Bootstrap Simulation & Response Surface Optimization in Forest Management

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What is the BEST-

- **target stand distribution**
- **cutting cycle**
- **target stand basal area**

for

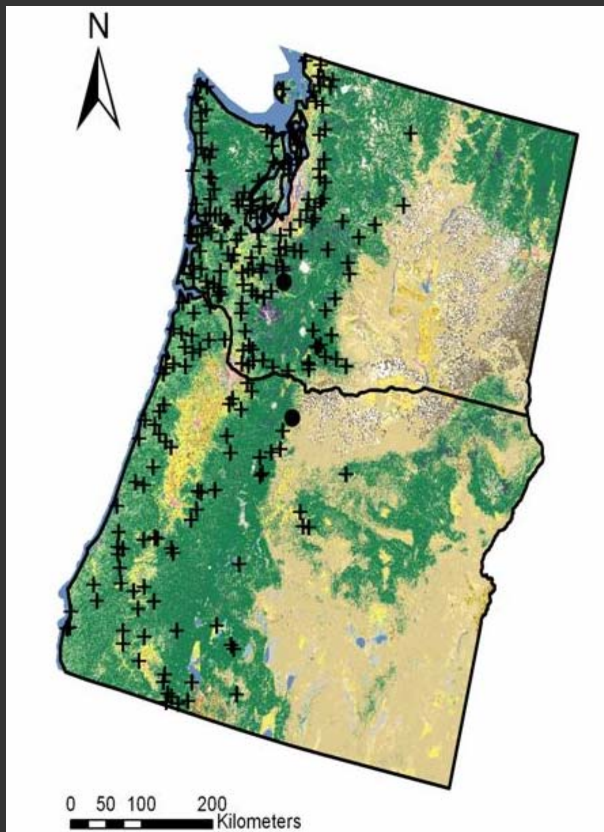
- **financial return**
- **wood quality**
- **ecology**

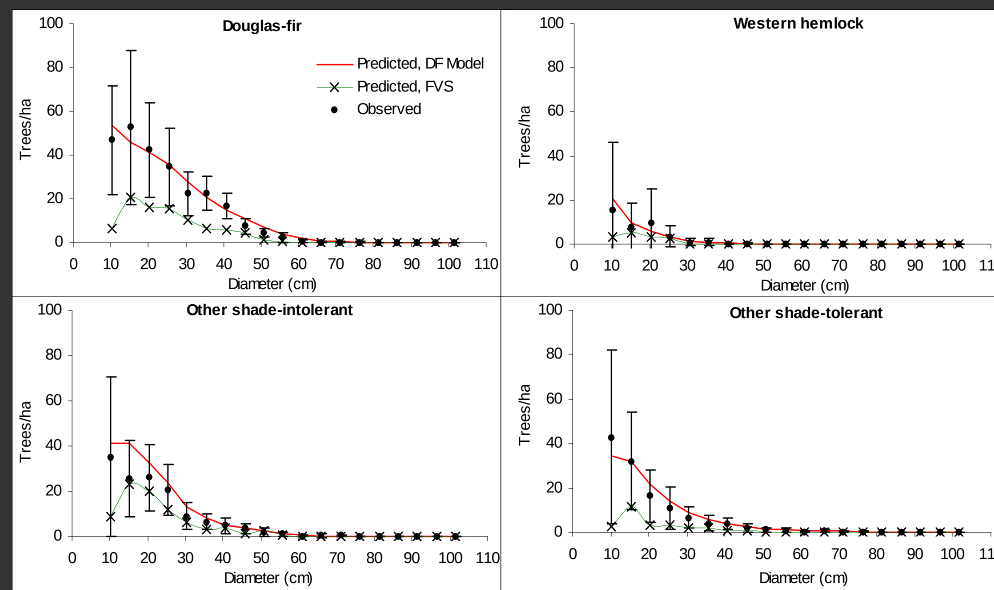
?

