Modelling paradigms – Hybrid models to make mensurationists smile

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Stand level or tree level models?

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& Euan Mason

Outline

- Background
- Objectives
- Data & Methods
- Results
  - Model components
  - Comparisons of approaches
- Conclusions

Background

- Tree level information is important
- Representing trees in models
  - 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

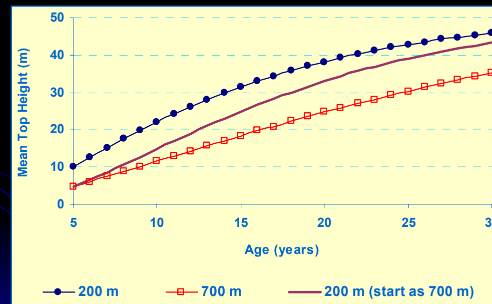
Chapman-Richards polymorphic:

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

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

Altitude effect on MTH

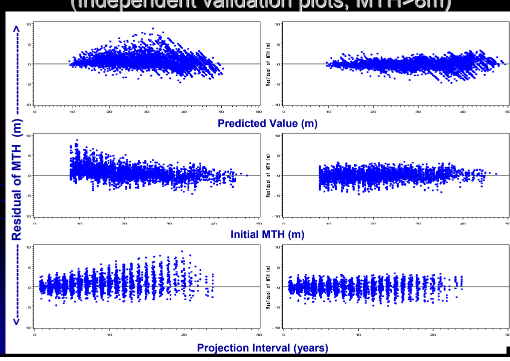
(P. radiata)



Comparison of MTH projections

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

(Independent validation plots; MTH>8m)



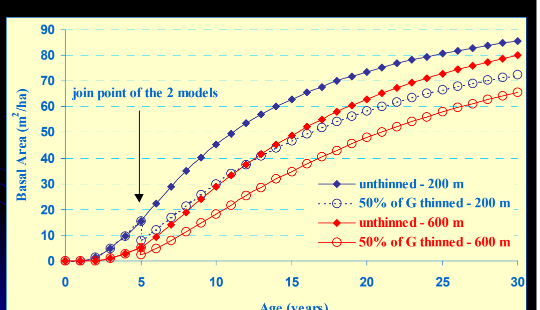
Selected Basal Area equation for all species

Schumacher Polymorphic:

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

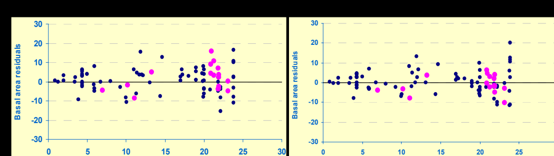
parameters a & b modified by Altitude and Thinning Indices (for NZ grown species)

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)

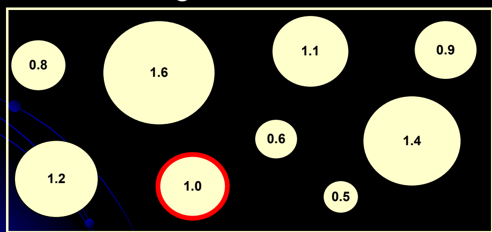


Statistic	PPM88	New model
Mean	0.78	0.48
Standard deviation	6.12	5.92
Skewness	0.00	0.51
Minimum	-15.4	-11.6
Maximum	16.5	20.2

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

Relative Basal Area (R)

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

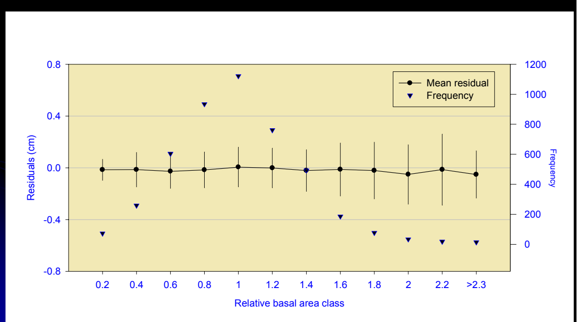


R projection equation selected for all species

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

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

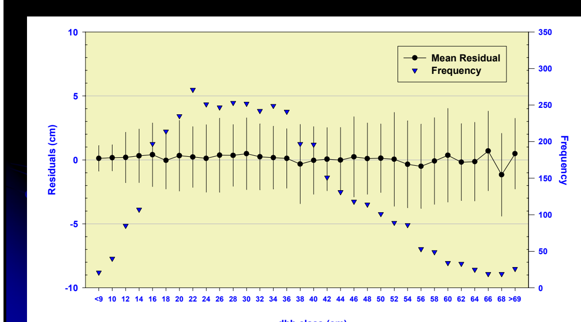
Douglas-fir

$$\Delta D = \exp\left[a_0 + a_1\ln(CHG\_PD) + a_2\frac{dbh}{QMD} + a_3\frac{N}{1000} + a_4RS + a_5RS^2\right]$$

