Provisional, Forested Ecological Sites in the Northern Appalachians and Their State-and-Transition Models

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Case Study

Provisional, Forested Ecological Sites in the Northern Appalachians and Their State-and-Transition Models

By Patrick J. Drohan and Alex W. Ireland

On the Ground

- The identification of unique areas of vegetative potential across the Northern Appalachians is complicated by a long land-use history of vegetation management.
- We introduce provisional ecological sites and associated state-and-transition models for the region, which can be differentiated by latitudinal drivers of: precipitation and temperature; local parent material and resulting soil differences; and landscape position, slope, or aspect.
- Identification of ecological sites and associated States or Phases in the Northern Appalachians provides land managers with quantifiable benchmarks for assessing forest compositional shifts due to natural or anthropogenic disturbance.

Keywords: forest, ecological site, Appalachian.

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The development of provisional ecological sites (ESs) in the northern Appalachians is an important step toward helping land managers better understand the changing dynamics in forested communities as a host of human-induced and naturally occurring stressors act upon forest composition. We developed a methodology that objectively identifies provisional ESs for the Northern Appalachians,[1] and thus provides a starting point for within-area analysis of ESs at finer resolutions.

In brief, our analysis encompassed an 815,000 ha area of the Northern Appalachians and was confined to lands owned by the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry (Fig. 1A). The Bureau of Forestry maintains an active survey of plant communities across the study area (Table 1). These plant community data were used in conjunction with topographic, soil and climate data in a hierarchical cluster analysis and a principal components analysis to develop provisional ESs (Figs. 1B-1E) across Major Land Resource Areas 124, 127, 130A, 140, and 147 (Fig. 1F). All geospatial variables used are available in public data sources and are commonly used in a variety of peer-reviewed literature. Soil variables were derived from a State Soil Geographic (STATSGO)-based dataset, Conterminous United States Multi-Layer Soil Characteristics (CONUS-SOIL).[2] Five topographic variables were calculated from a 30-m digital elevation model (elevation, topographic position index, slope, curvature, and folded aspect). Climatic variables (mean annual temperature and annual total precipitation [1981-2013]) were drawn from the 4-km resolution PRISM model output.[i]

Ecological Sites and State-and-Transition Models

The provisional ESs (ES1-ES5) are presented in Figure 1 while state-and-transition models for each ES are presented in Figures 2-5. Table 2 presents the abiotic soil and climate variables across ESs. The Pennsylvania Department of Conservation and Natural Resource community codes[3] are used in each state-and-transition model and correspond to those used in the ES methodology paper.[1] Note that the vegetation communities include substantially larger species assemblages than the names imply. This species list can include understory forbs and/or herbaceous species and mid-canopy species in addition to the overstory dominants for which the communities are typically named.[3] Very limited research has occurred in this region with respect to delineation of ESs and development of associated state-and-transition models. Thus, the preliminary models presented herein use "Phases" as opposed to "States," which reflects uncertainty around potential rates and reversibility of shifts in forest communities within these landscapes. Wetland and riparian areas of the study region were excluded because the forest community data focus on potential timber stands and thus are poorly resolved in these

[i] PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu.

