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European Settlement-Era Vegetation of the Monongahela National Forest, West Virginia

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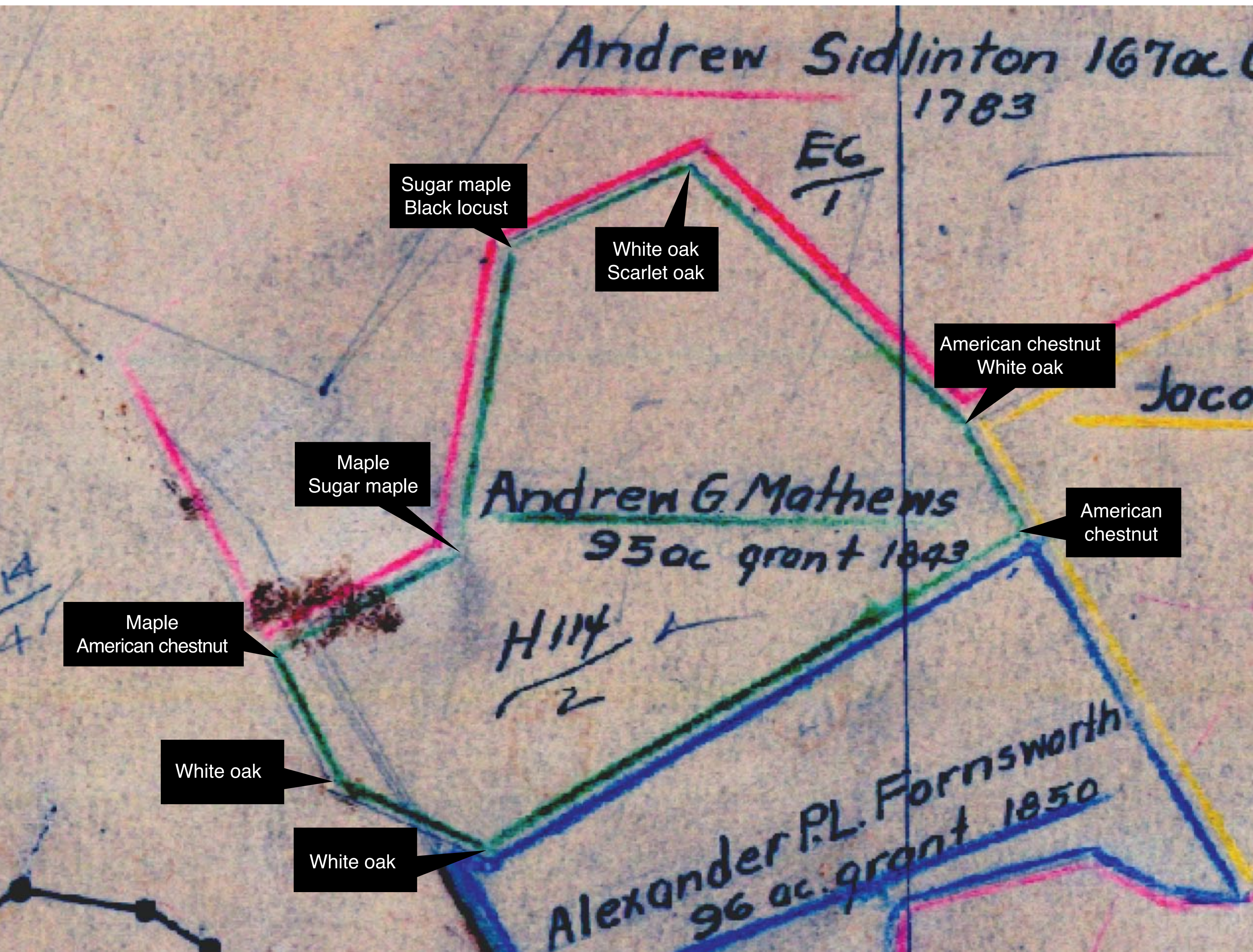

Abstract

Forest restoration would be greatly helped by understanding just what forests looked like a century or more ago. One source of information on early forests is found in old deeds or surveys, where boundary corners were described by noting nearby trees known as witness trees. This paper describes the creation and analysis of a database of witness trees from original metes and bounds surveys of what became the Monongahela National Forest in West Virginia. We include an estimate of positional error from the conversion of paper maps to digital format. The final database contains 15,589 corners and 22,328 trees of 49 species from deeds dating from 1752 to 1899. White oak was the most frequent witness tree, followed by sugar maple, American beech, and American chestnut, and distribution patterns were recognizable across the study area.

In early forests of the study area, magnolia, sugar maple, and black cherry were found on high-elevation ridges. Red spruce, hemlock, birch, and American beech were found on high-elevation toe slopes. Basswood was found in high-elevation coves, and red oak was associated with bench landforms at high elevations. At moderate elevations American chestnut and chestnut oak were associated with ridges, white pine and yellow pine occurred on benches, and an unknown species called spruce-pine was found on valley landforms. Blackgum was associated with toe slopes on low elevations, and black walnut was found on low-elevation benches. Low-elevation valleys contained white oak, elm, and sycamore. An important finding from this analysis is that some associations between species and environmental variables differed based on the ecological setting. Indicator kriging, using presence-absence data, resulted in probability of occurrence maps for selected species. We estimate that white oak covered 26 percent of the study area, sugar maple 19 percent, American chestnut 3 percent, and red spruce 2 percent.

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Cover Photo: The witness trees of one parcel, the Andrew G. Mathews grant of 95 acres in 1843, are shown. The image is a portion of a digitally scanned map from the 1930s of land grants covering what later became the Monongahela National Forest near Clover Lick in Pocahontas County, West Virginia. (Photo by Melissa Thomas-Van Gundy, U.S. Forest Service.)

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INTRODUCTION

Information on historical forest conditions is sparse for much of the eastern United States due to early settlement and forest clearing by Europeans and intensive timber harvesting at the start of the 20th century. Nevertheless, descriptions and quantitative assessments of early forests and grasslands are useful in restoration ecology and can come from many sources such as land survey records, travelers' accounts, and photographs (Whitney 1994). In the absence of large old-growth forests, these historical references are often the best source of information on forest characteristics at the time of European settlement. They can provide clues to Native American influences and other disturbances on the landscape, and can provide an ecological baseline to inform restoration actions.

Unlike early surveys in the Midwest, systematic grid surveys such as those under the Government Land Office (GLO) were uncommon in the original colonies. There, land transfers followed survey methods called metes and bounds. Metes and bounds surveys consist of a series of bearings and distances with trees, posts, rock piles, or natural features recorded to describe corners where bearings changed. These trees used as the parcel corner or located close to the corner are called witness trees. Deeds or grants documenting transfer of ownership of a parcel of land also document tree species existing at the time of transfer through these witness trees (Abrams and Ruffner 1995; Black and Abrams 2001a, b; Rentch and Hicks 2005; Whitney and DeCant 2003).

Witness tree data give a snapshot of forest composition at the time of early European settlement. Witness tree data have been used to document changes in species composition in current forests (Abrams and McCay 1996, Rentch and Hicks 2005) and other changes in forest conditions (Dyer 2001, Wang et al. 2009, Whitney and DeCant 2003) or show consistency in species distribution patterns (Strahler 1972). Relationships between vegetation and site conditions can also be determined through analysis of witness tree locations on the landscape (Abrams and McCay 1996, Black and Abrams 2001a, Wang 2007). Species abundance may also provide information on historical disturbance regimes. When combined with archeological data, witness tree information can also reveal Native American influences on forest composition (Black et al. 2006). This glimpse into the past may be useful for understanding historical conditions and informing current land management.

Surveyor bias toward certain tree species has been addressed in witness tree studies based on GLO methods (Bourdo 1956, Liu et al. 2011) and metes and bounds (Black and Abrams 2001a). In contrast with GLO surveys, in metes and bounds surveys the surveyor was not required to scribe information on witness or bearing trees. Therefore, a bias toward smooth-barked trees was not likely. Unusual tree species may have been more likely to be used as a witness tree, as was found for Public Land Survey records in Wisconsin (Liu et al. 2011), because these trees would have made the corner easier to re-locate. Longer-lived species would likely be chosen over others if available.

Like most other eastern states, West Virginia retains only a few fragments of old-growth forests documenting early forest composition. Often these fragments are found in uncommon ecological settings; existing old-growth remnants may underrepresent more common ecological settings and forest types. In contrast, witness tree information from land grants and deeds contains a record of forest composition at the time of European settlement across a wide range of ecological settings.

In 2005, paper maps from the 1930s depicting witness trees found on what is now the Monongahela National Forest (MNF) were converted to a digital format. The witness tree dataset built from the 1930s paper maps was explored to answer questions on the composition of European settlement-era forests of the MNF. A previous analysis of a subset of these data was made by Abrams and McCay (1996). The analysis presented here is based on a larger number of points and uses different methods; we hope it will give greater detail of the early forest that can inform ecosystem restoration actions. Specifically, the objectives of this analysis were to: (1) quantify the positional error of this witness tree database as a result of conversion to digital format, (2) characterize the spatial relationships of the witness trees, (3) characterize the species-site relationships in the early forests, and (4) interpolate among witness corners to provide continuous forest composition from the witness trees.

STUDY AREA

The MNF is located in east-central West Virginia (Fig. 1) and has complex topography as most of the area is located in the Allegheny Mountains and Ridge and Valley physiographic sections, with a small portion in the Northern Cumberland Mountains section (Cleland et al. 2007). This complexity results in a variety of landforms and conditions supporting diverse vegetation. The study area (MNF proclamation boundary buffered by 5 km) is approximately 1,014,000 ha, and includes all or portions of the following counties: Barbour, Grant, Greenbrier, Nicholas, Pendleton, Pocahontas, Preston, Randolph, Tucker, and Webster.

This unglaciated area includes the faulted and folded mountains of the Ridge and Valley physiographic section and the uplifted and eroded Allegheny Mountains. The Allegheny Front divides the two physiographic sections, creating a rain shadow effect to the east. Sedimentary rocks of Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician age underlie the study area. Lithology includes sandstones, shales, siltstones, coal, and limestone. Differing substrates and rates of erosion help create the varied soils and topography of the study area.

The physiographic sections that cover the MNF can be further subdivided to describe the diversity of ecological conditions. Subsections in the study area are as follows: Eastern Allegheny Mountain and Valley (EAMV), Eastern Coal Fields (ECF), Northern High Allegheny Mountain (NHAM), Ridge and Valley (RV), Southern High Allegheny Mountains (SHAM), Western Allegheny Mountain and Valley (WAMV), and Western Allegheny Mountains (WAM) (Cleland et al. 2007; Table 1). In general, the RV subsection is warm and dry and the WAMV subsection is dry with moderate temperatures. The ECF subsection is warm and moderate in overall moisture. The EAMV subsection is moderate in both moisture and temperature regimes, and the WAM subsection is cool with moderate moisture. The SHAM and NHAM subsections are both wetter and cooler than the other subsections, but NHAM has the lowest average temperatures (Table 2).

Table 1.—Ecological subsections of the Monongahela National Forest study area (Cleland et al. 2007), area within the proclamation boundary, and percentage of total for each subsection.

Subsection	Hectares	Percent of study area
Eastern Allegheny Mountain and Valley	161,518	15.9
Eastern Coal Fields	35,078	3.5
Northern High Allegheny Mountain	215,591	21.2
Ridge and Valley	137,390	13.6
Southern High Allegheny Mountains	243,468	24.0
Western Allegheny Mountain and Valley	48,184	4.8
Western Allegheny Mountains	151,138	14.9
Other	21,426	2.1
Total	1,013,793	100.0

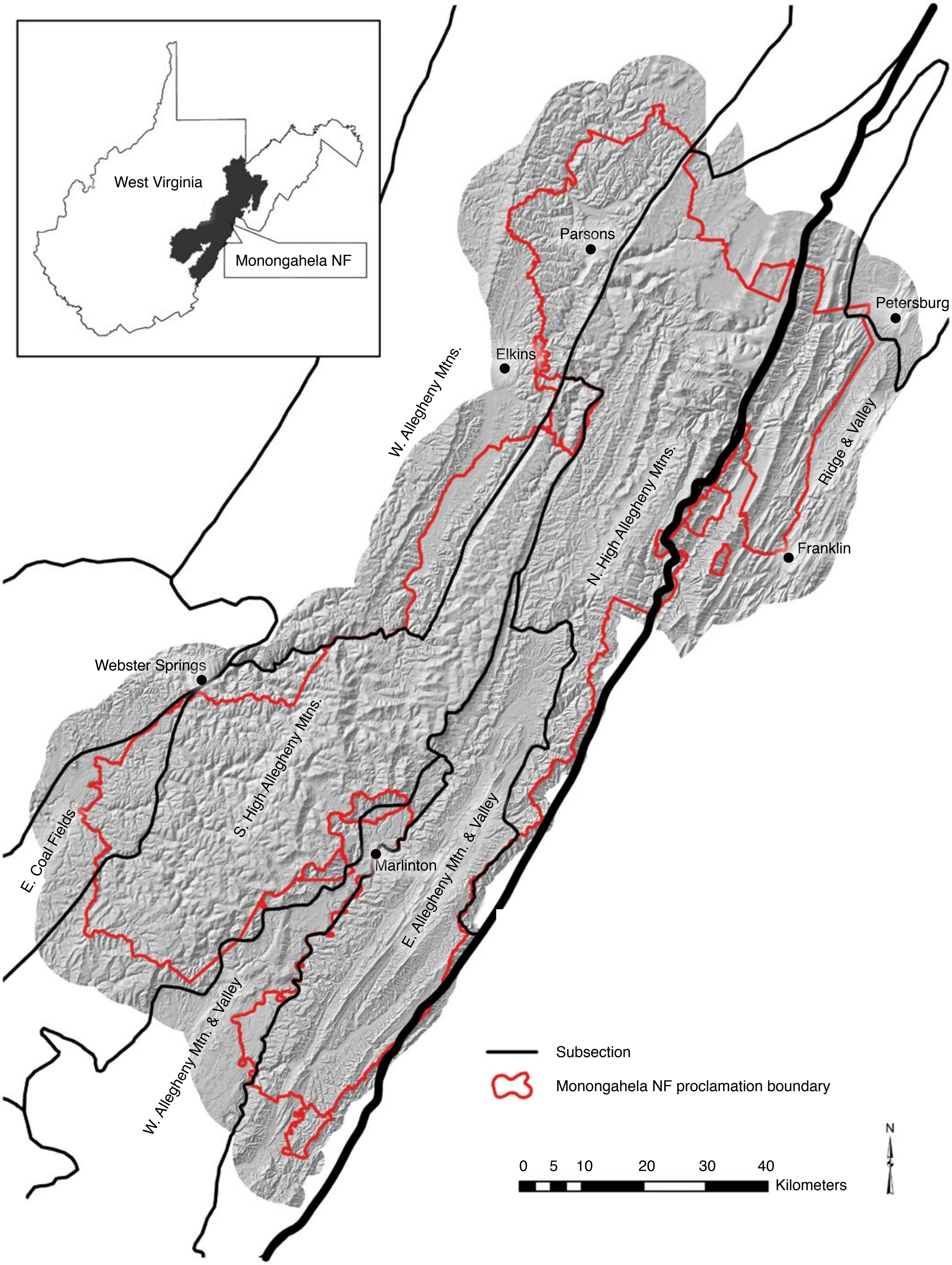

Figure 1.—Study area location and physiographic subsections. Thicker boundary line is between Northern Ridge and Valley, and Allegheny Mountains sections.

Table 2.—Selected subsection climate and potential natural vegetation attributes (Cleland et al. 2007). Elevation figures are summarized from a 1:4800 scale digital elevation model of the study area. Subsection abbreviations: EAMV = Eastern Allegheny Mountain and Valley, ECF = Eastern Coal Fields, NHAM = Northern High Allegheny Mountain, RV = Ridge and Valley, SHAM = Southern High Allegheny Mountains, WAMV = Western Allegheny Mountain and Valley, and WAM = Western Allegheny Mountains.

Subsection	Ave. ann. max. temp. (°C)	Ave. ann. min. temp. (°C)	Ave. Jan. min. temp. (°C)	Ave. ann. snowfall (cm)	Ave. ann. precipitation (cm)	Min. elev. (m)	Max. elev. (m)	Mean elev. (m)
EAMV	16.5	2.6	-8.8	120.5	111.0	523.3	1,461.8	824.5
ECF	17.5	4.5	-6.8	94.9	113.7	526.1	956.8	761.0
NHAM	14.5	2.0	-9.4	263.5	128.2	511.5	1,454.5	1,020.2
RV	17.3	4.1	-7.1	82.6	102.3	284.7	1,482.5	712.8
SHAM	15.2	2.4	-9.0	224.5	138.1	446.8	1,478.6	1,043.7
WAMV	17.1	4.3	-7.0	85.6	99.7	529.1	1,101.5	731.7
WAM	15.1	3.0	-8.8	187.8	122.2	418.2	1,226.8	733.0

	Potential Natural Vegetation (percent)				
	Appalachian oak forest	Mixed mesophytic forest	Northeastern spruce-fir forest	Northern hardwoods	Oak-hickory-pine forest
EAMV	58.9	0.0	0.2	40.9	0.0
ECF	28.1	51.7	0.0	20.2	0.0
NHAM	0.0	0.0	14.3	80.4	5.4
RV	49.1	0.0	0.7	9.2	40.9
SHAM	4.5	23.3	21.1	51.2	0.0
WAMV	85.9	1.1	0.0	13.0	0.0
WAM	26.6	38.0	0.0	35.3	0.1

Appalachian oak forest is the primary potential natural vegetation for the RV, EAMV, and WAMV subsections. (Common and scientific names of species are found in Table 3.) In contrast, a mixture of northern hardwoods and red spruce is the primary potential natural vegetation for the NHAM and SHAM subsections. The mixed mesophytic type is the primary potential natural vegetation for the WAM and ECF subsections (Cleland et al. 2007; Table 2).

The extractive logging boom (and associated fires and soil loss) that reshaped the original forest of West Virginia occurred between 1870 and 1920, reaching a peak in 1909. As with European settlement elsewhere, however, there was small-scale extraction as evidenced by the first sawmill in Tucker County in about 1776 (Stephenson 1993). In the upland counties of the MNF, commercial timber was first removed in areas close to navigable rivers and streams starting around 1865 (Stephenson 1993) with interstate rail lines reaching the region in the 1850s and 1870s (Lewis 1998). Large-scale forest removal occurred after narrow-gauge railroads were built into the remote upland forest starting around 1884 (Stephenson 1993); rail lines reached the headwaters of the Greenbrier River in Pocahontas County in 1903 (Lewis 1998). Other technologies that made large-scale timber removal possible included the Shay locomotive to navigate the narrow-gauge rail lines and the bandsaw. The largest expansion of sawmills utilizing bandsaws across West Virginia occurred between 1890 and 1910 (Lewis 1998). The MNF became a National Forest in 1920, although the first land was purchased in 1915 near Parsons, WV, under the authority of the Weeks Act of 1911.

