Native Tree Community Establishment on a 17-Year Old FRA-Reclaimed Coal Mine

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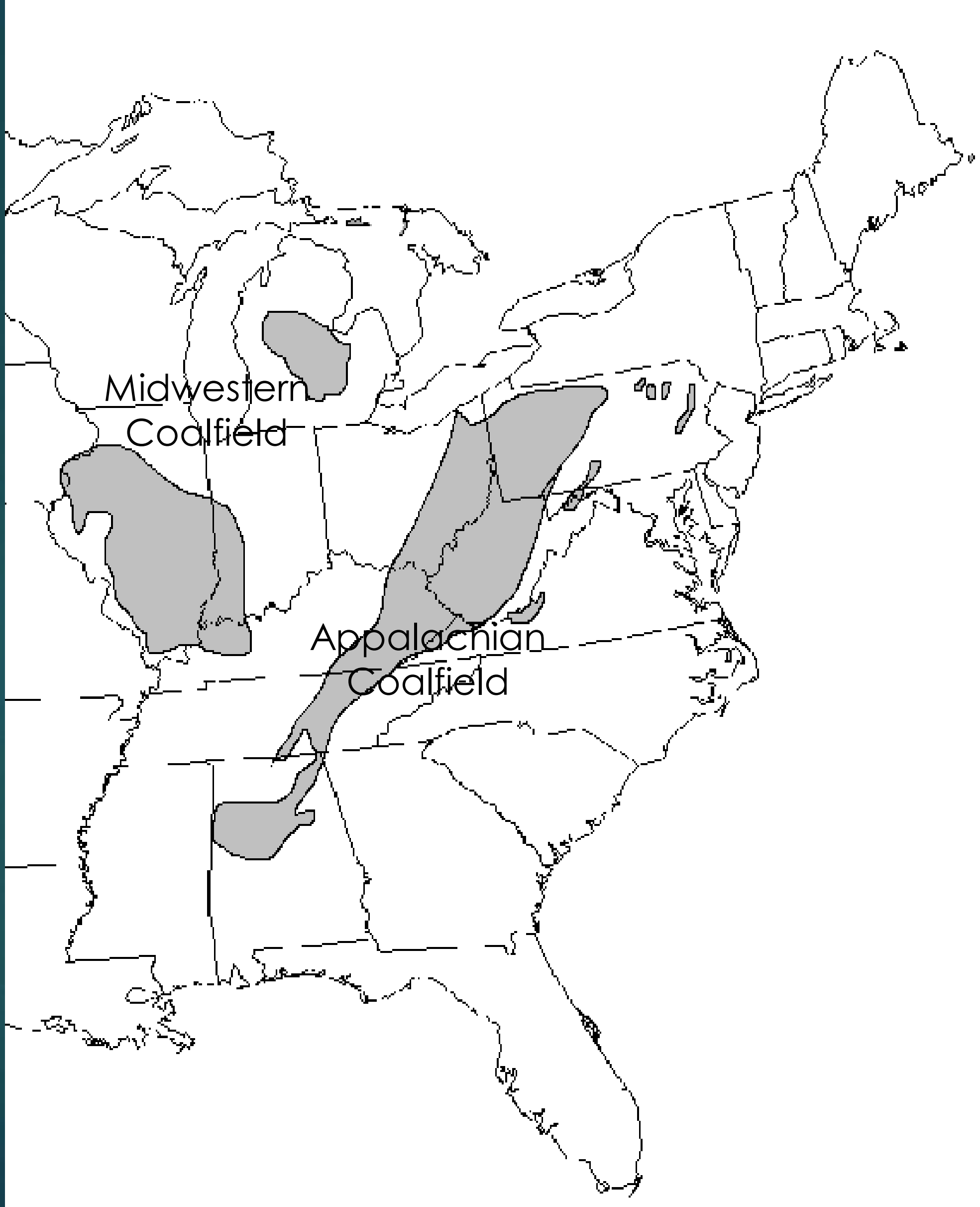
Background: Coal Mining Disturbance



More than 1.5 million acres disturbed by mining in central Appalachia alone (Pericak et al. 2018)

Background: Ecosystem Services

- Water quality & yield
- Flood control
- Carbon sequestration
- Biodiversity
- Wildlife habitat
- Cultural uses
- Ecotourism

Constanza et al. 1997. Value of ecosystem services. *Nature* (3 X products)


Photo: Richard Calmes

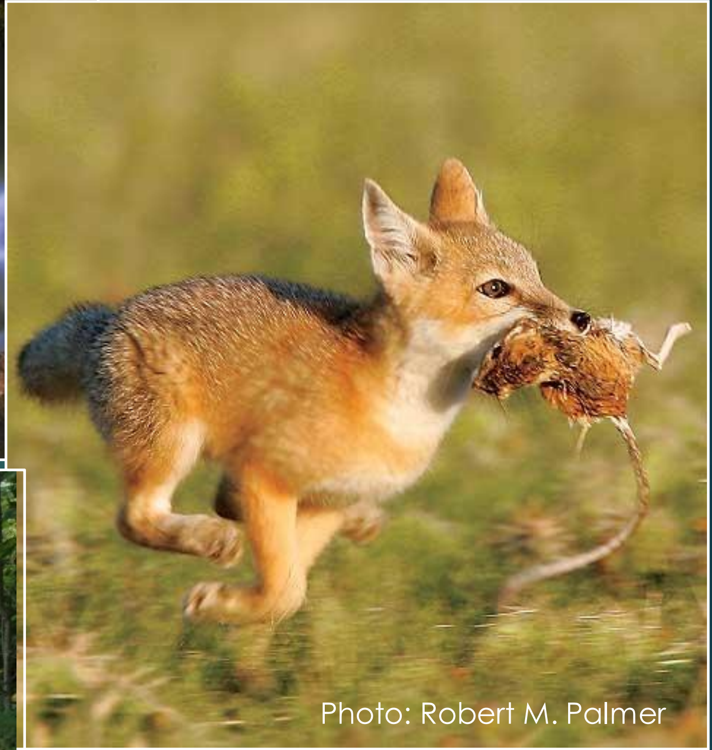
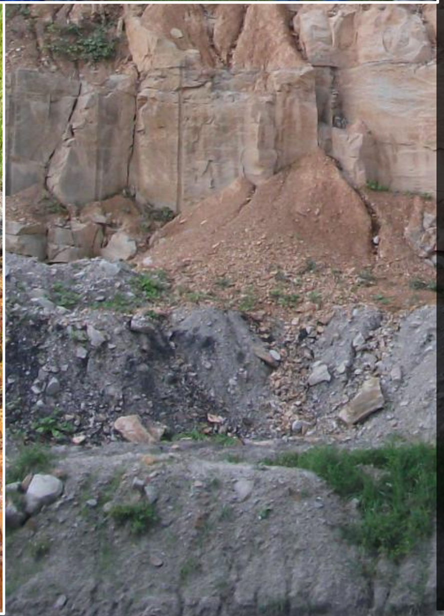