Models Involved

• forest growth	stand growth model	S
• financial return	stumpage price model	S
	interest rate model	S
• wood quality	log grade model	
• ecology	Shannon's diversity	

Stand growth model



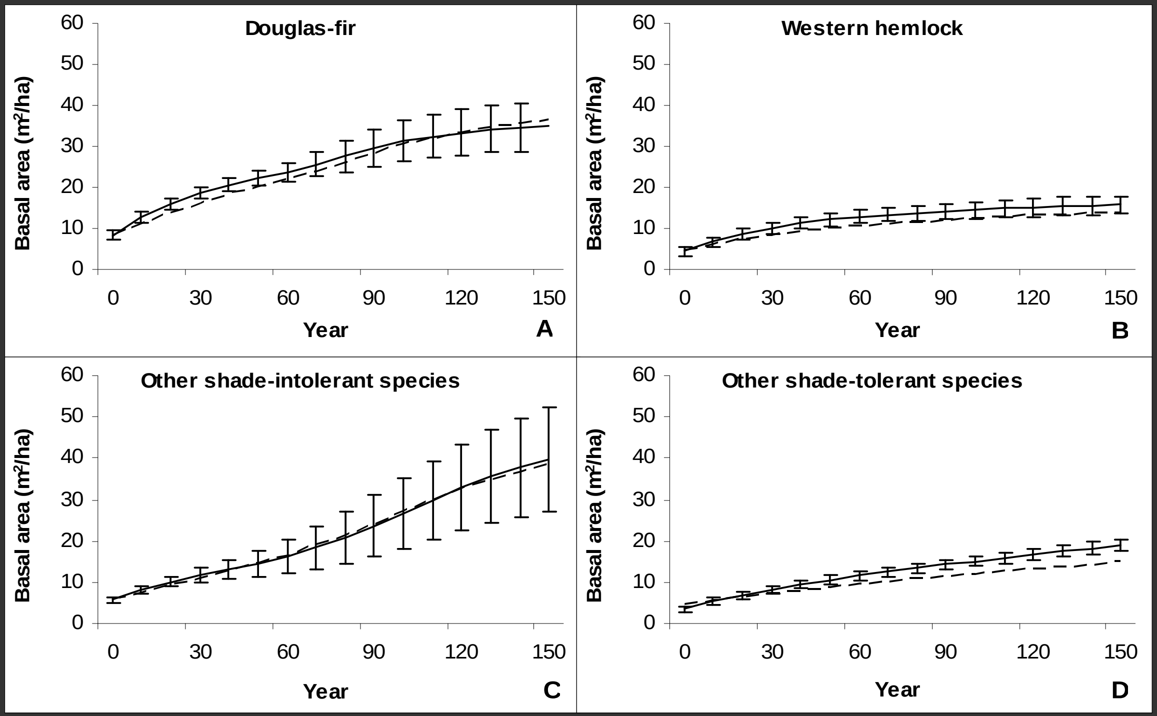


Liang, Buongiorno, Monserud. 2005. Growth and Yield of All-aged Douglas-fir/western hemlock Stands: A Matrix Model with Stand Diversity Effects. *Can. J. For. Res.* 35: 2369-2382.

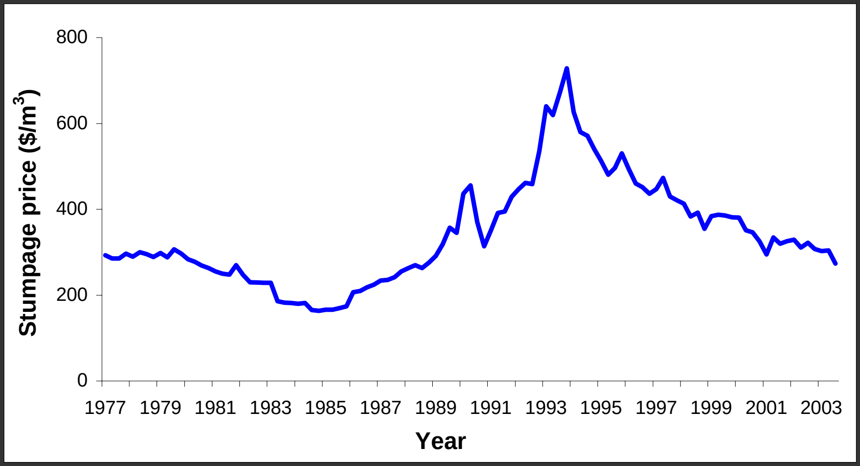
Stand growth model

$$\mathbf{y}_{t+1} = \mathbf{G}(\mathbf{y}_t)\mathbf{y}_t + \mathbf{R}(\mathbf{y}_t) + \mathbf{u}_{t+1} \Leftarrow \mathbf{e}_{t+1} = \mathbf{y}_{t+1} - \hat{\mathbf{y}}_{t+1}$$

