SuFoRun

Models and decision SUpport tools for integrated FOrest policy development underglobal change and associated Risk and UNcertainty

Modeling Natural Regeneration in Pennsylvania Forests

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(Source: wikimedia.org)

Summary

- Objectives
- Study Area and Data
- Methods (censored regression)
- Results
- Discussion

Objectives

The specific objectives of our study were:

- To assess the ecological factors that interfere with the natural regeneration process:
  - To check the success of the natural regeneration of forest species.
  - To check whether closed canopies have a positive effect on woody plant regeneration.

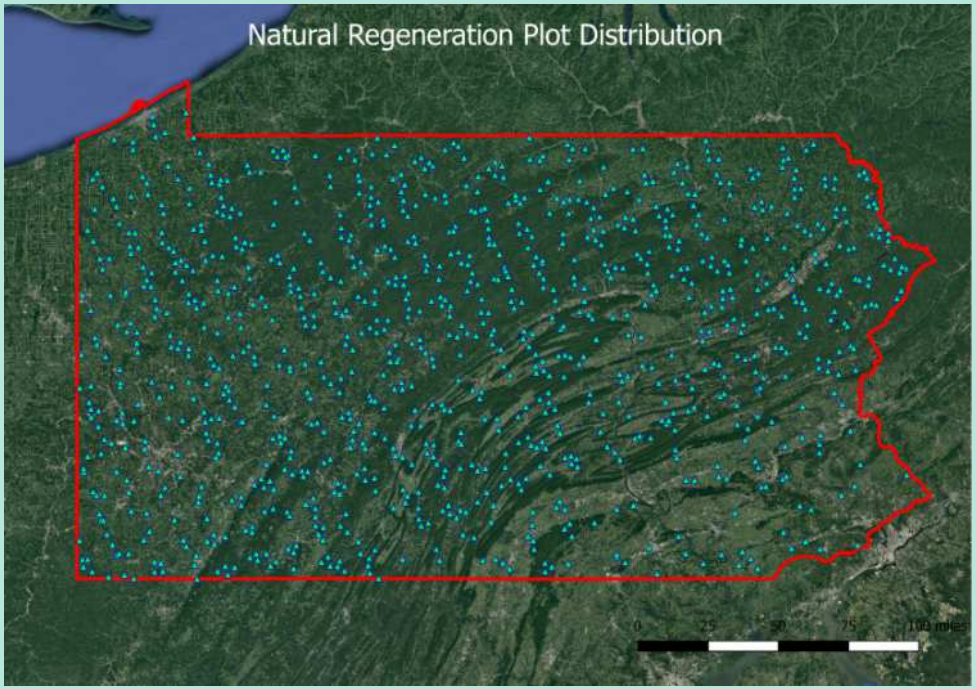
Study Area

- 16.9M acres
- 86% consist of primarily Northern Hardwood/Mixed Oak
- 70% total forest area is privately owned
- $27B per year industry

