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INFLUENCES OF NATIVE AMERICANS AND SURVEYOR BIASES ON METES AND BOUNDS WITNESS-TREE DISTRIBUTION

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Abstract. Witness trees recorded in surveyors' notes have been extensively used to describe presettlement forest vegetation throughout eastern North America. Relatively few studies, however, have discussed surveying inconsistencies that could affect the quality of witness-tree data in Colonial metes and bounds surveys. To increase the accuracy of these data, we developed techniques to quantify and mitigate the effects of several irregularities in metes and bounds witness-tree data using Lancaster County, southeastern Pennsylvania, USA, as a model. Irregularities included unequal sampling intensities among regions of contrasting topographic relief, and on a finer scale, unequal sampling among landform classes. We mitigated the effects of these inconsistencies by subdividing the study area into physiographic (topographic) sections, and then subdividing each physiographic section into landform classes before witness-tree analysis. Pre-European settlement forests were dominated by *Quercus velutina* and *Q. alba,* with *Carya* spp. in regions of low topographic relief and *Castanea dentata* in regions of high topographic relief. We then assessed the effects of Native Americans using catchment analysis in which we tallied witness trees within 5 and 7 km of Susquehannock village sites and compared the forest composition to edaphically similar catchment areas of low Native American activity. Elevated frequencies of *Carya* spp., *Juglans* spp., and *Robinia pseudoacacia,* with depressed frequencies of *Quercus alba,* occurred on sites with a history of Native American occupation, possibly as a result of disturbance or active cultivation. Together, bias-correction techniques and catchment analysis greatly extend the usefulness of witness-tree data by improving methods for evaluating pre- and post-European settlement disturbance on forest change.

Key words: catchment analysis; metes and bounds surveys; Native American effects on forest composition; Pennsylvania (USA), southeastern; physiographic analysis of forests; pre-European-settlement forests; surveyor bias, correction of; tree species–site relationships; witness-tree densities across the landscape.

INTRODUCTION

Witness (bearing) trees recorded in surveyors' notes are frequently used to describe forest composition at the time of European settlement in eastern North America (Lutz 1930, Spurr 1951, Bourdo 1956, McIntosh 1962, Siccama 1971, Seischab 1990, Abrams and Ruffner 1995). They are often the only source of information on presettlement forests in regions where all original forest has been cleared or altered. Even where old-growth forest remains, it may have been altered by human activity. Also, accurate interpolation between isolated patches of old-growth forest is difficult, if not impossible (Bourdo 1956, Ruffner and Abrams 1998). Thus, witness trees provide an important data source for determining forest composition at the time of European settlement (Lutz 1930, Bourdo 1956, Siccama 1971, Seischab 1990). Also, species–site relationships may be established by analyzing data with respect to topographic or edaphic factors, and species distributions in presettlement forests can be analyzed to explore the role of disturbances such as windthrow and fire (Lorimer 1977, Whitney 1982, Grimm 1984, Abrams and McCay 1996, Abrams and Ruffner 1995).

In order for witness trees to represent presettlement forests accurately, trees must be properly identified and located on the landscape and the sample must be unbiased. However, these criteria are often violated. Trees may have been misidentified, and unidentifiable names occasionally appear in the witness-tree record (Siccama 1971, Loeb 1987, Seischab 1990). Also, careless or fraudulent surveys in which lines and corners were never established in the field may introduce error (Lutz 1930, Whitney 1982, Loeb 1987). But even more serious than these potential discrepancies is surveyor bias. Surveyors may have based their selection of witness trees on criteria of economic value, ease of inscription, size, vigor, longevity, age, or relative abundance (Russell 1981, Grimm 1984, Schulte and Barnes 1996). Several tests have been developed to quantify the degree of species and size bias in rectangular survey systems such as the Public Land Surveys, but most applications of these tests have failed to detect significant bias (Kenoyer 1930, Bourdo 1956, Hushen et al.

