Comparisons of Approaches to Modelling Stand Structure and Dynamics in Planted Forests

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Stand level vs tree level models

Outline

- Background
- Objectives
- Data & Methods
- Results
  - Model components
  - Comparison of approaches
- Conclusions
- Demonstration of the model

Background

- Tree level information is important
- Growth modelling approaches
  - individual tree models
  - dis-aggregative methods (e.g. Weibull distributions)

Background (cont.)

- Tree-level and stand-level estimates should be compatible
- Comparisons of individual-tree models *vs.* stand-level models constructed with the same data are scarce

Main methodological objective

- To compare 3 approaches for predicting stand structure and dynamics with comparable output resolution, namely:

  ⇒ diameter distribution model (reverse Weibull)
  ⇒ relative-basal-area-based dis-aggregative approach
  ⇒ individual tree model

Main practical objective

To develop growth models providing increasing levels of resolution for increasing levels of detail in the input data

Compatibility

MODEL TYPE

- whole-stand
- diameter distribution
- individual-tree

Data

Data supplied by **Fletcher Forests Ltd.** (gratefully acknowledged)

- Douglas-fir (NZ)
  - 251 plots; 2 650 measurements
  - 7.3 - 84.2 years
- *P. radiata* (NZ)
  - 973 plots; 10 520 measurements
  - 0.4 - 72 years

Required model components (Stand-level; *Tree-level*)

Component	DDM	RBA	ITM
MEAN TOP HEIGHT	X	X	*
BASAL AREA	X	X	*
STOCKING	X	X	*
STANDARD DEVIATION of dbh's	X		
MAXIMUM DIAMETER	X		
RELATIVE BASAL AREA		X	
PROBABILITY OF TREE MORTALITY		X	X
DIAMETER INCREMENT			X

For calculating volumes: individual-tree height model; tree and stand volume equations

*** only required if the ITM is to be adjusted**

Methodology (1 of 2)

- Growth intervals
  - stand-level models: **all possible**
  - individual tree models: **annual intervals**
- Redundant data and autocorrelation were minimised by subsampling.
- Various equation forms and modelling techniques were examined for each component.

Methodology (2 of 2)

Comparisons

- Basal area and stocking estimates:
  - plots of residuals
  - analysis of residual statistics (mean, std. dev., etc.)
- Diameter distributions
  - error indices (Reynolds *et al*. 1988)

Results (1)

Main model components

Selected Mean Top Height equation for all species

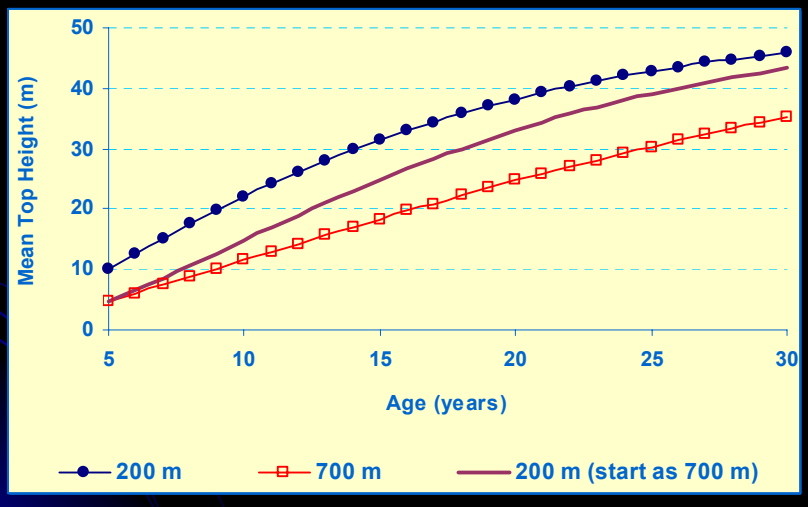
Chapman-Richards polymorphic:

$$H_2 = a\left(\frac{H_1}{a}\right)^{\frac{\ln(1-\exp(-kt_2))}{\ln(1-\exp(-kt_1))}}$$

$a=a_0+a_1*ALT/100$
$k=k_0+k_1*ALT/100$ (for NZ grown species)

