



Modelling effects of both overstory density and competing vegetation on height increment for Douglas-fir

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Outline

- Objectives
- Background
- Problem
- Data
- Modelling
- Results
- Conclusions



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Objectives

- To develop a biological height growth model:
 - incorporating all competing vegetation effects (trees, understory),
 - representing growth of trees of all sizes,
 - that does not depend on length of period of observation or projection.

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Juvenile height growth

- Important in forest management
 - Pruning, free-growing surveys, spacing, and harvest (depends on the juvenile height levels)
- The greatest potential for improving growth rates is during juvenile development.
 - Juvenile height → future height development (silvicultural decisions).
- Juvenile development is crucial for simulation models

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Problem

- Height growth models are based mainly on large, dominant trees.
 - Therefore, models provide good estimation for large trees, but not for small trees
- Models of small trees are different from large trees
 - Allometric relations between conventional measures of size break down for small trees
- Models of small-tree growth are not congruent with models for large trees

- Current (few) juvenile models have shown a high variability of juvenile height growth.
 - Competing vegetation effects have been omitted, only based on age. (e.g., Nigh and Love 1999)
- Competition from overstory trees has been incorporated into juvenile height growth
 - Stage (1973), Wykoff (1986), Lencar and Marshall (2001), Froese (2002), Temesgen (2002), Boisvenue *et al* (2004)
 - The usual approach, using regression, incorporates tree, stand and site characteristics into a single equation only if “significant”.
 - Some studies have shown unexpected behavior of model parameters

■ Models that account for competing vegetation

- Mason et al (1997), Loveall (2000), Watt et al (2004)
- Focused on plantations (clear cutting=develop without overstory effects)
- It can not be applied to other harvesting systems, and uneven-aged or mixed stands

■ Other relevant studies:

- Monserud and Ek (1977), Golser and Hasenauer (1997)
- Reduction of a potential height growth
- Using distance-dependent indices

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Data

■ Study area

- Inland Northwest region

■ Juvenile trees dataset

- Small tree and competing vegetation study of the Inland Northwest Growth and Yield Cooperative (INGY).
- 1671 Douglas-fir trees
- 23 stands, 161 plots.