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1966, Siccama 1971, Delcourt and Delcourt 1974, Delcourt 1976). In addition, frequent agreement between qualitative forest descriptions and quantitative witness-tree data indicates that witness trees provide an accurate description of presettlement forest composition (Siccama 1971, Lorimer 1977, Whitney 1986).

In colonial times (i.e., pre-1785), properties of original landholders were generally not surveyed using a rectangular system, but rather with the irregular ‘‘metes and bounds’’ system in which surveyors would follow a seemingly haphazard route, often along stream banks, ridgelines, or ‘‘Indian paths’’ (Munger 1991, Abrams and Ruffner 1995). Unlike grid surveys, there are no tests for species or size biases in metes and bounds witness-tree data. Also, given the irregularities in these data, new biases arise that would not occur in rectangular surveying systems. In rectangular systems, corner locations are essentially a systematic sampling of the landscape (Bourdo 1956). Ideally, the set of grid-line intersections include every topographic region and landform in roughly the same proportion as it occurs on the landscape. However, property size, property shape, and number of witness trees per survey vary considerably in the metes and bounds system, causing witness-tree density (number of trees per square kilometer) to differ among physiographic (topographic) provinces. Also, surveyors had considerable freedom in marking property boundaries, and consequently they often chose easily navigated courses across the landscape, selecting a disproportionately large number of witness trees on easily traveled landforms. For example, surveyors were consistently biased against sideslopes and toward stream valleys and ridgetops in southeastern Pennsylvania (Black 1998). Without taking these landform biases and variations in witness-tree density into account, perceptions of presettlement vegetation could be distorted. To date, no techniques have been developed to quantify and mitigate the effects of these inconsistencies in metes and bounds witness-tree data.

Witness-tree data corrected for landform bias and variable density may be used to describe the composition of forests at the time of European settlement, as well as to investigate interactions between Native Americans and vegetation. Many studies suggest that a number of Native American practices may have altered forest composition. Agricultural activity and exploitation of forests for firewood may have facilitated the establishment of early successional tree species (Chapman et al. 1982). Also, certain mast-bearing species such as *Carya* spp. (hickory), *Castanea dentata* (American chestnut), or *Juglans nigra* (black walnut) may have been cultivated (Munson 1986, Wykoff 1991, Loeb 1998). In addition, Native Americans probably used fire to improve browse for game, cultivate berries and mast, and clear underbrush to maintain agricultural fields or facilitate hunting (Day 1953, Mellars 1976, Chapman et al. 1982, Pyne 1983).

Interactions between Native Americans and vegetation can be investigated using witness trees in catchment analysis. Catchment analysis is accomplished by defining catchment areas surrounding known habitations in which foraging and clearing activities were likely to have been most intense (Vita-Finzi and Higgs 1970). Forest cover in these catchment areas is compared to cover within control catchment areas located in edaphically similar regions of low Native American activity (Ruffner 1999). Differences in forest composition can be interpreted with respect to Native American land uses to explore the possibility of any Native American and vegetation interactions (Ruffner 1999). Unlike previous studies using witness trees, fossil pollen, or descriptions by travelers and settlers, this method allows for a direct and statistical comparison between forest composition in areas of high and low Native American activity.

Lancaster County, in southeastern Pennsylvania (USA), offers a unique opportunity to investigate the ecology of presettlement forests, evaluate the quality of witness-tree data, and explore Native American and vegetation interactions. The high concentration of four witness trees per square kilometer not only allows for a detailed reconstruction of presettlement forests, but also a description of variations in witness-tree density among physiographic sections and landforms within those sections. Lancaster County contains >1200 Native American archaeological sites, including several Susquehannock villages that contained populations of more than 2000 individuals, making it an ideal location to explore Native American impacts on the pre-European settlement forests (Kent 1984, Baker 1998, Pennsylvania Historical and Museum Commission [Harrisburg, Pennsylvania, USA]) Pennsylvania Archaeological Site Surveys, *unpublished data*. Therefore we use this information to describe and quantify variations in witness-tree density and landform sampling biases, and we propose corrective methods to increase the accuracy of metes and bounds witness-tree data. We then analyze witness trees with respect to physiography and landform to establish species–site relationships, to describe forest types, and to explore the ecological processes that regulated their distributions. Finally, interactions between Native Americans and forest composition are evaluated using catchment analysis.

