Formulating climate sensitive yield projections using transfer functions

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Yield Projections

- Silvicultural planning
- Supports Allowable Annual Cut (AAC) determinations
- Carbon Budget Monitoring
- National wood supply
- …many other applications

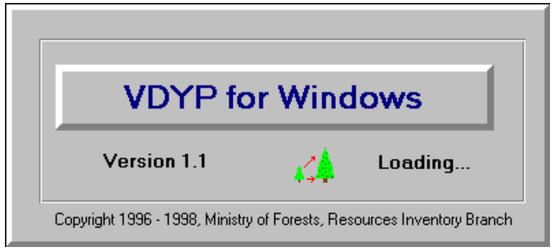
Yield Projection Systems and Climate

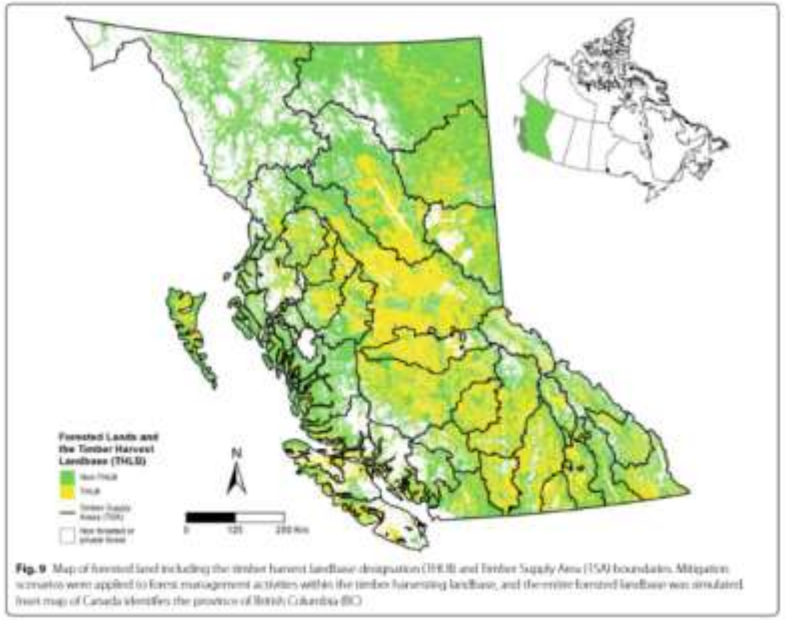
- **Why the need for climate variables within G&Y models?**
  - Climate change is accelerating
  - Longer projection periods
  - Climate affects productivity (30% of variability in Site Index due to climate[a])
  - CBST
  - Blue Ribbon Panel Report (2018); Penner Report (2021); Fletcher Report (2023)
- **BC models: climate static**
  - AB*, SK, and MB models climate static (*climate vars added to MGM)
  - ON – climate sensitive site index curves
  - NB (NS, PEI) and QC – some climate sensitive functions

[a] Monserud et al. 2006

Yield Projection Systems in BC

Unmanaged stands





Smyth et al. 2020

Managed stands

Stand-level
Crown closure, Basal area, Site Index

Pure and mixed-species
TSR and inventory updates
Deterministic

Individual tree (TASS)
Mixed-species (TASS III)

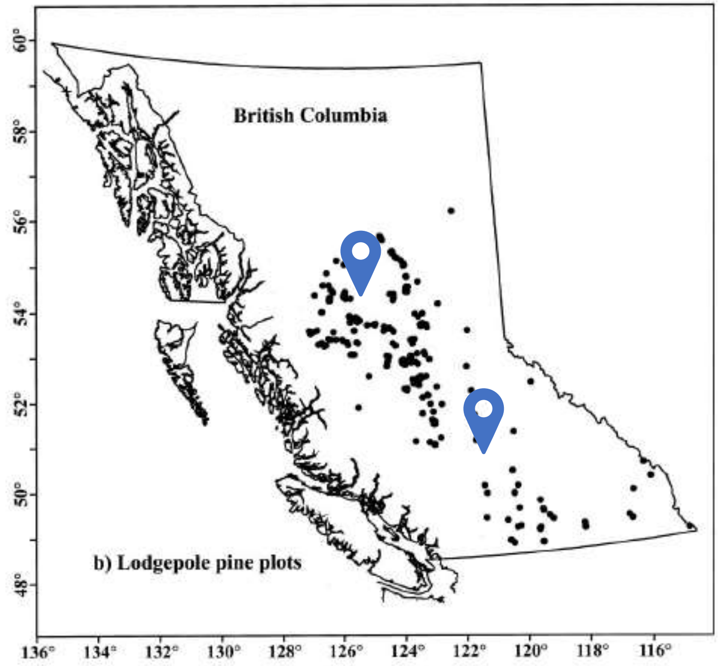
Meta-model (TIPSY)
Stand-level (TIPSY)
TSR (TIPSY)

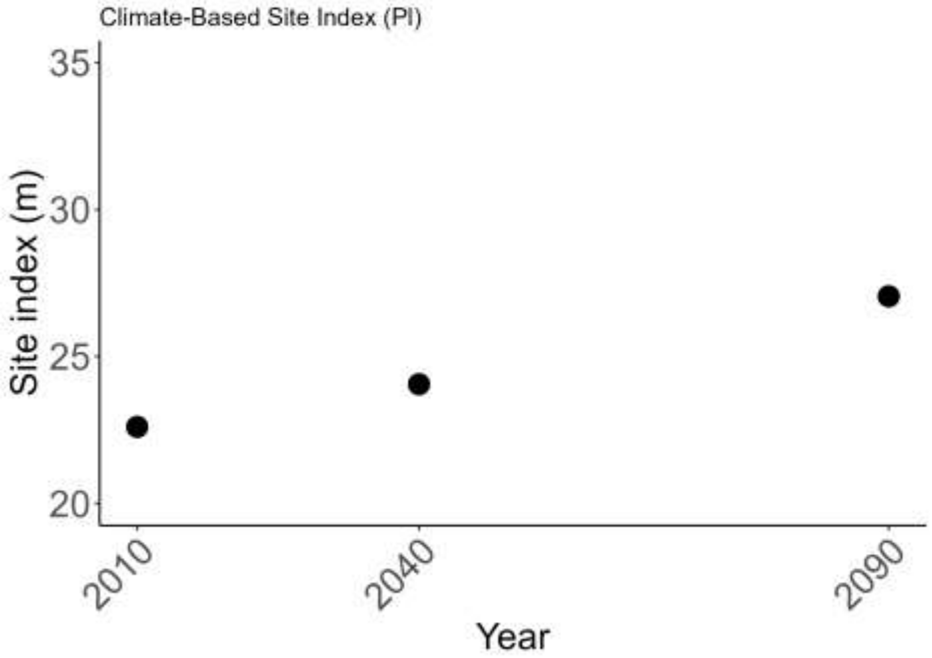
TASS

TIPSY

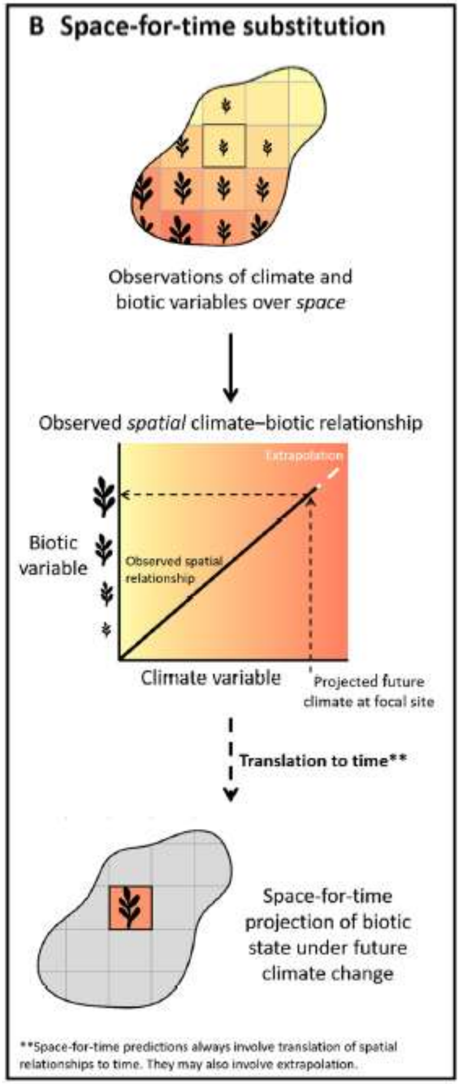
How to incorporate climate effects into G&Y?

1. **Temporary Sample Plots (Space-for-time substitution)**
    - Sample population = locally adapted trees
    - Most studies predict increased site productivity
    - Nigh et al. (2004) for site index [SI = f(Climate Vars.)]





Model from Nigh (2004)