Bootstrapped from



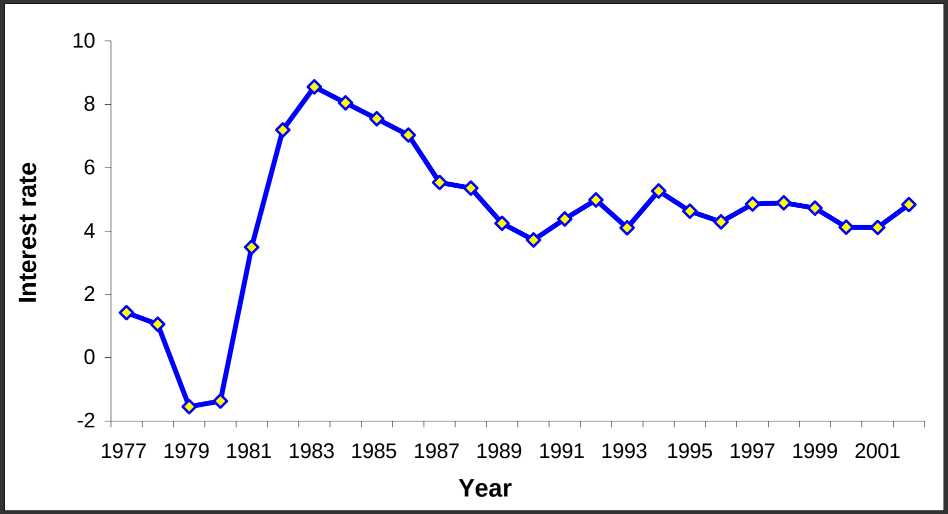
Stumpage price model



Oregon Quarterly stumpage prices of Douglas-fir Grade I logs

$$\Delta P_{t+1} = -0.6\Delta P_t - 0.9e_t + e_{t+1}$$

Interest rate model



Interest rate in real term of AAA bonds

$$r_{t+1} = 0.72 + 0.81 \cdot r_t + \varepsilon_{t+1}$$

Log grade model

I: peeler

II: #1 sawmill

III: #2 sawmill

IV: #3 sawmill

V: other grades

$$\ln\left(\frac{\pi_l}{\pi_m}\right) = \beta_{l0} + \beta_{l1} \cdot D + \beta_{l2} \cdot S$$

Dependent variable	Independent variable	*Coefficient*	
Douglas fir			
π_1/π_4	*Constant*	2.91	*
	D	0.04	**
	S	-0.10	**
π_3/π_4	*Constant*	1.66	
	D	0.04	**
	S	-0.10	*
Western hemlock			
π_1/π_4	*Constant*	-8.94	*
	D	0.41	**
	S	-0.40	*
π_2/π_4	*Constant*	-8.37	*
	D	0.35	**
	S	-0.30	*
π_3/π_4	*Constant*	-5.90	**
	D	0.26	**
	S	-0.13	**

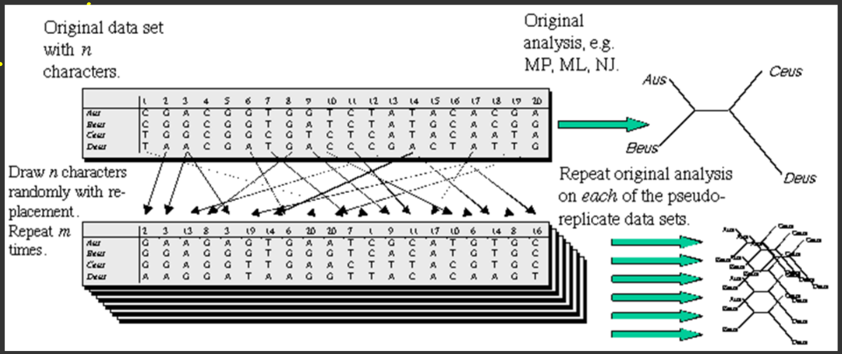
Bootstrap simulation

Bootstrapped
random shock

D stand growth model → stand growth model **S**

D stumpage price model → stumpage price model **S**

D interest rate model → interest rate model **S**



a demonstration of Bootstrap procedure

Measure of performance

- land expectation value

$$LEV = \sum_{w=0}^{W} \frac{\mathbf{vh}_{w\theta}}{(1+r)^{w\theta}} + \frac{\mathbf{vy}_{50}}{(1+r)^{50}} - \mathbf{vy}_0$$