Altitude effect on MTH

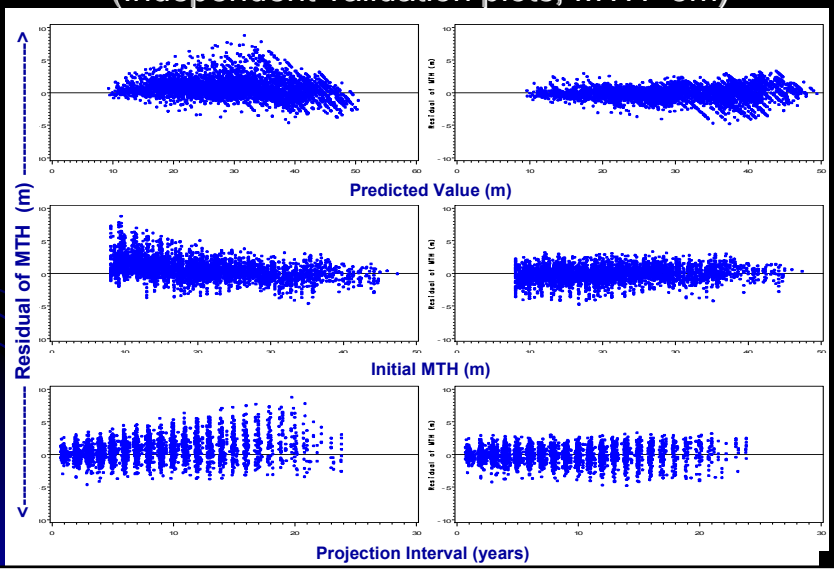
(P. radiata)



Comparison of MTH projections

KGM3/PPM88 (left) *vs.* new model (right)

(Independent validation plots; MTH>8m)



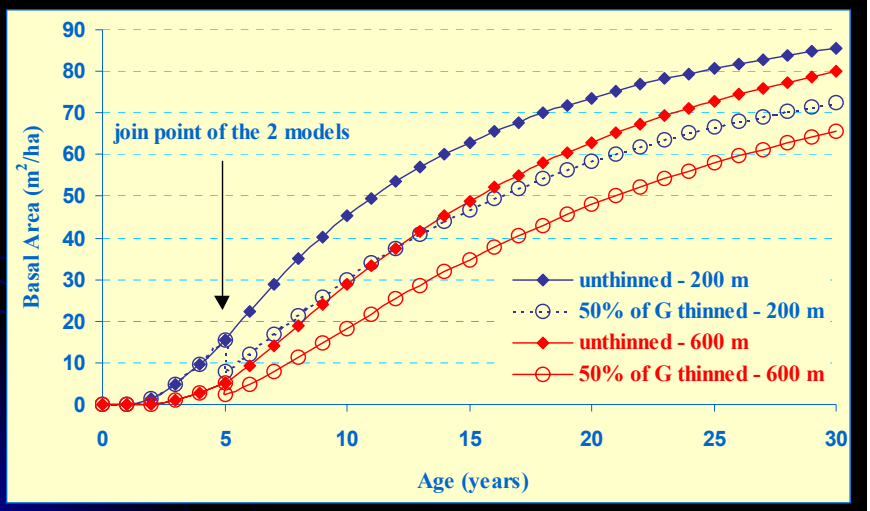
Selected Basal Area equation for all species

Schumacher Polymorphic:

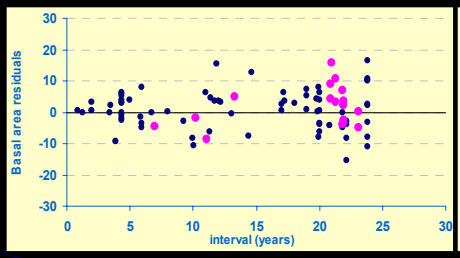
$$G_2 = G_1^{(t_2/t_1)^b} \exp\left\{a\left[1-\left(\frac{t_1}{t_2}\right)^b\right]\right\}$$

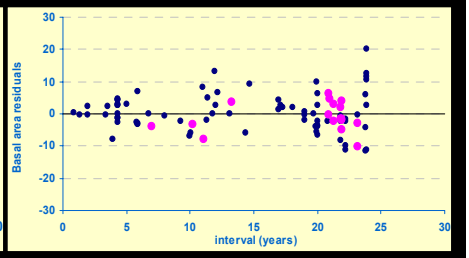
parameters a & b modified by Altitude and Thinning Indices (for NZ grown species)

Altitude & Thinning effects on B.A. *(P. radiata)*



(Limited) comparison of B.A. projections from PPM88 (left) and the new model (right)
(Independent validation plots; MTH>8m)