Photo: Robert M. Palmer


Photo: Bob Beyfuss

Background: Coal Mine Reclamation



- Pre-1977: No federal reclamation/reforestation requirements
- Some reforestation work, but…
  - Many highwalls left
  - Unstable slopes
    - Landslides, large rockfalls, subsidence
  - Impacts to water quality
    - Sedimentation
    - Acid mine drainage
    - Salts, heavy metals

Top left M. Crawford 2014; top right Appalachian Voices 2009; bottom J Skousen; background WL Daniels

Background: Surface Mine Control and Reclamation Act (SMCRA, 1977)

Photo: WL Daniels - Highwall-bench-outslope landform in SW Virginia. Unstable outslopes such as these caused water quality degradation.

- Federal law requiring environmentally responsible coal mining and reclamation, as well as began program for reclamation of abandoned mine lands
- Focus on soil stabilization and water quality

Background: Grassland Replacement Approach (1977-2007)

Goal: Hayland-pasture, unmanaged forest

Background: Coal Mine Succession

- Unmanaged grasslands succumb to scrub
- Dominated by exotic, invasive species
  - Often planted purposefully – dense cover to reduce erosion (Zipper et al. 2011)
- Many former coal mines in arrested succession (Fields-Johnson 2011, Pericak et al. 2018, Zipper et al. 2021, Putnam 2025)

Background: Reclamation Before/After SMCRA

Typical pre-SMCRA mined lands above and post-SMCRA mined lands below

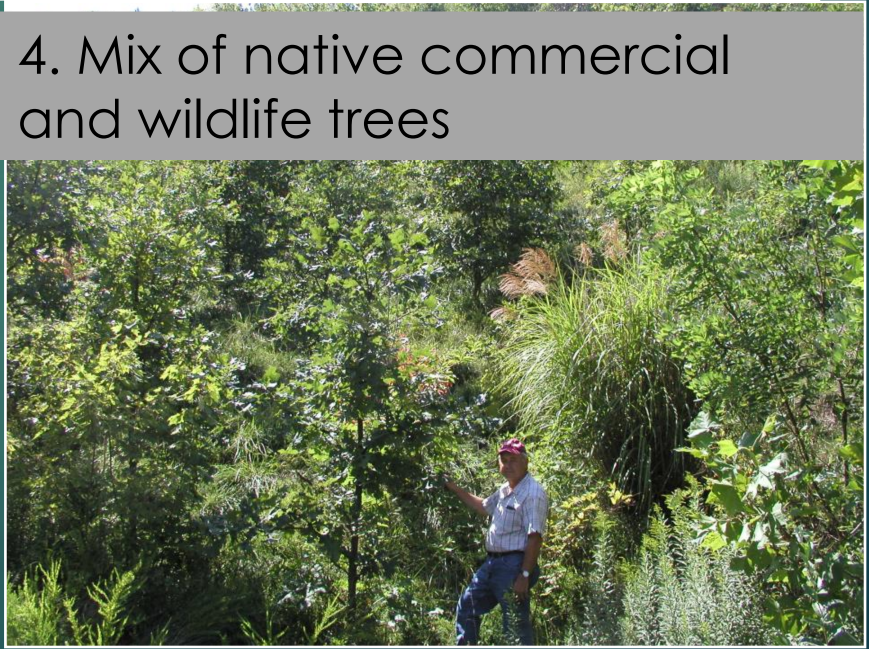
Background: Forestry Reclamation Approach

1. 4’ of topsoil, weathered sandstone, or best available material

2. Site preparation: loose, uncompacted surface

3. Tree-compatible ground cover
5. Proper tree planting (e.g. professional tree planters)

4. Mix of native commercial and wildlife trees



(Burger et al. 1992, Burger et al. 2005, Burger and Zipper 2011)

Methods: Study Goals

- Experiment established between 2007-2008 to test grading x seeding treatments (Fields-Johnson 2011)
  - Quantify tree community composition in grading x seeding treatments

Methods: Study Setup

- Graded/seeded by winter 2007/2008
- Block characteristics
  - Block 1 weathered/unweathered SS
    - pH 5.51 to 5.96
    - Southerly aspect
  - Block 2 unweathered SS, SiS, Sh
    - pH 7.46 to 8.10
    - Easterly aspect
- Plots 1-3 Loose, plots 4-6 Smooth

(Fields-Johnson 2011)

