Assessing model prediction uncertainty in forecasting long-term tree diameter vs. basal area increment for the primary Acadian tree species

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2010 ECANUSA Forest Science Conference
October 14-16, 2010

Center for Advanced Forestry Systems

Background

- Adequately modeling tree increment largely drives forest growth and yield estimates
- Modeling tree secondary growth can take many forms
  - Tree diameter or basal area growth
    - No difference in terms of model precision (West 1980)
- Few growth simulators account for model error
  - Simulations provide confidence limits of projections
- Performance of diameter/basal area growth has not been assessed using
    - Long-term projections
    - Range of stand types
    - Contemporary modeling techniques

Tree secondary growth: what to model?

- Basal area increment (Δba)
  - Management decisions are usually based on basal area, not diameter
  - Highly correlated with initial diameter
  - Dependent on initial tree size

<u>OR</u>

- Diameter increment (Δdbh)
  - What is actually measured
  - Ultimately determines volume

2000-2005:
red spruce grew 8 cm (0.005 m^2)
What better represents growth:
8 cm or 0.005 m^2?

Modeling tree radial increment

Dependent variable	**Region**	**Species**	**Source**
Δdbh	Québec, Canada	Northern hardwoods	Fortin et al. 2008
Δdbh	Pacific Northwest, USA	Douglas fir, western hemlock	Hann et al. 2003
Δdbh	Alberta, Canada	lodgepole pine, trembling aspen, white spruce	Nunifu 2009
Δdbh	Michigan, USA	Northern hardwoods	MacFarlane and Kobe 2006
Δdbh (relative growth)	Germany	Norway spruce	Yue et al. 2008
Δba	Rocky Mountains, USA	Mountain conifers	Wykoff 1990
Δba	Mississippi, USA	Bottomland hardwoods	Zhao et al. 2004
Δba	Austria	*Picea* spp., *Pinus* spp., *Quercus* spp.	Monserud and Sterba 1996
Δba	Alberta, Canada	trembling aspen	Yang et al. 2009
Δba (relative growth)	Ontario, Canada	red pine	Larocque 2002