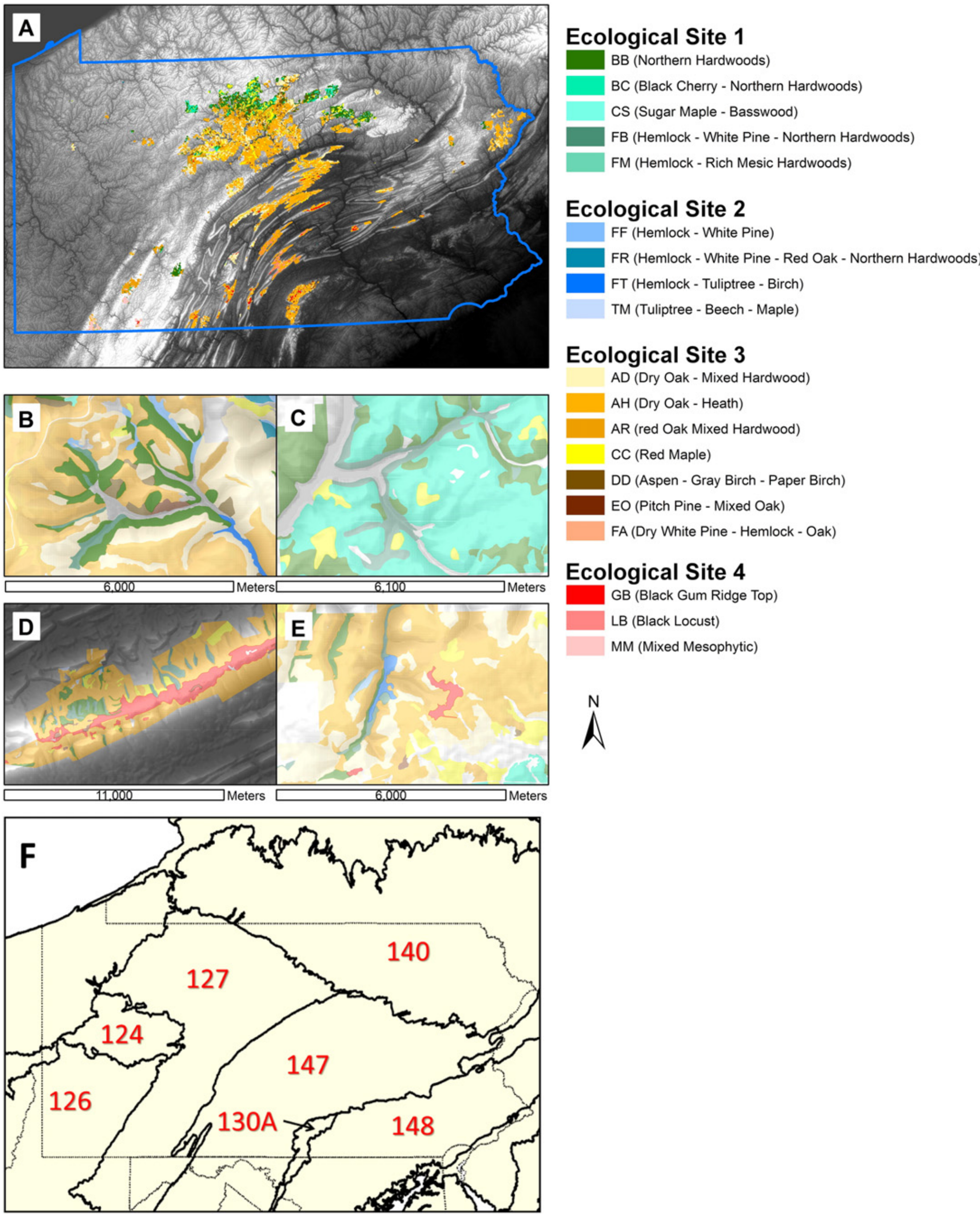

Figure 1. A, Provisional ESs on Pennsylvania state lands and their respective species groups. Figures **B** through **E** show selected local views of groups (60% transparency) overlying the digital elevation model used in analysis. **B**, ES3 on the southern Allegheny Plateau. **C**, ES1 on the northern Allegheny Plateau. **D**, ES3 and ES4 in the Ridge and Valley. **E**, A mixed area on the eastern Allegheny Plateau. **F**, Study Major Land Resource Areas. (Modified from Ireland and Drohan.[1])

settings. Lastly we excluded a barren/urban/suburban/disturbed lands State/Phase and an agricultural Phase for any of our models because they are obvious and ubiquitous.

The four provisional ESs can be differentiated by latitudinal drivers of precipitation and temperature, local parent material and resulting soil differences, and landscape position, slope, and aspect (Table 2). ES1 is typical of northern hardwood dominated forests and occurs on deep, higher-pH soils, steep slopes, and at high elevations. More southern latitudes will have ES1 on north or east facing slopes. ES2 is characterized by mesic, hemlock-dominated forests and can be found at low elevations or in low landscape positions on concave landforms. Silty soils are common and the ES is best represented on north or east facing slopes. ES3 is dominated by dry upland oak–maple–hemlock hardwood forests. ES3 occurs at high elevations or high landscape positions, on convex landforms, and often on south- or west-facing slopes. ES4 consists of several different vegetation communities. These are common in high temperature and precipitation environments across the region and on high permeability soils.