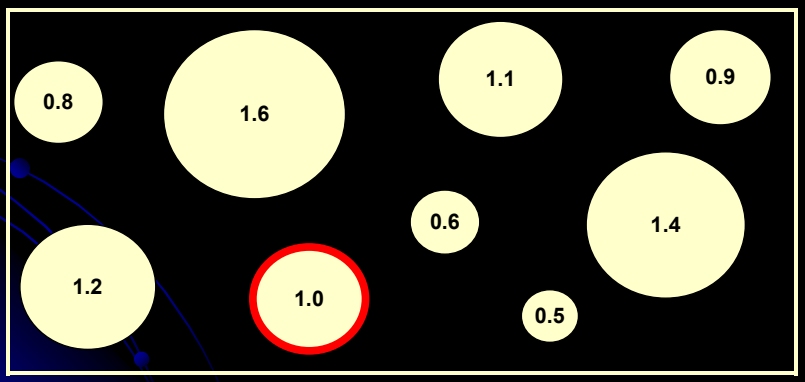


Statistic	PPM88	New model
Mean	0.78	0.48
Standard deviation	6.12	5.92
Skewness	0.00	0.51
Minimum	-15.4	-11.6
Maximum	16.5	20.2

PPM88	New model
0.97	0.19
6.15	5.69
0.09	0.51
(MTH > 5m)	

Relative Basal Area (R)

$$R_i = \frac{g_i}{\bar{g}} \Rightarrow R_i = \frac{g_i}{G/N}$$

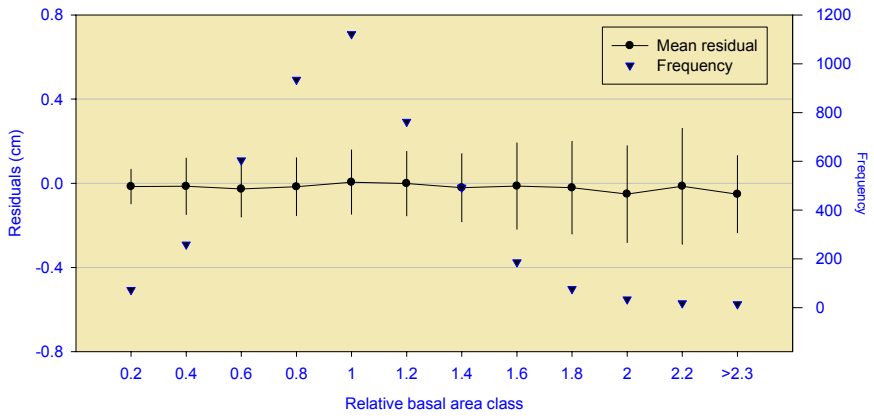


R projection equation selected for all species

One-parameter model proposed by Clutter & Allison (1974):

$$R_2 = R_1^{(T_2/T_1)^{\beta}}$$

Validation of RBA model
P. radiata (up to 20-yr projections)



Individual-Tree Mortality

Logistic model

- predicts probability of survival (0~1)
- from stand-density and tree-hierarchy variables

Annual Diameter Increment

E. grandis

$$\Delta D = a_0 + a_1 \frac{dbh}{QMD} + a_2 \frac{MTD}{t} + a_3 \ln(SDI) + \frac{a_4}{SDI} + \frac{a_5}{SI}$$

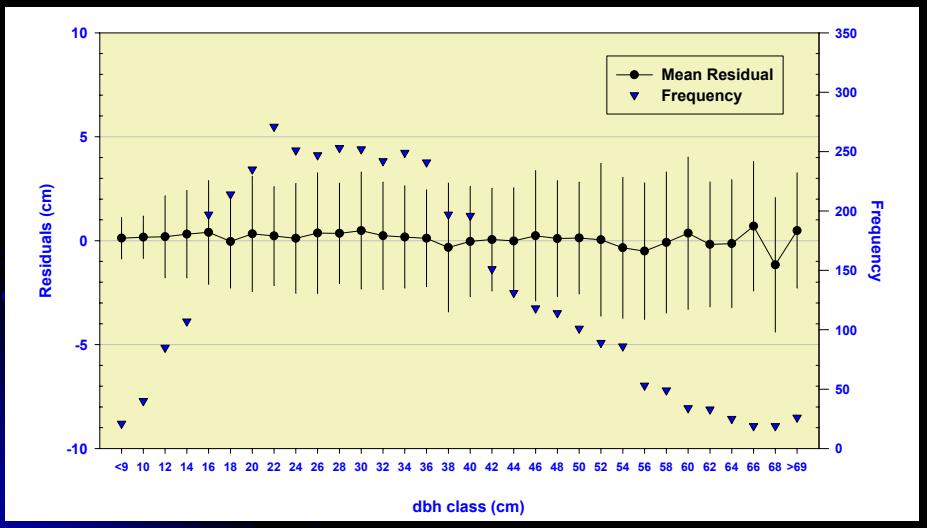
Douglas-fir

$$\Delta D = \exp\left[a_0 + a_1 \ln(CHG\_PD) + a_2 \frac{dbh}{QMD} + a_3 \frac{N}{1000} + a_4 RS + a_5 RS^2 \right]$$