METHODS

Study area

Lancaster County occupies ~2453 km^2 in southeastern Pennsylvania, USA, virtually all within the Piedmont Physiographic Province (Fenneman 1938, Custer 1985). Three distinct sections of the Piedmont occur in Lancaster County: the Piedmont Uplands, the Piedmont (Conestoga) Lowlands, and the Triassic–Jurassic (Gettysburg–Newark) Lowlands (Fig. 1). The Piedmont Uplands extend across the southern third of

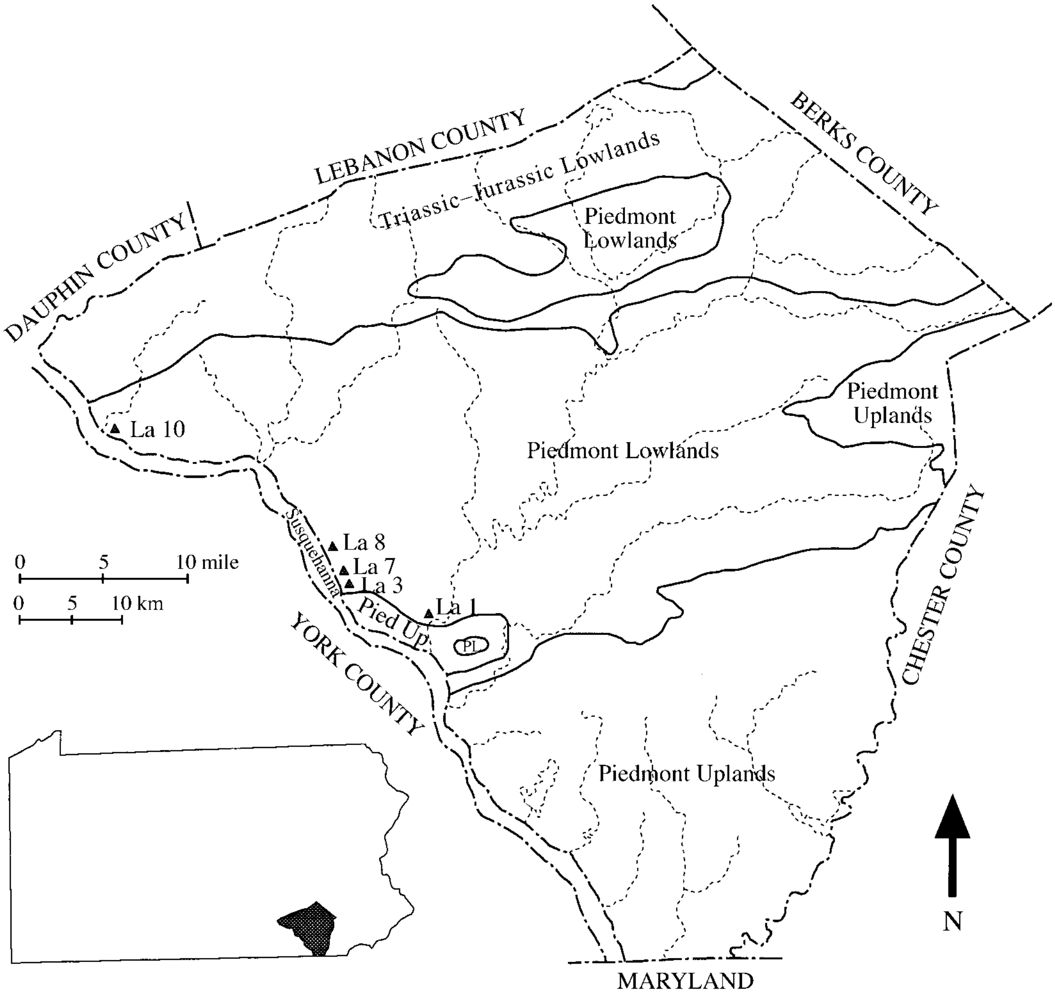

FIG. 1. Physiography, hydrology, and Susquehannock village sites of Lancaster County, Pennsylvania, USA. Susquehannock sites include: La 1 (Roberts Farm), La 3 (Strickler), La 7 (Schultz), La 8 (Washington Boro), and La 10 (Billmyer Quarry).

Lancaster County and were formed from Lower Paleozoic quartzite, gneiss, granite, and schist. Broad, gently rolling hills dissected by relatively deep, steeply sloping, and often-rocky stream valleys typify the topography of this area (Custer 1985, Ciolkosz et al. 1989). The northern third of Lancaster County lies within the Triassic–Jurassic Lowlands. Abrupt ''trap'' ridges of diabase, an igneous rock, interrupt rolling lowlands formed from softer, easily weathered sandstone and shale (Fenneman 1938, Custer 1985). The northernmost tip of the county falls within the Reading Prong section of the New England Province and is excluded from this study (Fig. 1).

In the Piedmont Lowlands of central Lancaster County, low topographic relief, combined with well-drained calcareous ultisols, make this region some of the best agricultural land in the eastern United States (Cuff et al. 1989). To the north, Silurian sandstone and shale underlie the acidic soils of the Bedington association (Custer 1985, Ciolkosz et al. 1989). Although the Bedington soil association is typically classified as a part of the Piedmont Lowlands, its parent materials and topography are more similar to those of the Triassic–Jurassic Lowlands. For these reasons, it is classified as a part of the Triassic–Jurassic Lowlands in this study (Fig. 1).