Where disturbance occurs in any of the four ESs (fire intensity, erosion, deer browsing, timber regeneration failures,

Table 1. Pennsylvania Bureau of Forestry forest stand types used in sampling environmental variables for delineation into ecological sites

ID	Stand type name	Area (ha)
FM	Hemlock rich mesic hardwood forest	397
FT	Hemlock tuliptree birch forest	1,275
LB	Black locust forest	2,889
GB	Black gum ridge top forest	3,564
EO	Pitch pine mixed oak forest	4,449
FF	Hemlock (white pine) forest	4,677
MM	Mixed mesophytic forest	4,715
CS	Sugar maple basswood forest	4,762
TM	Tuliptree (beech) maple forest	4,834
FR	Hemlock (white pine) red oak mixed hardwood forest	8,123
FA	Dry white pine (hemlock) oak forest	8,226
FB	Hemlock (white pine) northern hardwood forest	14,833
DD	Aspen/gray (paper) birch forest	16,983
BC	Black cherry northern hardwood forest	33,558
CC	Red maple forest	36,763
AD	Dry oak mixed hardwood forest	92,205
AR	Red oak mixed hardwood forest	107,640
BB	Northern hardwood forest	161,252
AH	Dry oak heath forest	303,012

anthropogenic disturbance) a graminoid landscape Phase (Little bluestem [*Schizachyrium scoparium*]/Pennsylvania sedge [*Carex pensylvanica*] grassy opening)[3] can predominate. More research is needed to address whether such species assemblages could represent a State shift in each respective ES. Boulder fields (>80% surface boulder cover) occur on backslopes of the Allegheny Plateau and Valley and Ridge physiographic provinces. These landscape features are likely relicts of the region's former periglacial climate[4] and may well represent a unique ES.

Important Challenges for Land Management

The development of ESs across the region provides a potential foundation for using associated state-and-transition models to understand and explain forest compositional change. While many of the region's forest communities have been shown to have unique site characteristics related to topography, soils, and lithology, a number of factors (some interacting) are responsible for present day forest composition.

The most significant and longest-lasting effect on the region's forests is historic logging,[5,6] which resulted in the subsequent removal of dominant tree species that extensively covered the region. Historic harvesting in combination with the introduction of new pathogens/disease, such as chestnut blight that obliterated the American chestnut, has resulted in a present-day forest composition that is markedly different from pre-European contact. For example, initial clear-cutting and long-term forest management dramatically lessened the proportion of beech and hemlock and increased sugar maple[5] across ES1 and ES2. Beech and hemlock, once dominant in ES1 and ES2, are today seemingly more restricted (ES1, 1a, and 1b) and less abundant than they were historically, especially where out-competed by faster growing species (ES1, 1d, and 1e), promoted specifically or inadvertently by management (most Phases in ES2). Hemlock's future is uncertain with the introduction of hemlock woolly adelgid. Beech biomass has declined due not only to historic harvesting but also beech bark disease, although not to the extent that American chestnut has from chestnut blight, which in essence eliminated the once widespread tree across ES3 and ES4. Sugar maple appears to have been of relatively low biomass proportion in ES1 and ES2, but increased following harvesting around the turn of the 20th century, potentially due to reduced competition from harvested species. Over the last 35 years, a combination of stressors and management goals for other species has been implicated in reducing sugar maple biomass.[7] The ultimate result of the harvesting between 1880 and 1910 across all ESs, and biotic