P. radiata

$$\Delta D = \frac{b_1 dbh^{b_2} - b_1 dbh/120(1-b_2)}{1+\exp\left(x_0 + x_1 CHG\_PD + \frac{x_2}{t} + x_3 \sqrt{SDI} + x_4 \frac{BAL}{dbh} \right)}$$

Validation of ΔD model
P. radiata (up to 20-yr projections)



Individual tree heights

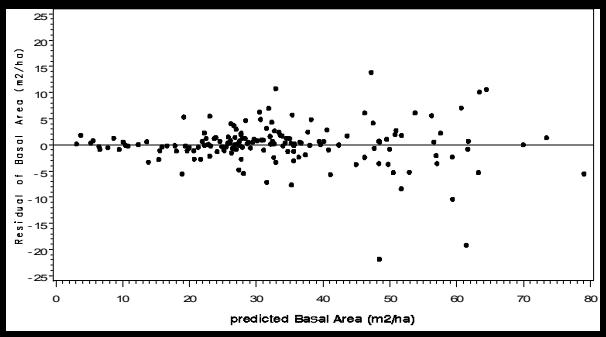
- Twenty one 2-parameter models of the form **h = *f* {dbh}** were tried

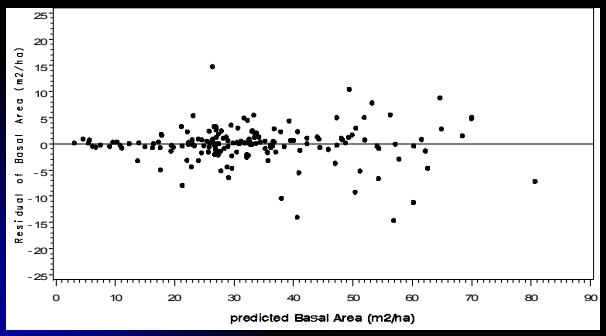
  e.g. Petterson eq.

$$h = 1.4 + \left(\alpha + \frac{\beta}{dbh} \right)^{-2.5}$$

Results (2)

Comparison of modelling approaches





Basal Area Residuals

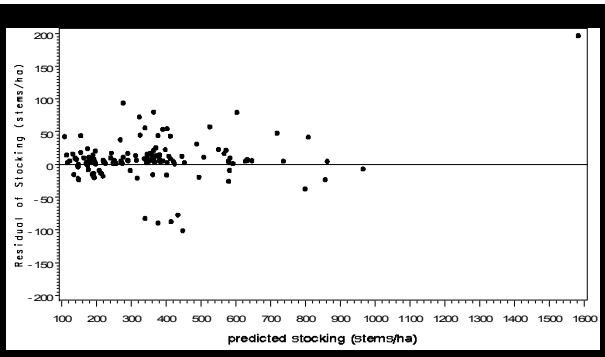
(*P. radiata*; valid. plots)

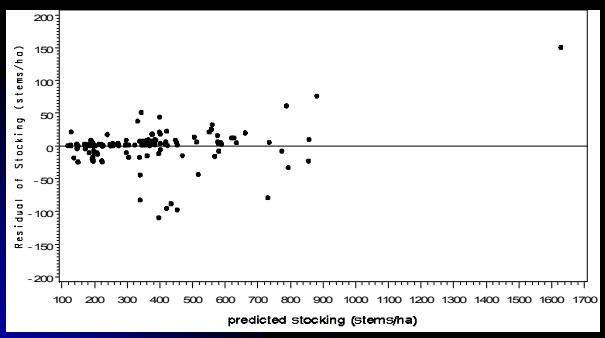
Individual tree model.

Mean residual= 0.08 m^2/ha

Stand model.

Mean residual= -0.05 m^2/ha





Residuals of stocking

(*P. radiata*; valid. plots)

Individual tree model.

Mean residual= 7.5 stems/ha

Stand model.

Mean residual= -0.08 stems/ha

Comparing diameter distribution depictions

Error Index (Reynolds *et al*. 1988)

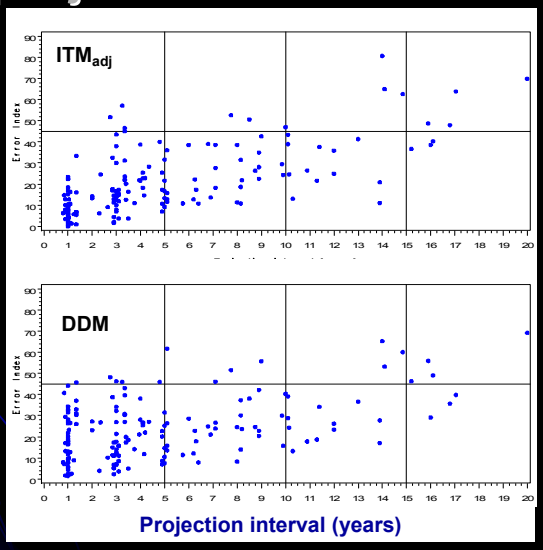
$$EI = \sum \left| (obs\_freq_i - pred\_freq_i) W_i \right|$$

where **i** indicates the i^{th} diameter class, and
W is a weighting factor (e.g. tree volume)