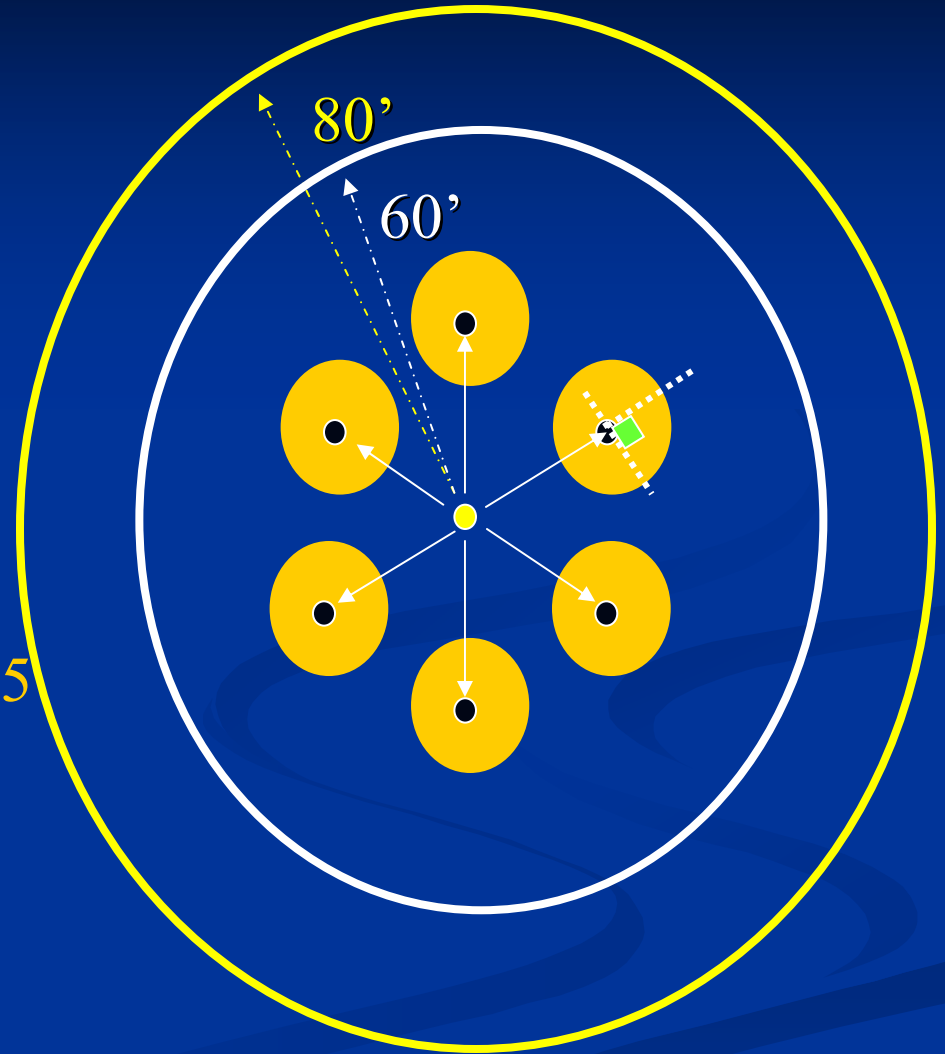
Plot design

* 0.46 acres (large tree plot)
[$dbh > 27$ cm]

* 0.26 acres (medium tree plot)
[$dbh > 8.9$ cm]

