A Growth and Yield Simulator for Northeastern Uneven-Aged Hardwood Stands

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Uneven-aged Silviculture

- Management of uneven-aged northern hardwood stands based on the single-tree selection system
- Involves re-entering stands at regular intervals based on a defined cutting-cycle
- Requires a thorough understanding of and the ability to predict tree- and stand-level growth responses

Hansen Simulator

- A program written in 1983 to evaluate effects of different residual diameter distributions in uneven-aged northern hardwood stands.
- Four driving functions
  - Diameter growth
  - Mortality
  - In-growth
  - Harvest

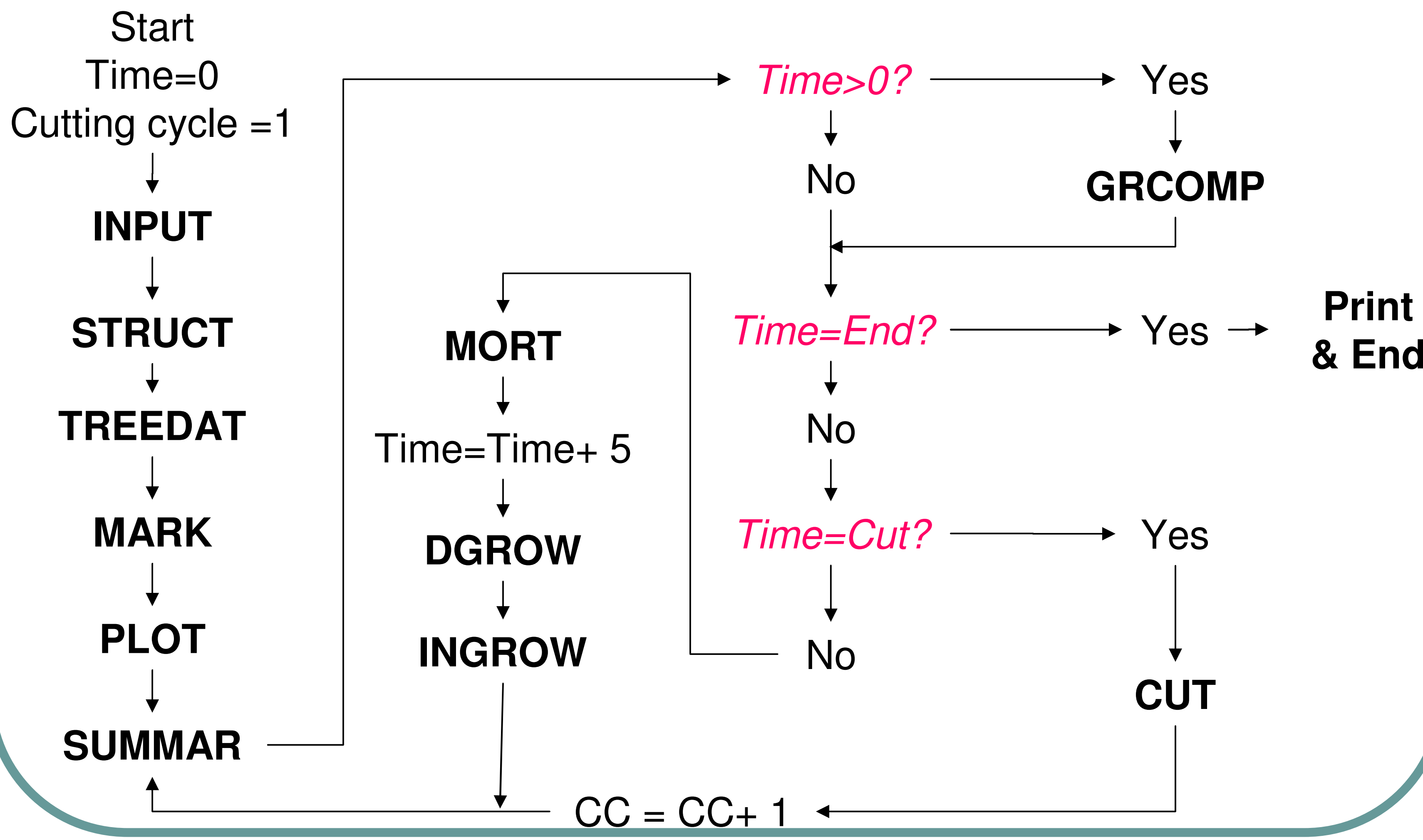
Hansen Simulator

- Eleven subroutines were called by a main program to create a simulated stand based on inputted stand structure.
- An exponential distribution for each user-defined size class created based on the q-factor calculated by size class.
- Trees from the simulated stand are then randomly assigned to plots to provide growth estimates.