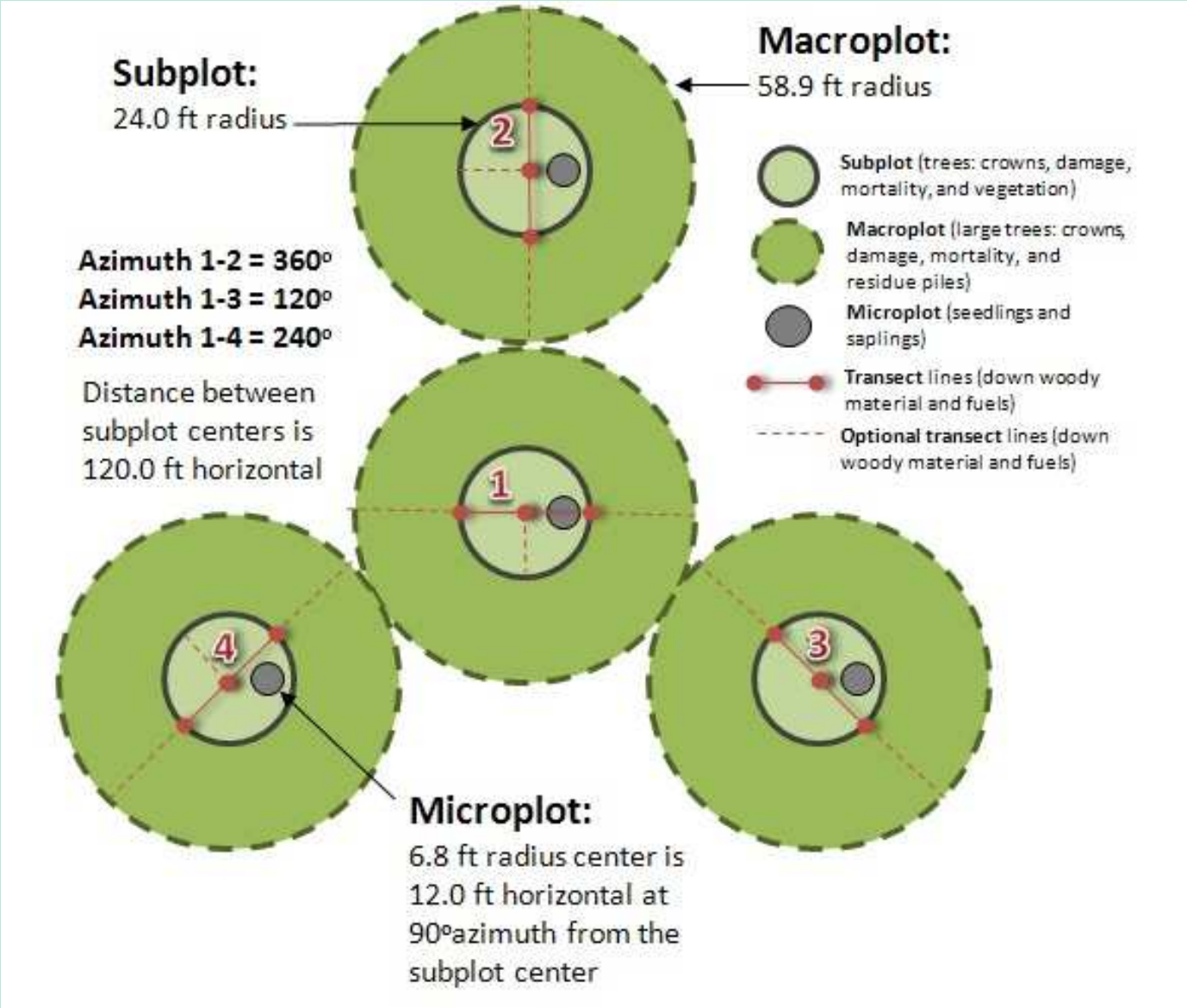
(Source: fs.fed.us)

Data

- Forest Service Forest Inventory Analysis plots (FIA)
- 1009 plots
- Each plot = 1/6 Acre
- Plots were sampled by Forest Service between 2001 to 2010



FIA Plots



(Source: fs.fed.us)

Data - Site Conditions

- Site soil moisture:
  91% of plots have mesic soil

- Understory vegetation:
  On plots where it was present, mountain laurel had the highest percent of coverage with approximately 30%, though it also occurred on the fewest number of plots.
  Miscellaneous vegetation had the smallest area coverage with 9%.

- Tree size:
  68% of plots have trees =<5 inches DBH
  98% of plots have trees >5 inches DBH

- Height class:
  Saplings and seedlings under 36 inches averaged 1.5 per plot.
  Saplings above 36 inches averaged less than 1 per plot.

Tree Species Groupings

- **<u>Shade tolerant</u>:** Not only are they able to establish in the understory, but they are able to persist.
  - This doesn't necessarily mean they are putting on a lot of growth, but they are staying alive.

  Species Group: Hemlock, Eastern White Pine, Maple

- **<u>Intermediate tolerance</u>:** Able to establish in the understory but they cannot survive for extended periods

  Species Group: Hickory, Red/White Oaks

- **<u>Shade intolerant</u>**: May establish in the understory, but normally die out in dense shade
  - When released following extended periods of low light they respond with sluggish growth

  Species Group: Ash, Birch, Cherry, Elm, Gum, Poplar, Pioneer

Further Data Grouping

Aspect: NE/SE/SW/NW

Deer Impact: Deer browsing index on scale from 1 to 5, if the sapling shows indication of browsing.

Basal area classes (overstory species): number of trees with less (more) than 5 inches DBH

Understory species classes: BH/Ferns/Grass/Herbaceous/Misc/ML/Shrubs/ST/Vines

Methods - Model architecture

We need models capable of providing reliable predictions under complex environmental scenarios.

The height of the trees is never 0, yet the data reports zero values as earlier growth is not reported. As a result, the data is censored on the left side of the curve, to take into account the growth that is not reported in the dataset

Censored regression is appropriate when the true value of the dependent variable is unobserved above or below a certain known threshold.