METHODS

Witness Tree Locations

In the 1930s, personnel on the MNF obtained copies of the first land grant or deed for parcels that would later become the MNF from county courthouses. MNF staff then used the bearings and distances listed in the deeds and land grants to plot the parcels. As these deeds were under the metes and bounds system of land survey and not GLO surveys, only the species of corner trees are given in the original deed. The individual deeds were referenced by the owner's name, date of deed, and a location number. The resulting parcel maps each covered an area approximately 11,300 ha and overlap to varying degrees. There are 83 of these maps covering the area roughly contained by the proclamation boundary of the MNF. In 2005, the 1930s paper maps were scanned and georeferenced to be used in a geographic information system (GIS) and to preserve the information. The digital versions of the 1930s paper maps were used for digitizing the corners of individual parcels.

Point features were manually digitized in a GIS (ArcGIS 9.2, 2002, ESRI, Redlands, CA) with corners placed using the 2005 digital maps as visual guides. The 2005 digital maps were of parcel boundaries, often with no indication as to corner number or witness tree species. To assign the witness trees to the correct corners, the deed survey descriptions were used to determine corner number and tree species, or other marker, defining that corner. Along with tree species, the locator number and date of deed or survey were recorded in the ArcGIS attribute file. A crosswalk of common names appearing in the deeds and current scientific names was used in attributing the corners (Table 3). If a species was not noted for a witness tree in the deed (e.g., oak, maple, birch), those witness trees were recorded at the genus level. There is duplication of corners as the deeds themselves reference adjoining parcels. For this database, duplicate points were retained if new species were included as witness trees or the survey was made 10 or more years after the first survey using the shared corner.

Spatial and Attribute Uncertainty

Errors in corner location were introduced in the creation of the digital maps and dataset from the hand-drawn paper maps. The 1930s maps were scanned at a resolution of 200 dots per inch (JPEG format) and georeferenced using the ESRI ArcGIS georeferencing extension. At least four corners or tie points were used from the scanned maps to reference actual coordinates. Latitude and longitude were noted on most of the 1930s maps, making georeferencing easier. Georeferencing of maps continued until root mean square error rates for all four corners were less than 10 m (Strager 2008).

Corner points were placed through manual digitizing at a mapping scale of 1:5,000 using many features of the maps as guides and the deed for bearings and distances. The scanned base maps included hand-drawn parcels, most of which were highlighted by colored pencil lines. For some parcels only the colored pencil line existed on the maps to aid in placing corners. Some tracts were preprinted on the map with corners identified by circles. All of these map markings introduced positional error when used to place corners in space. In addition, because of the scale used to create the digital point (1:5,000), the actual digital point was not placed at the exact middle of the guide marker, introducing another error factor.

To estimate total positional error across all points (Equation 1), random points were located in the study area in GIS and used to locate map elements to sample. Measurements were made using the ArcGIS measuring tool at a map scale of 1:1,000. At the 50 random locations, the widths of pencil lines, colored pencil lines, and printed lines were measured. Also at 50 random locations, the diameters of printed circles were measured. The distance from the electronic data point to the center of the base map corner location was measured at 50 random locations. These 50 measurements per map element were not necessarily taken at the same locations because not all map elements were found at the same location. Error terms 1 through 4 were averaged and divided in half (Kelly et al. 2008) since the target placement of the digital corner would have been the center of these map elements. Total error was calculated by summing the squares of each term and taking the square root of the total (Equation 1; Kelly et al. 2008). Included in this total calculation is an average root mean square error of 9 m for the georeferencing process (Strager 2008).

Equation 1

$$e_{total} = (e_1^2 + e_2^2 + e_3^2 + e_4^2 + e_5^2 + e_6^2)^{1/2}$$

where:

e_1 = ½ average width of hand-drawn pencil parcel lines
e_2 = ½ average width of hand-drawn colored pencil lines
e_3 = ½ average width of printed parcel lines
e_4 = ½ average diameter of printed corner circles
e_5 = distance to actual corner from digitized corner
e_6 = 9 m, average root mean square error associated with georeferencing

Table 3.—Common and scientific names of witness trees cited in deeds dated 1752 to 1899 on the Monongahela National Forest. A question mark after a scientific name represents uncertainty in the assignment of a scientific name to that name used in deeds.

Common name used in deeds	Scientific name	Stems tallied
Balsam fir, fir, balsam	*Abies balsamea*	4
Striped maple	*Acer pensylvanicum*	1
Sugar or hard maple, sugar tree, sugar	*Acer saccharum*[a]	2,252
Maple	*Acer* spp., *A. rubrum?*	1,265
Buckeye	*Aesculus* spp.	48
Serviceberry, service, sarvice	*Amelanchier* spp.[a]	62
Black or sweet birch	*Betula lenta*	3
River birch	*Betula nigra*	6
Birch	*Betula* spp.	1,007
Hornbeam, ironwood, hophornbeam, or bluebeech	*Carpinus caroliniana; Ostrya virginiana*	303
Hickory	*Carya* spp.	1,010
Chestnut	*Castanea dentata*	1,373
Dogwood	*Cornus* spp.	318
Hazel, witch hazel	*Corylus* spp.?, *Hamamelis virginiana*	6
Hawthorn, white thorn, thorn	*Crataegus* spp.	34
American beech	*Fagus grandifolia*	1,938
Ash	*Fraxinus americana*	421
Holly	*Ilex opaca*	1
Butternut, white walnut	*Juglans cinerea*	136
Black walnut, walnut	*Juglans nigra*	128
Red cedar, cedar	*Juniperus virginiana*	3
Yellow-poplar, poplar, tulip tree, tulip	*Liriodendron tulipifera*[a]	455
Indian wood, Indian bitter	*Maclura pomifera?*[a, b]	5
Magnolia, cucumber, elkwood	*Magnolia acuminata* or *M. fraseri*[c]	260
Apple, crab apple, plum, and peach	*Malus* spp.	10
Mulberry	*Morus* spp.	5
Spruce-pine	None, likely red spruce[d] or hemlock[a]	399
Blackgum, gum, sour gum	*Nyssa sylvatica*	284
Sourwood	*Oxydendrum arboretum*	10
Red spruce, spruce, black spruce, yew pine	*Picea rubens*[a, e]	683
Yellow, pitch, Virginia, or black pine	*Pinus rigida, P. virginiana,* or *P. pungens*	116
Pine	*Pinus* spp.	1,030
White pine	*Pinus strobus*	214
Sycamore	*Plantanus occidentalis*	82
Aspen, cottonwood	*Populus* spp.	1
Black or wild cherry	*Prunus serotina*	265
White oak	*Quercus alba*	3,779
Scarlet, span, Spanish, or pin oak	*Quercus coccinea*[b]	443
Chestnut or rock oak	*Quercus prinus*[a]	1,111
Northern red oak	*Quercus rubra*	736
Oak	*Quercus* spp.	18
Black oak	*Quercus velutina*	501
Locust	*Robinia pseudoacacia*	220

(Table 3 continued on next page)

Table 3.— Continued.

Willow	*Salix* spp.	1
Sassafras	*Sassafras albidum*	6
Yew	*Taxus canadensis,* possibly spruce?	11
Basswood, yellow or white lynn, lin	*Tilia* spp.[a]	911
Hemlock, hemlock-spruce	*Tsuga canadensis*[b]	354
Elm	*Ulmus* spp.	90
Unknown		2

[a] Strausbaugh and Core 1978; [b] U.S. Forest Service undated a; [c] Webster-dictionary.org; [d] Strahler 1972; [e] U.S. Forest Service undated b.

Landform Bias

Bias toward certain landforms was noted in similar metes and bounds witness tree datasets (Black and Abrams 2001a). To assess the degree of bias toward landforms in the study area, witness tree locations were compared to a systematic sample (Black and Abrams 2001a). A 0.8-km square grid was created over the study area and the resulting center points tallied by landform (landforms used in this analysis are defined below). A Chi-square test was used to compare the landform frequencies from the metes and bounds (irregular) survey to the systematic survey. The 0.8-km grid size was chosen for systematic sampling to simulate a GLO grid survey.

Spatial Analyses

Tree species are not located randomly in space as environmental and biological factors influence their presence and abundance at any given location (Cooper 1859, Küchler 1964, Whittaker 1956). Ecological data often violate the assumptions of many statistical models by exhibiting spatial autocorrelation (Legendre 1993). Spatial autocorrelation is the property of pairs of random variables having values that are more similar (positive autocorrelation) or less similar (negative autocorrelation) than expected for random pairs of observations (Legendre 1993). One benefit of spatial autocorrelation is that if positive spatial autocorrelation is found, then predictions can be made of unknown values using surrounding known values. Spatial heterogeneity is an inherent property of ecosystems, not the product of a random process, and for this reason is important to describe (Legendre 1993).

To describe the spatial characteristics of the witness tree dataset, clusters of high and low values and spatial outliers were determined for selected species across the study area through the calculation of Anselin's local Moran's I (Anselin 1995) in ArcMap 9.3.1 (2009, ESRI, Redlands, CA). To reduce errors associated with small sample sizes, only those species with 50 or more occurrences were assessed (McCune et al. 2002, Whitney 1990). At each witness tree location, a relative frequency of each species was calculated by dividing the number of trees of each species by the total number of trees at the corner (Wang et al. 2009). This relative frequency was used as the attribute value for the calculation of spatial autocorrelation by species.

The study area as a whole was used, as opposed to ecological subsections to reduce edge effects due to the shapes of the subsections. The results of the local Moran's I calculations are Z-scores with high positive scores indicating surrounding points have similar values, either similar high values or similar low values. Low negative Z-scores indicate a statistically significant ($\alpha = 0.05$) spatial outlier. The Z-scores were used to classify the study points into statistically significant High-High (HH) or Low-Low (LL) points ($\alpha = 0.05$), where HH points are those with a high abundance of a particular species surrounded by other high-abundance points of that same species and LL points are the opposite. Significant spatial outliers were classified as High-Low (HL) if the point has a high value and is surrounded by points with low values, or Low-High (LH) if the opposite occurs. Euclidian distance was used in all spatial calculations with weights calculated by inverse distance; data were standardized by row totals to account for potential sampling bias.

Indicator Species Analysis

If patterns in species abundance are determined from the mapping of local spatial autocorrelation, then it may be possible to describe underlying environmental variables that are influencing species distribution. To characterize the associations between tree species and ecophysical characteristics, environmental variables associated with the corner points (buffered by the error term) were extracted from existing spatial datasets and also derived from a digital elevation model (DEM). Ecophysical characteristics assessed were: topographic roughness, moisture index, aspect, landform, elevation, and soil series.

Topographic roughness is a measure of surface variability that may influence the distribution of species in an area or cause patterns in other physical variables influencing species distributions. For this analysis, a topographic roughness index (TRI) for each cell was calculated as the square root of the sum of squared differences in elevation between a cell and its eight neighboring cells (Riley et al. 1999). The moisture index was calculated for each cell as a function of flow accumulation and slope (Equation 2; Anderson et al. 1998).

Equation 2

Moisture index = ln (flow accumulation +1) / (slope +1)

Elevation, moisture index, and TRI were all calculated as averages around the corner location buffered by the positional error term calculated in Equation 1. These averages were then classified in ArcMap into high, medium, and low based on unbiased quantiles with each class containing an equal (or nearly equal) number of features. The use of quantiles, three equal-sized groups of the raw calculated factors, reduces the influence of outliers and extremes (Isaaks and Srivastava 1989). The use of quantiles reduced the likelihood that cutoffs would be biased toward any given species' environmental requirements.

The use of quantiles resulted in elevations of 298.4 to 731.7 m classed as low, 731.8 to 892.5 m as moderate, and >892.5 m as high elevation. The moisture index ranged from -4.26 to 7.3 with breaks at -2.78 for low/moderate and -1.53 for moderate/high. The TRI ranged from 1 to 224.7 m, with 1 to 39.9 m as low, 40.0 to 71.6 m as moderate, and 71.7 to 224.7 m classed as high TRI.

Aspect, slope, elevation, topographic roughness, and flow accumulation (a component of the moisture index) were derived through ArcMap Spatial Analyst from an 18-meter DEM of the study area resampled from a 3-meter DEM to reduce computing time. Aspect was transformed so that 0 - 22.5 degrees and 337.5 - 360 degrees both resulted in north aspect. Landform and soil series were extracted from existing spatial datasets of the MNF with the corners buffered by the positional error term and all landforms and soil series within that radius tallied.

Landform data are from the MNF ecological classification system and were assigned during soil surveys (Natural Resources Conservation Service [NRCS] 2010a). Landforms are as follows: ridge, bench, toe slope, side slope, cove, and valley. In the original database, slope landforms were separated into generic and mountain with an elevation cutoff for mountain slopes at approximately 300 m. The generic and mountain slope landforms were combined for this analysis because much of the MNF is above 300 m in elevation and elevation was assessed as a separate variable regardless of landform. Narrow ridges, broad ridges, saddles, shoulders, knobs, and peaks were combined for the ridge landform category. Side slopes and middle/back slope landforms were combined for the side slope category, and floodplains, newer terraces, older terraces, alluvial fans, valley floors, flats, plains, and valleys were combined for the valley category.

Soil series were obtained from the MNF soils GIS data layer based on the county soil surveys originally mapped at a scale of 1:20,000. Soil series that described less than 1 percent of the corners were dropped from the analysis, as were the associated survey corners. The original soil series used in the MNF GIS layer were combined by slope and stoniness categories. Complexes of soils were summarized by the first soil series listed in the complex; for example, we grouped Berks-Weikert soils with Berks soils for this analysis (Table 4).

The frequency counts of species and ecophysical variables by subsection were analyzed by indicator species analysis in PC-ORD (McCune and Mefford 2006); significance was tested through Monte Carlo methods (4,999 permutations; $\alpha = 0.05$). Categorical ecophysical variables (TRI, moisture index, aspect, landform, elevation, and soils) were used as grouping factors and each witness tree record served

Table 4.—Soil series of the Monongahela National Forest used in indicator species analysis. Soils data are from the Monongahela National Forest GIS soils data layer, originally from county soil surveys. For analysis, soil series were grouped by first soil listed in a series or complex, and slope and stoniness classes were grouped together.

Soil Series Used in Analysis	Original GIS Layer
Allegheny	Allegheny Loam
Atkins	Atkins Loam
	Atkins Silt Loam
	Atkins-Philo-Potomac Complex
Belmont	Belmont Silt Loam
	Belmont Stony Silt Loam-Rock Outcrop Complex
	Belmont-Cateache Silt Loams
Berks	Berks Channery Loam
	Berks Channery Silt Loam
	Berks Channery Silt Loam, Moist
	Berks, Weikert, and Calvin Soils
	Berks-Dekalb Complex
	Berks-Weikert Channery Silt Loams
	Berks-Weikert Shaly Silt Loams
Blackthorn	Blackthorn Channery Loam
	Blackthorn Channery Sandy Loam
	Blackthorn Very Channery Loam
	Blackthorn-Dekalb-Elliber
Buchanan	Buchanan and Ernest Stony Soils
	Buchanan Channery Fine Sandy Loam
	Buchanan Channery Loam
Calvin	Calvin Channery Silt Loam
	Calvin Silt Loam, High Base Substratum
	Calvin Stony Silt Loam, High Base Substratum
	Calvin-Dekalb-Berks Complex
	Calvin-Dekalb-Hazelton Complex
Cateache	Cateache Channery Silt Loam
	Cateache Silt Loam
Dekalb	Dekalb Channery Loam
	Dekalb Channery Sandy Loam
	Dekalb Extremely Stony Loam
	Dekalb Rubbly Loam
	Dekalb, Hazleton, and Lehew Stony Soils
	Dekalb, Hazleton, and Lehew Very Stony Soils
	Dekalb-Elliber
	Dekalb-Elliber-Blackthorn
	Dekalb-Hazleton Complex
	Dekalb-Rock Outcrop Complex
Ernest	Ernest Rubbly Silt Loam
	Ernest Silt Loam
Gilpin	Gilpin Channery Silt Loam
	Gilpin Silt Loam
	Gilpin Stony Silt Loam
	Gilpin-Buchanan Complex
	Gilpin-Dekalb Complex
	Gilpin-Dekalb Stony Complex
	Gilpin-Laidig Association
Laidig	Laidig and Buchanan Soils
	Laidig Channery Loam
	Laidig Channery Silt Loam
	Laidig Stony Loam
	Laidig Very Stony Loam
Lily	Lily Loam
	Lily Sandy Loam
Macove	Macove Channery Silt Loam
Mandy	Mandy Channery Silt Loam
Meckesville	Meckesville Stony Silt Loam
Opequon	Opequon Silt Loam
	Opequon-Caneyville Silty Clay Loams
Potomac	Potomac Cobbly Loam
	Potomac Fine Sandy Loam
	Potomac Loam
	Potomac Very Cobbly Fine Sandy Loam
	Potomac Very Gravelly Fine Sandy Loam
	Potomac Gravelly Loam
Shouns	Shouns Channery Loam
	Shouns Silt Loam
Weikert	Weikert Channery Silt Loam

as a plot. Tree species with more than 50 occurrences in the study area were included in indicator species analysis. After this initial filter, a species had to have at least 10 occurrences with a study variable to be included in the indicator species analysis (Whitney 1982). Indicator species analysis combines the species abundance in a given group with the faithfulness of occurrence of a species to a group and has been used to describe site-species relationships (Godefroid et al. 2007, Phillips et al. 2003). The indicator value is the product of the proportional abundance of a species in a group relative to the abundance of that species in all groups and the mean proportion of sample units in each group that contain the species (Dufrene and Legendre 1997, McCune et al. 2002). If a species is a perfect indicator of a given group, it should always be present in that group and exclusive to that group.

Spatial Interpolation

To create continuous coverage for selected species, species abundances were converted to presence or absence and indicator kriging (IK) was used to map the probability of occurrence between locations. Indicator kriging has been used on presence/absence witness tree data to create spatially continuous representations of presettlement-era vegetation (Wang 2007), and is the only kriging method appropriate for binary data. Semivariograms were constructed and fitted in ArcMap. The lag size was varied to reduce the nugget effect, which is the amount of variation at the origin (zero distance between pairs of observations) of the semivariogram and represents measurement error in the data or variation at a scale finer than measured in the model. Sparse data may also lead to a greater than expected nugget effect. Anisotropy, the property of spatial data where differences in values differ by distance and direction between pairs of observations, was found in the distributions of some species and was accounted for in the final models to adjust for the directional influence of the spatial autocorrelation. The directional trend was incorporated into the models by setting the directional search to the direction of the axis of the anisotropic ellipse. Spherical models were fit to the semivariograms because the sample variograms showed linear behavior near the origin (Isaaks and Srivastava 1989); stable models were used for some species to reduce error. Interpolations were made for common species (white oak and sugar maple), and species of interest for restoration efforts (red spruce and American chestnut). Species with similar site variable associations (based on indicator species analysis) were assessed either alone or in combination (e.g., white oak and white pine). By using a threshold of 30-percent probability of occurrence (Manies and Mladenoff 2000, Wang 2007), the area covered by each species was calculated for the study area.