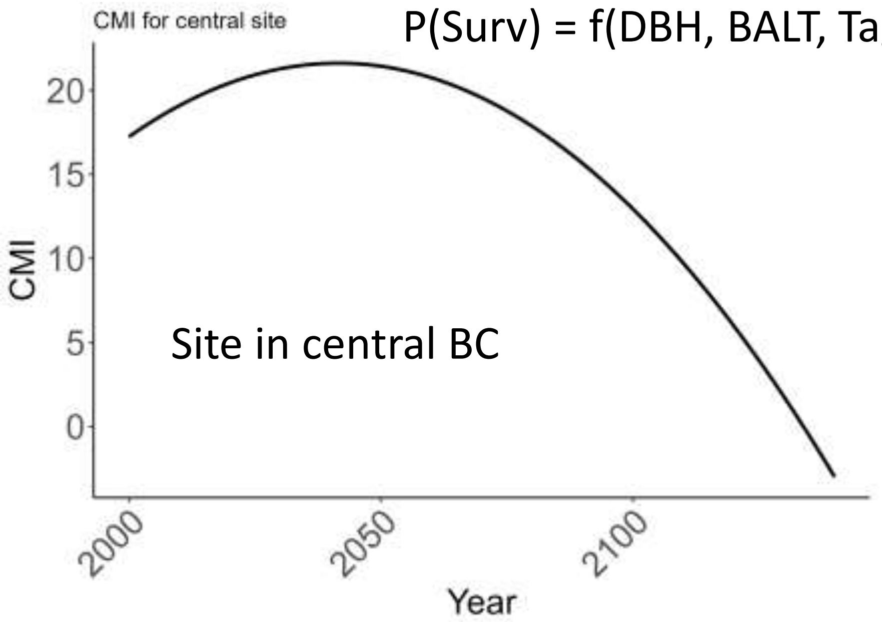
Lovell et al. 2023

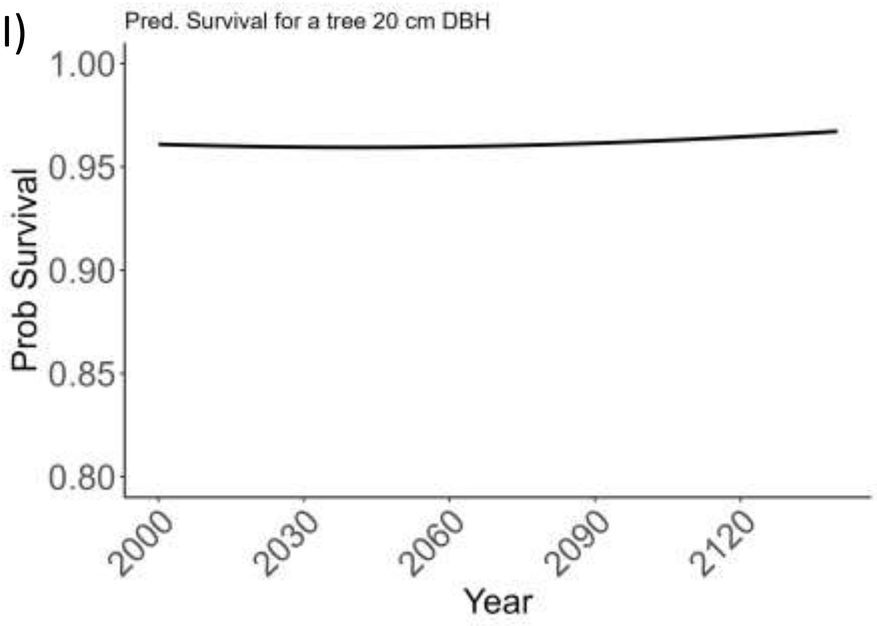
How to incorporate climate effects into G&Y?

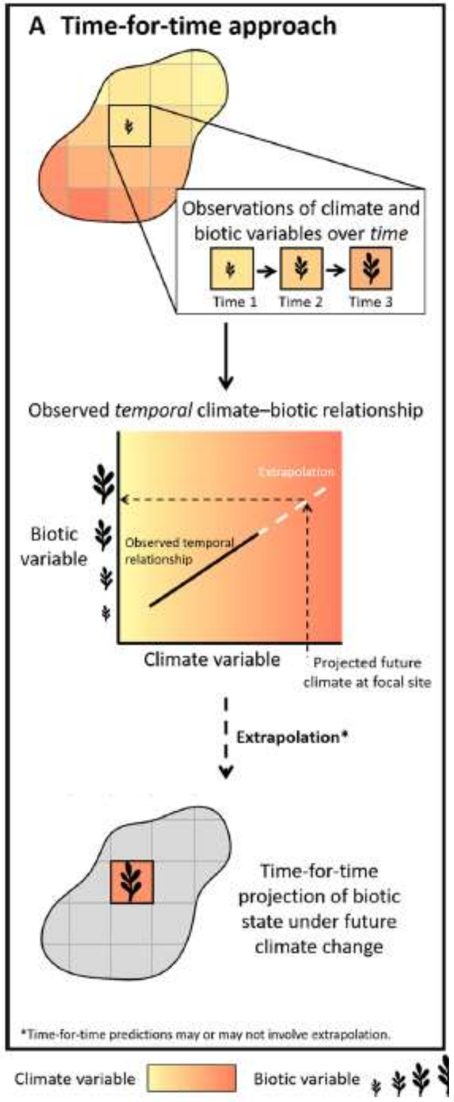
2. Permanent Sample Plots (time-for-time)

- Sample population = locally adapted stands
- "Marginal effect" of climate is usually small
- Oboite and Comeau (2020) for diameter growth, Cortini et al. (2017) for survival in MGM

P(Surv) = f(DBH, BALT, Tag, CMI)





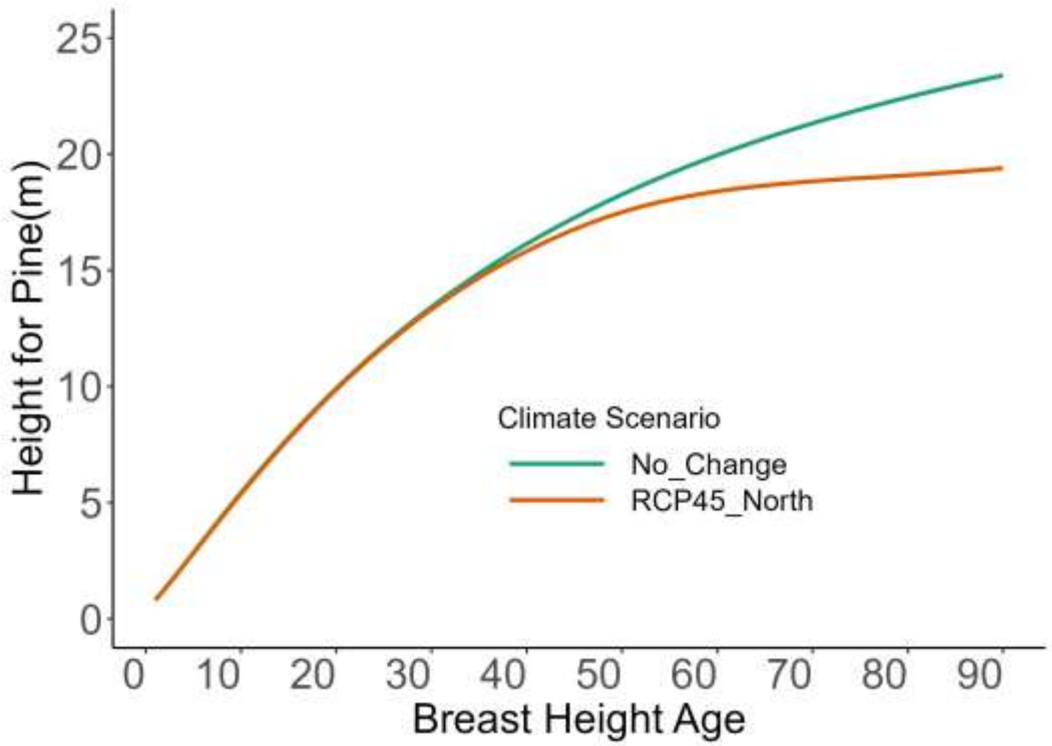


Lovell et al. 2023

How to incorporate climate effects into G&Y?

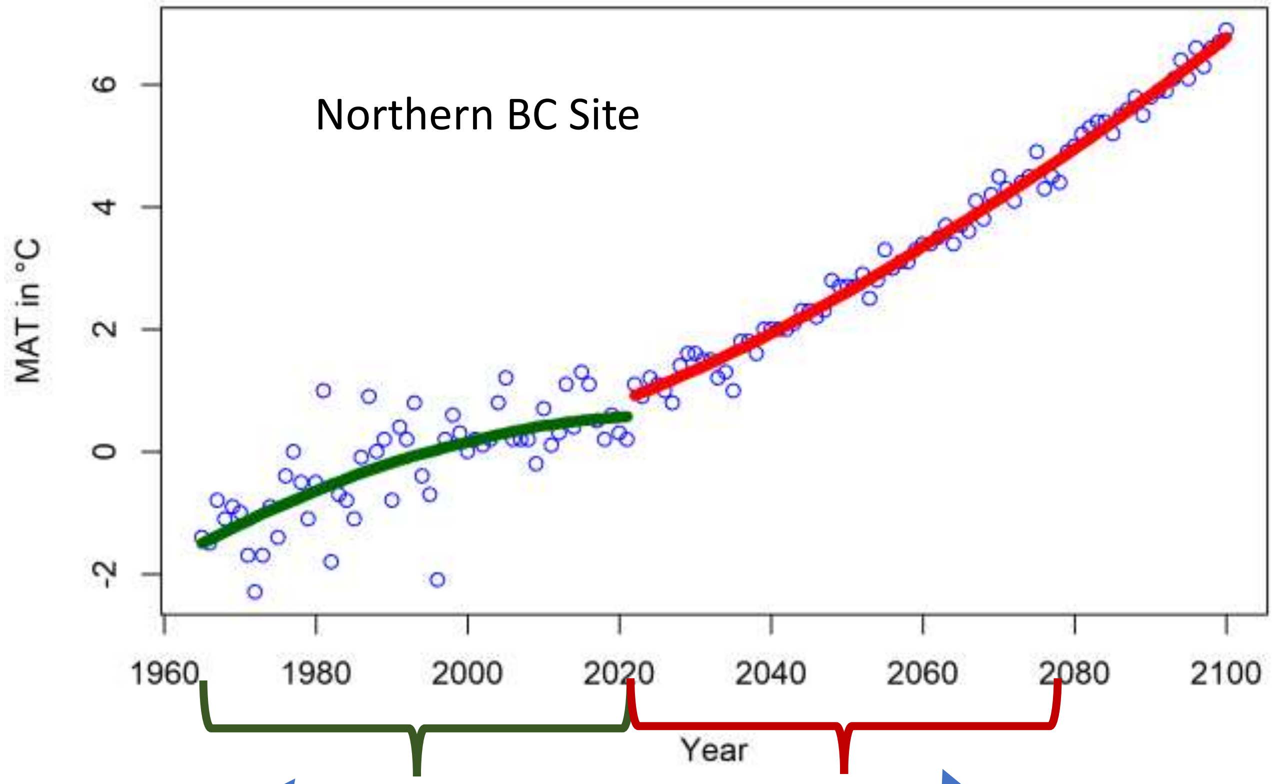
3. Stem analysis

- Sample population = locally adapted trees
- Uncertainty around sample tree history
- Sharma et al. (2015) for Height-age (Site index) curves



How to incorporate climate effects into G&Y?