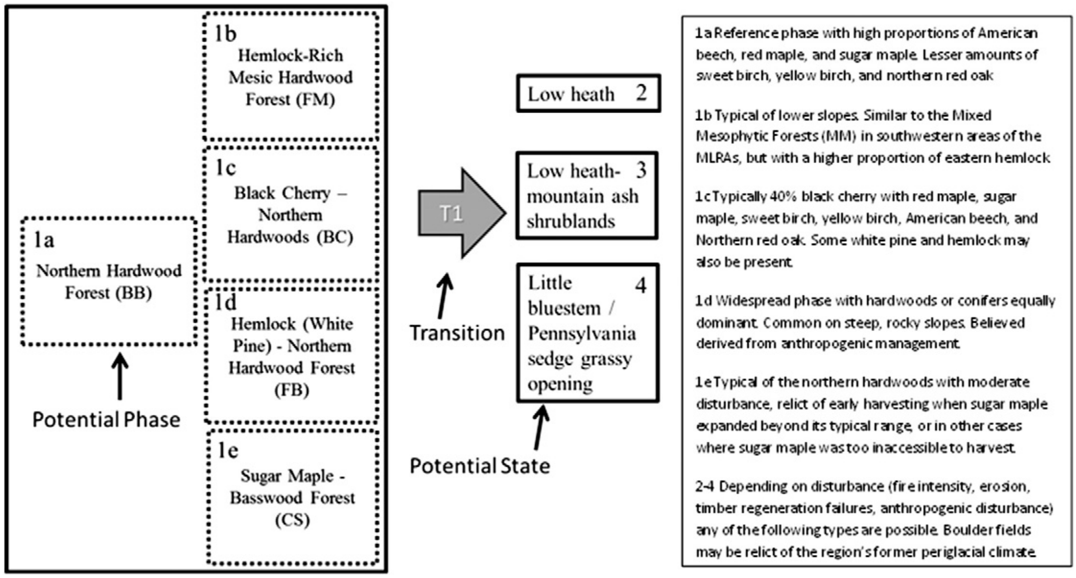

Figure 2. State-and-transition model for ES1. Box to the right describes the Phases and their potential transitions. Community codes refer to Fike.[3]

stressors like insect defoliation, is that today's forest communities are largely a product of past disturbances. The consequence of this history for any of the provisional ESs is that the true reference State is uncertain and likely an unrealistic management target. A management-oriented, least-disturbed reference State is likely more practical in these highly modified landscapes (e.g., 1a in the case of ES1 or ES2).

Insect defoliation outbreaks and deer browsing are disturbance constants with differing effects related to differing forest compositions across the provisional ESs. A complex history of forest management[8–10] has resulted in spatially extensive areas of ES3. ES3 has two potential reference conditions (1a or 1b) depending on land manager goals and funds; 1a is typically more costly to implement due to required herbicide to control recalcitrant species[11] and fencing to limit deer browsing of stump sprouts. A consequence of widespread oak species in ES3 has been spatially extensive oak-focused insect defoliation events that have resulted in rapid and substantial declines/diebacks of several oak species. Such defoliation episodes have from time-to-time impacted forest communities common to ES3, most strongly affecting forest communities AH, AR, FA, and AD (Fig. 4, Phases 1a and 1g). Defoliation disturbance may result in opportunistic species proliferating (e.g., red maple)[12] or changing site environmental factors,[13] either potentially resulting in Phase shifts in ES3 to 1b or 2 to 4. When large scale tree death occurs due to widespread defoliation rapid salvage logging