Methods: Study Setup

- Three seed mixes
  - AR (1 & 6): Annual rye
  - CON (2 & 4): Conventional mix (including orchardgrass, Korean lespedeza)
  - TC (3 & 5): Tree compatible mix (lower SR, non-competitive species)

Methods: Tree Planting

- Trees professionally planted as bare-root seedlings in winter 2007/2008; 2nd planting in 2009
- Mix of chestnuts (AC, CC, hybrids) planted into Loose plots

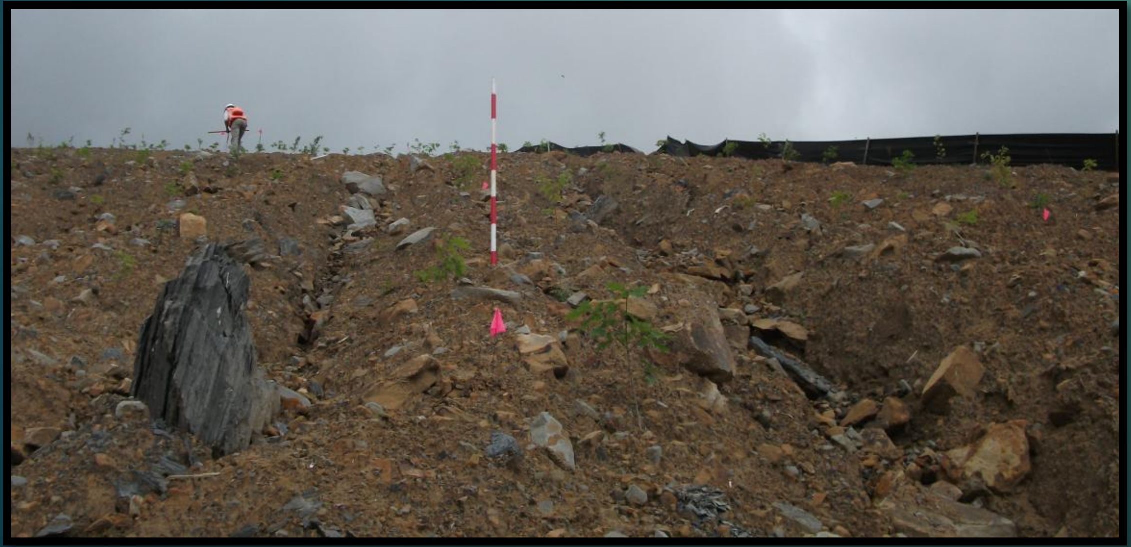
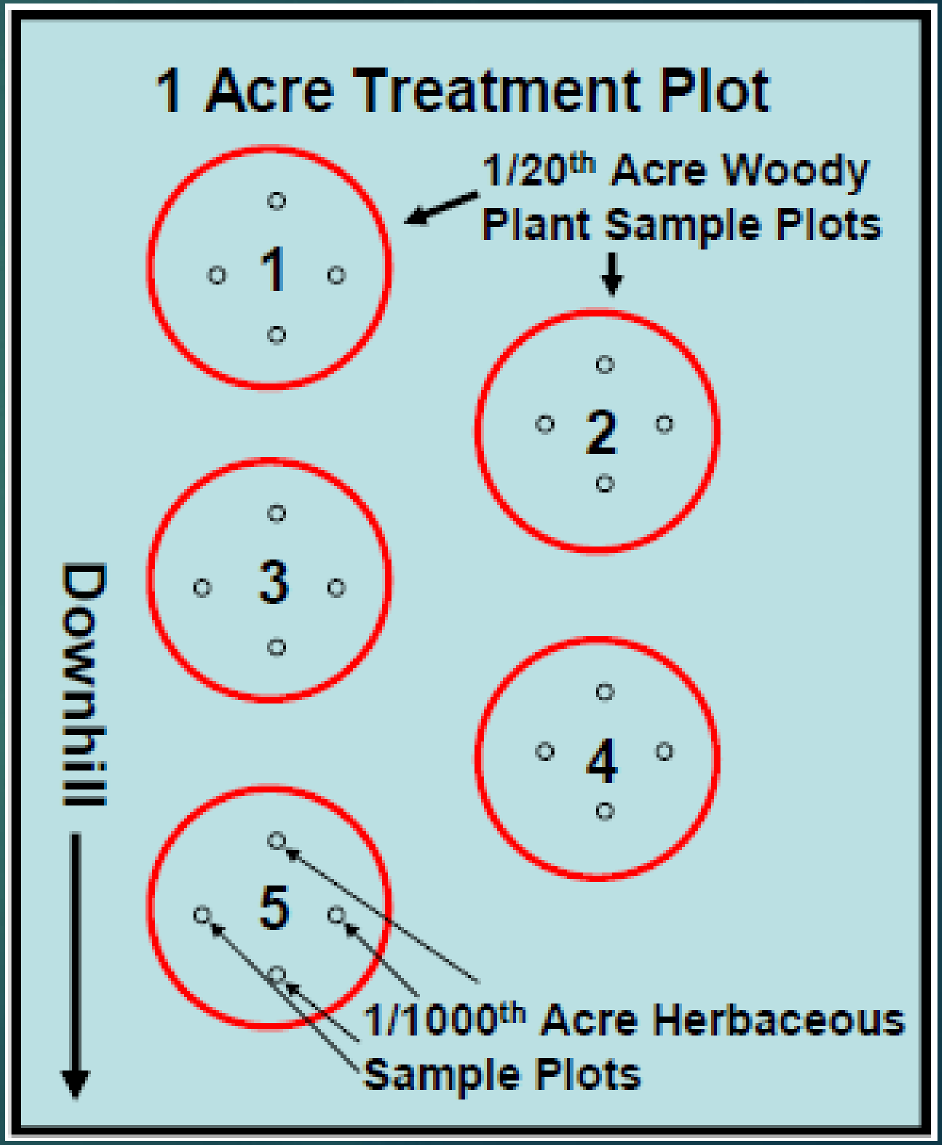


