

# Digital Soil Assessment of Landscape-Scale Forest Restoration Using a Species Distribution Model

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# Red Spruce Ecosystem

- Historic extent: ~600,000 ha in West Virginia (Rentch 2007)
  - Extensive logging in between 1860's and 1920's removed much of the spruce forests
  - Wildfires, pests, and conversion to pasture hindered spruce regrowth
- Current extent: ~24,000 ha in West Virginia (Adams et al. 2001)
  - One of the most endangered forest types in Central Appalachians (Noss et al. 1995)



# Red Spruce Restoration

- Red spruce forests provide multiple ecosystem services
  - Water storage
  - Soil carbon sequestration
  - Habitat for sensitive, threatened, and endangered species
- Broad interest in restoring red spruce forests
  - State and federal governments and non-governmental organizations
  - Focus on landscape connectivity



# Pedoeological Mapping

- Ecosystem-level state factor model (Jenny 1961, 1980)

$$l, v, s, a = f(L_0, P_x, t)$$

- Soils and vegetation community co-evolve
  - Similar drivers
  - Strong interactions
- Disturbance can degrade spodic horizons
  - Depodzolization



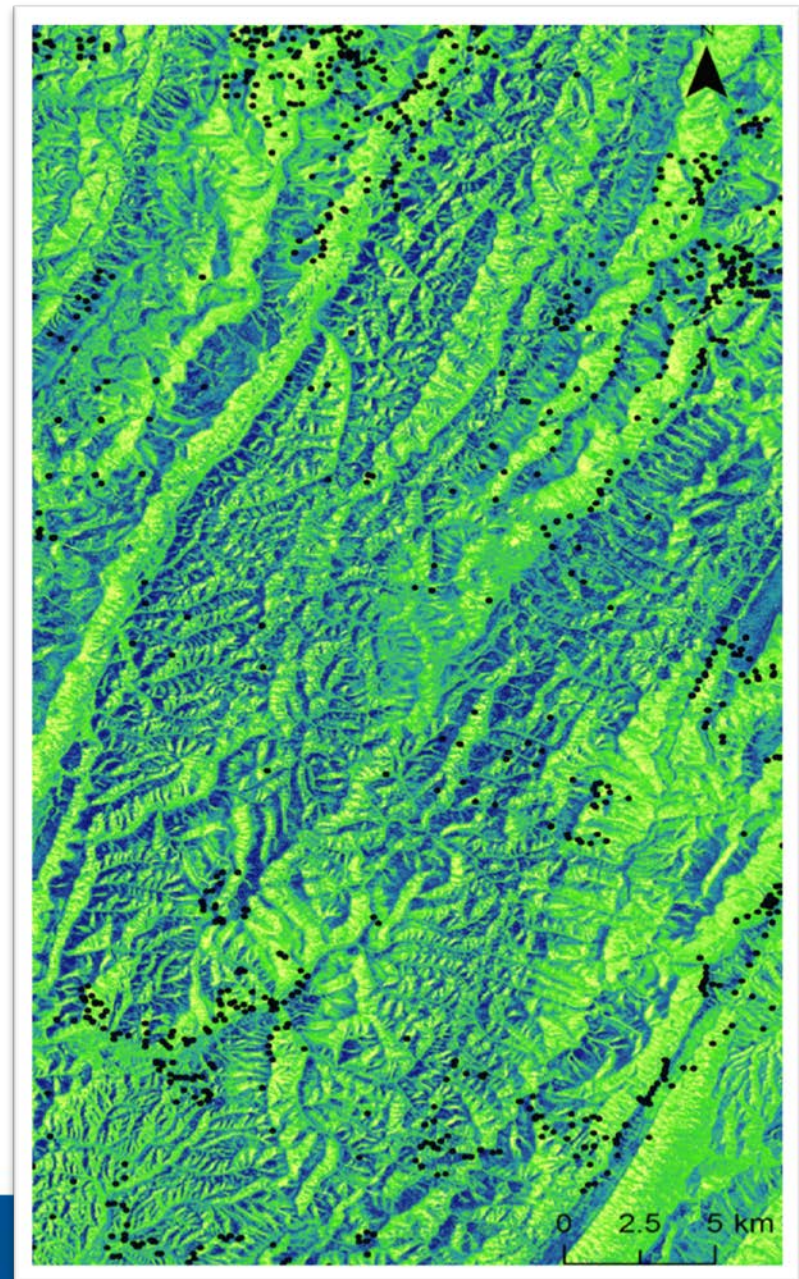
# Impetus for Research

- Observed spodic soil properties reflect greater conifer extent before “Great Cut” (1860’s-1920’s)
  - Recent observations in West Virginia indicate greater distribution of spodic soil properties than existing inventories
- Many areas now under hardwood that have spodic soils used to be conifer
  - disturbance has shifted community states
- Digital soil mapping methods can be employed to improve soil survey products (e.g., to guide forest management and restoration)