RESULTS

Species Abundances

The full database consists of 15,692 corners from approximately 1,450 individual parcel descriptions from deeds dated 1752 to 1914. For the subsequent analyses reported here, corners and associated trees dated after 1899 were removed. Corners dated after 1899 totaled 103, with an associated 141 trees from five deeds, leaving 15,589 corners representing 22,328 witness trees (Fig. 2). About 54 percent of the corners recorded only one witness tree, two witness trees were recorded on about 38 percent of the corners, and about 7 percent of the corners recorded three witness trees. Corners listing four to six trees represented about 1 percent of the total. About 24 percent of the corners date to the late 1700s. The greatest numbers of corners were established in the 1840s and 1850s at 17.8 percent and 29.3 percent of the total, respectively (Fig. 3). Some corners in the dataset were not used for analysis as they fell outside the state boundary or occurred on minor subsections.

Forty-nine species (or genera) were used at least once as witness trees in the deeds, 28 of which were overstory species with sufficient numbers of occurrences for spatial analysis (Table 3). Spruce-pine (likely red spruce or hemlock) and Indianwood witness trees were retained as separate species although a current common or scientific name could not be confidently assigned to them.

As expected, species composition varied by ecological subsection. White oak was the most common species across the study area, with a mean relative frequency of 19.4 percent. White oak accounted for 17 to 38 percent of the witness trees in the EAMV, RV, WAMV, and WAM subsections based on mean relative abundance (Table 5). American chestnut was the most frequent species in the ECF subsection (18.4 percent), American beech in the NHAM (18.2 percent), and sugar maple in the SHAM subsection (18.2 percent). After white oak, the most abundant species

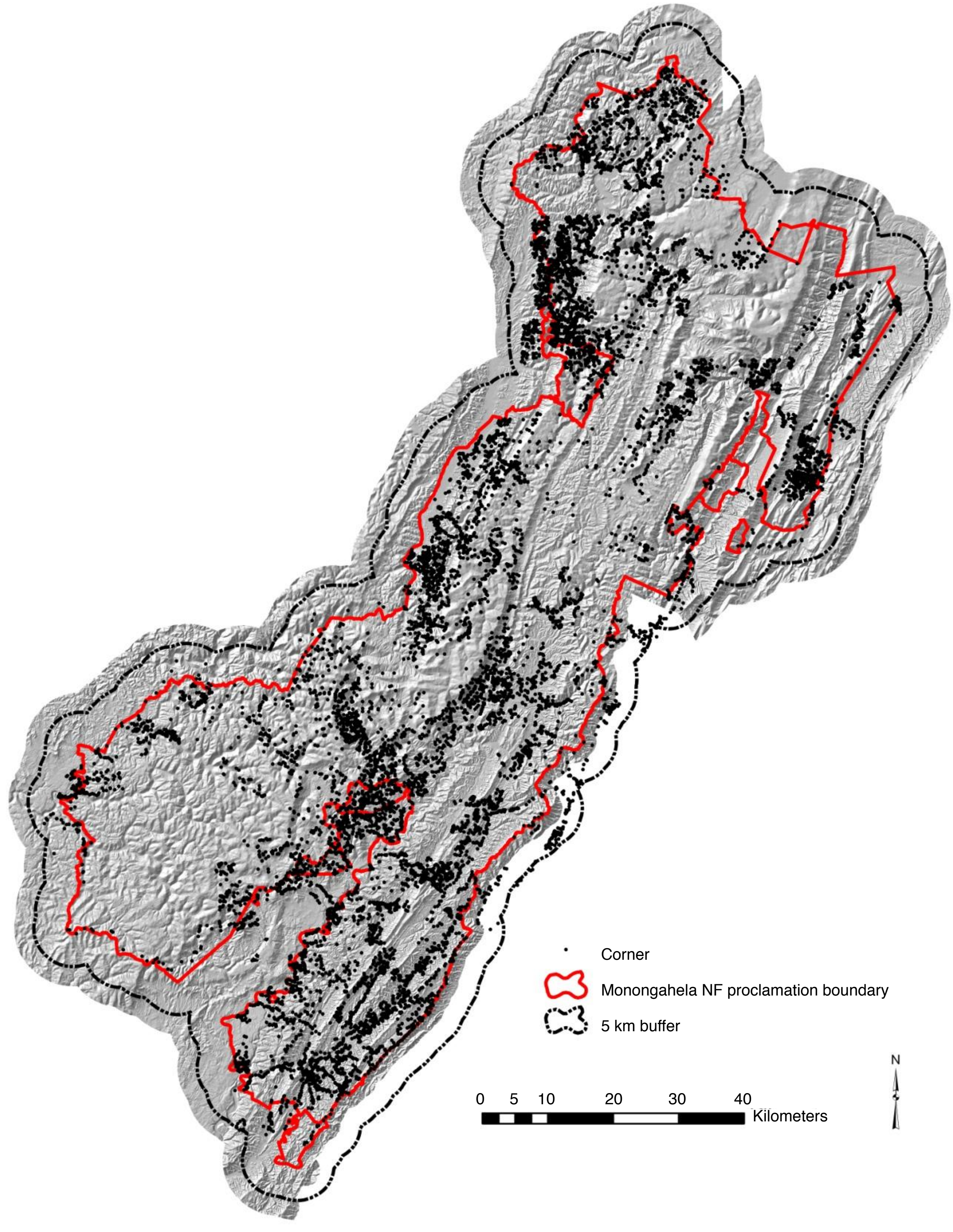

Figure 2.—Locations of corners from all deeds in relation to the proclamation boundary of the Monongahela National Forest and this boundary buffered by 5 kilometers.

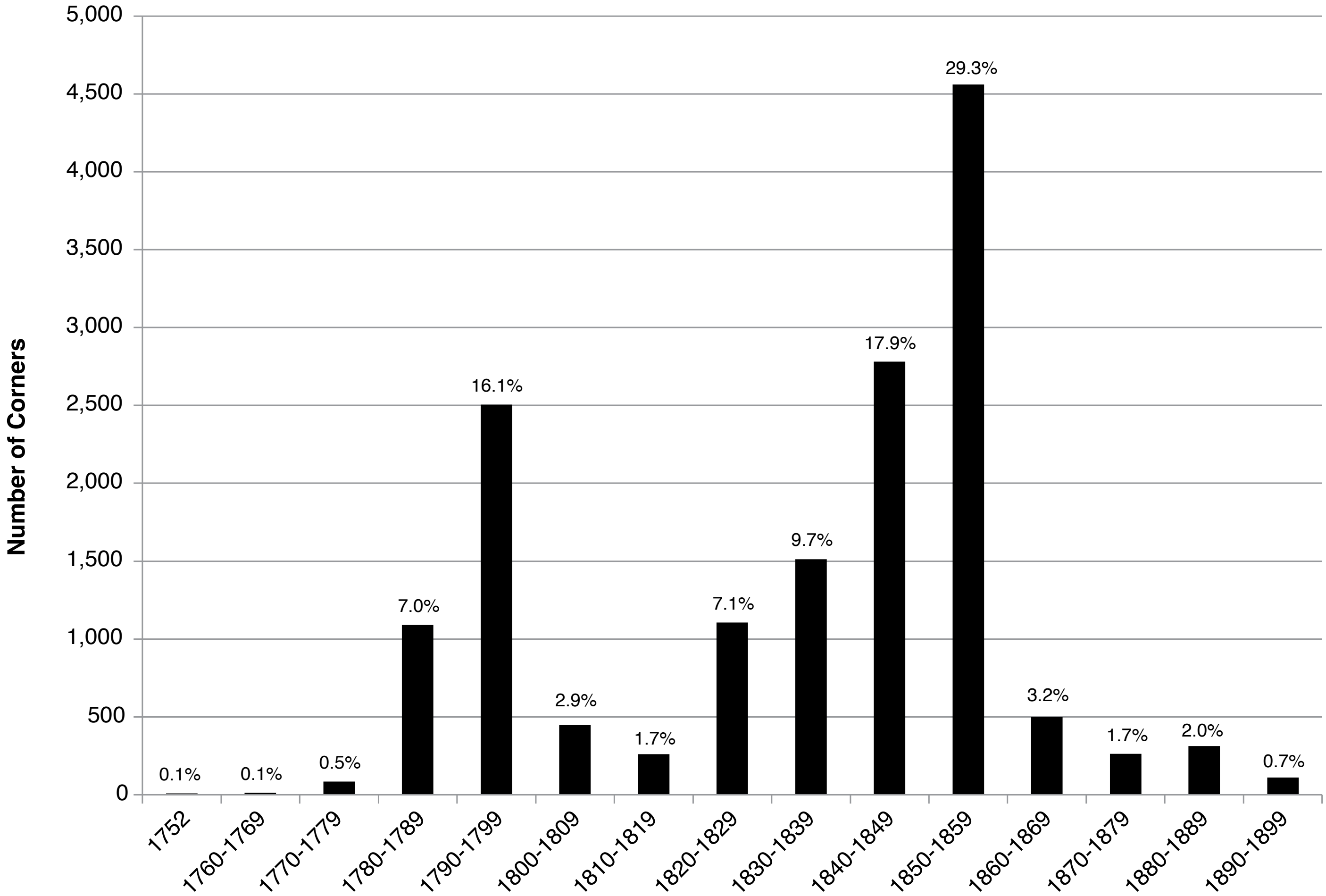

Figure 3.—Number of corners per decade, and percent of total number of corners, based on deed date. Twelve deeds with unknown dates were not included.

across the study area were sugar maple (10.1 percent), American beech (8.4 percent), American chestnut (6.3 percent), and chestnut oak (5.2 percent). Surprisingly, red maple was not cited in any deeds, although it is likely that "maple" refers to red maple. If this is the case, then red maple made up 5.0 percent of the relative abundance across the study area, and ranked 6th overall. It was most common in the ECF subsection, where its relative abundance was 11.4 percent, second only to American chestnut.

When we summarized species as absolute counts by subsection, similar patterns of species abundances emerge (Table 5). White oak was still the most abundant witness tree across the study area and for four of the subsections, ranking 4th (ECF), 7th (NHAM), and 9th (SHAM) in the others. Of those species with greater than 50 occurrences across the study area, elm and serviceberry were the least common witness trees.

Spatial Error and Landform Bias

During creation of the dataset, the conversion of paper maps to digital format and the manual placement of corner points using the maps as guides introduced positional error. The measurements taken for Equation 1 resulted in an estimate of positional error of 20.9 m around each witness tree corner. This error estimate was rounded to 21 m and used as a radius to buffer the corner locations for the calculation of elevation, moisture index, TRI, and tallies of landform, aspect, and soil series associated with the corners for indicator species analysis.

The Chi-square comparison of landform frequencies from witness tree locations to systematic sampling showed no difference ($p = 0.575$). Thus, there was no bias in witness tree locations by landform in this study area and dataset.

Table 5.—Mean relative frequency and occurrence (N) by species and ecological subsection, for species or genus with 50 or more occurrences across the study area. Relative frequencies were calculated at each point by dividing the number of trees of each species or genus by the total number of trees at the corner; occurrence is based on the presence of the species or genus at a corner.

Species or genus	EAMV	ECF	NHAM	RV	SHAM	WAMV	WAM	Study area
White oak	32.5 (1,794)	10.7 (44)	5.7 (129)	28.3 (568)	3.9 (175)	38.2 (351)	17.0 (600)	19.4 (3,661)
Sugar maple	4.5 (298)	10.1 (44)	17.1 (407)	7.0 (177)	18.2 (902)	7.3 (80)	7.3 (295)	10.1 (2,201)
American beech	1.2 (81)	8.3 (36)	18.2 (447)	0.8 (21)	17.2 (881)	2.9 (26)	9.1 (377)	8.4 (1,869)
American chestnut	6.3 (393)	18.4 (76)	4.0 (115)	4.0 (89)	4.7 (226)	6.1 (67)	9.3 (376)	6.3 (1,342)
Chestnut oak	6.0 (364)	3.0 (13)	2.3 (59)	12.3 (255)	1.0 (50)	2.2 (22)	7.6 (293)	5.2 (1,056)
Maple	5.6 (387)	11.4 (58)	6.6 (192)	2.0 (59)	4.7 (271)	3.9 (51)	5.0 (223)	5.0 (1,241)
Pine	9.1 (528)	0 (0)	1.8 (35)	8.5 (170)	4.0 (190)	4.2 (40)	0.6 (22)	5.0 (985)
Birch	1.2 (97)	1.8 (10)	6.1 (171)	1.1 (25)	9.1 (484)	1.8 (17)	4.7 (187)	4.2 (991)
Hickory	6.1 (431)	2.2 (13)	1.3 (39)	4.5 (119)	1.7 (101)	5.1 (57)	5.3 (237)	4.1 (997)
Basswood	2.6 (182)	4.7 (23)	5.9 (143)	3.1 (76)	6.9 (353)	1.5 (16)	2.4 (89)	3.9 (882)
Northern red oak	2.8 (190)	2.9 (15)	3.4 (93)	4.8 (123)	3.1 (167)	2.2 (27)	2.6 (112)	3.1 (727)
Spruce	1.4 (94)	0 (0)	3.0 (90)	0.8 (16)	5.9 (291)	0.4 (3)	3.5 (126)	2.9 (620)
Black oak	2.7 (198)	4.0 (17)	0.2 (7)	5.6 (121)	0.7 (31)	5.0 (58)	1.4 (56)	2.2 (488)
Yellow-poplar	1.1 (76)	10.4 (46)	1.3 (35)	1.2 (25)	1.1 (52)	1.4 (15)	4.7 (203)	2.0 (452)
Scarlet oak	0.9 (68)	0.5 (3)	2.1 (54)	2.0 (44)	0.9 (44)	3.8 (46)	4.3 (179)	2.0 (438)
Spruce-pine	2.9 (169)	3.0 (11)	2.4 (59)	1.5 (33)	1.4 (66)	0.2 (2)	0.8 (30)	1.8 (370)
Ash	0.7 (58)	0.5 (3)	2.1 (64)	1.7 (43)	2.4 (146)	0.7 (9)	2.3 (95)	1.7 (418)
Hemlock	0 (0)	0 (0)	6.5 (175)	0.3 (7)	3.4 (139)	0 (0)	0.2 (6)	1.6 (327)
Blackgum	1.1 (84)	2.5 (10)	0.6 (17)	1.3 (35)	0.6 (28)	1.2 (13)	2.1 (94)	1.2 (281)
Black walnut/butternut	0.7 (41)	0.9 (5)	1.1 (29)	2.3 (63)	1.4 (66)	1.4 (16)	0.9 (38)	1.2 (258)
Magnolia	0.1 (6)	0.5 (2)	2.2 (55)	0.5 (12)	1.2 (71)	0 (0)	2.4 (110)	1.1 (256)
Dogwood	1.8 (147)	1.4 (8)	0.3 (11)	1.5 (46)	0.2 (11)	1.8 (24)	1.3 (68)	1.1 (315)
Hophornbeam/hornbeam	1.1 (86)	0.2 (1)	1.3 (45)	1.2 (34)	1.7 (102)	0.8 (8)	0.4 (23)	1.1 (299)
Black cherry	0.7 (45)	0.2 (1)	1.8 (55)	0.2 (5)	2.2 (125)	0.6 (7)	0.5 (21)	1.0 (259)
White pine	3.1 (191)	0 (0)	0.1 (2)	0.5 (10)	0 (0)	0 (0)	0.3 (10)	1.0 (213)
Black locust	0.7 (63)	0.3 (2)	0.7 (19)	0.9 (26)	1.0 (54)	1.2 (15)	0.9 (38)	0.8 (217)
Yellow pine	1.4 (75)	0 (0)	0 (0)	0.3 (6)	0 (4)	2.9 (21)	0.1 (4)	0.6 (110)
Sycamore	0.4 (19)	0.4 (1)	0.1 (2)	0.6 (13)	0.2 (10)	0.3 (3)	1.2 (38)	0.5 (86)
Elm	0.4 (23)	0 (0)	0.3 (10)	0.8 (21)	0.3 (17)	1.1 (11)	0.2 (7)	0.4 (89)
Serviceberry	<0.1 (8)	0.5 (3)	0.5 (16)	<0.1 (2)	0.1 (11)	0 (0)	0.4 (19)	0.2 (59)
Total (N)	6,196	445	2,575	2,244	5,068	1,005	3,976	21,509

Local Clustering

The corner locations themselves, regardless of species, were significantly clustered when spatial autocorrelation was assessed across the study area. The local clustering analysis determined whether species were significantly clustered in one of four categories: high-high (HH), low-low (LL), high-low (HL), or low-high (LH). Overall, LL points were found only for sugar maple, American beech, and white oak (Figs. 4 and 5). Analysis of white oak witness trees, shows a distribution of LL points highlighting the near absence of white oak in the wetter, colder, and higher-elevation subsections (SHAM and NHAM) and part of the WAM subsection (Fig. 5). Most HH points for white oak were in the EAMV subsection. There were HH points across the study area for American chestnut, but most were located in the EAMV and WAM subsections (Fig. 5). Most of the HH points for red spruce witness trees were located in the SHAM subsection (Fig. 6). For witness trees tallied as simply maple, there were more HH points in the EAMV subsection, and this species did not show a pattern similar to sugar maple, suggesting these were red maples (Fig. 7).

The significant LL points for American beech all were found in the RV and EAMV subsections; HH points were found in SHAM, NHAM, and WAM subsections (Fig. 4). The distribution of local clustering was similar for sugar maple, although no LL clusters appear for sugar maple in the RV subsection (Fig. 4). Higher concentrations of yellow-poplar were found in the WAM subsection and very few HH points for this species were found in either SHAM or NHAM subsections (Fig. 8). Significant HH or HL points for basswood were scattered throughout the study area (Fig. 9).

The oaks (other than white oak) and hickories all had similar distributions of HH points, with few found in the moist and higher-elevation SHAM and NHAM subsections (Figs. 10, 11, and 12). Northern red oak is the exception to this pattern, with more HH points found in these subsections compared to the other oak species. Yellow pine and pine had similar distributions of high abundance points with nearby high abundance points (HH); most were found in the EAMV or RV subsections (Fig. 17). In contrast, there were no HH points for hemlock in the EAMV subsection; HH points for this species were generally located in the northern half of the study area and at higher elevations (Fig. 7).

Most HH points for birch witness trees were found in the higher-elevation subsections (Fig. 6). Cluster analysis for sycamore shows no HH points in the NHAM subsection (Fig. 14). The cluster of HH points of black walnut (Fig. 15) in the RV subsection appears unusual and may represent more mesic conditions along coves and/or stream bottoms within this generally dry subsection. Groups of HH points were found for blackgum in the WAM and EAMV subsections (Fig. 16). For magnolia species, most HH points were located in the WAM subsection or the border of WAM and SHAM (Fig. 13). Analyses were made for other species: black cherry (Fig. 8), ash (Fig. 9), spruce-pine (Fig. 13), elm (Fig. 14), butternut (Fig. 15), and black locust (Fig. 16); the graphical results are displayed, but their cluster distributions are not discussed further.

