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Inventory-based sensitivity analysis of the large tree diameter growth submodel of FVS Southern Variant

Giorgio VACCHIANO
University of Torino (Italy), Dept. AgroSelviTer

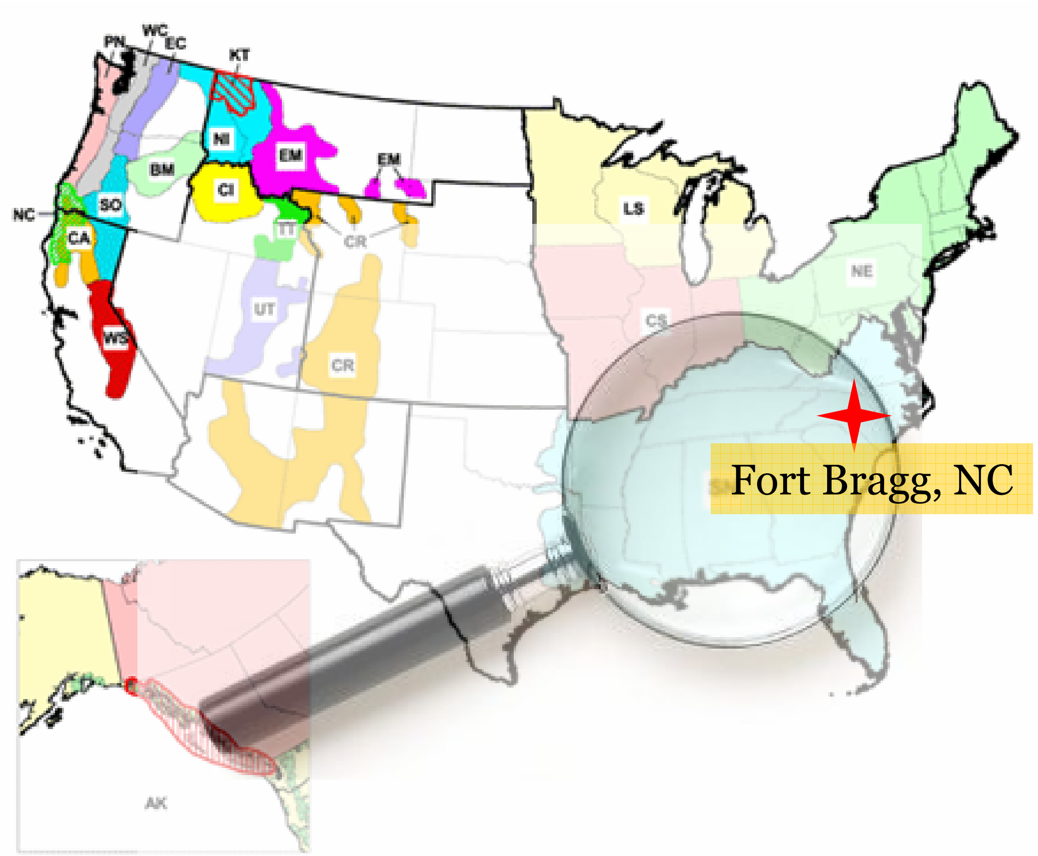
RJ DeRose, JN Long
Utah State University,
Dept. of Wildland Resources

JD Shaw
USDA Forest Service, Rocky Mountain RS

Outline

- Project background
- Inside FVS: dbh increment submodel(s)
- Approaches to sensitivity analysis
- The SIMLAB package
- Variations on the analysis
- Conclusions

Introduction



FVS Southern Variant (2001):

- 13 states
- well-documented
- few localized models
  - Species
  - EUC
  - Forest type

Introduction

.loc
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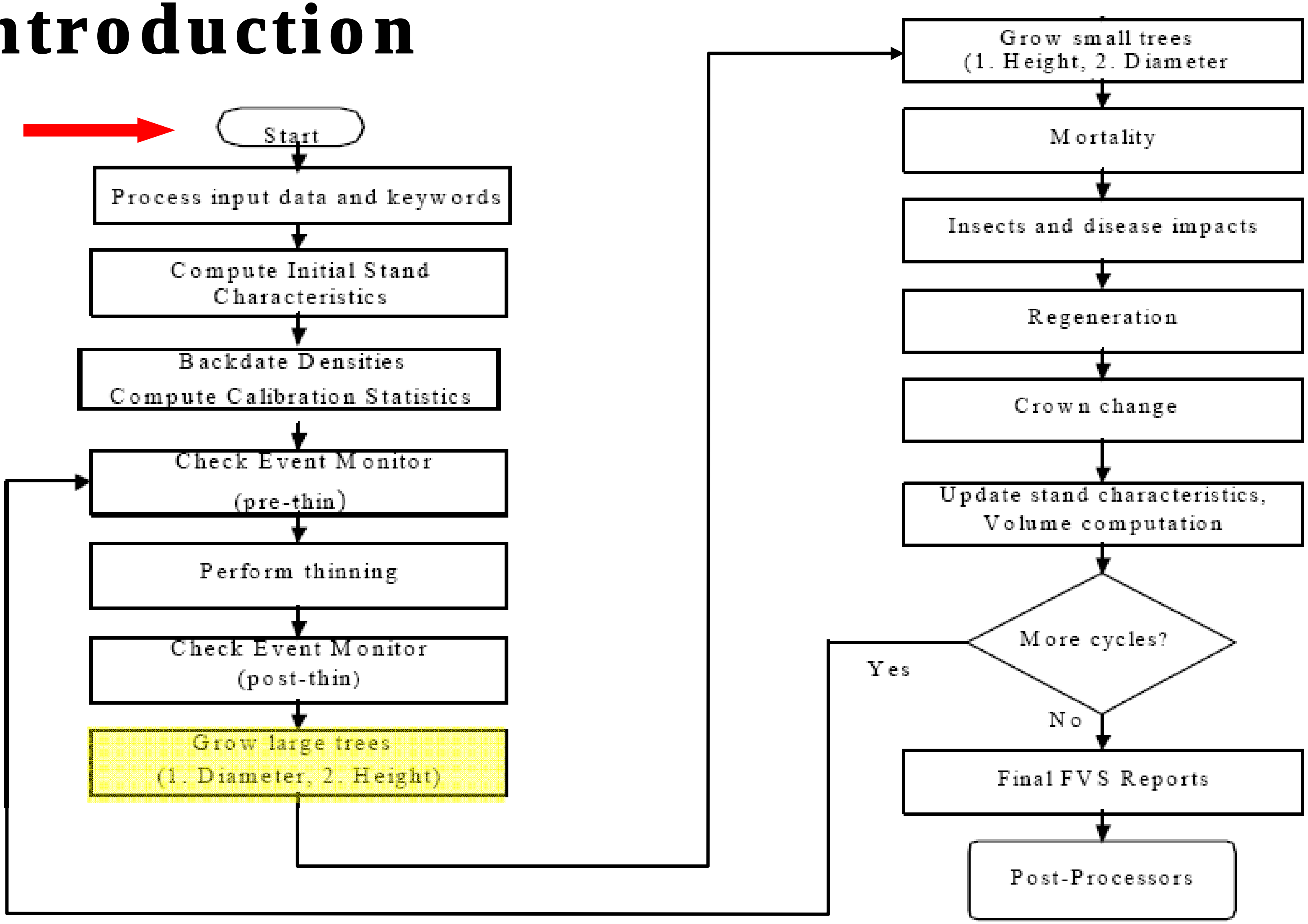


Introduction

Diameter increment for large trees (≥3”):

- 14-parameter exponential model
- scaling on local increment data (if any)
- randomization (tripling)
- senescence bounding function
- bark submodel

Introduction

"…it is unreasonable to assume that growth responses in locations with substantially different environmental limitations will be the same."