# Previous Work

- Random Forest (Nauman et al., 2015)
  - Full model (n=322)
    - Out Of Bag error = 29.5%
  - Independent validation
    - Training set (n=208)
    - Test set (n=114)
    - 0.57 probability threshold
    - Error = 30%
  - Independent plot data (n=24)
    - 88.1% accuracy
- 70-88% accuracy



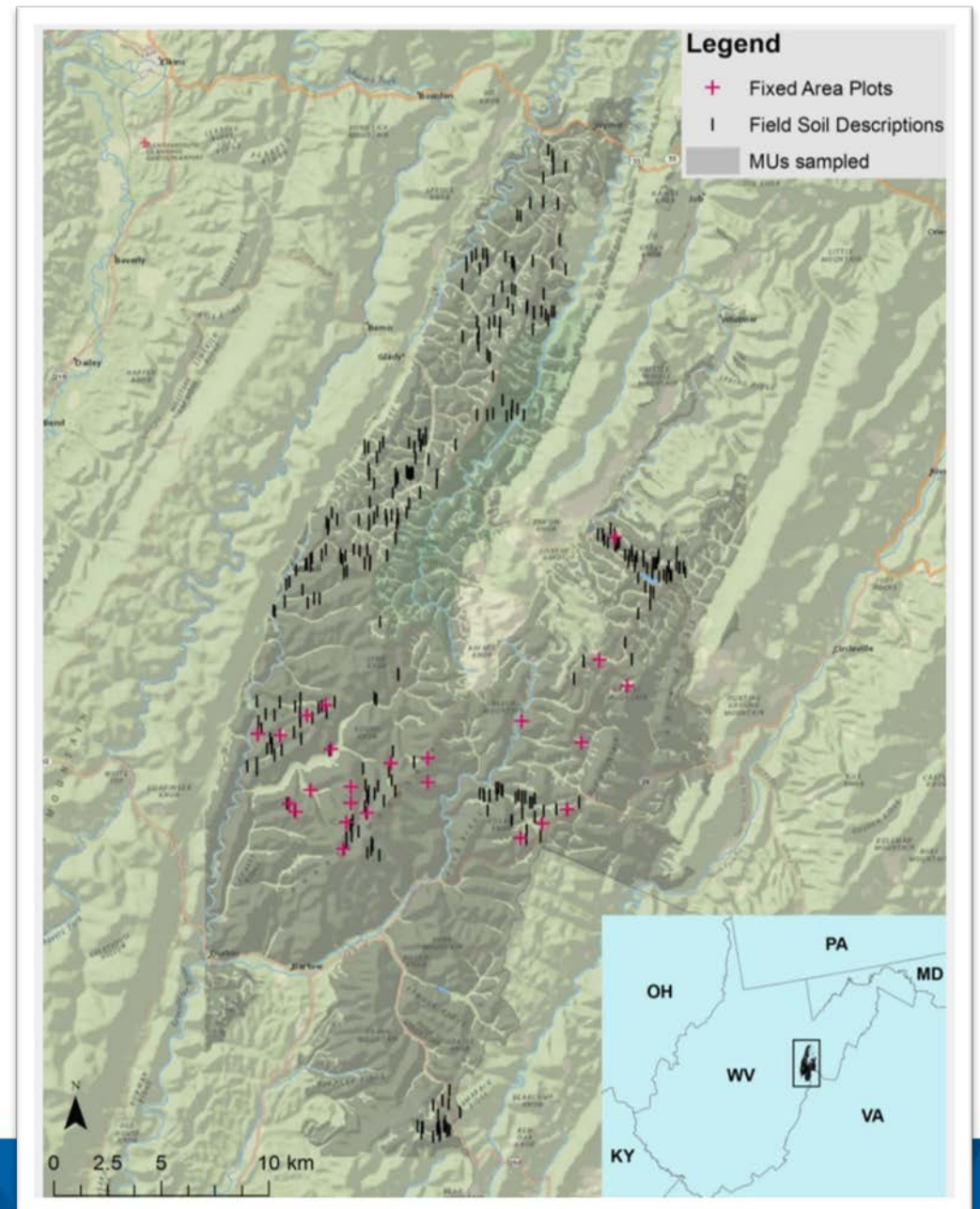
# Species Distribution Models

- Recent work by forest ecologists has led to the application of species distribution models (SDM) to predict the current (and future) geographic distribution of red spruce in the Central Appalachians
- SDM identify ~~species~~<sup>soil</sup>-environment relationships to estimate the geographic range of a species (Daniel 2014)
  - Based on the concept of the ecological niche
  - Derived from the environmental conditions where the ~~species~~<sup>soil</sup> is known to exist
  - Determine which environmental variables or conditions are important to the ~~species~~<sup>soil</sup>
- SDM → DSM