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)



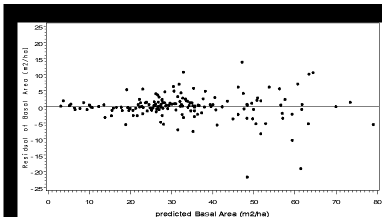
Individual tree heights

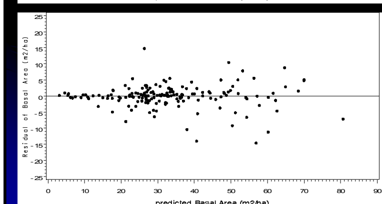
- Twenty one 2-parameter models of the form **h = *f* {dbh}** were tried
  e.g. Petterson eq.

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

Results (2)

Comparison of modelling approaches



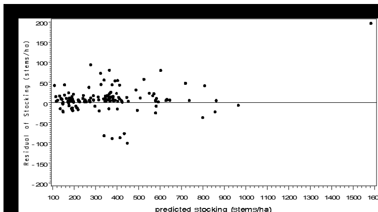


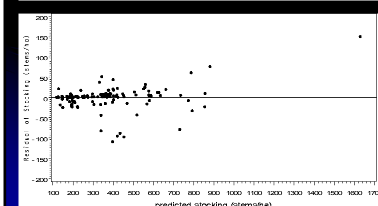
Basal Area Residuals

(***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)

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

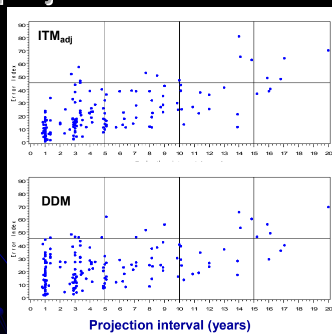
where **i** indicates the i^{th} diameter class, and W is a weighting factor (e.g. tree volume)

Average Error Indices

(*P. radiata*, validation plots)

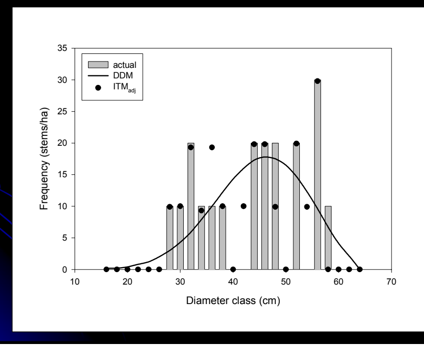
Method	Weighting factor		
	Tree volume (p=0.642)	Tree b. area (p=0.367)	None (p=0.232)
ITM	226	21.2	184
ITM_adj	220	20.6	180
RBA	233	21.8	197
DDM	249	23.5	203

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

Modelling effects of weed competition on growth of *Pseudotsuga menziesii*: A hybrid approach

Euan Mason
Robin Rose
Lee Rosner

Outline

- Outline of Starker critical period study
- Results of study
- Modeling the results
- Conclusions
- Implications for hybrid modelling

Basic IGM equation

$$Y_T = Y_0 + \alpha T^{\beta}$$

- Y=height, dbh or basal area, T=time, α & β = coefficients
- Fitted to a range of species
- Accounts for a decline in relative growth rate with tree size
- Allows for
  - changes in allocation of carbon
  - increased self shading
  - Changes in leaf dimensions

Mason & Whyte (1997)
Mason (2001)
Kirongo & Mason (2003)

Starker CPT study

Layout

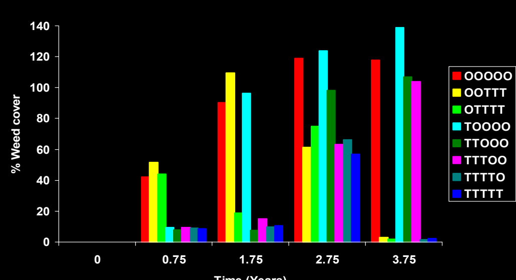
- 4 species
  - Douglas fir, western hemlock, western red cedar, grand fir
- 8 vegetation management schedules
- 4 replications
- Planting at 3.1*3.1 m
- 64 trees/plot, 36 central trees measured

Vegetation management schedules

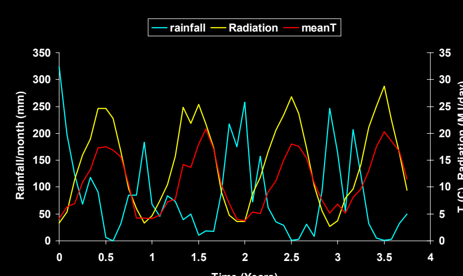
- T =treated, March-May
- O =not treated