(Donnelly et al., 2001)

Large tree dbh increment: **9190 observations**
Goodness-of-fit: **R-squared =0.520**
Calibration of full model: **flawed params**

Introduction

	Variable	Description	
ln(dds)* =	b_0	intercept	**Tree potential**
	$+ b_1 \cdot \ln \text{dbh}$	log of dbh (at beginning of estimation period)	
	$+ b_2 \cdot \text{dbh}^2$	squared dbh	
	$+ b_3 \cdot \ln \text{crwn}$	log of percent crown ratio	
	$+ b_4 \cdot \text{hrel}$	relative height	**Competition**
	$+ b_5 \cdot \text{SI}$	site index for the species	
	$+ b_6 \cdot \text{plttba}$	plot basal area	
	$+ b_7 \cdot \text{pntbal}$	plot basal area in trees larger than subject tree	
Predictable?	$+ b_8 \cdot \tan \text{slp}$	tangent of slope in degrees	**Site factors (constant or non influential)**
Predictable?	$+ b_9 \cdot \text{f cos}$	tangent of slope, cosine of aspect	
Predictable?	$+ b_{10} \cdot \text{f sin}$	tangent of slope, sine of aspect	
	$+ b_{11} \cdot \text{fortype}$	categorical variable for forest type group	
INVARIANT	$+ b_{12} \cdot \text{ecounit}$	categorical variable for ecological unit group	
INVARIANT	$+ b_{13} \cdot \text{plant}$	categorical variable for planted stands	

* dds = (diameter inside bark at time$_o$ + periodic diameter growth)^2 – diameter inside bark^2 (Wykoff et al., 1982).

Sensitivity analysis

Aim: variable ranking

(F.Bragg-based effectiveness in predicting BAI)

Sensitivity analysis:

"A systematic search for those model entities to which the model is most sensitive".

(Innes, 1979)

Precision	Parameters	Input variables	Model form

Sensitivity analysis

Herring and Radtke, 2007

Hamilton, 1997:

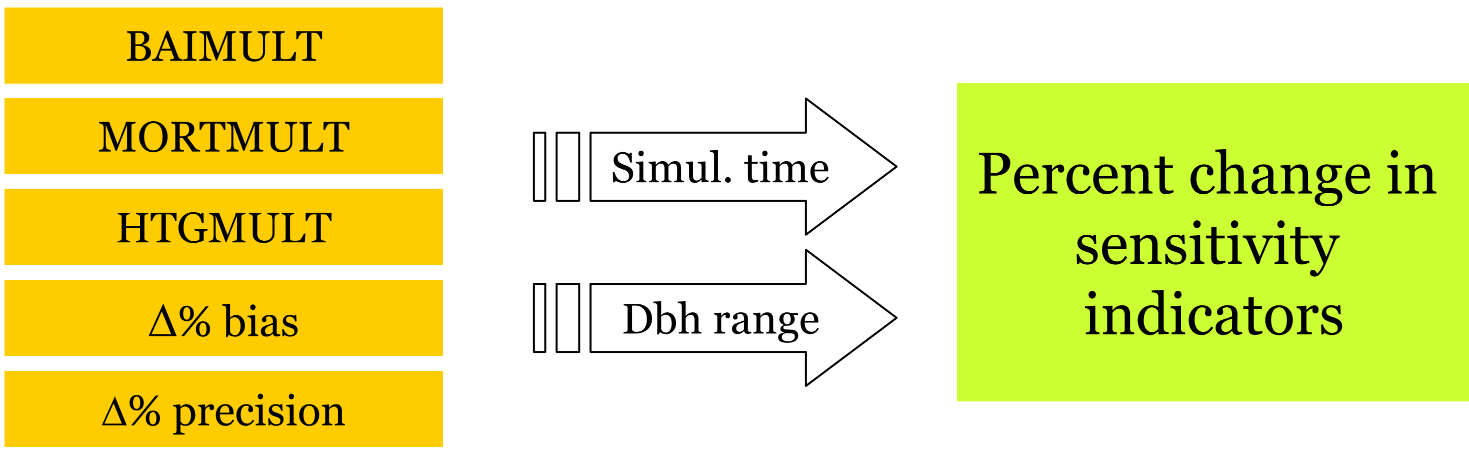
"Guidelines for Sensitivity analysis of FVS".

Submodel output Measurement accuracy Measurement precision (LCR, dbh, height)	➔	Total volume Tree density QMD Top height Basal area

Sensitivity analysis

The Hamilton approach:

Multiplicative perturbation of model input (one factor at a time).



Sensitivity analysis

LOCAL SA:

local response of the output(s) by varying input parameters one at a time, holding others constant.

GLOBAL SA:

global response (averaged over the variation of all the parameters) of model by exploring a finite or infinite input space.