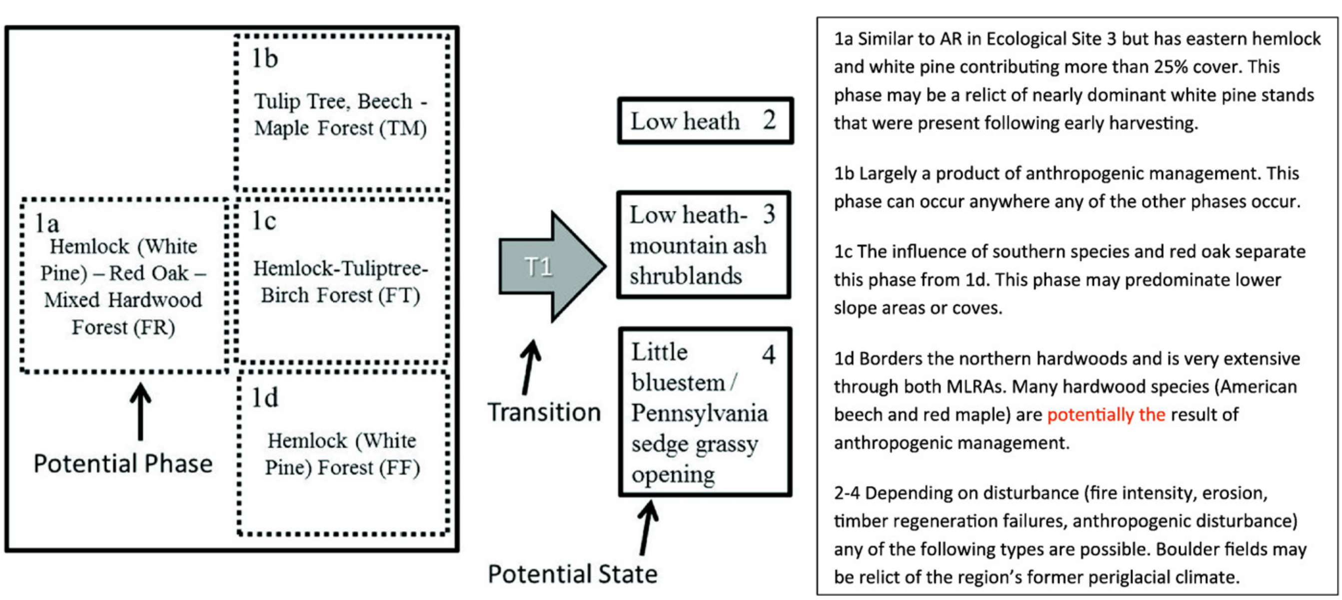

Figure 3. State-and-transition model for ES2. Box to the right describes the Phases and their potential transitions. Community codes refer to Fike.[3]

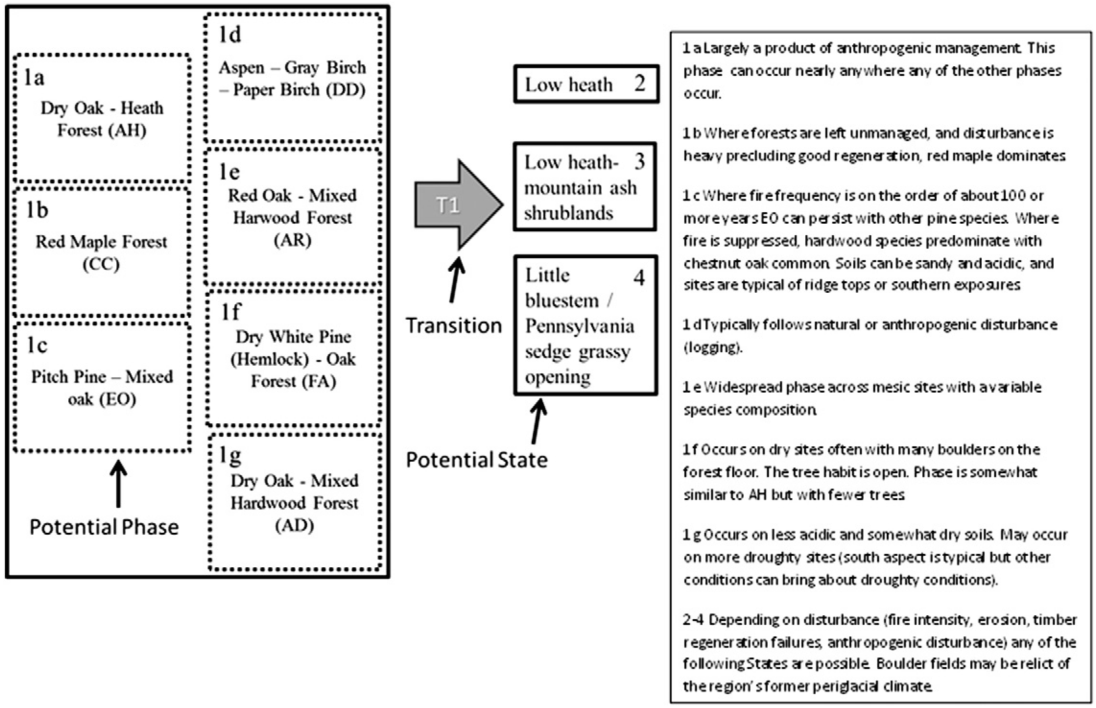

Figure 4. State-and-transition model for ES3. Box to the right describes the Phases and their potential transitions. Community codes refer to Fike.[3]

must take place and regeneration success is very dependent on site browsing by deer and inherent site potential/forest productivity relationships.

