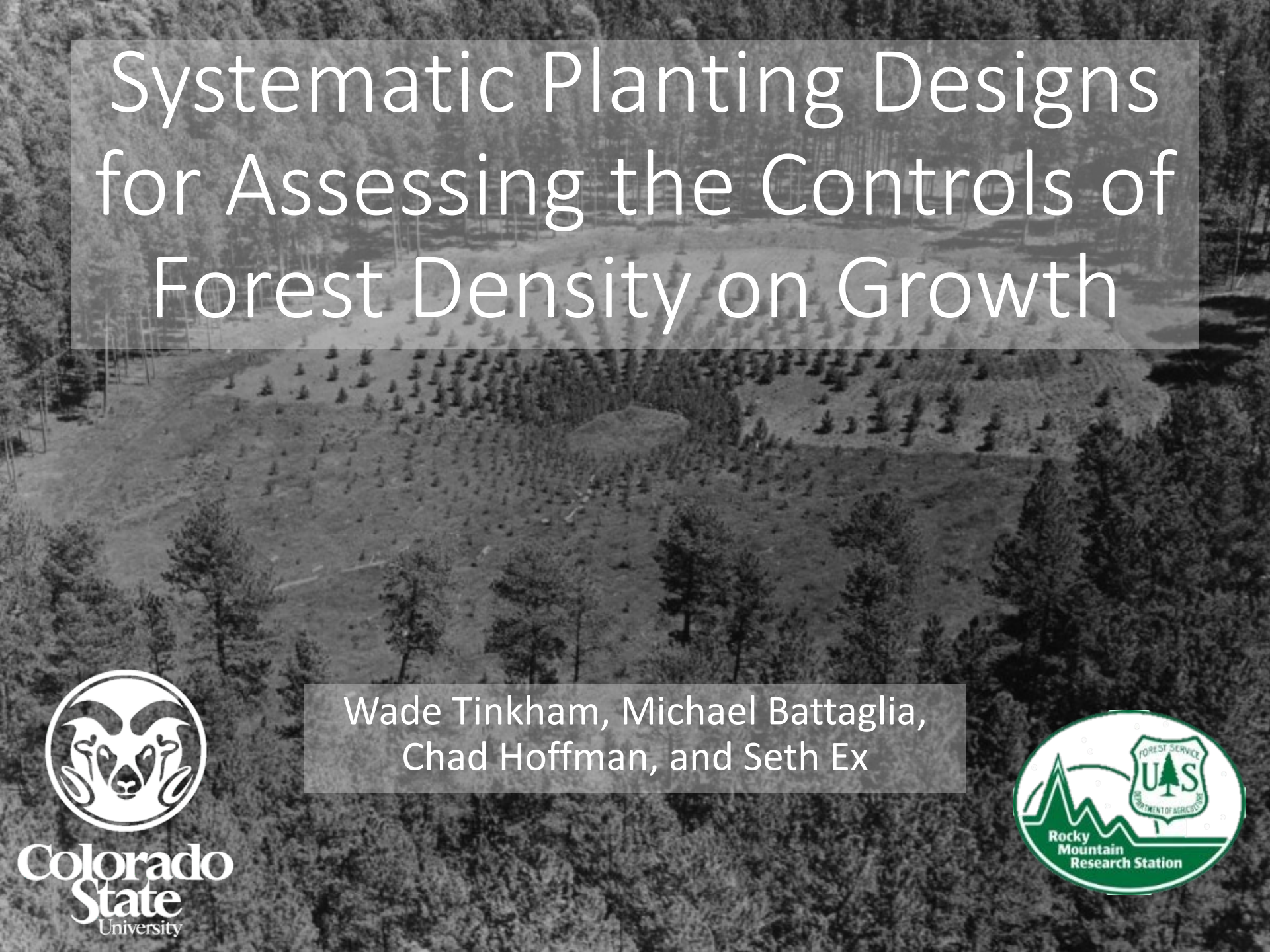
Systematic Planting Designs for Assessing the Controls of Forest Density on Growth



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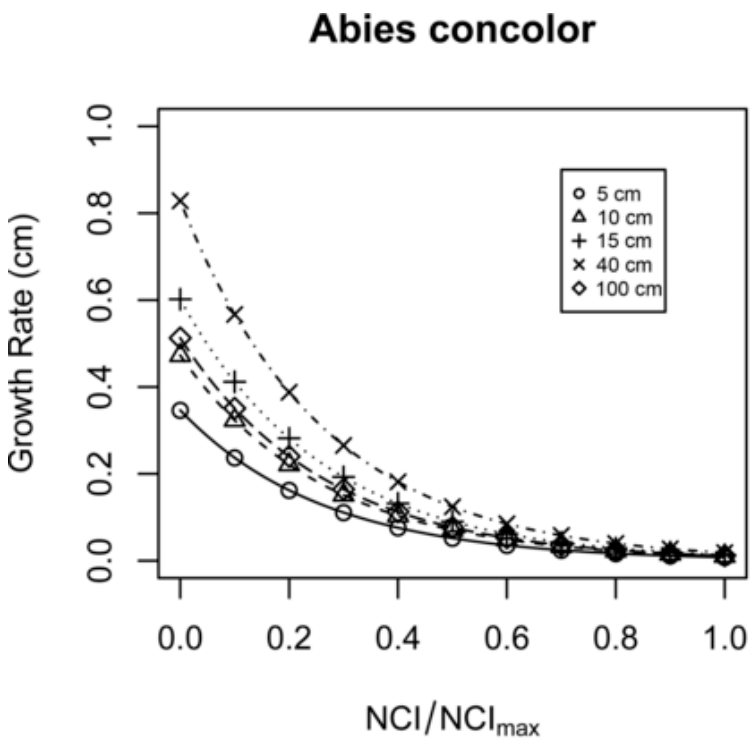
Outline

- Use of Planting Trials in Forestry
- Understanding Nelder Plots
- Analytical Challenges
- Example from South Dakota
  - Density Effects on Size and Growth
  - Lessons learned in assessing drought resistance and resilience

Use of Planting Trials in Forestry

Competition

"When the immediate supply of a single factor necessary for growth falls below the combined demands of the individual plants, competition begins."



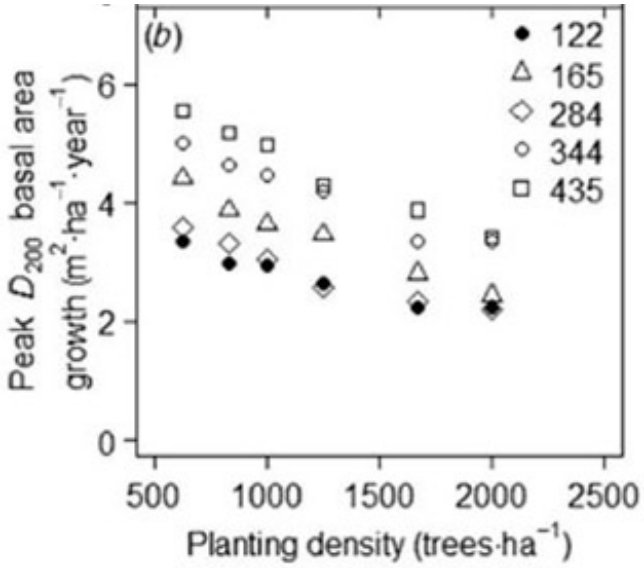
~ Clements

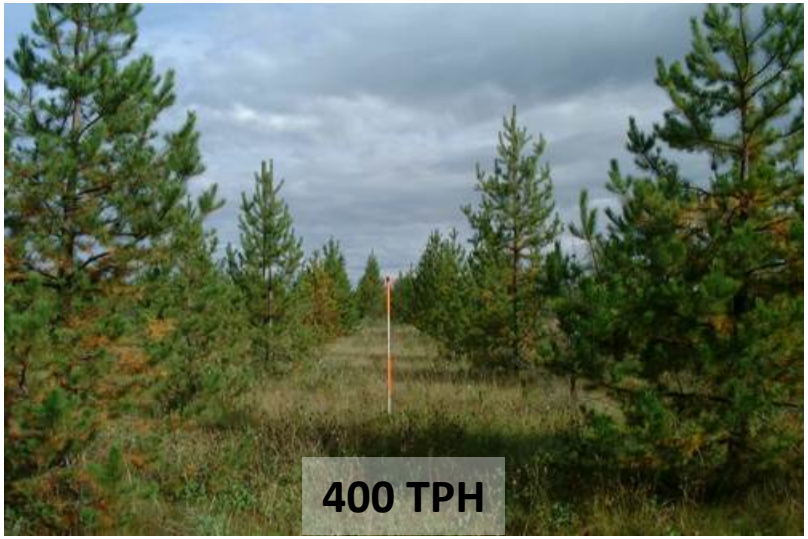
(Donald, C.M. 1963. Competition among crop and pasture plants. *Adv. Agron.* 15, 1-118)

Use of Planting Trials in Forestry

Block Replicated Experiments

- There is extensive literature about the use of block replicated spacing studies.
- Guiding many silvicultural systems in western forests.