Methods - the censored model

$$y_i^* = x_i\beta + u_i, \quad i = 1, 2, \ldots, N, \quad u_i \mid x_i \sim \mathrm{N}(0, \sigma^2),$$

$$y_i^* \sim N(\mu^*, \sigma^2)$$

$$Y_i = \begin{cases} Y_i^*, \ if \ \ Y_i^* \geq \mathrm{c} \\ \mathrm{c}, \ if \ \ Y_i^* \prec \mathrm{c} \end{cases}$$

where

N is the number of observations;

$\boldsymbol{y_i}$ is the observed variable;

y_i^* **is the latent**

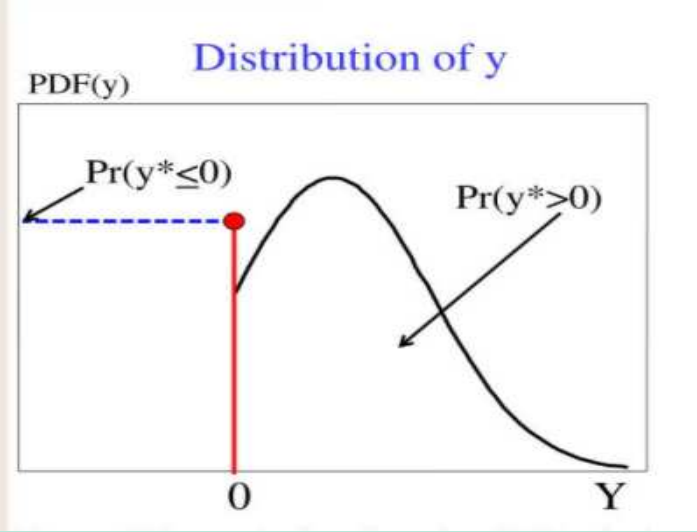
$\boldsymbol{x_i}$ is a vector of independent variables;

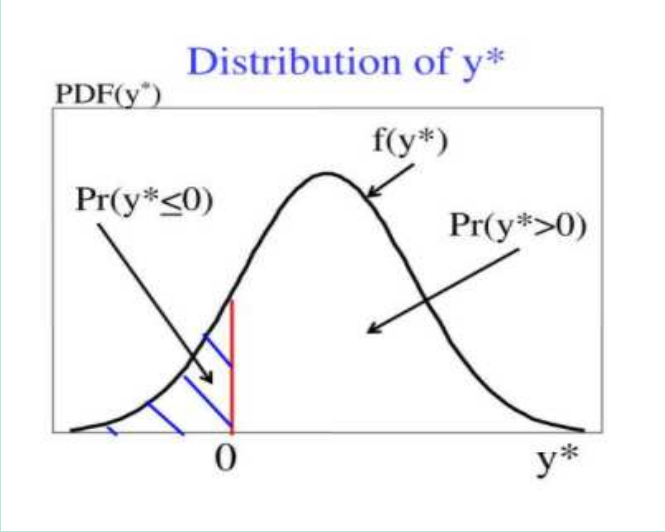
$\boldsymbol{\beta}$ is a vector of estimable parameters, and ε_i is a normally and independently distributed error term with zero mean and constant variance $\sigma 2$.

c is the threshold for censoring.

Methods - the censored model

$$y_i = \begin{cases} Y_i^*, \ if \ \ Y_i^* \geq \mathrm{c} \\ 0, \ if \ \ Y_i^* \prec \mathrm{c} \end{cases}$$





Methods - Estimation with Maximum Likelihood

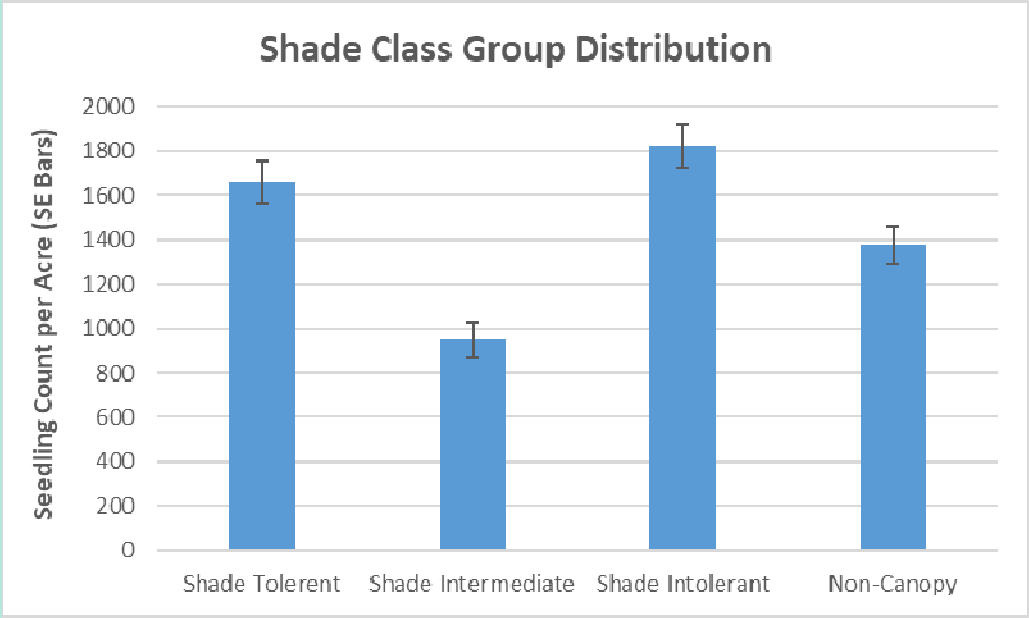
$$L(\beta,\sigma^2 \mid y,x) = \sum_{y_i \succ 0} \frac{1}{2}\left[\ln(2\pi) + \ln\sigma^2 + \frac{(y_i - x_i\beta)^2}{\sigma^2}\right] + \sum_{y_i=0} \ln\left[1 - \Phi\left(\frac{x_i\beta_i}{\sigma}\right)\right]$$