European settlement of Lancaster County began near the beginning of the 18th Century, ~40 yr after the Susquehannocks had relocated to smaller villages in Maryland, Virginia, or on the western banks of the Susquehanna in York County, Pennsylvania (Kent 1984, Henderson 1989, Baker 1998). Initial settlement occurred in the Piedmont Lowlands and then shifted to the less desirable Piedmont Uplands and Triassic–Jurassic Lowlands. Witness trees in the Piedmont Lowlands date from an initial wave of surveys between 1715 and 1725 and a larger series of surveys between 1735 and 1755. Witness trees in the Piedmont Uplands and Triassic–Jurassic Lowlands were recorded between 1735 and 1765 (Black 1998). Although surveys continued into the early 19th Century, few additional witness trees were marked after 1780 (Black 1998).

Witness-tree environmental analysis

Colonial forests of Lancaster County were reconstructed using original warrant maps. The county surveyor, after completing the first survey of a tract of land, drew a warrant map showing property boundary lengths and bearings, the location and nature of corner markers (whether a tree, post, or stone), and any significant geographic landmarks, including streams, mountains, ''Indian paths,'' or roads (Munger 1991). In Lancaster County a total of 9880 witness, or bearing, trees were recorded by vernacular name on some 3400 warrant maps. These warrant maps have been connected into contiguous township warrantee maps for all 42 townships in Lancaster County and are available at the Pennsylvania State Archives in Harrisburg, Pennsylvania (USA).

We transcribed township warrantee maps onto 27 U.S. Geological Survey (USGS) 7.5-min quadrangles and tallied the location of each witness-tree with respect to physiographic section and landform. Physiographic-section boundaries were delimited by grouping similar soil parent materials. We identified four landform classes: ''side slope'' describes an exposed, sloping site; ''cove'' describes a site protected on three sides, ''hilltop'' describes an exposed, level site, and ''stream valleys'' describes riparian zones. These landform classes are comparable throughout the study area, but the nature of each landform varies somewhat with degree of topographic relief, and thus with physiographic section. For example, topography in the Piedmont Uplands and Triassic–Jurassic Lowlands is well defined compared to the more level Piedmont Lowlands. Therefore, side slopes tend to be steeper, stream valleys tend to be deeper, and hilltops tend to be more exposed in the Piedmont Uplands and Triassic–Jurassic Lowlands.