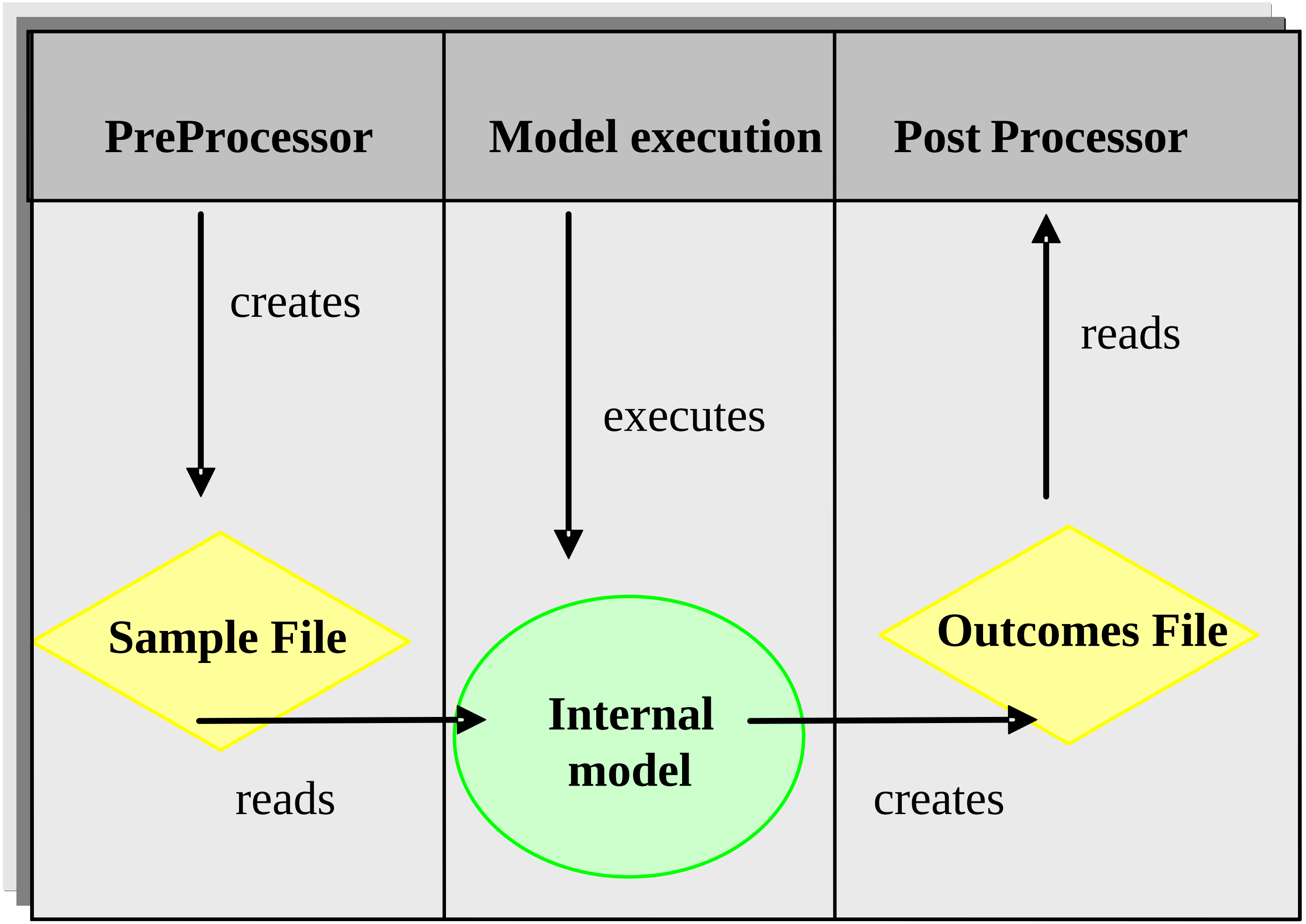
Sensitivity analysis

SIMLAB (2004) Version 2.2

Simulation Environment for Uncertainty and Sensitivity Analysis

developed by the Joint Research Centre of the European Commission.

SIMLAB


PreProcessor
Model execution
Post Processor
creates
executes
reads
Sample File
Internal model
Outcomes File
reads
creates

SIMLAB

1. Statistical description of input variables imputed from field data
   - Shape of distribution
   - Mean, standard deviation
1. Iterative MC-based sampling
2. Input propagation through model
3. Uncertainty analysis
4. Sensitivity analysis

Database

Tree variables	**Stand (plot) variables**
ID codes	ID codes
Inventory type	Inventory type
Species (FIA codes)	Inventory date
Dbh	Spatial location (UTM NAD_{83})
Rank (stand-wise dbh distribution)*	Trees per hectare *
Point Basal Area Larger*	Quadratic mean dbh*
Total Height	Basal area*
Crown width$_{1,2}$	Additive Stand Density Index*
Crown width mean*	Reineke's Stand Density Index*
Crown ratio estimate	$SDI_{sum}/SDI_{Reineke}$ ratio
Tree crown class estimate	Relative SDI*
Height to crown base	Species-specific Site Index
Live crown ratio	Species-specific asymptotic height]*
Radial increment	Point Basal Area*
5-year diameter increment	Slope %
Basal Area (outside bark)*	Slope (°)*
Age at breast height	Aspect (°)
Age*	Forest type code
Relative height (Height H_{40}^{-1})*	EUC
Tree condition code[	H_{40}*
Bark thickness	Age minimum, maximum*
Bark ratio*	Age mean, median*

Analisi di sensitività

Input	Definition	Distrib.	Range	Units
dbh	Diam. breast height	Normal	2 - 30	In
crwn	Live crown ratio	Normal	1 – 100	%
h	Tree height	Normal	10 – 101	Feet
H40	Height of 40 thickest trees ac^{-1}	Normal	40 – 140	Feet
SI	Site Index	Normal	44 – 132	Feet
BA	Basal area (stand)	Normal	5.5 – 158	$feet^2$ ac^{-1}
BAp	Basal area (plot)	Normal	10 – 270	$feet^2$ ac^{-1}
rank	%ile of tree's dbh in plot	Uniform	0 – 1	-
slope	plot mean slope	Discrete	0 – 0.8	rad
aspect	plot mean aspect	Uniform	0 – 2π	rad
EUC	Ecological unit code	Constant	0	categ.
forcode	Forest cover type	Discrete	0 – 1	categ.
plant	Plantation origin	Constant	0	binary

7,300 Longleaf pine trees

Database

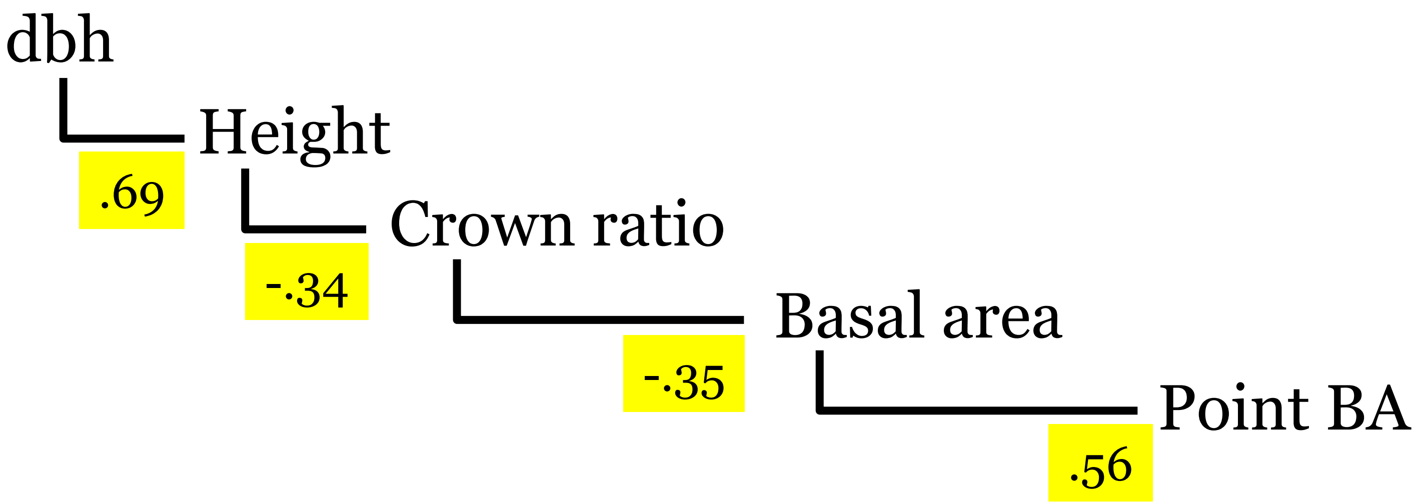
- PDFs of sample variables were tested for normality by means of one-variable Kolmogorov-Smirnov test ($p < 0.05$)

- Truncation to field-based minima and maxima helped avoiding sampling outliers.

- Biologically relevant correlations were assessed and entered in a tree-like structure.