MLE methods are computed by solving a likelihood function L, where for a distribution with two parameters b1 (mean) and b2 (variance), L(b1, b2) defines the likelihood of matching the observed distribution of data.

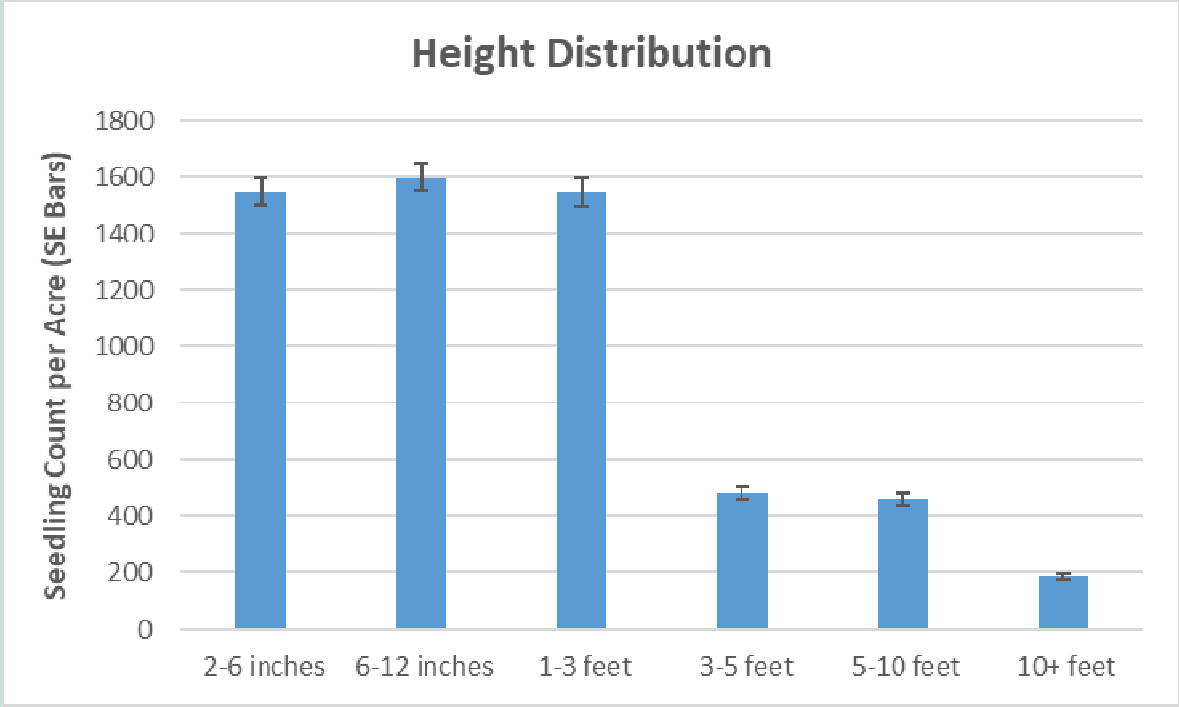
Methods

- Statistics Analysis and model fitting was done using R statistical software.
- Several models were examined.
- The best model was selected based on its explanatory power (AIC, RQME), interpretability, and a visual judgment of goodness of fit