Photo credit: S. Klopf

Species types and species	Planting density
<u>Crop Tree Species</u>	Trees/ha
White ash (*Fraxinus americana*)	205
White oak (*Quercus alba*)	205
Sugar maple (*Acer saccharum*)	205
Black cherry (*Prunus serotina*)	205
Red oak (*Quercus rubra*)	205
Chestnut oak (*Quercus prinus*)	205
Black oak (*Quercus velutina*)	205
Tulip poplar (*Liriodendron tulipifera*)	124
<u>Wildlife and Nurse Tree Species</u>	
Gray dogwood (*Cornus racemosa*)	54
Red mulberry (*Morus rubra*)	25
Redbud (*Cercis canadensis*)	54
White pine (*Pinus strobus*)	91
Shagbark hickory (*Carya ovata*)	62
TOTAL	1845

Methods: Plot Measurements

- Five 0.05 ha tree plots established in 2008 in each grading x seeding treatment plot
  - Corners and plot centers relocated (re-monumented as needed)
  - Spring 2025: cover x species
  - Richness and S-W diversity calculated from cover data
    - Native vs. non-native richness and cover calculated
    - Diversity calculated for overall plots (few NN species in relatively few plots



Results: Early Survival and 2025 Canopy Cover

	2008 Planting Rate	2008 Survival	2009 Planting Rate	2009 Survival	2014 Survival	2025 Mean Canopy
Species	trees ha^{-1}	%	trees ha^{-1}	%	%	%
Gray Dogwood	54	50	27	113	950	11
Eastern White Pine	91	6	85	127	143	10
Tulip-poplar	124	27	91	71	80	9
White Oak	205	58	86	73	77	6
Black Cherry	205	45	112	79	90	6
Red Oak	205	43	117	53	39	5
Black Oak	205	32	140	95	68	3
Redbud	54	50	27	66	67	3
White Ash	205	67	67	68	90	3
Sugar Maple	205	14	177	51	58	3
Chestnut Oak	205	33	138	57	57	2
Red Mulberry	25	49	13	87	117	1
Shagbark Hickory	62	4	59	18	31	1
Total / Average	1,845	39	1,139	74	135	63

- Low early survival in 2008; replanted in 2009 resulting in improved survival and significant cover in 2025

Results: General Observations

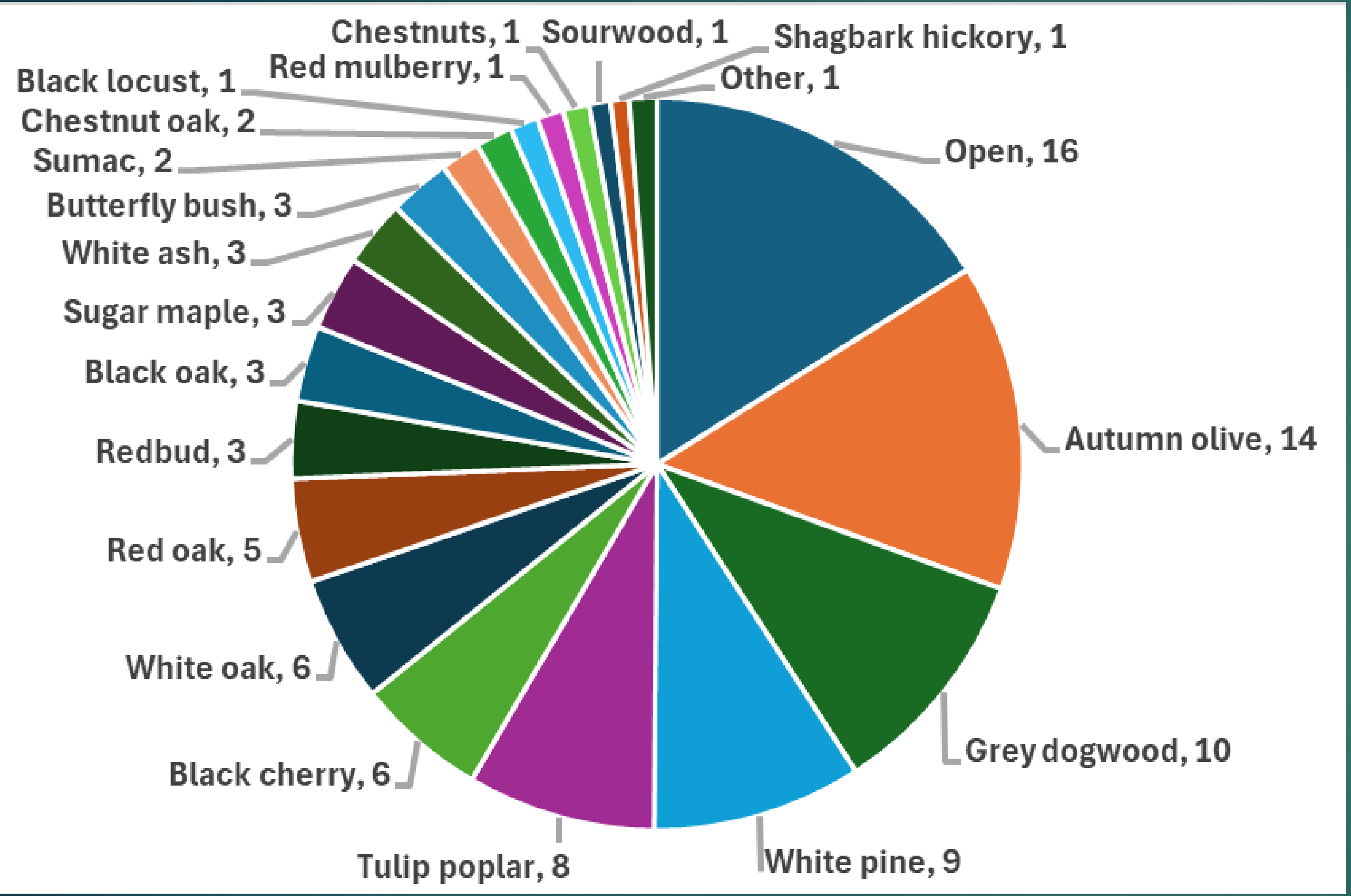
- Overall, B1 plots at/near closed canopy; B2 much more open
- Native volunteers
  - Sourwood (B1); staghorn sumac (B2); black locust (B2)
- Non-native volunteers
  - AO (B2); butterfly bush (B2)