Hansen Simulator

- Plot data is summarized by number of trees, basal area and volume.
- Growth, ingrowth, mortality, and harvest are calculated dependent on tree size and point of time within cutting cycle.
- Mortality, survivor growth and ingrowth data is summarized and converted to a per hectare basis.

Hansen Simulator



Modified Simulator

- Receives inputted data from user via the keyboard and outputs to separate files
- The eleven subroutines are now stand alone modules making it easy to affect changes in the programming
- Diameter distribution based on user-defined size classes (# of trees/ha, upper/lower limits, and class width)

Limitations

- Original growth model based on most recent five-year measurements taken from 221 destructively sampled trees
- Assumed that immediate 5-year post-cut growth response remained constant for projection period
- Growth predictions were accumulated in 5-year steps up to 30 years
- No measure to account for variation due to site

Re-measurement Data

- All stands managed using selection system
- Initial measurement post-cut with all re-measurements taken within cutting cycle
- Model dominant species separately
  - sugar maple, beech, white ash, yellow birch
- 2 sites
  - northern and central New York
- Data randomly divided with 80:20 split for calibration and validation datasets, respectively

Re-measurement Data

Site	Stand Name	Number: Plots	Number: Trees	Year	re-measurements	Basal area ($m^2\ ha^{-1}$) at initial measurement Mean (min-max)
Central New York (Cuyler Hill, NY)	H-1 (55)	10	72	1980	0, 19, 25	11.2 (3.2-16.3)
	H-1 (70)	11	108	1980	0, 11, 19	15.9 (7.6-23.3)
Northern New York (Newcomb, NY)	Gooseberry Mtn.	57	1266	1988	0, 17	11.6 (3.9-23.0)
	Old Military Rd.	69	731	1986	0, 9, 19	11.7 (3.9-22.7)
	Junction Rd.	28	444	1989	0, 6, 16	16.4 (5.4-25.3)

New diameter growth model - Mixed Model

- Mixed model to account for the temporal autocorrelations present in repeated measures
- General Linear Mixed Model

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u} + \varepsilon$$

- Necessary to characterize variance and covariance behavior of **u** and ε
  - R-matrix to model covariance structure of subject's data
  - G-matrix to model variance components

Error Structure Determination

- Comparison of model performance with different within-subject covariance structures (R-matrix) (smaller is better)

Evaluation Criteria	Covariance Structure[1]		
	AR(1)	UN	ANTE(1)
AIC	5113.0	5114.3	5114.3
BIC	5154.6	5160.5	5160.5

[1]AR(1) autoregressive ; UN = unstructured; ANTE(1) = ante-dependency

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Mixed Model
- Improvement over OLS regression

- All structures produced a significant improvement over OLS ($p<0.001$)

Model	AICc
OLS	5872.2
Repeated measures	5482.8
Random coefficient	5180.0
Both random and repeated	5113.0

New diameter growth model

$$
\begin{aligned}
D_{t_{ij}} &= \beta_0 \cdot (D_{0_{ij}}) \\
&+ \beta_1 \cdot (D_{0_{ij}} \cdot B_j) \\
&+ \beta_2 \cdot (t) \\
&+ \beta_3 \cdot (D_{0_{ij}} \cdot t) \\
&+ \beta_4 \cdot (D_{0_{ij}}^2 \cdot t) \\
&+ \beta_5 \cdot (BA_0 \cdot t) \\
&+ d_{ij} \\
&+ \varepsilon_{ijk}
\end{aligned}
$$

- fixed effect of initial diameter on the i^{th} subject from the j^{th} block
- interaction between initial diameter and block j
- fixed effect of time
- interaction between initial diameter and time
- interaction between initial diameter squared and time
- interaction between initial stand basal area and time
- random effect of the i^{th} subject from the j^{th} block
- random error associated with the i^{th} subject in the j^{th} block at the k^{th} time

