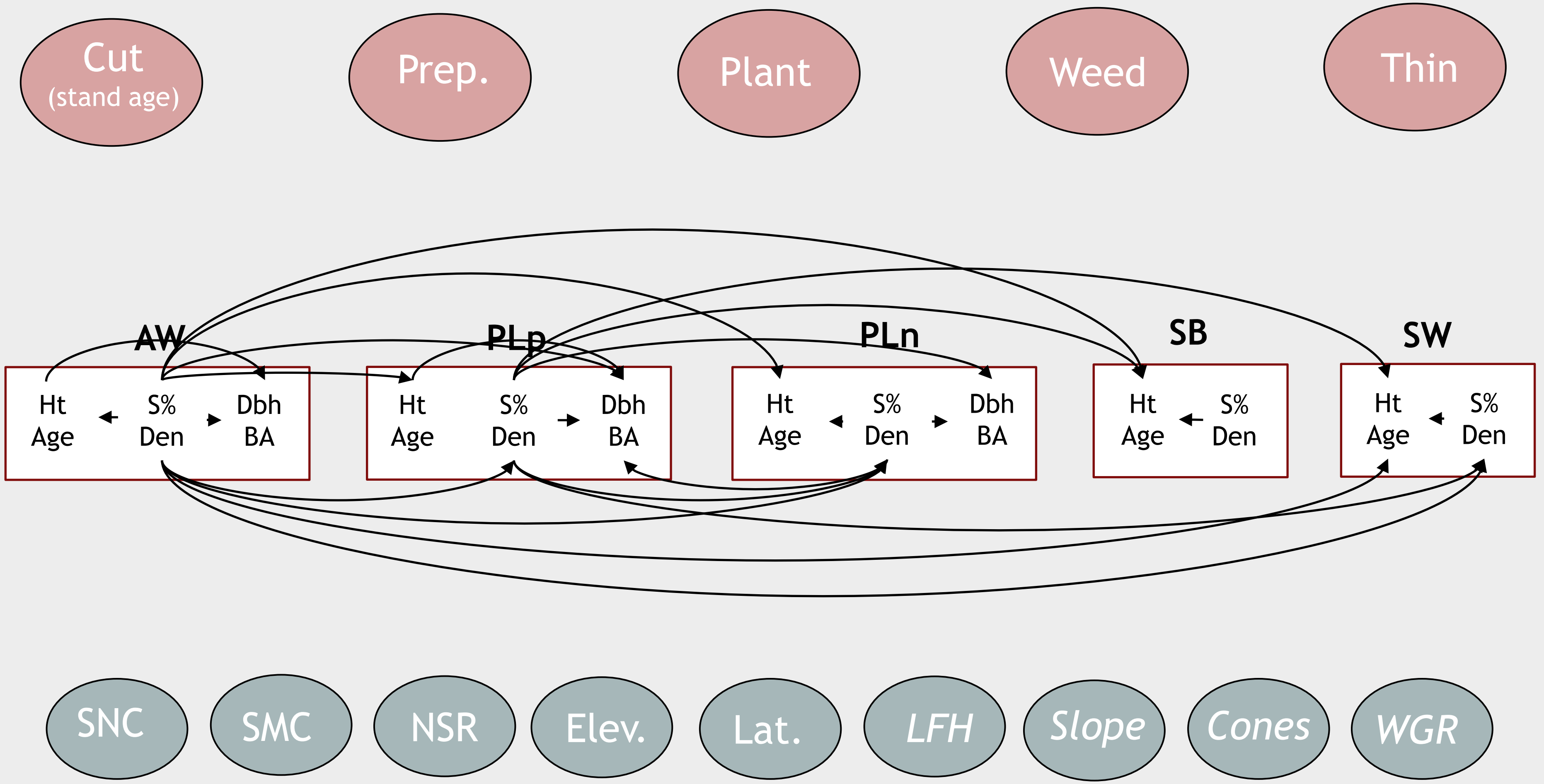
Regeneration model: dependencies on treatments