Photos: NC arboretum; University of Minnesota Extension, Oregon State University Extension, The Nature Conservency

Results: General Observations

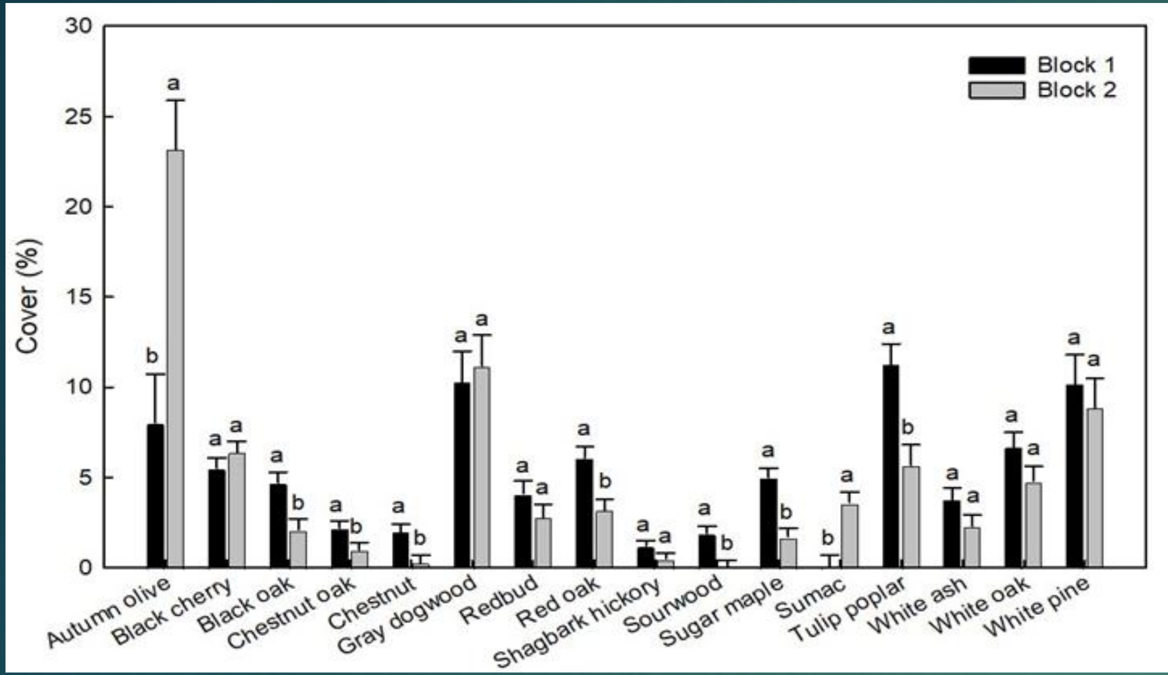
- Significant browse (elk, white-tailed deer) in Block 2, particularly in Loose-graded plots
  - Which came first?
    - Lower tree establishment and higher grass cover more attractive to grazers?
    - More grazers reduced tree growth such that grasses, etc. were not shaded out?

Results: Community Composition



- All planted species still surviving within plots
- Additional species volunteering on site
  - Native: sourwood, black locust, staghorn sumac
  - Non-native: autumn olive, butterfly bush

Results: Block Effects



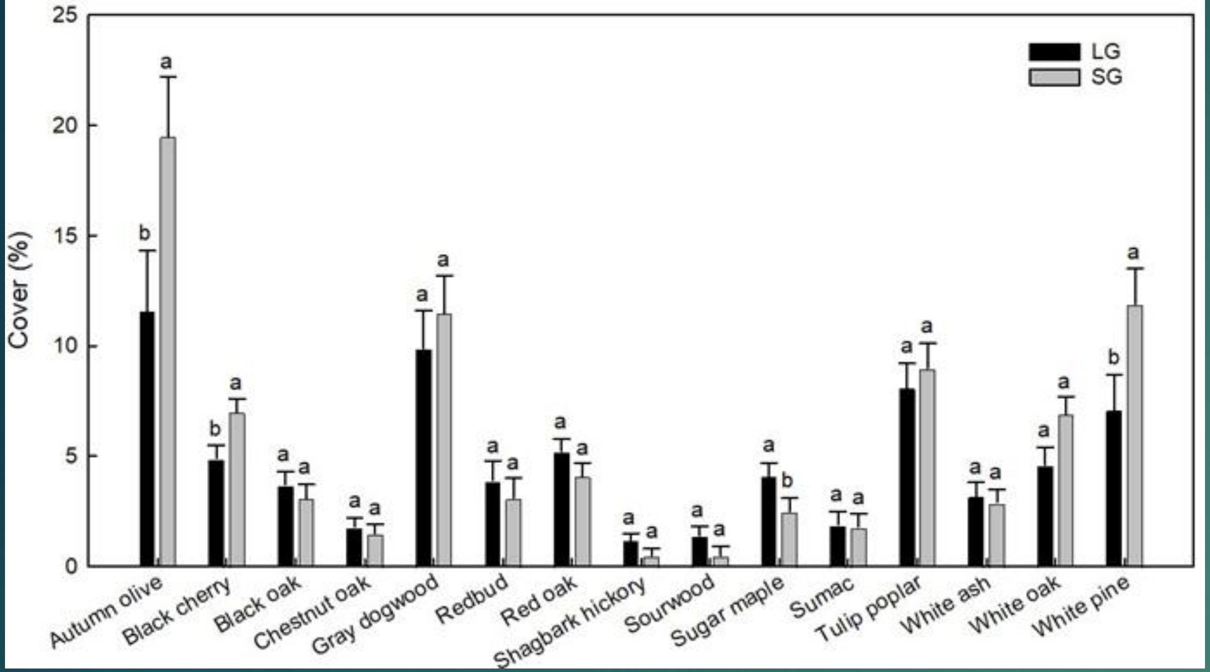
		Native	Non-native
Richness (S)	Block 1	11.4 ± 0.4 a	1.0 ± 0.2 b
	Block 2	9.7 ± 0.4 b	1.5 ± 0.2 a
Diversity (H')	Block 1	2.2 ± 0.0 a	
	Block 2	1.9 ± 0.0 b	
Cover (%)	Block 1	77.6 ± 2.7 a	8.7 ± 2.7 b
	Block 2	58.4 ± 2.7 b	28.8 ± 2.7 a