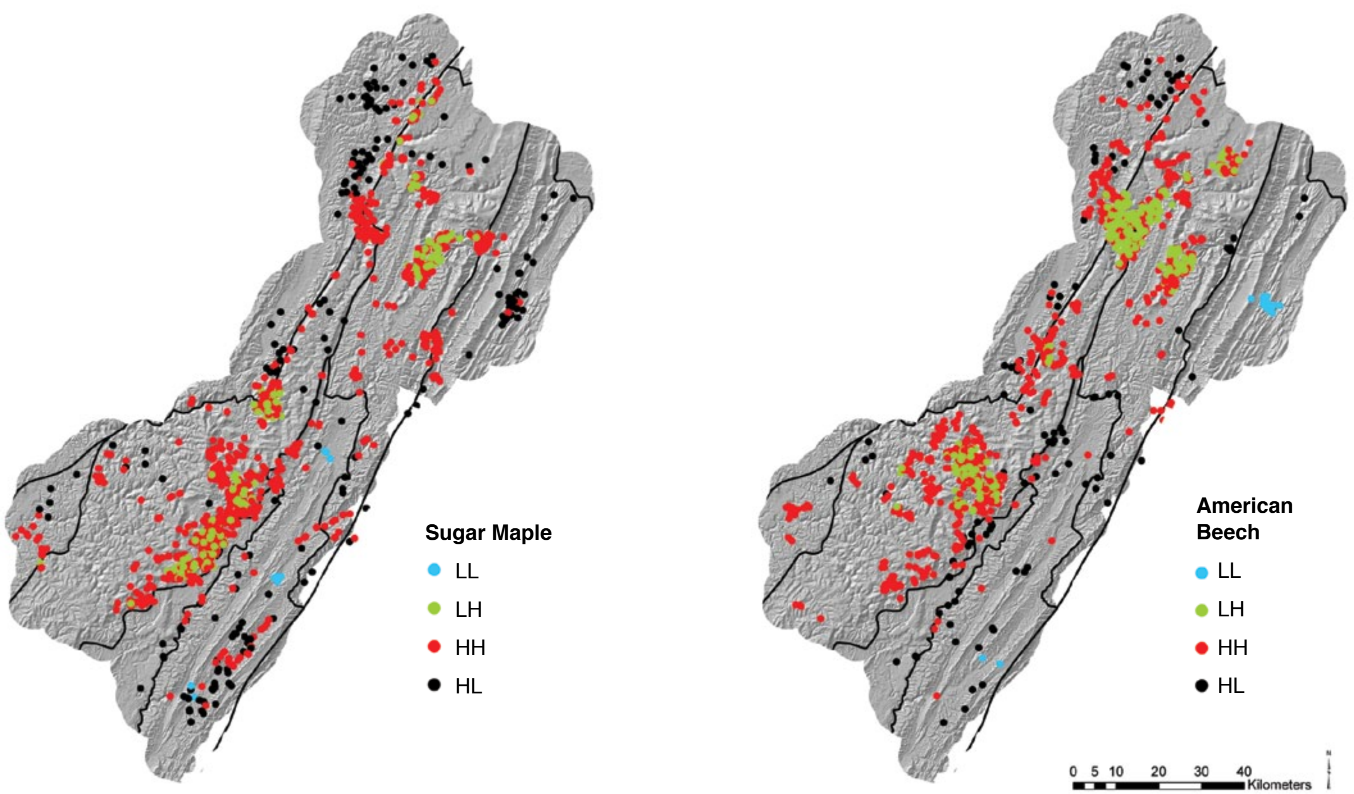

Figure 4.—Results of local cluster analysis for sugar maple and American beech witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

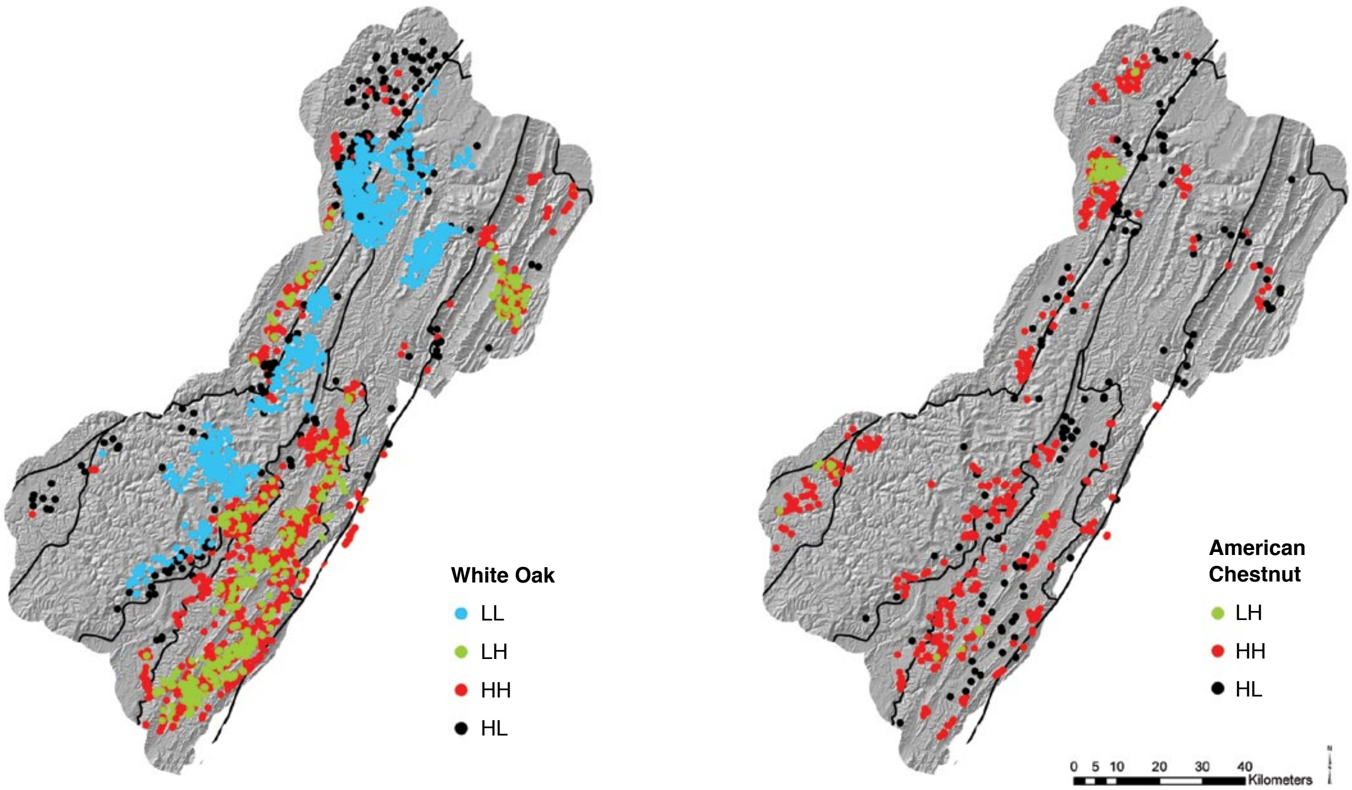

Figure 5.—Results of local cluster analysis for white oak and American chestnut witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

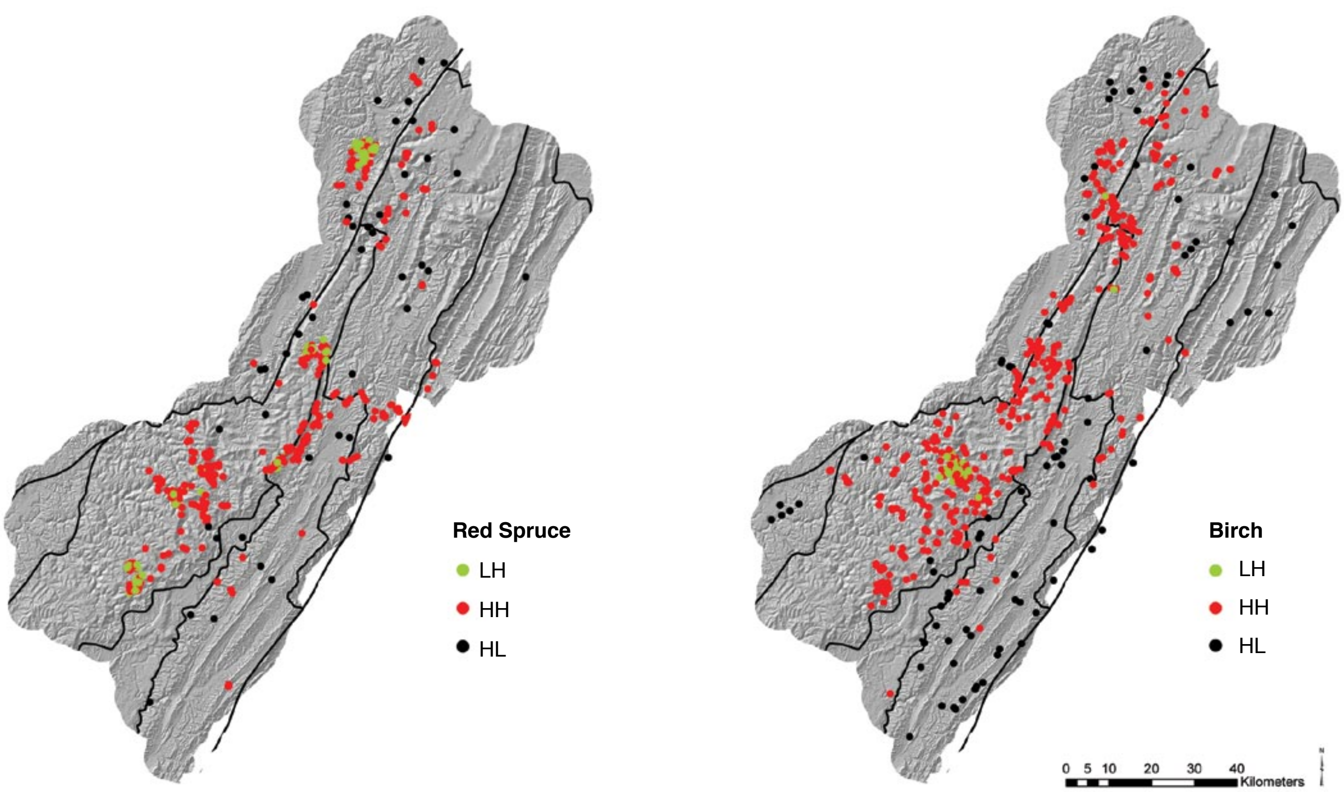

Figure 6.—Results of local cluster analysis for red spruce and birch witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

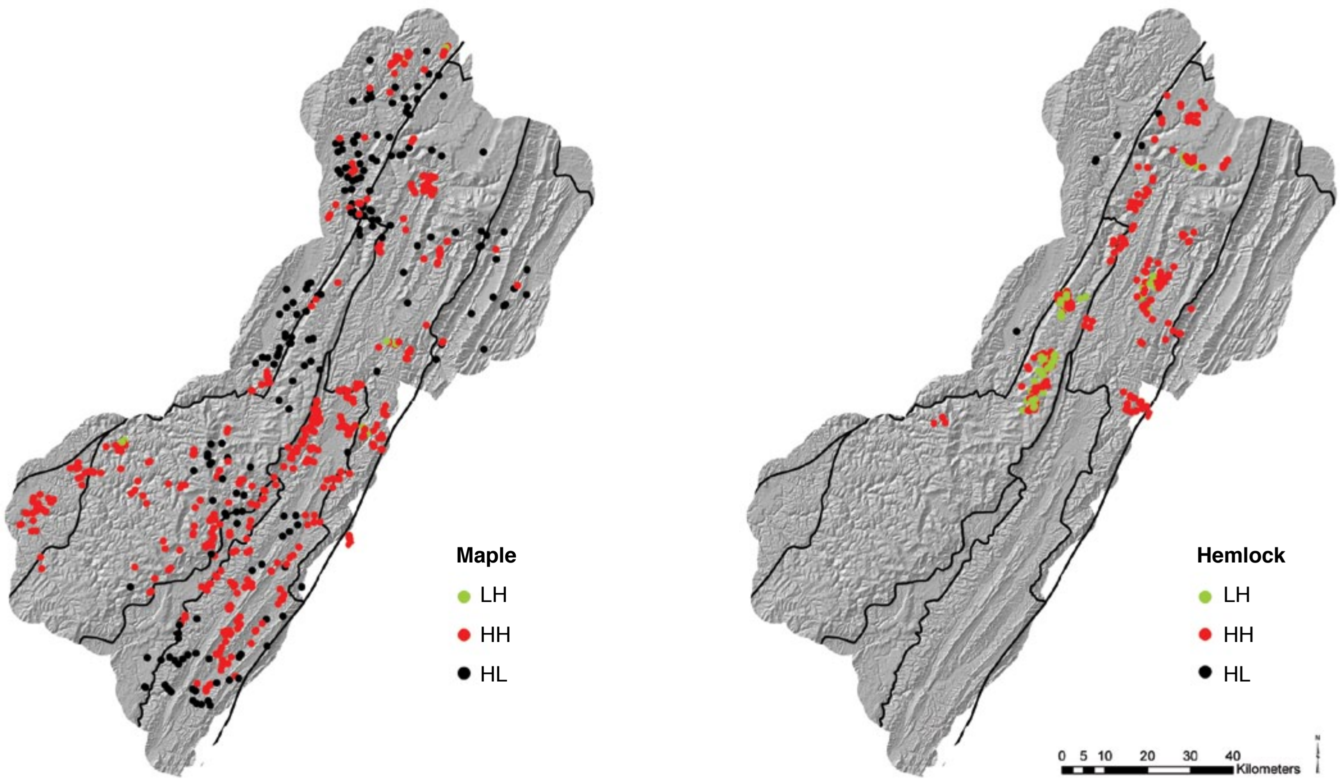

Figure 7.—Results of local cluster analysis for maple and hemlock witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

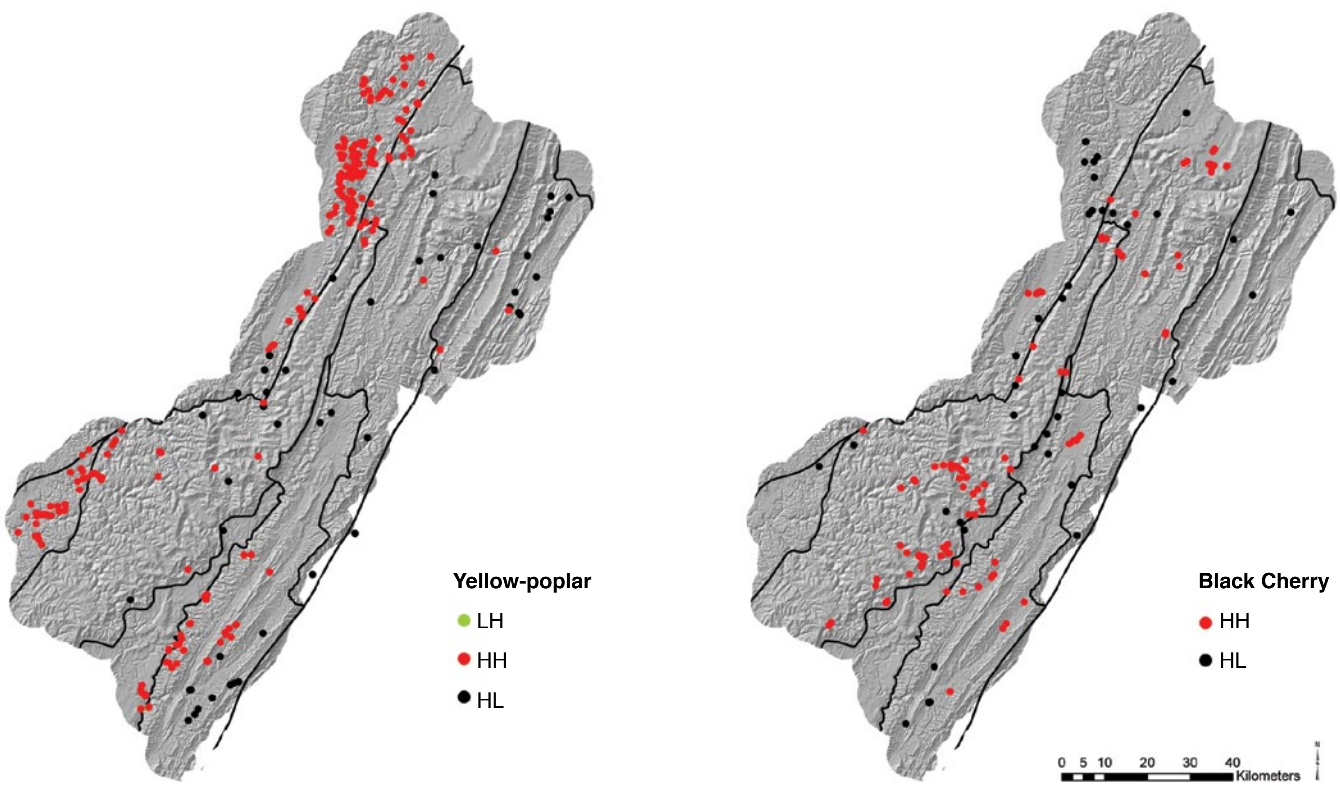

Figure 8.—Results of local cluster analysis for yellow-poplar and black cherry witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

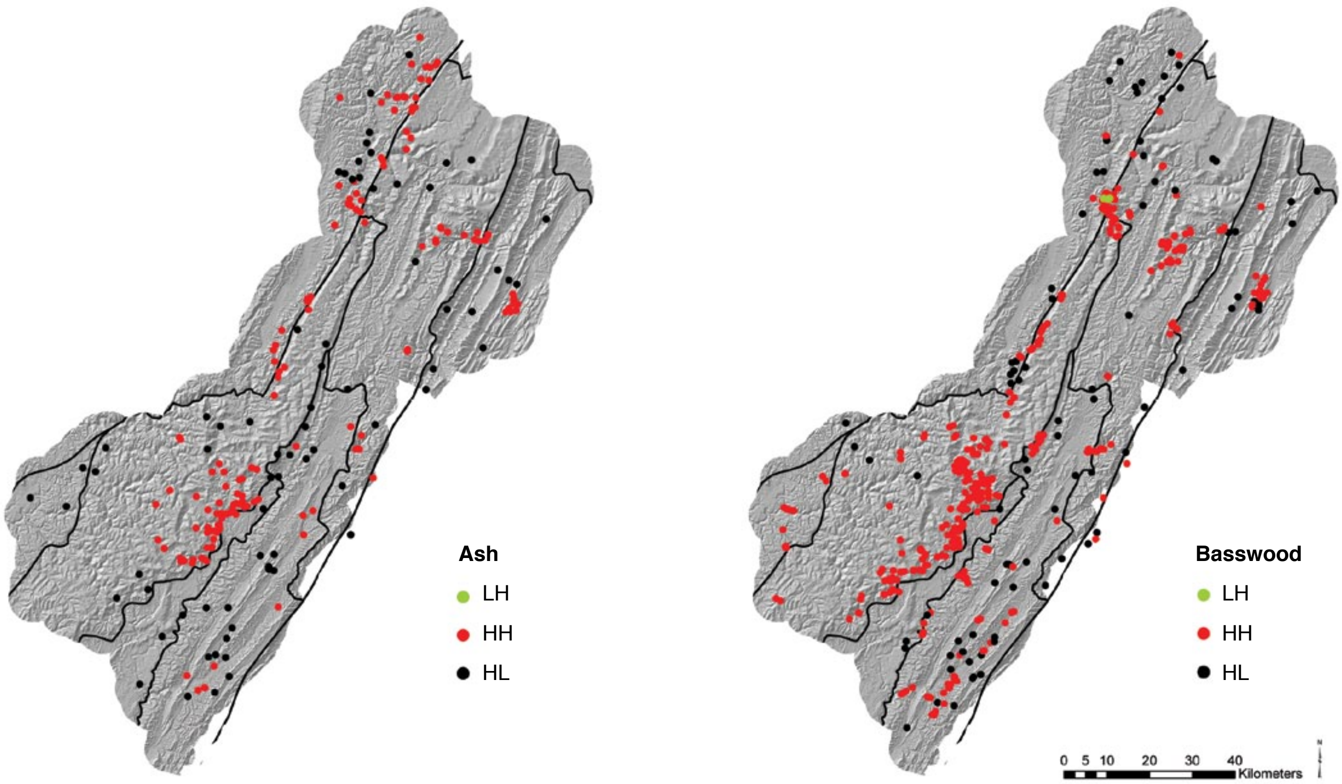

Figure 9.—Results of local cluster analysis for ash and basswood witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