- Approach 2 requires large extrapolation
- Future migration lag is underestimated
- Not designed to accommodate seed transfer
- Ignore genetic-by-environment interaction

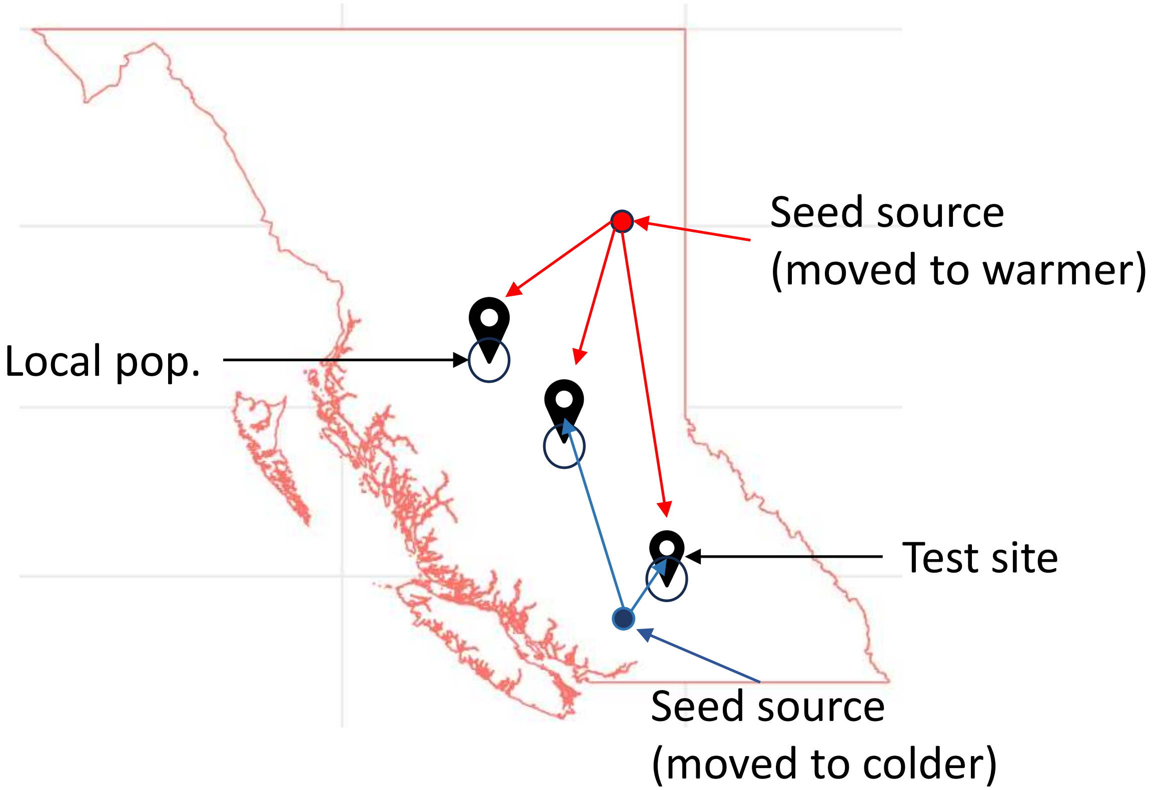


delta MAT ~ 1°C

delta MAT ~ 3.5°C

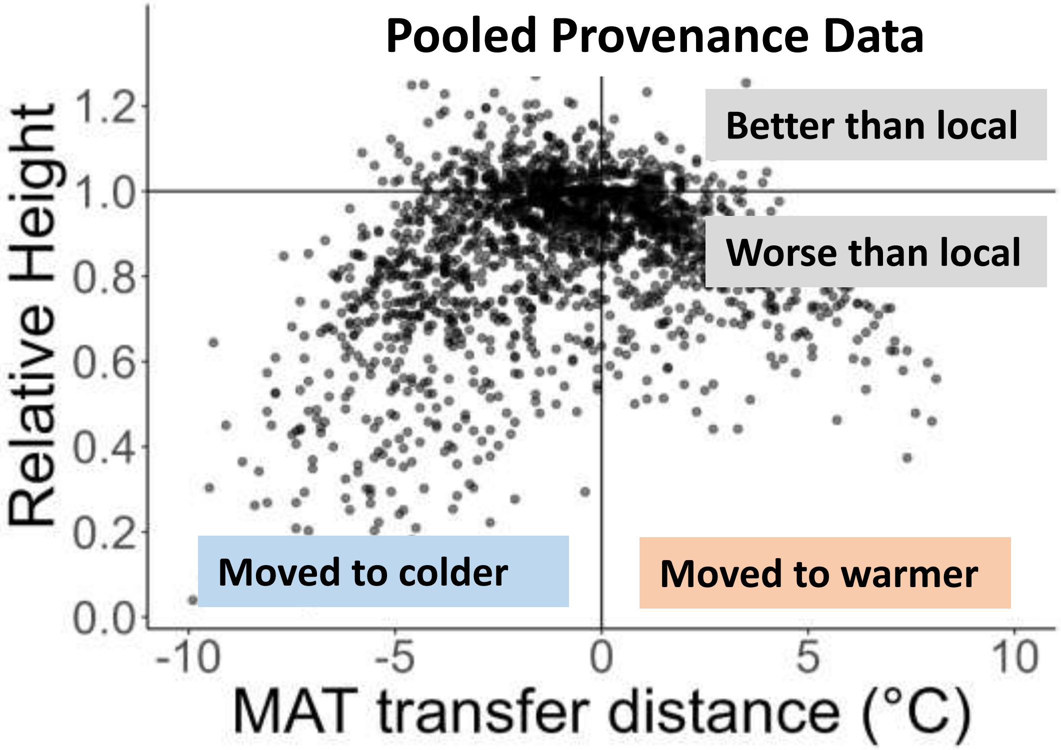
Transfer Functions and Climate Change

- TFs relate attributes (e.g., HT, Survival) to climate transfer distance



Transfer Functions and Climate Change

- TFs relate attributes (e.g., HT, Survival) to climate transfer distance
- Population-specific response to climate change
- Accounts for climate-maladaptation
- Less extrapolation
- **How to link to G&Y models?**
- **Of limited use within TSR**



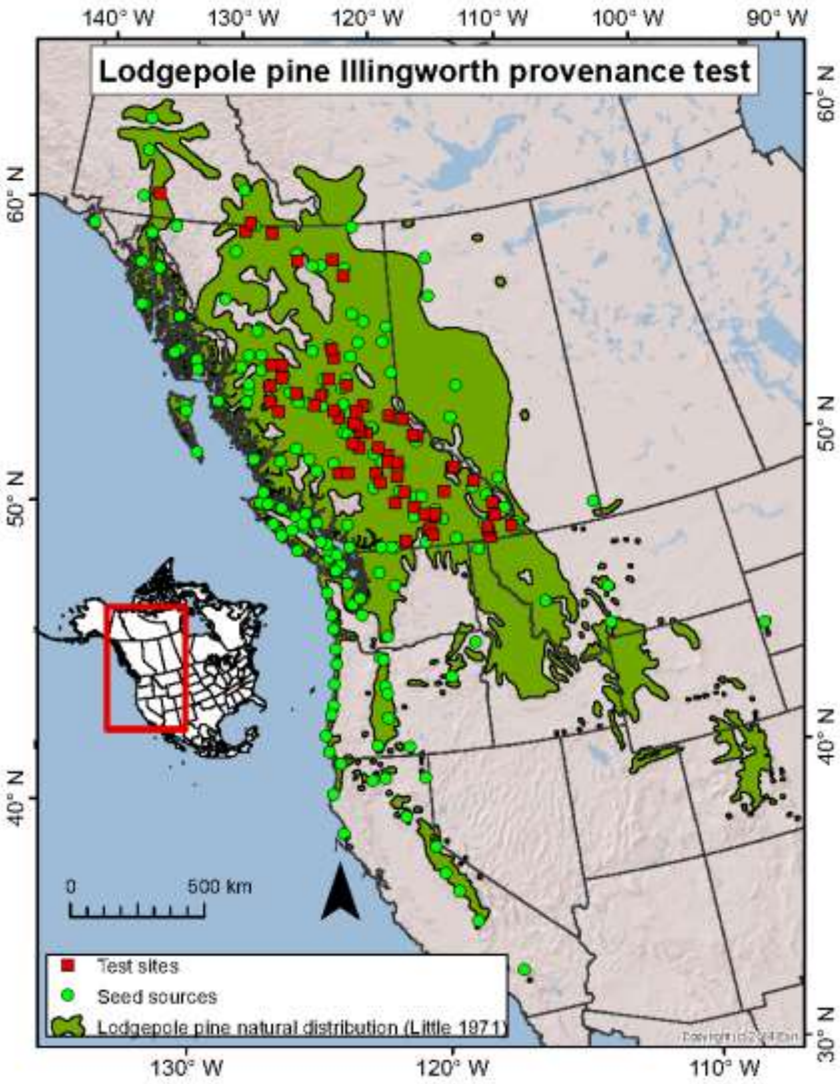
Transfer functions in Growth and Yield Modeling

O'Neill and Nigh (2011): Adjust **Height-Age curves** for Lodgepole Pine using **Transfer Function for Relative Height**

- Illingworth Data (est. 1974, 60 sites, 142 pops.)
- Tested in TASS

Objectives:

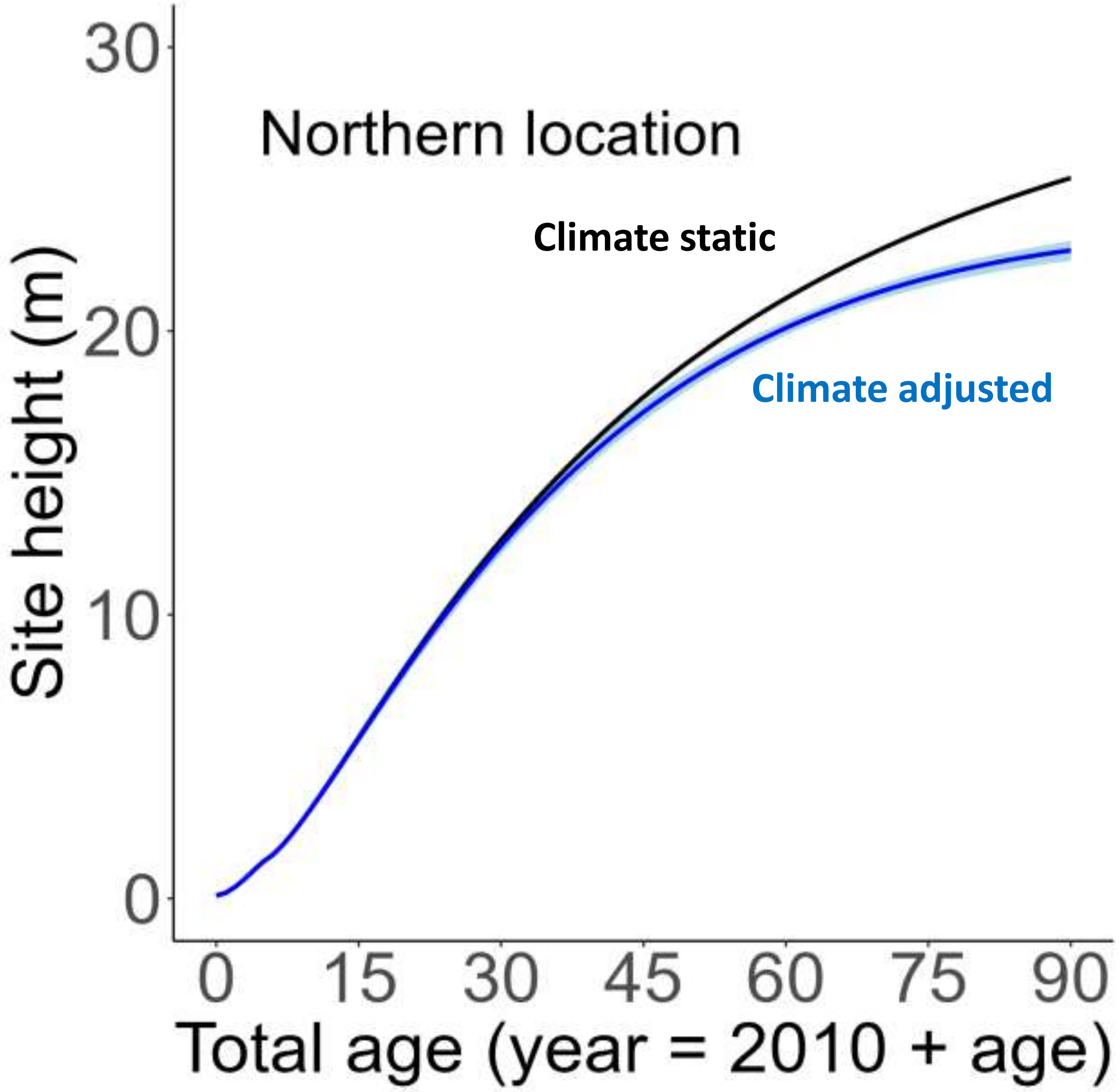
1. Revisit TF for Height
2. Formulate a TF for Survival
3. Link both the TF for Height and TF for survival to a GY model



Source: Amy Vallarino

Using TFs to modify gr

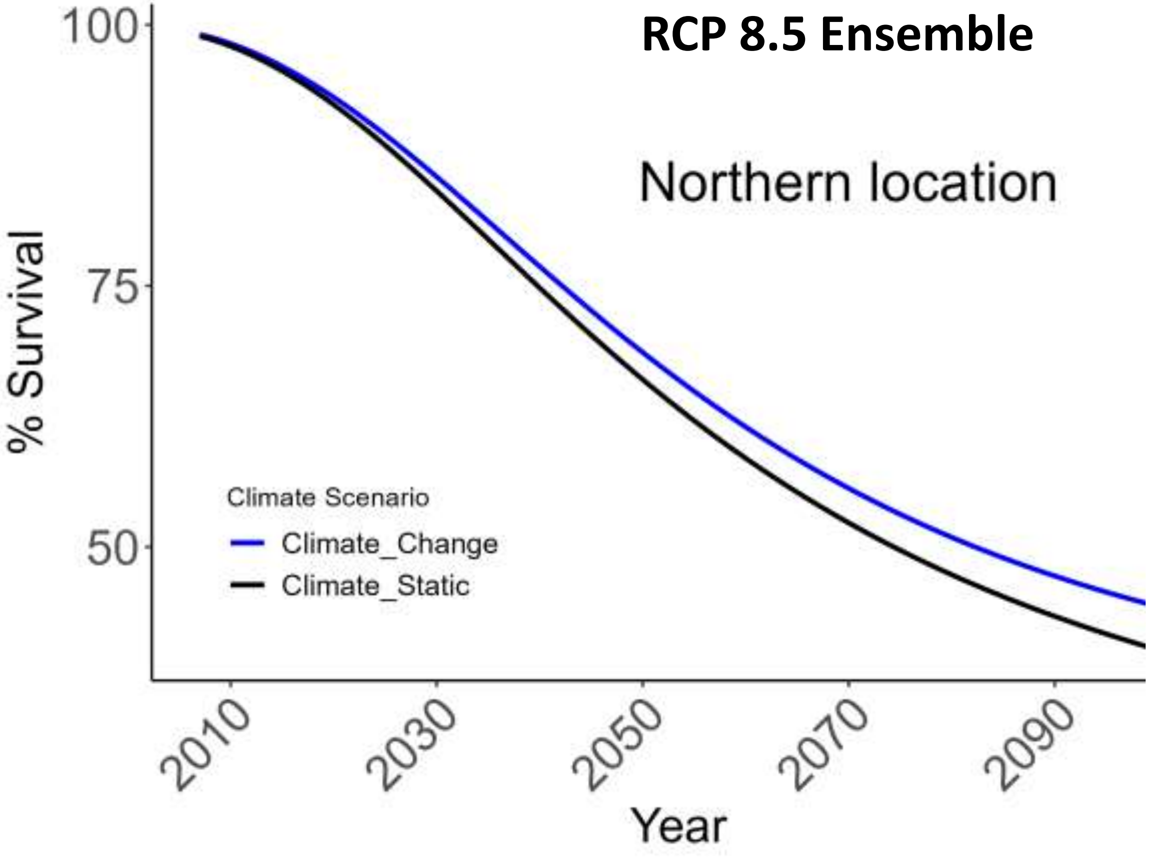
- **Revised TF for Relative Height (Hp)**
  - Includes a population-specific interaction term
  - **GLM** $(Y \sim N(u, \sigma^2))$, where: $(g(\mu) = ln(\mu))$
- Relative Height (Hp) used as a multiplier in Height-Age equations



Using TFs to modify growth models

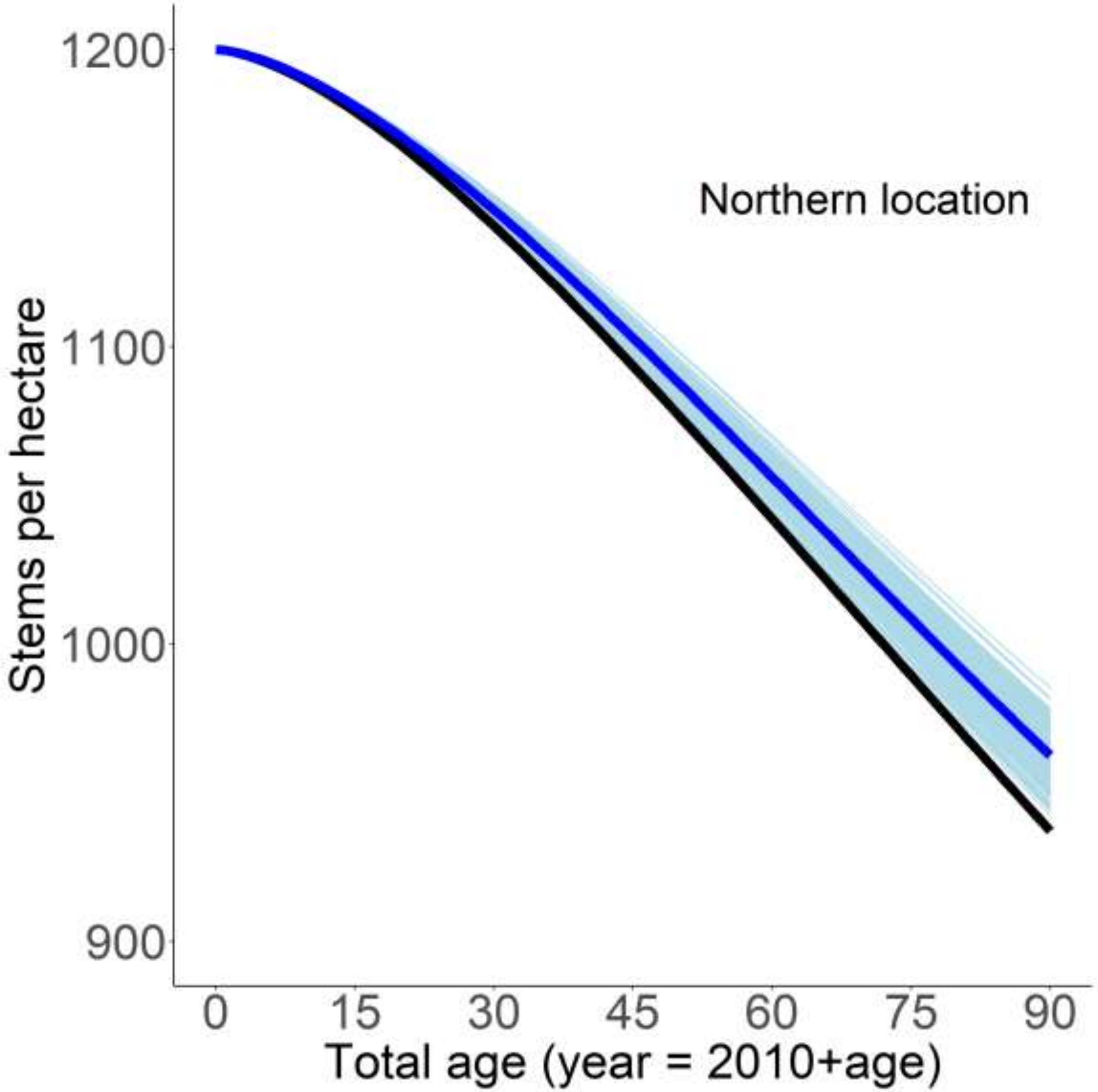
- **TF for Survival**
  - Dynamic over time
  - Model fit using repeated measures from Illingworth Trial
  - Genetic-by-environment interaction