Use of Planting Trials in Forestry

Block Replicated Experiments

- These approaches utilize an area based approach to define the sampling unit (i.e. each block is 1 sample).
- This study of 2 species:
  - ~5 acres per block set
  - 6 replicates
  - 12 densities
  - 110 trees in each

6 x 12 x 110 =
7,920 trees to track

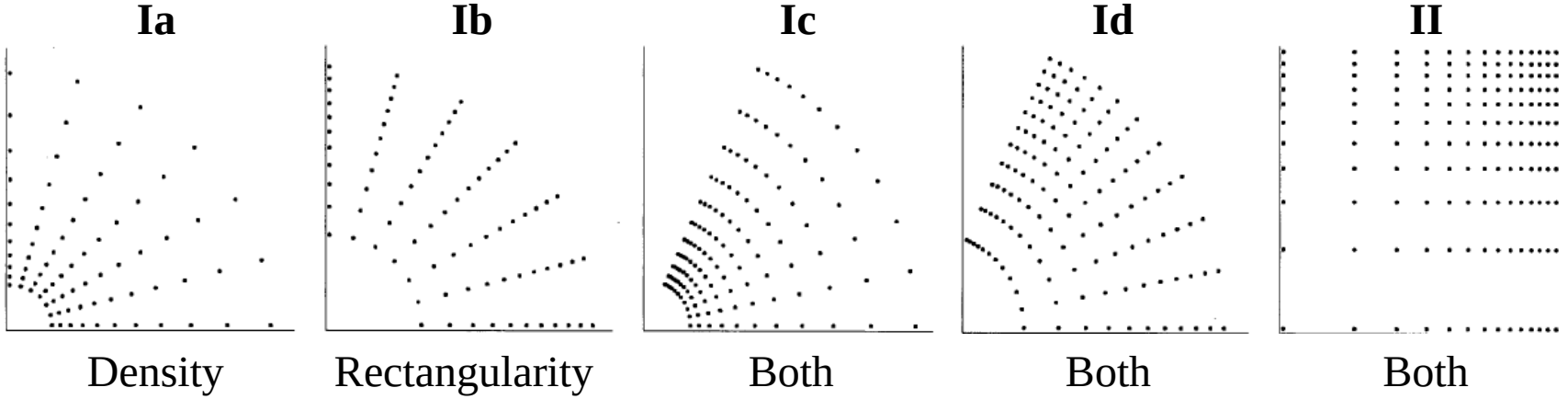
~30 acres invested

Add a second species, double everything.

Understanding Nelder Plots

Individual Focused – Systematic Experiments

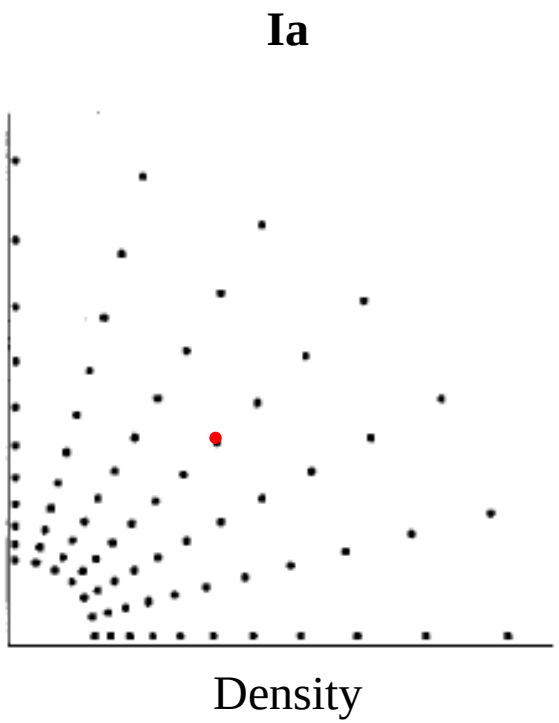
- John Nelder – a British Statistician trying to identify ideal agricultural plant spacing.
  - Nelder, J.A. 1962. New kinds of systematic designs for spacing experiments. *Biometrics*, 18, 283-307.
- Proposed 5 designs for varying spacing and rectangularity:



Understanding Nelder Plots

Individual Focused – Systematic Experiments

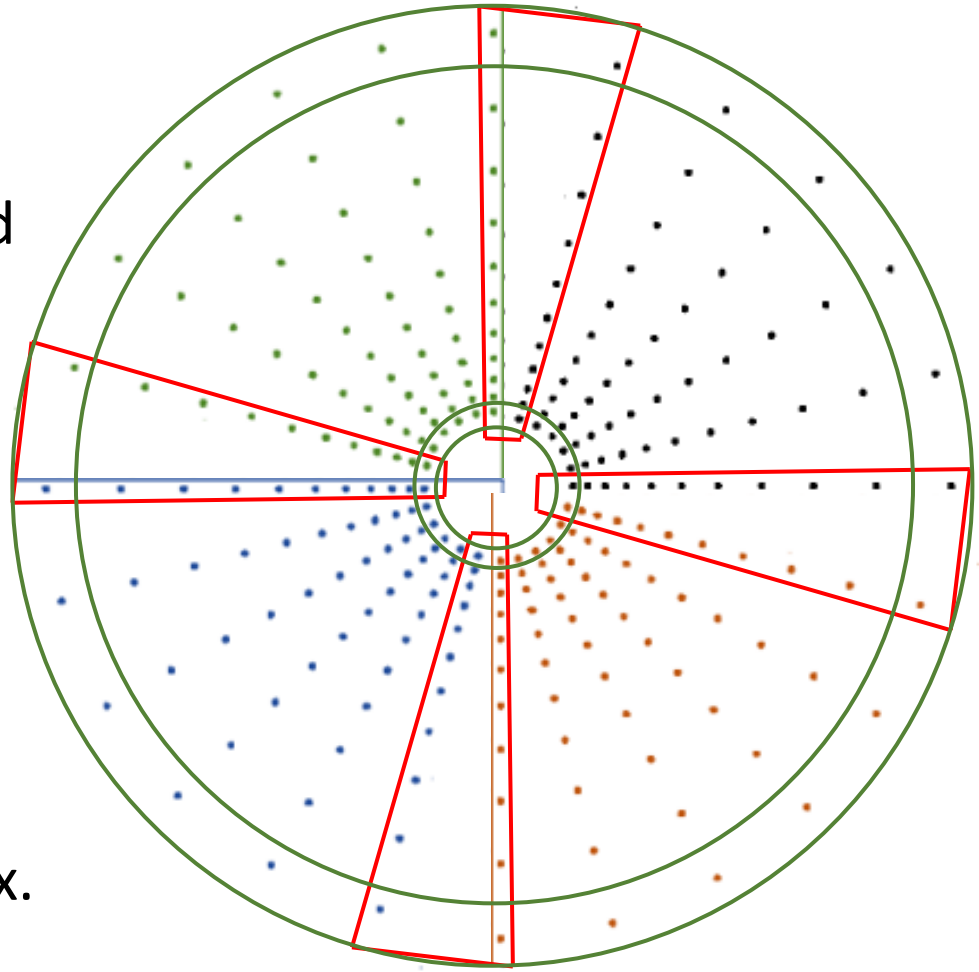
- The Ia design has been the most widely adapted for forestry applications.
  - Maintains rectangularity at ~1:1 while varying spacing.
  - Each tree along a spoke represents a different density.
  - Each spoke represents a replicate.
- While this shows one quadrant, these are commonly installed as full circles.



Understanding Nelder Plots

Individual Focused – Systematic Experiments

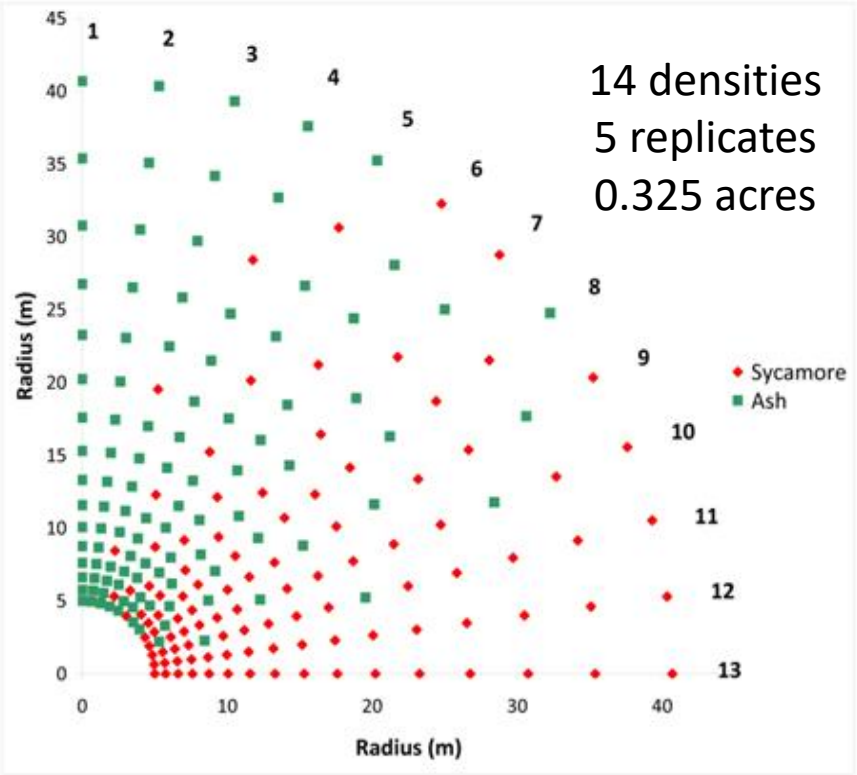
- Full plots can be divided to investigate site prep, species, providence, etc.
- Effects are separated by guard spokes.
- Density is maintained by guard arches.
  - This scenario produces 4 replicates of 9 densities.
  - Depending on spacing, this could take as little as 1 acre
- Multiple plots could be used to investigate across site index.