* 6 - 0.007 acres (small tree plots)
[tol.sp: $h > 15$ cm, intol.sp: $h > 30.5$ cm]

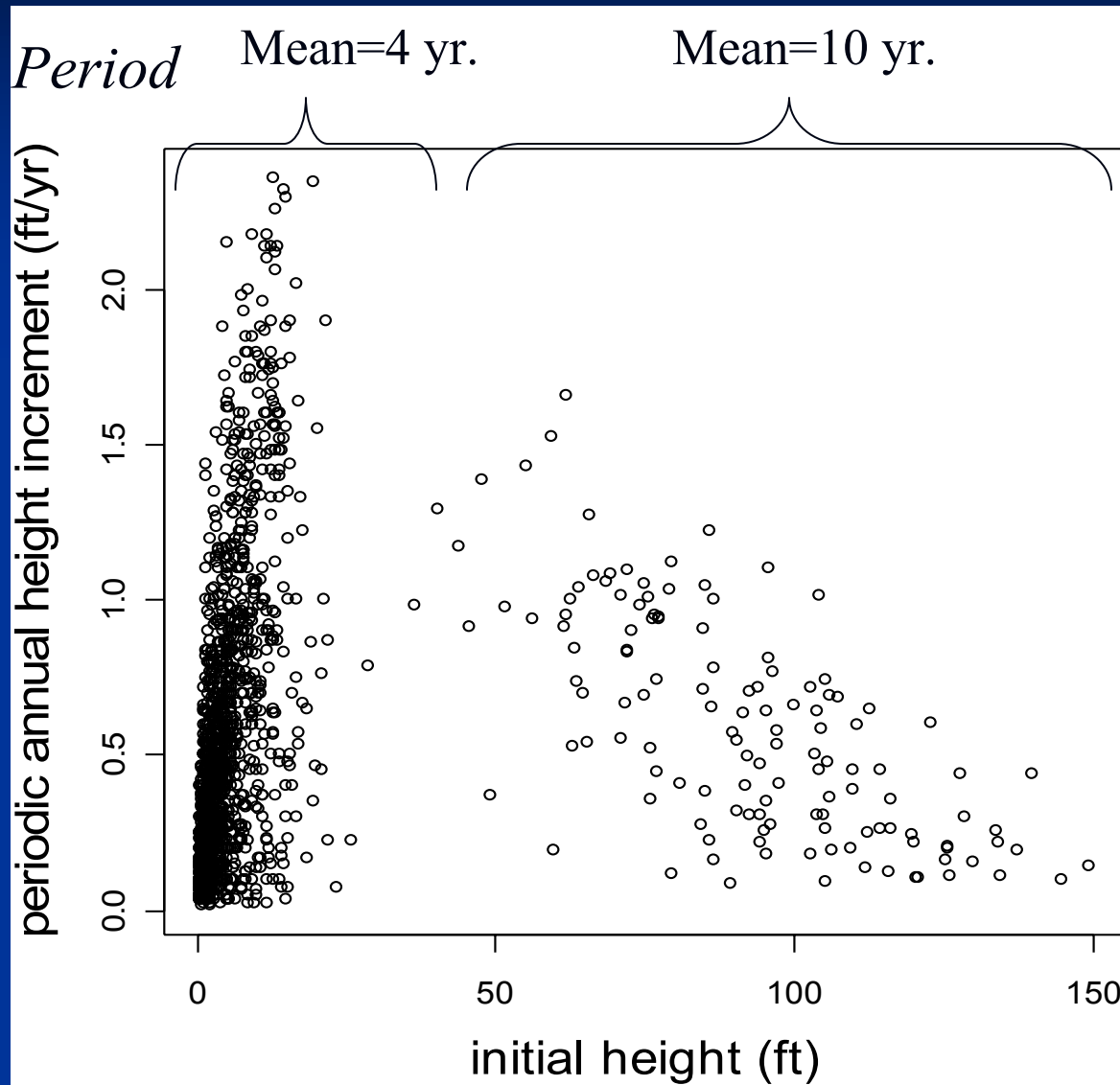
* 6 - 1 m² (understory plots)