Results

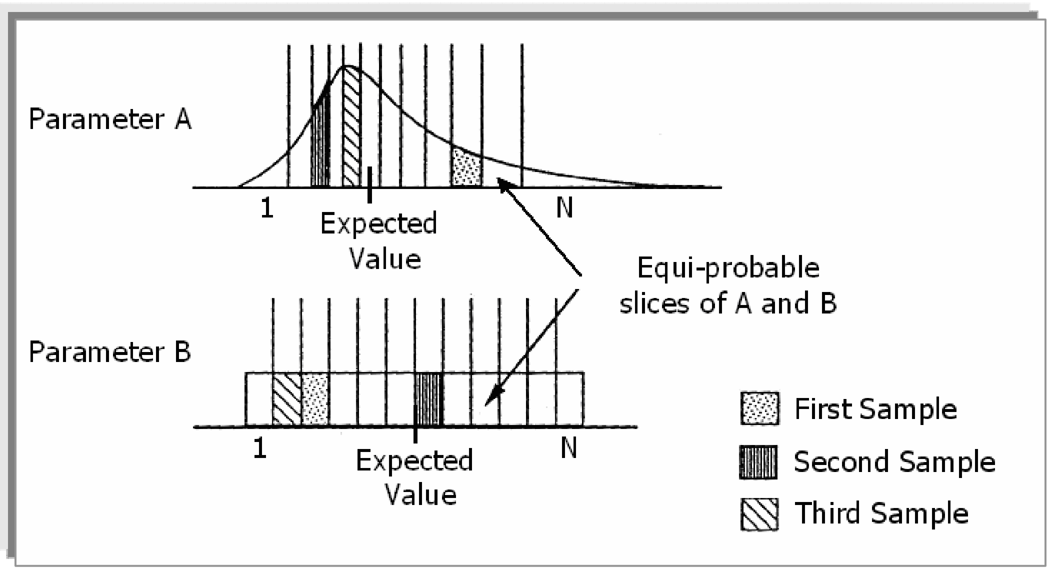
Correlated inputs (Pearson's r):



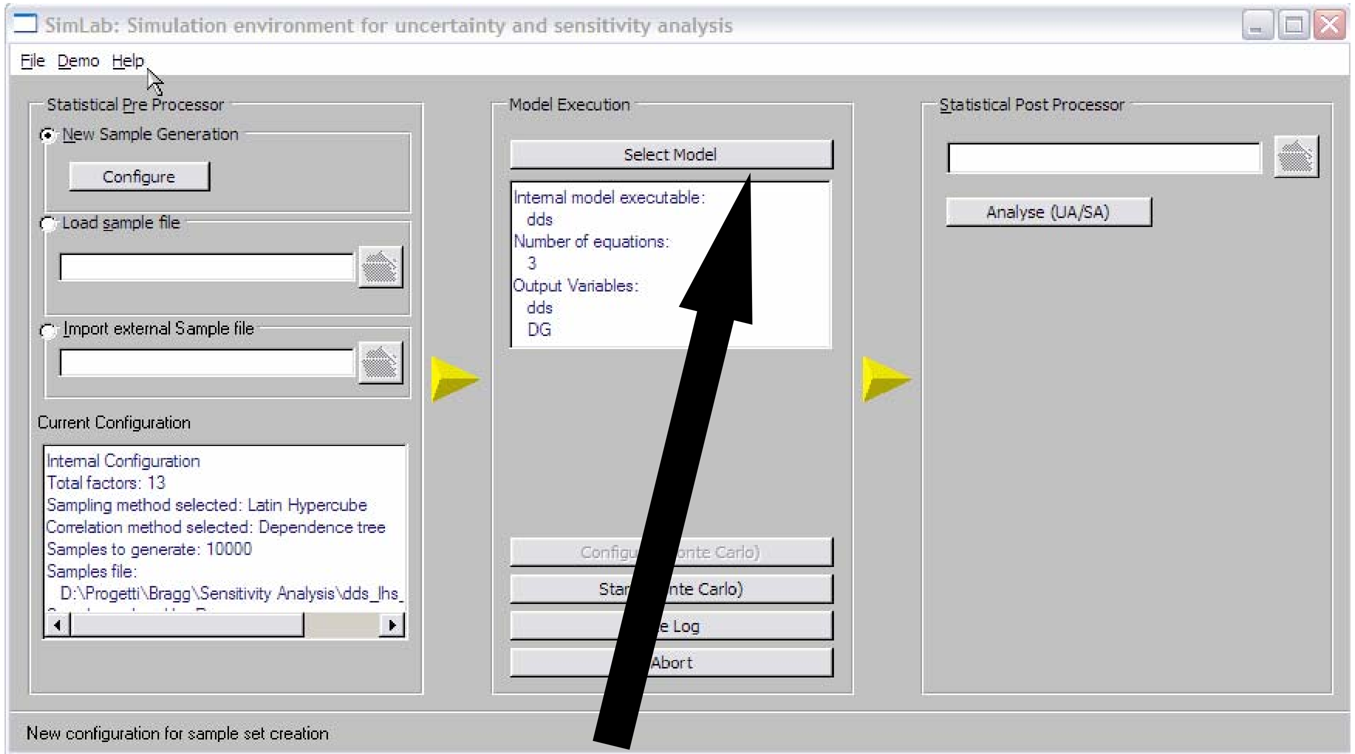
Sampling

Latin Hypercube Sampling (10,000 runs):

Probability distributions of model inputs are divided into N equi-probable intervals. For each simulation, a value for each parameter combination is selected from one of these intervals at random, and without replacement.



Model propagation



exp(-1.3311+1.0981*log(D)-0.0018*(D**2)+0.1845*log(CR)+0.0088*SI+
+0.2252*tan(slope)+0.0869*tan(slope)*cos(aspect)+0.1074*tan(slope)*sin(aspect)+
+0.388*H/H40-0.0022*BA-0.0029*PointBA*(1-rank)+EUC+forcode+planted)

Model propagation

<u>Modeled output:</u>

dds: change in squared inside bark dbh

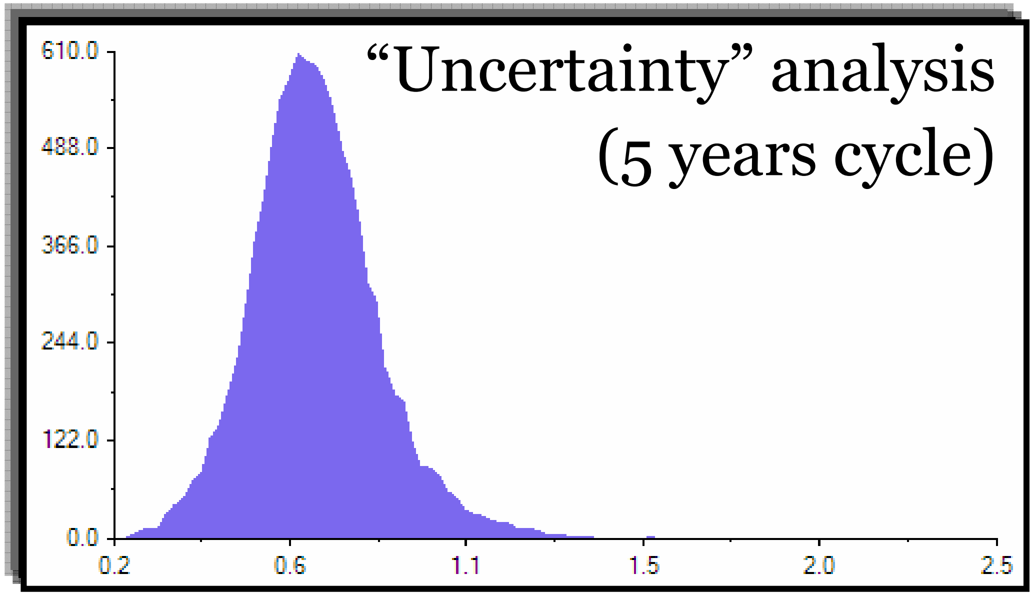
Dg: inside bark diameter growth

$$D_g = \sqrt{dib^2 + dds} - dib$$

$$dib = \frac{1}{k} dbh$$

Field-based bark thickness ratio (k = 1.129)

Results



Dg [in]	Mean	SE	Range	Skewness
Data	0.57	0.0030	0.08 – 2.36	1.403
Model	0.71	0.0018	0.17 – 1.01	

SA is needed!