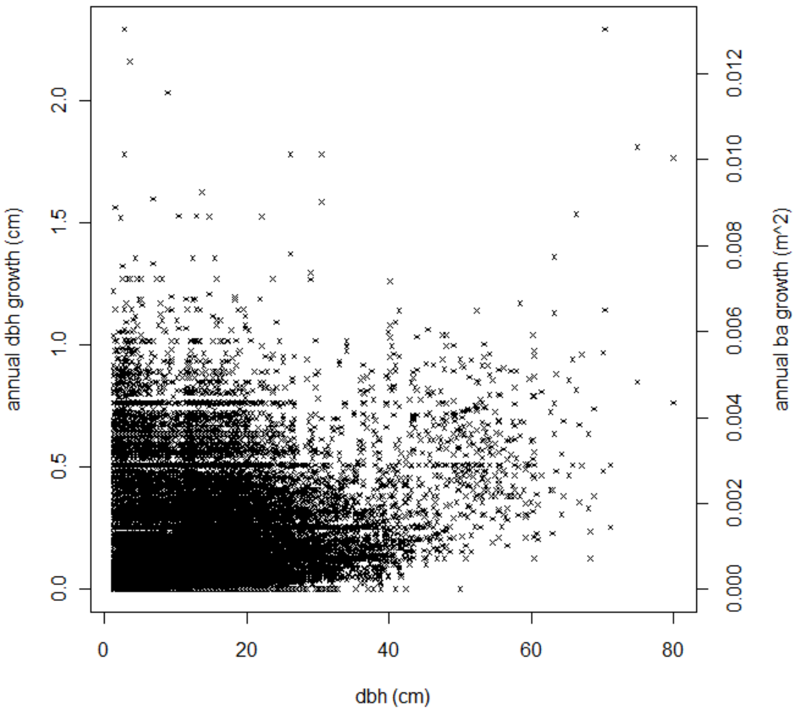
Objectives

1. Fit Δba and Δdbh equations using long-term data for six conifer and four hardwood species in the Acadian region.

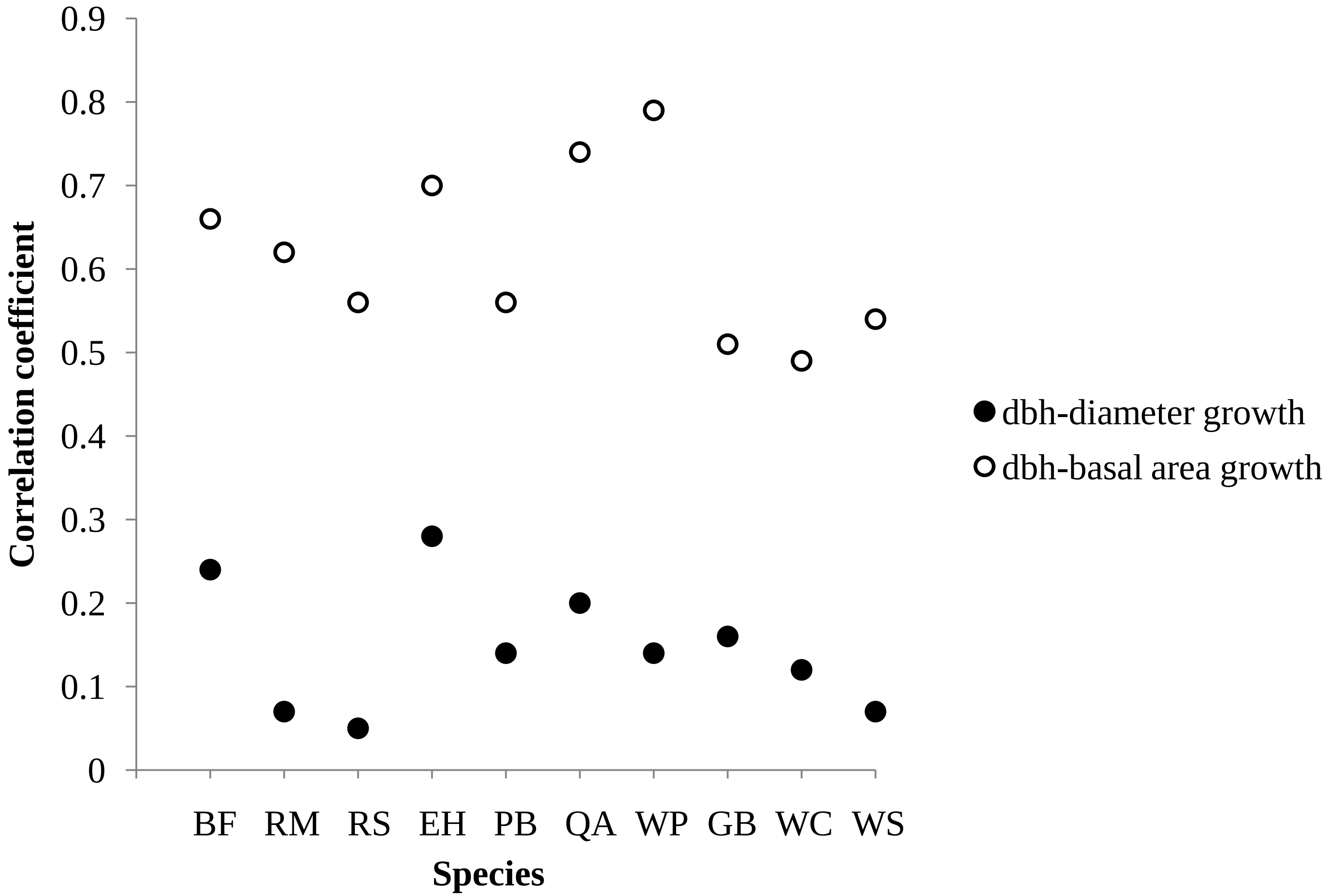
2. Evaluate goodness-of-fit measures for the individual equations.