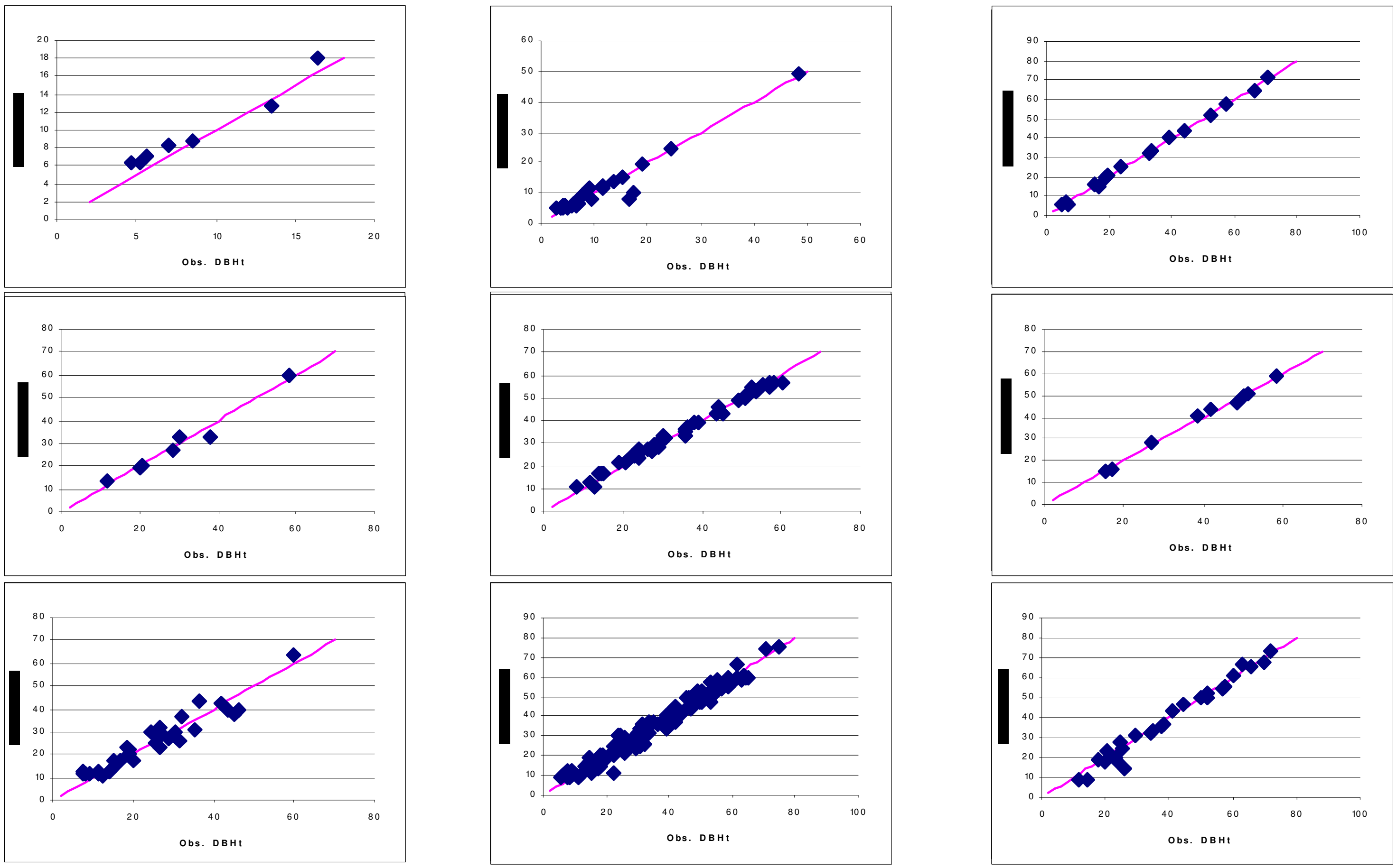
New diameter growth model - parameter estimates

Variable	MAPLE	BEECH	ASH/BIRCH
D_0	1.0377	1.1761	1.0418
D_0*B	-0.0197	n.s.	n.s.
t	0.4288	0.3082	0.6405
D_0*t	0.0046	0.0337	n.s.
D_0^2*t	-0.0001	-0.0010	n.s.
BA*t	-0.0075	-0.0066	-0.0092