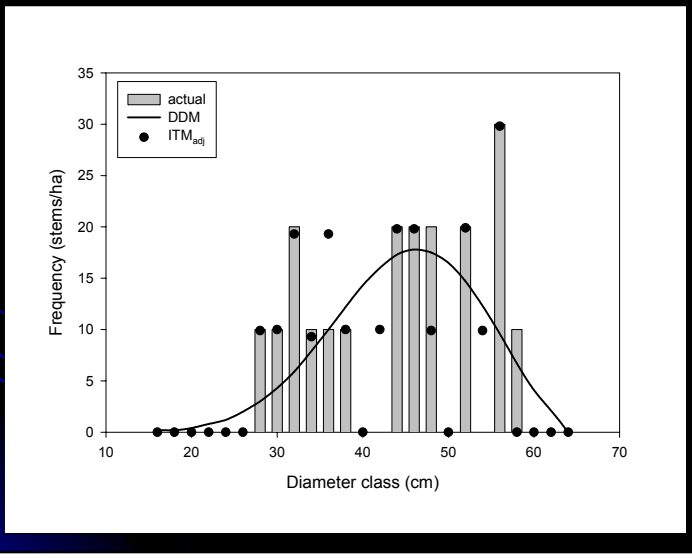
Average Error Indices
(*P. radiata*, validation plots)

Method	Weighting factor		
	Tree volume (p=0.642)	Tree b. area (p=0.367)	None (p=0.232)
ITM	226	21.2	184
ITM adj	220	20.6	180
RBA	233	21.8	197
DDM	249	23.5	203

Trend of error index with projection interval



Example: PSP 19445 (*P. radiata*) t1=20.15, t2=25.05, 190 stems/ha



Conclusions (1 of 2)

- Including altitude improved models
- Use of long projection intervals:
  - better performance of the new MTH model as compared to the MTH model of KGM3/PPM88 over long projections
  - good performance of DDM over long projections
- **Basal area** estimates from unadjusted ITM were unbiased, whereas **stocking** estimates were biased.

Conclusions (2 of 2)

- Diameter distribution depiction. Ranking of methods by decreasing error index:

  ITM_{adj} - ITM - RBA - DDM

- ITM_{adj} was the best approach overall (also compatible with stand level models).
- DDM also useful:
  - when there are no tree lists available
  - long projections

Application

Compatible Individual-Tree And Stand Simulators (CITASS) were programmed with VBA under Excel® environment

Hybrid modeling of growth and yield

Euan Mason, Helge Dzierzon and Joe Landsberg

Potential for hybrid models

- Potential for representing rotation-length impacts of regeneration practices
- Geographic Information Systems
  - More known about each site and stand
- Variation in growth pattern from site to site
  - Less need for regional models
- Variation in weather from year to year
  - Predicting the past
- Variation in monthly climate offers monthly predictions
- Climate change may affect growth patterns
- Kyoto protocol
  - Carbon storage explicit in some models

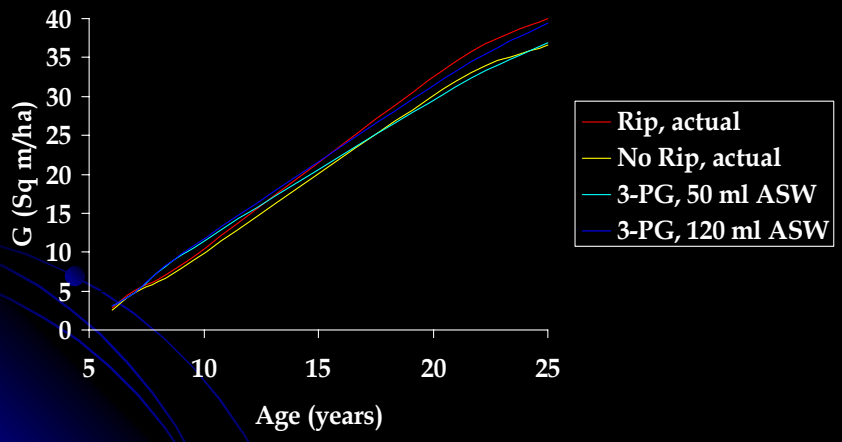
An example "hybrid" model

3-PG Model (Landsberg & Waring 1997)

$$NPP = \varepsilon \sum_{t=1}^{T} APAR_t \, f_\theta \, f_D \, f_T \, f_F \, f_S$$