Regeneration model: dependencies on site variables



Regeneration model: dependencies within and between cohorts



FRIPSY

- Crispy Chicken Chips Snack
- Only €0.13
- Superior long-lasting recipe – fun snack
- Superior flavor
- Unbeatable prices
- Undeniable fun

Foothills Reforestation Interactive Planning System

AUTHOR
FGrOW

PUBLISHED
Oct 01, 2021

SUBJECT AREA
Forest Management
Resource Management

RECORD TYPE
GIS Products
Tools and Apps

Related Programs

- Foothills Pine Project Team

Related Projects

- Regenerated Lodgepole Pine Project

Linking silviculture to growth and yield

FRIPSY (Foothills Reforestation Interactive Planning System) is a quantitative planning tool to assist management of Alberta's lodgepole pine forests. It is designed to:

- Encourage and facilitate application of research undertaken by the FGrOW Foothills Pine Project;
- Assist silviculturists in selecting what combination of treatments (mechanical site preparation, planting, herbicide application, and pre-commercial thinning) best meet objectives for reforestation following harvesting;
- Support timber supply planning by linking regeneration performance to predictions of long-term growth and yield.

The application is run in Microsoft Excel, using either of two interactive processing modes: single-stand or batch. It comes with a comprehensive user guide, including easy-to-follow instructions, plus more detailed background information on design and structure of the system.

Download the program file and user guide here

FRIPSY | User Guide

FRIPSY

https://fgrow.ca/publications/foothills-reforestation-interactive-planning-system

- Decision support tool
- Microsoft Excel app
- Interactive user interface
- Single-stand and batch processing modes
- Training videos and downloads

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	13	AW	10.0	3.29	10.3	182		
(before)		PL	13.0	5.94	93.9	4476		
Thin	13	AW	3.1	1.42	0.4	9		
(after)		PL	13.0	5.94	93.9	3208		
Performance	14	AW	4.0	1.58	0.7	15		
		PL	14.0	6.40	93.8	3192		
Handover	18	AW	7.3	2.39	4.6	104	0.55	0.00
		PL	18.0	8.25	93.8	2500	9.47	17.60
		SB						
		SW						

Yield Projection to age of PL MAI culmination at 67 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	16.3	0.10	6.5	56.3	16.8	102	14.9	1.8
PL	22.6	5.45	364.9	67.0	24.9	1037	21.5	37.6
SB								
SW								
Con		5.45	364.9			1037	21.5	37.6

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

FRIPSY

Example of regeneration forecast and yield projection

- Pre-commercial thinning

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 (before)		AW						
		PL						
Thin (after)		AW						
		PL						
Performance	14	AW	10.9	3.69	10.3	171		
		PL	14.0	6.40	93.7	4444		
Handover	18	AW	14.7	5.88	10.3	136	2.73	0.08
		PL	18.0	8.25	91.8	2983	8.31	16.20
		SB	15.1	2.80	4.8	48	Dens. too low to project!	
		SW	12.1	2.27	9.0	106		

Yield Projection to age of PL MAI culmination at 70 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	16.3	0.25	17.2	66.7	18.5	128	17.9	3.2
PL	22.6	5.04	352.6	70.0	25.4	1018	21.2	35.8
SB	14.4	0.00	0.0			0		0.0
SW	15.9	0.25	17.3	64.1	17.1	106	20.6	3.5
Con		5.28	369.8			1124	21.1	39.3