Specific anthropogenic influences on forest composition may include those brought about by harvest regeneration failures, atmospheric deposition, or oil and gas well exploration (among others). Harvest regeneration failures[14] can result in a less desirable forest community (e.g., red maple Phases) or recalcitrant understory (sweet fern, hay-scented fern[11]) Phases that shade desirable seedlings. Substantial management (herbicides and deer fencing) is required to shift an ES back to the least disturbed Phase. The lack of this intervention results in a persistent degraded Phase, which could perhaps be described as a "State." Subtle shifts in species composition due to atmospheric deposition are debated across the region and it is unknown if any of the Phases of the provisional ESs are reflective of atmospheric deposition. Atmospheric deposition (sulfur and nitrous oxides specifically)

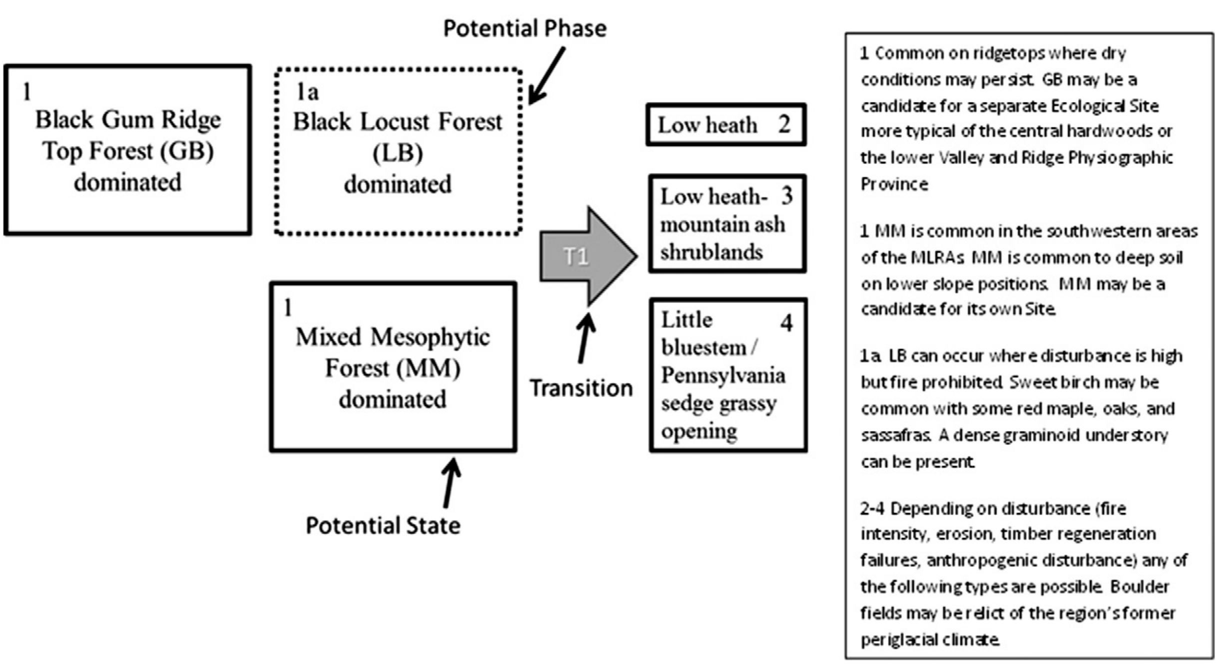

Figure 5. State-and-transition model for ES4. Box to the right describes the Phases and their potential transitions. Community codes refer to Fike.[3]