Contingency-table analysis was used to evaluate species association with each class of landform and physiographic section (environmental parameters) (Strahler 1978). First, presence and absence contingency tables were constructed for every combination of species and environmental parameter. We used a G^2 statistic to test for independence between species distribution and environmental parameter in each contingency table (Sokal and Rholf 1969). Because the G^2 value of 0 cannot be calculated, a sample size of 0.001 was substituted for any class of an environmental parameter with a value of 0 when all other classes had sample sizes ≥ 1. This way, all classes were factored into the analysis. At this point, species with fewer than six individuals in more than two thirds of the ''expected'' contingency-table cells were excluded from analysis because of inadequate sample size (Steel et al. 1997). After calculation of the G^2 statistic, species without a significant response ($\alpha < 0.05$) were removed from further analysis. Cells of the species tables with a significant response to the environmental parameter were converted from frequency counts to standardized residuals. The standardized residuals were then further corrected with respect to cell variance according to the method of Haberman (1973). A positive corrected standardized residual indicated a positive association with the environmental parameter, while a negative corrected standardized residual indicated a negative association (Strahler 1978).

Witness-tree density variations

We compared witness-tree densities among physiographic sections and among soil parent-material classes within physiographic sections. Three parent-material classes were identified within the Piedmont Uplands, three within the Piedmont Lowlands, and four within the Triassic–Jurassic Lowlands. Soil series within each physiographic section and within each parent-material class served as replicates. Witness-tree densities were calculated by dividing the number of witness trees by the total area of the soil series, which was determined using the Lancaster County soil survey. We used one-way analysis of variance with Tukey's method of multiple comparisons to identify significant ($\alpha = 0.05$) density differences among physiographic sections and then among parent-material classes of Lancaster County.

We assessed the influence of survey area on witness-tree density by comparing mean survey areas (acres in a survey) among the three physiographic sections. For the tally, any survey lying within more than one section was assigned to the dominant section. We tested for significant differences among mean survey areas for each physiographic section using one-way ANOVA with Tukey's method of multiple comparisons ($\alpha = 0.05$).

Landform sampling bias

To assess the degree of landform sampling bias, a 0.8-km (0.5-mile) square grid was aligned to the north and placed over the topographic quadrangles of Lancaster County. The 3953 grid intersections served as unbiased, systematically chosen points on the landscape and were tallied by landform position using a four-state classification method. The six landform-position classes were condensed into four classes by combining ''north sideslope'' and ''south sideslope'' into ''sideslope'' and combining ''north cove'' and ''south cove'' into ''cove.'' This increased sample size within the landform classes. We used a chi-square test to compare the landform positions of witness trees recorded in the irregular metes and bounds system with the systematic sampling obtained using the 0.8-km square grid (Steel et al. 1997).

Catchment analysis

Five known Susquehannock sites (Schultz, Washington Boro, Roberts Farm, Billmyer Quarry, and Strickler; Fig. 1) that occur on the Piedmont Lowlands were selected for catchment analysis. All sites used in the study were abandoned before surveys in the area began. Schultz, the oldest of the five sites, was inhabited between the years of 1575 and 1600 and had an estimated population of 1300 individuals (Kent 1984). The next-oldest major village was the Washington Boro site, home to ~1700 Susquehannocks between 1600 and 1625. Although Billmyer and Roberts are not as well studied, they are believed to have been occupied simultaneously between 1625 and 1645. Approximately 900 Susquehannocks lived in the Roberts village (Kent 1984). The most recent and largest of the five sites, Strickler, was inhabited from 1645 to 1660 with a population of 2900 (Fig. 1). The locations of Susquehannock sites in Lancaster County were identified using Pennsylvania Archaeological Site Surveys (PASS files, Pennsylvania Historical and Museum Commission, Harrisburg, Pennsylvania, USA). These and other sources provided dates of occupation, size, and population data for the sites (Kent 1984, Baker 1998).