Allocation varies with fertility

Application of 3-PG
25-year old experiment



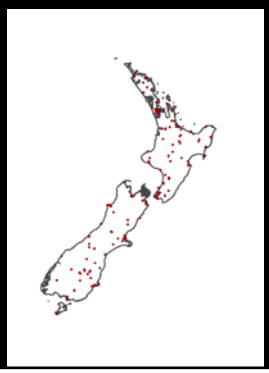
Potential issues with 3-PG

- Allocation of C is derived from allometry
- Recursiveness, compounded errors
- Over parametarisation
- Fertility is inadequately represented
- Stand and stem geometry are not modelled
- Circularity
  - DBH->Carbon, Carbon->DBH
  - Measurement of LAI may partially solve this

An idea among many

- Time = accumulated light
- Use 3-PG type quantum efficiency modifiers to accumulate *potentially used* light
- Use sigmoidal difference equations as usual, fitted to PSP data
- Avoids some of 3-PG's problems
  - Compounded errors
  - Allocation of C
  - Overparametarisation
  - Lack of stand geometry

$$MTH2 = a\left(\frac{MTH1}{a}\right)^{\frac{\ln(1-\exp(-k\cdot RAD_2))}{\ln(1-\exp(-k\cdot RAD_1))}}$$



An idea among many

- Estimate genetic components of seasonal variations in primary and secondary growth
- Different radiation sums for primary and secondary growth

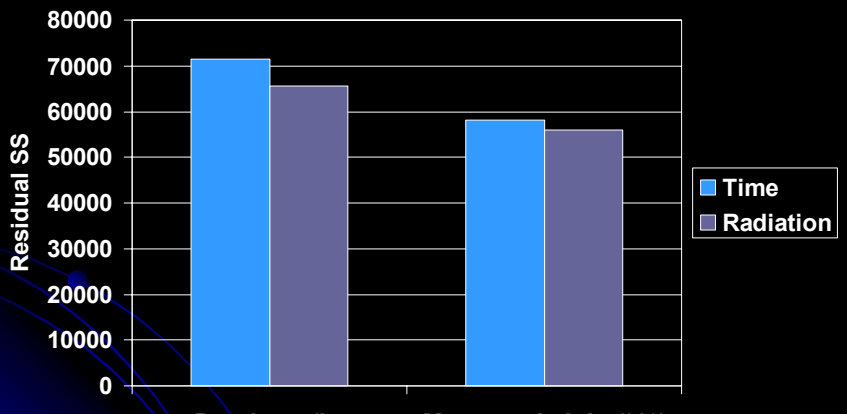
An idea among many

- Climatic variables as well as stocking and radiation sum estimates in mortality model
- NB: Fertility of soils is not well sorted
- To what extent can *temporal* variation in climatic influences inform us about influences on crop growth and mortality of *spatial* variation in climate?

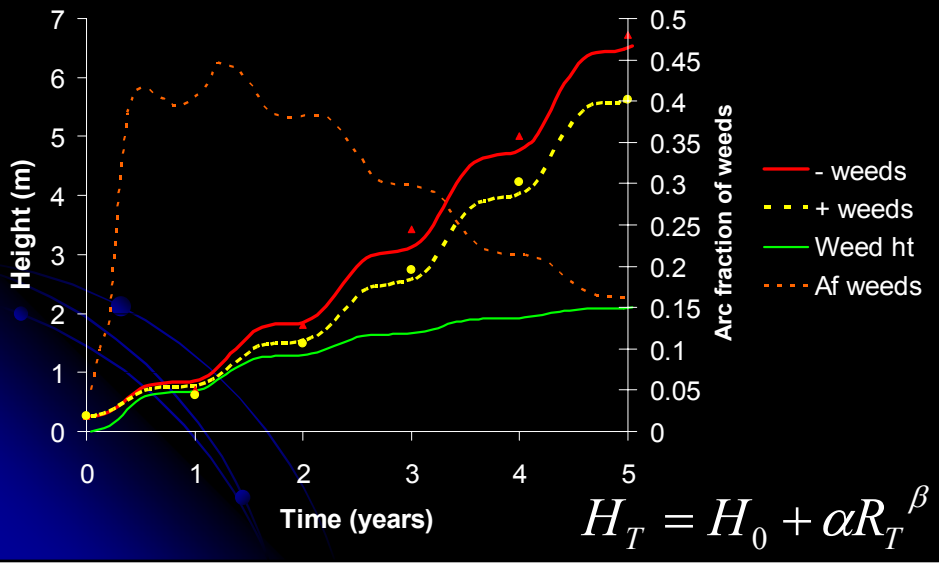
An idea among many

- Compatible stand, distribution & individual tree projection systems
- Models that represent height vs basal area growth as functions of site variables
- Models that respond to climatic and local weather variation
- Models specific to each site
- Models that naturally provide growth estimates within years