Results - descritive statistics



Results - descritive statistics



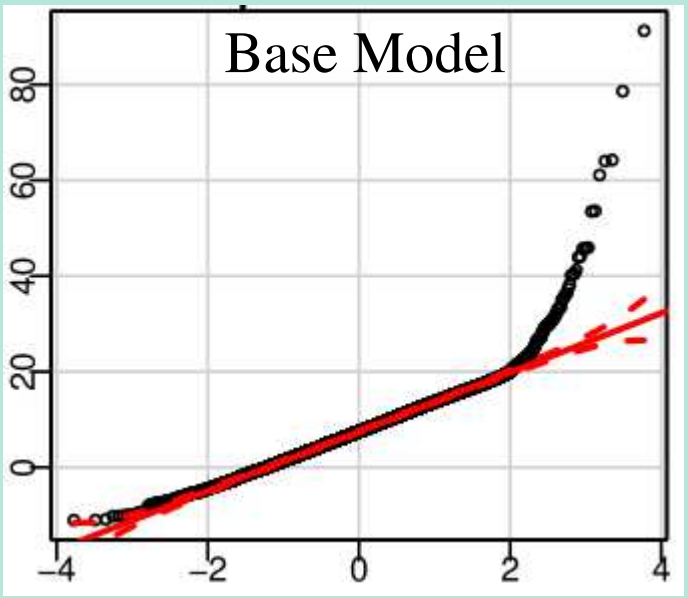
Variable	Canopy - Shade Tolerant		Canopy - Shade Intermediate		Canopy - Shade Intolerant		Non-Canopy	
(Intercept):1	-6.957	0.002	-11.390	0.000	-12.510	0.000	-15.360	0.000
(Intercept):2	0.223	0.000	0.403	0.000	0.335	0.000	0.416	0.000
Latitude	0.283	0.000	-0.060	0.251	0.144	0.001	0.328	0.000
Longitude	0.053	0.000	-0.163	0.000	-0.085	0.000	-0.008	0.673
Elevation	0.000	0.000	0.000	0.000	0.000	0.783	0.000	0.001
Site Class – Poorer (Base is Richer)	-0.039	0.286	0.221	0.000	0.064	0.121	0.053	0.251
Soil – Xeric (Base is Mesic)	-0.383	0.000	-0.346	0.001	0.034	0.702	-0.036	0.703
Northeast and Percent Slope	-0.015	0.000	-0.015	0.000	-0.011	0.000	-0.001	0.720
Southeast and Percent Slope	-0.002	0.406	-0.003	0.167	-0.004	0.087	0.002	0.442
Southwest and Percent Slope	0.002	0.433	0.012	0.000	0.000	0.894	0.007	0.018
Northwest and Percent Slope	0.000	0.891	-0.001	0.660	-0.005	0.048	0.006	0.010
Deer Browse Impact	-0.243	0.000	-0.296	0.000	-0.142	0.000	-0.234	0.000
Physiographic Region – Other (Base: Appalachian Plateau)	-0.531	0.074	-0.410	0.280	-0.348	0.249	-0.553	0.129
Physiographic Region – Ridge and Valley (Base: AP)	0.040	0.486	0.164	0.035	0.061	0.357	0.024	0.741
Regeneration Type – Oak and Hickory	-0.153	0.001	0.490	0.000	0.034	0.513	0.324	0.000
Regeneration Type – Softwood and Other Hardwood	-0.304	0.000	0.271	0.004	0.079	0.269	-0.152	0.064
Average Diameter	-0.003	0.883	0.137	0.000	-0.020	0.298	0.065	0.004
Average Diameter^2	0.000	0.580	-0.008	0.000	0.001	0.341	-0.003	0.007
Basal Area Greater than 5	0.002	0.089	0.000	0.966	0.000	0.958	0.000	0.762
Basal Area Greater than 5^2	0.000	0.092	0.000	0.404	0.000	0.420	0.000	0.984
Basal Area Less than 5	0.054	0.000	0.029	0.001	0.053	0.000	0.056	0.000