# Study Area

- Hardwood-conifer ecotone
  - Higher elevations (880-1320 m)
- Upland soil map units
  - Devonian-age acidic shale and siltstone
- Stratified random sample
  - Vegetation, slope gradient, slope curvature
  - 322 field soil profile descriptions
- Environmental variables
  - Topographic layers (30-m DEM)
  - Remote sensing layers (Landsat Geocover)
- Spodic expression



# Spodic Intensity (SI) Index

## Rating   Meaning

0.0   No evidence of podzolization

0.5   Very weak expression of podzolization

- There is only slight physical evidence of podzolization. A slightly darker spodic horizon is present at the top of the B horizon, but the hue is less than one Munsell hue redness. The spodic horizon is non-smeary.

1.0   Weak expression of podzolization (Cambisol)

- Spodic materials are present, but the diagnostic spodic horizon is weakly expressed. A weakly expressed Bs horizon is present. The Bs horizon is usually underlying horizon. Bhs material is usually absent. An albic E horizon is sometimes weakly smeary.

1.5   Moderate expression of podzolization (Umbrisol)

- Spodic materials do not meet the criteria for a diagnostic spodic horizon. A moderately expressed spodic horizon with pockets of Bhs material. An albic E horizon is not present. The spodic material is smeary.

2.0   Strong expression of podzolization (Spodosol)

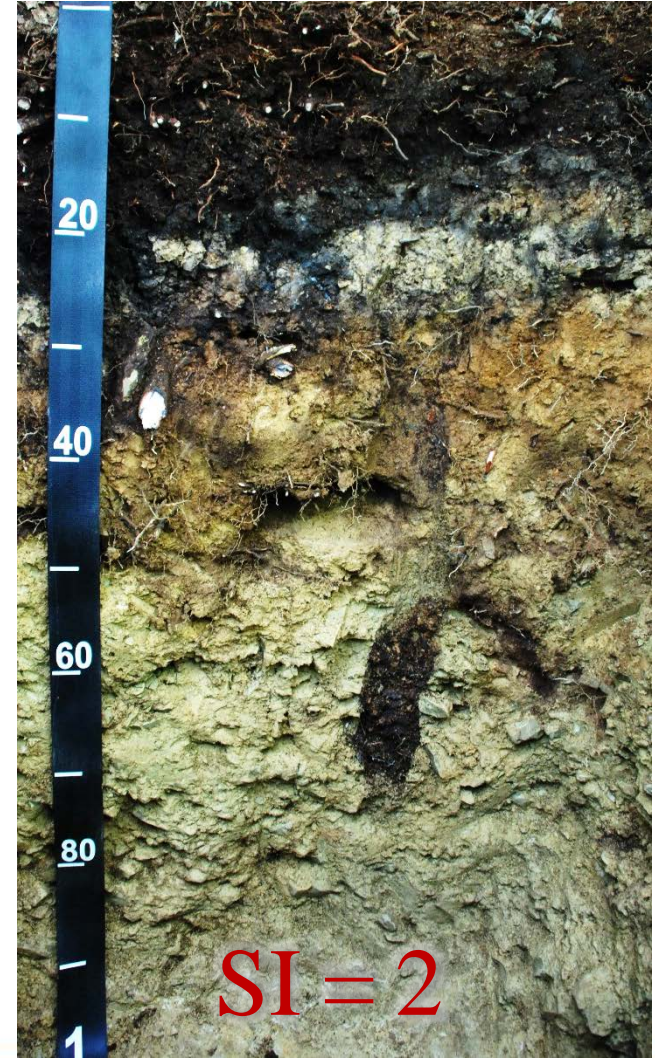
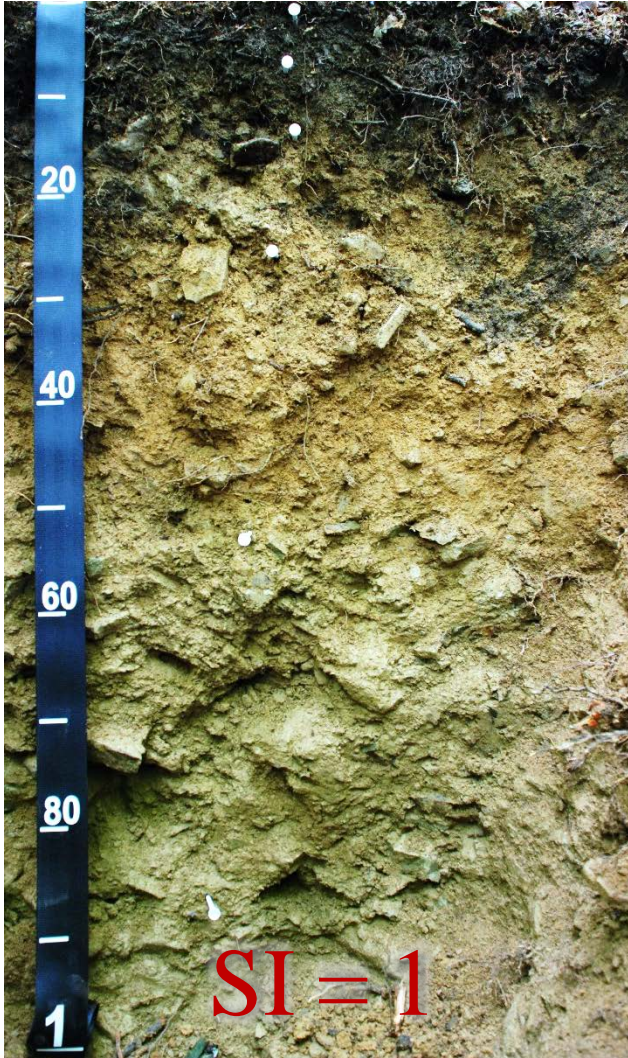
- A diagnostic spodic horizon is present usually underlying an albic E horizon. A Bhs or Bh horizon is continuous across at least 85 percent of the pedon. The spodic materials are often moderately smeary.