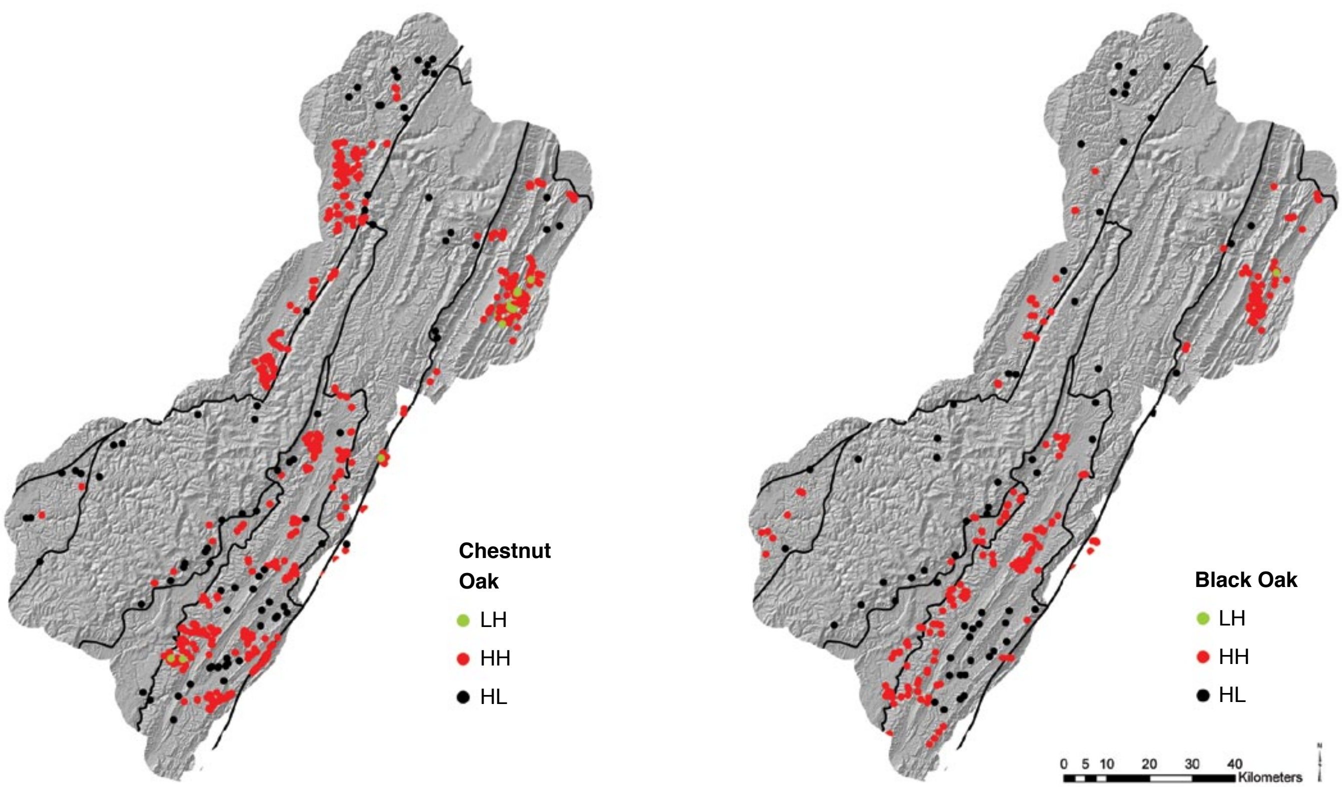

Figure 10.—Results of local cluster analysis for chestnut oak and black oak witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

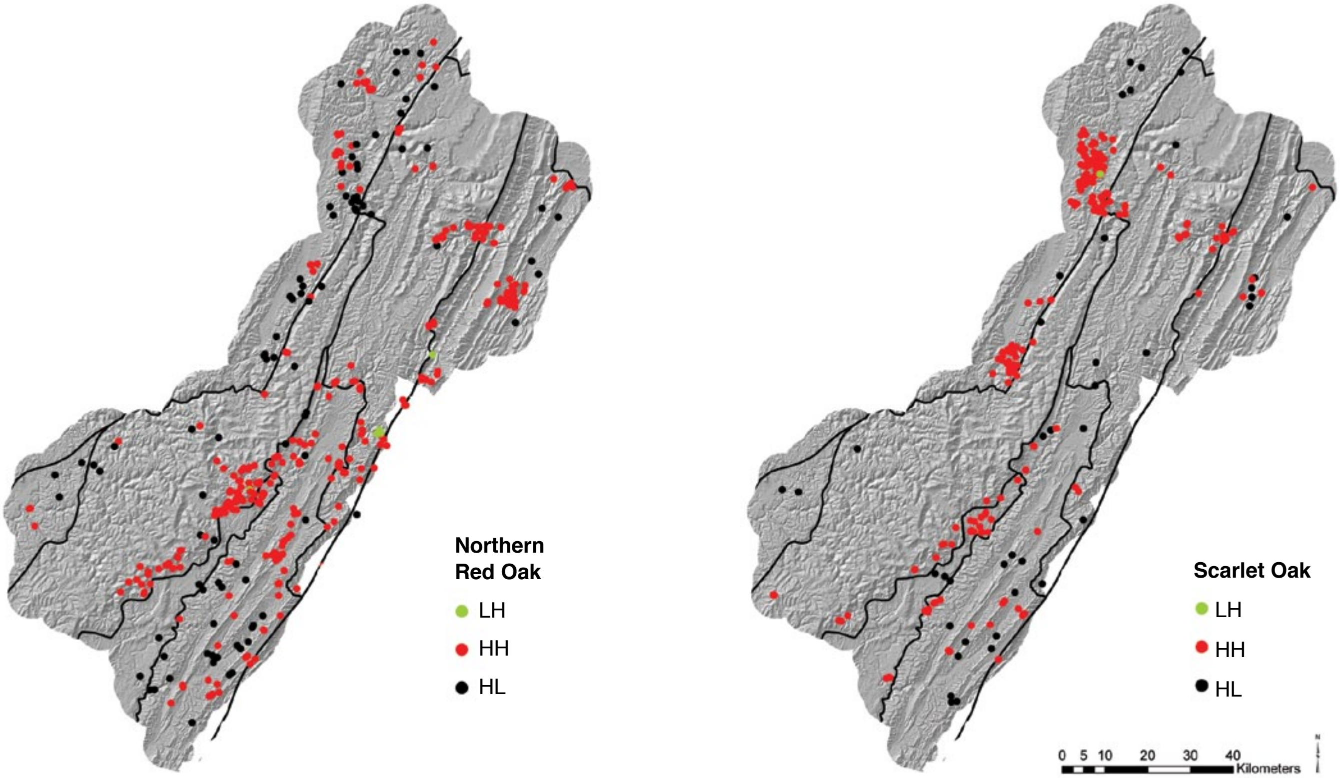

Figure 11.—Results of local cluster analysis for Northern red oak and scarlet oak witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

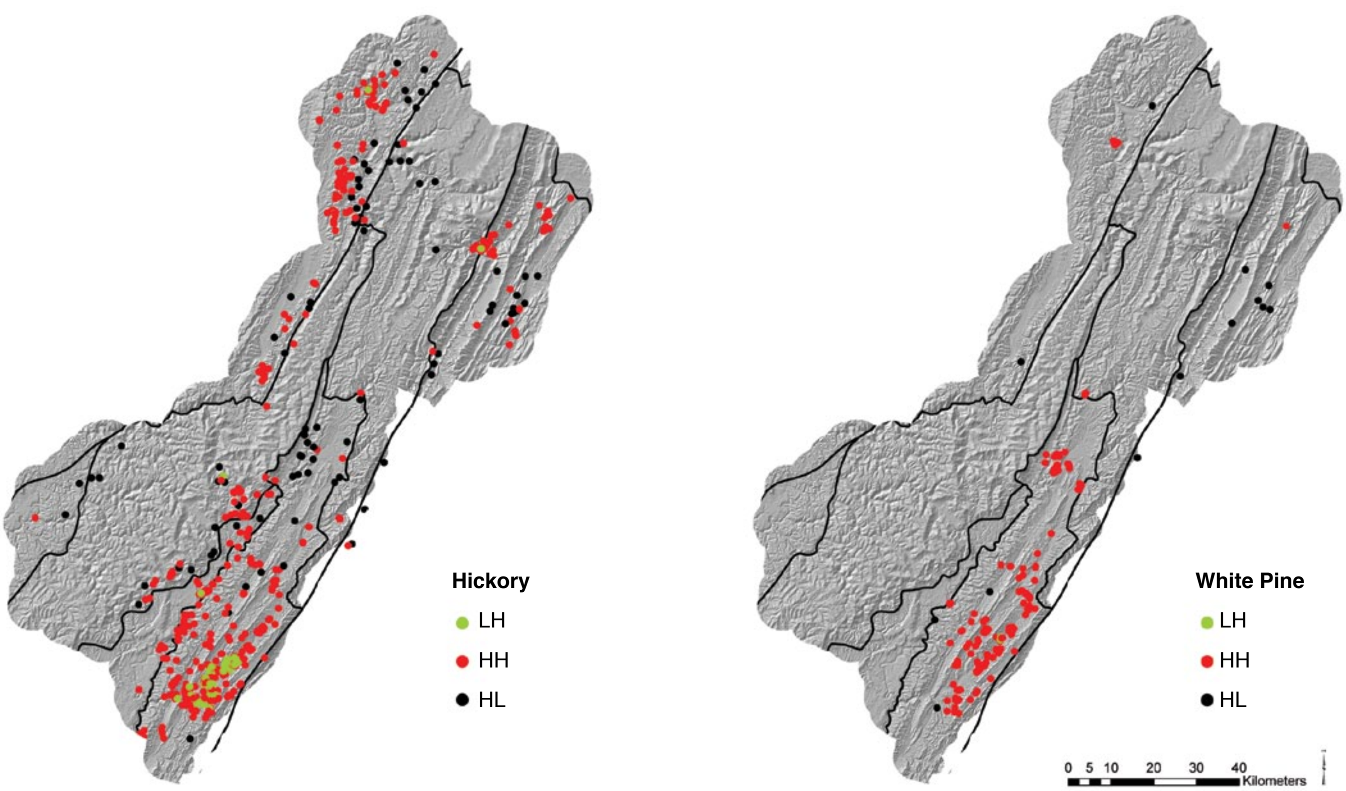

Figure 12.—Results of local cluster analysis for hickory and white pine witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

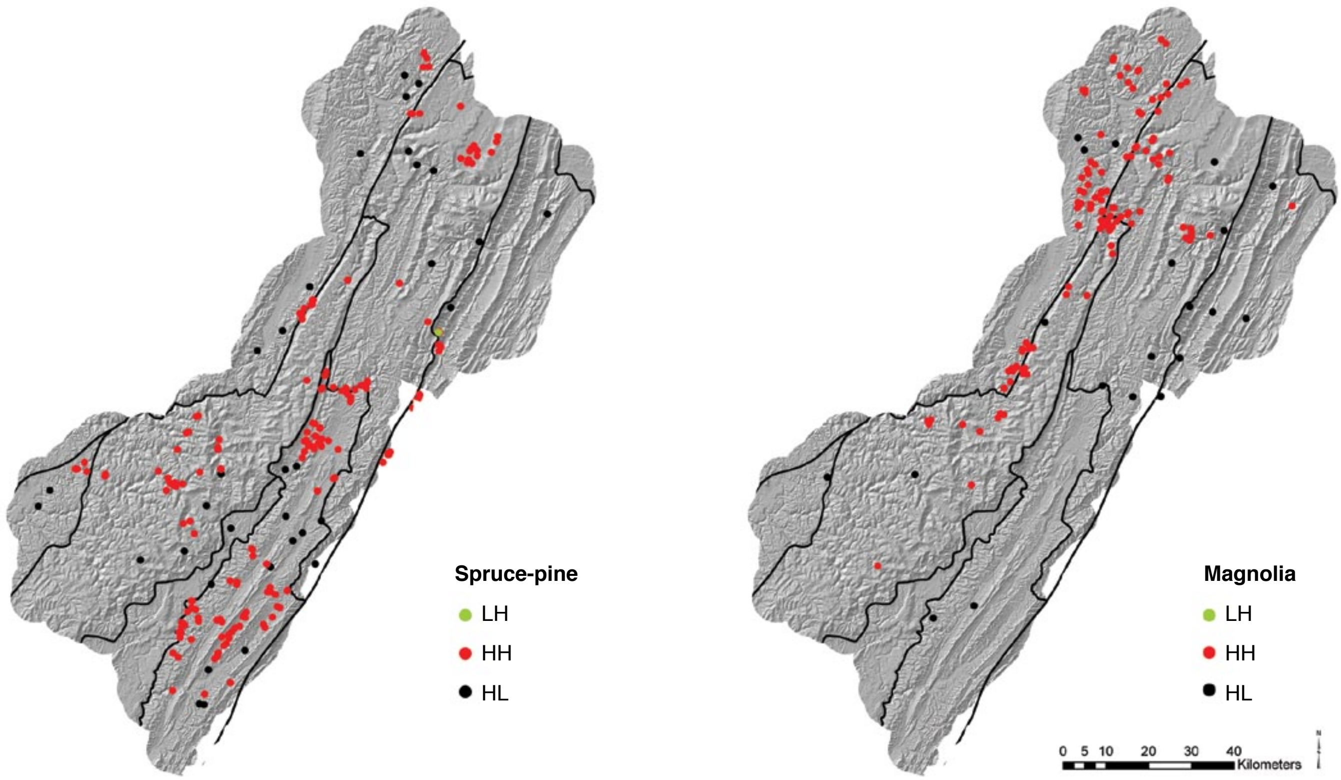

Figure 13.—Results of local cluster analysis for spruce-pine and magnolia witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

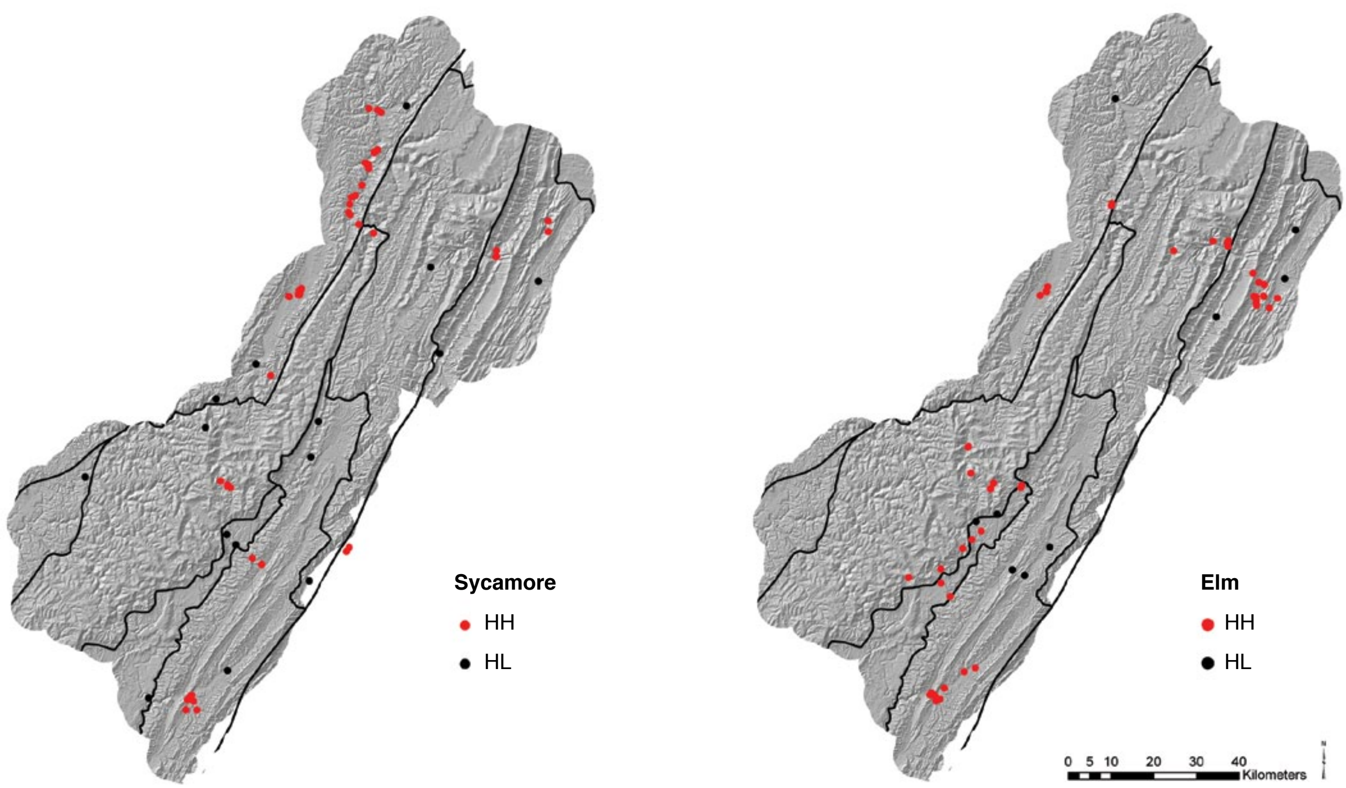

Figure 14.—Results of local cluster analysis for sycamore and elm witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