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

FRIPSY

Example of regeneration forecast and yield projection

- No pre-commercial thinning

The way forward

Innovation to create better and more widely applied solutions

Scope

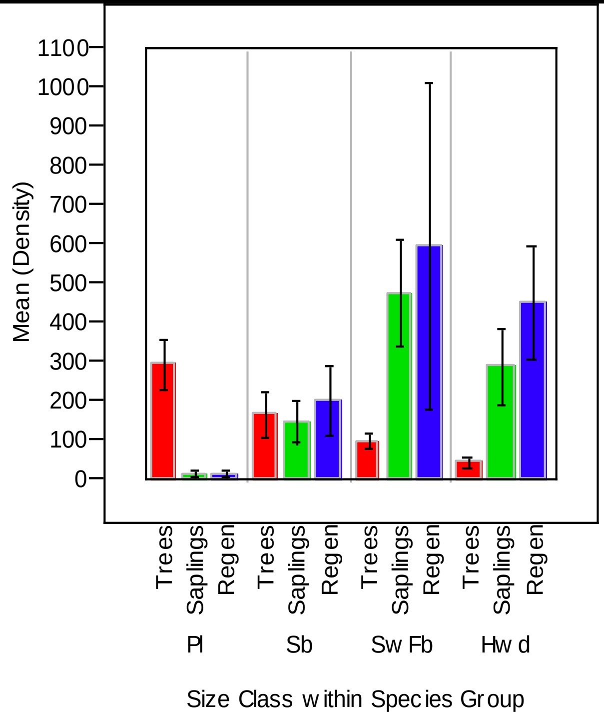
Species

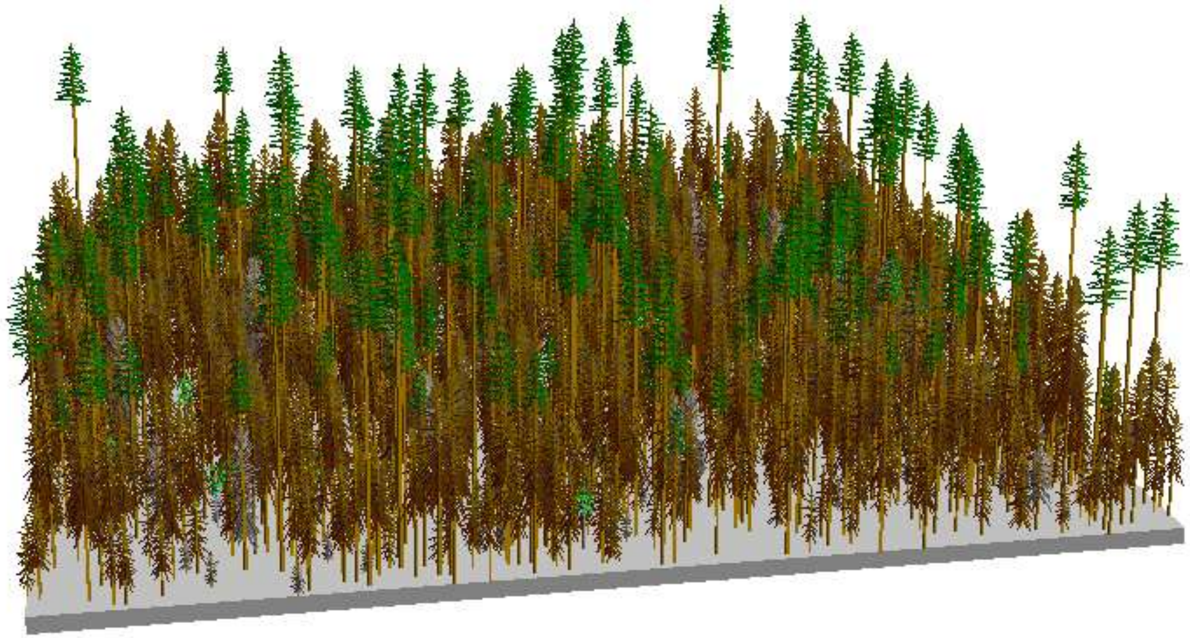
Scope

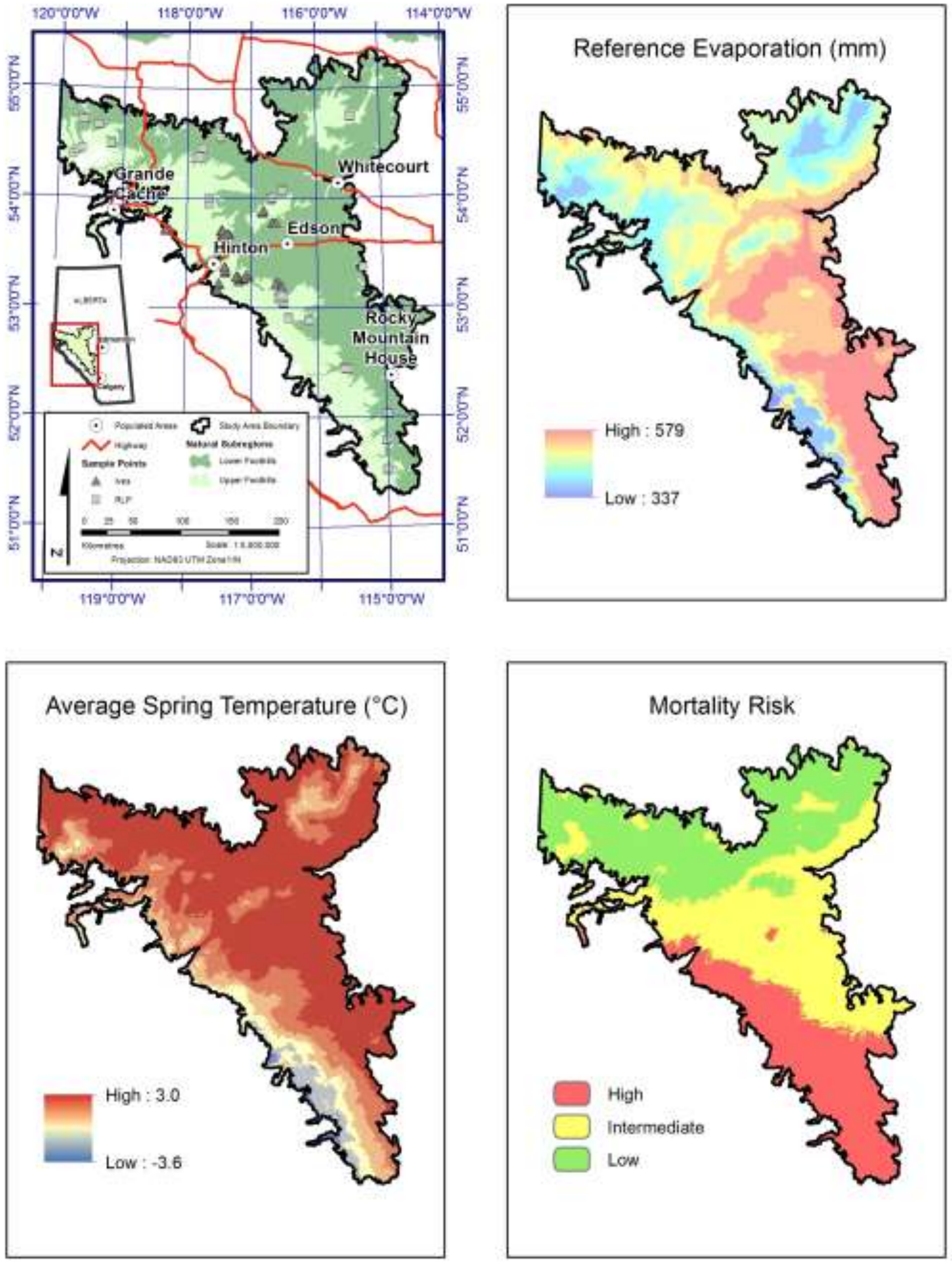
Ecoregions

Scope

Natural disturbance





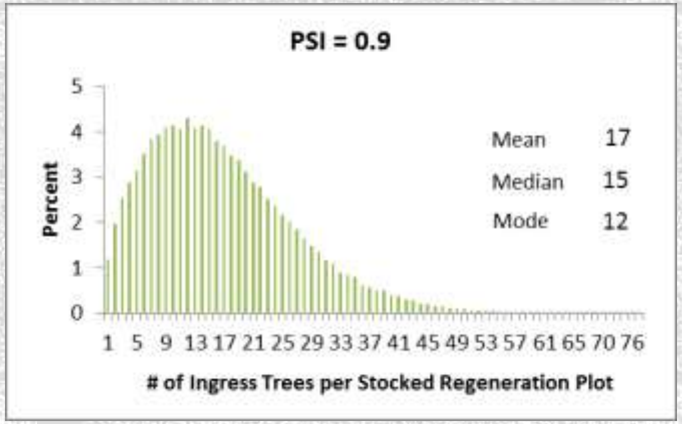


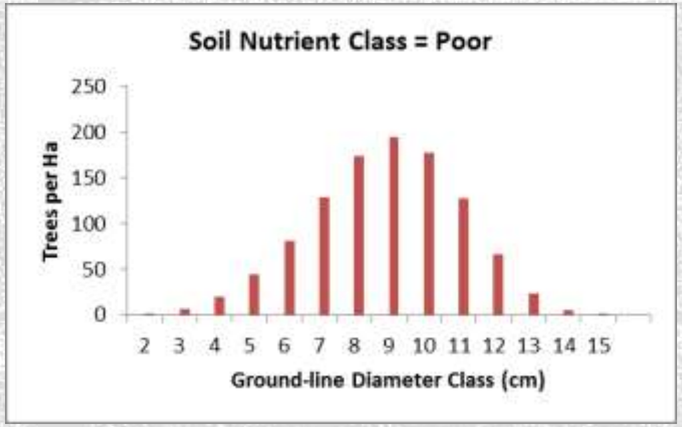
Scope

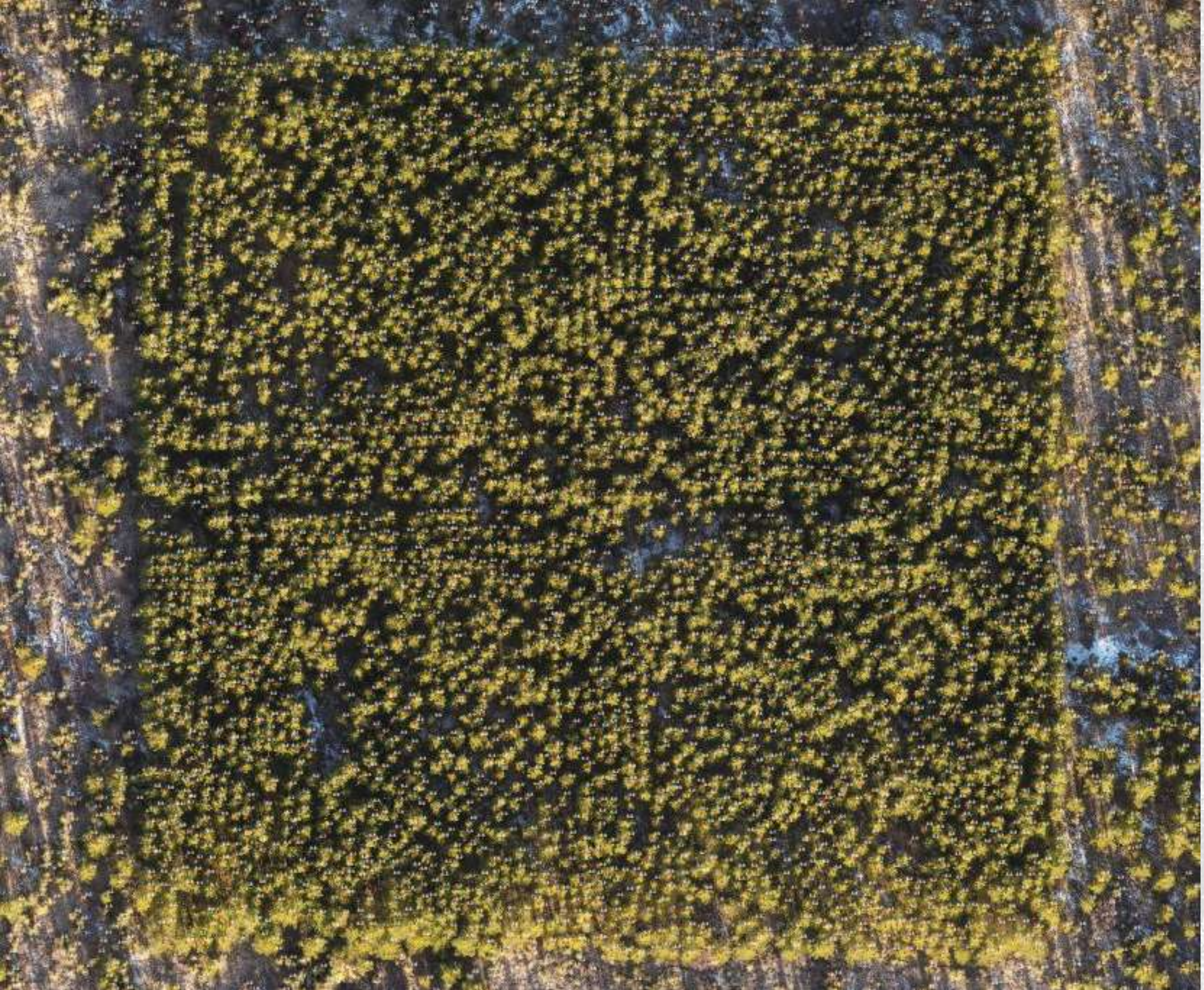
Climate

