Bootstrap Simulation & Response Surface Optimization in Forest Management

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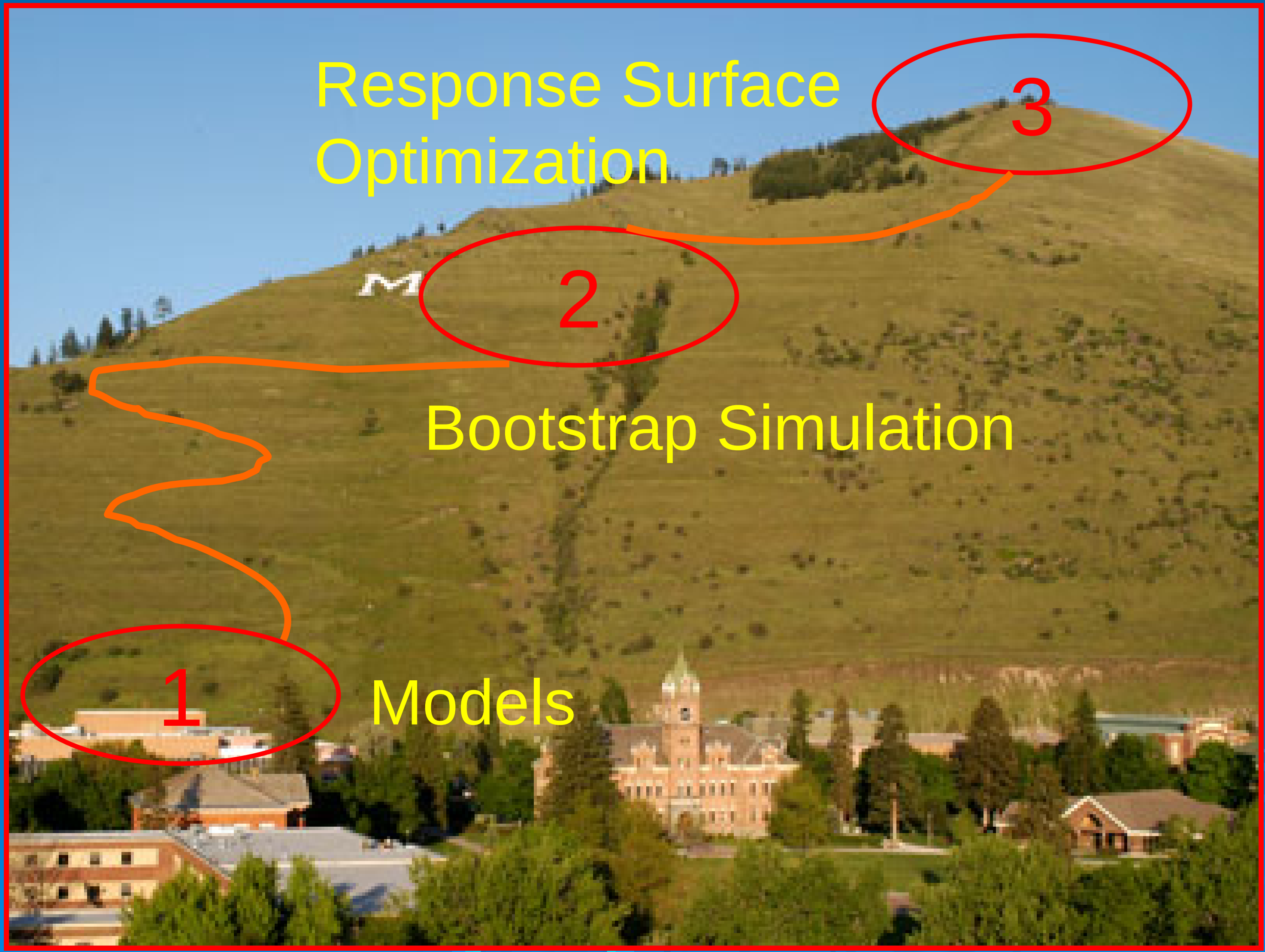
OBJECTIVE

To locate optimal management regimes, defined by a specific target distribution and cutting cycle, while recognizing fully the main stochastic elements of the problem:

- forest growth,
- timber prices,
- interest rates.

ROADMAP



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Models Involved in Simulation

- Stochastic stand growth
- Stochastic stumpage price
- Stochastic interest rate

Note: Welcome to the fluid session at 8:00pm TONIGHT for a demo of WestProPlus.

Stochastic Growth Model

$$\mathbf{y}_{t+1} = \mathbf{G}(\mathbf{y}_t)\mathbf{y}_t + \mathbf{R}(\mathbf{y}_t) + \mathbf{u}_{t+1}$$ [1]

$$\mathbf{e}_{t+1} = \mathbf{y}_{t+1} - \widehat{\mathbf{y}}_{t+1}$$

1: Liang, J, J. Buongiorno, and R.A. 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: Submodels-

- Diameter growth model:

$$g = \alpha_1 + \alpha_2 D + \alpha_3 D^2 + \alpha_4 B + \alpha_5 C + \alpha_6 H_s + \alpha_7 H_d + \mu$$

- Mortality model:

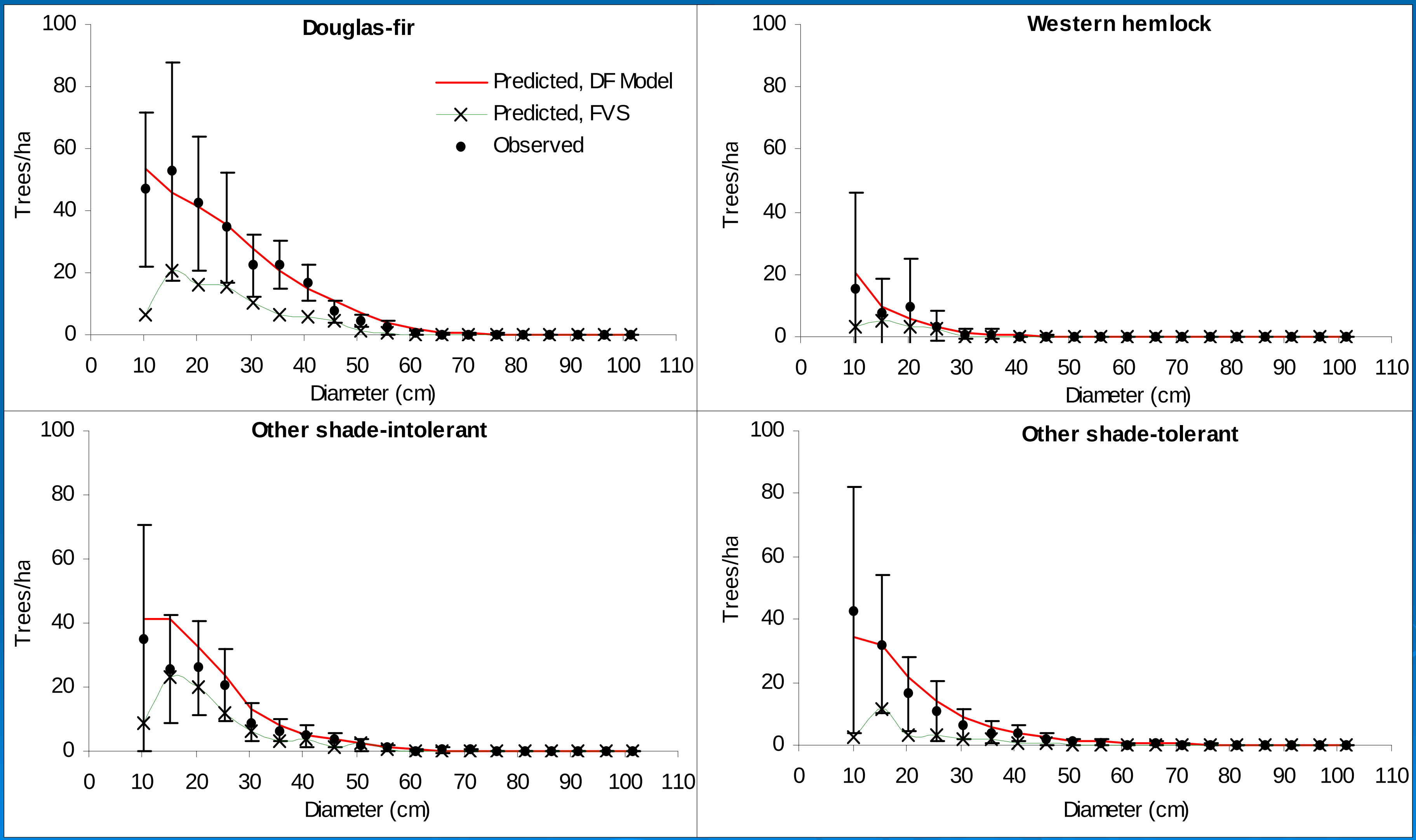
$$m = \Phi(\delta_1 + \delta_2 D + \delta_3 D^2 + \delta_4 B + \delta_5 C + \delta_6 H_s + \delta_7 H_d + \xi)$$

- Recruitment model:

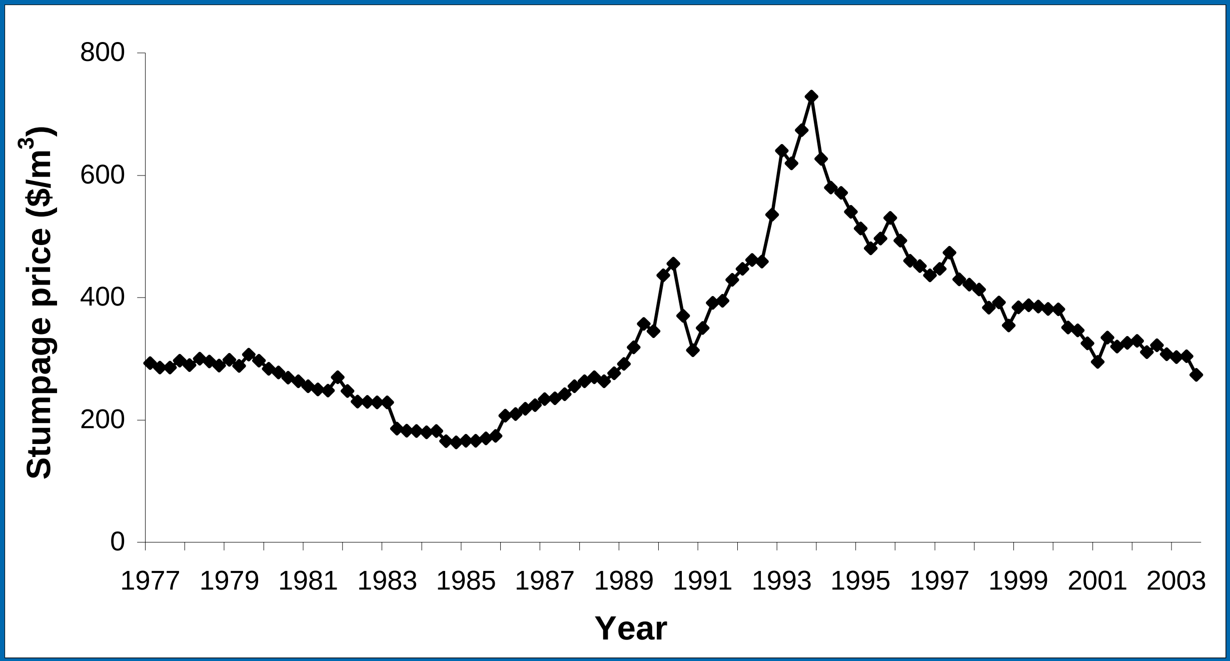
$$R = \Phi(\boldsymbol{\beta}\mathbf{x} / \sigma)\boldsymbol{\beta}\mathbf{x} + \sigma\phi(\boldsymbol{\beta}\mathbf{x} / \sigma)$$

$$\boldsymbol{\beta}\mathbf{x} = \beta_1 + \beta_2 B + \beta_3 N + \beta_4 C + \beta_5 H_s + \beta_6 H_d + \upsilon$$