**Color, smeariness, presence and persistence of E/Bh/Bhs/Bs horizons**



# Spodic Intensity (SI) Index

SI = 0



# Maximum Entropy Species Distribution Modeling (MaxEnt)

- Bayesian
  - Identifies the geographic distribution using the constraints defined by the available data while making the fewest assumptions
- Presence-only data
  - Approximate the “fundamental niche” for spodic soil properties
  - Absence data may be problematic because of disturbance, depodzolization
- Environmental variables
  - Continuous (e.g., elevation)
    - Linear, quadratic, product, threshold, hinge
  - Categorical (e.g., geology)
- “MaxEnt is by far the most popular presence-only SDM in use today.”  
(Daniel 2014)

<http://www.cs.princeton.edu/~schapire/maxent/>



# Maximum Entropy Species Distribution Modeling (MaxEnt)

- Elith, J.E., J.R. Leathwick. 2009. Species distribution models: ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution and Systematics* 40: 677-697.
- Elith, J., Phillips, S.J., Hastie, T., Dudik, M., Chee, Y.E., and C.J. Yates. 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions*. 17: 43-57.
- Merow, C., M.J. Smith, and J.A. Silander. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography*, 36:1058-1069.
- Pearson, R.G. 2010. Species' distribution modeling for conservation educators and practitioners. *Lessons in Conservation*, 3: 54-89
- Phillips, S.J., Dudik, M., and R.E. Schapire. 2004. A maximum entropy approach to species distribution modeling. *In Proceedings of the 21st International Conference on Machine Learning*. ACM Press. New York. p 655-662.
- Phillips, S.J., Anderson, R.P., and R.E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling*. 190: 231-259.
- Phillips, S.J., M. Dudik. 2008. Modeling of species distributions with MaxEnt: new extensions and a comprehensive evaluation. *Ecography*. 31:161-5.



Maximum Entropy Species Distribution Modeling, Version 3.3.3k

**Samples**  
 File: alpresencedata\spodicpropsnotzero.c Browse

**Environmental layers**  
 Directory/File: on\Desktop\SI\_data\asciitravis\_covariates Browse  
 Continuous

aacn2  
 baselevel  
 contribar  
 converge  
 dem  
 eastness  
 green  
 Isfactor  
 mir  
 mrrtf  
 mrvbf

Linear features  
 Quadratic features  
 Product features  
 Threshold features  
 Hinge features  
 Auto features

Output directory: \Users\jathor  
 Projection layers directory/f

Run Settings Help

Maximum Entropy Parameters

Basic Advanced Experimental

Random seed  
 Give visual warnings  
 Show tooltips  
 Ask before overwriting  
 Skip if output exists  
 Remove duplicate presence records  
 Write clamp grid when projecting  
 Do MESS analysis when projecting

Random test percentage:   
 Regularization multiplier:   
 Max number of background points:   
 Replicates:   
 Replicated run type: Bootstrap

Test sample file:

Maximum Entropy Parameters

Basic Advanced Experimental

Add samples to background  
 Add all samples to background  
 Write plot data  
 Extrapolate  
 Do clamping  
 Write output grids  
 Write plots  
 Append summary results to maxentResults.csv file  
 Cache ascii files

Maximum iterations: 5000  
 Convergence threshold: 0.00001  
 Adjust sample radius: 0  
 Log file: maxent.log  
 Default prevalence: 0.5  
 Apply threshold rule:

Bias file:  Browse



# Model Evaluation

- Area Under the Curve
  - Plot of sensitivity vs. specificity
  - Number of presence points correctly predicted vs. number of absence points incorrectly predicted

*AUC = 0.957*



# Variable Importance

- All covariates
  - Elevation
  - Relative Height indices
  - TWI
  - Landsat bands (green, MIR, NIR)
  - Eastness
- Random Forest (Nauman et al., 2015)
  - Eastness, Northwestness
  - Landsat Middle Infrared band
  - Convergence
- Only terrain covariates
  - Elevation
  - Relative Height indices
  - TWI
  - Northwestness
  - Plan Curvature

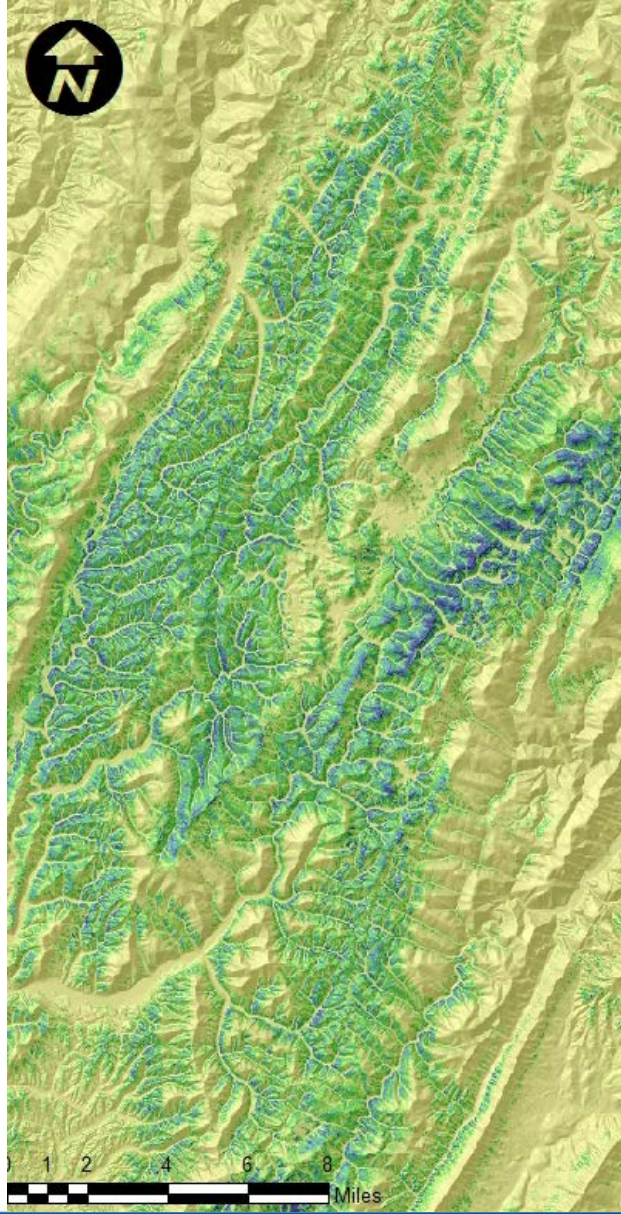


# Variable Importance

- Variable influence on model gain (improvement) when that only that variable is used or when only that variable is omitted