Analytical techniques

- Frequency distributions (e.g. Dempster and Gulyas 2017)
- Combined probability models (e.g. Li *et al*. 2011)
- Segmented regression (e.g. Vanderschaaf and Burkhart 2008)
- Advanced machine learning e.g.
  - Random Forest (Venier *et al*. 2019)
  - XGBoost, LightGBM (Yang and Meng 2022)







Remote sensing

Image of RLP trial installation

- Area: 1 ha (100 m x 100 m)
- Planting: 4444 stems ha^{-1} (1.5 m x 1.5 m), June 2002
- Flight date: October 2021
- LiDAR density: 470 ppm
- LiDAR flight height: 80 m
- Minimum tree height: 1.3 m
- Ortho flight height: 120 m
-

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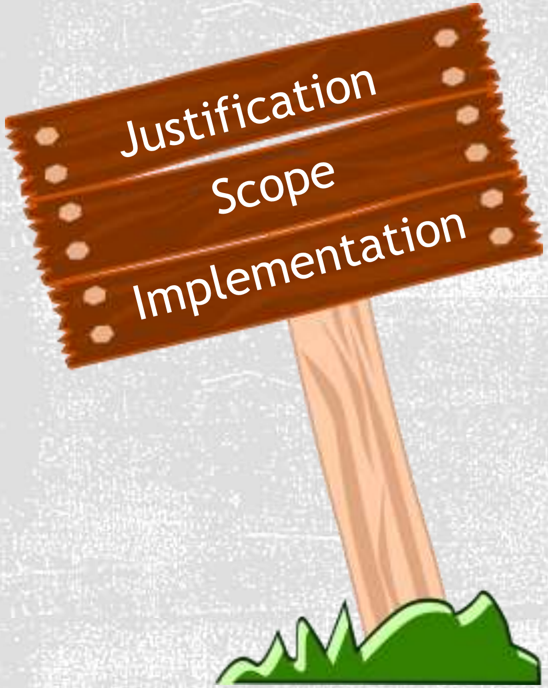
-

Conclusions

1. **Justification** There is a compelling need to improve representation of regeneration dynamics in forest growth and yield models for Canada’s boreal forest region, where new algorithms are required to properly represent post-disturbance forest stand dynamics.
2. **Scope** The currently limited scope of regeneration modelling should be expanded to embrace climate variables, and more species, natural sub-regions, and types of disturbance.
3. **Implementation** Advances and innovations in climate data, analytical techniques, and remote sensing are available to facilitate input data capture, model development, and validation.



Acknowledgements

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- Weyerhaeuser (Grande Prairie and Pembina Timberlands)
- Alberta Forestry Parks and Tourism
- Canadian Forest Service
- Foothills Research Institute
- Forest Resource Improvement Association of Alberta
- University of Alberta

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