Uncertainty analysis

Data variability is reduced by model

Lower variability in SN calib. data

Model-induced simplification

BUT: adj.R^2 of default SN is much lower (0.52 vs 0.91)

Uncertainty analysis

Diameters were split into very small (3-5"), small (5-10"), medium (10-15") and large (15"+) classes.

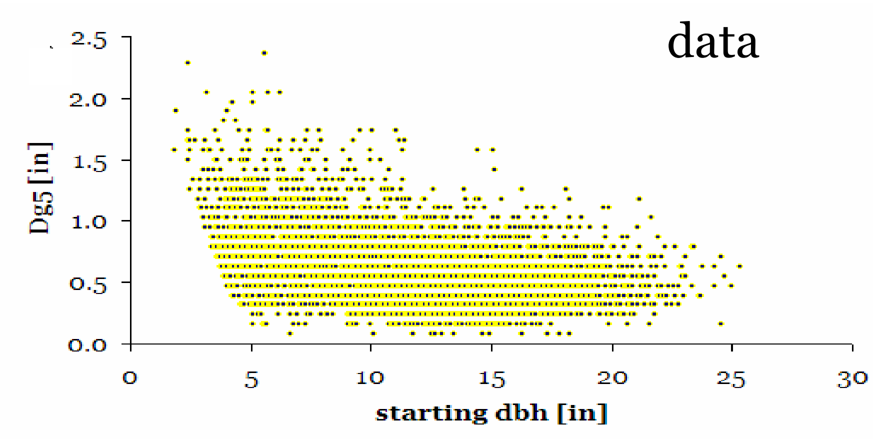
Size class	Mean		Range		R^2
Very small	0.82	0.54	0.39–2.58	0.16–1.26	
Small	0.59	0.60	0.36–0.99	0.08–1.89	
Medium	0.57	0.59	0.34–0.98	0.08–2.99	
Large	0.47	0.61	0.25–0.82	0.08 –3.15	

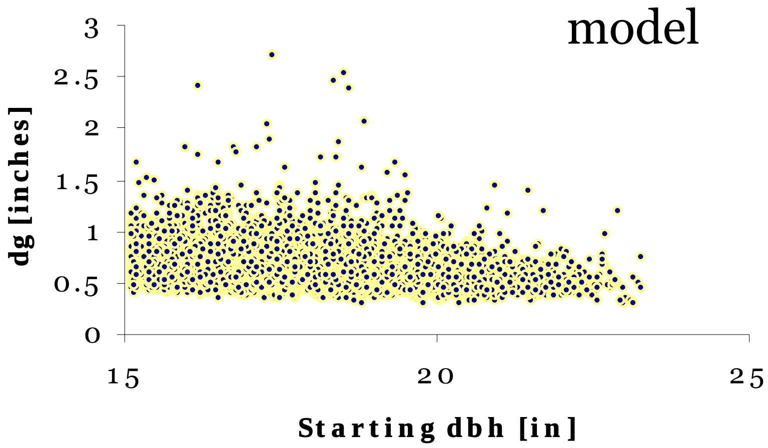
Field data (yellow) Simulated results (white)

Uncertainty analysis

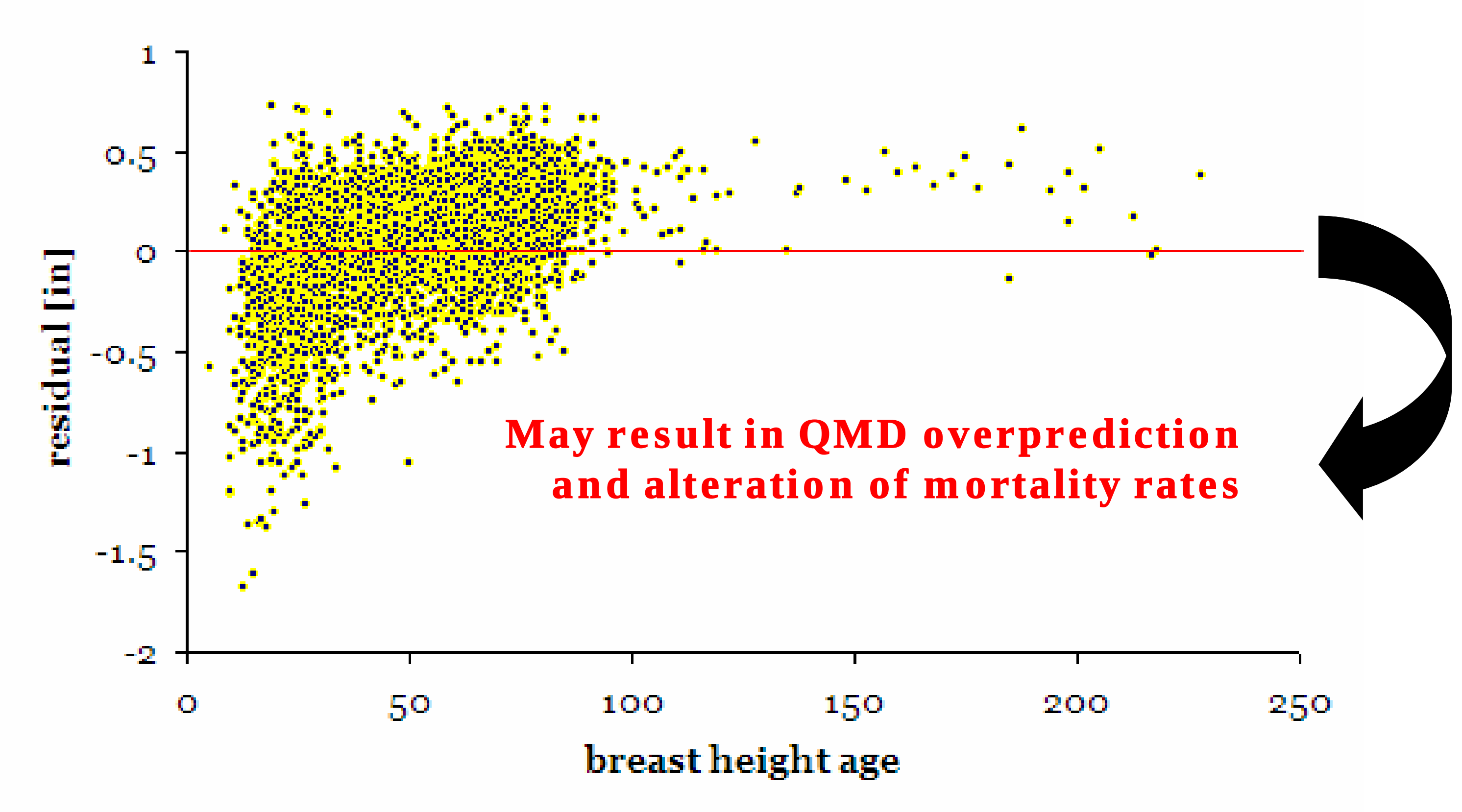
<u>Small & medium trees:</u>
Competition unexplained, lower end of growth range.

<u>Medium & large trees:</u>
Less variation explained, overestimation of growth rate (0.21", 0.14"), upper end of Dg range. Age-related decline?





Uncertainty analysis



<u>Age-related decline</u> (MAGNITUDE)

Evaluate role of senescence bounding function.

Uncertainty analysis

"If research is available showing diameter growth relationships for aged, very large trees, it could be incorporated into the variant."