Plot center

- Three vegetation treatments (herbicide: one application, repeat application, and control)
 - Several variables were measured at different years.
 - Variables: Overstory density variables, cover and crown volume of understory, periodic tree height growth (1 per tree).
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- **Older trees dataset**
 - Site index study in the same region (Monserud 1984).
 - 390 stem analysis Douglas-fir trees
 - 135 clusters of four variable radius plots
 - Variables: Overstory density measured on plots, understory competition estimated based on FVS (Shrub and Cover, Regen extension), last periodic tree height growth measured (1 per tree)

Periodic annual height increment for Douglas-fir in the Inland Northwest



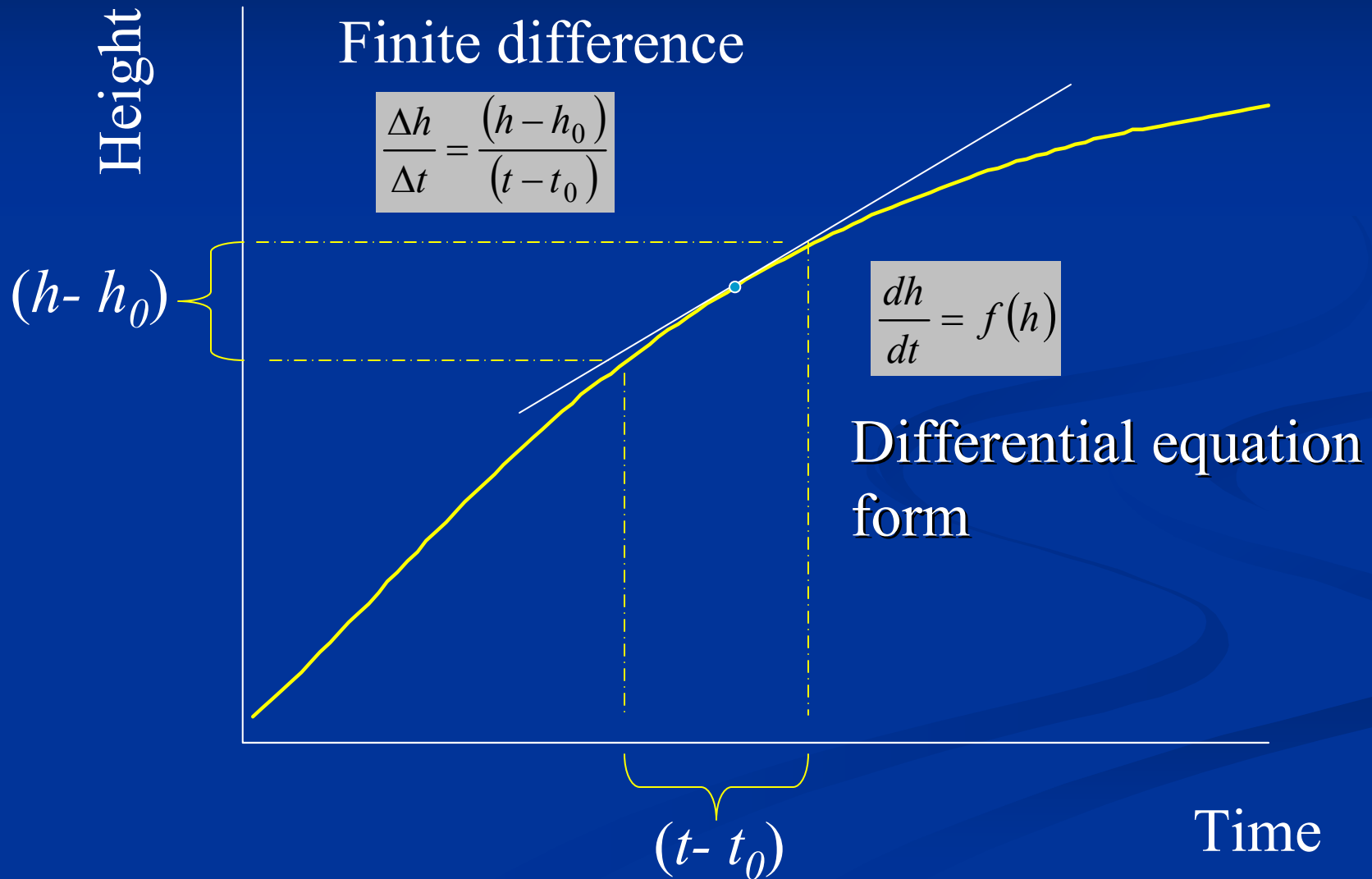
$n=2061$
trees

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Modelling strategy



The origin of the base model

$$\frac{dh^c}{dt} = b(a^c - h^c)$$

- Differential linear equation (power transformation) (García 1983)
- Ornstein-Uhlenbeck process (Uhlenbeck and Ornstein 1930)

integration

$$\frac{dh^c}{(a^c - h^c)} = b dt$$



$$\int \frac{1}{(a^c - H^c)} dh^c = \int b dt$$



$$-\ln(a^c - h^c) \Big|_{h_0^c}^{h^c} = b(t) \Big|_{t_0}^t$$

and so on....

Reordering, we obtain:

$$h = a \left[1 - \left(1 - h_0^c / a^c \right) \cdot e^{-b(t-t_0)} \right]^{1/c}$$

Growth function

■ If $t_0 = h_0 = 0$

$$h = a \left(1 - e^{-b \times t} \right)^{1/c}$$

■ Richards' model (1959)

■ variables

h = tree height at t time;

t_0 = initial time;

h_0 = tree height at t_0 time

■ parameters

a = upper asymptote;

b = scale (growth rate);

c = shape

The model

$$h = a' \left[1 - \left(1 - h_0^{c'} / a'^{c'} \right) e^{-b'(t-t_0)} \right]^{1/c'}$$

a'

b'

c'

- Parameters to be modified due to overstory and understory competition

Adding competition effect to the asymptote (a')

$$a' = a \cdot \left(2 - \left[1 + e^{(\alpha_0 - \alpha_1 \cdot OVER - \alpha_2 \cdot CVEG)} \right]^{-1} \right)$$

■ variables

a = asymptote (without competition effect), from Site index curves (Monserud 1984) using SI and forest habitat types.

