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Mapping Pyrophilic Percentages across the Northeastern United States using Witness Trees, with Focus on Four National Forests

Melissa A. Thomas-Van Gundy
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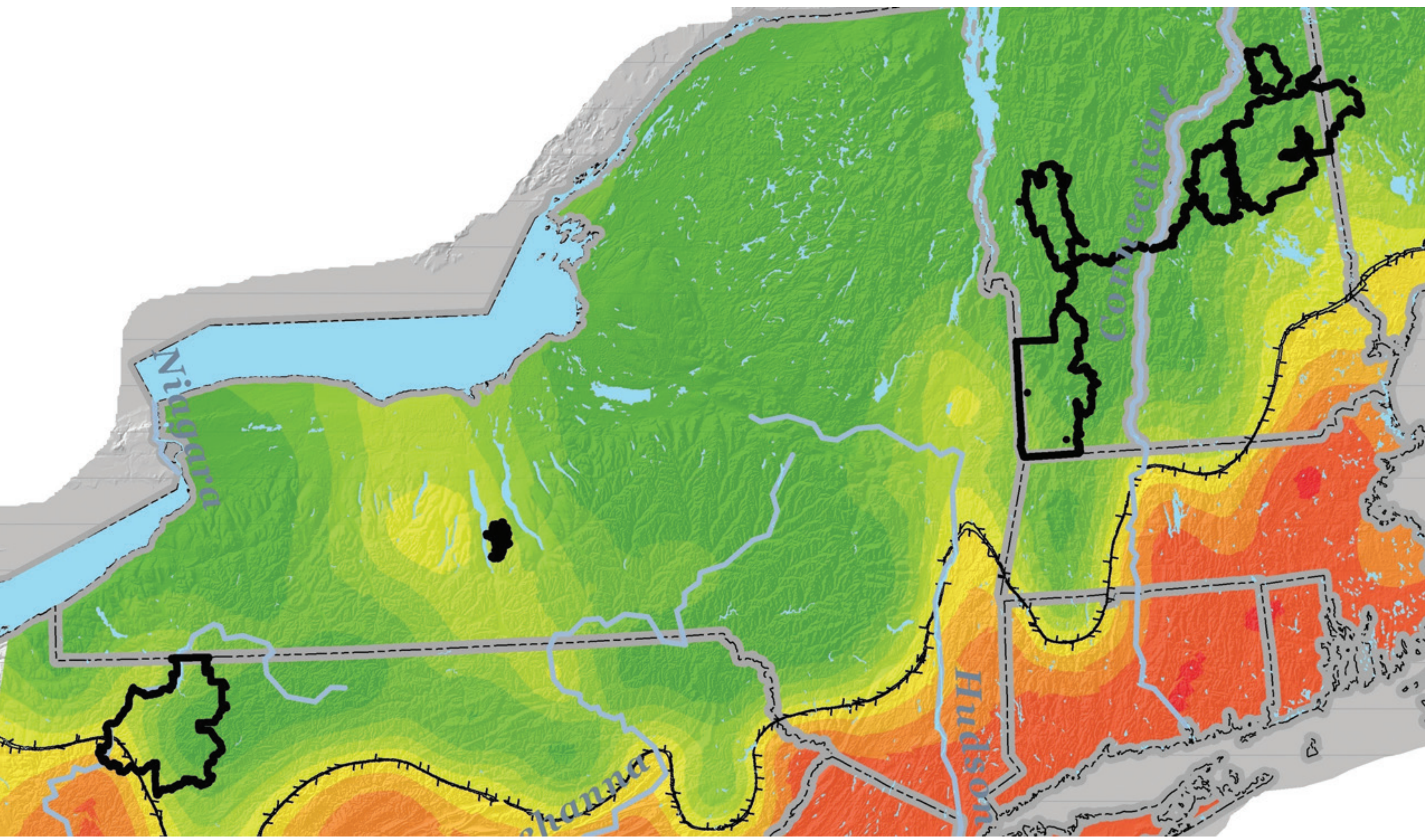

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Abstract

Witness trees provide information fundamental for restoration ecology, often serving as baselines for forest composition and structure. Furthermore, when categorized by fire relations, witness trees can shed light on past disturbance regimes. Kriging was applied to witness-tree point data to form a contiguous surface of pyrophilic percentage for four national forests in the northeastern United States. Fire was found to be an important disturbance agent on the Allegheny and Finger Lakes National Forests, often corresponding to large river systems and lakesides where Native American activities were concentrated. In contrast, fire was relatively unimportant on the Green Mountain and White Mountain National Forests based on the witness-tree record. There, the cool, moist year-round climate, coupled with lower Native American population densities greatly subdued fire, supporting the local view of these as "asbestos" forests. When applying this method to town-level witness-tree data for the entire northeastern United States, we found a distinct east-west line dividing areas of high (south) and low (north) pyrophilic percentage. Known as the tension zone line, the undulating character of this boundary, penetrating northward along major river valleys, underscores the importance of Native Americans as a disturbance agent on the presettlement landscape.

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INTRODUCTION

Europeans have transformed the environment since their New World arrival (Mann 2005, Whitney 1994). This effect is especially true for the Northeast (Foster and Motzkin 1998), where Europeans have a long history through early settlement and interactions with Native cultures, perhaps dating back to the Vikings (Barnes 2001). European influences moved across the continent in waves, often far in advance of their appearance (Richter 2001). The fur trade was the first major European activity with far-reaching impacts, quickly depleting beaver (*Castor canadensis* Kuhl) populations and allowing widespread conversion of open riparian habitats to forests, possibly accompanied by increased stream incision and erosion (Innis 1999, Parker et al. 1985, Richter 2001). Early encounters with Europeans proved devastating to Native American peoples through the transmission of diseases (Cook 1973, Crosby 1967, Dobyns 1993, Ramenofsky 2003), leading to mass pandemics with severe cultural and social upheavals and land-use repercussions (Mann 2005, Richter 2001). As Native American populations waned and were forced westward, European populations expanded, led by a surge of forest clearing for timber and agriculture during the 17th and 18th centuries (Foster and Motzkin 1998). By the mid-1800s, soil degradation and market access to the fertile Midwest led to the retraction of agriculture in New England, allowing for widespread reforestation as exemplified by eastern white pine (*Pinus strobus* L.) (Raup 1966). Even today, with urban and suburban development, the region still remains largely forested, especially in New England (Brooks 2003).

The forests that covered the northeastern United States before European settlement are long gone, but they can be reasonably reconstructed through the use of witness trees from early land warrants (Cogbill et al. 2002, McIntosh 1972, Seischab 1990, Whitney 1990). When incorporating ecophysiological and fire relations knowledge, we can further use witness trees to reconstruct past fire regimes, helping specify where fire was an important disturbance agent on the presettlement landscape (Thomas-Van Gundy and Nowacki 2013). All forms of information, witness-tree-based compositions, structures, and disturbance regimes, are vitally important for land managers and conservationists involved in ecological restoration, with the understanding of disturbance regimes helping guide the return of fire back onto landscapes that formerly burned (Brose et al. 2001, Nowacki et al. 2009, Nowacki and Carr 2013). To aid this cause, we apply a recently published method (Thomas-Van Gundy and Nowacki 2013) converting witness trees to pyrophilic-percentage maps to help identify presettlement fire gradients across four northeastern national forests: Allegheny (ANF), Finger Lakes (FLNF), Green Mountain (GMNF), and White Mountain (WMNF). Furthermore, town-level witness tree data (Thompson et al. 2013) allowed us to project pyrophilic percentages at a regional scale, helping to define the division (i.e., tension zone line) between southern oak-pine (*Quercus-Pinus*) and northern hardwood systems bisecting the region (sensu Cogbill 2000, Cogbill et al. 2002) and the relationship of this boundary line to fire. The production of maps at multiple scales will help land managers, conservationists, and researchers understand local pre-European settlement fire regimes and their context within a larger regional perspective.

METHODS

Study Areas

The national forests in this analysis cover portions of five states in the northeastern United States: Pennsylvania, New York, Vermont, New Hampshire, and Maine (Fig. 1). The entire northeast region spans five ecological provinces, although only three are represented on the national forests. The ANF lies within the Northeastern Mixed Forest Province, the

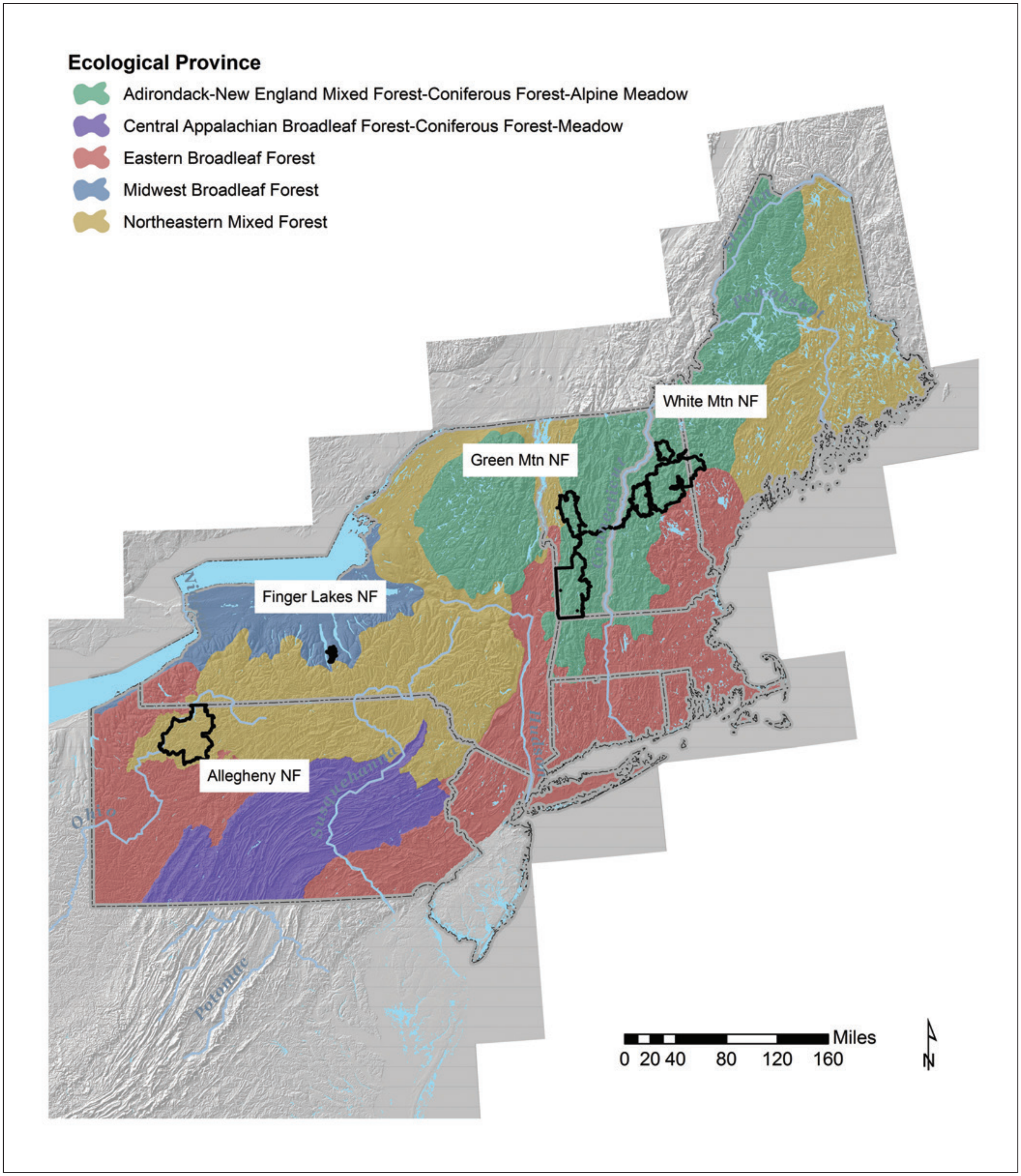

Figure 1.—Locations of the four national forests and five ecological provinces in the study area.