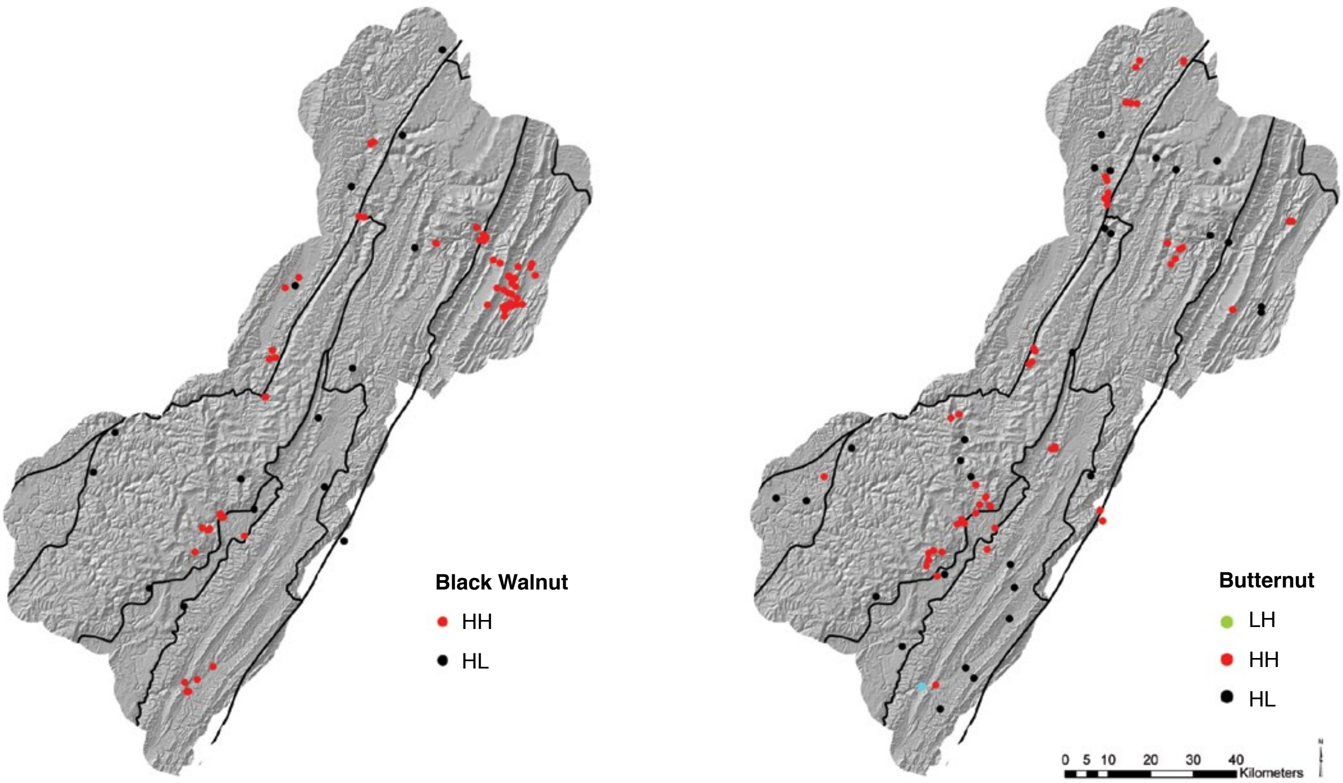

Figure 15.—Results of local cluster analysis for black walnut and butternut witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

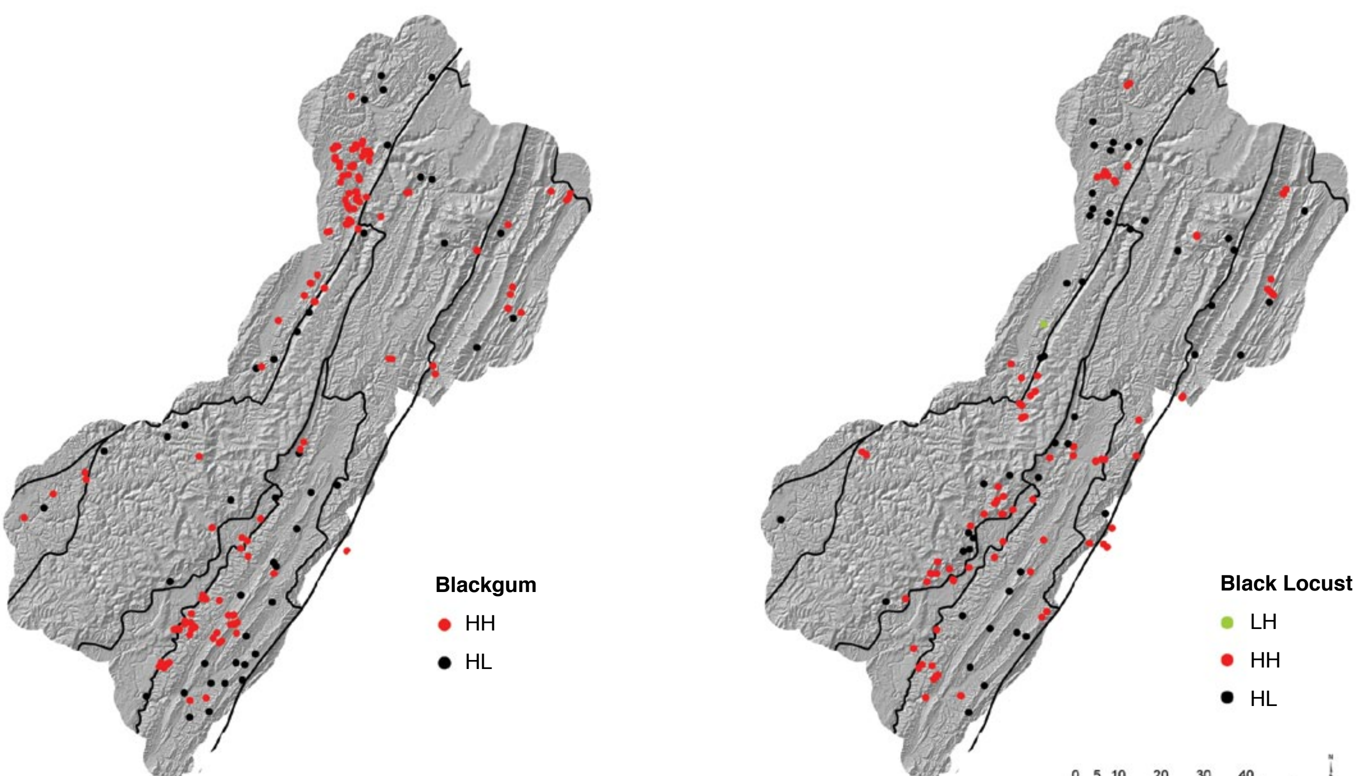

Figure 16.—Results of local cluster analysis for blackgum and black locust witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

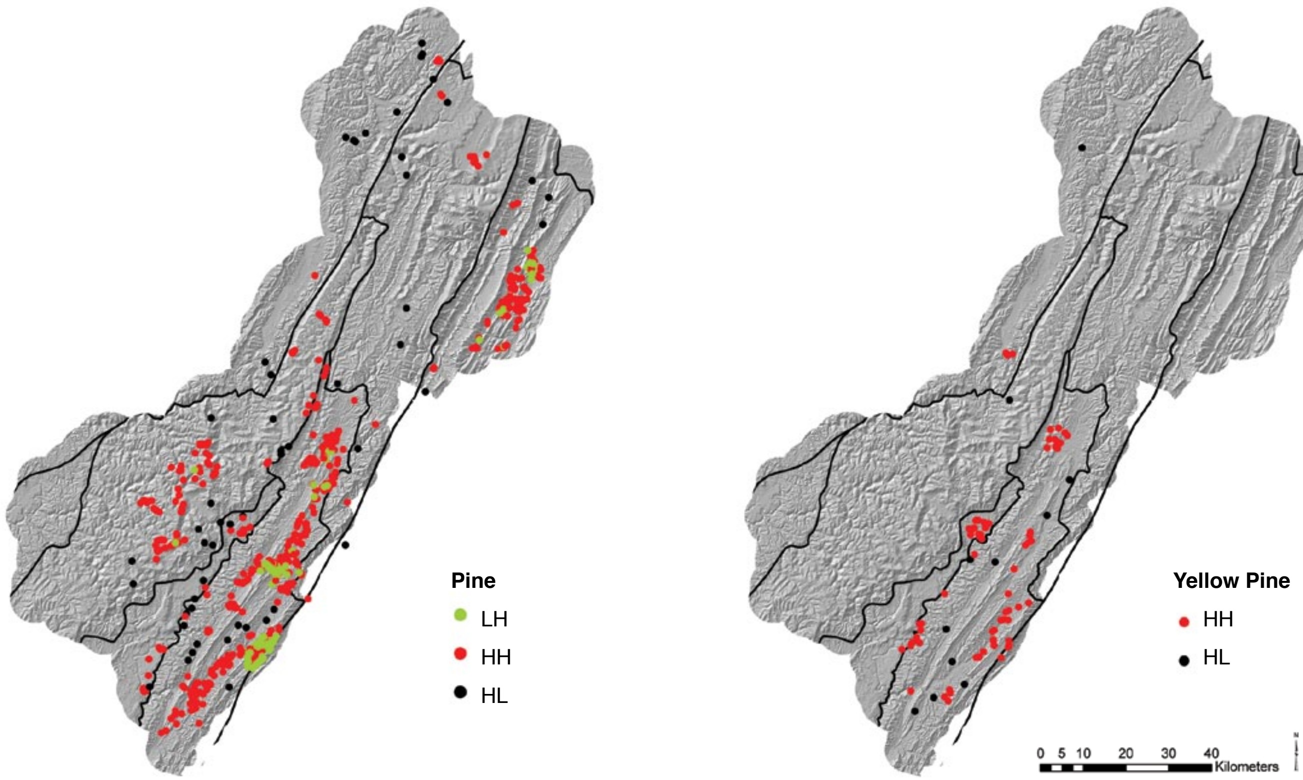

Figure 17.—Results of local cluster analysis for pine and yellow pine witness trees. Analysis results in the identification of hot spots (HH), cold spots (LL), and spatial outliers (HL or LH). Points without a cluster designation are not displayed.

Species-Site Associations

Indicator species analysis showed that across the study area red spruce, hemlock, birch, American beech, magnolia, basswood, sugar maple, ash, northern red oak, and black cherry were all associated with higher elevations; red spruce, hemlock, birch, and American beech were found on toe slopes (Table 6). At high elevations, Mandy soils on toe slopes were associated with red spruce and birch, hemlock was found on toe slopes on Buchanan soils, and black cherry was associated with Mandy soils on ridges. American beech, magnolia, and basswood were found on Meckesville soils and sugar maple and ash were associated with Belmont soils. Northern red oak witness trees stand out in this high-elevation group as being found on southeast aspects, on Cateache soils, and with sites low in moisture.

Moderate elevations supported maple, pine, white pine, yellow pine, American chestnut, chestnut oak, scarlet oak, and spruce-pine, with American chestnut and chestnut oak more likely on ridges and locations with Lily soils, high TRI, and low moisture. Spruce-pine witness trees were more likely on valley landforms in the Potomac soil series with low TRI and high moisture. Low-elevation sites with high moisture were more likely to support black walnut, white oak, elm, and sycamore. White oak, elm, and sycamore were associated with the valley landform. Hickory and yellow-poplar witness trees were associated with sites of high TRI and low elevation. Low-elevation toe slopes on Lily soils were associated with blackgum witness trees.

No elevation class was significantly associated with butternut or black locust witness trees. Butternut was associated with toe slopes on Cateache soils; black locust, with southeast slopes over Laidig soils.

The species-site associations differed by subsection for some species and ecophysical variables (Tables 7-13). The most frequent witness tree species, white oak, was found on Weikert soils when assessed across the study area but also was associated with Laidig soils (NHAM subsection; Table 9). Weikert and Laidig soils are geographically associated, forming in place from sandstone, siltstone, and shale (NRCS 2010b). White oak witness trees were associated with toe slopes in the RV, SHAM (Table 11), and WAMV

(Table 12) subsections and valleys in the WAM subsection (Table 13). The association of white oak with TRI class varied by subsection as well, covering all three classes: high in the NHAM, moderate in the EAMV, and low in the WAM subsections. In the NHAM and SHAM subsections, white oaks were found on areas of low moisture.

Sugar maple, the next most frequent witness tree, differed in associated soil series between the study area as a whole and the RV and WAM subsections, with Belmont, Calvin, and Meckesville soils determined to be significant. These three soil series are geographically associated with each other (NRCS 2010b). Indicator species analysis determined two other landform associations for sugar maple witness trees: toe slopes in the EAMV subsection and valleys in the ECF subsection (Table 8), along with the association with ridges in the study area overall. Some differences of interest between analyses by subsection versus study area as a whole can be found for sugar maple in the EAMV subsection, where sugar maple was found at low elevations, in areas of high moisture, and on northeast-facing toe slopes. Basswood, which was often found in similar areas as sugar maple, was also associated with toe slopes, Belmont soils, and low elevations in the EAMV subsection.

While associated with an upland soil series when assessed across the study area, American beech witness trees were associated with Potomac and Atkins soils and cove landforms, in the SHAM and ECF subsections. In the EAMV subsection, American beech was associated with high-elevation, frigid Mandy soils.

American chestnut witness trees were mainly associated with ridges across the study area and in the EAMV, ECF, WAMV, and WAM subsections, but were associated with toe slopes in the SHAM subsection. Chestnut oaks had associations very similar to American chestnut in the study area as a whole and in the EAMV and WAM subsections. Northern red and black oak witness trees were found on a variety of landforms based on subsection and followed similar patterns. Both northern red and black oaks were found on ridges in the EAMV subsections, valleys in the ECF subsections, and toe slopes in the RV subsection.

Witness trees cited simply as maple differ in soil series; these trees are associated with the alluvial Atkins soil in the SHAM subsection and Laidig soils in the study area as a whole. The species (or group of species) represented by the maple witness trees exhibits a range of site associations by subsection from toe slope (EAMV) and ridge (ECF) to bench (SHAM) landforms, on southwest (SHAM) aspects, and from areas of high (EAMV) to low (NHAM) moisture.

Pine (no species given) witness trees were associated with the alluvial Allegheny soils in the study area overall, but with the residual Mandy soil in the SHAM subsection. Also in the SHAM subsection, these witness trees were found to be associated with high elevations.

Red spruce witness trees were associated with a variety of landforms depending on subsection. This species was found on toe slopes (study area and EAMV), ridges (RV), bench (SHAM), and valley (WAM) landforms. Overall, this species was associated with high elevations, but when assessed by subsection, red spruce was associated with low elevations in the WAM subsection. Northerly aspects were favored by red spruce with northeast aspects across the study area and north (EAMV) and northwest (SHAM) aspects also significant.

Black cherry witness trees were found on the alluvial Atkins soil and toe slope landforms in the WAM subsection. Across the study area, this species was associated with Mandy soils, a high-elevation residual soil, and ridge landforms. Similarly, blackgum witness trees were associated with Atkins soils and valley landforms in the ECF subsection, ridges and Lily soils in the EAMV subsection, and Ernest soils in the RV subsection. Ash in the EAMV subsection were associated with Mandy soils of high moisture in contrast to the mainly limestone-derived Belmont soils associated with this species across the study area.

Table 6.—Significant associations (α = 0.05; n ≥10) between tree species or genus and environmental variables for the study area. Blank cells indicate no significant association for that species-variable combination.

Species or genus	Elevation	Moisture	TRI	Landform	Aspect	Soil series
Red spruce	high	moderate	low	toe slope	NE	Mandy
Hemlock	high		low	toe slope		Buchanan
Birch	high			toe slope	NE	Mandy
American beech	high	moderate		toe slope	NE	Meckesville
Magnolia	high		high	ridge		Meckesville
Basswood	high		high	cove	E	Meckesville
Sugar maple	high	moderate	high	ridge	E	Belmont
Ash	high			bench		Belmont
Red oak	high	low	high	bench	SE	Cateache
Black cherry	high		low	ridge		Mandy
Maple	moderate		low			Laidig
Pine	moderate	high	low	bench	W	Allegheny
White pine	moderate			bench		Weikert
Yellow pine	moderate	low		bench		Lily
American chestnut	moderate	low	high	ridge		Lily
Chestnut oak	moderate	low	high	ridge	NW	Lily
Scarlet oak	moderate		high			Lily
Spruce-pine	moderate	high	low	valley		Potomac
Black walnut	low	high		bench		Opequon
White oak	low	high	low	valley	SE	Weikert
Elm	low	high		valley	W	Atkins
Sycamore	low	high	low	valley		Atkins
Hickory	low		high		W	Macove
Yellow-poplar	low		high			Gilpin
Black oak	low	low			SE	Lily
Blackgum	low			toe slope		Lily
Butternut				toe slope		Cateache
Black locust					SE	Laidig

Table 7.—Significant associations (α = 0.05; n ≥10) between tree species or genus and environmental variables for the EAMV subsection. Blank cells indicate no significant association for that species-variable combination.

Species or genus	Elevation	Moisture	TRI	Landform	Aspect	Soil series
Red spruce	high			toe slope	N	Shouns
Birch	high		high	toe slope	E	Mandy
American beech	high			toe slope	NE	Mandy
Red oak	high		high	ridge		
Black oak	high	low		ridge	SE	
American chestnut	high	low	high	ridge	NW	Lily
Chestnut oak	high	low	high		NW	Lily
Scarlet oak	high		high	toe slope		
Black locust	high			ridge		
Pine	moderate	high	low	bench		Allegheny
Yellow pine	moderate	low	high			
White oak	moderate		moderate			
White pine	low			cove		
Sugar maple	low	high		toe slope	NE	Belmont
Basswood	low	high	high	toe slope	E	Cateache
Black walnut	low			bench		
Hickory	low		high			
Elm	low			valley		
Sycamore	low	high		valley		Atkins
Butternut	low			ridge		
Black cherry			low			Mandy
Ash		high	low	bench		Mandy
Yellow-poplar			high		E	
Blackgum			moderate	ridge		Lily
Maple		high	low	toe slope		
Spruce-pine		high		toe slope		
Magnolia						Cateache

Table 8.—Significant associations (α = 0.05; n ≥10) between tree species or genus and environmental variables for the ECF subsection. Blank cells indicate no significant association for that species-variable combination.

Species or genus	Elevation	Moisture	TRI	Landform	Aspect	Soil series
Black oak	moderate			valley		Atkins
Basswood	moderate					
Yellow-poplar	moderate					
Spruce-pine	low	high		valley		
Chestnut oak				ridge		
Red oak				valley		
Sugar maple				valley		
Blackgum				valley		Atkins
American beech				cove		Atkins
Maple				ridge		
American chestnut				ridge		
Scarlet oak						
Ash						
Butternut						
Magnolia						
Black locust						
Hickory						
Birch						
Red spruce						
Hemlock						
Black cherry						
Pine						
White pine						
Yellow pine						
Black walnut						
White oak						
Elm						
Sycamore						

Table 9.—Significant associations (α = 0.05; n ≥10) between tree species or genus and environmental variables for the NHAM subsection. Blank cells indicate no significant association for that species-variable combination.