Understanding Nelder Plots

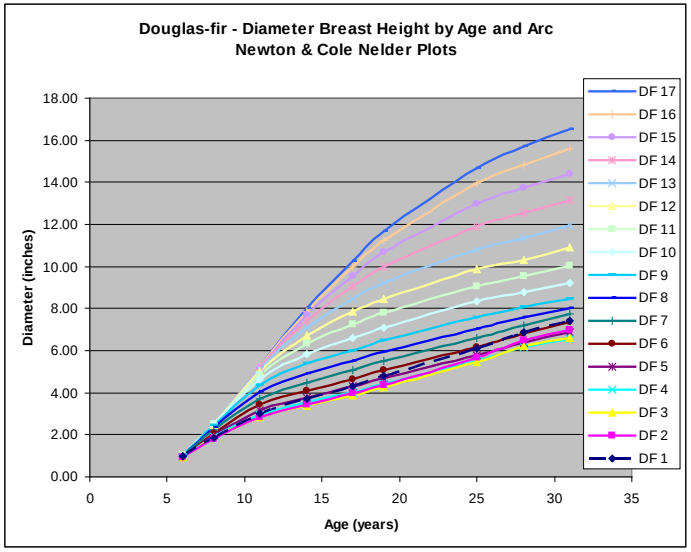
Individual Focused – Systematic Experiments

- Example of mixed species planting for assessing intra-species competition.



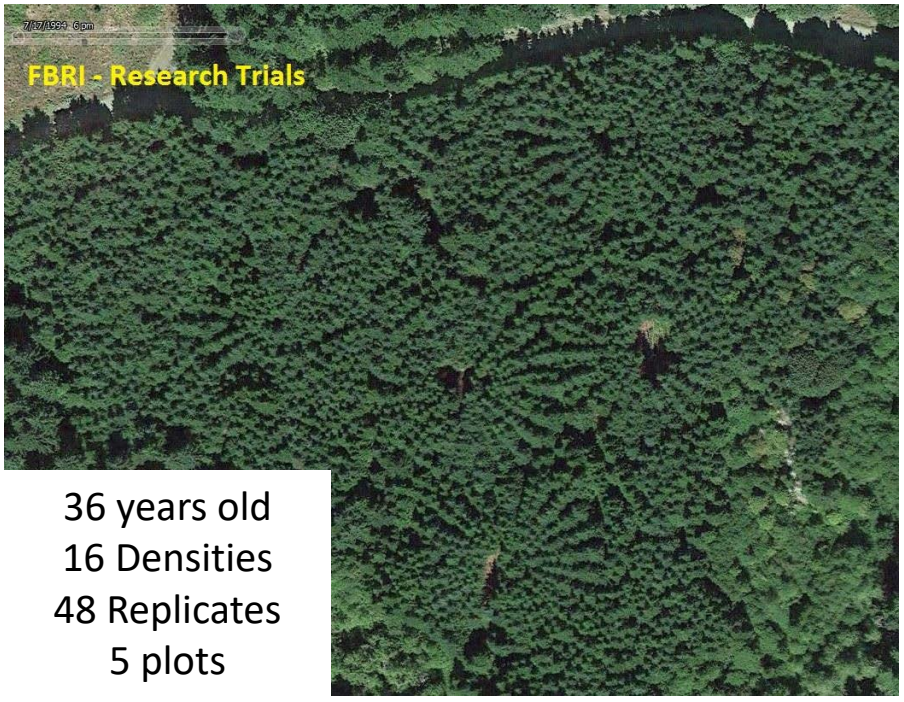
625 – 25,267 TPH

Understanding Nelder Plots

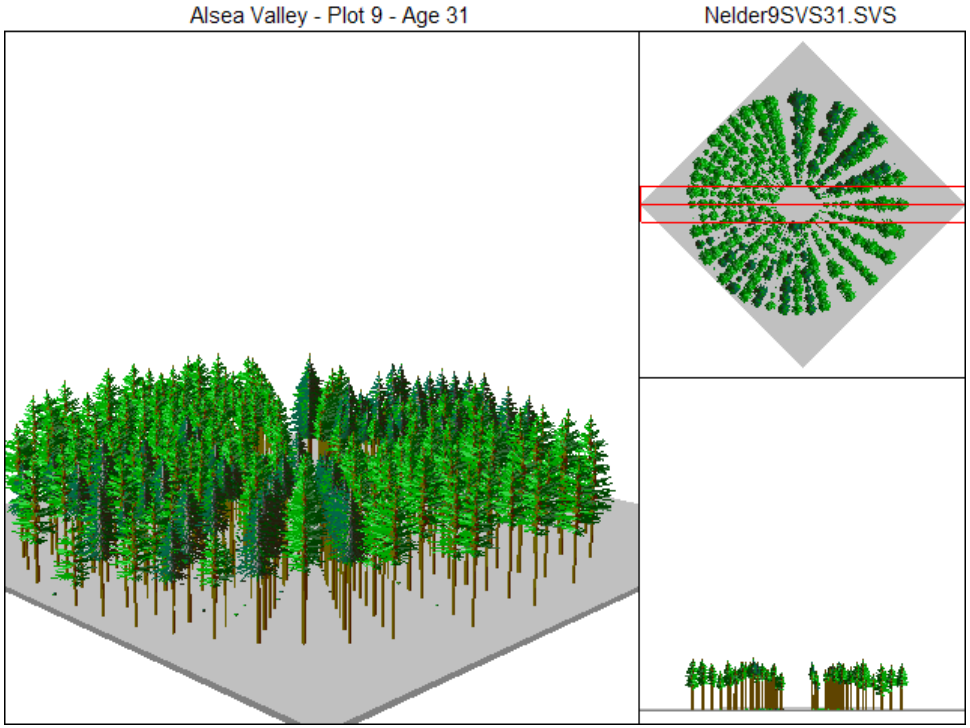


Individual Focused – Systematic Experiments

- Replicated Douglas-fir plots in Oregon
- Done with a modified Nelder Ia design



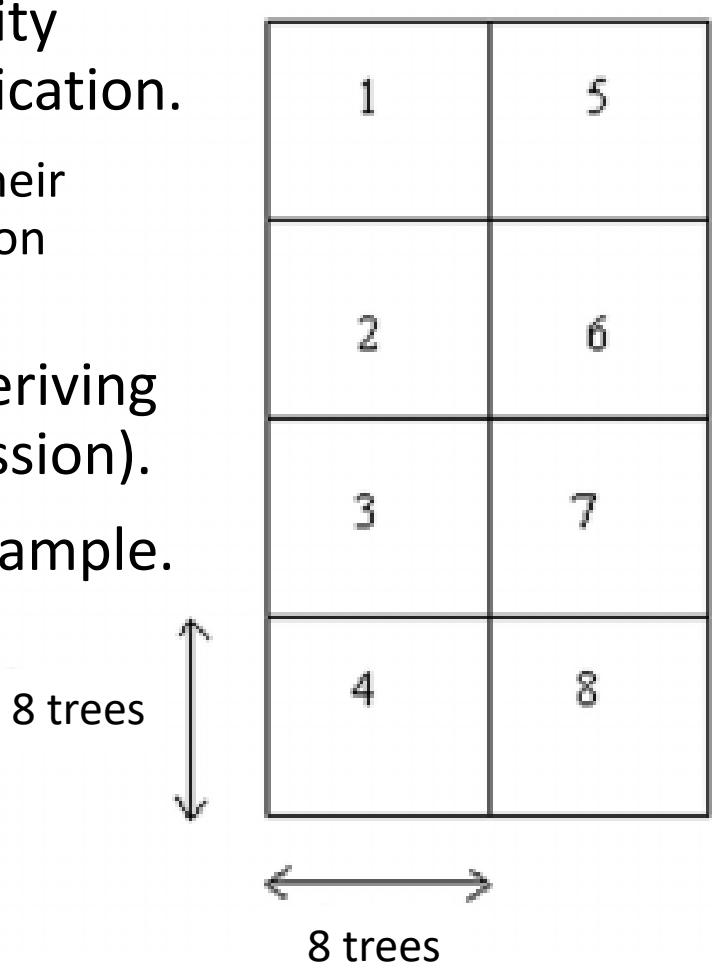
36 years old
16 Densities
48 Replicates
5 plots



Analytical Challenges

Block Replicated Experiments

- Independent blocks representing density levels, with sets of blocks creating replication.
  - Randomizing block arrangements ensures their independence and allows us to meet common analysis assumptions.
- Designed for analysis of variance for deriving inference (i.e. ANOVA and linear regression).
- Each set of blocks represents a single sample.