FLNF within the Midwest Broadleaf Forest Province, and the GMNF and WMNF lie within the Adirondack-New England Mixed Forest-Coniferous Forest-Alpine Meadow Province (Cleland et al. 2007).

The topography and surficial geology of the FLNF, GMNF, and WMNF were directly shaped by past glaciations, especially the Wisconsin glaciation. Over more rugged terrain (GMNF and WMNF), overriding glaciers were more erosional in nature, scouring mountains and leaving behind a thin veneer of locally derived sediments on ridge tops and side slopes with thicker accumulations on lower valley floors (Van Driver 1987). On flat to rolling terrain (FLNF), glaciation was more depositional in nature, leaving behind thicker deposits of unconsolidated materials often in distinct landforms such as moraines and drumlin fields (Van Driver 1985). Although not directly impacted by the Wisconsin glaciation, the ANF was affected by periglacial processes (freeze-thaw action, solifluction, nivation) due to its close proximity to the ice sheet leaving behind distinct features in some cases (talus slopes, patterned ground). Glacially driven land cover changes were profound during the Holocene, generally passing from ice (FLNF, GMNF, and WMNF) or tundra conditions (ANF) through open woodlands to forests (Davis and Jacobson 1985). Waves of arboreal species moved independently across the region largely reflecting their mode of dispersal and sensitivity to temperature, with light-seeded, cold-tolerant species emerging first (Pielou 1991). In general, Holocene vegetation shifted from poplar (*Populus* spp.) and spruce (*Picea* spp.) to pine dominance before succeeding to hemlock, maple, and beech (*Tsuga-Acer-Fagus*) communities in the north and oak-dominated communities in the south (Bernabo and Webb 1977, Davis and Jacobson 1985).

Witness-tree Data

Witness-tree databases with species and digital point locations were compiled from original land survey records contained in various archives by Charles Cogbill, funded in part by the U.S. Forest Service. An additional 106 points were included for the FLNF from a scanned map of corner trees for the area around Hector, NY. Two survey systems were represented in our study, a rectangular system similar to the Government Land Office (GLO) system in Pennsylvania (ANF) and New York (FLNF), and the proprietary town system in Vermont and New Hampshire (GMNF and WMNF). In both systems, witness trees were represented as corner or bearing trees; however, unlike in the GLO system, no information other than species/genera was recorded for each tree.

Analysis Methods

Witness-tree point locations were converted to pyrophilic percentage maps following the procedures of Thomas-Van Gundy and Nowacki (2013). First, witness trees were categorized as either pyrophilic or pyrophobic at the genus and/or species levels (Table 1). For this analysis, we focused on species traits adapted (or not) to a long-term regime of recurrent surface fire, although many species may take advantage of conditions created after a single fire (e.g., yellow birch [*Betula alleghaniensis*], yellow-poplar [*Liriodendron tulipifera*], black cherry [*Prunus serotina*]). Witness trees possessing traits for persistence under recurring fire were considered pyrophilic; those possessing fire-sensitive, mesophytic traits were considered pyrophobic (Table 1). Because all survey corners were represented by only one witness tree, the categorization resulted in points being either 0 or 100 percent pyrophilic. For the four national forests, ordinary kriging was used to interpolate between the points (survey corners with witness trees) to create a continuous surface of predicted pyrophilic percentages. Ordinary kriging is an interpolation technique where the best linear unbiased estimator is calculated for locations with unknown values and for the mean residual error to equal to zero (Isaaks and Srivastava 1989). For all national forests and regional-level witness trees, a maximum of five and a minimum of two neighboring points were used for interpolation.

Table 1.—Species listed as witness trees in early land surveys of the Northeast and their assignment as pyrophobic or pyrophilic

Common name used in surveys	Scientific name	Relationship to fire	Vital attribute related to fire	References
Ash	*Fraxinus americana*	Pyrophobic	Fire-discouraging leaves, mesophyte	FEIS
Basswood, linden, linn, linnwood, white wood	*Tilia* spp.	Pyrophobic	Thin bark, shallow roots, fire-discouraging leaves, mesophyte	FEIS
Beech, red beech	*Fagus grandifolia*	Pyrophobic	Thin bark, fire discouraging leaves, mesophyte	FEIS
Birch	*Betula* spp.	Pyrophobic	Thin bark, fire-discouraging leaves, poor sprouting, mesophyte	FEIS
Black ash	*Fraxinus nigra*	Pyrophobic	Fire sensitive, landscape position	Burns and Honkala 1990, FEIS
Black jack	*Quercus velutina*	Pyrophilic	Thick bark, sprouting, fire-encouraging leaves, xerophyte, tap root	FEIS
Black oak	*Quercus velutina*	Pyrophilic	Thick bark, sprouting, fire-encouraging leaves, xerophyte, tap root	FEIS
Black spruce	*Picea mariana*	Pyrophobic	Landscape position in study area	Burns and Honkala 1990, FEIS
Butternut, white walnut	*Juglans cinerea*	Pyrophobic	Mesophyte, fire-discouraging leaves	FEIS
Buttonwood	*Plantanus occidentalis*	Pyrophobic	Thin bark, mesophyte	FEIS
Cedar	*Thuja occidentalis*	Pyrophobic	Landsdscape position, thin bark, shallow roots	Burns and Honkala 1990, FEIS
Cherry	*Prunus serotina*	Pyrophobic	Thin bark, fire-discouraging leaves, mesophyte	FEIS
Chestnut	*Castanea dentata*	Pyrophilic	Sprouting, thick bark, fire-encouraging leaves, tap root, rot resistance	Delcourt and Delcourt 1998, Perry and Ison 2003
Chestnut or rock oak	*Quercus prinus*	Pyrophilic	Thick bark, sprouting, fire-encouraging leaves, xerophyte, tap root	FEIS
Cucumber, elkwood	*Magnolia acuminata*	Pyrophobic	Thin bark, mesophyte	Burns and Honkala 1990
Dogwood	*Cornus* spp.	Pyrophilic	Susceptible to fungal disease under closed canopy	FEIS, Holzmueller et al. 2008
Elm, white elm, red elm	*Ulmus* spp.	Pyrophobic	Thin bark, fire-discouraging leaves, mesophyte	FEIS
Fir	*Abies balsamea*	Pyrophobic	Thin bark	FEIS
Gum	*Nyssa sylvatica*	Pyrophilic	Thick bark	Abrams 2007, FEIS

(Continued on next page)

Table 1 (continued).

Common name used in surveys	Scientific name	Relationship to fire	Vital attribute related to fire	References
Hackmatac, tamarack	*Picea mariana or Larix laricinia*	Pyrophobic	Landscape position in study area, thin bark, shallow roots	Burns and Honkala 1990, FEIS
Hard maple, sugar maple, rock maple, white maple	*Acer saccharum*	Pyrophobic	Thin bark, fire-discouraging leaves, shade tolerant, mesophyte	FEIS
Hemlock, spruce pine	*Tsuga canadensis*	Pyrophobic	Thin bark, shallow roots, mesophyte	FEIS
Hickory	*Carya* spp.	Pyrophilic	Thick bark (most species), xerophyte, tap root	FEIS
Hornbeam, ironwood, water beech, leverwood, hazel, witch hazel, elk horn	*Ostrya virginiana, Carpinus caroliniana, Hammamelis virginiana, Corylus* spp.	Pyrophobic	Thin bark, shade tolerant, mesophyte, fire-encouraging leaves	FEIS
Juneberry/ serviceberry	*Amelanchier* spp.	Pyrophobic	Thin bark, fire-discouraging leaves	FEIS
Laurel	*Rhododendron* spp. or *Kalmia* spp.	Pyrophilic	Fire-encouraging leaves	FEIS
Maple	*Acer* spp.	Pyrophobic	Thin bark, fire-discouraging leaves, mesophyte, red maple increases in absence of fire	FEIS
Moose bush	*Viburnum alnifolium*	Pyrophobic	Mesophyte, fire sensitive	FEIS
Moose willow, moosewood	*Acer pensylvanicum*	Pyrophobic	Thin bark, fire-discouraging leaves, mesophyte	FEIS
Mulberry	*Morus* spp.	Pyrophobic	Thin bark, fire-discouraging leaves, mesophyte	
Oak	*Quercus* spp.	Pyrophilic	Thick bark, sprouting, fire-encouraging leaves, xerophyte, tap root	Abrams 1990, Abrams 2000
Pitch pine	*Pinus rigida*	Pyrophilic	Cone serotiny, sprouting, needle volatility, xerophyte	FEIS, Keeley 2012
Poplar, aspen	*Populus* spp.	Pyrophilic	Thick bark, sprouting	FEIS
Red ash	*Fraxinus pensylvanica*	Pyrophobic	Landscape position	FEIS
Red oak	*Quercus rubra*	Pyrophilic	Thick bark, sprouting, fire-encouraging leaves, tap root	FEIS
Red or yellow birch	*Betula allegheniensis*	Pyrophobic	Thin bark, fire-discouraging leaves, opportunist but not fire-adapted	Burns and Honkala 1990, FEIS
Round top	*Sorbus americana*	Pyrophobic	Thin bark, landscape position	FEIS
Sassafras	*Sassafras albidum*	Pyrophilic	Thick bark, sprouting, xerophyte	FEIS

(Continued on next page)

Table 1 (continued).

Common name used in surveys	Scientific name	Relationship to fire	Vital attribute related to fire	References
Soft maple	*Acer rubrum*	Pyrophobic	Thin bark, fire-discouraging leaves, mesophyte, red maple increases in absence of fire	FEIS
Spicewood	*Lindera benzoin*	Pyrophobic	Landscape position, facultative wetland plant in many areas	NRCS 2014
Spruce	*Picea rubens*	Pyrophobic	Thin bark, shallow roots, mesophyte	FEIS, White and Pickett 1985
Water birch	*Betula nigra* or *lenta*	Pyrophobic	Thin bark, fire-discouraging leaves, mesophyte	Burns and Honkala 1990
White birch	*Betula papyrifera*	Pyrophilic	Sprouting, re-seeds post fire, flammable bark	FEIS
White oak	*Quercus alba*	Pyrophilic	Thick bark, sprouting, fire-encouraging leaves, xerophyte, tap root	FEIS
White pine	*Pinus strobus*	Pyrophilic	Thick bark on older trees, seedbed requirements, needle volatility	Abrams 2001, FEIS, Keeley 2012

We estimated user resolution of the interpolated pyrophilic percentage data by employing average nearest neighbor analysis (Mitchell 2005). Nearest neighbor distances were averaged from pairwise comparisons of witness-tree points in ArcMap 10 using the Spatial Statistics tool (ESRI 2010). The average nearest neighbor distance was then squared to determine an estimate of user resolution for each interpolated pyrophilic percentage map for the four national forests; the recommended user resolution for the regional witness tree data came from Thompson et al. (2013).

To investigate the role of Native Americans on forest dynamics in the Northeast, we mapped known Native American settlements, represented spatially as points, from published literature (Table 2). These settlements were transferred to digital maps using descriptions in the published literature and modern maps as guides. These point locations were buffered by 5 and 10 km to analyze Native American relations to species composition (Black et al. 2006). Mean pyrophilic percentages were calculated on a 500 m grid for the continuous surface of predicted percentages. From this grid, mean pyrophilic percentages were calculated for the area within and outside of 5 and 10 km radii from Native American settlements; the area in lakes was removed from the binomial analysis. We used a generalized linear model via PROC GLIMMIX (SAS 2013) to compare pyrophilic percentages within and beyond 5 and 10 km of Native American sites. Because the data were percentages, we used the beta distribution with the logit link function. Distance from American Indian settlement was the only fixed effect in the model. We used LSMEANS to compare the results; all analyses were conducted at $\alpha = 0.05$ significance.