3. Assess model uncertainty through Monte Carlo simulations and compare model predictions with observed growth data.

USFS Penobscot Experimental Forest Long-term Silvicultural Study



- Nine experimental units with a range of silviculture
  - Stands with no harvesting between measurements
  - NAT, UNREG, SW2, SW3, SW3PCT
- 110 permanent sample plots
- 58,293 individual trees
- Up to 6 remeasurements on individual trees (1977-2009)



Correlation coefficient
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
BF
RM
RS
EH
PB
QA
WP
GB
WC
WS
Species
dbh-diameter growth
dbh-basal area growth

Increment modeling

$$\Delta gr_{ijk} = (\beta_1 + b_i + b_{ij}) dbh_{ijk}^{\beta_2} \exp\left(\frac{\beta_3 dbh_{ijk}^{2}}{100}\right) + \varepsilon_{ijk}$$

β_i = fixed effects parameters

b_i, b_{ij} = random effects parameters for experimental unit, experimental unit/plot

Δgr_{ijk} = annual tree diameter or basal area growth

dbh_{ijk} = diameter at breast height

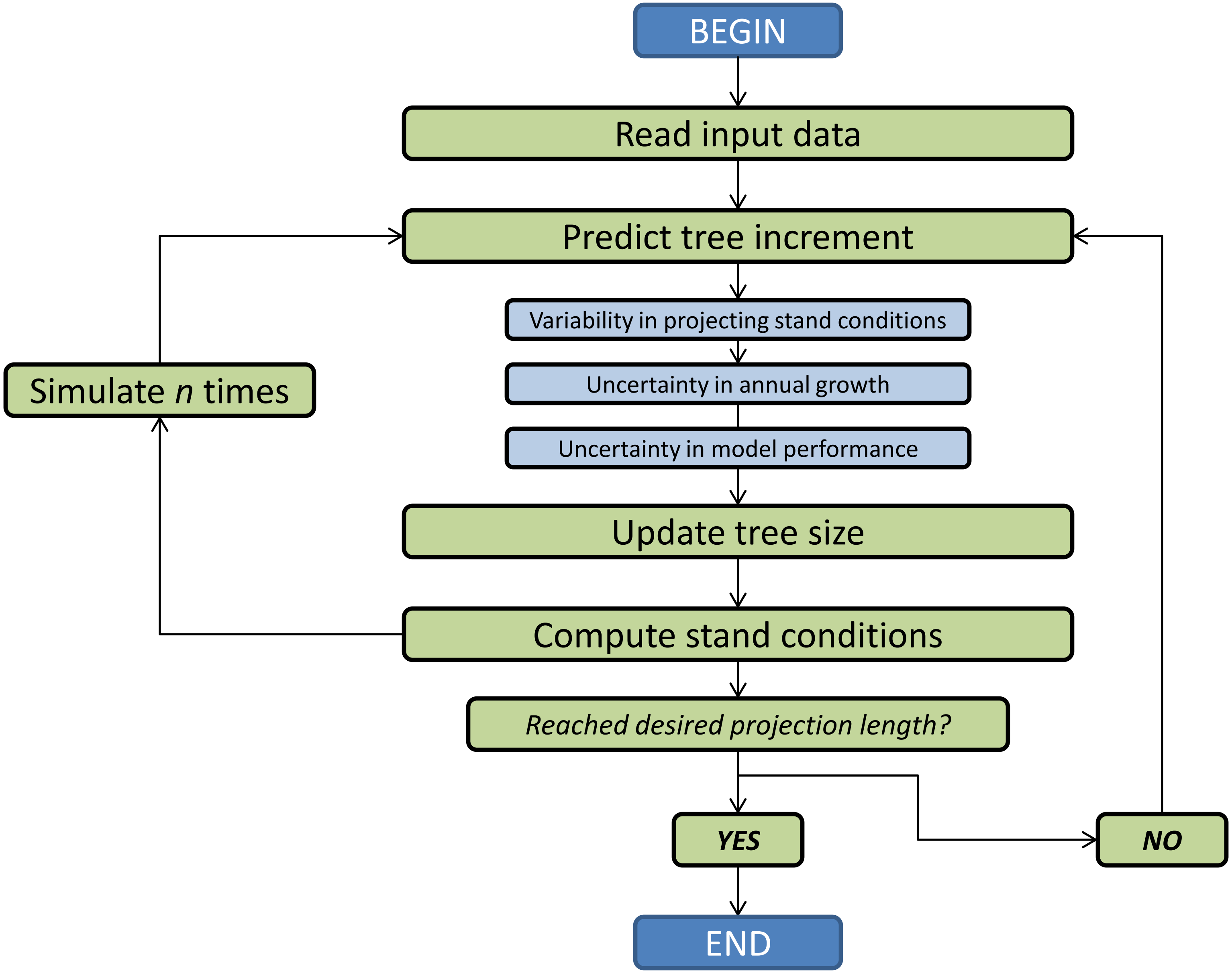
ε_{ijk} = random error

- Nonlinear mixed-effects modeling
- Annualized fitting technique
- Continuous autocorrelation structure

Model fitting

Species	Trees	Fit index		Mean absolute bias (dbh)	
		Δdbh	Δba	Δdbh	Δba
BF (*Abies balsamea*)	25177	0.37	**0.64**	0.58	**0.29**