Post Sample Validation



Stochastic Stumpage Price Model

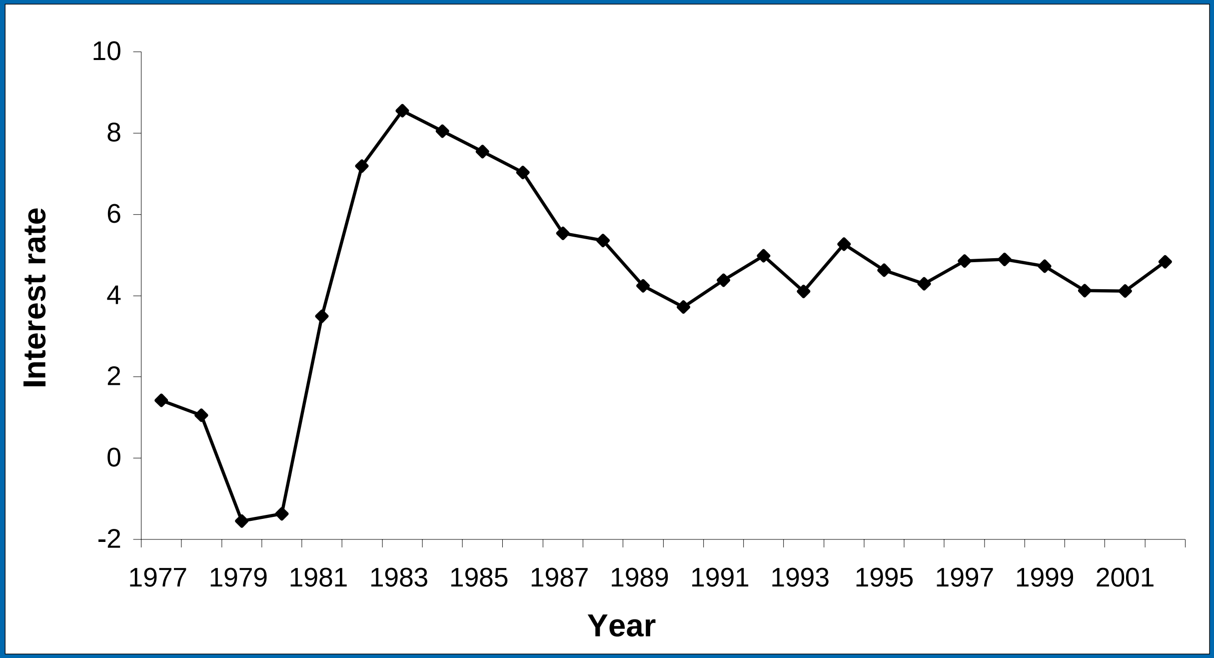


Oregon Quarterly stumpage prices of Douglas-fir Grade I logs

Stumpage price model:

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

Stochastic Interest Rate Model

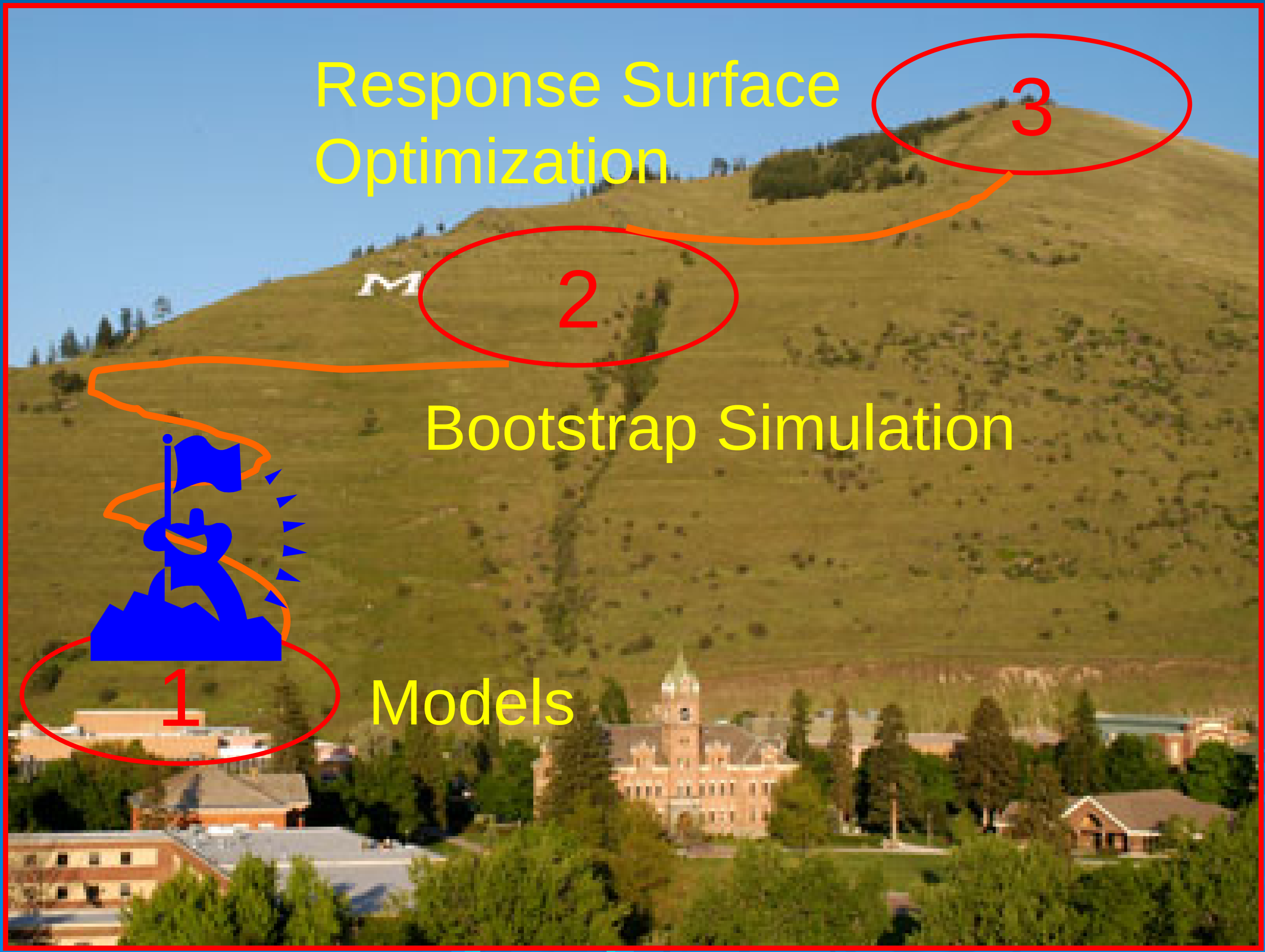


Interest rate in real term of AAA bonds

Interest rate model:

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

ROADMAP



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BOOTSTRAP

- A strap that is looped and sewn to the top of a boot for pulling it on

- To help oneself, often through improvised means

Bootstrapping

- B. Efron (1979). Bootstrap methods: another look at the Jackknife. *The Anals of Statistics* 7(1):1-26.
- In stochastic simulation, Bootstrap picks the random shock from the observed errors randomly, with replacement.
- Bootstrap is a superior nonparametric method where the sample distributions are not normal.