Species or genus	Elevation	Moisture	TRI	Landform	Aspect	Soil series
Hemlock	high	high	low			
Black cherry	high		low			
Sugar maple	high		high			
American beech	moderate			toe slope		
White oak	moderate	low	high			Laidig
Hickory	low				SW	Allegheny
Yellow-poplar	low		high			
Blackgum	low					
Birch				bench	N	
Red oak			high	bench	S	
Basswood			high			
Chestnut oak		low		bench	S	
Scarlet oak						
Maple		low				
Magnolia		low				
Spruce-pine		high	low			
Butternut					NE	
Black oak						
Red spruce						
Elm						
American chestnut						
Ash						
Pine						
White pine						
Yellow pine						
Sycamore						
Black walnut						
Black locust						

Table 10.—Significant associations (α = 0.05; n ≥10) between tree species or genus and environmental variables for the RV subsection. Blank cells indicate no significant association for that species-variable combination.

Species or genus	Elevation	Moisture	TRI	Landform	Aspect	Soil series
Sugar maple	high			ridge		Calvin
American chestnut	high					
Basswood	high					
Ash	moderate					
Maple	moderate					
Scarlet oak	moderate			cove		Shouns
Black oak	low	high	low	toe slope		
Yellow-poplar	low	high		valley		Potomac
Pine				bench		Macove
Yellow pine				bench		
Sycamore				valley	SW	
Spruce-pine			high			
Red oak				toe slope		
White oak				toe slope		
Red spruce				ridge		
Chestnut oak					W	Lily
Hickory						Allegheny
White pine						Ernest
Blackgum			low			Ernest
Black locust						Buchanan
Birch						
American beech						
Hemlock						
Magnolia						
Black cherry						
Black walnut						
Elm						
Butternut						

Table 11.—Significant associations (α = 0.05; n ≥10) between tree species or genus and environmental variables for the SHAM subsection. Blank cells indicate no significant association for that species-variable combination.

Species or genus	Elevation	Moisture	TRI	Landform	Aspect	Soil series
Red spruce	high	moderate	low	bench	NW	Berks
Hemlock	high	high	low	toe slope		Ernest
Pine	high		low	ridge		Mandy
White oak	moderate	low		toe slope	S	Potomac
Sugar maple	moderate		high	ridge		Belmont
Blackgum	moderate		moderate	toe slope		Atkins
Elm	moderate					
Maple	low		low	bench	SW	Atkins
Yellow-poplar	low			valley		
Black walnut	low					
American beech				cove		Potomac
Spruce-pine				valley		
Magnolia					N	Mecksesville
Red oak		low	high	bench	SE	Berks
Hickory			high	side slope	SE	
Birch				toe slope		
American chestnut				toe slope		Laidig
Chestnut oak					SE	
Butternut			high			
Sycamore				bench	SW	
Ash				bench		
White pine						
Basswood			high			
Black cherry				ridge		
Black locust					SE	Laidig
Black oak						
Scarlet oak						
Yellow pine						

Table 12.—Significant associations ($\alpha = 0.05$; $n \geq 10$) between tree species or genus and environmental variables for the WAMV subsection. Blank cells indicate no significant association for that species-variable combination.

Species or genus	Elevation	Moisture	TRI	Landform	Aspect	Soil series
Birch	high				NE	
Sugar maple	high					
Red oak		low				
Basswood			moderate		N	
White oak				toe slope		
Black oak						Calvin
Black locust					SE	Calvin
American chestnut				ridge		
Maple			high			
Pine					SE	
Elm					W	
White pine						
Yellow pine						
Chestnut oak						
Ash						
Yellow-poplar						
American beech						
Blackgum						
Black walnut						
Sycamore						
Spruce-pine						
Butternut						
Red spruce						
Hemlock						
Magnolia						
Black cherry						
Scarlet oak						
Hickory						

Table 13.—Significant associations (α = 0.05; n ≥10) between tree species or genus and environmental variables for WAM subsection. Blank cells indicate no significant association for that species-variable combination.

Species or genus	Elevation	Moisture	TRI	Landform	Aspect	Soil series
Sugar maple	high				E	Mecksesville
Basswood	high		high			Cateache
Scarlet oak	high		high			
Butternut	high			cove		
Magnolia	high			ridge	SE	
Black cherry	high			toe slope		Atkins
Yellow-poplar	moderate			ridge		
American chestnut	moderate	low	high	ridge		Allegheny
Chestnut oak	moderate	low	high			Allegheny
Maple	moderate		moderate			
Red spruce	low	high	low	valley	NE	Allegheny
White oak	low		low	valley		
Sycamore	low	high	low	toe slope		
Blackgum	low	high		toe slope		
Birch			high	cove	NE	
American beech		high			NE	
Ash				ridge		
Black walnut		high	low	toe slope		
Black oak					N	
Spruce-pine				toe slope		
Black locust				toe slope		
White pine				valley		
Red oak			high			
Pine						
Yellow pine						
Hickory						
Elm						
Hemlock						

Indicator Kriging

Spatial interpolation through IK was calculated for the presence/absence of sugar maple, red spruce, white oak, and American chestnut witness trees and the combinations of sugar maple or basswood, sugar maple or American beech, red spruce or birch, white oak or white pine, American chestnut or chestnut oak, and red, scarlet, black or chestnut oak occurrences. The calculated anisotropy, although varying by species, tracked well with the Allegheny Front, the geological formation of known importance in the study area that runs northeast-southwest.

The graphical results of IK (Figs. 18 – 22) are consistent with the local clustering results. The lowest probabilities for the occurrence of sugar maple and sugar maple or American beech were found in the EAMV subsection (Figs. 18 and 19). Red spruce was more likely to be found in the cool and moist SHAM and NHAM subsections (Fig. 19). White oak and American chestnut had low probabilities of occurrence in the cool and moist NHAM and SHAM subsections (Figs. 20 and 21). The probability of occurrence for white oak or white pine was greatest in the EAMV subsection (Fig. 21). When the locations of northern red, scarlet, black, or chestnut oak were interpolated, the lowest probability of occurrence was found in the SHAM and NHAM subsections (Fig. 22).

With 30-percent probability of occurrence as a threshold, white oak remained dominant across the study area among single species analyzed at about 26 percent of the study area (Table 14). Including corners where white pine was recorded did not increase the area covered by the two species. Sugar maple, the next most abundant witness tree based on counts, covered about 19 percent of the study area after interpolating between points, with coverage increasing to 27 percent when basswood points were included or 41 percent when American beech points were included (Table 14). When assessed alone, American chestnut covered 3 percent of the study area, increasing to 12 percent when chestnut oak points were included. Red spruce alone was estimated to cover 2 percent of the study area, increasing to nearly 10 percent when birch points were included. Oak species other than white oak were estimated as present on 18 percent of the study area.

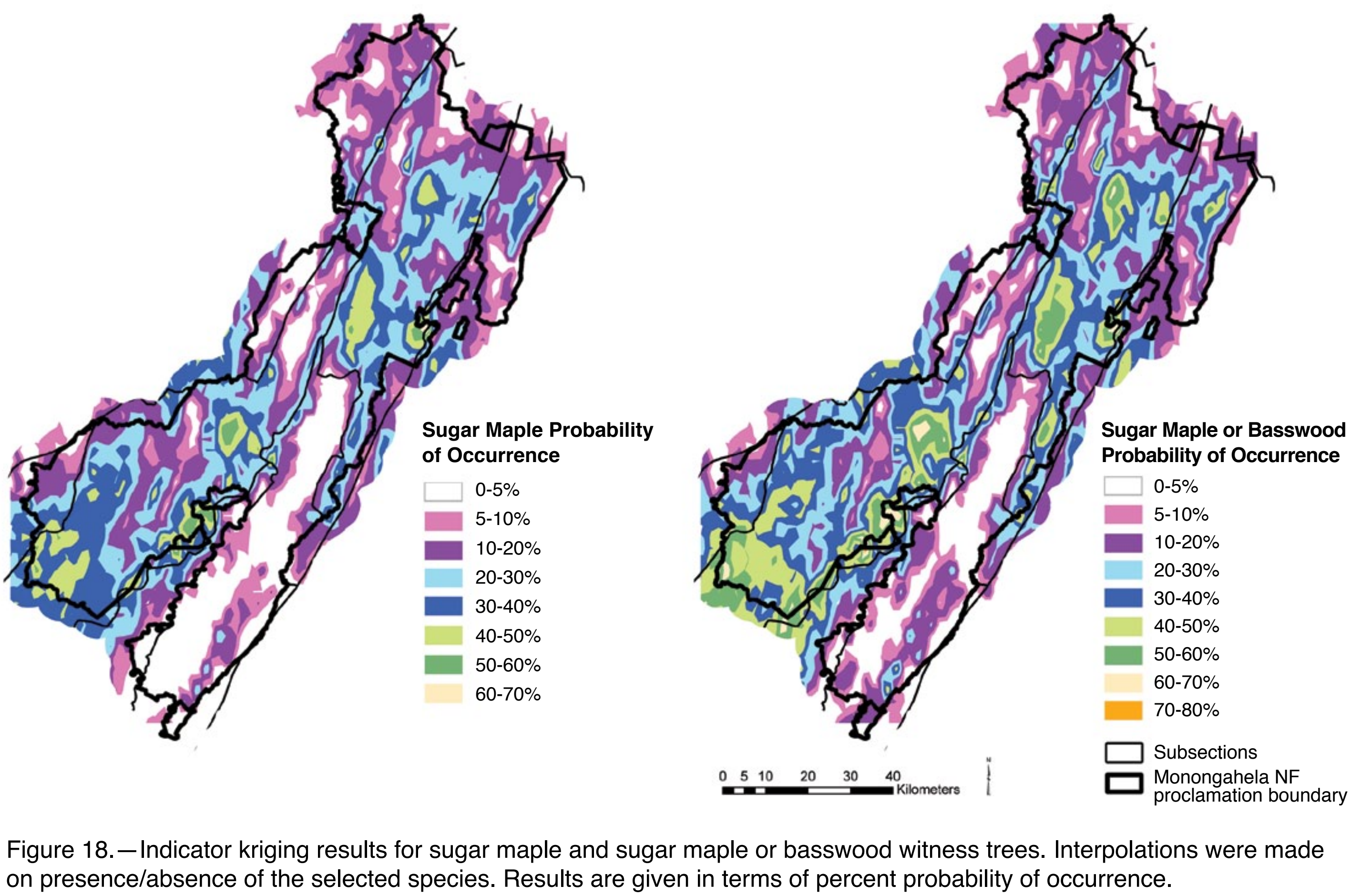

Figure 18.—Indicator kriging results for sugar maple and sugar maple or basswood witness trees. Interpolations were made on presence/absence of the selected species. Results are given in terms of percent probability of occurrence.

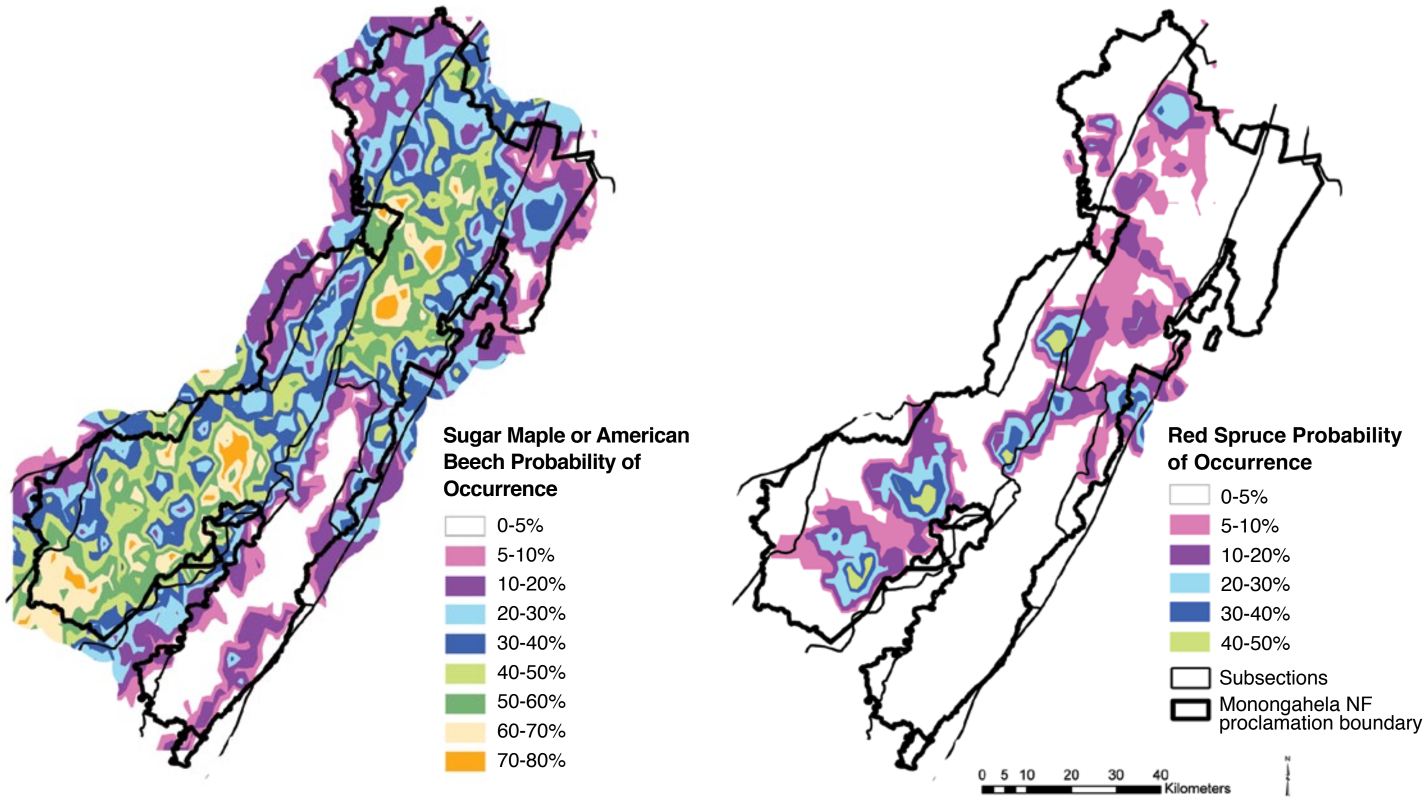

Figure 19.—Indicator kriging results for sugar maple or American beech and red spruce witness trees. Interpolations were made on presence/absence of the selected species. Results are given in terms of percent probability of occurrence.

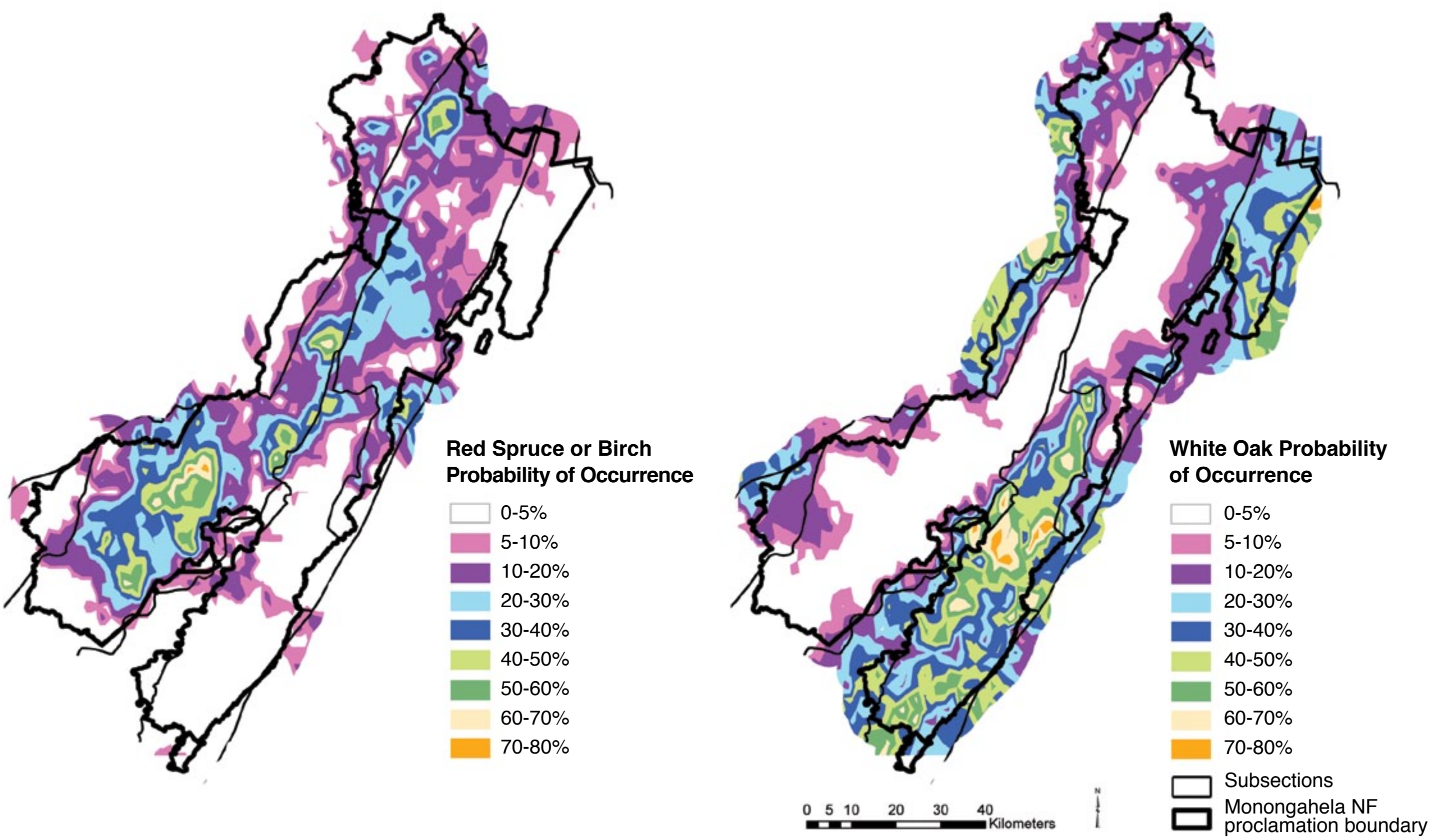

Figure 20.—Indicator kriging results for red spruce or birch and white oak witness trees. Interpolations were made on presence/absence of the selected species. Results are given in terms of percent probability of occurrence.