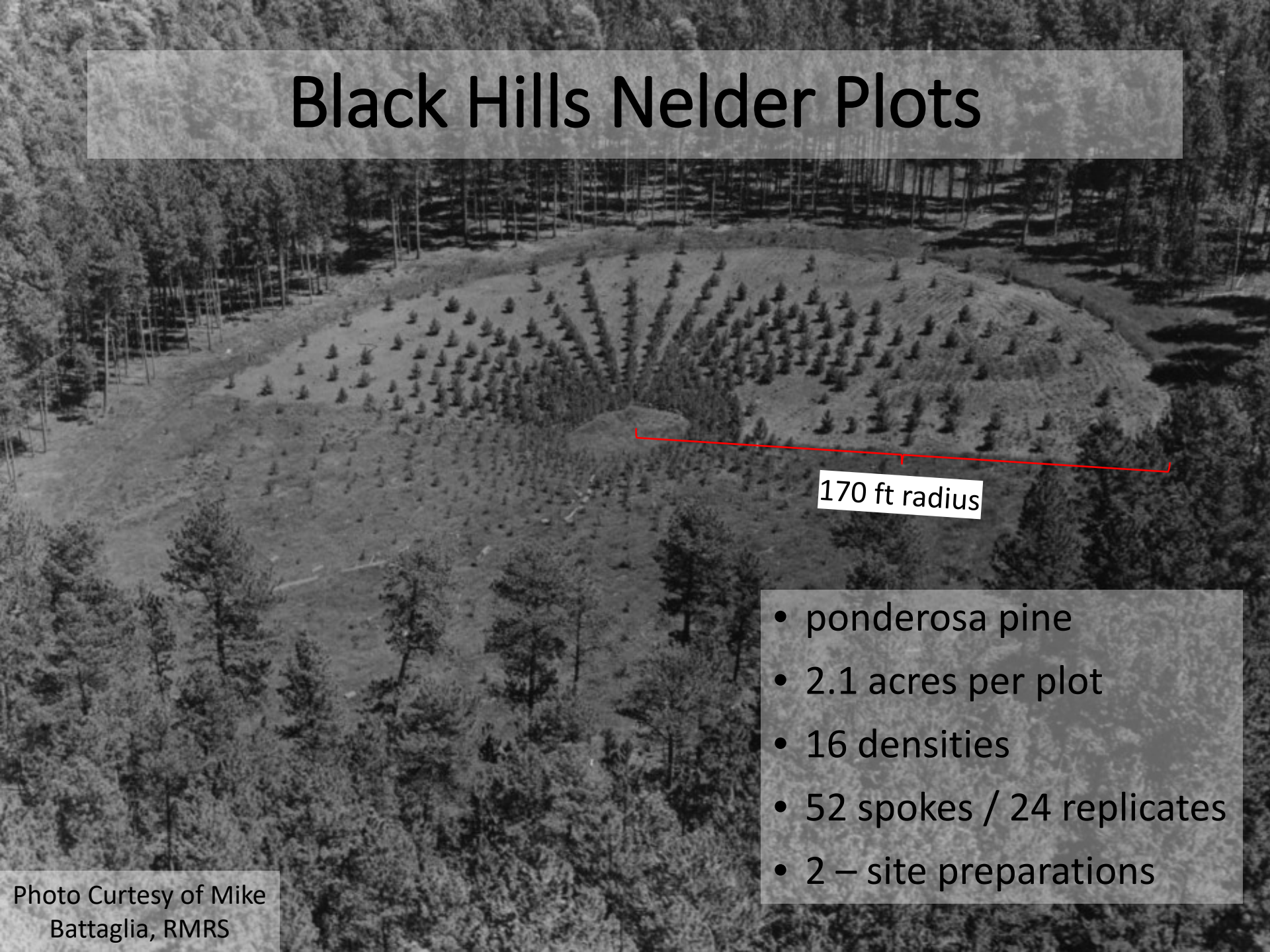


Analytical Challenges

Individual Focused – Systematic Experiment

- Each arch represents a density level, with trees in the arch creating replication.
  - Since there is no way to randomize this, we don't meet the assumptions for analysis of variance.
- Designed for model-based inference approaches.
- Each spoke provides a single sample for each density level.

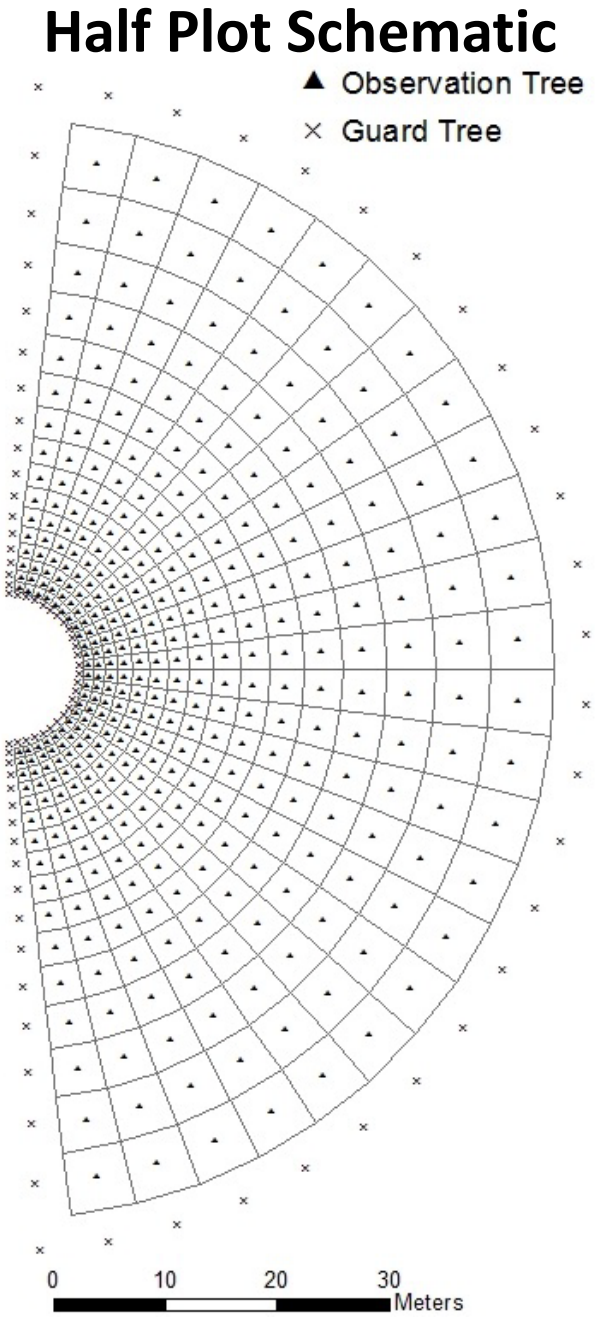
Black Hills Nelder Plots



- ponderosa pine
- 2.1 acres per plot
- 16 densities
- 52 spokes / 24 replicates
- 2 – site preparations

Photo Curtesy of Mike Battaglia, RMRS

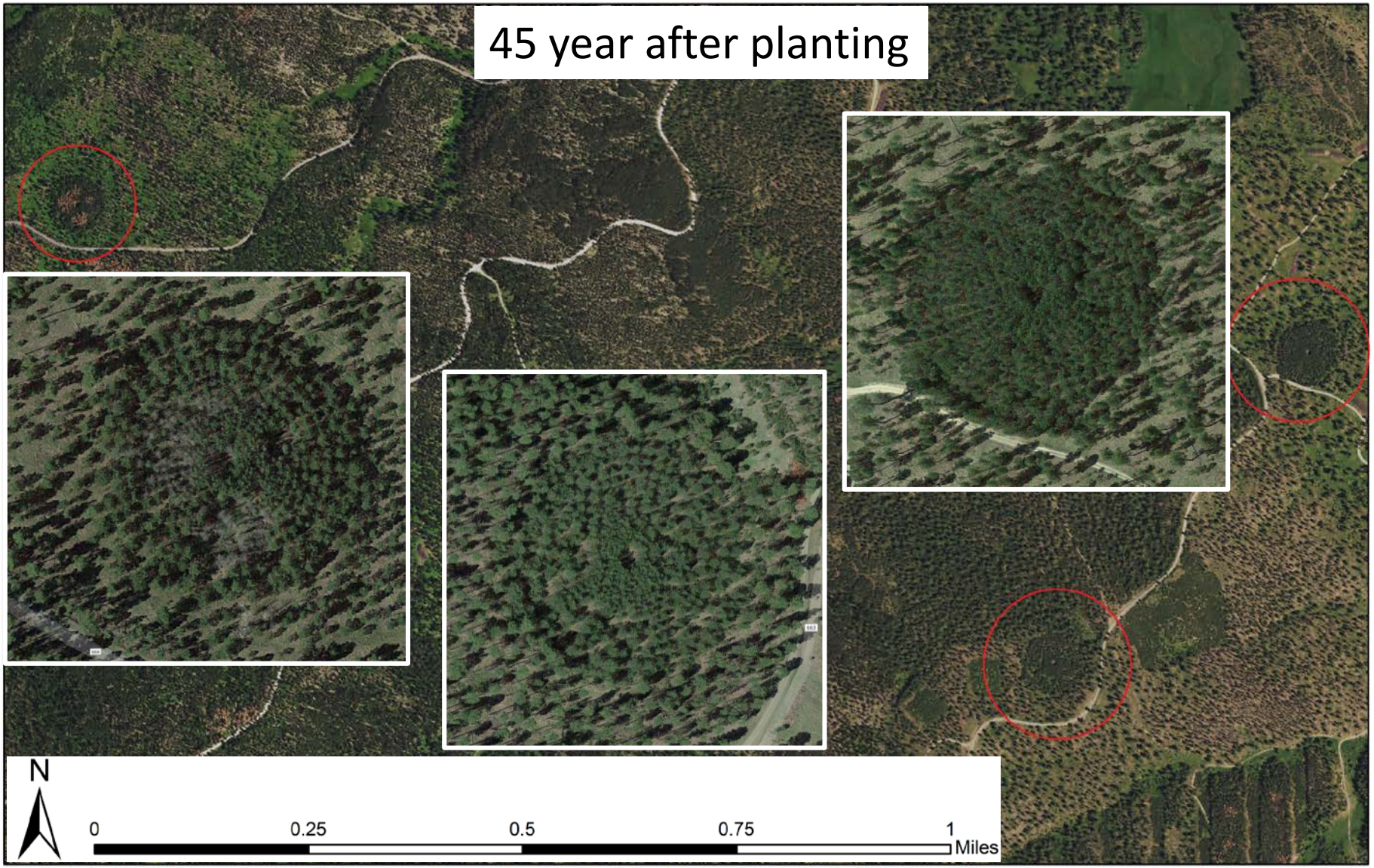

1 year after planting
Photo Curtesy of Mike Battaglia, RMRS



Study Design

- 3 – Nelder Ia design plots at SI of 50-60
- Planted in 1969 with 2 year old seedlings
  - Implemented by Charles Boldt of Rocky Mountain Forest and Range Experiment Station, USDA Forest Service
- Spacing from 3x3 ft to 19x19 ft
  - Or 4,808 to 118 trees per acre
- Each plot has 24 replicates of each spacing and treatment
  - 2,304 possible sample trees each time step
- Inventories of DBH and height at ages:
  - 3, 6, 8, 9, 11, and 12 then again at age 45
  - Increment cores collected from 3 trees at each density in each plot – 144 cores

Plot Locations in the Black Hill's Experimental Forest



Objectives & Methods

Objectives

How does spacing and site preparation impact tree size and growth increment?