- 6 native species, including volunteer sourwood ($p<0.05$) higher cover in B1; chestnuts higher cover in B1 ($p<0.05$); AO and staghorn sumac ($p<0.001$) higher in B2

- Native richness ($p=0.002$), native cover ($p<0.001$), and diversity ($p<0.001$) higher in B1

- Non-native richness ($p<0.001$) and cover ($p<0.001$) higher in B2

Results: Grading Effects

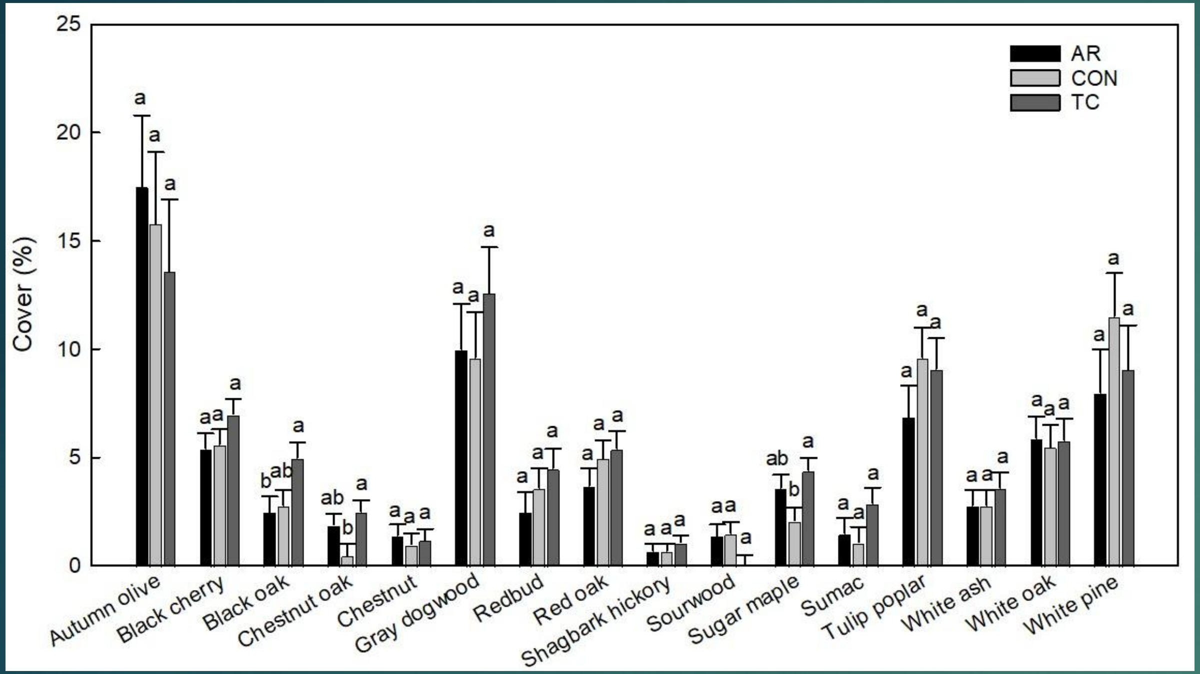


<table>
<tr><th></th><th></th><th>Native</th><th>Non-native</th></tr>
<tr><td rowspan="2">S</td><td>LG</td><td>11.3 ± 0.4 a</td><td>1.3 ± 0.1 a</td></tr>
<tr><td>SG</td><td>9.8 ± 0.4 b</td><td>1.2 ± 0.1 a</td></tr>
<tr><td rowspan="2">H'</td><td>LG</td><td colspan="2">2.1 ± 0.1 a</td></tr>
<tr><td>SG</td><td colspan="2">1.9 ± 0.1 a</td></tr>
<tr><td rowspan="2">Cover (%)</td><td>LG</td><td>67.0 ± 3.3 a</td><td>16.5 ± 3.0 a</td></tr>
<tr><td>SG</td><td>69.0 ± 3.3 a</td><td>21.0 ± 3.0 a</td></tr>
</table>

- Higher sugar maple cover in Loose grade ($p=0.032$)
- Higher AO ($p=0.044$), black cherry ($p=0.015$, white pine ($p=0.037$)cover in Smooth grade
- Loose graded plots in Block 2 HEAVILY grazed