(Donnelly et al., 2001)

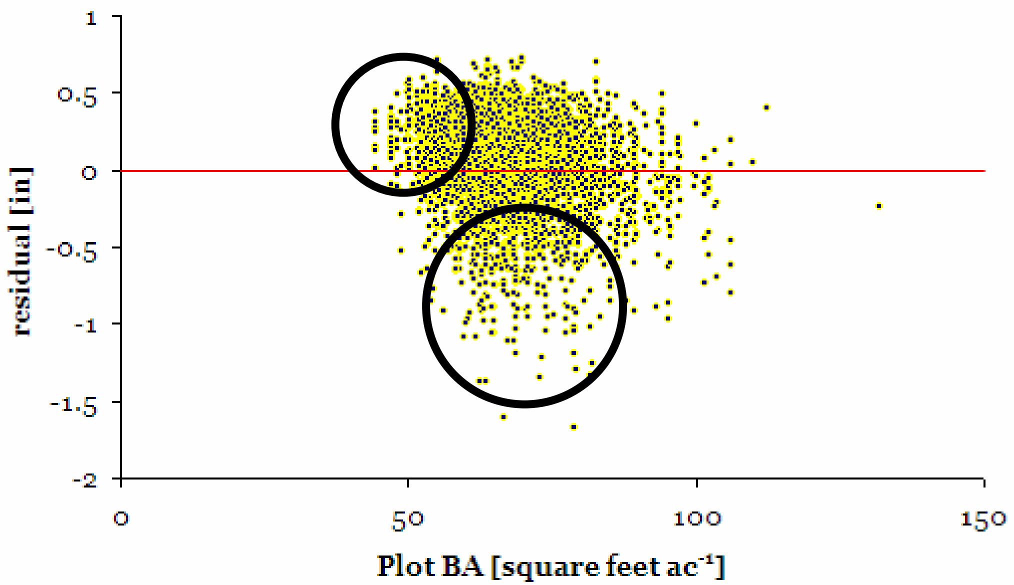
FVS-SN calibration data:

9300 tree records
95% smaller than 17.4 in.
Maximum dbh: 28.3 in.
Dbh bounding limits:
low 15.9 in, high 24.4 in

Fort Bragg:

7302 site trees (67,294 LL)
25.5% larger than 15.9 in
Mean dbh, all trees: 28.2 in
Max dbh, all trees: 40 in

Uncertainty analysis

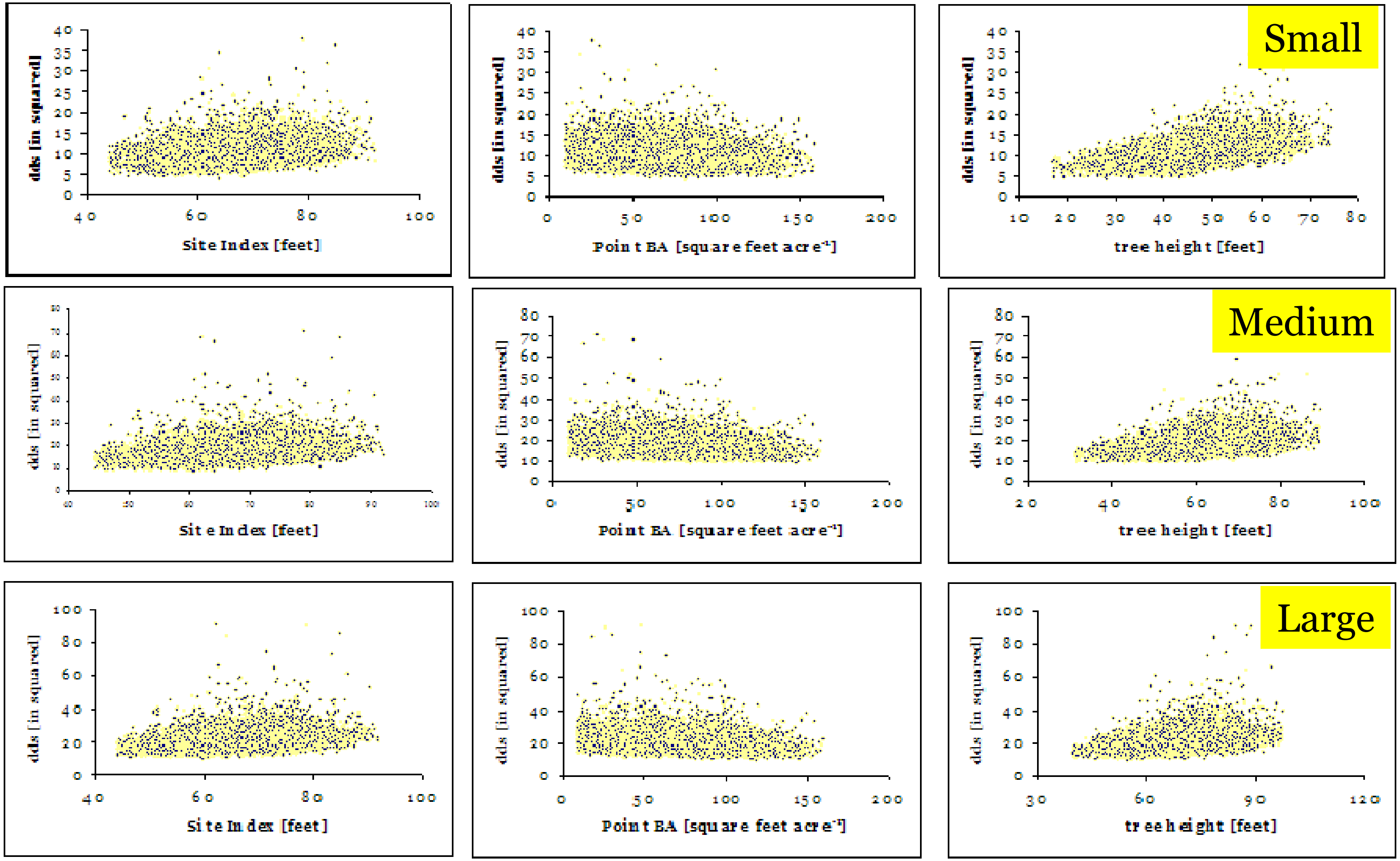


Functional form may not entirely reflect the effect of competition:

Overestimation for OGT (also in HD model, Shaw et al. 2006)