Catchment analysis first entails identifying an ''exploitation territory'' where inhabitants would have consistently procured natural resources (Vita-Finzi and Higgs 1970). The size of the exploitation territory is a factor of the availability of the desired resource and the energy needed to travel the distance to acquire it (Flannery 1976). In this study, catchment areas of two radii, 5 and 7 km, were established around each Susquehannock village. The 5-km radius should represent the area subjected to the most intense land use where Susquehannocks would have established agricultural crops and acquired wood for fuel and building. The 7-km radius represents the region from which the Susquehannocks would have obtained mast resources (Flannery 1976, Ruffner 1999). A 3-km radius catchment area lacked sufficient sample size and a 9-km radius led to excessive overlap among adjacent catchment areas.

Schultz, Strickler, and Washington Boro sites are very close to one another and are unique in that they lie in a valley along the Susquehanna River that contains extensive evidence of continuous habitation from Paleoindians to Susquehannocks (Kent 1984, Baker 1998). For these reasons, Washington Boro, Schultz, and Strickler were combined into a single catchment area consisting of all three overlapping exploitation territories. Thus, a total of three Native American catchment areas were used in this study: Billmyer, Roberts, and Washington Boro-Strickler-Schultz (W-S-S). All of these catchments areas are primarily within the Piedmont Lowlands, so catchment analysis was performed only in this physiographic section. Regions falling within the Piedmont Uplands or Triassic–Jurassic Lowlands were excluded.

Three control catchment areas were selected in regions of low Native American activity as close as possible to the village catchment areas. To verify that control and village catchment areas were edaphically comparable, we used ArcInfo and ArcView GIS (Environmental Systems Research Institute, Redlands, California, USA) to calculate proportions of parent materials and soil series within the two catchment types. We compared topography of the control and village sites by calculating the mean elevation and standard deviation from mean elevation in a digital elevation model of the catchment areas. *T* tests were conducted between village and control catchment areas on the relative frequencies of each tree species.

RESULTS AND DISCUSSION

Surveyor witness-tree biases

Witness-tree densities did not differ significantly ($\alpha = 0.05$) among parent-material classes within any physiographic section (Fig. 2). Witness-tree densities did, however, vary considerably among physiographic sections. In the mountainous Piedmont Uplands, tree density averaged 6.4 trees/km^2, similar to the density of 5.5 trees/km^2 in the Triassic–Jurassic Lowlands. In contrast, density in the Piedmont Lowlands was only 1.8 trees/km^2, significantly less ($P < 0.001$) than the other two provinces.

A number of interrelated factors, including property size, time of settlement, topography, and soil fertility, can account for variations in witness-tree density. The Piedmont Lowlands contain some of the finest agricultural land in the county and were therefore settled first (Ellis and Evans 1883, Custer 1985, Cuff et al. 1989, Henderson 1989). Land was inexpensive and widely available during the early settlement period and settlers purchased large tracts, resulting in the marking of relatively few witness trees (Henderson 1989). Also, the gently rolling terrain allowed surveyors to follow straight courses across the Piedmont Lowlands, leading to a somewhat grid-like surveying pattern. Land became more expensive as the Piedmont Uplands and Triassic–Jurassic Lowlands were settled, and, as a consequence, property sizes decreased (Henderson 1989). Indeed, the mean survey areas in the Piedmont Uplands and Triassic–Jurassic Lowlands were significantly smaller ($P < 0.001$) than those in the Piedmont Lowlands. In addition, difficult terrain in the Piedmont Uplands and Triassic–Jurassic Lowlands forced surveyors to change course much more frequently, resulting in the marking of a large number of witness trees per survey. Because witness-tree density varies with relief, witness-tree frequencies must be calculated within each topographic (physiographic) section to accurately interpret metes and bounds witness-tree data. Otherwise, species associated with the mountainous regions of the