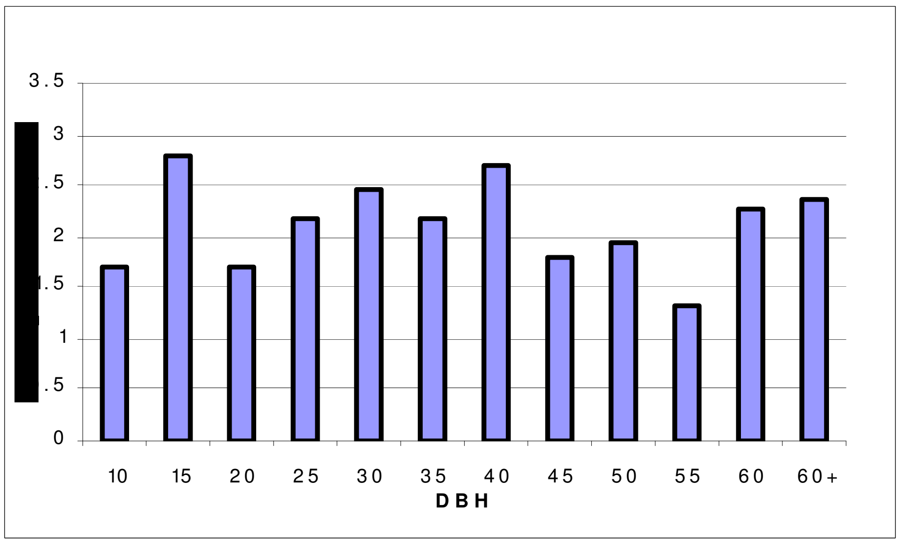
Evaluation using validation data

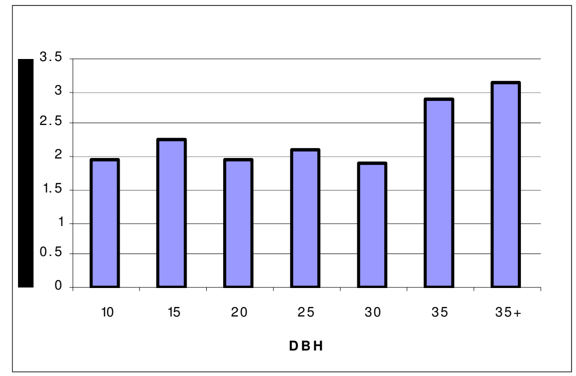
Species Group	Average Residual (cm)	Average Absolute Residual (cm)	RMSE (cm)
Sugar Maple	0.0311	2.1495	2.9044
Beech	-0.4837	2.1123	2.7575
White ash/ Yellow Birch	-0.2300	2.2661	3.0700

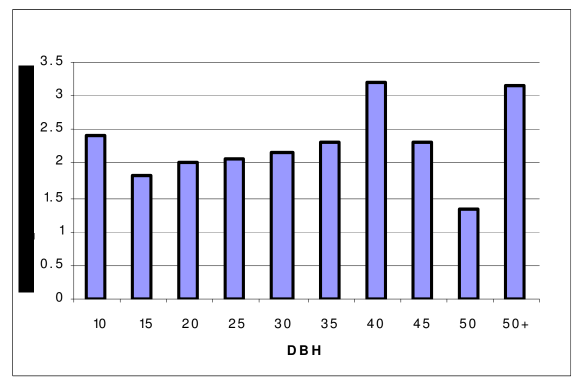
Model Validation (s.maple grouped by time period and basal area)