Basal Area Less than 5^2	-0.001	0.000	0.000	0.189	-0.001	0.007	-0.001	0.000
Blueberry-Huckleberry	0.004	0.312	0.026	0.000	-0.012	0.008	0.007	0.162
Blueberry-Huckleberry^2	0.000	0.117	0.000	0.000	0.000	0.220	0.000	0.516
Blueberry-Huckleberry (Presence/Absence)	0.101	0.118	0.610	0.000	0.363	0.000	0.474	0.000
Ferns	0.012	0.000	0.001	0.760	0.005	0.107	0.003	0.341
Fern^2	0.000	0.000	0.000	0.387	0.000	0.007	0.000	0.175
Ferns (P/A)	0.123	0.018	0.132	0.064	0.065	0.263	0.242	0.000
Grass	-0.006	0.048	-0.003	0.468	-0.005	0.126	0.008	0.024
Grass^2	0.000	0.483	0.000	0.582	0.000	0.953	0.000	0.225
Grass (P/A)	0.078	0.132	0.255	0.000	0.265	0.000	0.189	0.004
Herbaceous	-0.003	0.284	0.008	0.040	0.011	0.000	-0.001	0.773
Herbaceous^2	0.000	0.170	0.000	0.003	0.000	0.000	0.000	0.155
Herbaceous (P/A)	0.233	0.000	0.080	0.352	0.027	0.709	0.357	0.000
Miscellaneous	-0.005	0.475	0.001	0.940	-0.011	0.153	-0.007	0.367
Miscellaneous^2	0.000	0.361	0.000	0.605	0.000	0.505	0.000	0.733
Miscellaneous (P/A)	0.100	0.152	0.125	0.184	0.213	0.005	0.209	0.014
Mountain Laurel	-0.011	0.018	-0.017	0.006	-0.023	0.000	-0.007	0.301
Mountain Laurel^2	0.000	0.534	0.000	0.302	0.000	0.007	0.000	0.871
Mountain Laurel (P/A)	0.037	0.676	0.081	0.495	0.130	0.207	-0.033	0.776
Shrubs	-0.002	0.361	0.010	0.000	0.011	0.000	0.010	0.000
Shrub^2	0.000	0.262	0.000	0.000	0.000	0.000	0.000	0.001
Shrubs (P/A)	0.230	0.000	0.276	0.000	0.659	0.000	0.358	0.000
Small Trees	-0.006	0.199	-0.002	0.800	0.004	0.417	-0.006	0.336
Small Trees^2	0.000	0.625	0.000	0.501	0.000	0.268	0.000	0.658
Small Trees (P/A)	-0.032	0.610	0.174	0.040	-0.031	0.663	0.204	0.008
Vines	-0.002	0.533	-0.002	0.625	0.000	0.899	-0.001	0.812
Vine^2	0.000	0.955	0.000	0.907	0.000	0.914	0.000	0.321
Vines (P/A)	-0.011	0.857	0.153	0.057	0.215	0.001	-0.018	0.807