For the regional product, we used the witness-tree data from a set of 701 proprietary towns covering Maine, New Hampshire, Vermont, Massachusetts, Connecticut, New York, Rhode Island, Pennsylvania, and New Jersey (Harvard Forest Dataset HF210; Thompson et al. 2013). For each proprietary town, the relative abundances for each genera or species were calculated. The species or genera were categorized as either pyrophilic or pyrophobic as explained above. The percentage of pyrophilic witness trees was calculated for each town by summing the relative abundances for blackgum (*Nyssa sylvatica*), American

Table 2.—Documented Native American settlements near the Allegheny, Finger Lakes, Green Mountain, and White Mountain National Forests

National forest	Site number	Site name	General location	References
Allegheny	1	Buckaloons	Mouth of Brokenstraw Creek; near present-day Irvine.	Sipe 1930, Kent et al. 1981, Ruffner and Abrams 2002, Black et al. 2006
	2	Conewango	Mouth of Conewango Creek; near present-day Warren.	Sipe 1930, Deardorff 1946, Kent et al. 1981, Black et al. 2006
	3	Genesinguhta, Old Town, Tiozinossongochta (NY)	Nine miles above Jenuchshadega on northwest side of Allegheny River in New York State.	Wallace 1952, Deardorff 1946
	4	Goschgoschunk, Goschgoschink, Goshgoshing, Damascus, Conenugaya[a]	Locations spread from mouth of West Hickory Creek to the mouth of Tionesta Creek; from present-day communities of West Hickory to Tionesta.	Sipe 1930, Deardorff 1941, Deardorff 1946, Kent et al. 1981
	5	Lawunakhannek, Hickory Town[b]	Mouth of Hickory Creek; near present-day East Hickory.	Sipe 1930, Deardorff 1946, Kent et al. 1981
	6	Jenuchshadega, Cornplanter, Dionesadage	On Allegheny River; 6 mi east of present-day Scandia.	Sipe 1930, Deardorff 1941, Wallace 1952, Kent et al. 1981
	7	Tidioute	On the Allegheny River; near present-day Tidioute.	Deardorff 1941; Deardorff 1946, Black et al. 2006.
Finger Lakes	8	Kendaia, Appletown	East shore of Lake Seneca.	Jordan 2010, Marks and Gardescu 1992, Sullivan Expedition Map[c]
	9	Kanadesaga, Kanasadega	Northwest corner of Lake Seneca.	Jordan 2010, Sullivan Expedition Map[c]
Green Mountain	10	Skitchewaug	West side of Connecticut River near present-day Windsor, VT.	Chilton 2002, Petersen and Cowie 2002
	11	Fort Hill	East side (NH) of Connecticut River across from present-day Brattleboro, VT.	Chilton 2002, Petersen and Cowie 2002
White Mountain	12	Winnepesaukee (near center of Winnepesaukee population)	West of Lake Winnipesaukee near present-day Meredith Center, NH.	Cook 1976, Calloway 1990
	13	Cowass (center of Coosuc population)	Mouth of the Ammonoosuc River near present-day Woodville.	Cook 1976, Calloway 1990
	14	Ossipee (center of Ossipee population)	West side of Ossipee Lake.	Cook 1976, Calloway 1990
	15	Pigwacket, Pequaket	On the Saco River near present-day Fryeburg, ME.	Cook 1976, Calloway 1990
	16	Conway	Located along the Saco River near present-day Intervale Park, Conway, NH.	Calloway 1990, Boisvert 1999
	17	Randolph	Located along the Moose River near present-day Randolph, NH.	Boisvert 1999
	18	Mt. Jasper	Near Berlin, NH.	Boisvert 1999
	19	Israel River Complex	Near present-day Jefferson, NH.	Boisvert 1999

[a] Actually consists of three towns (Upper Town, Middle Town, Lower Town) along six river miles (Deardorff 1946).
[b] Village known by both names (Kent et al. 1981).
[c] http://sullivanclinton.com/maps/images/iroquoisinvasion.jpg

chestnut (*Castanea dentata*), hickory (*Carya*), oak, pine, and poplar. Ordinary kriging was used to interpolate pyrophilic percentage between town polygons.

RESULTS

The density of witness trees varied by survey (Table 3), but being rectangular or town-based, this variation is not completely tied to the underlying topography like metes-and-bounds surveys elsewhere. Land surveys in the areas that later became the individual national forests largely took place from the late 1700s through the early 1800s. Compiled town surveys across the entire Northeast region spanned a longer time period from roughly 1670 to 1890 (Thompson et al. 2013). Witness-tree samples were most densely clustered on the FLNF (averaging 1.35 trees/mi^2) and least on the WMNF (0.16 trees/mi^2).

A broad mix of pyrophobic and pyrophilic witness trees was present on the ANF and FLNF (Table 4). Spatially, pyrophilic trees were concentrated within the western sectors of both national forests immediately adjacent to water bodies, specifically the Allegheny River on the ANF and Seneca Lake on the FLNF (Figs. 2, 3). In contrast, witness trees were overwhelmingly pyrophobic on the GMNF and WMNF (Table 4; Figs. 4, 5).

Table 3.—Descriptive parameters of witness tree data used in local (national forest) and regional analyses

National forest	Survey type	Survey time period (not inclusive)	No. of witness trees/towns	Study area* (mi^2)	Avg. no. of witness trees/ mi^2 (range)	Estimated user resolution of pyrophilic percentage map
Allegheny	Rectangular	1790-1889	3,003	2,594	1.15 (0 - 12)	109 ac
Finger Lakes	Rectangular	1790-1796	585	433	1.35 (0 - 5)	173 ac
Green Mountain	Town	1770-1870	1,007	2,834	0.35 (0 - 15)	91 ac
White Mountain	Town	1751-1798	748	4,562	0.16 (0 – 11)	227 ac
Northeast Region	Public land surveys, rectangular surveys, and deeds	1672-1890	701	160,175	N/A	39 mi^2

* Study area = area of kriged surface; see individual NF maps for reference. Generally these are the square extent of the witness tree points used as input to kriging, minus larger bodies of water.

Table 4.—Witness tree counts (percentages in parentheses) by pyrogenicity for four national forests in the northeastern United States

Witness tree type	Allegheny	Finger Lakes	Green Mountain	White Mountain
Tsuga	485	14	68	75
Acer	375	107	101	67
Fagus	955	118	387	204
Other pyrophobe	445	106	447	373
All pyrophobes	2,260 (75%)	345 (59%)	1,003 (≈100%)	719 (96%)
Pinus	138	41	2	13
Quercus	360	146	0	5
Carya	50	22	0	0
Other pyrophobe	195	31	2	11
All pyrophiles	743 (25%)	240 (41%)	4 (<1%)	29 (4%)
Total	3,003	585	1,007	748

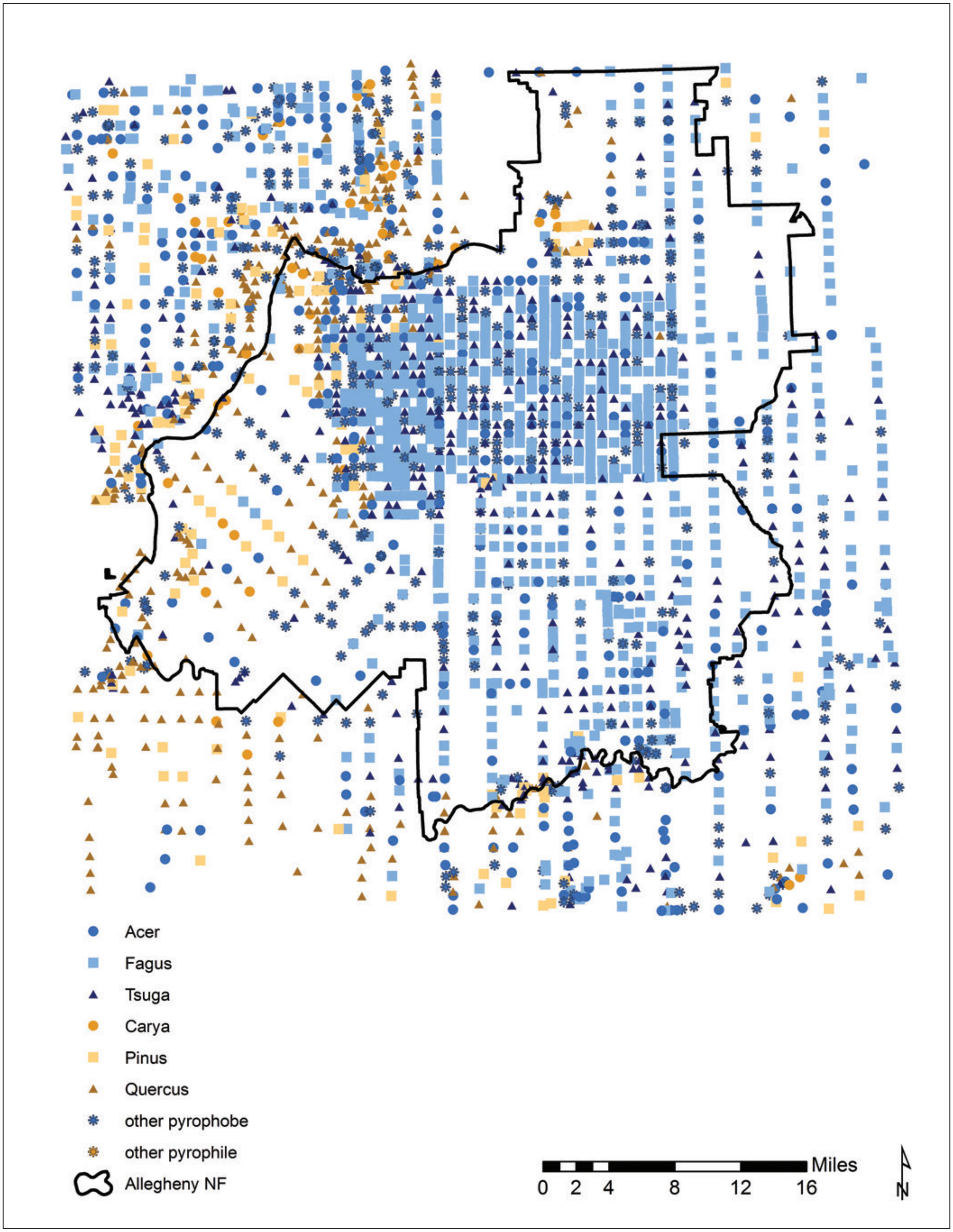

Figure 2.—Witness tree locations by indicator class for the Allegheny National Forest.