Measures of Performance

- The land expectation value (LEV)

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

- Annual production
- Percentage of peeler logs in stock
- Stand basal area
- Species diversity
- Size diversity

Measures of Tree Diversity: Shannon's Index

- Species diversity:

$$H_s = -\sum_{i=1}^{m} \frac{B_i}{B} \ln\left(\frac{B_i}{B}\right) \qquad \max = \ln(4) = 1.39$$

- Size diversity:

$$H_d = -\sum_{j=1}^{n} \frac{B_j}{B} \ln\left(\frac{B_j}{B}\right) \qquad \max = \ln(19) = 2.94$$

Simulation Parameters-

- Simulation length: 50 years
- Cutting cycle: 10, 15, 20, 25, 30 years

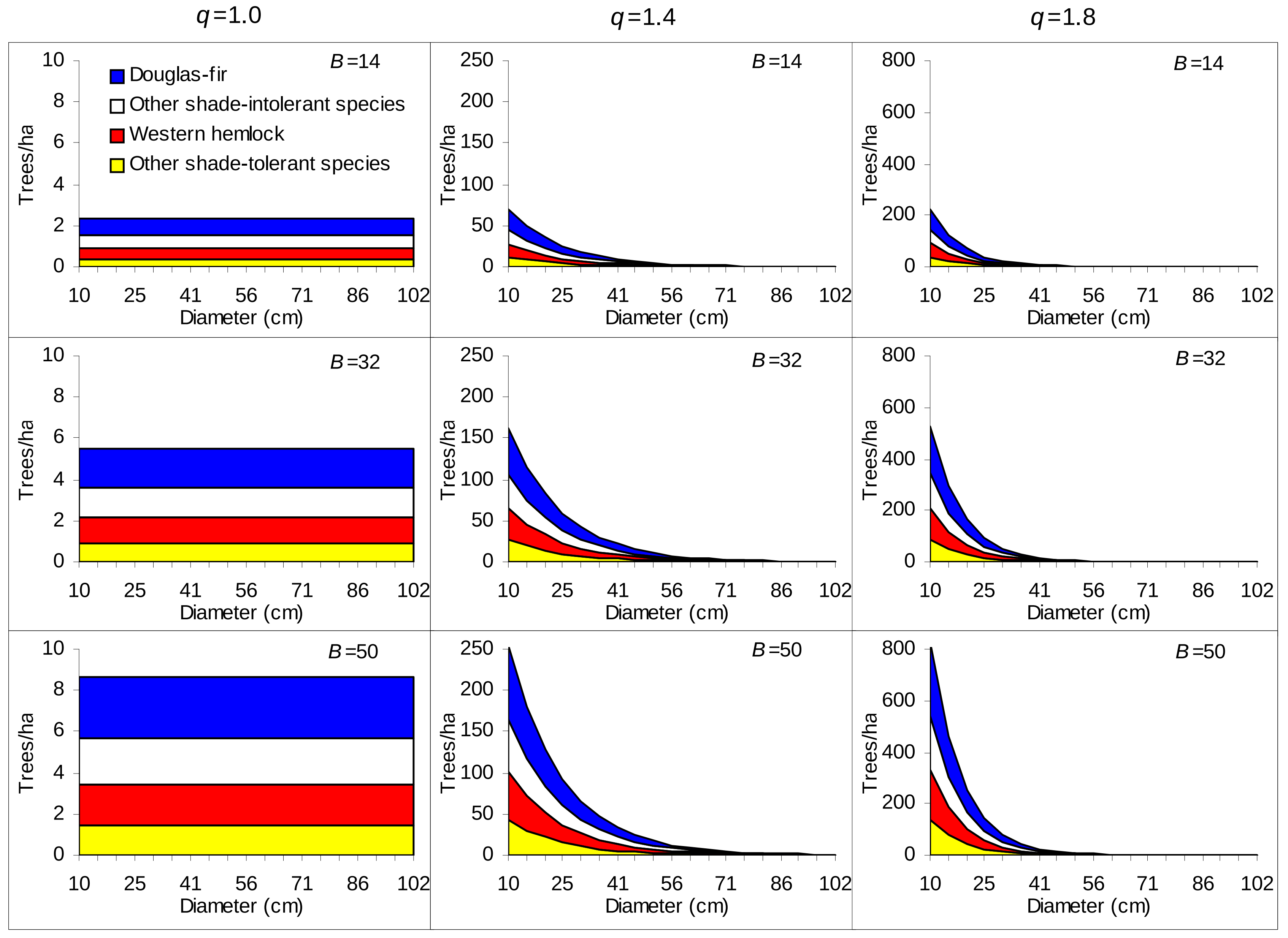
- Target Stand Distribution defined by BDq:

Basal area: 60, 120, 180, 240, 300 ft^2/ac

Diameter limit: 40 in

q-ratio: 1.0, 1.2, 1.4, 1.6, 1.8

Target Stand Distribution defined by BDq



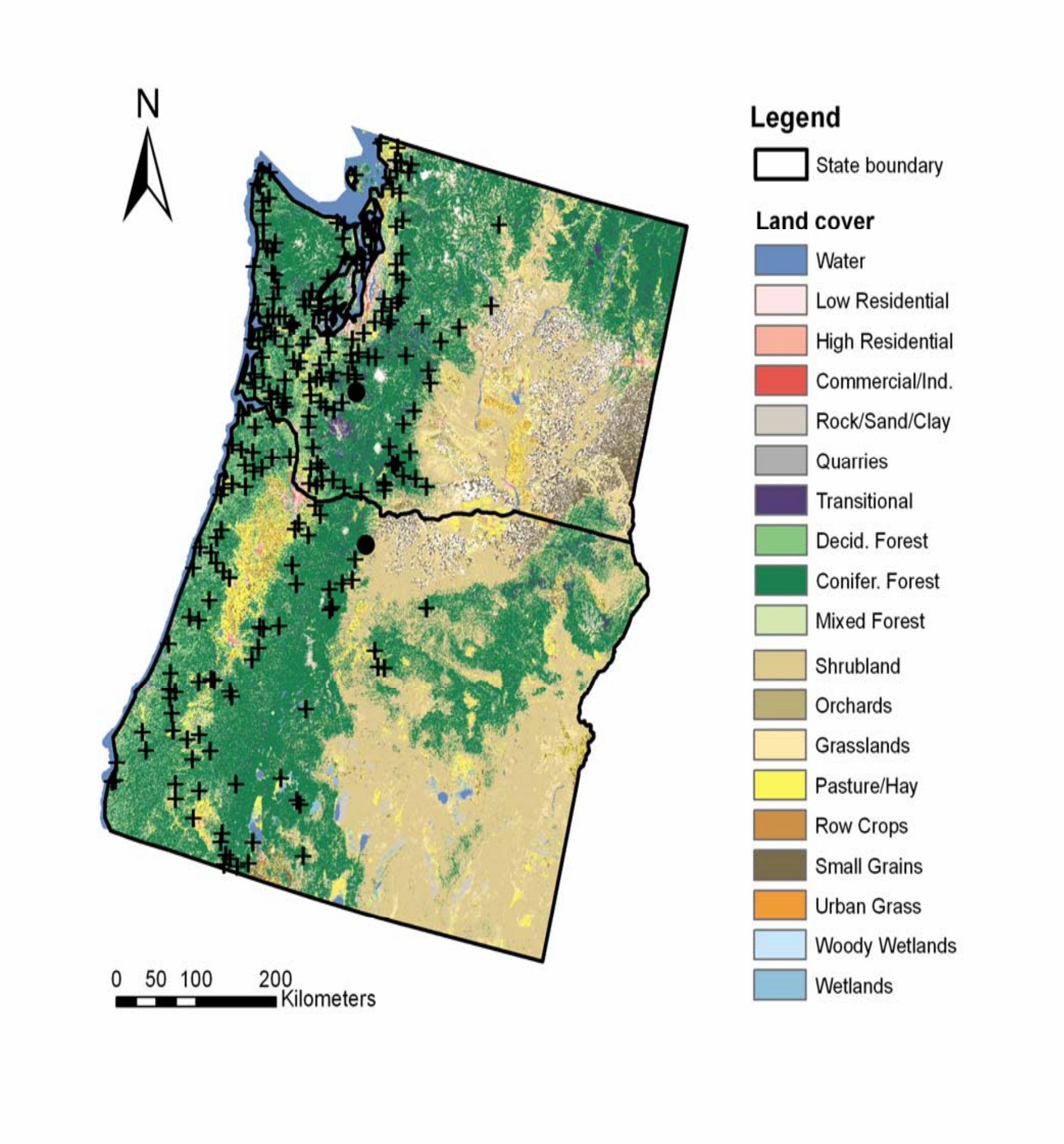
Simulation Parameters-cont'd

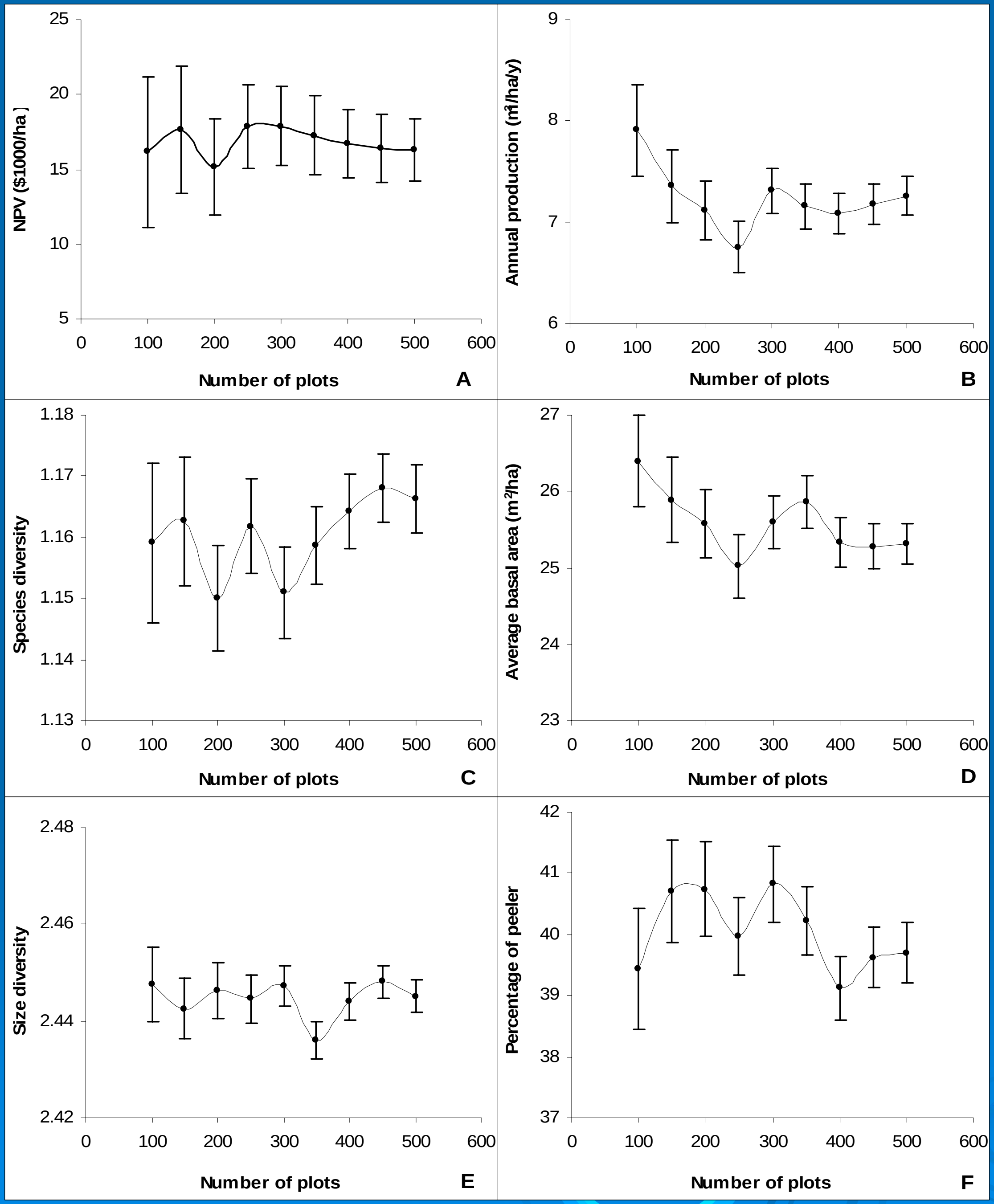
Initial stand distribution:

500 replications were randomly selected, with replacement, from the 2,706 permanent Douglas-fir/western hemlock plots in the Pacific Northwest used to calibrate the growth model [1].

1: Liang, J, J. Buongiorno, and R.A. 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.