- percentage of peeler logs in stock

- species/size diversity

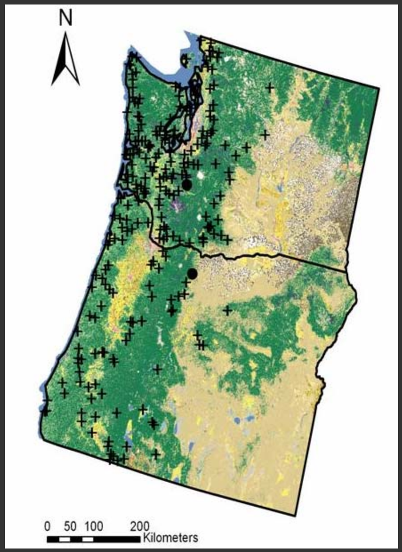
$$H_s = -\sum_{i=1}^{m} \frac{B_i}{B} \ln\left(\frac{B_i}{B}\right)$$

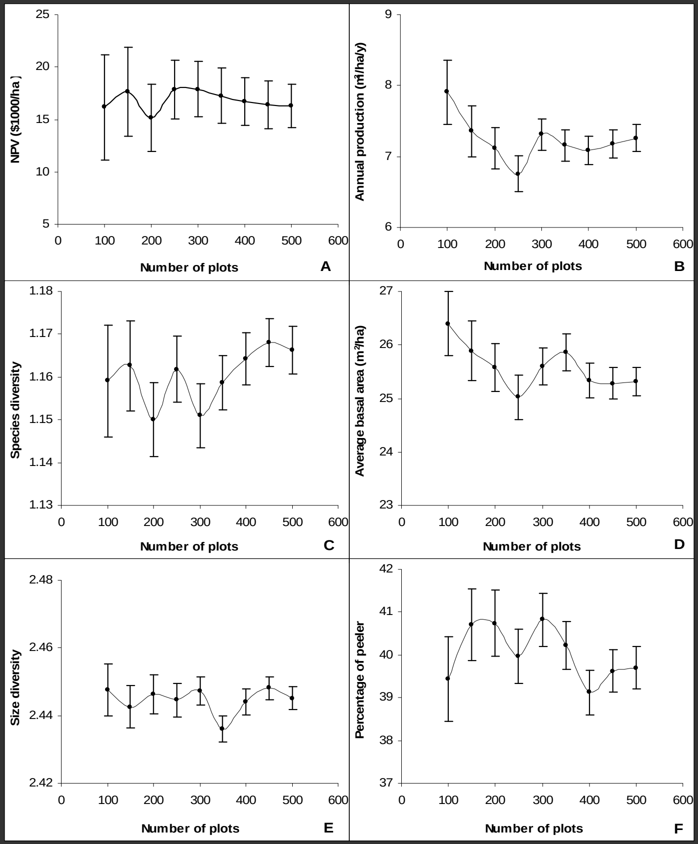
Simulation parameters

- target stand distribution: BDq selection method
  - Basal area: 60, 120, 180, 240, 300 (ft^2/ac)
  - Diameter: 40 (in.)
  - q-ratio: 1.2, 1.4, 1.6, 1.8
- cutting cycle: 10, 15, 20, 25, 30 (yr)
- timespan: 50 (yr)

Initial stand distribution

500 plots bootstrapped from the 2,706 initial Douglas-fir/western hemlock plots in the Pacific Northwest