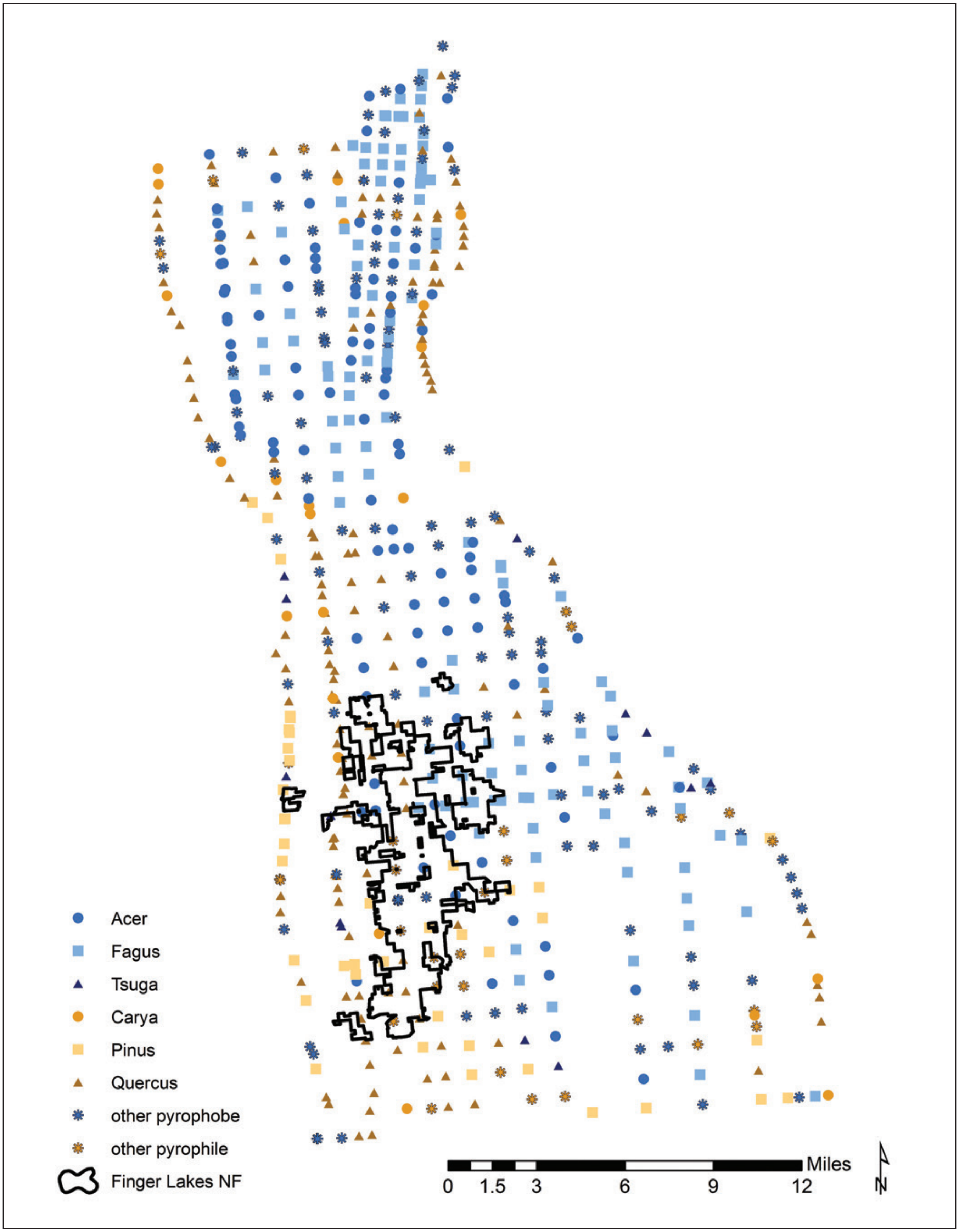

Figure 3.—Witness tree locations by indicator class for the Finger Lakes National Forest.

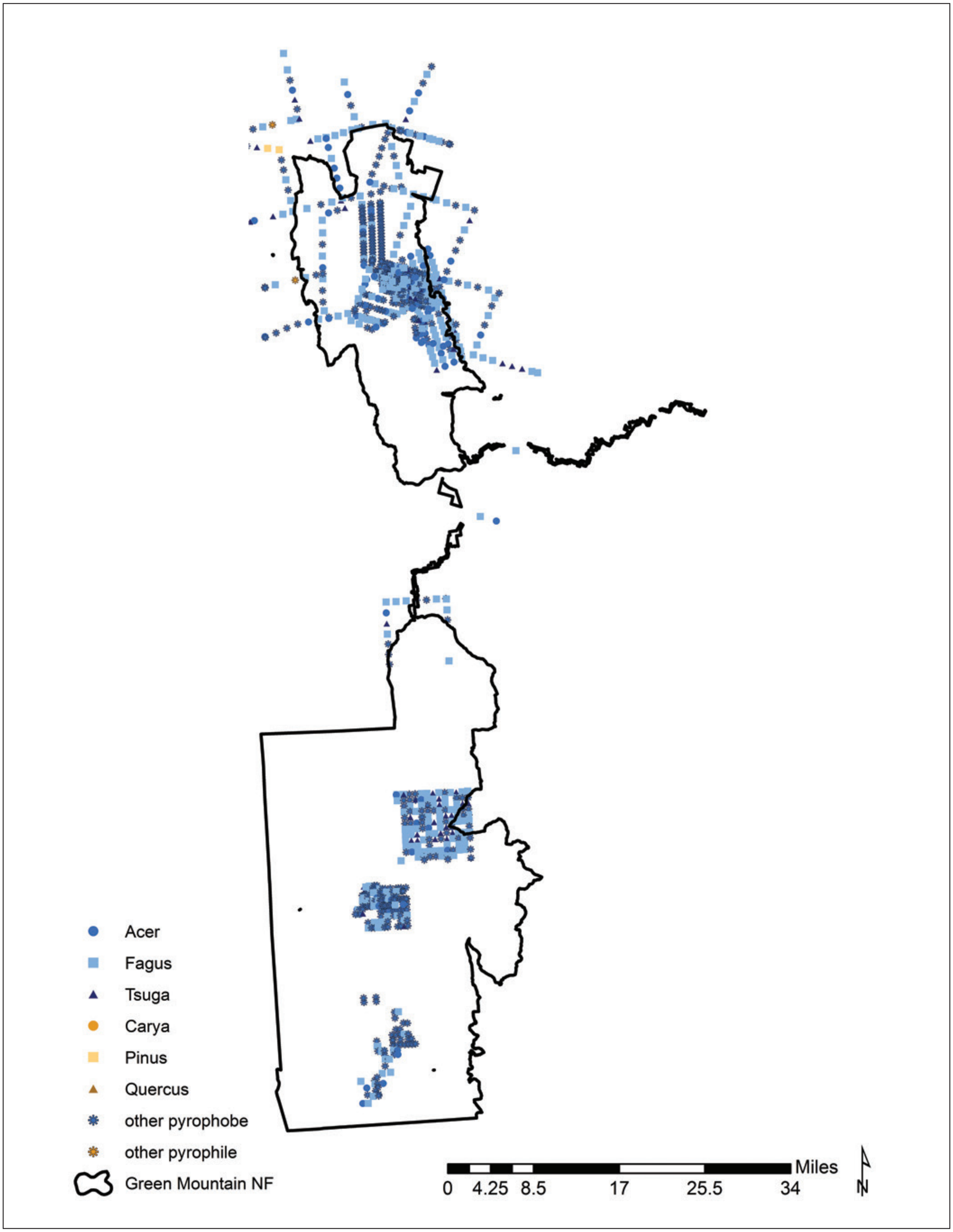

Figure 4.—Witness tree locations by indicator class for the Green Mountain National Forest.

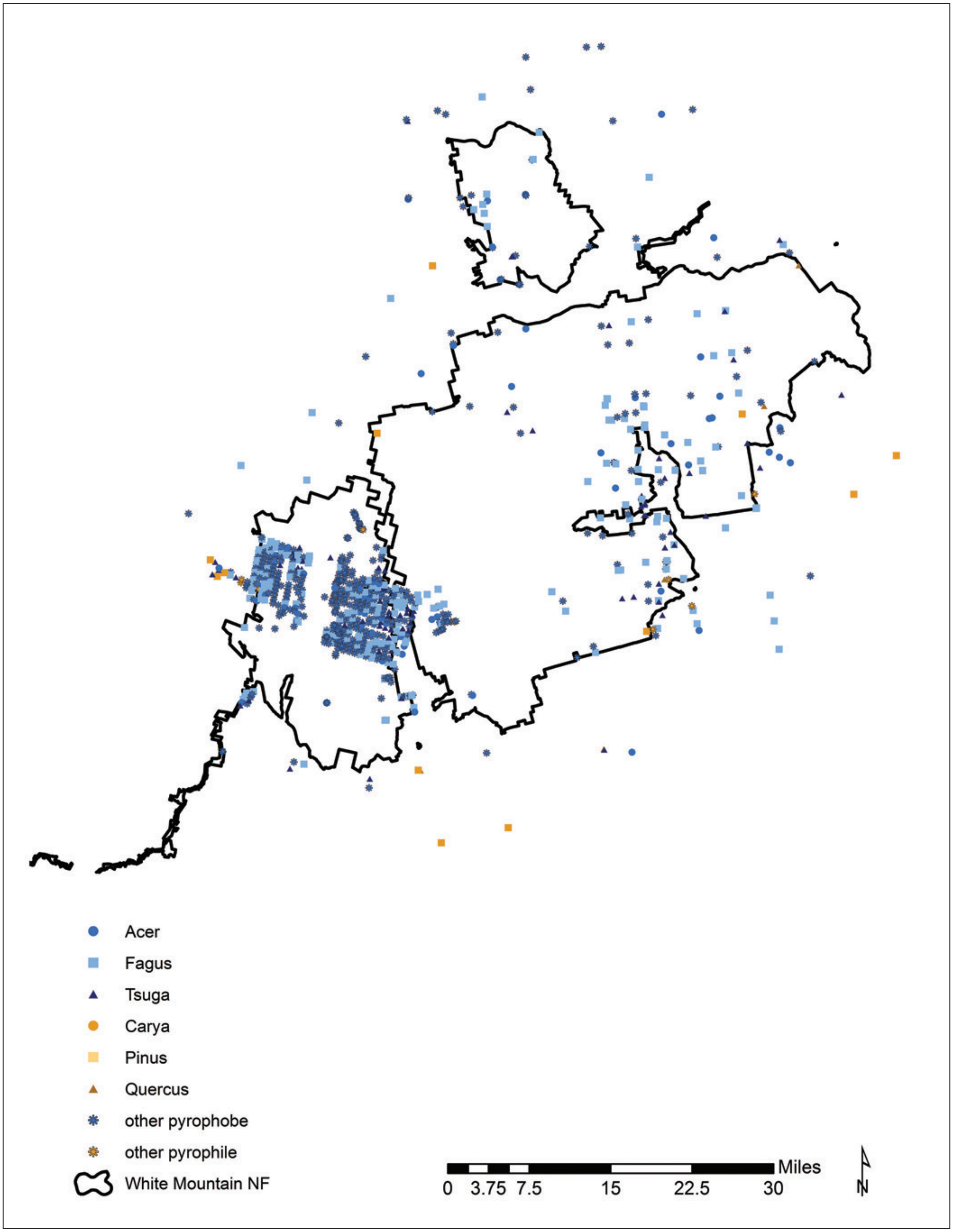

Figure 5.—Witness tree locations by indicator class for the White Mountain National Forest.

The distributional patterns displayed by witness-tree points (Figs. 2 through 5) were transformed into continuous surfaces of pyrophilic percentages through kriging (Figs. 6 through 9). Accordingly, pyrophilic percentages were high (≥51%) along most of the course of the Allegheny River (Fig. 6) and along Seneca Lake (Fig. 7), the latter actually enveloping the south half of the FLNF within Hector Falls and Tug Hollow Creek drainages. The FLNF was the most pyrogenic in terms of pyrophilic tree representation (41%; Table 4) and areal coverage in pyprophilic percentages above 50 percent (59%; Table 5). On the ANF, 25 percent of the witness trees were categorized as pyrophilic (Table 4), resulting in 17 percent of the area having pyrophilic percent class above 50 percent (Table 5). Because very few witness trees were categorized as pyrophilic on the GMNF and WMNF (<1% and 4%, respectively; Table 4), low pyrophilic percentages (≤ 20%) predominated in these national forests and surrounding areas (Table 5; Figs. 8, 9).

Possible Native American influence on pyrogenicity is apparent in the analysis of least square mean pyrophilic percent within set distances of known Native American settlements (Table 6). Least square mean pyrophilic percentages within 5 and 10 km of known Native American sites on the ANF were significantly higher than means outside those radii (61% vs. 37% and 52% vs. 32%, respectively). For the FLNF, pyrophilic percentages were significantly different only within 5 km of known Native American sites (59% within vs. 45% beyond; Table 6). There were too few locations and grid cells within the analysis area for meaningful analysis of the GMNF. On the WMNF, the relationship found on the ANF and FLNF is reversed with increased arithmetic mean pyrophilic percentages beyond 5 and 10 km; however, the least square means followed the trend on the ANF and FLNF, suggesting the differences may be ecologically insignificant. Although the arithmetic mean differences are statistically significant on the WMNF, all pyrophilic percentage means are less than 25 percent, so regardless of distance from Native American settlement, the landscape is overwhelmingly pyrophobic.