RM (*Acer rubrum*)	8380	0.25	**0.56**	0.55	**0.30**
RS (*Picea rubens*)	7486	0.31	**0.55**	0.64	**0.32**
EH (*Tsuga canadensis*)	4429	0.52	**0.75**	0.53	**0.37**
PB (*Betula papyrifera*)	3941	0.36	**0.55**	0.49	**0.24**
QA (*Populus tremuloides*)	2194	0.36	**0.73**	0.68	**0.34**
WP (*Pinus strobus*)	2079	0.36	**0.80**	1.08	**0.58**
GB (*Betula populifolia*)	1891	0.47	**0.61**	0.59	**0.25**
WC (*Thuja occidentalis*)	1696	0.10	**0.32**	0.45	**0.40**
WS (*Picea glauca*)	820	0.40	**0.70**	0.55	**0.33**

Simulation systems allow one to assess model error



Assessing Monte Carlo simulation uncertainty

- Δdbh and Δba were simulated using initial tree list and forecasting up to 29 years (n=100)
- Simulated predictions compared with observed values
- Goodness of fit statistics
  - Root mean square error
  - Mean absolute bias
  - Mean percent bias

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{n} \left| y_{\mathrm{i}} - \hat{y}_{\mathrm{i}} \right|^{2} / n}$$

$$\mathrm{MAB} = \sum_{i=1}^{n} \left| y_{\mathrm{i}} - \hat{y}_{\mathrm{i}} \right| / n$$

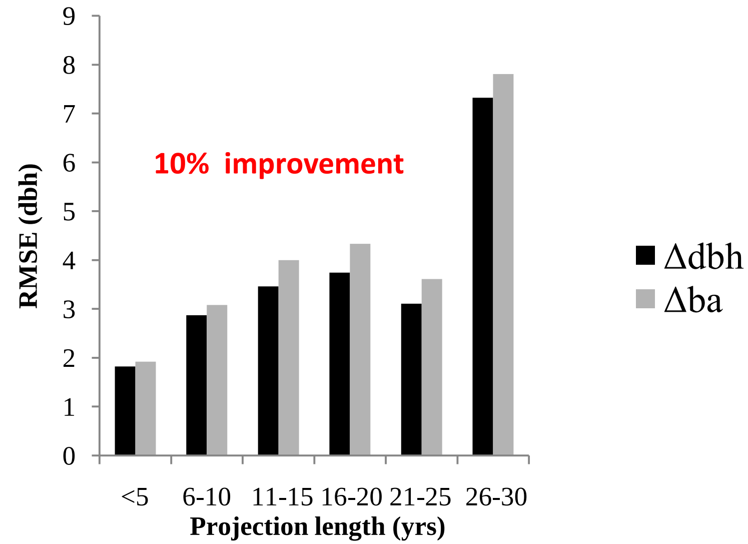
$$\mathrm{MPB} = 100 \times \frac{\sum_{i=1}^{n} \left| y_{\mathrm{i}} - \hat{y}_{\mathrm{i}} \right|}{\sum_{i=1}^{n} y_{\mathrm{i}}}$$