OOOOO	OOTTT	OTTTT
TOOOO	TTOOO	TTTOO
TTTTO	TTTTT	

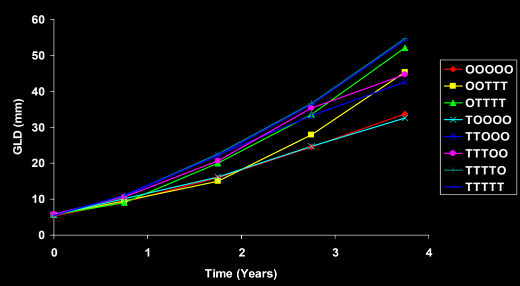
Estimated weed cover within 2 m diameter zones around trees



Climate by month

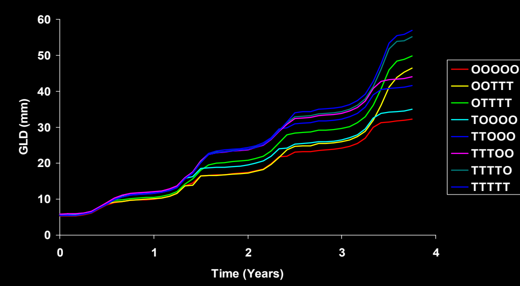


Observed Ground Line Diameter



N.B.: Analysis of Douglas fir only

Modeled Ground line diameter



N.B.: Analysis of Douglas fir only

How do we know this?

An example “hybrid” model

3-PG Model (Landsberg & Waring 1997)

$$NPP \quad = \quad \varepsilon \sum_{t=1}^{t} APAR_t \min\left[f_\theta \; f_D\right] f_T \; f_F \; f_S$$

Allocation varies with fertility

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

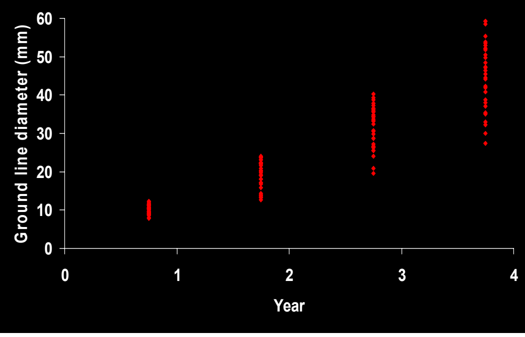
Solution – Blend mensurationist’s methods with 3-PG

- Substitute potentially useable light sum for time in equation

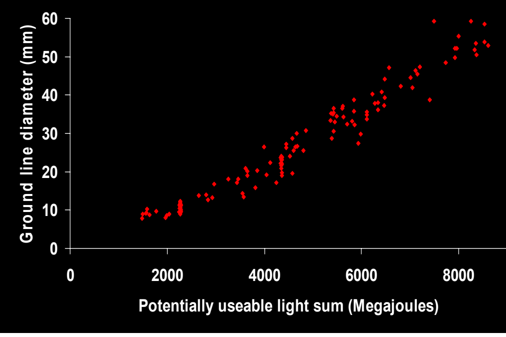
$$Y_T = Y_0 + \alpha R^{\beta}$$

- R=Modified light sum from time of planting to time T
  - Modified by the capacity for plants to use light, given Temperature, VPD, Soil water

GLD versus time



GLD versus PULSE

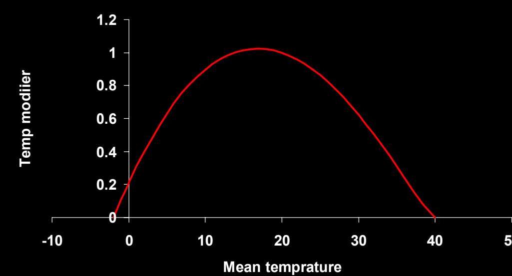


Temperature modifier

- Calculate temperature modifier for each month in each plot (3PG modifier)

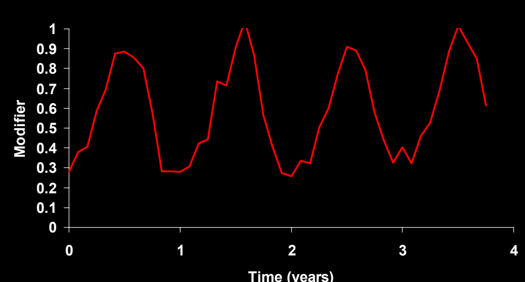
$$f_T(T_a) = \left(\frac{T_a - T_{min}}{T_{opt} - T_{min}}\right)\left(\frac{T_{max} - T_a}{T_{max} - T_{opt}}\right)^{(T_{max} - T_{opt})/(T_{opt} - T_{min})}$$