At the regional level, the tension zone described by Cogbill (2000) is clearly demarcated by the abrupt change in pyrophilic percentages across the Northeast (roughly along the 50 percent break point as shown in Fig. 10). Northward protrusions of the tension zone line (TZL) were affiliated with major river valleys, including the Allegheny (PA), Susquehanna (West and Main branches, PA), Delaware (PA and NY), Hudson (NY), Connecticut (MA), and Merrimack (NH). All four national forests are located north of this line, except for the southwest quadrant of the ANF, which skirts it. This regional depiction corroborates the high level of pyrophobicity found on the national forests. However, an island of slightly elevated pyrophilicity is located in the western portion of the Finger Lakes Region (yellow area; Fig. 10), which corresponds to the pyrophilic percentage map derived from local witness-tree data (Fig. 7).

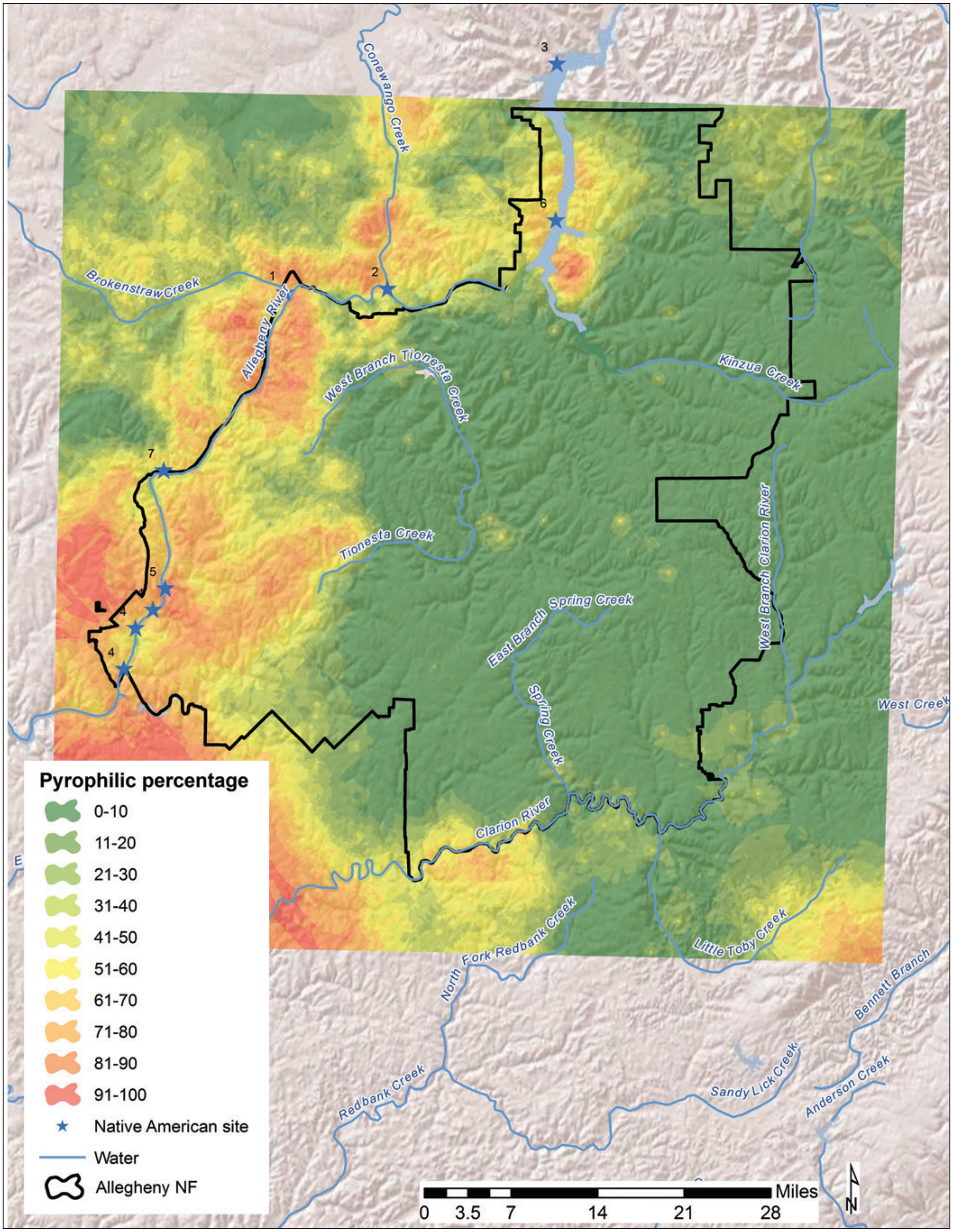

Figure 6.— Pyrophillic percentage interpolated from witness trees on the Allegheny National Forest. Refer to Table 2 for Native American site names and information.

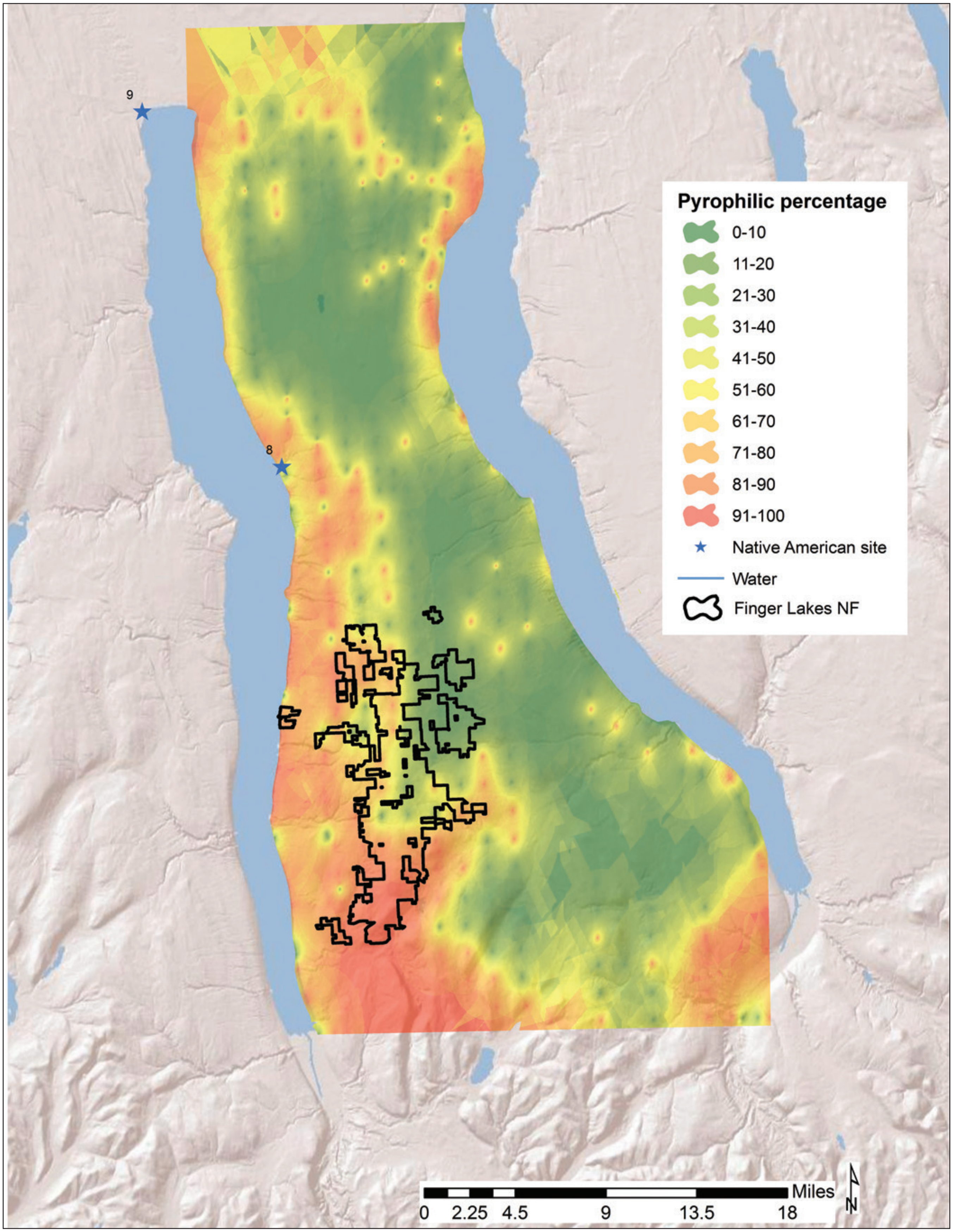

Figure 7.—Pyrophilic percentage interpolated from witness trees on the Finger Lakes National Forest. Refer to Table 2 for Native American site names and information.

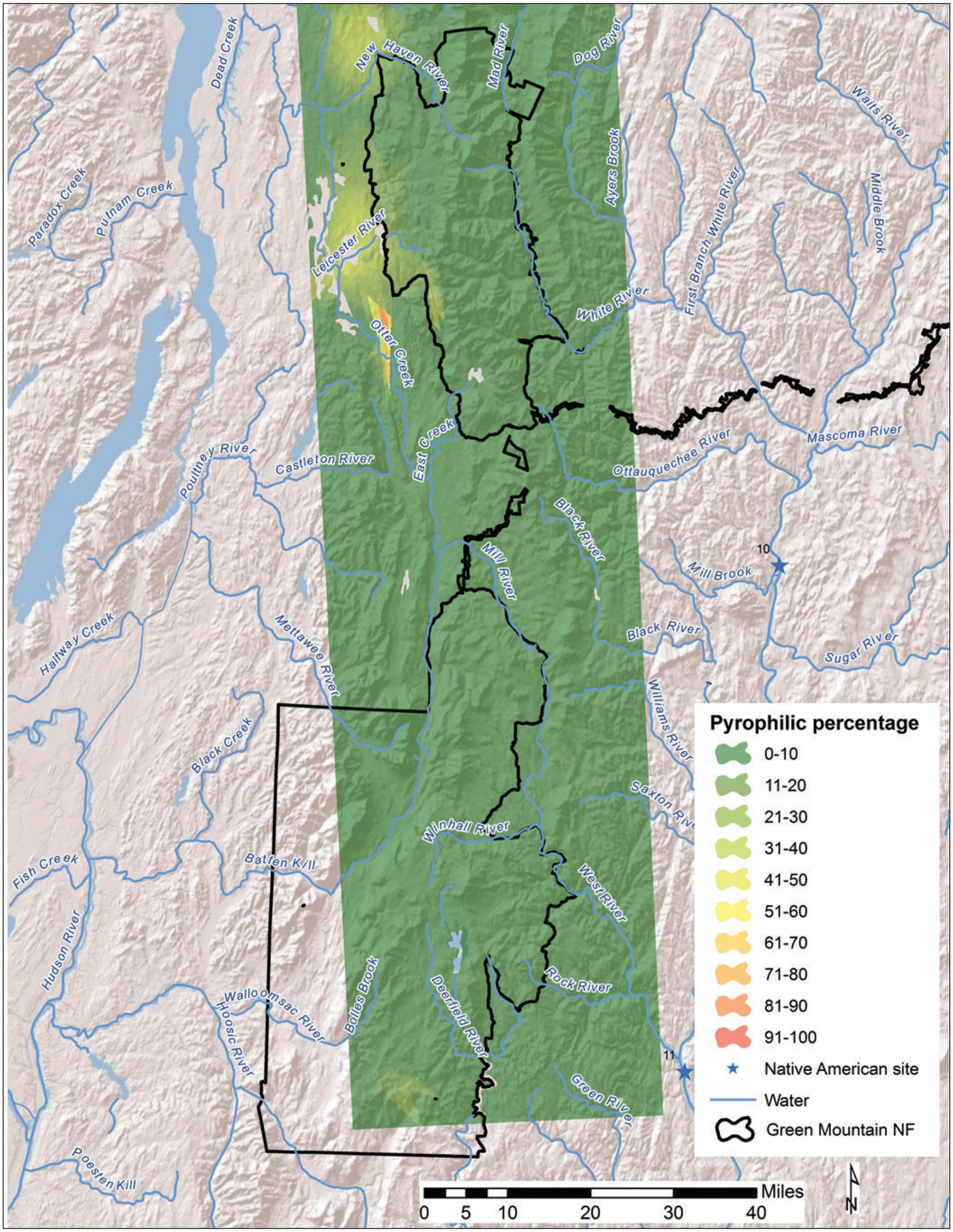

Figure 8.— Pyrophilic percentage interpolated from witness trees on the Green Mountain National Forest. Refer to Table 2 for Native American site names and information.