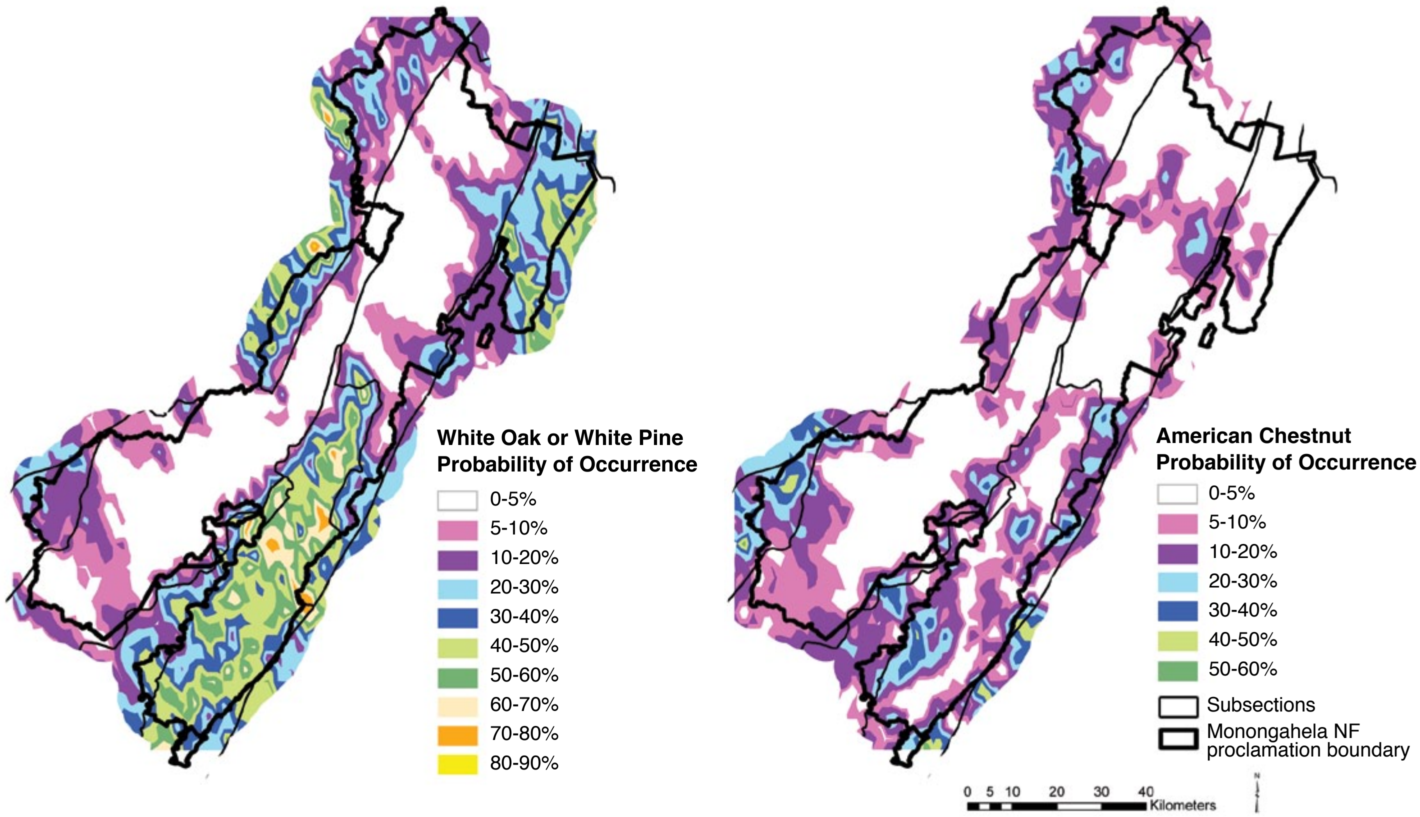

Figure 21.—Indicator kriging results for white oak or white pine and American chestnut witness trees. Interpolations were made on presence/absence of the selected species. Results are given in terms of percent probability of occurrence.

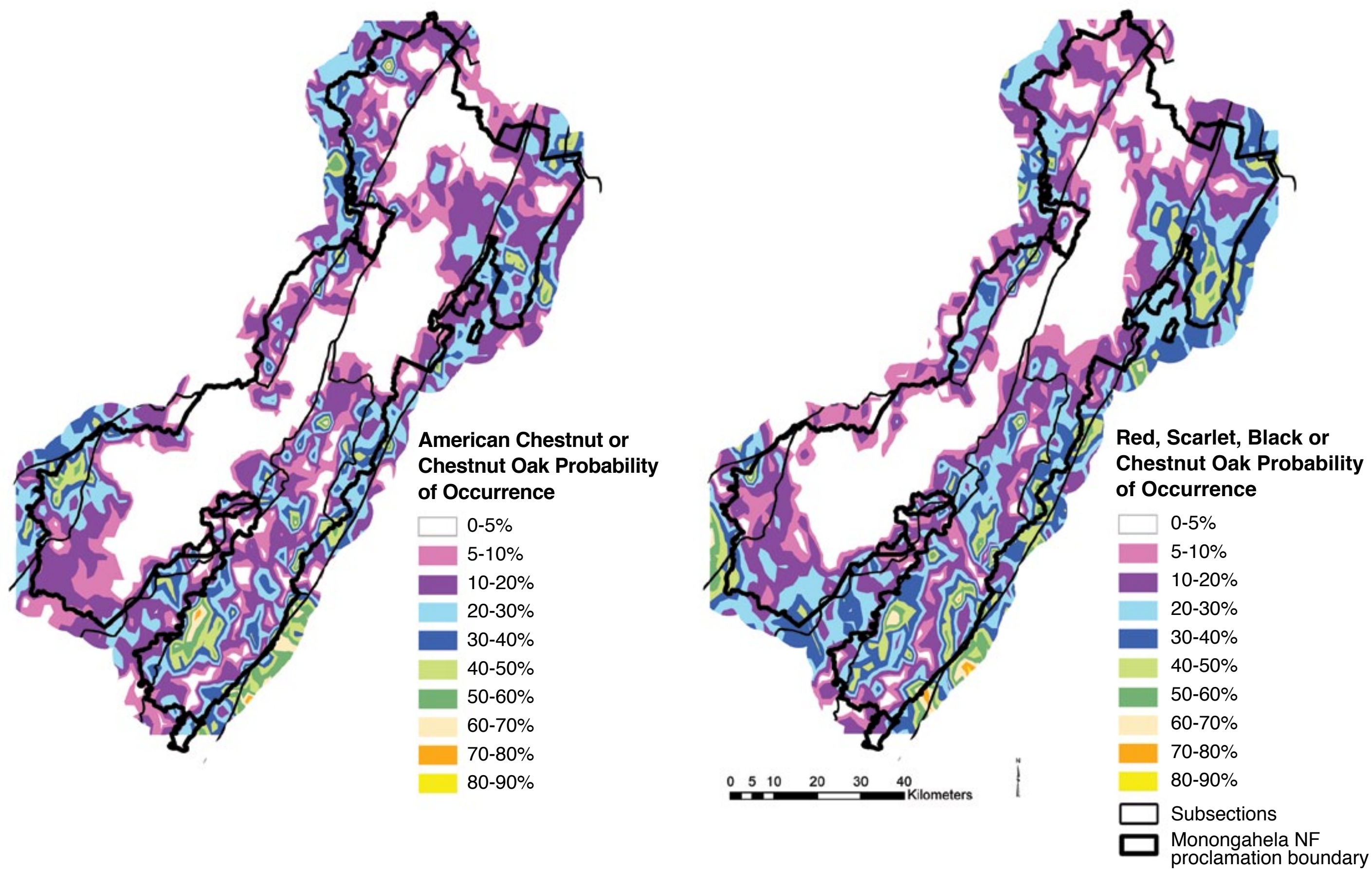

Figure 22.—Indicator kriging results for American chestnut or chestnut oak and red, scarlet, black, or chestnut oak witness trees. Interpolations were made on presence/absence of the selected species. Results are given in terms of percent probability of occurrence.

Table 14.—Percent of the study area in selected species based on IK results using 30-percent probability of occurrence as threshold.

Species	Hectares	Percent of study area
Sugar maple or American beech	418,815	41.3
Sugar maple or basswood	278,897	27.5
White oak or white pine	264,749	26.1
White oak	261,656	25.8
Sugar maple	188,297	18.6
Northern red, scarlet, black, or chestnut oak	185,791	18.3
American chestnut or chestnut oak	118,049	11.6
Red spruce or birch	97,621	9.6
American chestnut	29,162	2.9
Red spruce	21,457	2.1

DISCUSSION

The witness trees listed as pine in the SHAM subsection were likely red spruce. The indicator species analysis showed these trees recorded as pine were significantly associated with ridge landforms of low TRI and high elevation on Mandy soils. Soils in the Mandy series are strongly to extremely acid and have a frigid temperature regime (NRCS 2010b). A frigid soil temperature regime is likely to favor red spruce over hardwoods in undisturbed forests and not likely to support any pine species. The witness trees recorded as spruce-pine were likely hemlock as they were associated with Potomac soils, valley landforms, and high moisture when assessed across the study area. Interestingly, no hemlock was recorded from deeds in the EAMV subsection although 169 spruce-pines were; they were found to be associated with high-moisture toe slopes.

Indicator kriging of red spruce points alone resulted in only 2 percent of the study area with greater than 30-percent probability of occurrence of red spruce. This value increased to nearly 10 percent when birch points were included in the analysis (Table 14; Fig. 22). The proportion of spruce-dominated forests in the MNF during the period prior to European settlement has been estimated at 10 to 25 percent (U.S. Forest Service 2006a). Assuming that the majority of the birch corners in the surveys were yellow birch, our IK estimate is at the low end of one made for the MNF based on potential vegetation developed as part of the MNF ecological land type classification (U.S. Forest Service 2006a). Restoration of red spruce-dominated forests is the goal of a management prescription applied to approximately 17 percent of the MNF under the current Forest Plan (U.S. Forest Service 2006b). The witness tree database could be used to validate areas proposed for restoration of spruce-dominated forests.

Across the study area, white pine witness trees were significantly associated with cove, bench, and valley landforms, similar to findings in the presettlement forest of central Pennsylvania (Nowacki and Abrams 1992). This result lends support to the idea that white pine was restricted to more mesic sites because of periodic understory fires (Abrams 2001). Larger white pines are considered fire resistant because of thick, insulating bark, although white pine seedlings and saplings are killed by understory fire (Carey 1993). In a mixed oak-white pine forest, dominance by either group is controlled by the frequency of understory fires, with longer fire-free periods resulting in white pine recruitment to the overstory (Abrams 2001).

Current difficulties regenerating northern red oak on mesic sites make northern red oak witness tree information important to land managers. Northern red oak witness trees rank 11th in terms of abundance across the study area, and their highest ranking (6th) was in the RV subsection. Based on indicator species analysis, northern red oaks were found on sites with low moisture and high TRI, at high elevations, and with southeast aspects.

A broader range of site conditions for northern red oak may be found by exploring the HH point locations determined from the local clustering analysis. These points could be queried for site conditions other than those assessed in this analysis and field visits could determine other site factors that may be important for supporting northern red oak.

Other assessments of witness trees have used contingency table analysis to determine species-site relationships (Abrams and McCay 1996; Black and Abrams 2001a, b; Dyer 2001; Strahler 1972; Wang 2007; Whitney 1990; Whitney and DeCant 2003). While this nonparametric method gives a measure of significant positive or negative association with environmental variables, the G statistic can give inaccurate results with small expected values (common for datasets including many site variables and species) (Dowdy et al. 2004), and the test assumes independence of the samples (Maddox and Wisnewski 2008). Since positive spatial autocorrelation was found in the data, we chose to use indicator species analysis with significance tested through Monte Carlo methods. Logistic regression could also be used to determine significant ecophysical variables associated with each species. Indicator species analysis was used in this analysis as a tool to describe the significant site-species associations of the species at each corner and not to predict occurrence of any species at a given point. Nothing in this analysis precludes future regression analysis to predict species occurrence, but this dataset is not a random sample and exhibits positive spatial autocorrelation that would need to be addressed in any regression model.

As was found for witness trees in the Central Hardwood Region of Ohio, Pennsylvania, and West Virginia (MNF was not included in that study area) (Rentch and Hicks 2005), white oak dominated the MNF witness tree record. Unlike the MNF data, black oak was the next most abundant species (Rentch and Hicks 2005). For the MNF, black oak ranked 13th overall, reaching 5th in the WAMV and RV subsections (Table 5). American chestnut was more common on the MNF than in the area assessed by Rentch and Hicks (2005), ranking 4th across the study area, 1st in the ECF subsection, 3rd in two subsections (WAM and WAMV), and 4th in the EAMV subsection (Table 5). Northern red oak was found to be a relatively minor component of the early forest in both studies.

An estimate of early forest composition reported that American chestnut made up about 12 percent of the forest of West Virginia (Brooks 1910). In the current study, American chestnut made up about 6 percent of the witness trees across the study area, and covered about 3 percent of the study area based on IK. When American chestnut was combined with chestnut oak, which occurred on similar site conditions, approximately 12 percent of the study area is estimated to include either species (Table 14).

The results of indicator species analysis suggest logical groupings of species into forest types. Sugar maple and basswood are similar in their site associations across the study area as a whole and in the EAMV subsection. Sugar maple and American beech across the study area were found to be associated with areas of moderate moisture, high elevation, and two geographically associated soils. Birch (likely yellow birch) and red spruce also had many similarities when assessed across the study area. Sycamore and elm witness trees across the study area were both associated with similar ecophysical variables. Chestnut oak and American chestnut often showed the same significant associations of soil, landform, and elevation. White oak stands out in comparison to the other oaks because of its significant association with valley landforms and areas of high moisture, while the other oaks, in general, were associated with areas of lower moisture. White oak and white pine were associated with the same soils and landforms across the study area. This same species combination and landform association was found in presettlement forests of the Ridge and Valley Province in Pennsylvania (Nowacki and Abrams 1992).

Ultimately, surveyors chose from species present on the site, where environmental factors constrained which species could occur at any given survey corner. Any mapping of forest types from the analysis of witness tree data is likely to be valid even though the trees used to create groupings were not strictly chosen at random by the original surveyor (Manies and Mladenoff 2000). Although the surveyor chose the species to record as a witness tree, site factors affected which species were available to choose from so that even if species bias exists, the mapping of vegetation at a landscape scale should not be significantly affected (Manies and Mladenoff 2000).

We believe that evidence for surveyor bias toward certain species in the MNF witness tree dataset was limited since surveyors used a variety of tree species as witness trees. Smaller-stature trees such as dogwood and serviceberry were documented in the deeds, although not in large numbers. The number of species used by the surveyors (Table 3) implies broad knowledge of common trees in the study area. Most telling is the very low occurrence of the generic oak (only 18 occurrences). An overwhelming number of deeds (and presumably surveyors) used specific oak names in parcel descriptions.

Elevation does not appear to be a driver in the distribution of tree species in the WAMV and ECF subsections. Only two species in the WAMV subsection and only four species in the ECF subsection displayed an association with any elevation class. The ECF subsection is the westernmost subsection in the study area and the farthest from the Allegheny Front. This distance from the more mountainous areas may allow for other environmental drivers to have greater influence on species distributions than does elevation. The study area includes only a portion of the larger WAMV subsection and is dominated by the Greenbrier River Valley, which may be influencing the analysis of environmental variables.

A previous study of witness tree data for the MNF determined that presettlement Ridge and Valley section forests were dominated by mixed oak (white oak, chestnut oak, black oak, and northern red oak), pines, American chestnut, and hickory on ridges (Abrams and McCay 1996). Valley floors of the Ridge and Valley section were dominated by white oak, sugar maple, pines, basswood, and hemlock. In the Allegheny Mountains section, presettlement forests were mainly American beech, hemlock, sugar maple, red maple, birch, and pine, with American beech, hemlock, and pine on the mountaintops and hemlock, maple, and birch on valley floors.

Unlike Abrams and McCay (1996), the current analysis used subsections instead of sections and more landforms were included. Species trends were generally similar in that oaks were found on drier landscapes and mesic landforms were dominated by northern hardwoods (American beech-birch-maple). With this current analysis, however, more detail is available for development of predictive models to assign forest types or species to certain landforms and subsections.

In the 1996 analysis, red spruce witness trees were conspicuously absent, with only one tallied for the Ridge and Valley Province and six in the Allegheny Mountains (Abrams and McCay 1996), compared to the 683 used in the current study. In the current study, duplicate corners were retained in the dataset if new tree species were added in subsequent surveys. The 1996 study covered approximately 80,000 ha of the MNF and included deeds ranging from 1780 to 1856. The current study was based on more than 15,000 corners and 22,000 trees; the 1996 study included only 1,015 trees.

Indicator kriging of witness trees from GLO surveys was not found to be useful in estimating the actual area occupied by different vegetation types because the spatial resolution of witness points was too coarse to recreate finer-scale and patchy patterns (Maines and Mlandenoff 2000). As a result, Manies and Mladenoff (2000) recommend that IK be used only to describe areas greater than 10,000 ha. In their study, positive spatial autocorrelation (which IK relies on) was not detected for all species. Of the species modeled through IK for the MNF dataset, only scarlet oak showed no spatial autocorrelation at the study area scale. Overall, probabilities of occurrence for most species and even combinations of species were low, and none reached 100 percent. Environmental variables could be used with the witness tree locations through co-IK for better interpolation between points.

CONCLUSIONS

Significant clustering patterns in the distribution of species of witness trees indicate positive spatial autocorrelation. This result was not unexpected as vegetation is known to be associated with environmental variables. These spatial patterns need to be considered when creating predictive models (Miller 2005). Using only those species/witness tree locations with clustered distributions should facilitate finding the strongest associations between species occurrences and modeled variables.

Information presented here could also be used to model past extents of species and compare results to current forests. Even without these models, the witness tree data could be compared to current forests in more general terms such as species composition by subsection. While the witness trees were treated as one point in time for this analysis, the dataset does cover 148 years and future analysis of the dataset could include temporal analysis.

Land managers can immediately use the results of this analysis to describe European settlement-era forests and aid in determining whether restoration goals are appropriate given this new information. Managers could also explore site conditions and patterns for individual species through the indicator species analysis and results of local clustering. This analysis has shown that while some species may be abundant in the witness tree record (white oak and sugar maple), their distributions were not homogenous across the study area. Analysis by ecological subsection captured the variability in the study area and its influence on the distribution of tree species.

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Forest restoration would be greatly helped by understanding just what forests looked like a century or more ago. One source of information on early forests is found in old deeds or surveys, where boundary corners were described by noting nearby trees known as witness trees. This paper describes the creation and analysis of a database of witness trees from original metes and bounds surveys of what became the Monongahela National Forest in West Virginia. We include an estimate of positional error from the conversion of paper maps to digital format. The final database contains 15,589 corners and 22,328 trees of 49 species from deeds dating from 1752 to 1899. White oak was the most frequent witness tree, followed by sugar maple, American beech, and American chestnut, and distribution patterns were recognizable across the study area.

In early forests of the study area, magnolia, sugar maple, and black cherry were found on high-elevation ridges. Red spruce, hemlock, birch, and American beech were found on high-elevation toe slopes. Basswood was found in high-elevation coves, and red oak was associated with bench landforms at high elevations. At moderate elevations American chestnut and chestnut oak were associated with ridges, white pine and yellow pine occurred on benches, and an unknown species called spruce-pine was found on valley landforms. Blackgum was associated with toe slopes on low elevations, and black walnut was found on low-elevation benches. Low-elevation valleys contained white oak, elm, and sycamore. An important finding from this analysis is that some associations between species and environmental variables differed based on the ecological setting. Indicator kriging, using presence-absence data, resulted in probability of occurrence maps for selected species. We estimate that white oak covered 26 percent of the study area, sugar maple 19 percent, American chestnut 3 percent, and red spruce 2 percent.

KEY WORDS: historical biogeography, land surveys, indicator species analysis, indicator kriging, spatial analysis


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