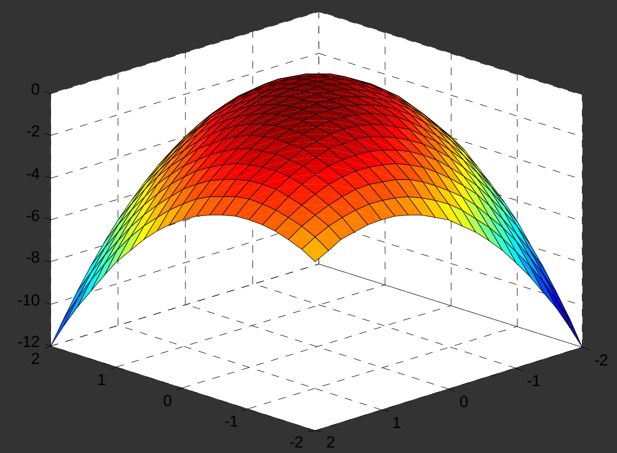
Response surface

- basal area: 60, 120, 180, 240, 300 (ft^2/ac)
- q-ratio: 1.2, 1.4, 1.6, 1.8
- cutting cycle: 10, 15, 20, 25, 30 (yr)

→ 5×4×5=100 management alternatives

response surface equations

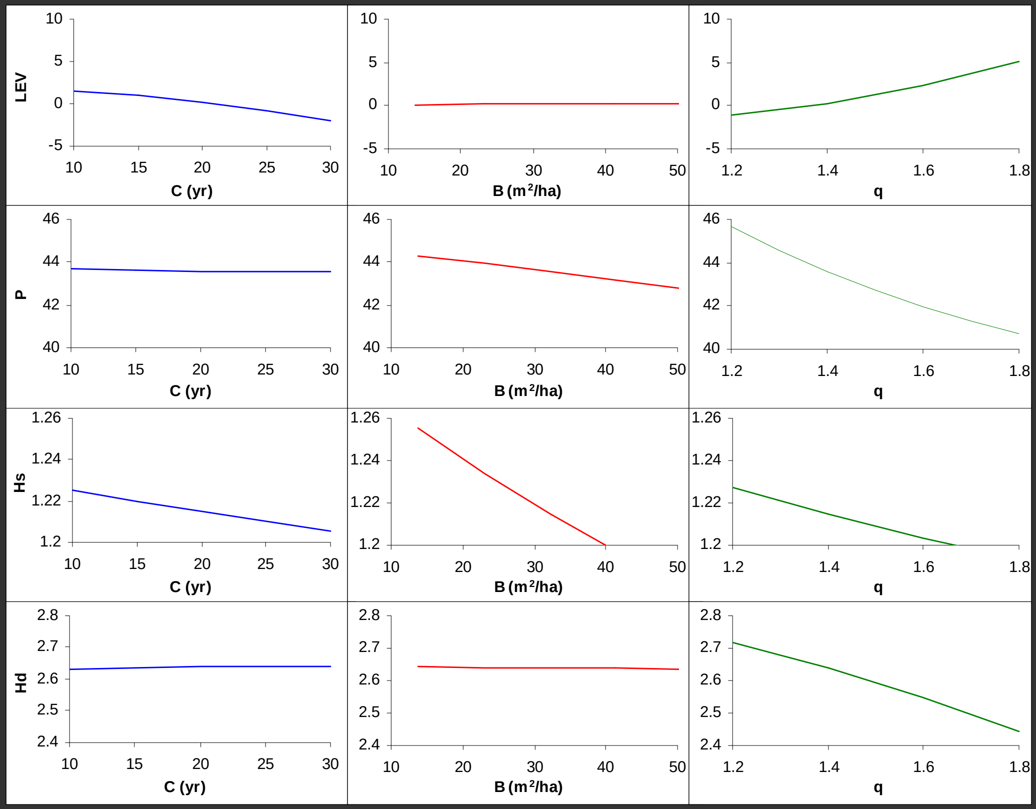
Equation	R^2
P=71.20** -1.61**C +0.21B -26.63**q +0.029C^2 - 2.10B^2 +5.62**q^2 -0.32CB -2.08Bq +1.09**Cq	0.97
Hs=1.35** +0.012C -0.15**B -0.05q +0.0005C^2 +0.11**B^2 +0.02q^2 -0.005CB -0.09**Bq -0.02**Cq	0.98
Hd=3.24** -0.12**C -0.09B -0.23**q -0.005C^2 - 0.03B^2 -0.16**q^2 -0.01CB +0.07Bq +0.11**Cq	0.99