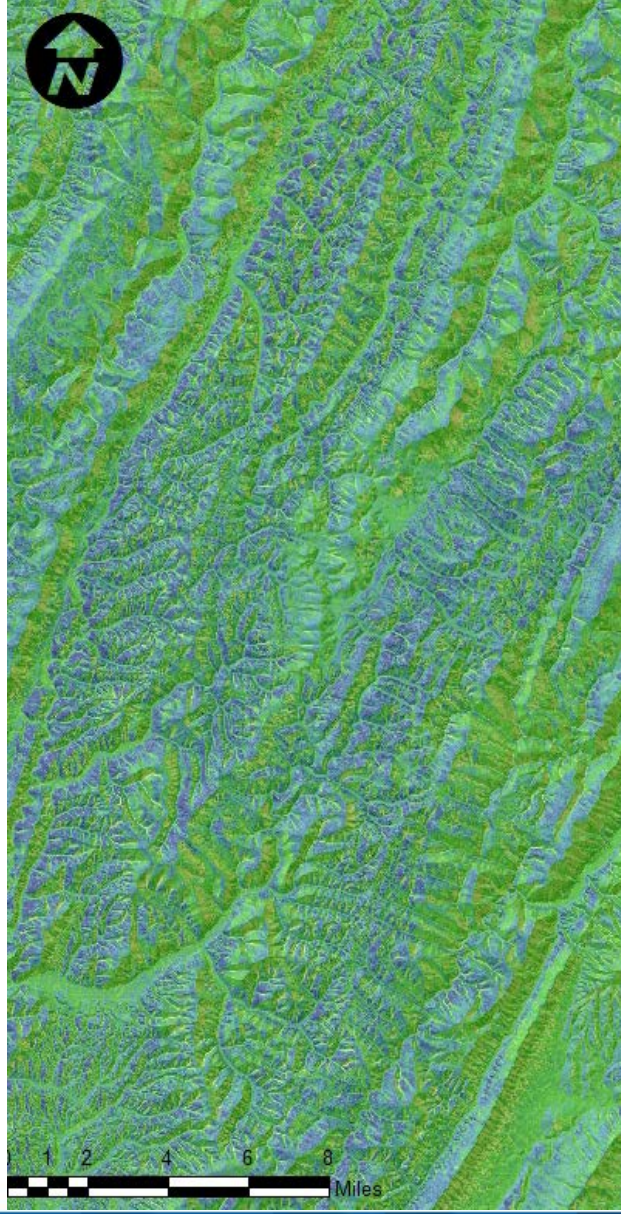
MaxEnt Model



Spodic Probability

1.0

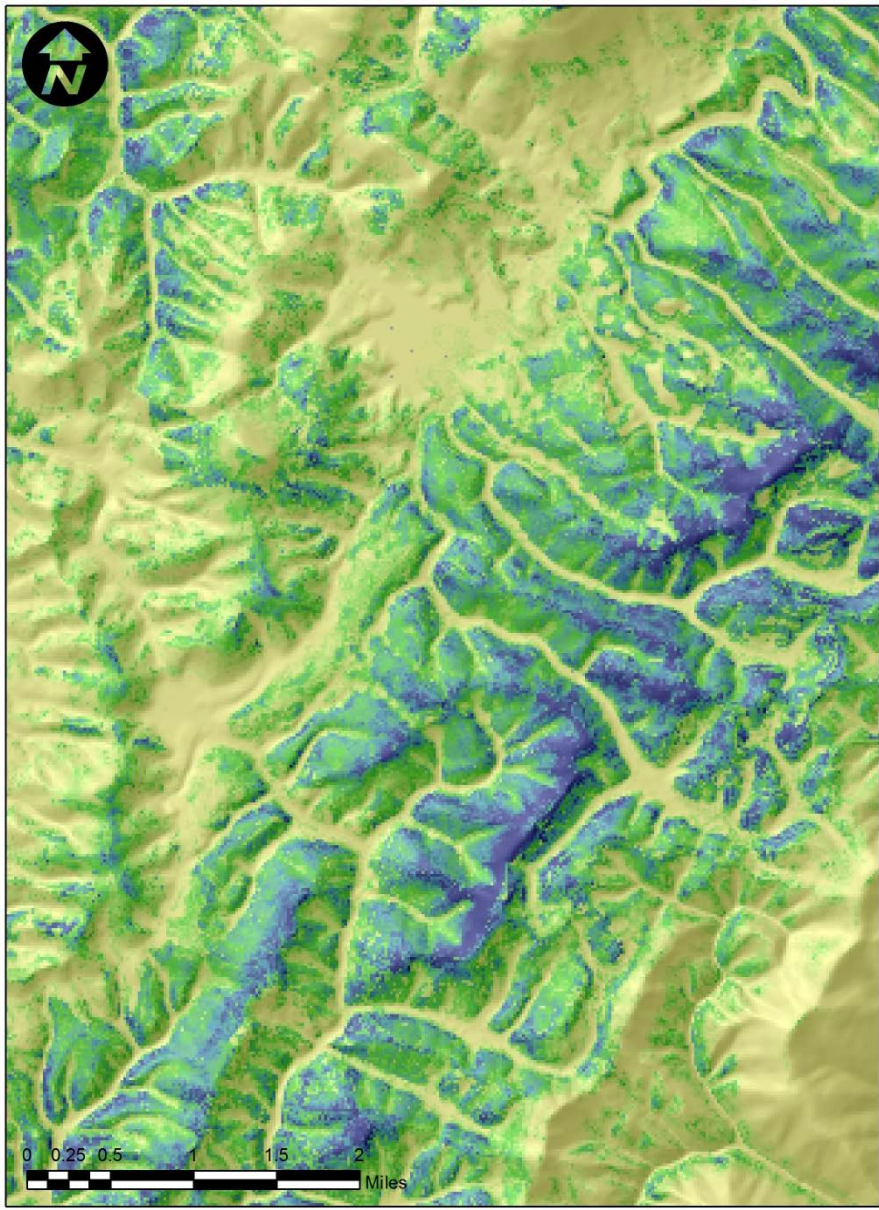
0.0



Random Forest Model (Nauman et al., 2015)