Does FVS accurately represent small tree growth?

How does spacing impact growth during drought periods?

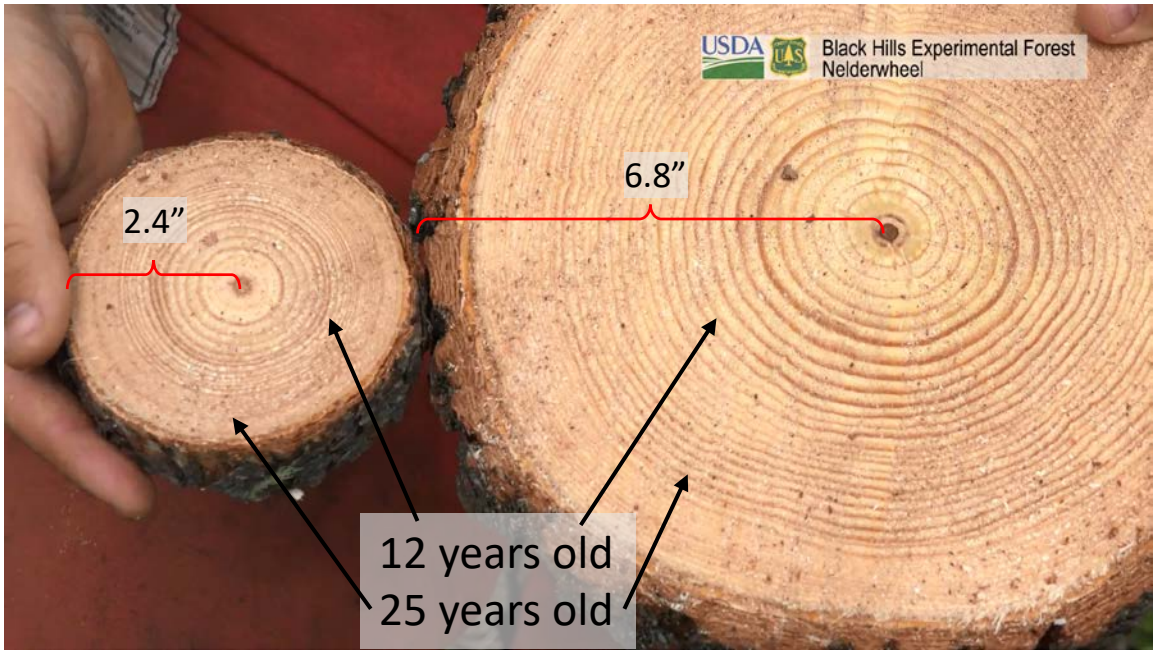
Methods

- Trees filtered for alive local neighborhoods
- Tree size – DBH and height
- Growth increment - Periodic Annual Basal Area Increment per tree
- Compared against bareground FVS simulations
- Increment cores to evaluate growth during droughts

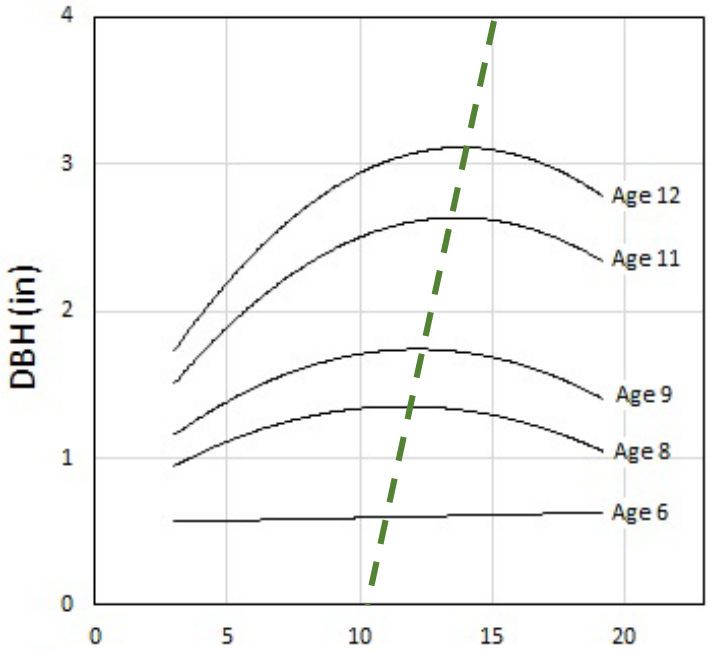
Results

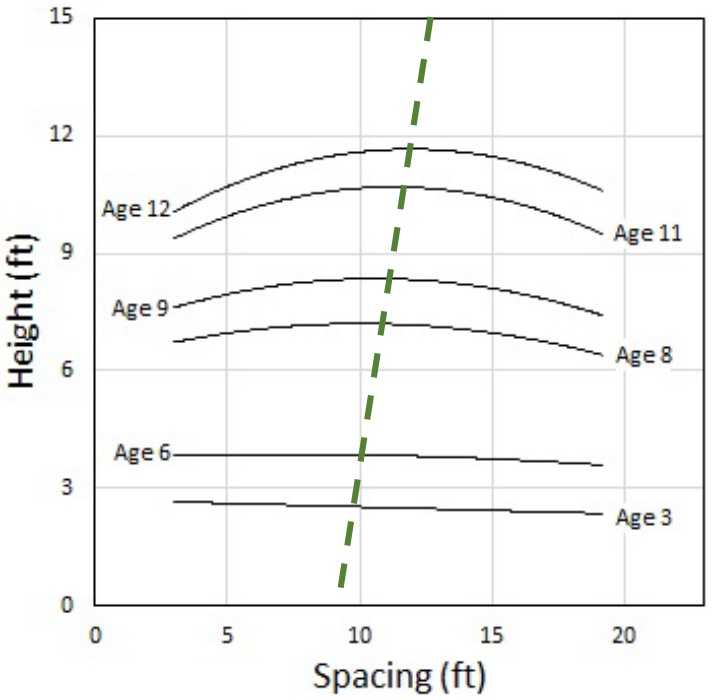
Spacing

- Optimal spacing increases with age
- This informs the timing of thinning to capture growth



USDA FS – Black Hills Experimental Forest Virtual Tour





Results

Site Preparation

- The effect of spacing is overwhelmed by grass competition

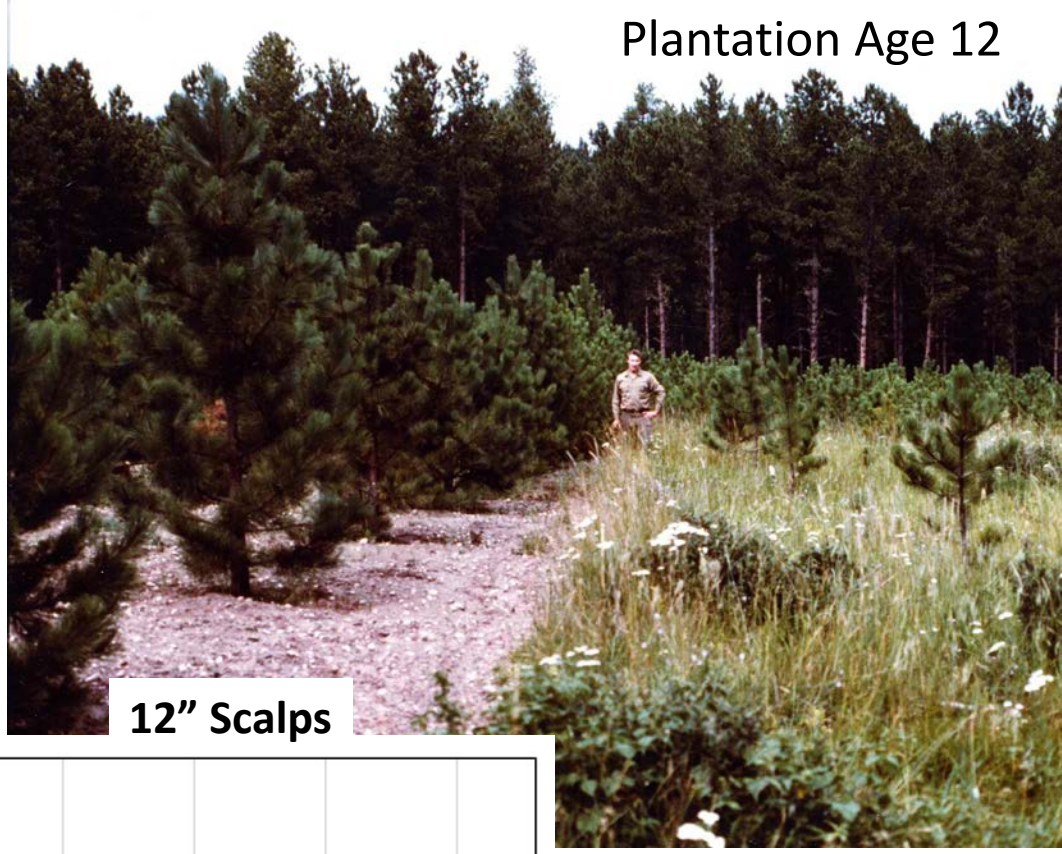
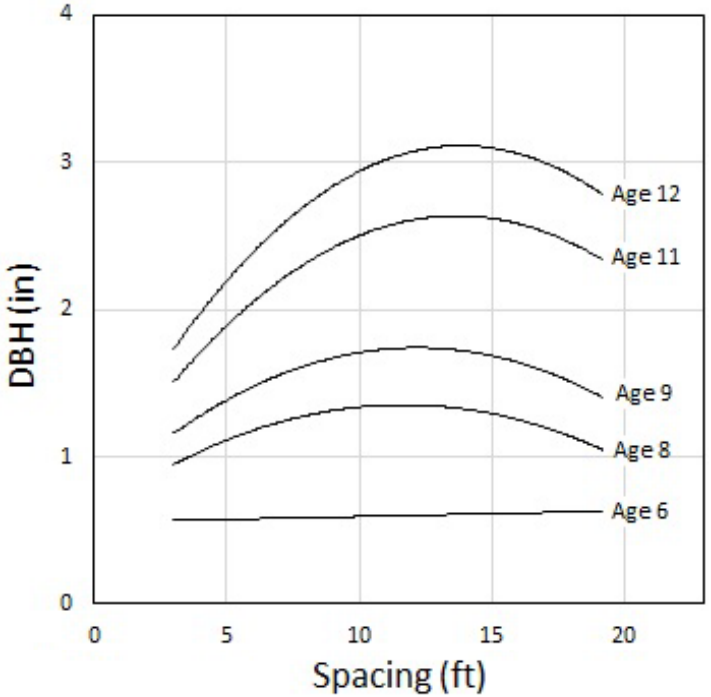
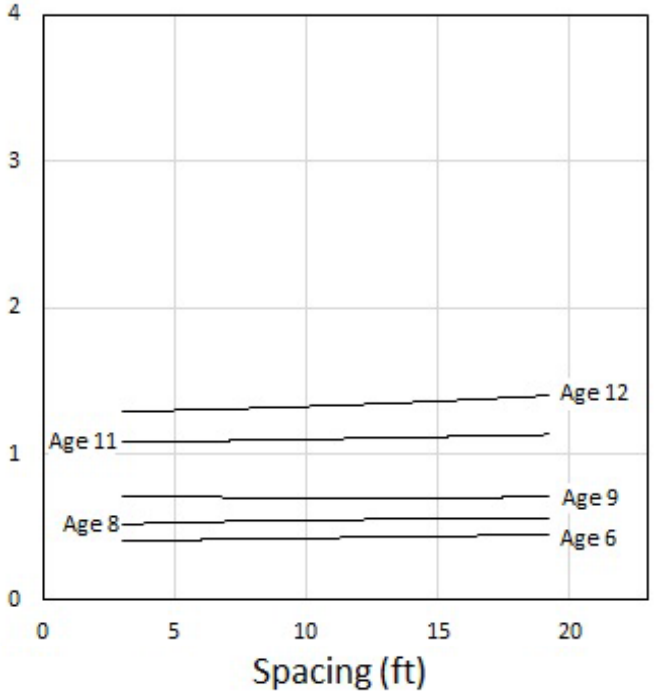