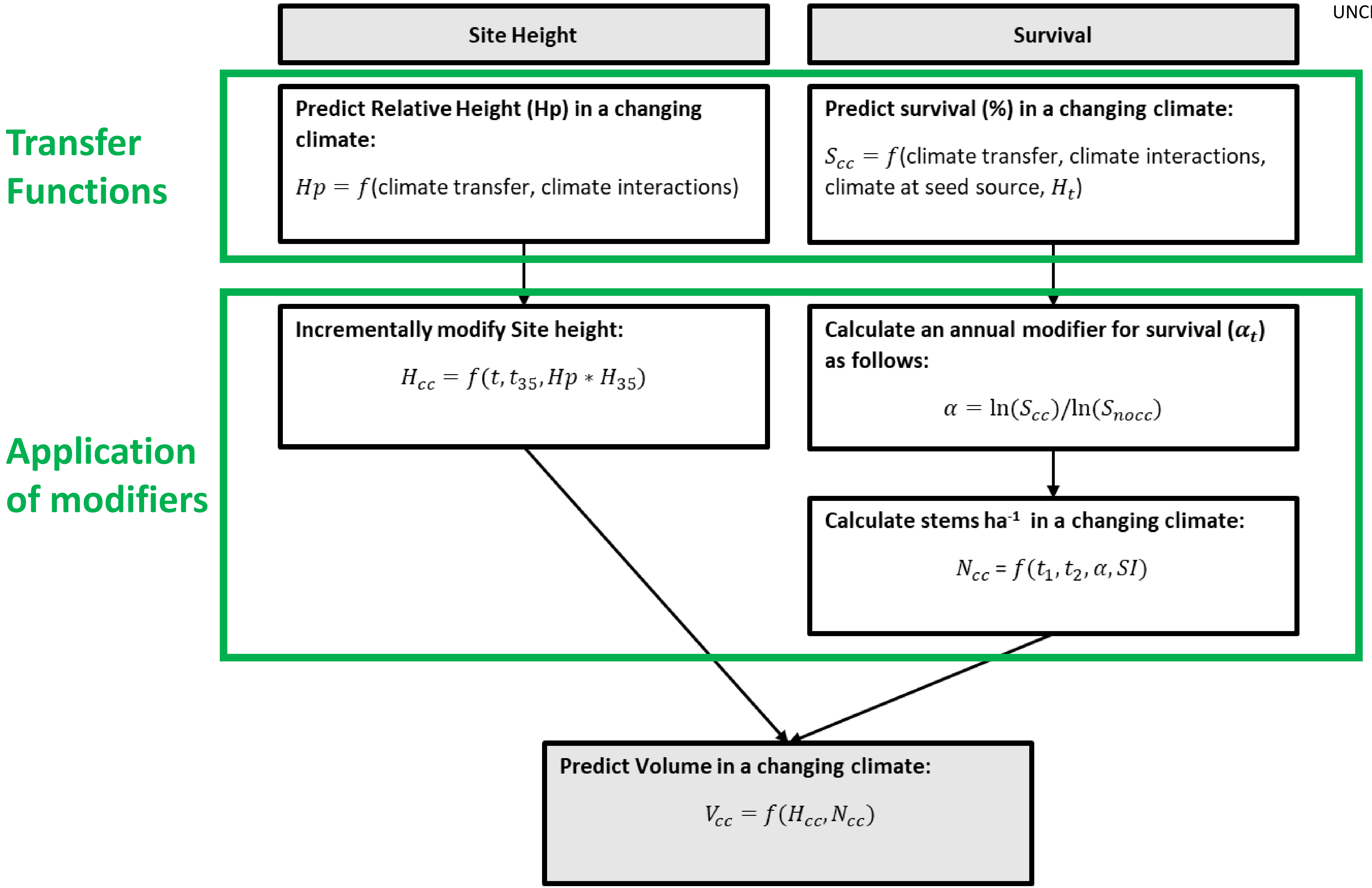
- **Tree Survival in TASS**
  - Mortality controlled by neighbourhood, crown size, random events
  - Too complex



Using TFs to modify growth models

- **Meta-model of TIPSY:**
  - Volume (m^3/ha) = *f*(Site Height, N)
  - Site Height = *f*(t, H_0, t_0)
  - $N_2 = f(t_2, t_1, N_{1,}$ SI)
- **Modification of N (Stems/ha):**
  - $\alpha = \ln(S_{cc}) / \ln(S_{nocc})$
  - $N_{cc} = f(\alpha, N_{nocc})$

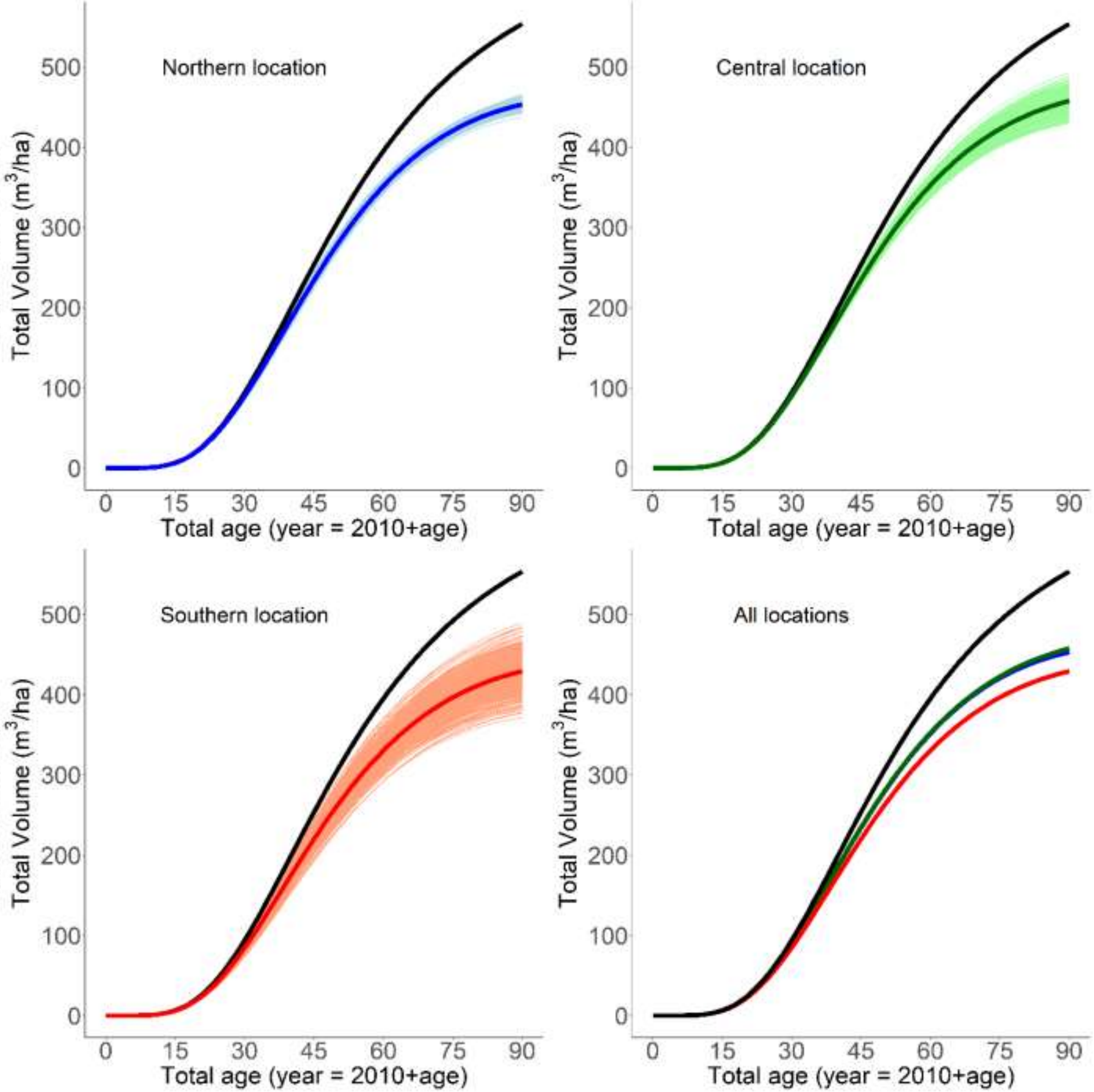



Site Height
Survival
Transfer Functions
Predict Relative Height (Hp) in a changing climate:
$Hp = f$(climate transfer, climate interactions)
Predict survival (%) in a changing climate:
$S_{cc} = f$(climate transfer, climate interactions, climate at seed source, H_t)
Application of modifiers
Incrementally modify Site height:
$H_{cc} = f(t, t_{35}, Hp * H_{35})$
Calculate an annual modifier for survival (α_t) as follows:
$\alpha = \ln(S_{cc})/\ln(S_{nocc})$
Calculate stems ha^{-1} in a changing climate:
$N_{cc} = f(t_1, t_2, \alpha, SI)$
Predict Volume in a changing climate:
$V_{cc} = f(H_{cc}, N_{cc})$

Simulations at three cutblocks (local seed)