Larger understimation for intermediate densities

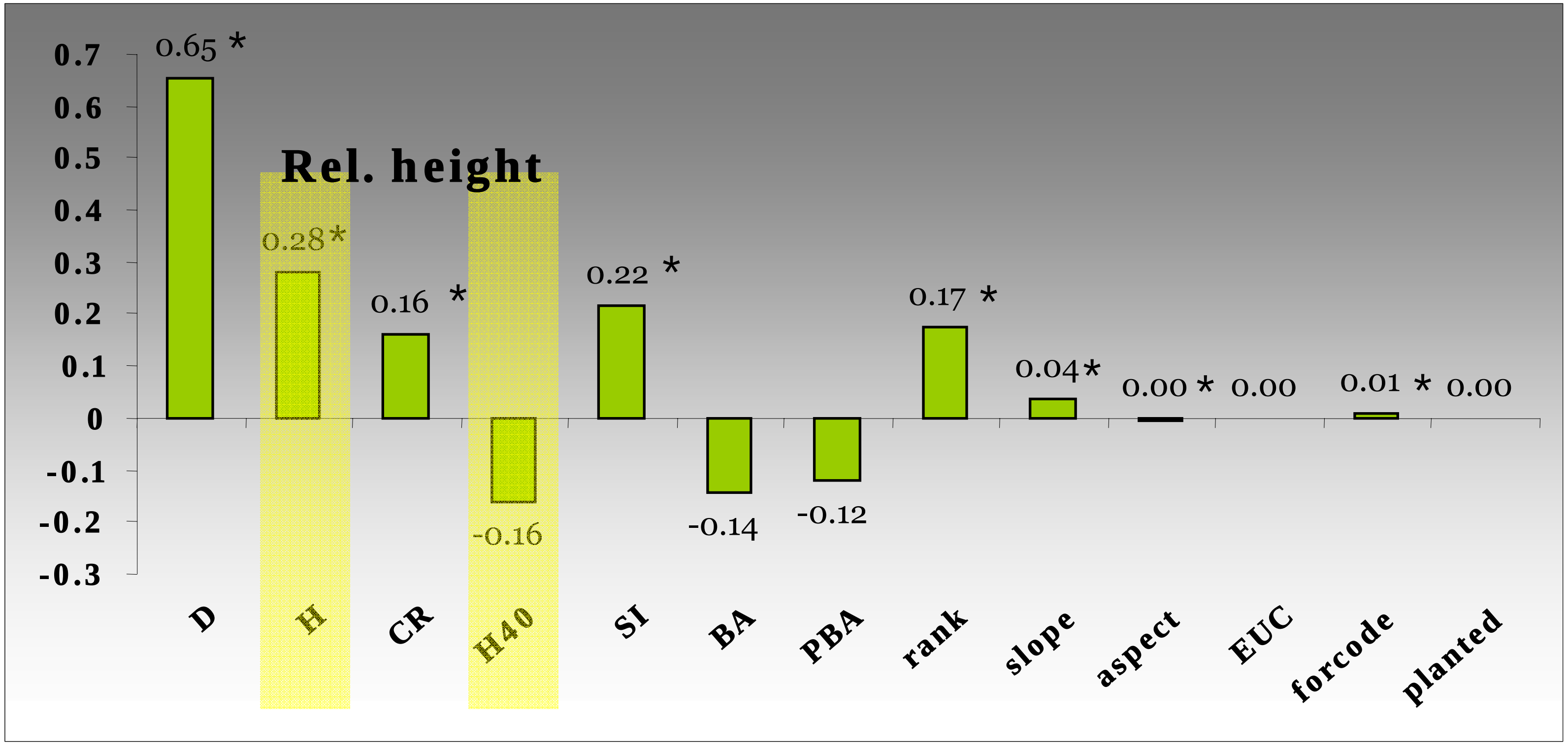
Sensitivity analysis (dds)



Sensitivity analysis (dds)

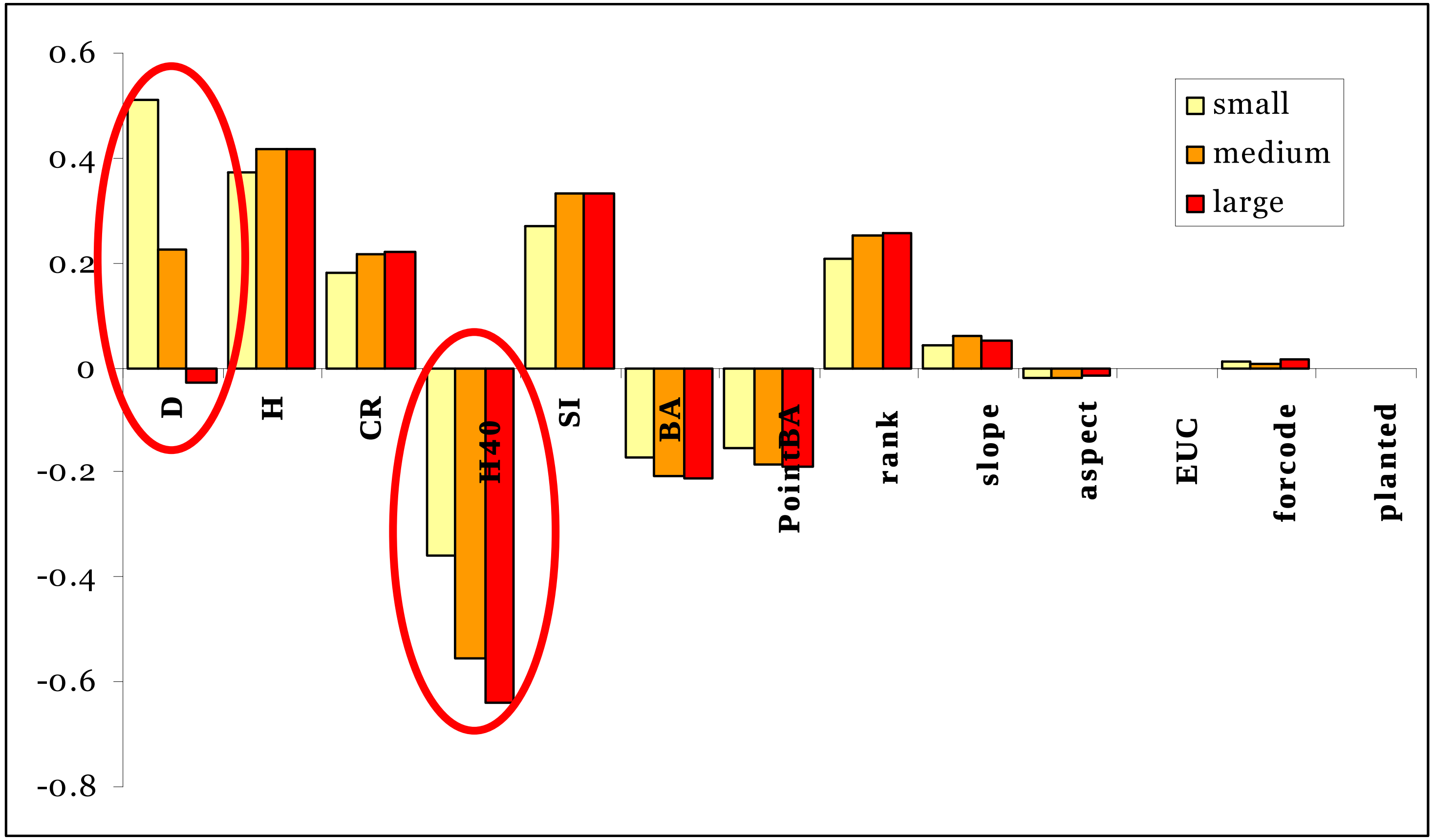
St. rank regression coefficients:

effect of varying a variable by a proportion of its variance.