- Higher native richness in Loose grade

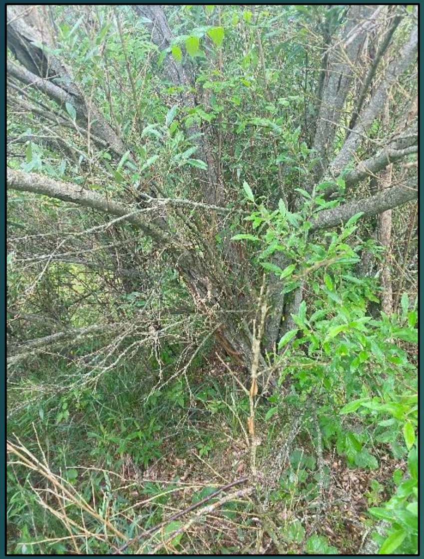
Results: Seeding Effects



		Native	Non-native
S	AR	10.0 ± 0.6 a	1.2 ± 0.1 a
	CON	10.6 ± 0.6 a	1.3 ± 0.2 a
	TC	11.2 ± 0.5 a	1.3 ± 0.1 a
H'	AR	2.0 ± 0.1 a	
	CON	2.1 ± 0.1 a	
	TC	2.2 ± 0.1 a	
Cover	AR	61.1 ± 5.1 b	22.9 ± 5.3 a
	CON	65.3 ± 4.9 ab	18.6 ± 3.4 a
	TC	77.5 ± 3.6 a	14.7 ± 3.9 a

- Highest black oak, chestnut oak, and sugar maple cover in TC seeding treatment
- Higher native cover in TC treatment, not different from CON
- Difs in communities not always significant, but there did appear to be advantages to TC (lower NN cover, higher diversity, etc)

Results: Other Observations





- Novel pathogen observed affecting AO on this site
  - Causing significant mortality of AO on this site
  - Overall effects on the plant communities unknown, but we intend to study this
  - Currently being studied in more detail - see my other talk for more details!