Planted Pine
SPH = 1200
SI = 20 m
90 yr projection, starting in 2010

17-22% reduction in stand volume



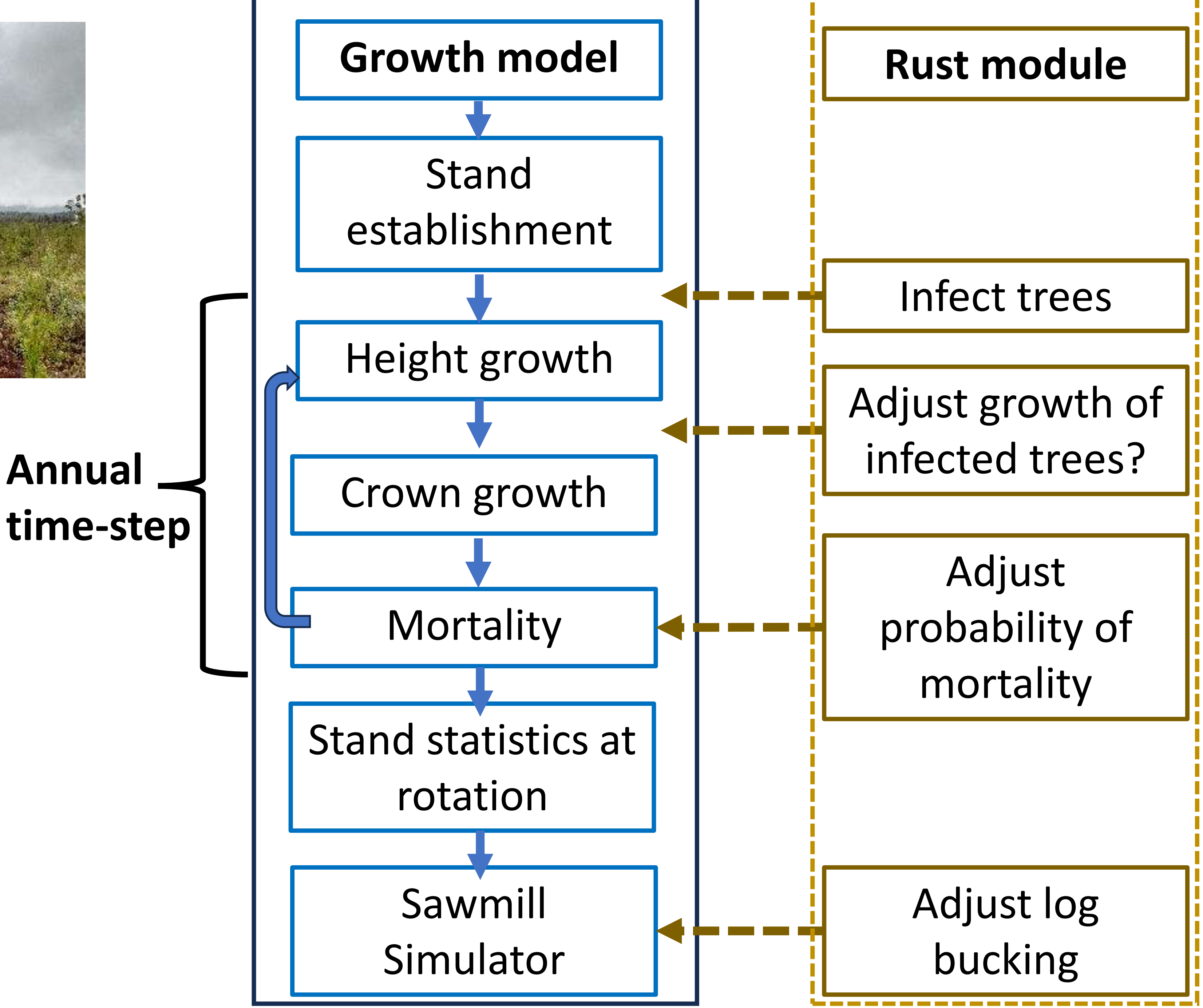
Limitations

- Provenance Trials ≠ G&Y Plots
  - No buffers
  - Single planting density
  - < 18 trees / population
  - No crown measurements
  - Trials << Rotation Age
- Transfer functions for all species?
  - TFs for Generalists and Specialists?

Next Steps

- Simulations with non-local seed
- Simulations with local/non-local seed mixtures
- Landscape-level analysis – harvest scheduler
- Adding the option to modify projections in TIPSY???

Simulating the impacts of pine rusts

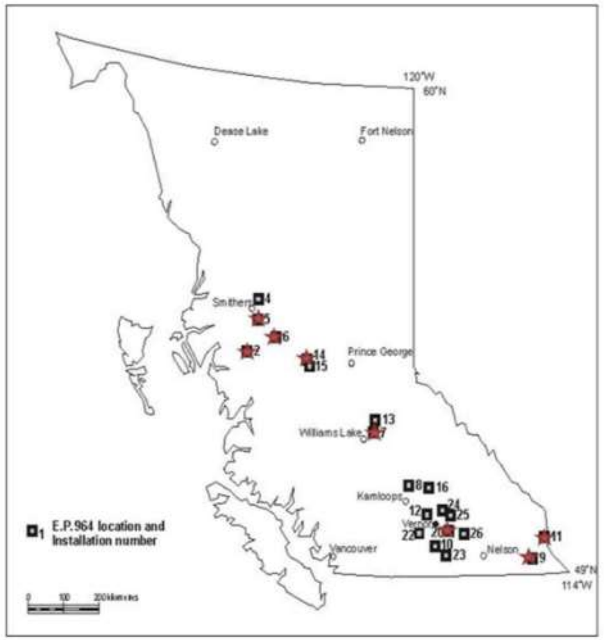

Growth model
Stand establishment
Height growth
Crown growth
Mortality
Stand statistics at rotation
Sawmill Simulator
Annual time-step
Rust module
Infect trees
Adjust growth of infected trees?
Adjust probability of mortality
Adjust log bucking

SIFIÉ

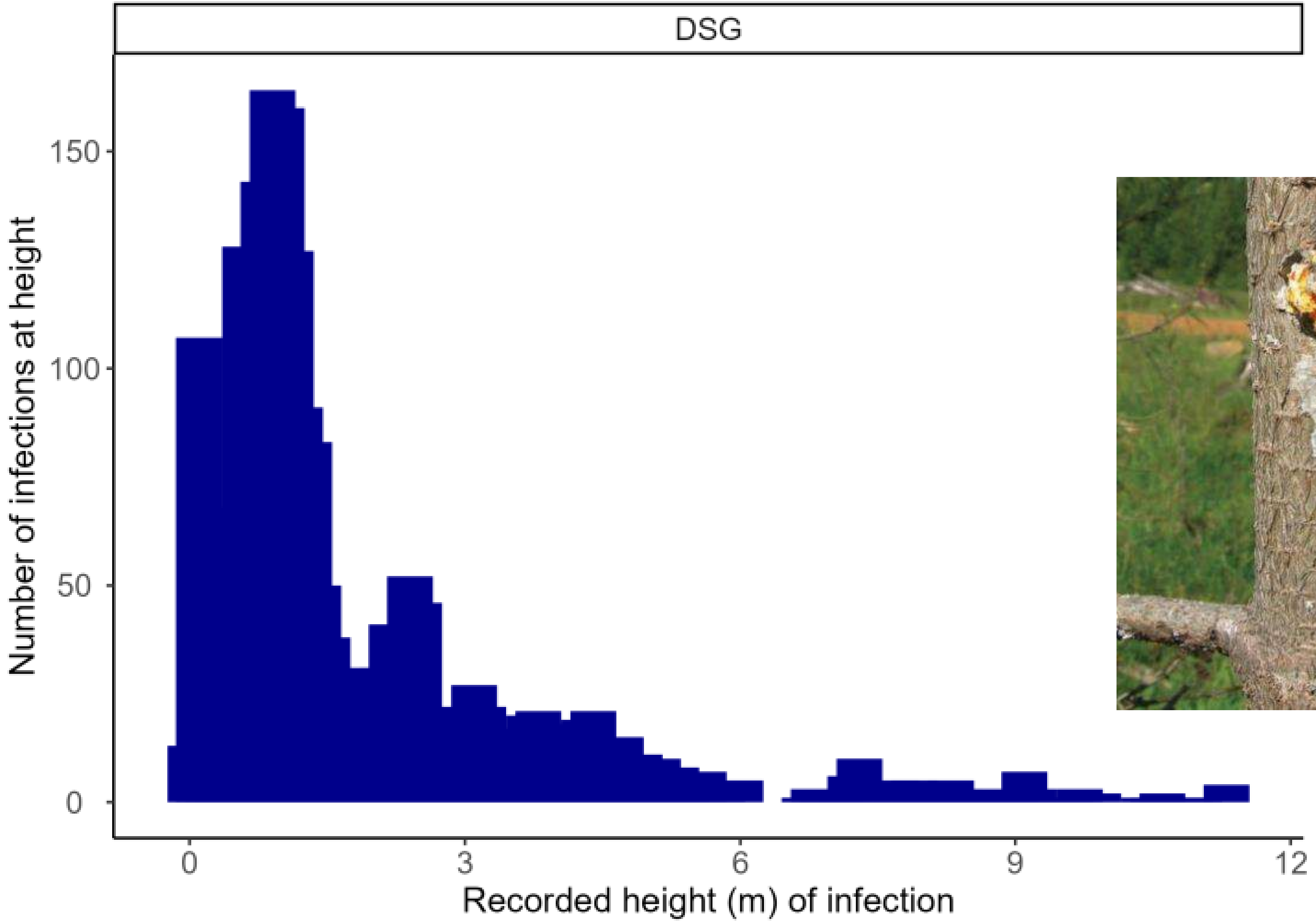
Data for model building

Main Data Sources:

- **EP 671 (1 installation; Est. 1968)**
  - 4 planting densities, each replicated in 6 plots (24 plots)
  - 64 trees/plot (+ buffers) measured at 8, 13 , 18, 23, 28, 33, and 41 years
  - Rusts surveys performed in 1997, 2002, 2005, 2014
- **EP 964 (5 installations; Est. 1987-1991)**
  - 5 planting densities, each replicated in 3 plots
  - 64 trees/plot measured every 5 or 10 years, up to 25 years
  - Rust survey performed in 2016
- **Bednesti (1 installation; Est. 1988)**
  - Various planting densities + treatments over 30 plots
  - Most plots measured annually up to 30 years
  - Rusts surveyed in 2010, 2011, 2015, 2016, 2017