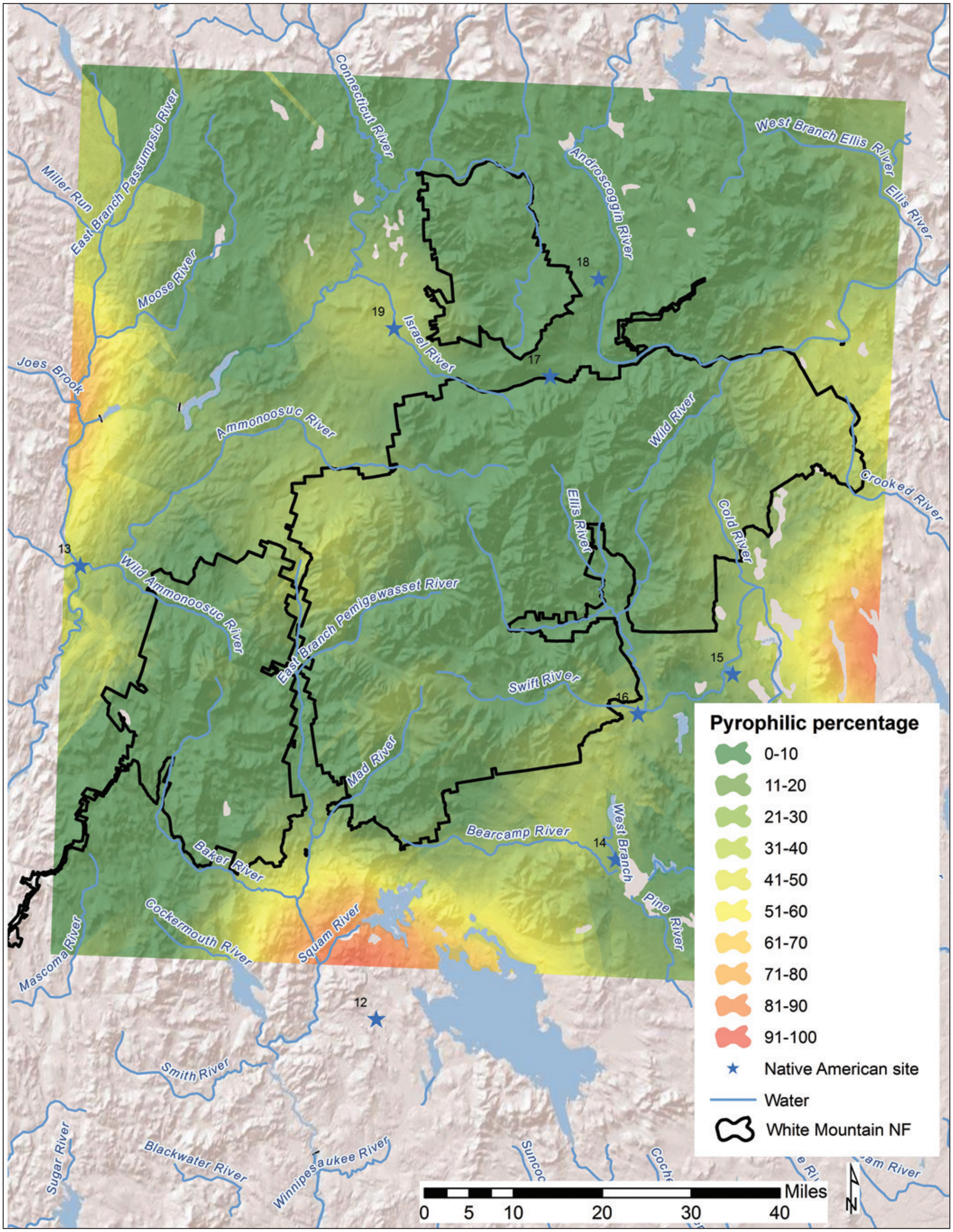

Figure 9.—Pyrophilic percentage interpolated from witness trees on the White Mountain National Forest. Refer to Table 2 for Native American site names and information.

Table 5.—Area by percent pyrophilic class for each national forest; area within national forest proclamation boundaries only (or within stands for the Finger Lakes)

	Allegheny		Finger Lakes		Green Mountain		White Mountain	
% pyrophilic class	area (ac)	%	area (ac)	%	area (ac)	%	area (ac)	%
0-10	464,024.9	63.2	2,124.9	13.0	640,972.1	98.5	768,972.5	82.1
10-20	49,868.3	6.8	765.8	4.7	9,948.9	1.5	107,806.2	11.5
20-30	32,387.1	4.4	1,145.6	7.0	33.6	0.0	55,258.4	5.9
30-40	34,127.7	4.7	1,160.7	7.1	0.0	0.0	4,226.0	0.5
40-50	28,292.3	3.9	1,474.5	9.0	0.0	0.0	0.0	0.0
50-60	35,409.7	4.8	1,549.1	9.5	0.0	0.0	0.0	0.0
60-70	40,741.2	5.6	2,071.7	12.7	0.0	0.0	0.0	0.0
70-80	35,456.1	4.8	1,476.5	9.1	0.0	0.0	0.0	0.0
80-90	12,624.1	1.7	1,614.6	9.9	0.0	0.0	0.0	0.0
90-100	844.9	0.1	2,916.3	17.9	0.0	0.0	0.0	0.0
Total	733,775.8		16,299.5		650,954.4		936,263.3	

Table 6.—Arithmetic and least square mean pyrophilic percentage scores in relation to distances to Native American sites and results of linear mixed model

	Arithmetic (and least square) mean pyrophilic percentage					
National Forest	Within 5 km of Native American sites	Beyond 5 km of Native American sites	P-value	Within 10 km of Native American sites	Beyond 10 km of Native American sites	P-value
Allegheny	60.7 (58.0)	36.7 (37.2)	<0.0001	51.8 (51.0)	32.2 (33.3)	<0.0001
Finger Lakes	59.2 (57.0)	44.6 (44.6)	<0.0001	45.7 (45.1)	44.9 (44.9)	0.8085
Green Mountain	0	0	NA	0	0	NA
White Mountain	18.6 (26.0)	23.4 (22.9)	<0.0001	19.7 (24.3)	24.1 (22.9)	0.0007

DISCUSSION

Ecosystem management, especially embedded restoration efforts (Society for Ecological Restoration International Science & Policy Working Group 2004), is predicated on understanding biotic compositions, structures, and dynamics of the past (Grumbine 1994, Landres et al. 1999). Thus, information on past disturbance regimes—formative processes that contributed to long-term vegetation expression—is critical (Engstrom et al. 1999, Pickett and White 1985, White et al. 1999). Although they represent a snap-shot in time and are not the only source of information for determining restoration activities, witness trees have been successfully used to reconstruct former vegetation conditions and document change across the eastern United States (Abrams and Ruffner 1995, Bourdo 1956, Friedman and Reich 2005, Schulte et al. 2007, Thompson et al. 2013, Wang et al. 2009, Whitney 1987). Furthermore, they have been used to document past disturbance types and regimes, either directly (Canham and Loucks 1984, Lorimer 1977, Seischab and Orwig 1991, Zhang et al. 1999) or indirectly (Thomas-Van Gundy and Nowacki 2013). By using the latter method, we were able to convert witness trees into pyro-indicators to gain perspective on past fire regimes at two spatial scales in the Northeast. However, nothing in this analysis should preclude the use of prescribed fire as a silvicultural tool at the site level where supported by other means.

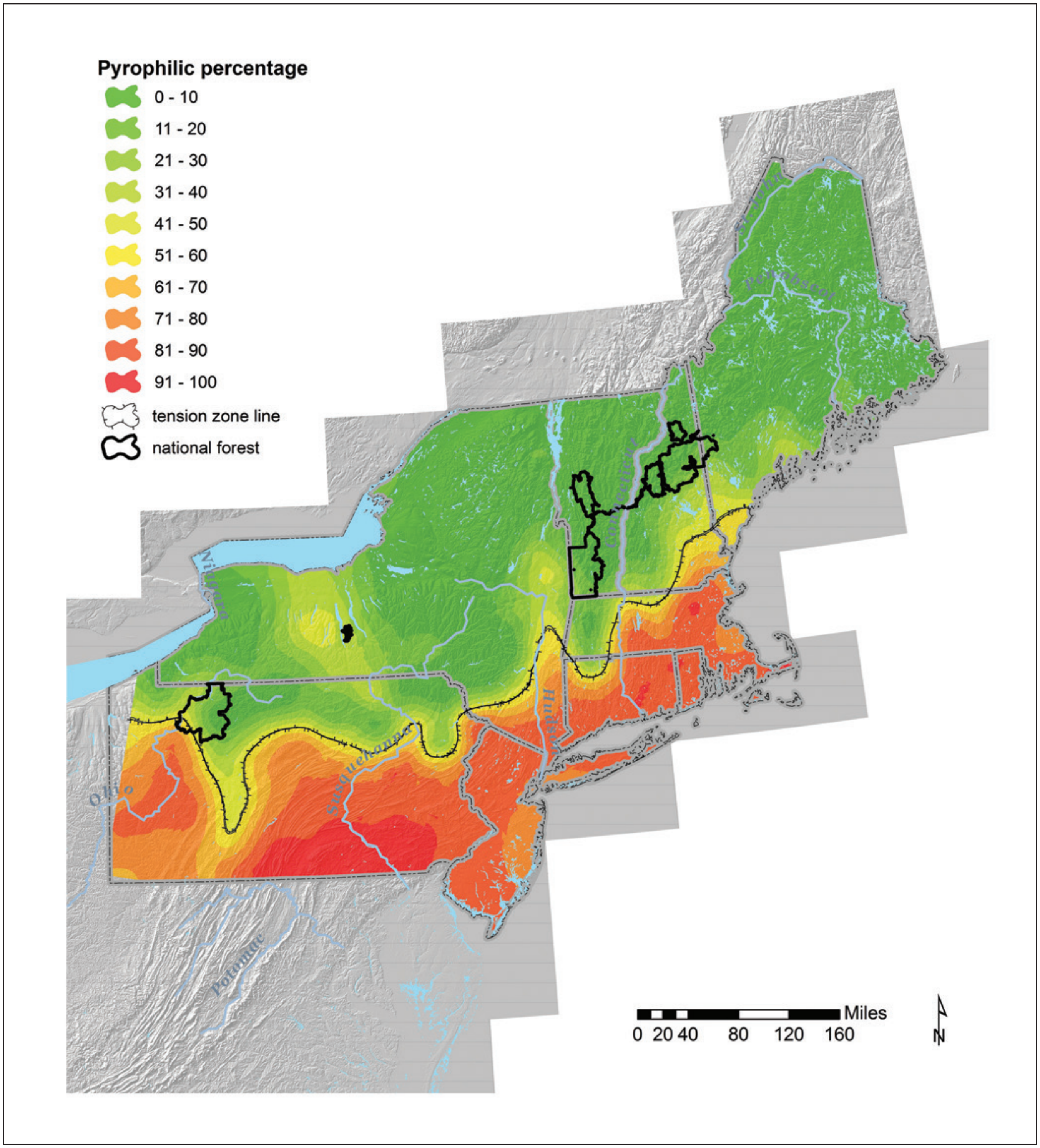

Figure 10.—Pyrophilic percentage as interpolated from town-level witness trees across the northeastern United States. Tension zone line is the 50 percent pyrophilic contour.