Table 2. Description of landscape attributes for ecological sites

Ecological Site	Area (ha)	Landscape and vegetation attributes	Community codes	Representative soil series
1	214,887	Deep, higher-pH soil, steep slope, high elevations, northern hardwood dominated forests; north or east facing slopes at more southern latitudes	BB, BC, CS, FB, FM	Leck Kill, Meckesville, Hartleton, Oquaga, Lordstown, Rayne, Wharton, Gilpin, Cookport, Leetonia
2	18,889	Low elevations or low landscape positions, mesic hemlock-dominated forests, concave landforms, low-bulk density soils, north or east facing slopes	FF, FR, FT, TM	Albrights, Ungers, Atkins, Narbour, Basher, Brinkerton, Gilpin, Ernest, Nolo
3	573,665	Dry upland oakmaple hemlock hardwood forests; high elevations or high landscape positions; convex landforms; south or west facing slopes	AD, AH, AR, CC, DD, EO, FA	Dekalb, Hazleton, Cookport, Clymer, Leetonia, Hartleton, Lehew, Berks, Weikert
4	11,176	High temperature and precipitation; high permeability soils	GB, LB, MM	Hazleton, Clymer, Dekalb, Laidig

varies substantially across ESs[15] with ES1 to ES3 having the most potential to be affected due to high deposition loads and soils typically with low buffering capacity. While it is suspected that atmospheric deposition has historically lowered base cation pools and soil pH,[16,17] costly additions of dolostone or limestone to buffer such acidity and improve tree health typically have species specific results at best.[18] Oil and gas operations can reduce forest biomass where infrastructure development is occurring and thus change forest core/edge extent.[19] Natural gas development is largely occurring in ES1, ES2, and ES3 with the extent and rate differing depending on whether conventional or unconventional gas is being developed. State-and-transition models for ESs undergoing natural gas development could be a useful tool for reclamation purposes by identifying potential target communities and/or trajectories for monitoring reclamation progress.

Applications to Decision-Making and Recommendations for Improvement

Identification of ESs and associated Phases (or States) in the northern Appalachians provides land managers with quantifiable benchmarks for assessing forest compositional shifts due to natural or anthropogenic disturbance. As in New Mexico, mapping of ESs can provide a valuable management tool for landscape analysis of State shifts,[20] and in conjunction with quantification of soil change[21,22] could provide land managers with trackable data on cumulative impacts of multiple stressors on forests and/or the effectiveness of management practices. Such metrics can be directly tied to conservation program metrics to efficiently focus efforts on improving commodity management, reclamation efforts, or general forest ecosystem management.

Improvement of current ESs and their Phases (or States) will come about with improved soil mapping in the region. At present, it appears that soils are too coarsely mapped to adequately capture some ES relationships. This is most evident in several cases where the same soil series occurs in multiple ESs (Table 2). However, identification of series that occur in multiple ESs will allow the United States Department of Agriculture, Natural Resources Conservation Service Soil Survey Program to target soil series concepts that should likely be re-examined and either mapped more specifically using new soil mapping techniques or split into more specific concepts. The historic focus on agriculture in the region is likely the cause of broadly mapped soils across forest lands.

Conclusions

The legacy of landscape change in the northern Appalachians presents a complicated picture of potential soil change and leaves many unanswered questions as to how soils have responded to long-term, varied disturbance. Discerning the "States" of an ES in the eastern United States, is not as clear a task as in the western United States. Multiple "States" likely exist on similar soils, which is reflective of historic management decisions. What is unknown is how many different "States" might exist and if thresholds have been crossed resulting in a "State" that would require significant external expenditures of resources (human time, soil amendments, etc.) to reverse.

The provisional ESs and their state-and-transition models, built upon an extensive regional forest inventory dataset provided by the Pennsylvania Department of Conservation and Natural Resources, are a guide for discussion and future hypothesis testing. Our models were derived using a statistical methodology and a large peer-reviewed literature that reflects the legacies of human actions in forest community composition in the eastern United States. It is important to remember that the region of this study, while extensive, has a very similar and predictable landscape pattern. It should be no surprise then that our initial number of provisional ESs and Phases with state-and-transition models are few; some may argue such extensive an area should have more. As discussed, wetland and riparian portions of the study area have been excluded. Development of ESs and associated state-and-transition models for these landscape features is an obvious next step.

Acknowledgments

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