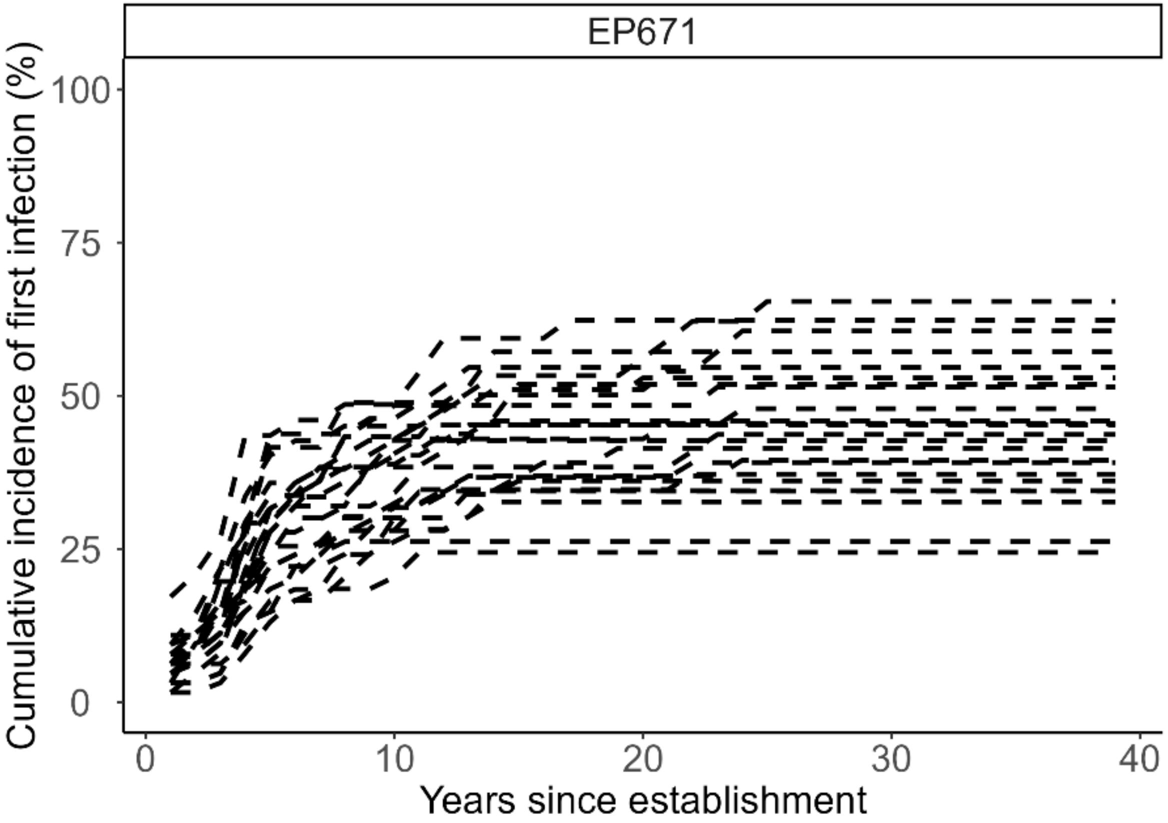


Heights of gall on main stem



Cumulative incidence of first infection

$$Cumulative\_Inc = \sum_{t=1}^{k} Incidence\ Proportion$$



Cumulative incidence of first infection

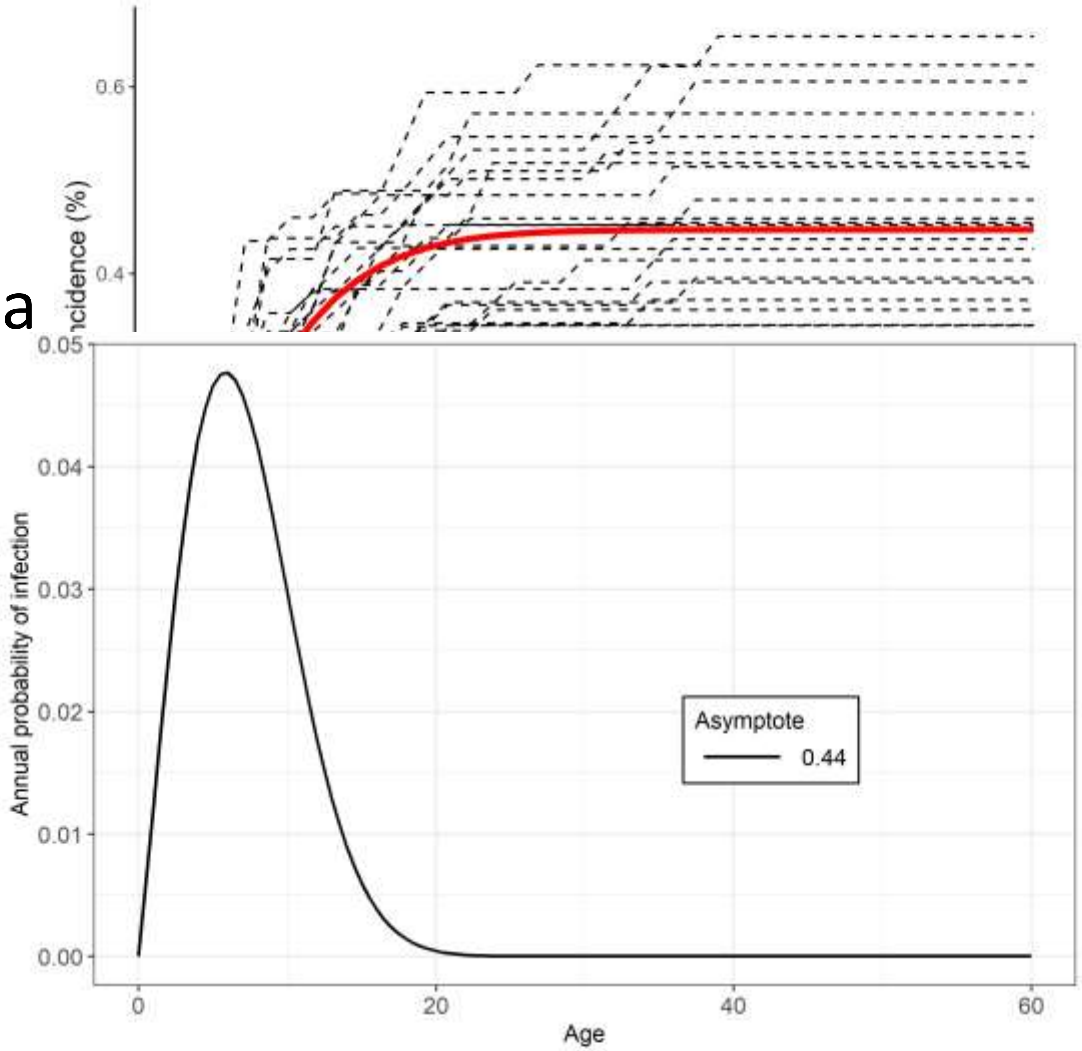
Weibull Growth Function

$$Cumulative\_Inc = \beta_1\left[1 - \exp\left(\beta_2 t^{\beta_3}\right)\right]$$

- Initialized using Free Growing Survey Data
- β_1= initialization variable

Differential form (annual probability):

$$\boldsymbol{P_{inf} = \beta_1 \beta_2 \beta_3 t^{\beta_3 - 1}\left[\exp\left(-\beta_2 t^{\beta_3}\right)\right]}$$



Modified probability of infection

Two parameter Weibull:

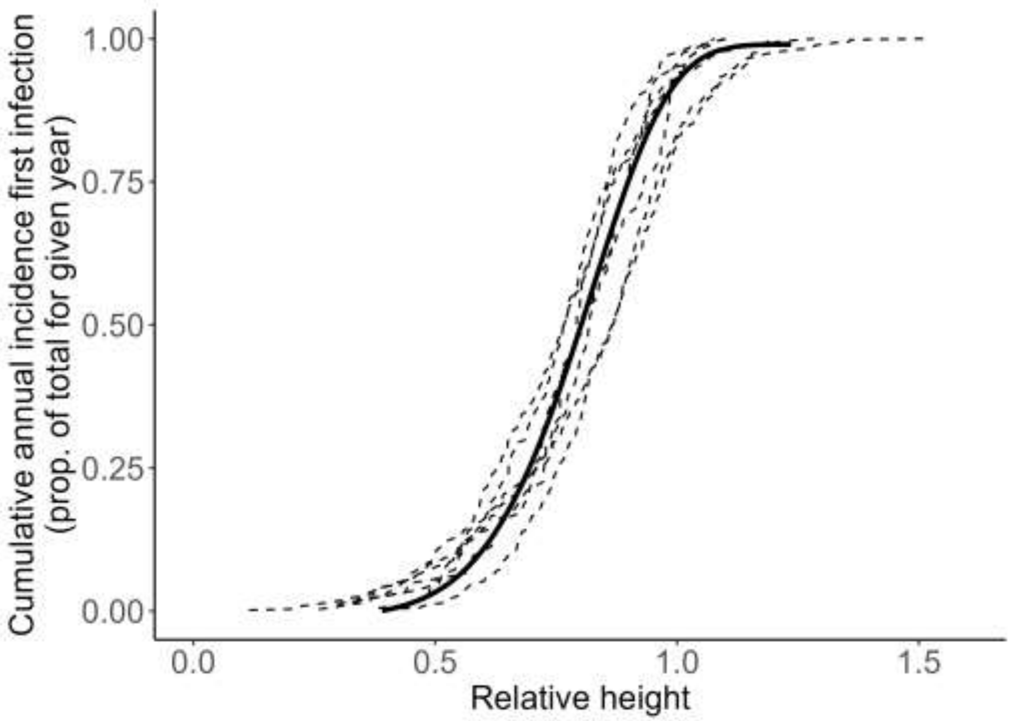
$$CAP_1 = 1 - \exp([-\left(\frac{RelH}{\alpha_1}\right)^{\alpha_2}]$$

Inverse transform:

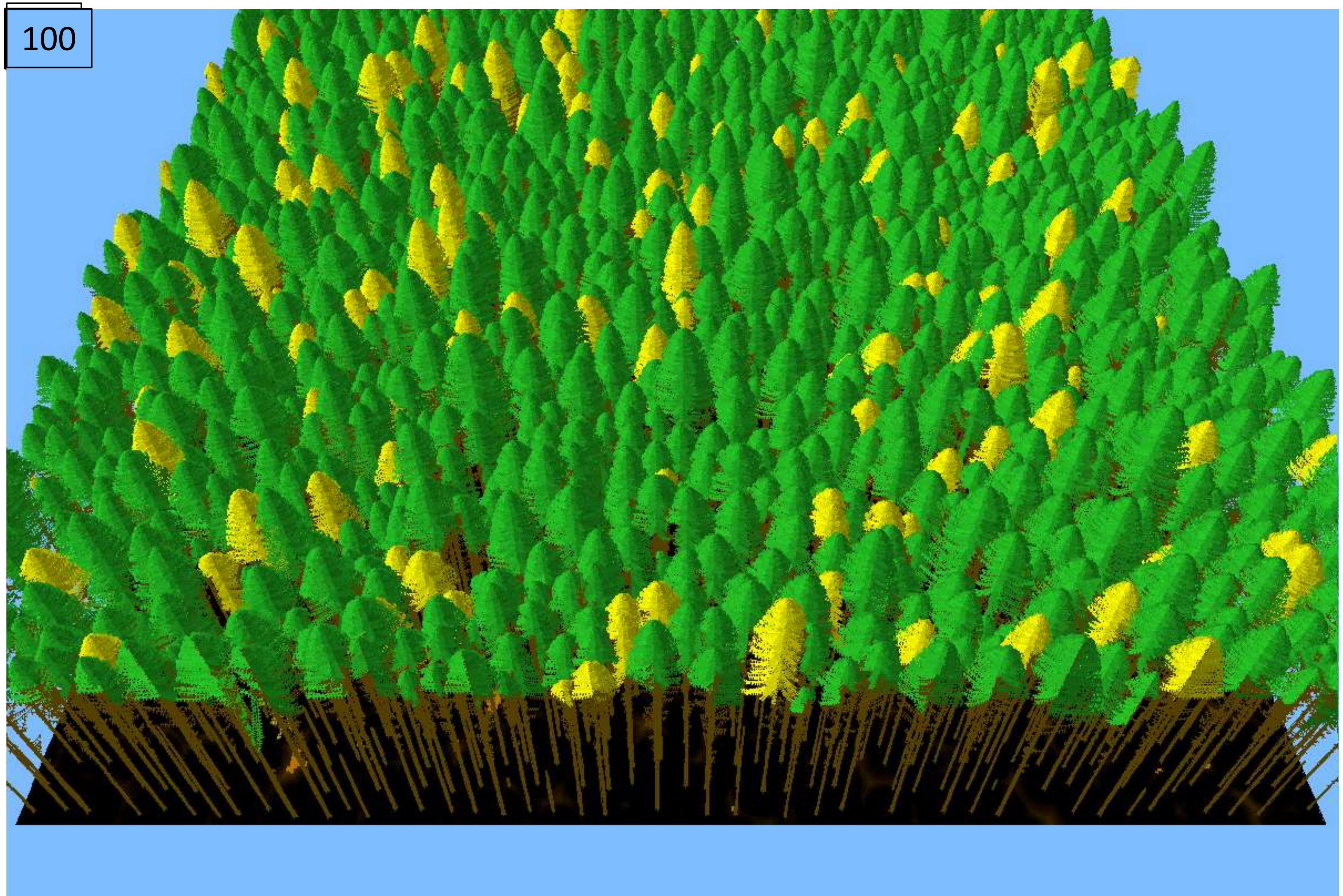
$$RelH_u = \alpha_1[-\ln(1-u)]^{1/\alpha_2}$$

(*maps $U(0,1)$ to Weibull distribution*)

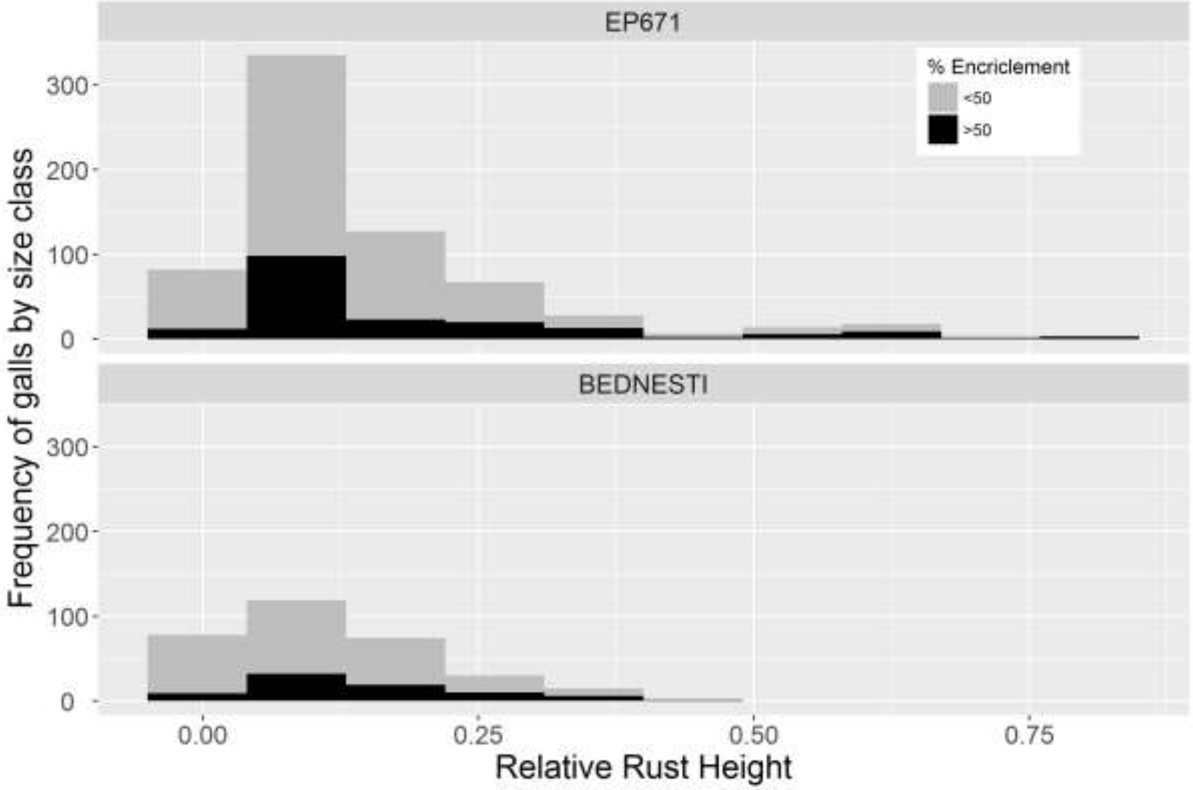
- Draw $u \sim U(0,1)$, generate $RelH_u$
- Infect trees where: $RelH_i < RelH_u$ until we reach P_{inf} for that year



2500/ha planted, 20% incidence, standard juvenile mortality



Galls >50% encirclement



Rust module

Infect trees

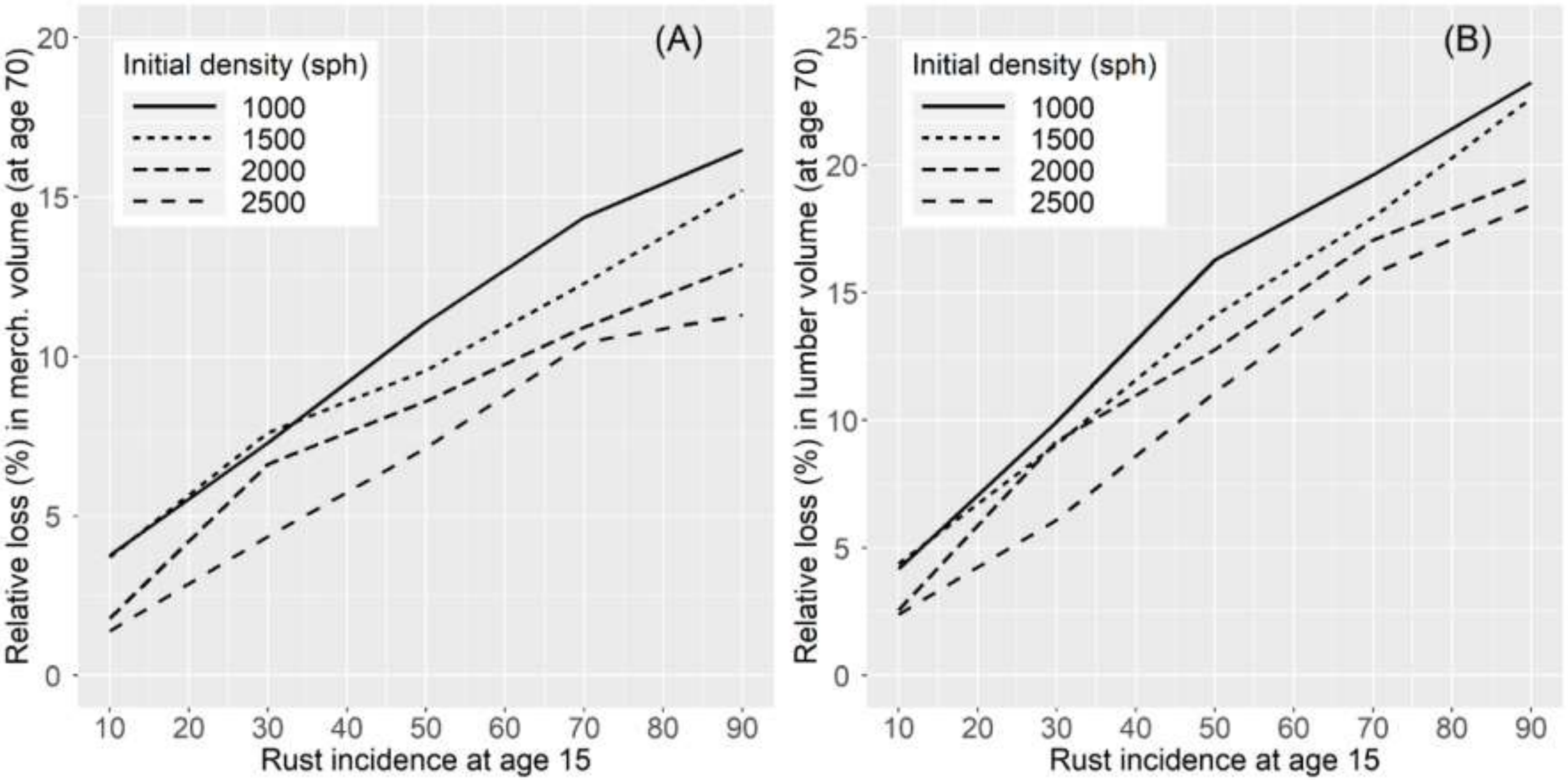
Adjust growth of infected trees?

Adjust probability of mortality

Adjust log bucking

- Is a Bernoulli random variable (either 0 or 1)
- If > 50% = 1, otherwise 0

Expected Loss in (A) Merch. Vol. and (B) Lumber



Questions?

Pedlar and McKenney (2017)