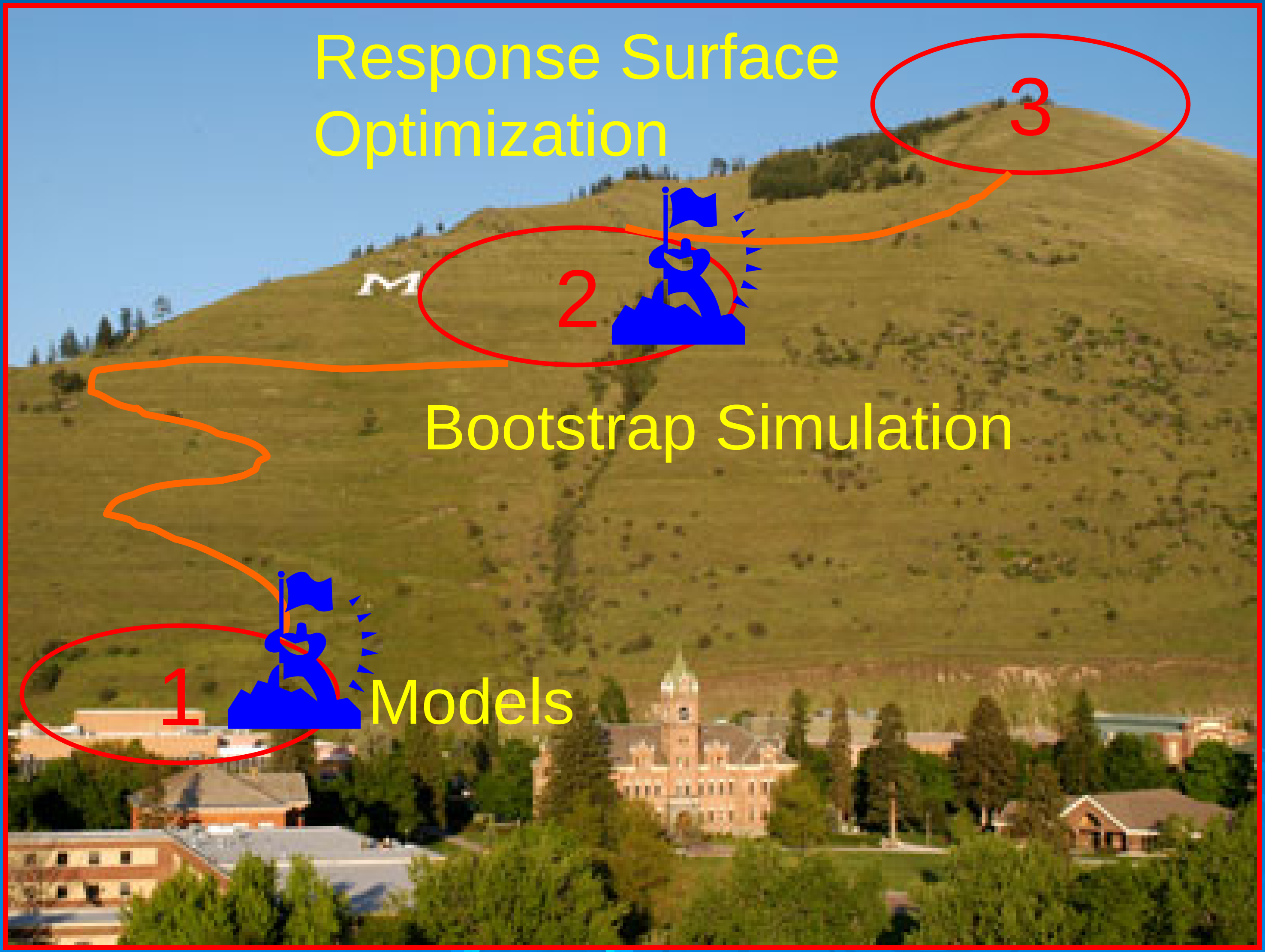
2,706 FIA permanent plots, IDB (V1.4)





Why use 500 replications?

ROADMAP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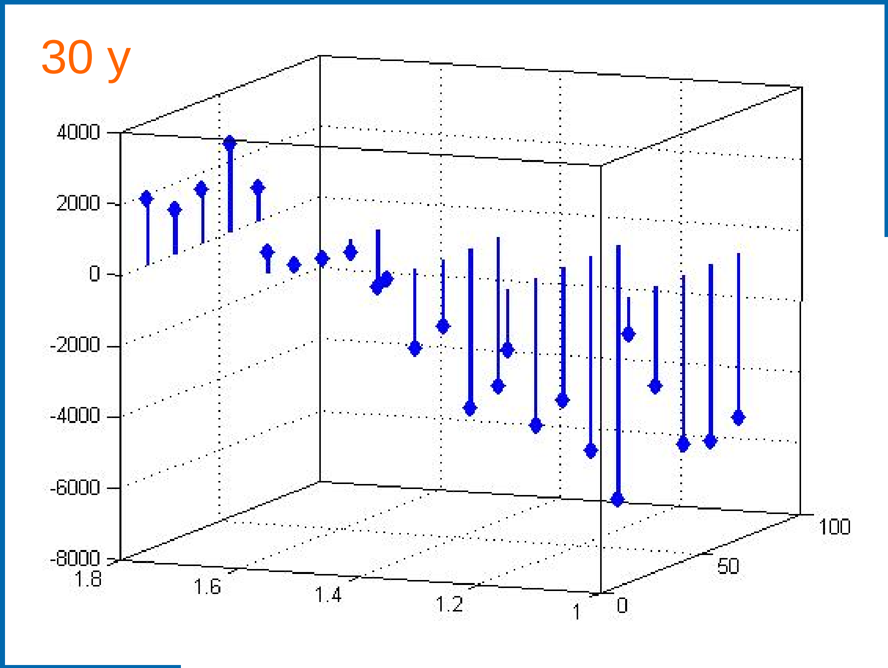
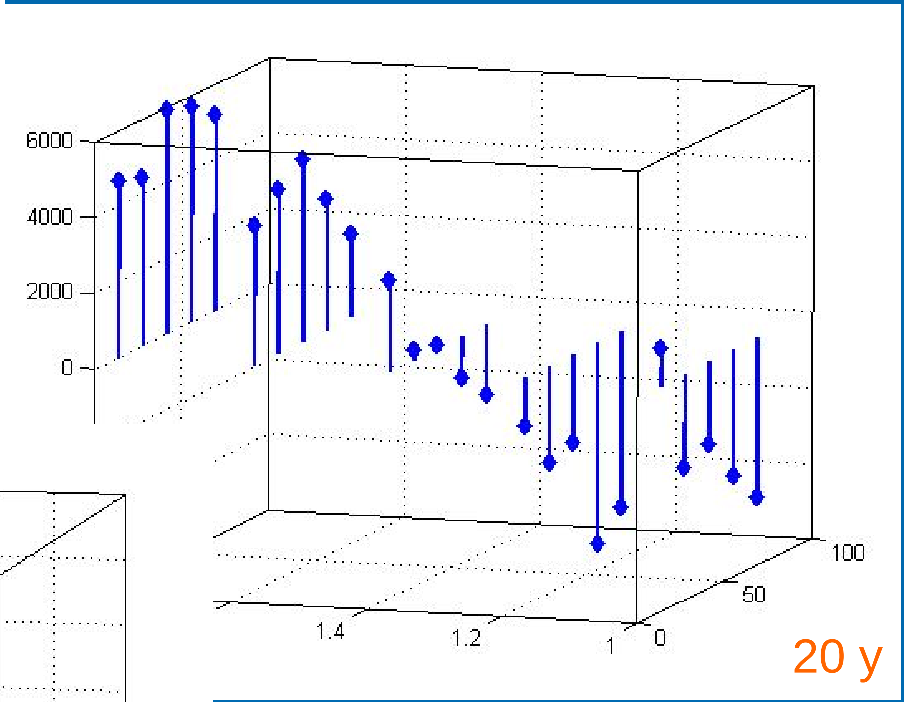
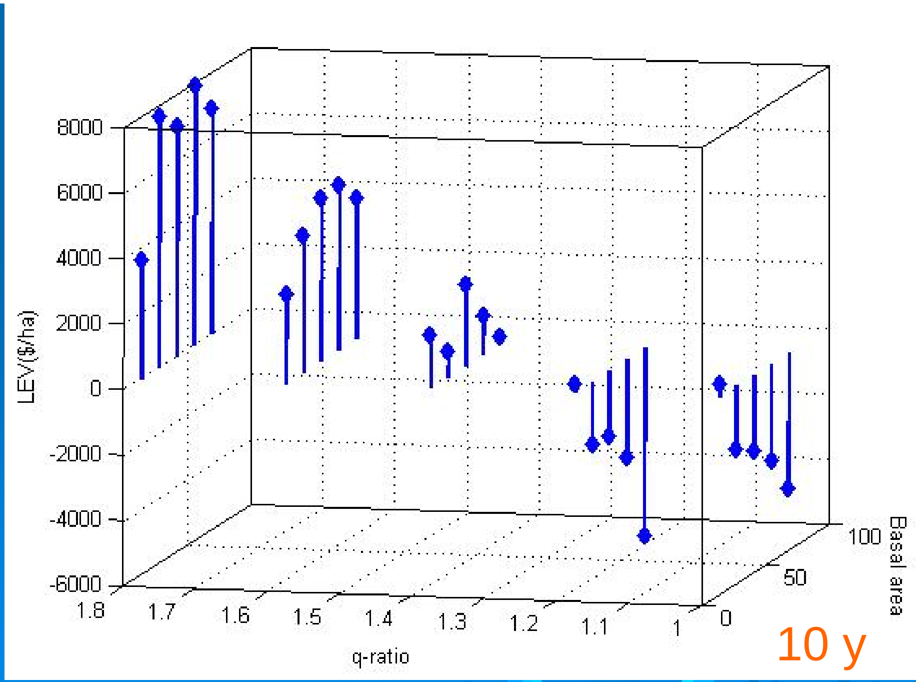
Predicted LEV by basal area, q-ratio, and cutting cycle.