Preliminary Example – *P. radiata* in Central North Island



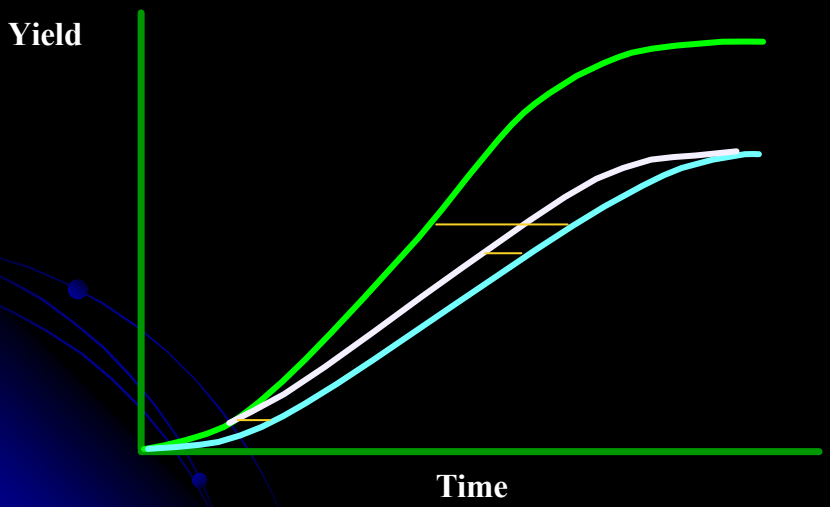
Light sum initial growth model: Competition for light in R1835/2



$$H_T = H_0 + \alpha R_T^{\beta}$$

Questions?

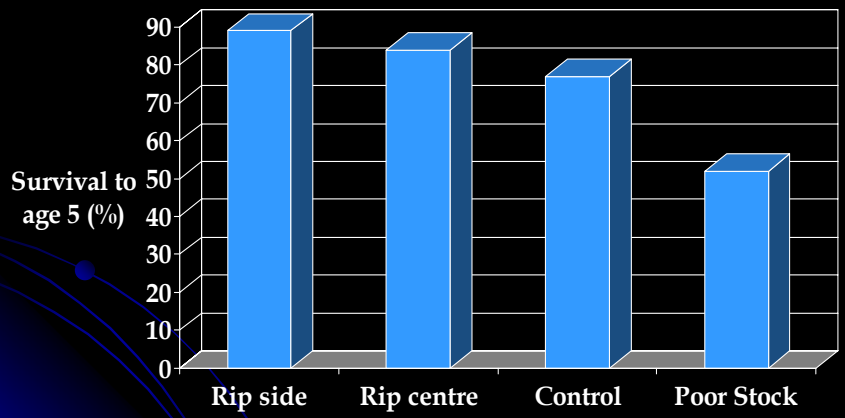
Rotation-length impacts



Assumptions for parallel growth trajectories

- Growth input change is temporary
- Site can support more rapid growth
- Future treatments do not bring about a resumption of the effect
- No significant change in allometry
- No significant physiological age effects
- No differences in biochemistry

Results - Compartment 558



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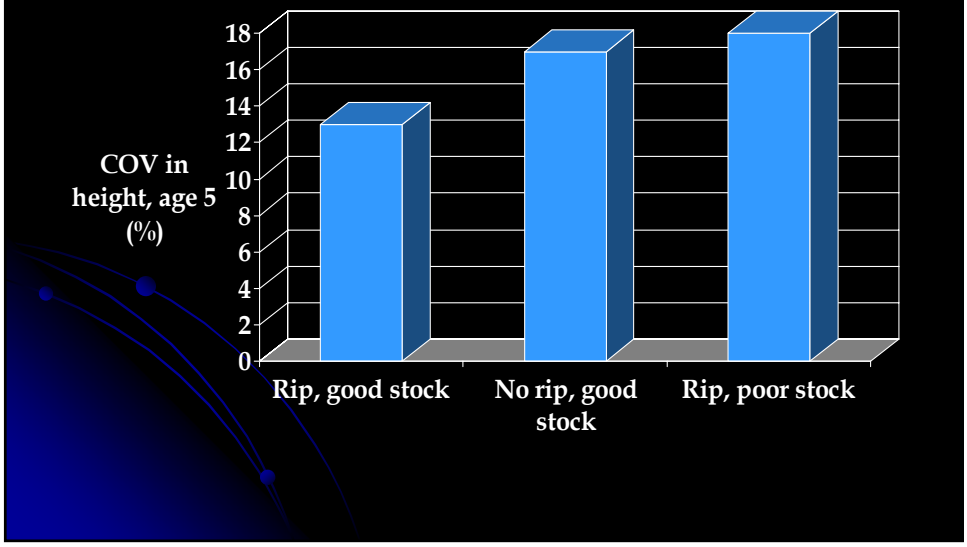