Douglas fir

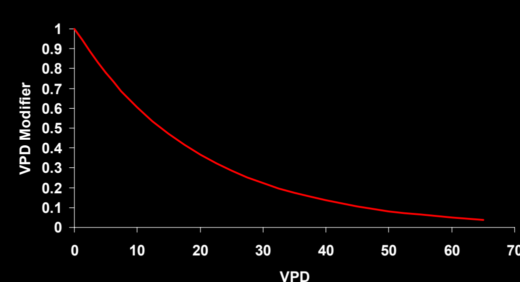


Values from Lewis *et al. 1999*

Temperature modifier

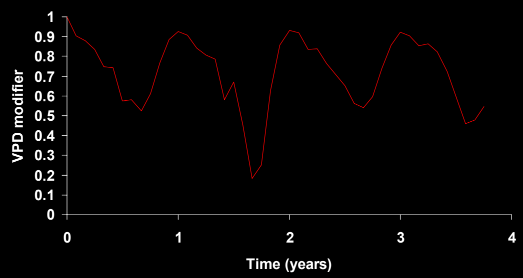


VPD Modifier



Landsberg & Waring 1997

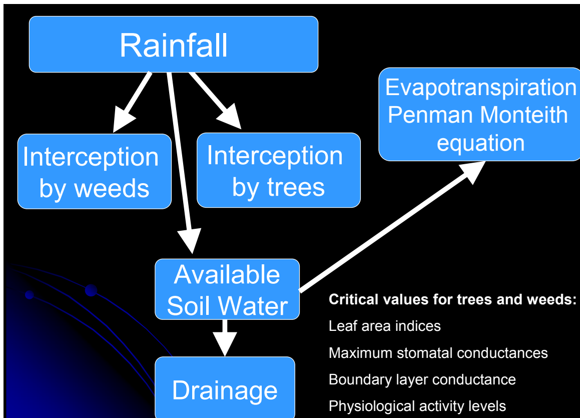
VPD modifier



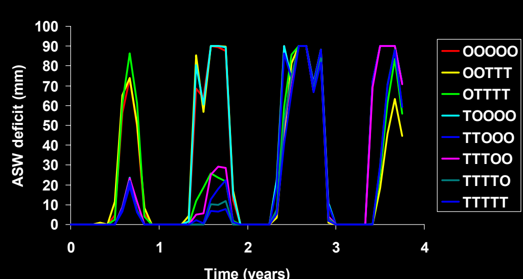
Soil water balance model

Soil characteristics

- Clay
- Depth of roots = 45 cm
- Gravimetric water content at field capacity = 0.4
- Max Available Soil Water = 180
- Gravimetric water content at minimum ASW = 0.2
- Min ASW = 90



Available soil water deficit



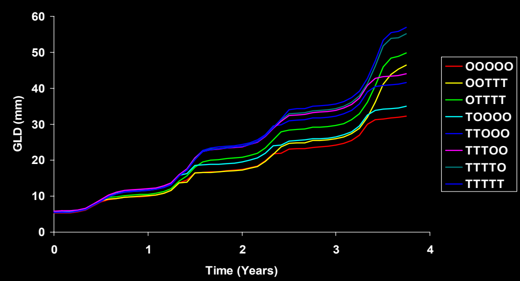
Model form

$$Y_T = Y_0 + \alpha R_T^{\beta}$$

$$R_T = \sum_{t=1}^{t} R_t \, f_T \min[f_D \; f_\theta] \, f_{LC}$$

Summed across months

GLD is represented by only *one* overall equation



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

Potentially useable light sum equation (PULSE) modelling

- 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

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

PULSE modelling

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

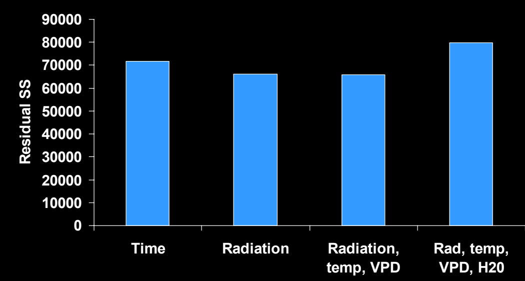
PULSE modelling

- 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?

PULSE modelling

- 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



Schumacher difference equation, basal area/ha

Conclusions

- Compatible stand and tree-level growth and yield models were complementary
  - Diameter distribution for longer projections
- Potentially useable light sum equations (PULSE) fitted experimental and PSP data better than models based on time
  - Link G & Y with ecophysiology
  - Within year estimates
  - Sensitive to site variation in space and *time*
  - May facilitate modelling effects of silvicultural treatments