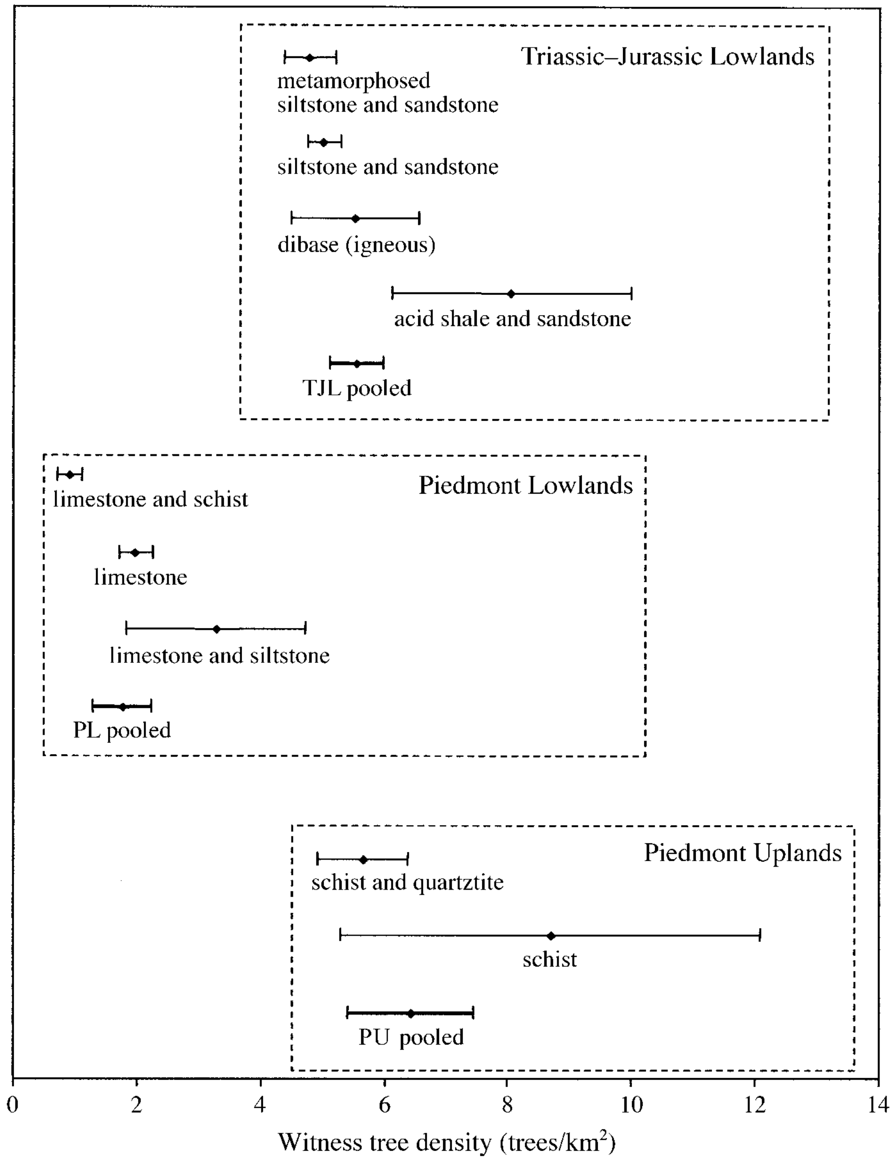

FIG. 2. Witness-tree density (means ± 1 SE) of parent-material classes in the three physiographic sections of Lancaster County, Pennsylvania, USA.

study area may be overrepresented in the witness tree-data.