Plot Photos: Loose Grade, Annual Rye

2009

2025

Block 1

Block 2

Plot Photos: Loose Grade, Conventional

2009

2025

Block 1

Block 2

Plot Photos: Loose Grade, Tree Compatible

2009

2025

Block 1

Block 2

Plot Photos: Smooth Grade, Annual Rye

2009

2025

Block 1

Block 2

Plot Photos: Smooth Grade, Conventional

2009

2025

Block 1

Block 2

Plot Photos: Smooth Grade, Tree Compatible

2009

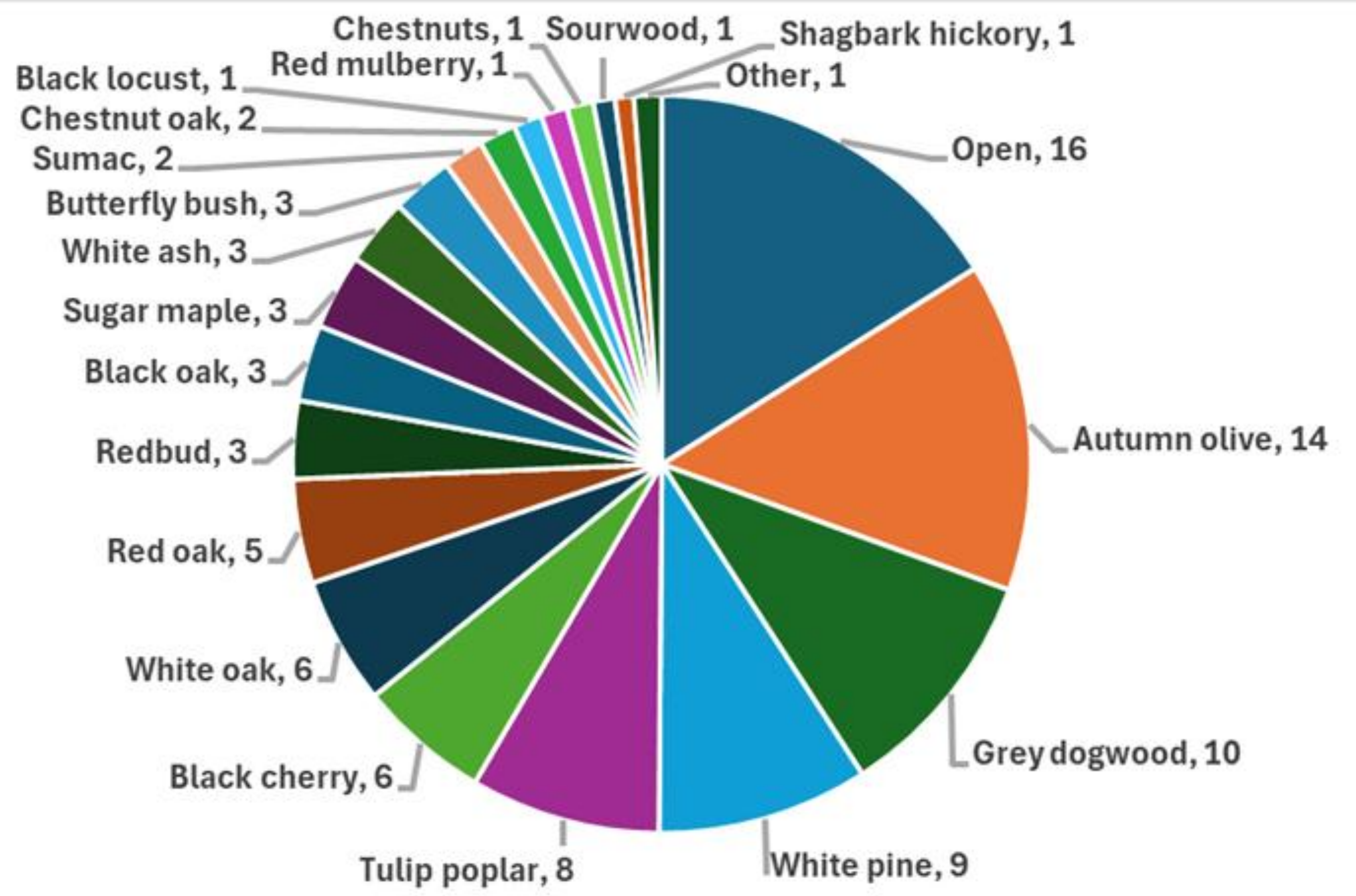
2025

Block 1

Block 2

Summary and Discussion

- All planted woody species found alive after 17 years is significant
  - Replanting to compensate for early mortality is a practice worth studying
  - Volunteers– more native volunteers in B1, more non-native volunteers in B2



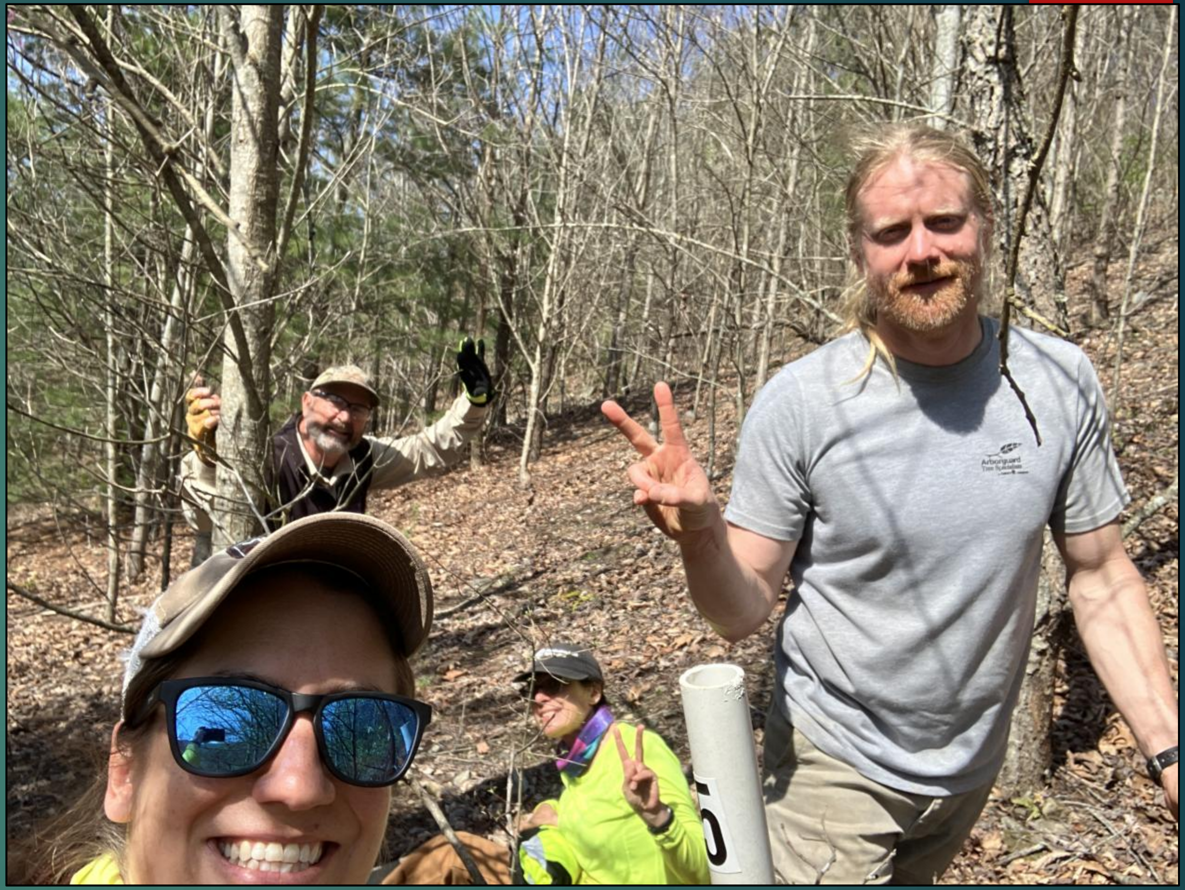
Summary and Discussion

- Some differences among grading treatments
  - Greater native woody richness in Loose and more recruitment of native volunteers
  - Smooth grading not aggressive enough to elicit differences?
    - Db/compaction not measured
- Some differences among seeding treatments
  - Higher native canopy cover in TC than AR
  - Higher cover of black oak, chestnut oak, and sugar maple in TC
  - While not always significant, there did appear to be advantages to the TC mix in early forest development (Franklin and Buckley 2006, Rizza et al. 2007, Franklin et al. 2012)
  - Other studies have shown growth medium can be more influential during early establishment (Kost and Vimmerstedt 1994)

Summary and Discussion

- Strong differences between Blocks
  - B1: Higher N richness and cover, higher diversity, higher cover of several native trees (and chestnuts)
  - B2: Higher NN richness and cover
- Why?
  - South (Block 1) vs. East (Block 2) aspects?
    - More water stress at S aspects, lower productivity (Burger et al. 2002, Burger and Zipper 2011, Davis et al. 2012)
  - Different spoil types (better pH, more weathered materials, and more fine materials (<2 mm) in Block 1) (Burger et al. 2002Angel 2008, Fields-Johnson 2011, Skousen et al. 2011, Sena et al. 2015)

Thanks!



Field assistance:

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Any Questions??

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