Overall, presettlement fire regimes were generally subdued on the four national forests studied. Pyrogenic signals embedded in witness trees were largely undetected on the national forests furthest east (WMNF and GMNF). This finding is not surprising given that, north of the TZL, "asbestos" conifer-northern hardwood communities historically dominated, largely comprised of thin-barked pyrophobic species such as maple, beech, and hemlock (Bormann and Likens 1979, Niering 1992, O'Keefe and Foster 1998). However, given the resolution of our pyrophilic percentages maps (91 to 227 ac; Table 3) and patchiness of the distribution of witness trees themselves, small areas with recurrent localized fires may have existed on these national forests. Indeed, there is precedence for fires on dry, pine-dominated ridges in northern Vermont (Engstrom and Mann 1991). However, they tended to be small due to the occurrence of natural firebreaks such as bedrock outcrops and cliffs. Native Americans might have augmented ignitions, but their populations were sparse due to marginal living conditions. Here, the harsh climate and mountainous terrain greatly curtailed agriculture and burning normally associated with it (compared to more productive and pyrogenic landscapes to the south; Nowacki et al. 2012). Altogether, low Native populations, their non-agricultural (hunting and gathering) basis of subsistence, and the persistently cool and damp climate greatly limited the number and effectiveness of their ignitions on the GMNF and WMNF.

Although residing within a similar climate regime supporting conifer-northern hardwoods, the FLNF and ANF possessed pyrophilic vegetation in certain locations, conspicuously adjacent to water bodies. This, coupled with the overall unfavorable fire climate (moist, humid conditions) and mesophytic character of this biome, strongly points toward humans as primary agents of fire. It is well documented that the Allegheny River and associated tributaries were actively used by Native Americans as travel corridors, lined with many shore villages (Chartier's Town, Kittanning, Venango, Goschgoschunk, Lawunakhannek, Tidioute, Buckaloons, Conewango, Jenuchshadega, Genesinguhta; Sipe 1930; Deardorff 1941, 1946; Wallace 1952; Kent et al. 1981). In 1775, the Seneca populated northern portions of the river (above present-day Warren, PA), whereas the Delaware and Shawnee settled in villages southward (Deardorff 1941).

The inferred association among Native Americans, fire, and pyrophilic vegetation is not new but has been proffered by others. For instance, Marquis (1975) attributed the oak type along the Allegheny River directly to Native American burning. Through dendrochronological research, Ruffner and Abrams (2002) documented that frequent, low intensity fires burned near the Buckaloons during Seneca Indian occupation, precisely the type of disturbance regime that would support local oak-hickory forests (see Fig. 6). The lack of a climatic signal in tree-ring growth is particularly telling, indicating that fire was driving vegetation dynamics in presettlement times and thus preventing the expression of the climatic climax (i.e., conifer-northern hardwoods). By establishing zones of Native American influence (NAI) from archaeological data and inference, Black et al. (2006) provided definitive linkages between Native Americans and the presence of pyrogenic oak-hickory-chestnut communities in northwest Pennsylvania. The fact that NAI was by far the most significant predictor of oak-hickory-chestnut occurrence compared to edaphic factors (geology, landform, elevation, etc.) further underscores the importance of human controls over certain presettlement landscapes of the ANF. This link is also evident in our comparative analysis of arithmetic and least square mean pyrophilic percentages within and beyond fixed distances from known Native American settlements on the ANF (Table 6).

The same phenomenon is thought to have occurred on the FLNF, with Native American villages, travel corridors, and activities concentrated along the eastern shores of Seneca Lake (see Fig. 11.3 of Marks and Gardescu 1992). Here, with prevailing westerly winds, fires lit near shoreline waypoints, encampments, and villages would effectively sweep eastward up slopes and valley draws. The latter may explain the prevalence of pyrophilic trees within the larger Hector Falls and Tug Hollow Creek drainages on FLNF's south side, including Burnt Hill. Note that an abrupt change from pyrophilic to pyrophobic vegetation coincides with an N-S ridgeline (Hector Backbone), a natural fire break that bisects the FLNF (Fig. 7). Regionally across the Military Tract (6,800 km^2), burn patches were recorded in survey notes, concentrated around the western portion of the Finger Lakes where FLNF is located (Marks and Gardescu 1992). Here, an old road ran up the eastside of Seneca Lake replete with "Indian clearings." Marks and Gardescu (1992) further reported that two-thirds of the witness trees located on west/southwest banks (east sides) of the Finger Lakes were pyrophilic oak, pine, and hickory; whereas pyrophobic hemlock, beech, and maple were most common on east-northeast banks (west sides of lakes). This finding adds support to the idea that Native American activities on east of lakes had a more profound effect on landscape vegetation (vs. west sides), with fires burning most effectively up drier west/southwest-facing terrain driven by prevailing westerlies. This relationship is further supported by our analysis of mean pyrophilic percentages within and beyond 5 km from known Native American settlements on the FLNF (Table 6).

Native American controls on pyrophytic distribution at the local scale (ANF and FLNF) seem to hold at the regional scale as well, given the crenulated configuration of the TZL. The conversion of witness trees to a pyroindicator function allowed this signal to be clearly visible (Fig. 10) and provided evidence that the TZL is driven by factors other than just climate or edaphics. Specifically, the tendrils of pyrophilic dominance extending up major river systems and along the Atlantic coast deep into the conifer-northern hardwood biome most closely adheres to the distribution of Native American populations and their related activities (Abrams and Nowacki 2008, Doolittle 2000, Mann 2005, Patterson and Sassaman 1988, Richter 2001). Indeed, with landscape fire removed from much of the eastern landscape, shade-tolerant, fire-sensitive northern hardwoods have greatly increased in importance south of the TZL (Nowacki and Abrams 2008). The TZL has great relevance in land management (Nowacki and Abrams 2014), generally depicting where fire can be broadly and routinely applied for ecosystem restoration (south of TZL) and where fire may be applied more site-specifically where local information documenting past fire exists (north of TZL). The FLNF and ANF are good examples of the latter, whereby local witness-tree data support the use of fire in specific areas for restoration purposes.

LITERATURE CITED

Abrams, M. D. 1990. **Adaptations and responses to drought in *Quercus* species of North America.** Tree Physiology. 7: 227-238.

Abrams, M.D. 2000. **Fire and the ecological history of oak forests in the eastern United States.** In: Yaussy, D.A., comp. Proceedings: workshop on fire, people, and the central hardwoods landscape; 2000 March 12-14; Richmond, KY. Gen. Tech. Rep. NE-274, Newtown Square PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 46-55.

Abrams, M.D. 2001. **Eastern white pine versatility in the presettlement forest.** BioScience. 51: 967-979.

Abrams, M.D. 2007. **Tales from the blackgum, a consummate subordinate tree.** BioScience. 57: 347-359.

Abrams, M.D.; Nowacki, G.J. 2008. **Native Americans as active and passive promoters of mast and fruit trees in the eastern USA.** The Holocene. 18: 1123-1137.

Abrams, M.D.; Ruffner, C.M. 1995. **Physiographic analysis of witness-tree distribution (1765-1798) and present forest cover through north central Pennsylvania.** Canadian Journal of Forest Research. 25: 659-668.

Barnes, G. 2001. **Viking America: the first millennium.** Suffolk, UK: Boydell & Brewer Ltd. 187 p.

Bernabo, J.C.; Webb, T., III. 1977. **Changing patterns in the Holocene pollen record of northeastern North America: a mapped summary.** Quaternary Research. 8: 64-96.

Black, B.A.; Ruffner, C.M.; Abrams, M.D. 2006. **Native American influences on the forest composition of the Allegheny Plateau, northwest Pennsylvania.** Canadian Journal of Forest Research. 36: 1266-1275.

Boisvert, R.A. 1999. **Paleoindian occupation of the White Mountains, New Hampshire.** Geographie physique et Quaternaire. 53: 159-174.

Bormann, F.H.; Likens, G.E. 1979. **Catastrophic disturbance and the steady state in northern hardwood forests.** American Scientist. 67: 660-669.

Bourdo, E.A., Jr. 1956. **A review of the General Land Office Survey and of its use in quantitative studies of former forests.** Ecology. 37: 754-768.

Brooks, R.T. 2003. **Abundance, distribution, trends, and ownership patterns of early-successional forests in the northeastern United States.** Forest Ecology and Management. 185: 65-74.

Brose, P.; Schuler, T.; Van Lear, D.; Berst, J. 2001. **Bringing fire back: the changing regimes of the Appalachian mixed-oak forests.** Journal of Forestry. 99: 30-35.

Burns, R.M.; Honkala, B.H., tech. coords. 1990. **Silvics of North America: 1. Conifers; 2. Hardwoods.** Agric. Hand. 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p.

Canham, C.D.; Loucks, O.L. 1984. **Catastrophic windthrow in the presettlement forests of Wisconsin.** Ecology. 65: 803-809.

Calloway, C.G. 1990. **The Western Abenakis of Vermont, 1600-1800: War, migration, and the survival of an Indian people.** Norman, OK: University of Oklahoma Press. 372 p.

Chilton, E.S. 2002. **"Towns they have none": Diverse subsistence and settlment strategies in Native New England.** In Hart, J.P.; Rieth, C.B., eds. Northeast subsistence-settlement change: A.D. 700-1300. Albany, NY: New York State Museum: 289-300.

Cleland, D.T.; Freeouf, J.A.; Keys, J.E., Jr.; Nowacki, G.J.; Carpenter, C.; McNab, W.H. 2007. E**cological Subregions: Sections and Subsections of the Conterminous United States [1:3,500,000] [CD-ROM].** Sloan, A.M., cartog. Gen. Tech. Report WO-76. Washington, DC: U.S. Department of Agriculture, Forest Service.

Cogbill, C.V. 2000. **Vegetation of the presettlement forests of northern New England and New York.** Rhodora. 102: 250-276.

Cogbill, C.V.; Burk, J.; Motzkin, G. 2002. **The forests of presettlement New England, USA: Spatial and compositional patterns based on town proprietor surveys.** Journal of Biogeography. 29: 1279-1304.

Cook, S.F. 1973. **The significance of disease in the extinction of the New England Indians.** Human Biology 45: 485-508.

Cook, S.F. 1976. **The Indian population of New England in the seventeenth century.** University of California Publications in Anthropology. 12: 1-91.

Crosby, A.W. 1967. **Conquistador y Pestilencia: the first New World pandemic and the fall of the Great Indian Empires.** Hispanic American Historical Review. 47: 321-337.

Davis, R.B.; Jacobson, G.L., Jr. 1985. **Late Glacial and Early Holocene landscapes in northern New England and adjacent areas of Canada.** Quaternary Research. 23: 341-368.

Deardorff, M.H. 1941. **The Cornplanter Grant in Warren County.** Western Pennsylvania Historical Magazine. 24: 1-22.

Deardorff, M.H. 1946. **Zeisberger's Allegheny River Indian towns: 1767-1770.** Pennsylvania Archaeologist. 16: 2-19.

Delcourt, P.A.; Delcourt, H.R. 1998. **The influence of prehistoric human-set fires on oak-chestnut forests in the southern Appalachians.** Castanea. 63: 337-345.

Dobyns, H.F. 1993. **Disease transfer at contact.** Annual Review of Anthropology. 22: 273-291.

Doolittle, W.E. 2000. **Cultivated landscapes of native North America.** Oxford, UK: Oxford University Press. 574 p.

Engstrom, F.B.; Mann, D.H. 1991. **Fire ecology of red pine (*Pinus resinosa*) in northern Vermont, U.S.A.** Canadian Journal of Forest Research. 21: 882-889.

Engstrom, R.T.; Gilbert, S.; Hunter, M.L., Jr.; Merriwether, D.; Nowacki, G.J.; Spencer, P. 1999. **Practical applications of disturbance ecology to natural resource management.** In: Szaro, R.C.; Johnson, N.C.; Sexton, W.T.; Malk, A.J., eds. Ecological stewardship: a common reference for ecosystem management—volume II. Oxford, UK: Elsevier Science Ltd.: 313-330.