Photo Curtesy of Mike Battaglia, RMRS

Herbicide and Tilling



12" Scalps



Growth Rate

Implications

Silviculture

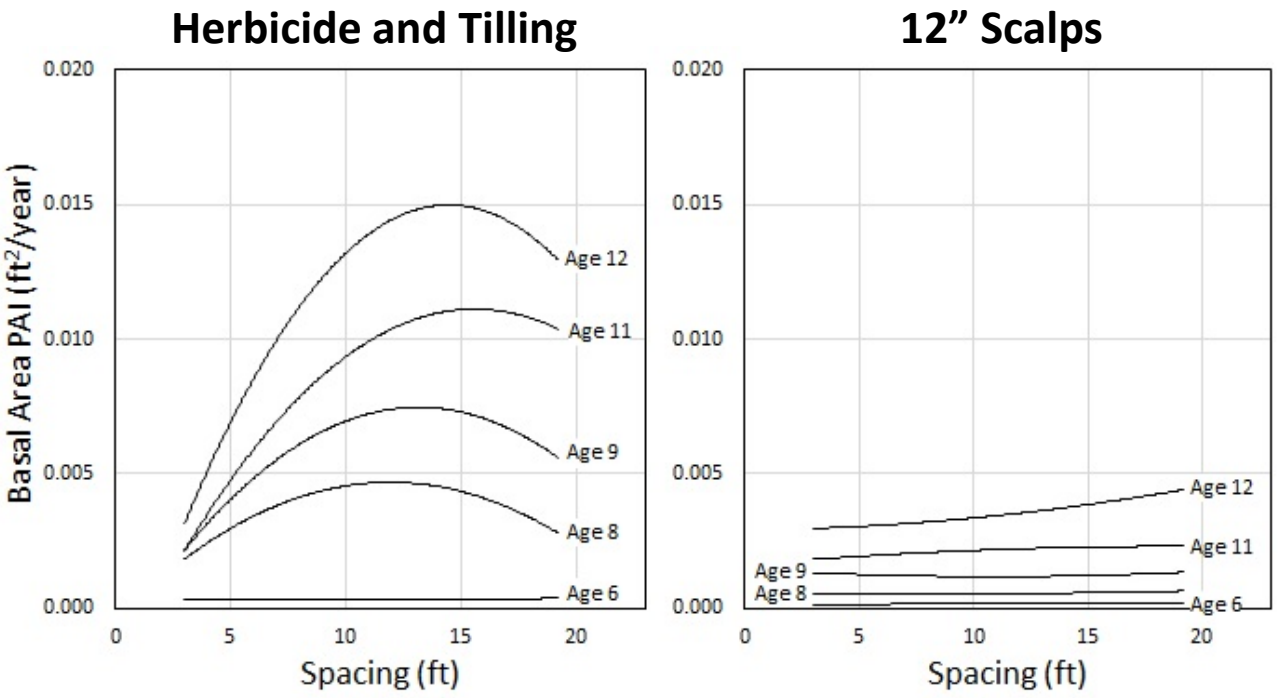
- Informing the timing of thinning

Wood Quality

- Impacts on wood density and knots

Growth & Yield

- Validating/refining modeling of tree growth



Relative Size at Age 45

USDA FS – Black Hills Experimental Forest Virtual Tour

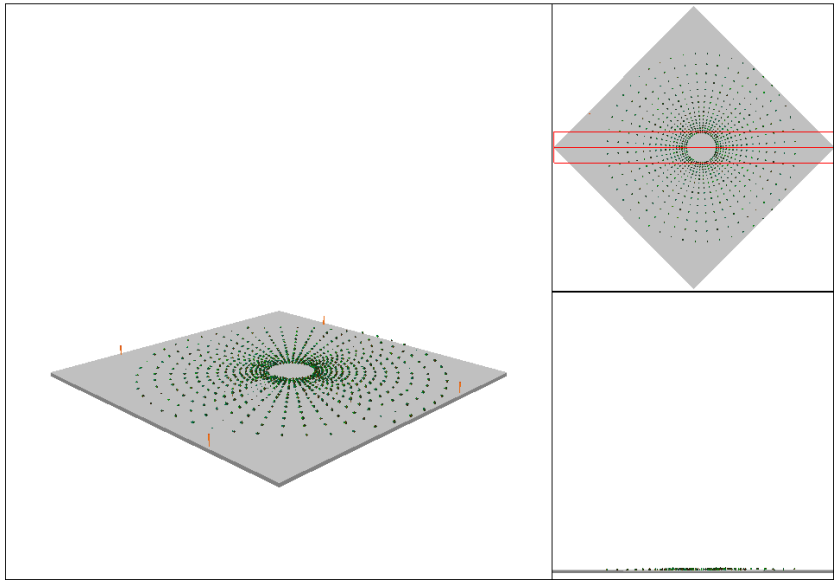
Validating FVS

Direct evaluation of Central Rockies variant small tree growth model

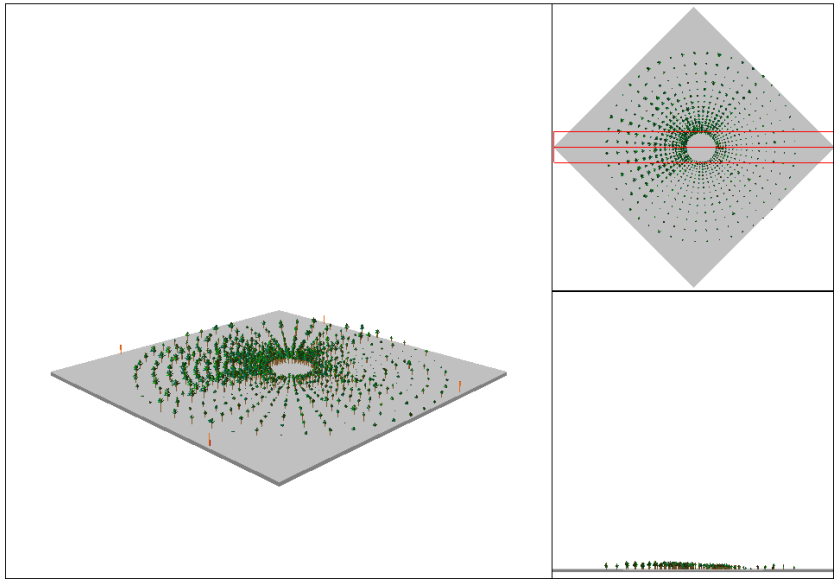
- Bareground simulations at 50, 55, and 60 for site index
- Treelist output at age 3, 6, 9, and 12