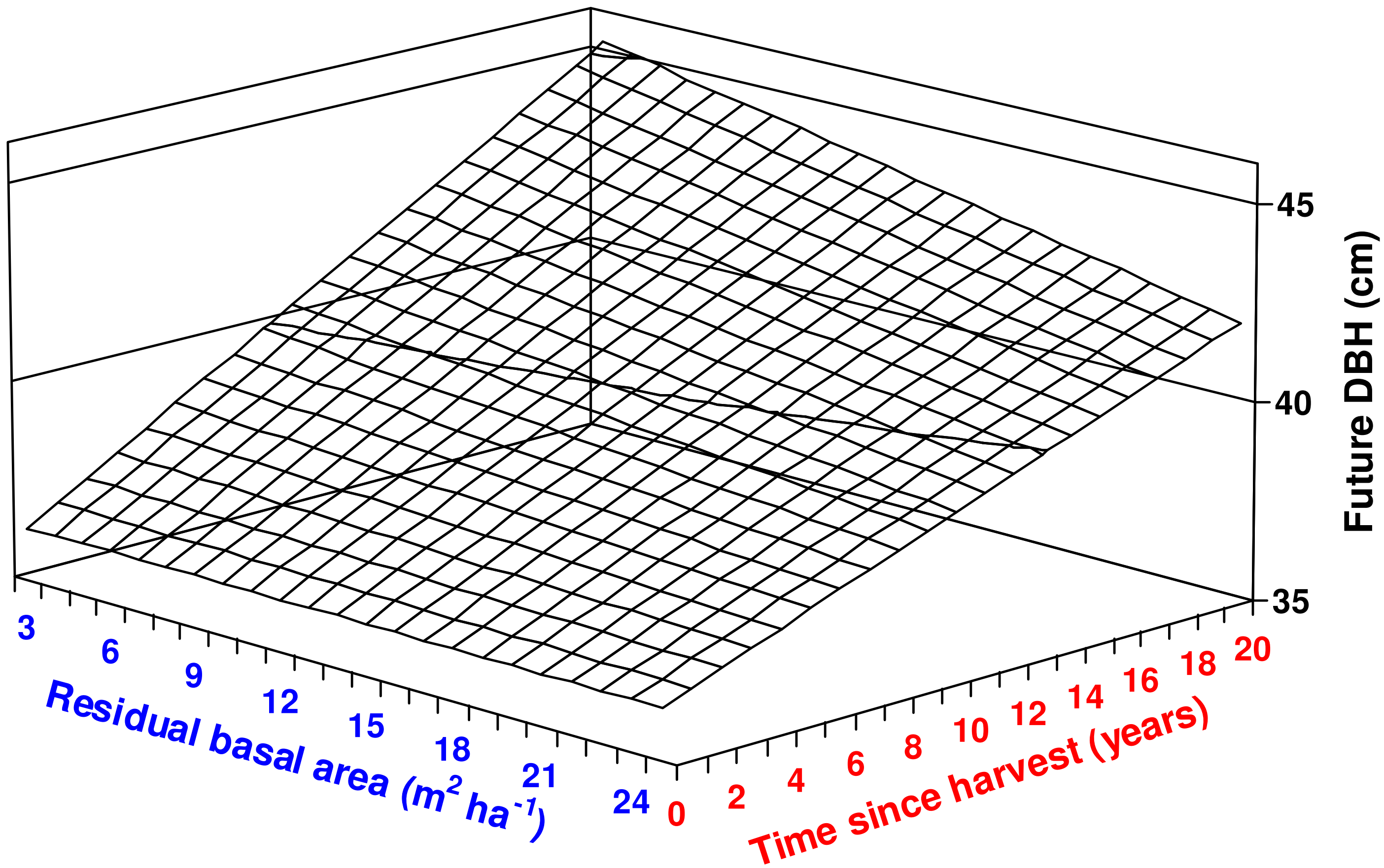
Plot of avg. absolute residual by 2 cm DBH class sugar maple, beech, yellow birch/white ash group







Predicted Potential Diameter for 35cm sugar maple tree



Diameter growth model

- Many existing models developed for generalized northern hardwood stands, not taking into account recent management activities
  - lack of data
- Average growth rate across species for 20-year period in this study
  - 0.42 cm/yr
- Average growth rate using FIA data for similar work with Minnesota hardwoods
  - 0.25 cm/yr

Selection System

- Re-measurement data from selection system stands affords the opportunity to see improvement in growth that occurs with sound silvicultural management

- Cutting cycle must be matched with the appropriate residual density

Selection System

- 10-yr cut cycle 17.2 m^2/ha res.density
  - S.Maple – 0.40 cm/yr for 35 cm tree
  - Beech – 0.66 cm/yr for 25 cm tree
  - W.Ash/Y.Birch – 0.46cm/yr for 15 cm tree
- 20-yr cut cycle 15.5m2/ha res. Density
  - S.Maple – 0.39 cm/yr for 25 cm tree
  - Beech – 0.56 cm/yr for 15 cm tree
  - W.Ash/Y.Birch – 0.46cm/yr for 15 cm tree

Uneven-aged simulator

- Allows the user to compare the growth of an uneven-aged stand using different cutting cycle lengths and residual post-cut stand structures
- A variety of landowner objectives can be evaluated at different times throughout the cutting cycle

Ongoing improvements to the uneven-aged simulator

- Mortality function completed and will be incorporated into simulator
- Ingrowth function next to be updated
- Create additional module to include a wildlife component to the simulator using Habitat Suitability Indices (HSI)

- Thank you for your time and attention