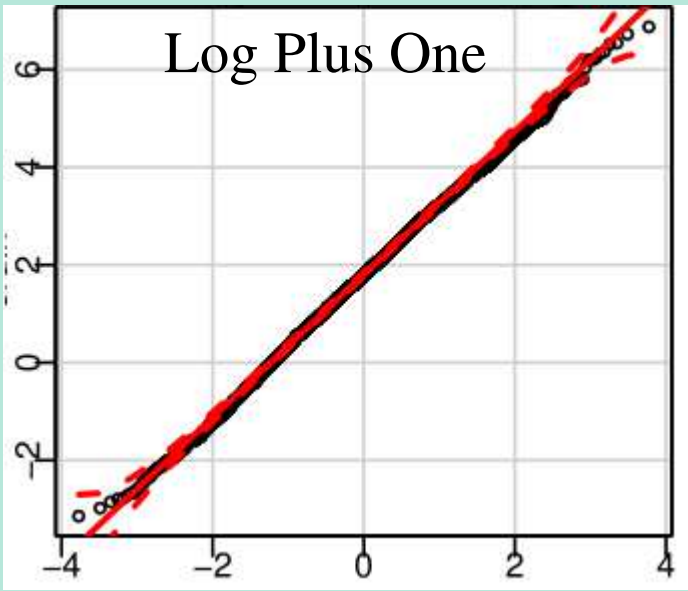
Variable	Canopy - Shade Tolerant		Canopy - Shade Intermediate		Canopy - Shade Intolerant		Non-Canopy	
Intercept	-3.615	0.018	-3.940	0.001	-6.988	0.000	-7.411	0.000
Latitude	0.186	0.000	-0.012	0.549	0.080	0.002	0.159	0.000
Longitude	0.037	0.000	-0.065	0.000	-0.058	0.000	-0.014	0.172
Elevation	0.000	0.000	0.000	0.000	0.000	0.996	0.000	0.005
Site Class – Poorer (Base is Richer)	-0.040	0.103	0.039	0.044	0.042	0.100	0.041	0.098
Soil – Xeric (Base is Mesic)	-0.243	0.000	-0.199	0.000	-0.001	0.983	-0.028	0.573
Northeast and Percent Slope	-0.008	0.000	-0.003	0.003	-0.006	0.000	0.001	0.566
Southeast and Percent Slope	-0.002	0.156	-0.002	0.090	-0.003	0.019	0.001	0.305
Southwest and Percent Slope	0.002	0.126	0.006	0.000	0.000	0.790	0.003	0.046
Northwest and Percent Slope	0.000	0.888	-0.002	0.106	-0.002	0.137	0.003	0.009
Deer Browse Impact	-0.176	0.000	-0.144	0.000	-0.111	0.000	-0.135	0.000
Physiographic Region – Other (Base: Appalachian Plateau)	-0.298	0.095	-0.111	0.426	-0.258	0.157	-0.242	0.173
Physiographic Region – Ridge and Valley (Base: AP)	0.030	0.447	0.085	0.005	0.015	0.697	0.020	0.603
Regeneration Type – Oak and Hickory	-0.155	0.000	0.193	0.000	0.046	0.147	0.177	0.000
Regeneration Type – Softwood and Other Hardwood	-0.238	0.000	0.086	0.010	0.094	0.031	-0.048	0.255
Average Diameter	-0.003	0.819	0.030	0.001	-0.016	0.182	0.028	0.013
Average Diameter^2	0.000	0.509	-0.002	0.000	0.001	0.209	-0.001	0.057
Basal Area Greater than 5	0.001	0.382	0.000	0.428	-0.001	0.263	-0.001	0.128
Basal Area Greater than 5^2	0.000	0.249	0.000	0.684	0.000	0.990	0.000	0.375
Basal Area Less than 5	0.040	0.000	0.015	0.000	0.037	0.000	0.032	0.000
Basal Area Less than 5^2	-0.001	0.000	0.000	0.019	0.000	0.016	-0.001	0.000
Blueberry-Huckleberry	0.000	0.866	0.009	0.000	-0.007	0.011	0.001	0.689
Blueberry-Huckleberry^2	0.000	0.499	0.000	0.000	0.000	0.262	0.000	0.838
Blueberry-Huckleberry (Presence/Absence)	0.028	0.529	0.325	0.000	0.216	0.000	0.251	0.000
Ferns	0.008	0.000	0.000	0.844	0.003	0.114	0.001	0.453
Fern^2	0.000	0.000	0.000	0.821	0.000	0.006	0.000	0.305
Ferns (P/A)	0.054	0.116	0.038	0.158	0.023	0.520	0.113	0.001
Grass	-0.006	0.001	-0.002	0.146	-0.004	0.046	0.005	0.006
Grass^2	0.000	0.383	0.000	0.850	0.000	0.797	0.000	0.115
Grass (P/A)	0.046	0.184	0.085	0.002	0.125	0.000	0.065	0.060
Herbaceous	-0.003	0.101	0.001	0.303	0.007	0.000	-0.001	0.568
Herbaceous^2	0.000	0.683	0.000	0.045	0.000	0.000	0.000	0.345
Herbaceous (P/A)	0.144	0.000	0.057	0.075	-0.017	0.683	0.155	0.000
Miscellaneous	-0.003	0.493	0.001	0.804	-0.006	0.201	-0.002	0.606
Miscellaneous^2	0.000	0.512	0.000	0.316	0.000	0.514	0.000	0.537
Miscellaneous (P/A)	0.058	0.210	0.017	0.647	0.141	0.003	0.112	0.015
Mountain Laurel	-0.007	0.009	-0.010	0.000	-0.010	0.001	-0.006	0.024
Mountain Laurel^2	0.000	0.301	0.000	0.016	0.000	0.015	0.000	0.169
Mountain Laurel (P/A)	-0.010	0.871	0.004	0.923	0.077	0.204	-0.031	0.603
Shrubs	-0.001	0.412	0.004	0.000	0.009	0.000	0.006	0.000
Shrub^2	0.000	0.597	0.000	0.001	0.000	0.000	0.000	0.000
Shrubs (P/A)	0.138	0.000	0.064	0.016	0.340	0.000	0.169	0.000
Small Trees	-0.006	0.059	0.000	0.950	0.003	0.432	-0.004	0.155
Small Trees^2	0.000	0.942	0.000	0.627	0.000	0.278	0.000	0.565
Small Trees (P/A)	-0.031	0.455	0.016	0.639	-0.024	0.584	0.115	0.006
Vines	-0.001	0.631	0.001	0.731	0.000	0.992	-0.002	0.444
Vine^2	0.000	0.981	0.000	0.398	0.000	0.851	0.000	0.526
Vines (P/A)	0.034	0.394	0.010	0.761	0.155	0.000	0.001	0.984