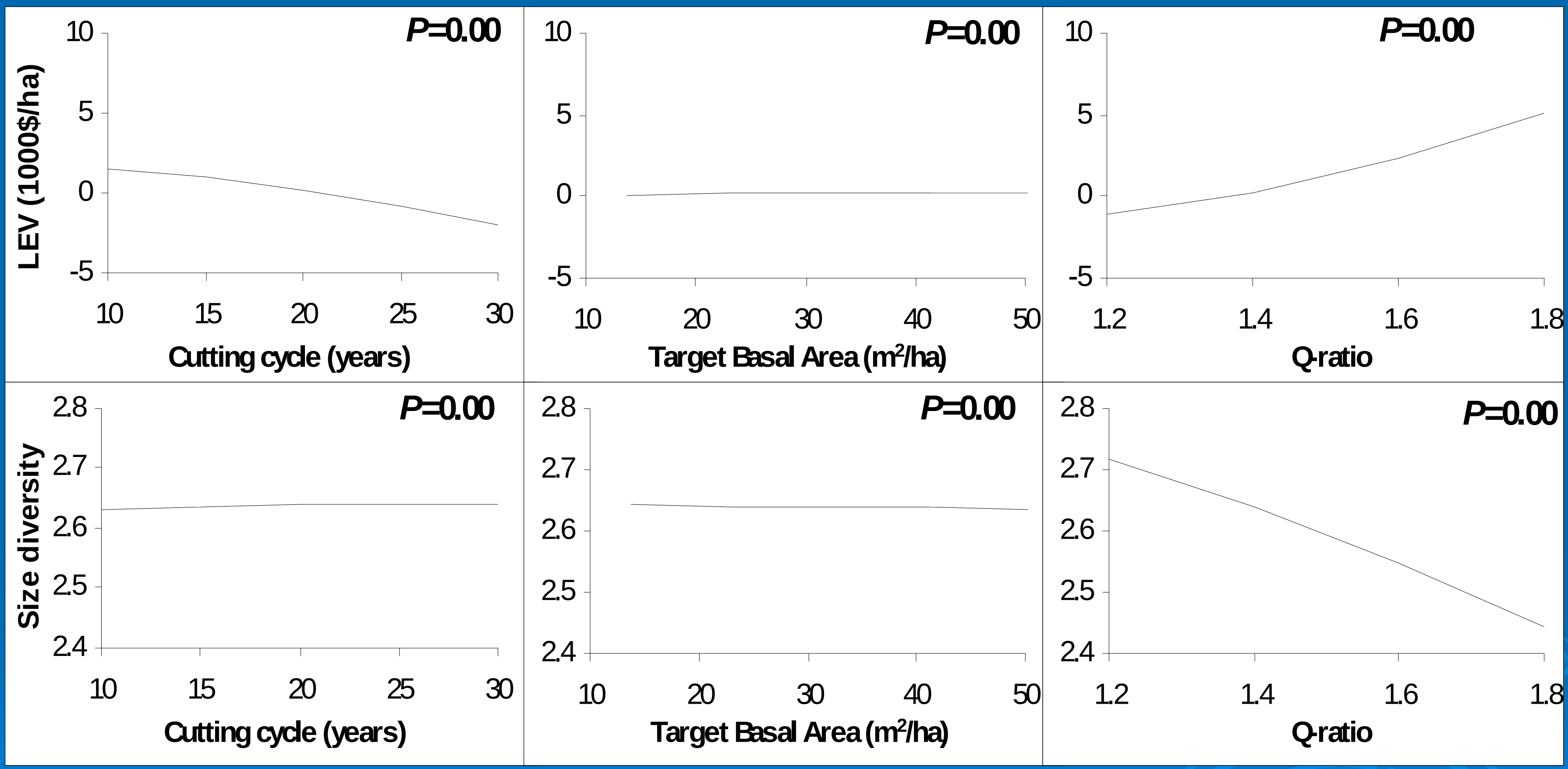
Effects of control variables on the expected value of the management criteria-