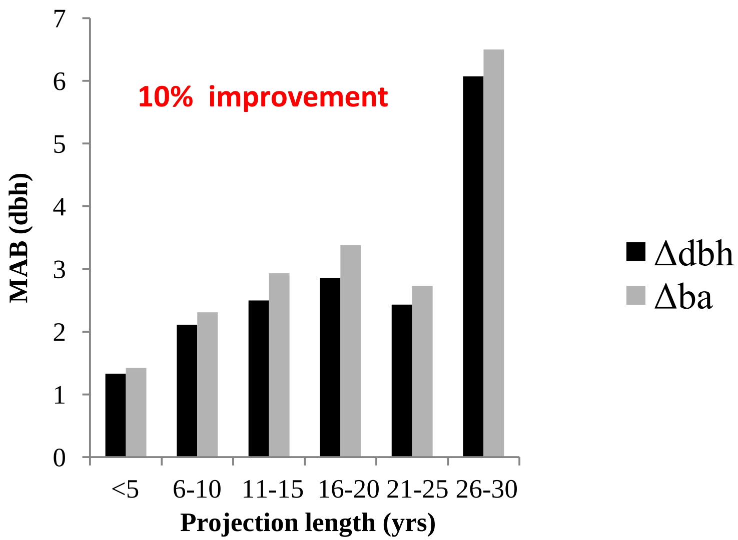
- Compared expected and observed coverage (Fortin et al. 2009)

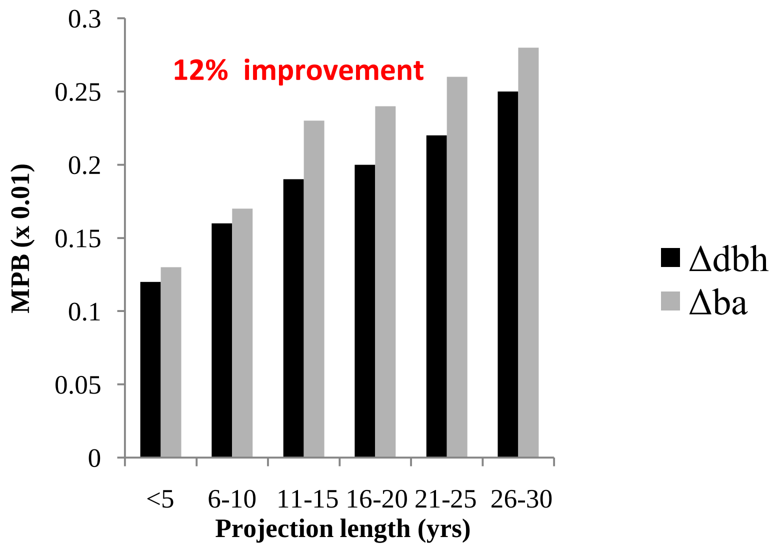
Assigning model error using random variables

Component	**Simulated uncertainty**
Model coefficients (β_i)	Normal (β_i , $SE_{\beta i}$)
Model random effects (b_i)	Normal (0, SE_{bi})
Model error (ε_{ijk})	Normal (0, ε_{ijk})
Actual annual diameter growth deviates ±25% from expected growth (Kangas 1998)	Δgr * Uniform [-0.25,0.25]