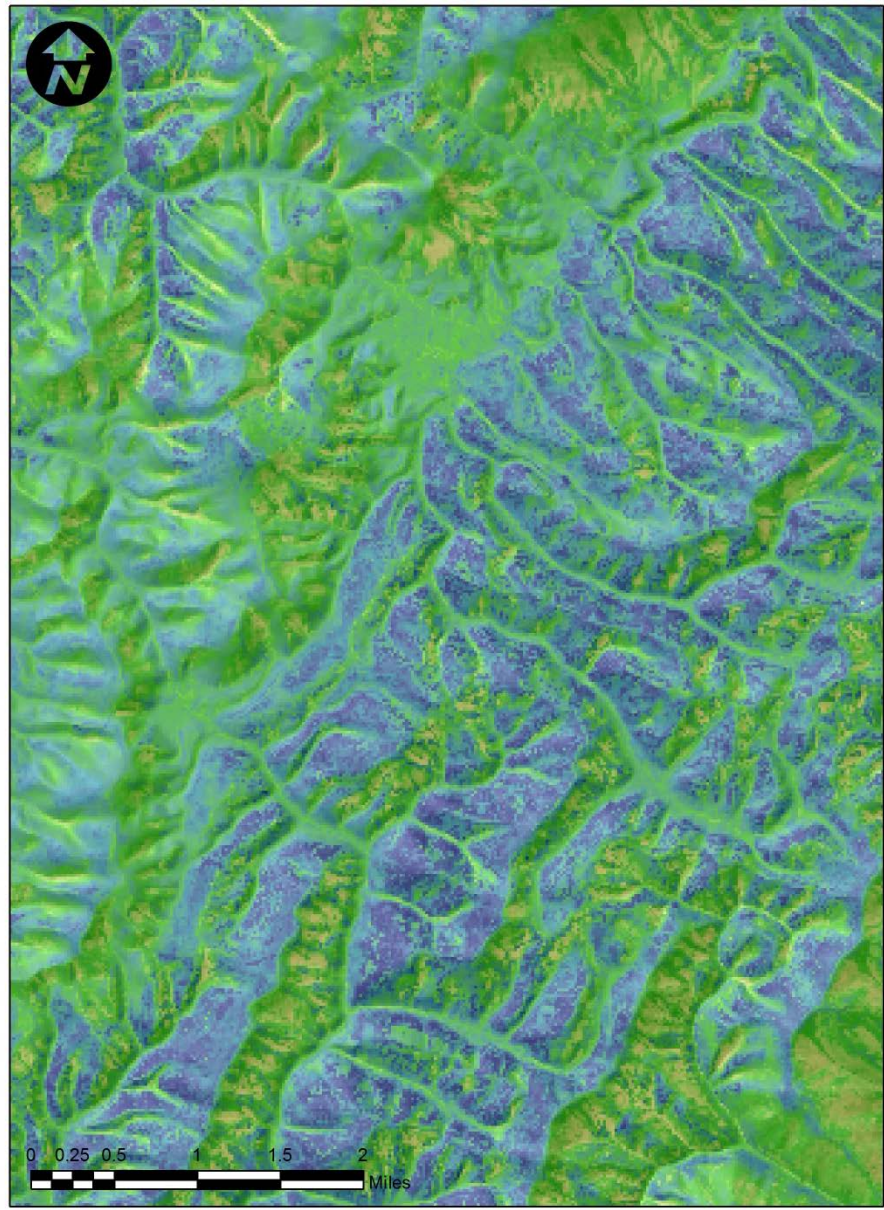
MaxEnt Model



Spodic Probability

1.0

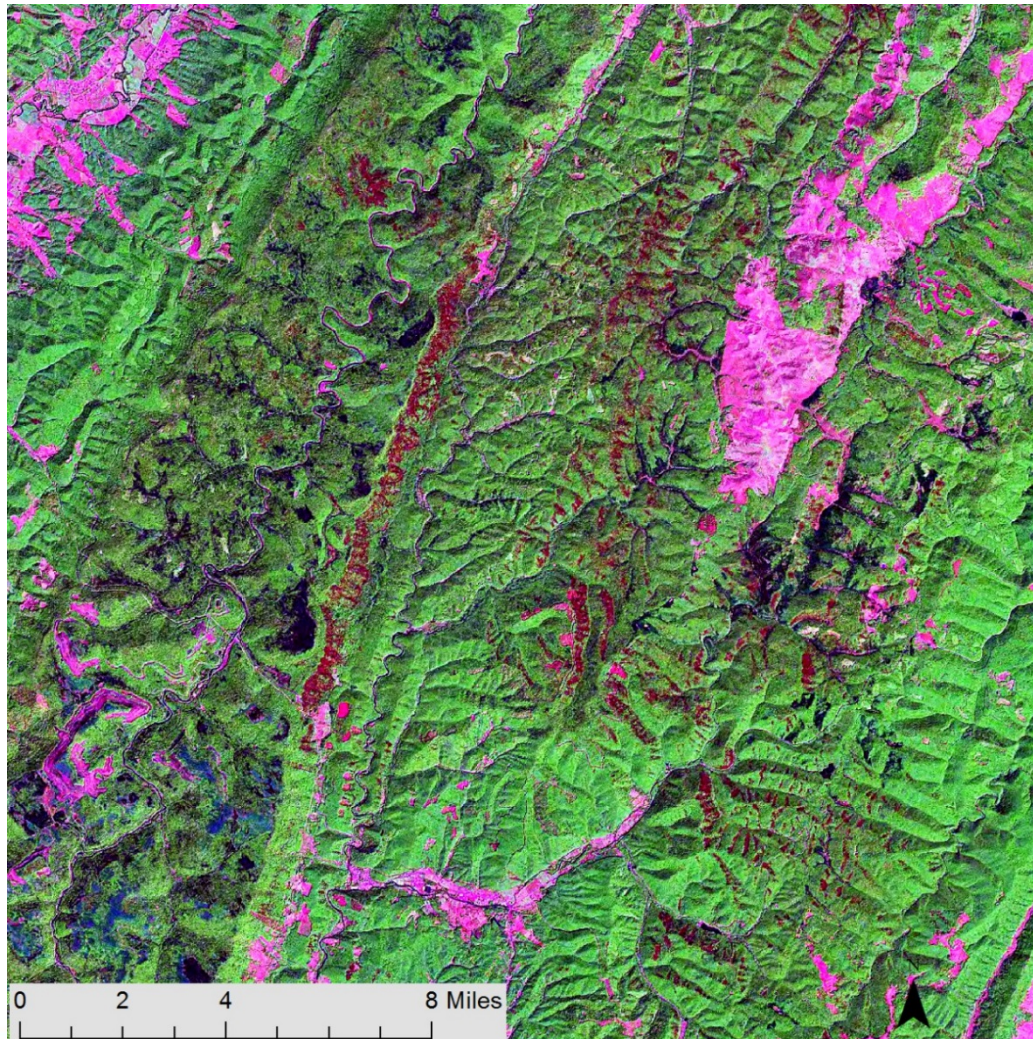
0.0



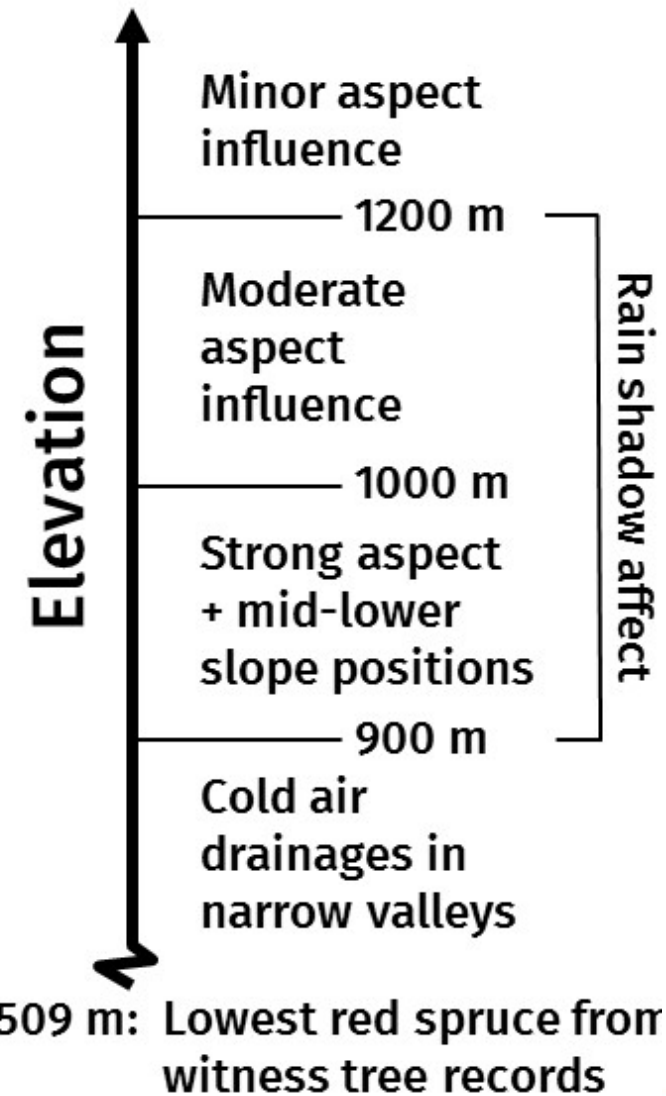
Random Forest Model (Nauman et al., 2015)



# (Historic) Spruce Distribution



>1300 m: Spruce most dominant



# Suitability for Red Spruce Restoration