Results

Tobit Model	Model	SD	RMSE	AIC
Base Model	Shade Tolerant	5.92	5.51	30184.1
Base Model	Shade Intermediate	5.20	4.86	18475.1
Base Model	Shade Intolerant	6.81	6.41	29242.8
Base Model	Non-Canopy	5.47	5.38	22267.0
Log Plus One	Shade Tolerant	*4.10*	*4.10*	17966.4
Log Plus One	Shade Intermediate	*3.10*	*3.60*	12467.9
Log Plus One	Shade Intolerant	*4.18*	*4.10*	17700.1
Log Plus One	Non-Canopy	*3.94*	*4.18*	16794.0

Italics indicate e^x adjusted



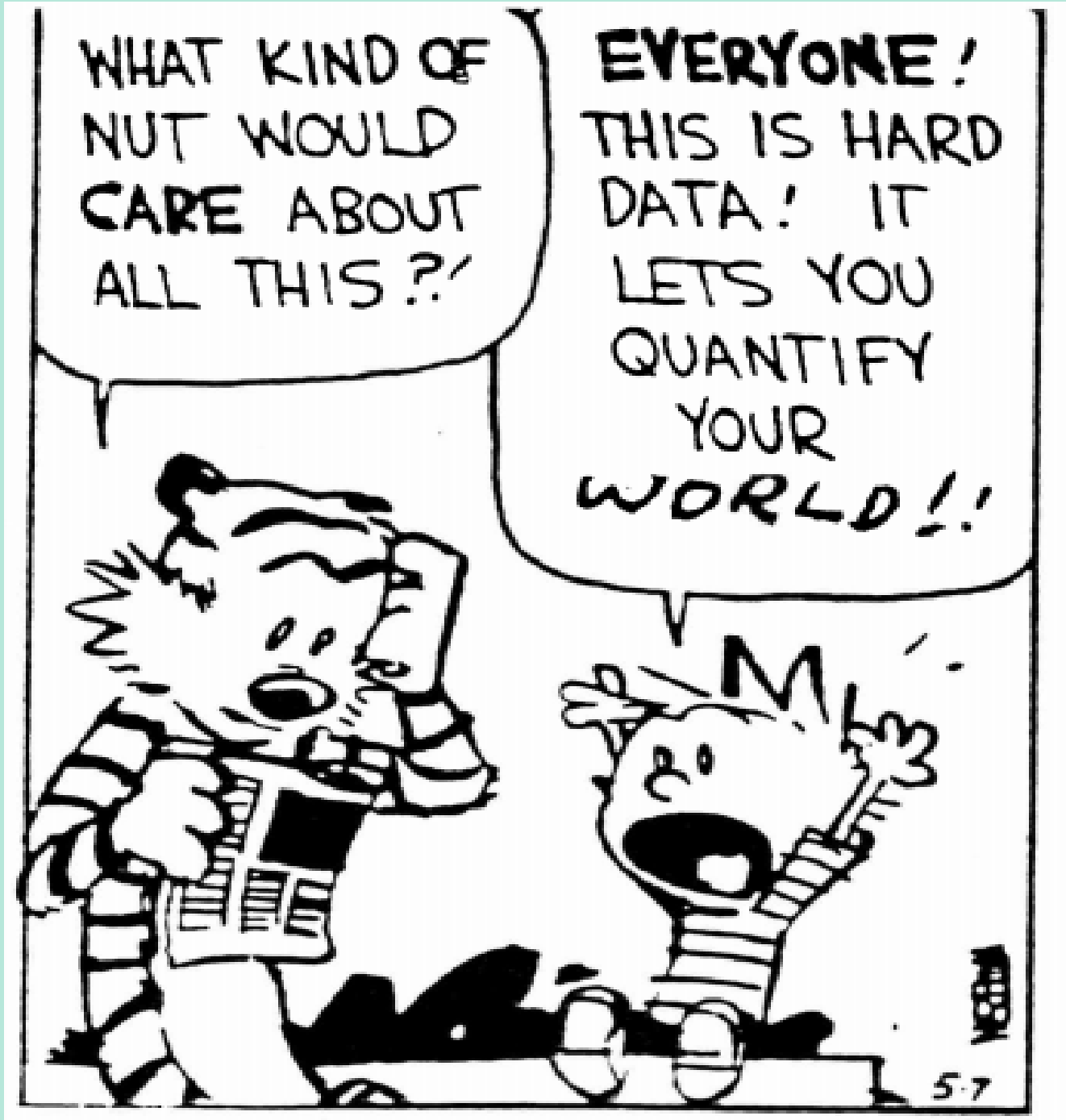


Discussion

-Deer browsing significantly reduced total sapling height in all 4 shade class models.

-Basal area of trees with less than 5 inches DBH was significant and positive for all 4 models, suggesting that basal area of small overstory trees was a good indicator of sapling total height.

-In all shade classes but one, an increased percentage of mountain laurel cover significantly reduced total sapling height.


WHAT KIND OF NUT WOULD CARE ABOUT ALL THIS?!
EVERYONE! THIS IS HARD DATA! IT LETS YOU QUANTIFY YOUR WORLD!!
5-7

Thank you