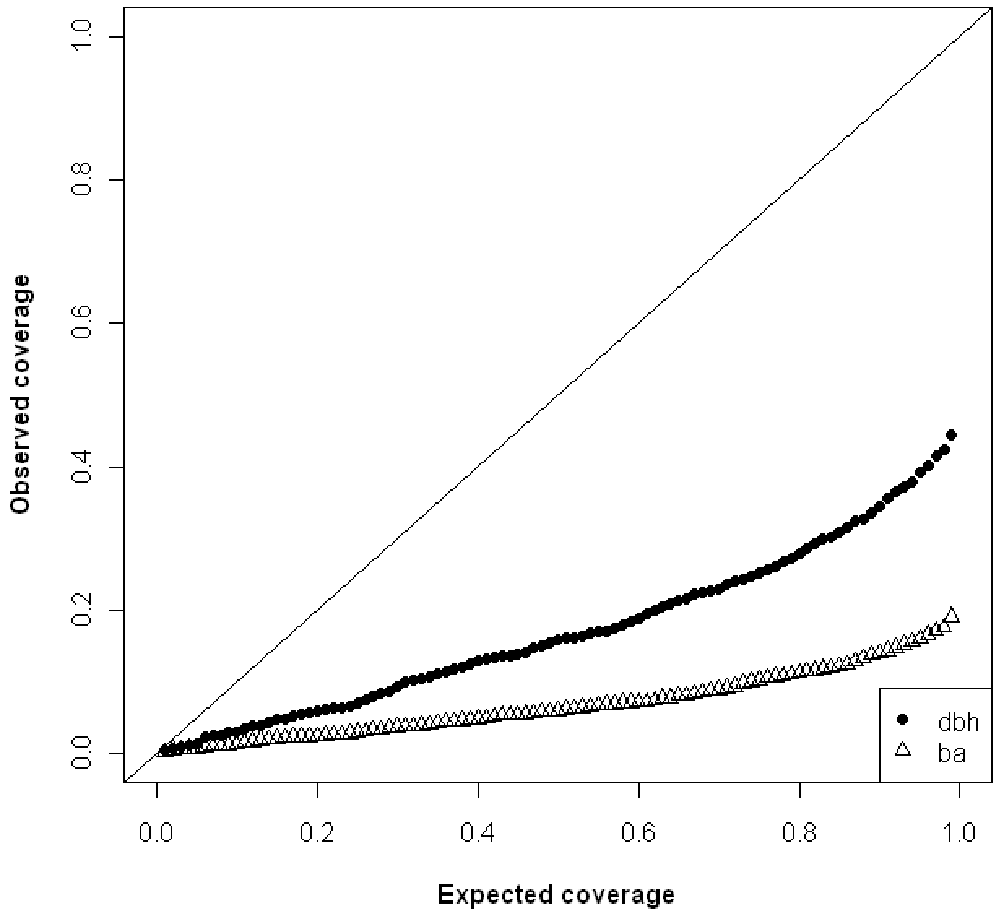
Projection interval (yrs)	Plots
< 5	62
6-10	85
11-15	71
16-20	57
21-25	23
26-30	9







Coverage is low, but results indicate Δdbh is superior



Discussion Points

- Modeling tree diameter/basal area increment assumes a perfect circle
  - Not necessarily the case in trees
  - Circumference is measured in the field
    - Modeling Δba extends the assumption of a circle
- Only one submodel is considered
  - Multiple equations that compose G&Y simulator will lend to greater variability
    - Mortality, ingrowth, volume, etc.
- Modeling dbh fits better with G&Y system (see later presentation in modeling stem bark thickness and tree taper)

Summary

- Using Δdbh over Δba increment resulted in up to 12% improvement in predicting future diameter
- Simulating models allows users to assess model variability and provides confidence limits of projections
- Analyses not possible without continued measurement and maintenance of long-term research studies