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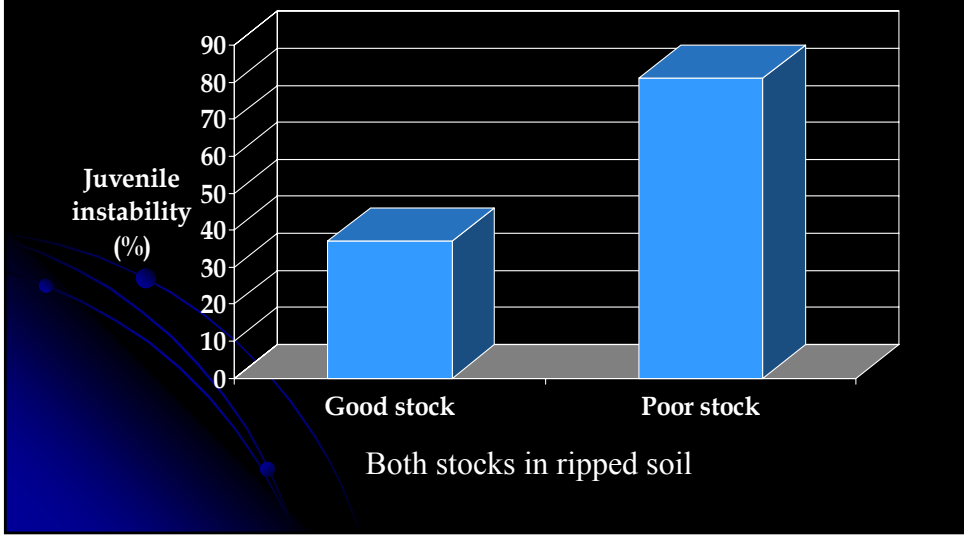
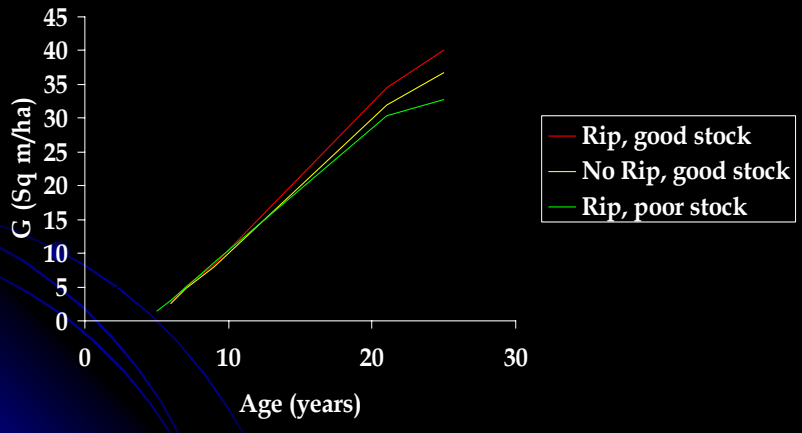


Both stocks in ripped soil

Results - Compartment 558

Results - Compartment 558



Results - Compartment 558

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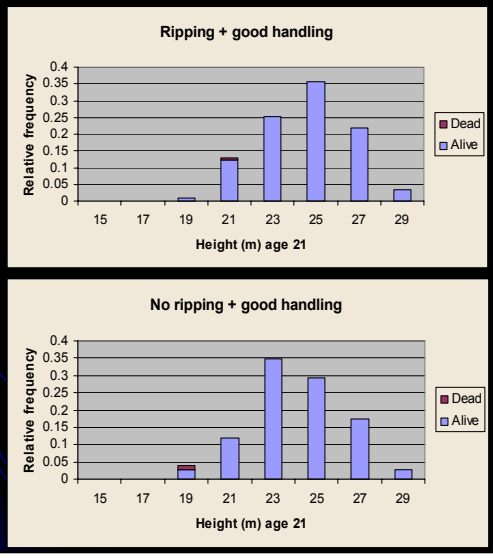
Mortality between ages 21 and 25



Results - Compartment 558

Mortality between ages 21 and 25