ESRI. 2010. **ArcMap 10.** ESRI, Inc.

Fire Effects Information System (FEIS). Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Available at www.fs.fed.us/database/feis (accessed April 17, 2014).

Friedman, S.K.; Reich, P.B. 2005. **Regional legacies of logging: departure from presettlement forest conditions in northern Minnesota.** Ecological Applications. 15: 726-744.

Foster, D.R.; Motzkin, G. 1998. **Ecology and conservation in the cultural landscape of New England: lessons from nature's history.** Northeastern Naturalist. 5: 111-126.

Grumbine, R.E. 1994. **What is ecosystem management?** Conservation Biology. 8: 27-38.

Holzmueller, E.J.; Jose, S.; Jenkins, M.A. 2008. **The relationship between fire history and an exotic fungal disease in a deciduous forest.** Oecologia. 155: 347-356.

Innis, H.A. 1999. **The fur trade in Canada: an introduction to Canadian economic history.** Toronto, Ontario: University of Toronto. 463 p.

Isaaks, E.H.; Srivastava, R.H. 1989. **Applied geostatistics.** New York: Oxford University Press, Inc. 561 p.

Jordan, K.A. 2010. **Not just "one site against the world": Seneca Indians intercommunity connections and autonomy, 1550-1779.** In: Scheiber, L.L.; Mitchell, M.D., eds. Across a great divide: continuity and change in Native North American societies, 1400-1900. Amerind Studies in Archaeology. Tucson, AZ: University of Arizona Press: 79-106.

Keeley, J.E. 2012. **Ecology and evolution of pine life histories.** Annals of Forest Science. 69: 445-453.

Kent, B.C.; Rice, J.; Ota, K. 1981. **A map of 18th century Indian towns in Pennsylvania.** Pennsylvania Archaeologist. 51: 1-18.

Landres, P.B.; Morgan, P.; Swanson, F.J. 1999. **Overview of the use of natural variability concepts in managing ecological systems.** Ecological Applications. 9: 1179-1188.

Lorimer, C.G. 1977. **The presettlement forest and natural disturbance cycle of northeastern Maine.** Ecology. 58: 139-148.

Mann, C.C. 2005. **1491: New revelations of the Americas before Columbus.** New York: Alfred Knopf. 465 p.

Marks, P.L.; Gardescu, S. 1992. **Vegetation of the central Finger Lakes Region of New York in the 1790s.** In: Marks, P.L.; Gardescu, S.; Seischab, F.K., contributors. Late eighteenth century vegetation of central and western New York State on the basis of original land survey records. New York State Museum Bulletin. 484: 1-35.

Marquis, D.A. 1975. **The Allegheny hardwood forests of Pennsylvania.** Gen. Tech. Rep. NE-15. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 32 p.

McIntosh, R.P. 1972. **Forests of the Catskill Mountains, New York.** Ecological Monographs. 42: 143-161.

Mitchell, A. 2005. **The ESRI guide to GIS analysis, volume 2 spatial measurements and statistics.** Redlands, CA: ESRI Press. 252 p.

National Resources Conservation Services (NRCS). 2014. **The PLANTS database (http://plants.usda.gov, 17 April 2014).** Greensboro, NC: U.S. Department of Agriculture, National Resource Conservation Service. Available at http://plants.usda.gov. (Accessed April 17, 2014).

Niering, W.A. 1992. **The New England forests.** Restoration and Management Notes. 10: 24-28.

Nowacki, G.J.; Ablutz, M.; Yaussy, D.; Schuler, T.; Dey, D. 2009. **Restoring oak ecosystems on National Forest System lands in the Eastern Region: an adaptive management approach.** In: Hutchinson, T.F., ed. Proceedings of the 3rd fire in the eastern oak forests conference; 2008 May 20-22; Carbondale, IL. Gen. Tech. Rep. NRS-P-46. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 133-139.

Nowacki, G.J.; Abrams, M.D. 2008. **The demise of fire and "mesophication" of forests in the eastern United States.** BioScience. 58: 123-138.

Nowacki, G.J.; Abrams, M.D. 2015. **Is climate an important driver of post-European vegetation change in the Eastern United States?** Global Change Biology. 21: 314-334.

Nowacki, G.J.; Carr, R.A. 2013. **Altered disturbance regimes: the demise of fire in the eastern United States.** In: Qu, J.J.; Sommers, W.T.; Yang, R.; Riebau, A.R., eds. Remote sensing and modeling applications to wildland fires. Beijing: Tsinghua University Press and Springer-Verlag: 305-321.

Nowacki, G.J.; MacCleery, D.W.; Lake, F.K. 2012. **Native Americans, ecosystem development, and historical range of variation.** In: Weins, J.A.; Hayward, G.D.; Safford, H.D.; Giffen, C.M., eds. Historical environmental variation in conservation and natural resource management. Chichester, UK: John Wiley & Sons, Ltd.: 76-91.

O'Keefe, J.F.; Foster, D.R. 1998. **An ecological history of Massachusetts forests.** In: Foster, C.H.W., ed. Stepping back to look forward: a history of the Massachusetts forest. Petersham, MA: Harvard Forest: 19-66.

Parker, M.; Wood, R.J., Jr.; Smith, B.H.; Elder, R.G. 1985. **Erosional downcutting in lower order riparian ecosystems: have historical changes been caused by removal of beaver?** In: Johnson, R.R.; Ziebell, C.D.; Patton, D.R.; Ffolliott, P.F.; Hamre, R.H., tech. coords. Riparian ecosystems and their management: reconciling conflicting uses. First North American riparian conference; 1985 April 16-18; Tucson, AZ. Gen. Tech. Rep. RM-GTR-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 35-38.

Patterson, W.A., III; Sassaman, K.E. 1988. **Indian fires in the prehistory of New England.** In: Nicholas, G.P., ed. Holocene human ecology in northeastern North America. New York: Plenum Publishing: 107-135.

Perry, J.; Ison, C. 2003. **The impact of fire on chestnut in the central hardwood region.** Journal of the American Chestnut Foundation. 17: 34-41.

Petersen, J.B.; Cowie, E.R. 2002. **From hunter-gatherer camp to horticultural village: Late Prehistoric indigenous subsistence and settlement.** In: Hart, J.P.; Rieth, C.B., eds. Northeast subsistence-settlement change: A.D. 700-1300. Albany, NY: New York State Museum: 265-288.

Pickett, S.T.A.; White, P.S. 1985. **The ecology of natural disturbance and patch dynamics.** San Diego, CA: Academic Press. 472 p.

Pielou, E.C. 1991. **After the Ice Age: the return of life to glaciated North America.** Chicago, IL: University of Chicago Press. 366 p.

Ramenofsky, A. 2003. **Native American disease history: past, present and future directions.** World Archaeology. 35: 241-257.

Raup, H.M. 1966. **The view from John Sanderson's farm: a perspective for the use of the land.** Forest History. 10: 2-11.

Richter, D.K. 2001. **Facing east from Indian Country: a native history of early America.** Cambridge, MA: Harvard University Press. 317 p.

Ruffner, C.M.; Abrams, M.D. 2002. **Dendrochronological investigation of disturbance history for a Native American site in northwestern Pennsylvania.** Journal of the Torrey Botanical Society. 129: 251-260.

SAS Enterprise Guide 6.1. 2013. Cary, NC: SAS Institute Inc.

Schulte, L.A.; Mladenoff, D.J.; Crow, T.R.; Merrick, L.C.; Cleland, D.T. 2007. **Homogenization of northern U.S. Great Lakes forests due to land use.** Landscape Ecology. 22: 1089-1103.

Seischab, F.K. 1990. **Presettlement forests of the Phelps and Gorham Purchase in western New York.** Bulletin of the Torrey Botanical Club. 117: 27-38.

Seischab, F.K.; Orwig, D. 1991. **Catastrophic disturbances in the presettlement forests of western New York.** Bulletin of the Torrey Botanical Club. 118: 117-122.

Sipe, C.H. 1930. **The principal Indian towns of western Pennsylvania.** Western Pennsylvania History. 13: 104-122.

Society for Ecological Restoration, International Science & Policy Working Group. 2004. **The SER international primer on ecological restoration.** Tucson, AZ: Society for Ecological Restoration International. Available at www.ser.org/resources/resources-detail-view/ser-international-primer-on-ecological-restoration. (Accessed April 14, 2014).

Thomas-Van Gundy, M.; Nowacki, G. 2013. **The use of witness trees as pyro-indicators for mapping past fire conditions.** Forest Ecology and Management. 304: 333-344.

Thompson, J.R.; Carpenter, D.N.; Cogbill, C.V.; Foster, D.R. 2013. **Four centuries of change in northeastern United States forests.** PLOS ONE. 8: 1-15 [e72540].

Van Driver, B.B. 1985. **Roadside geology of New York.** Missoula, MT: Mountain Press. 411 p.

Van Driver, B.B. 1987. **Roadside geology of Vermont and New Hampshire.** Missoula, MT: Mountain Press. 230 p.

Wallace, A.F.C. 1952. **Halliday Jackson's journal to the Seneca Indians, 1798-1800.** Pennsylvania History. 19: 117-147.

Wang, Y.-C.; Kronenfeld, B.J.; Larsen, C.P.S. 2009. **Spatial distribution of forest landscape change in western New York from presettlement to the present.** Canadian Journal of Forest Research. 39: 76-88.

White, P.S.; Harrod, J.; Romme, W.H.; Betancourt, J. 1999. **Disturbance and temporal dynamics.** In: Szaro, R.C.; Johnson, N.C.; Sexton, W.T.; Malk, A.J., eds. Ecological stewardship: a common reference for ecosystem management—vol. II. Oxford, UK: Elsevier Science Ltd.: 281-312.

White, P.S.; Pickett, S.T.A. 1985. **Natural disturbance and patch dynamics: an introduction.** In: Pickett, S.T.A.; White, P.S., eds. The ecology of natural disturbance and patch dynamics. San Diego, CA: Academic Press: 3-13.

Whitney, G.G. 1987. **An ecological history of the Great Lakes forest of Michigan.** Journal of Ecology. 75: 667-684.

Whitney, G.G. 1990. **The history and status of the hemlock-hardwood forests of the Allegheny Plateau.** Journal of Ecology. 78: 443-458.

Whitney, G.G. 1994. **From coastal wilderness to fruited plain: a history of environmental change in Temperate North America from 1500 to the present.** New York: Cambridge University Press. 451 p.

Zhang, Q.; Pregitzer, K.S.; Reed, D.D. 1999. **Catastrophic disturbance in the presettlement forests of the Upper Peninsula of Michigan.** Canadian Journal of Forest Research. 29: 106-114.

Thomas-Van Gundy, Melissa A.; Nowacki, Gregory J.; Cogbill, Charles V. 2015. **Mapping pyrophilic percentages across the northeastern United States using witness trees, with focus on four national forests.** Gen. Tech. Rep. NRS-145. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 26 p.

Witness trees provide information fundamental for restoration ecology, often serving as baselines for forest composition and structure. Furthermore, when categorized by fire relations, witness trees can shed light on past disturbance regimes. Kriging was applied to witness-tree point data to form a contiguous surface of pyrophilic percentage for four national forests in the northeastern United States. Fire was found to be an important disturbance agent on the Allegheny and Finger Lakes National Forests, often corresponding to large river systems and lakesides where Native American activities were concentrated. In contrast, fire was relatively unimportant on the Green Mountain and White Mountain National Forests based on the witness-tree record. There, the cool, moist year-round climate, coupled with lower Native American population densities, greatly subdued fire, supporting the local view of these as “asbestos” forests. When applying this method to town-level witness-tree data for the entire northeastern United States, we found a distinct east-west line dividing areas of high (south) and low (north) pyrophilic percentage. Known as the tension zone line, the undulating character of this boundary, penetrating northward along major river valleys, underscores the importance of Native Americans as a disturbance agent on the presettlement landscape.

KEY WORDS: fire, presettlement disturbance regimes, Native Americans

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