Photo Curtesy of Mike Battaglia, RMRS

Initiating Bareground Simulations



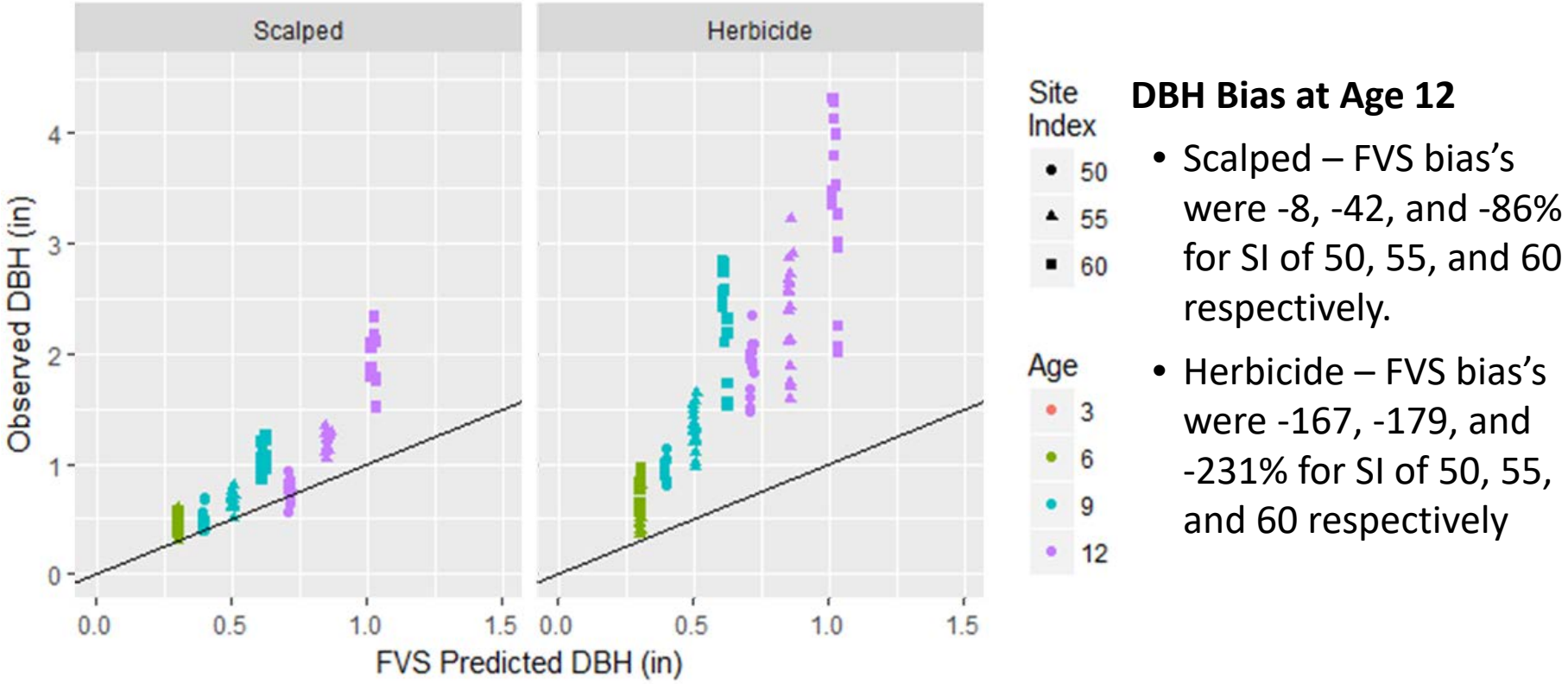
Year 12 of Bareground Simulations



Direct Evaluation of FVS Bias

DBH

- Underprediction that gets worse with age.
- Under accounts for the effect of site index in small trees.
- Under accounts for the effect of density.
- Good reason to incorporate site preparation into FVS.



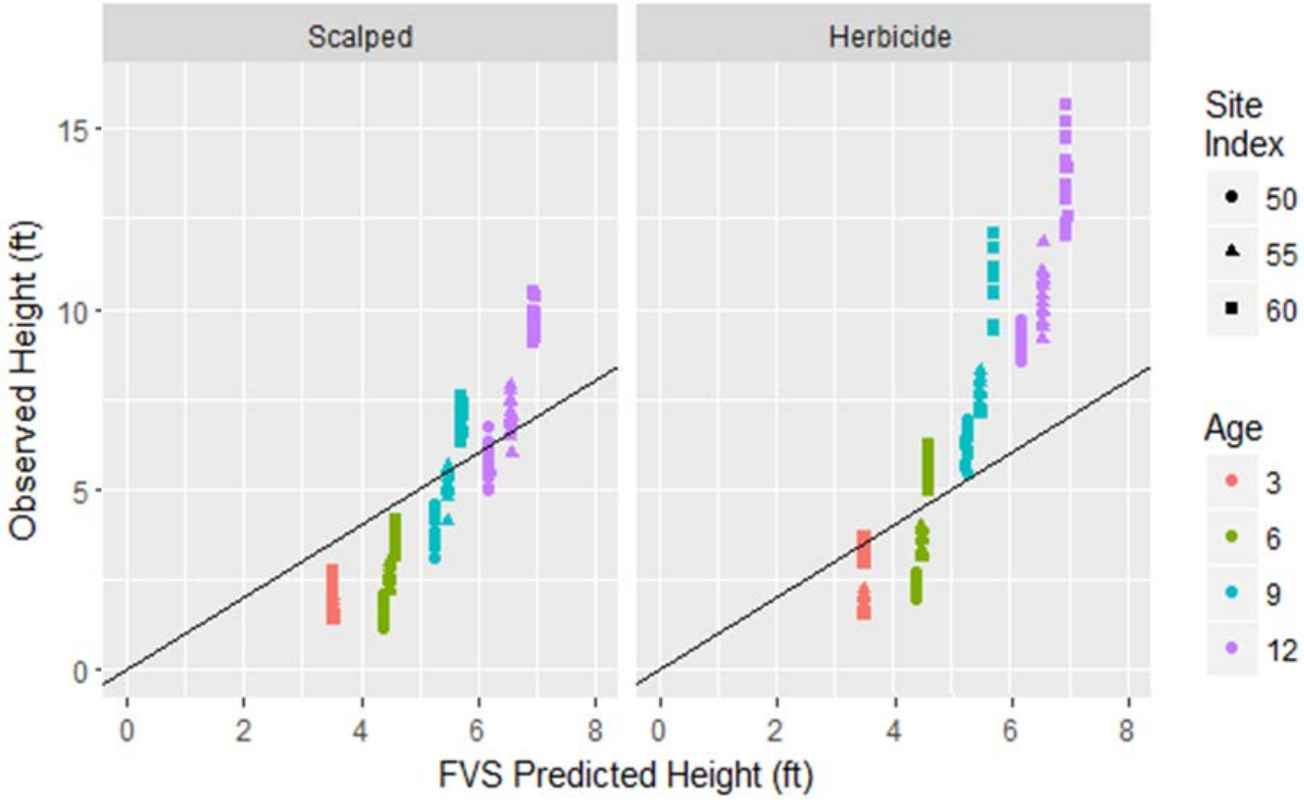
DBH Bias at Age 12

- Scalped – FVS bias's were -8, -42, and -86% for SI of 50, 55, and 60 respectively.
- Herbicide – FVS bias's were -167, -179, and -231% for SI of 50, 55, and 60 respectively

Direct Evaluation of FVS Bias

Height

- Generally capture the rate of height growth.
- Under accounts for the effect of planting density.
- Under accounts for the effect of site index in small trees.
- Good reason to incorporate site preparation into FVS.



Height Bias at Age 12

- Scalped – FVS bias's were +7, -8, and -39% for SI of 50, 55, and 60 respectively.
- Herbicide – FVS bias's were -48, -57, and -97% for SI of 50, 55, and 60 respectively.

Further analysis will evaluate model drift

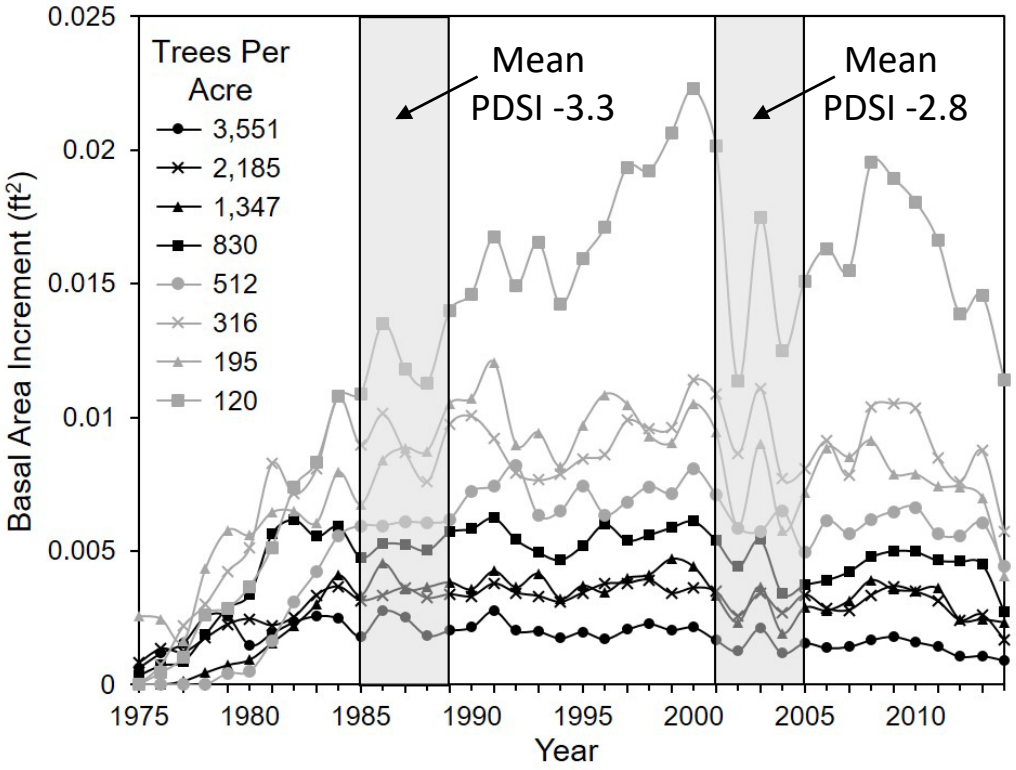
Evaluating Drought Impact on Growth

Competition impact on resistance / resilience to drought

- Droughts identified as periods of PDSI below -2.5
- Competition evaluated as relative stand density index (r-SDI)