	Control variable									
	C	B	q	C^2	B^2	q^2	$C \times B$	$B \times q$	$C \times q$	*Constant*
Land Expectation Value										
Coefficient	0.48	-0.16	-15.70	0.00	0.00	9.47	0.00	0.12	-0.31	5.34
P	0.00	0.00	0.01	0.12	0.72	0.00	0.04	0.00	0.00	0.23
R^2	0.87									
Annual Production										
Coefficient	4.12	-10.04	9.27	-0.53	-4.81	-0.84	-0.92	9.03	-1.58	-7.16
P	0.00	0.09	0.13	0.01	0.39	0.68	0.29	0.00	0.00	0.15
R^2	0.82									
Species Diversity										
Coefficient	0.012	-0.15	-0.05	0.0005	0.11	0.02	-0.005	-0.09	-0.02	1.35
P	0.12	0.00	0.24	0.72	0.00	0.20	0.38	0.00	0.00	0.00
R^2	0.98									
Size Diversity										
Coefficient	-0.12	-0.09	-0.23	-0.0047	-0.03	-0.16	-0.01	0.07	0.11	3.24
P	0.00	0.21	0.00	0.05	0.71	0.00	0.21	0.05	0.00	0.00
R^2	0.99									
Percentage of Peeler Logs										
Coefficient	-1.61	0.21	-26.63	0.029	-2.10	5.62	-0.32	-2.08	1.09	71.20
P	0.00	0.94	0.00	0.74	0.41	0.00	0.41	0.10	0.00	0.00
R^2	0.97									
Basal Area										
Coefficient	2.13	50.27	69.64	-0.29	-34.75	-22.70	-2.39	5.14	1.21	-51.78
P	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00	0.00
R^2	0.99									

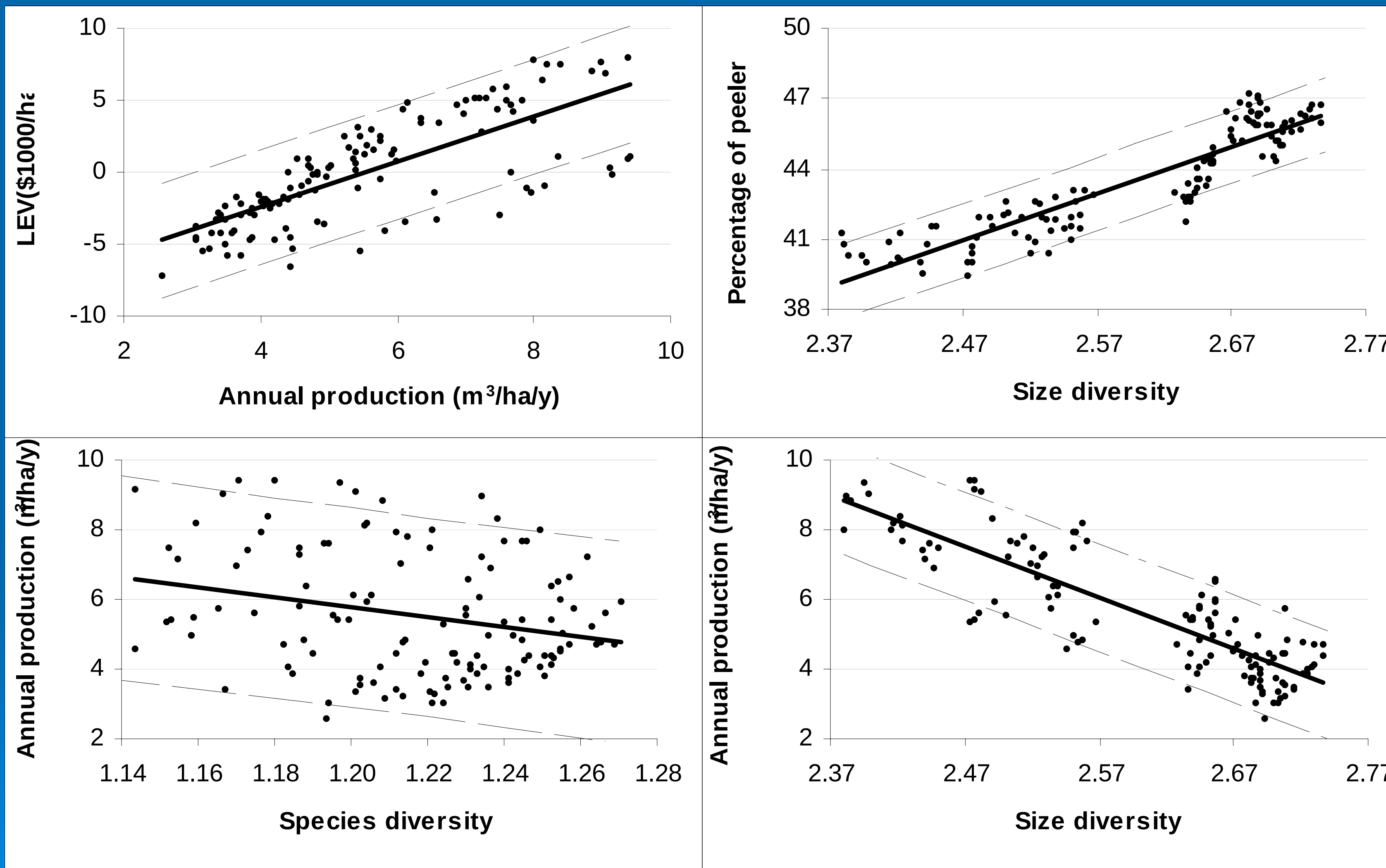
Maximum expected value of management criteria

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

Effects of control variables on the expected value of management criteria, with other control variables being held constant at their mean



Relationship between different criteria observed in all the simulations



Summary

- Within the *BDq* regimes investigated here, the *q* ratio had generally more influence on the management criteria than the residual basal area or the cutting cycle.
- 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.

Summary-cont'd

- Strong positive correlation between LEV and annual production, and between wood quality and size diversity

- Strong negative correlation between annual production and size diversity, and between annual production and wood quality.

Prospective Studies

- Forest fires and diseases, for example:
  - Fire Threaten Indices of different management regimes
  - Optimal management regimes, under the risks of fire and disease.

- New Models estimated with Bootstrap method

Acknowledgments

The research leading to this paper was supported in part by the USDA Forest Service, Pacific Northwest Forest Research Station, Human and Natural Resources Interaction Program, NRICGP grant 2001-35108-10673, and by the School of Natural Resources, University of Wisconsin-Madison.

We thank Dean Parry, Karen Waddell, and Susan Stevens Hummel for assistance with the data.