$OVER$ = overstory density (e.g., CCF , BA);

$CVEG$ = competing vegetation (e.g., $UCOVER$, UCV)

■ parameters

α_0 , α_1 and α_2

Adding competition effect to the growth rate (b')

$$b' = b \cdot \left(\beta_3 - \left[1 + e^{\left[\left(\frac{UH}{h_0^2} \right) \cdot (\beta_0 + \beta_1 \cdot CVEG + \beta_2 \cdot NST) \right]} \right]^{-1} \right) \cdot \beta_4 \cdot SI$$

■ variables

b = growth rate (Monserud 1984);

UH = average understory height;

h_0 = tree height at t_0 ;

$CVEG$ = competing vegetation (e.g., $UCOVER$, UCV);

NST = number of small trees per acre;

SI = Site index

■ parameters

β_0 , β_1 , β_2 , β_3 and β_4

Adding competition effect to c'

$$c' = c \cdot \left(\gamma_3 - \left[1 + e^{\left[\left(\frac{UH}{h_0^2} \right) \cdot (\gamma_0 + \gamma_1 \cdot CVEG + \gamma_2 \cdot NST) \right]} \right]^{-1} \right)$$

(same way that uses for b')

- **variables**

as previously defined

- **parameters**

γ_0 , γ_1 , γ_2 , and γ_3 .

Model fitting

■ Parameter estimation

- Maximum likelihood
- MATLAB 6.5 (`fminsearch`) Nelder-Mead algorithm

■ Mixed-effects model

- Recognizing hierarchical data (clustered data on Plot-location)
- Testing random structure of parameters (Within plot vs. Between plots)
- R (`nlme` package)

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Results

1. Assessing different predictor variables

Factors		
OVER	CVEG	Log-likelihood
<i>CCF</i>	<i>UCOVER</i>	-3633.4
	<i>UCV</i>	-3643.9
<i>BA</i>	<i>UCOVER</i>	-3639.6
	<i>UCV</i>	-3638.9
<i>TPA</i>	<i>UCOVER</i>	-3619.4
	<i>UCV</i>	-3624.4
<i>LAI</i>	<i>UCOVER</i>	-3716.8
	<i>UCV</i>	-3667.0

2. Does density affect height growth of older trees?

Approach	Group	Group No.	Log likelihood	Test	Like. Ratio	<i>p</i> -value
without density effects	Total	1	-4349.4			
	Juvenile trees	2	-3267.6			
	Older trees	3	-1081.8			
with density effects	Total	4	-3619.4	1 vs. 4	1460	<.0001
	Juvenile trees	5	-2617.7	2 vs. 5	1300	<.0001
	Older trees	6	-1001.8	3 vs. 6	160	<.0001

3. Mixed effects models

Random parameters	Model	df	AIC	Log likelihood
α_1	1	14	7561.6	-3766.8
β_1	2	14	7205.0	-3588.5
β_2	3	14	7243.3	-3607.63
β_1, β_2	4	16	7206.9	-3587.48
γ_2	5	14	7266.8	-3619.41
γ_3	6	14	6962.6	-3467.29

4. Statistics summary for the different approaches

Approach	Approach No.	df	Log likelihood	Test	Like. Ratio	<i>p</i> -value
Without density effects	1	3	-4349.4			
With density effects	2	12	-3619.4	1 vs.2	1460.0	<.0001
With density effects and mixed-effect model	3	14	-3467.3	2 vs.3	304.2	<.0001

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Conclusions

- There is a density effect on height growth of older trees of Douglas-fir
- Site index is influenced by density and competing vegetation
- Other variables should be used to predict site productivity (e.g., elevation, slope, ..)
- Recognizing the hierarchical structure of the data, using Mixed-effects models improves the fit of our proposed model

Next steps

1. **Take Site Index out of the model**
 - a. Use mixed-effects modelling to estimate a and b parameters for each specific plot-location
 - b. Regress a and b parameters on site variables (elevation, slope, aspect, forest habitat type)
2. **Incorporate stochastic effects. Adding a Brownian motion or Wiener process.**
3. **Incorporate measurement errors.**

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