Sensitivity analysis (dds)

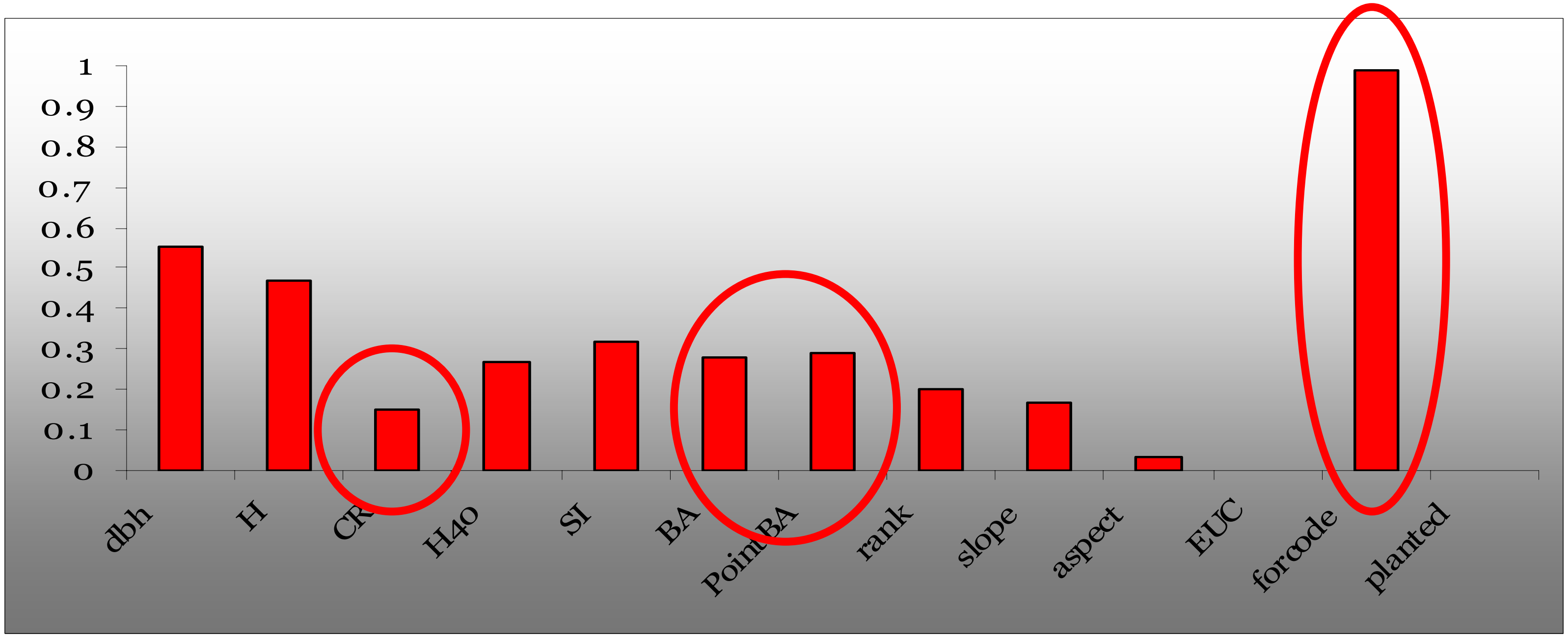
Standardized rank regression coefficients



Sensitivity analysis (dds)

Smirnov two-sample test:

Variable helps splitting behavioral vs. non-behavioral simulations.



Discussion

- "*Dbh at the beginning of projection cycle is the strongest single statistical determinant of diameter growth*". (Donnelly et al., 2001).
- Model relationships consistent with ecologically sound behavior.
- Tree potential variables are the most influential (dbh, height, Site index).
- LCR has negligible influence; forest type coding important when different than Longleaf pine.

Discussion

Model parsimony

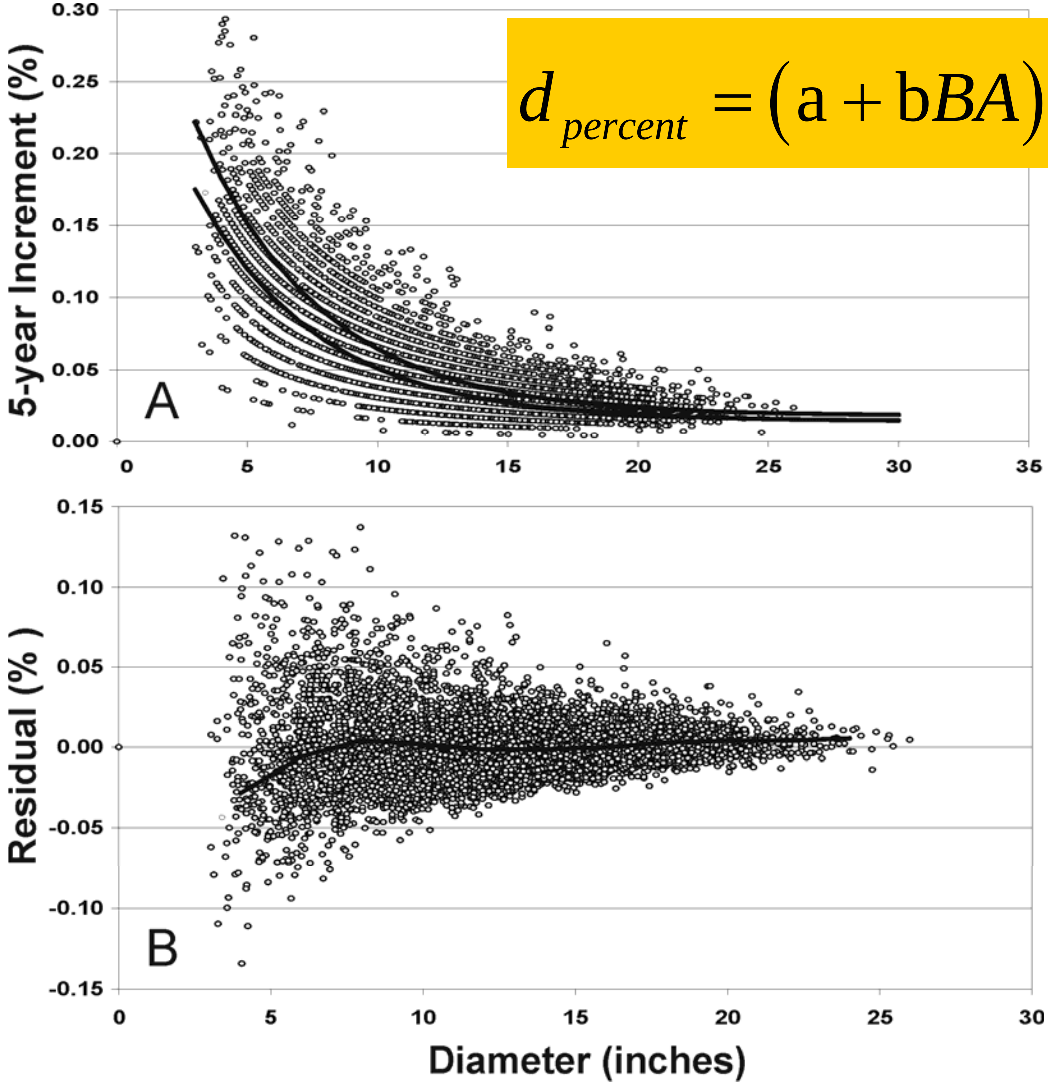
Take unifluential variables out of the model (e.g., COMP).

Model flexibility

Re-work model form according to variable ranking:

•stepwise calib
•intercept, slope, asymptotes...)

Discussion



$$d_{percent} = (\mathrm{a} + \mathrm{b}BA)\left(\mathrm{c} - e^{-\mathrm{d}dbh}\right)$$

$$R^2 = 0.73$$

Summary

Scope of sensitivity analysis:

1. Prior-to-calibration variable screening
2. Functional relationships
3. Data variability (uncertainty analysis)
4. Exploration of specific input space
5. Comparing alternative models

Further steps

- Extending SA to other species
- Ecological-oriented analysis (Rel. Density)
- FVS global sensitivity analysis:
  - Accounting for randomization and self-calibration routines
  - Accounting for small trees and senescence "soft boundaries" (may not be needed).
  - Chaining submodels

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Thank you for your attention.

Giorgio Vacchiano

Dep. AGROSELVITER - University of Turin
Via Leonardo da Vinci 44
10095 Grugliasco (TO) – ITALY

giorgio.vacchiano@unito.it

Tel. (39) 11 6708641 – Fax (39) 11 6708734