$$\text{Resistance} = \frac{BAI_{during}}{BAI_{pre}}$$

$$\text{Resilience} = \frac{BAI_{post}}{BAI_{pre}}$$



Trees Per Acre	1985 Drought			2002 Drought		
	n	DBH (in)	r-SDI	n	DBH (in)	r-SDI
120	7	2.9 (1.0)	0.03	8	7.4 (1.7)	0.15
195	8	2.4 (1.3)	0.04	8	6.0 (1.3)	0.17
316	7	2.9 (1.3)	0.09	8	6.0 (1.1)	0.28
512	7	1.9 (0.6)	0.07	8	4.9 (0.9)	0.32
830	9	2.2 (1.1)	0.16	9	4.6 (1.2)	0.49
1,347	8	1.6 (0.6)	0.14	8	3.7 (0.8)	0.56
2,185	8	1.7 (0.7)	0.28	8	3.7 (0.6)	0.89
3,551	7	1.5 (0.7)	0.35	8	3.0 (0.7)	1.02

* Only showing 8 of 16 densities

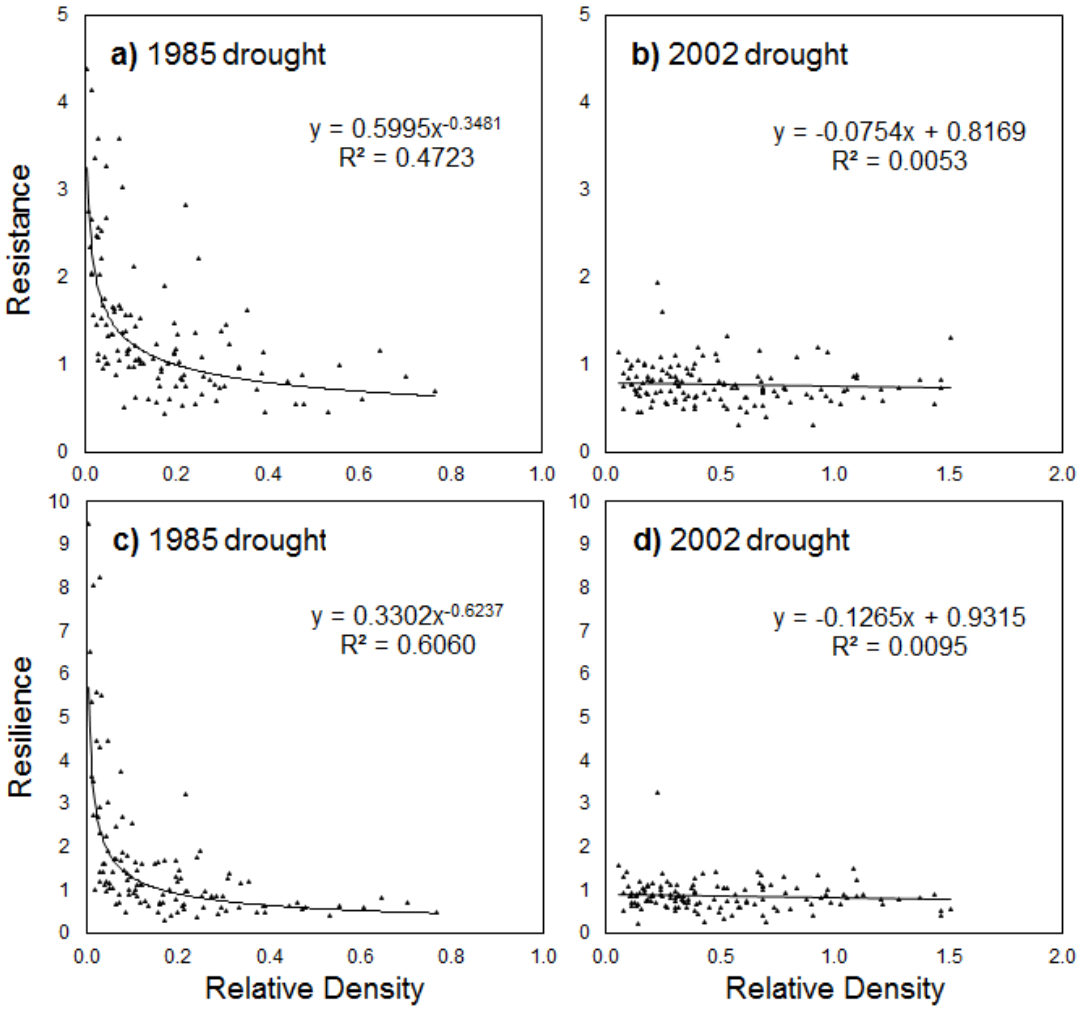
Evaluating Drought Impact on Growth

Competition impact on resistance / resilience to drought

- Strong density dependent response during 1985 event
  - Many trees above 1, meaning accelerating growth.
- No significant effect during 2002 event
  - Most trees below 1, meaning reduced growth.

Similar responses have been seen to these droughts in other datasets.

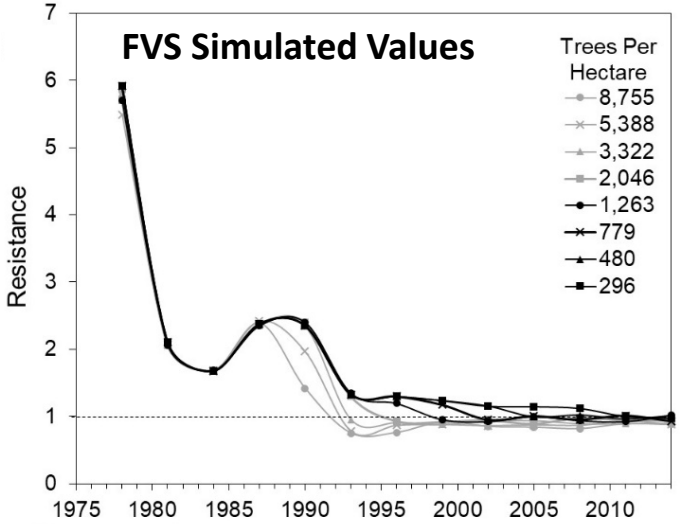
But the 1985 drought was more severe, so what is going on?

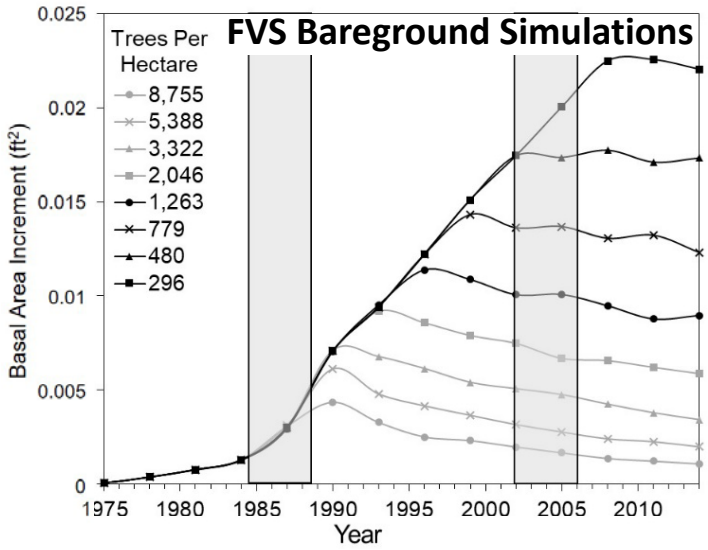


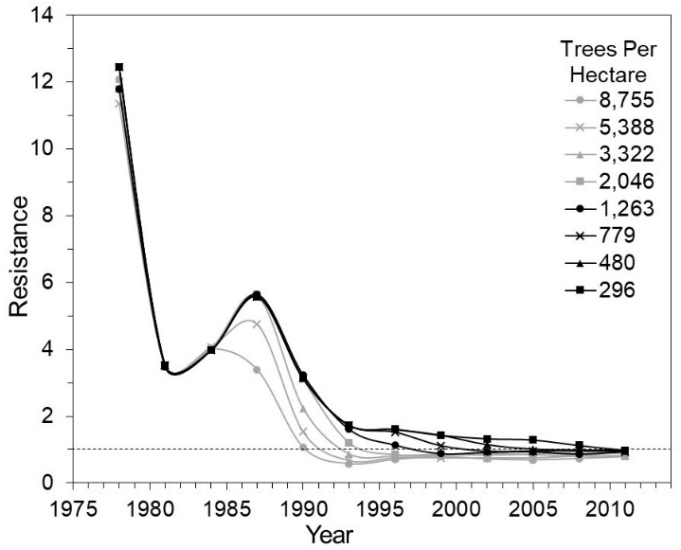
Evaluating Drought Impact on Growth

Stand development stage impact on resistance / resilience research

- Density dependent growth research makes it clear that trees follow a sigmoidal curve.
  - First drought occurred during the up swing of the sigmoidal curve.
  - Second drought occurred after/while trees began declining on the sigmoidal curve.
- This provides similar resistance/resilience values to those observed.







Questions?

Acknowledgements

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