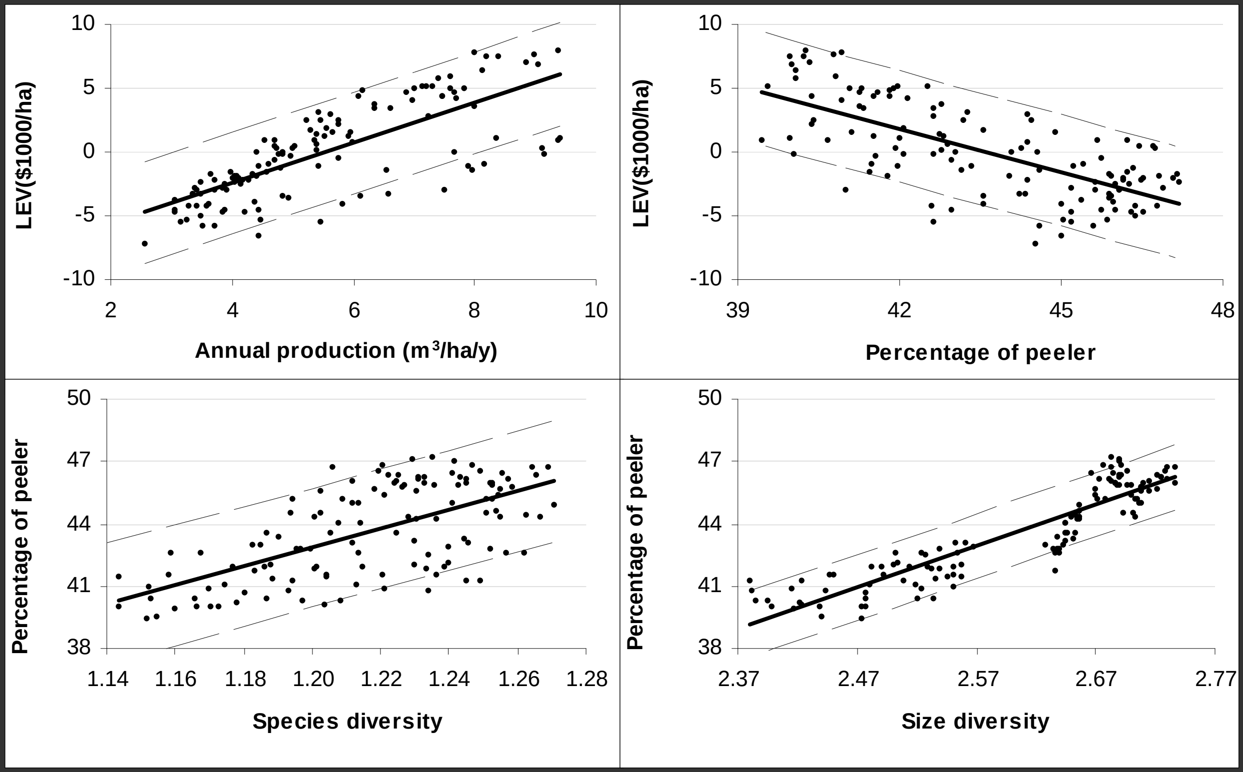
Optimization

Management criterion	Maximum	Control variable		
		Cutting cycle (year)	Basal area (m^2ha^{-1})	Target *q* ratio
Land expectation value (1000$ha^{-1})	8.20	10	51	1.8
Annual Production ($m^3ha^{-1}y^{-1}$)	9.00	10	51	1.8
Species diversity	1.27	10	14	1.2
Size diversity	2.74	10	14	1.2
Percentage of peeler logs	46.7	10	14	1.2
Stand basal area (m^2ha^{-1})	28.3	30	51	1.7

Sensitivity analysis



Inter-criterion correlation



Summary of study

- Bootstrap simulation
- Response Surface optimization
- Adjusting B, q, and C could control for more than 97% of the variability in species and size diversity, percentage of peeler logs, and basal area, but could control for less in LEV and annual production.
- Strong positive correlation between LEV and annual production, and between wood quality and size diversity
- negative correlation between LEV and wood quality.

Acknowledgement

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