Pronounced bias toward particular landforms occurred throughout the study area. Sampling of landform classes using the 0.8-km (0.05-mile) square grid-line intersections differed significantly ($P < 0.001$) from observed witness-tree landform tallies. Across Lancaster County, the more difficult terrain of the side slopes was consistently underrepresented (Fig. 3). Surveyors tended to follow the long ridges of the Triassic–Jurassic Lowlands and the deep stream valleys of the Piedmont Uplands (Fig. 3). In addition, landform bias was greatest in the mountainous Triassic–Jurassic Lowlands and Piedmont Uplands where side slopes were steepest. To mitigate the effects of landform biases and variable witness-tree density, witness-tree species frequencies must be calculated within each landform class of each physiographic section.

Although we cannot quantify witness-tree species or size bias in the metes and bounds surveys of Lancaster County, the witness-tree data suggest that species and size biases were probably minor. Colonial surveyors would have had considerable freedom to choose location of corners and were therefore not obligated to blaze uncommon species (Munger 1991). The fact that they recorded witness trees representing at least 40 species suggests minimal species bias and good identification skills (Spurr 1951). With respect to size bias, the inclu-

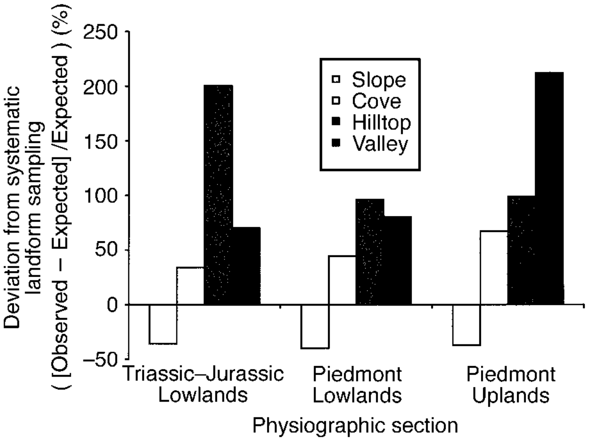

FIG. 3. Surveyor landform bias quantified as percentage differences between metes and bounds landform sampling (observed) and systematic landform sampling (expected).

sion of some ''saplings'' and ''grubs'' in the surveys indicates that surveyors marked small as well as large trees. In addition, surveyors recorded tree species of small stature such as *Cornus florida* (flowering dogwood) and *Lindera benzoin* (spice bush) (Table 1).

Distribution of irregular metes and bounds surveys

Metes and bounds surveys occurred throughout most of the eastern United States, from New England to Georgia (Fig. 4). However, some of the metes and bounds surveys were more irregular than others. The most irregular surveys occurred throughout the mid-Atlantic and southeastern states (Fig. 4) (Marschner 1959). In these regions, the probability of landform biases and variations in witness-tree density is highest. Exceptions include portions of Georgia, New York, Pennsylvania, and to a lesser extent Kentucky and Tennessee, where various rectangular surveying systems were used and the probability of irregularities is low (Marschner 1959, Clint 1979, Cadle 1991, Munger 1991). In New England, land was primarily surveyed by the town in a rectangular system, especially by the late 18th Century (Whitney 1994). Although the probability of landform bias is lower in New England than in more irregular metes and bounds surveys typical of the mid-Atlantic States and southeastern states, witness-tree densities often vary across the landscape (Siccama 1971, Foster et al. 1998). Mid-western and western states were surveyed under the federal Public Land Survey (PLS) system, which became standard in 1785 (Pattison 1970). In this rectangular system, the chances of landform biases and variable witness-tree densities are virtually zero. One exception is Texas, which was not surveyed under the PLS system. The western half of the state is characterized by rectangular surveys, but eastern portions may contain irregular surveying patterns, especially along rivers (Marschner 1959, Watkins 1964).

Pre-European settlement forest composition

The presettlement vegetation patterns correspond to spatial variations in physiographic section and landform. *Quercus velutina* (black oak) and *Q. alba* (white oak) codominated with *Carya* spp. on the gently rolling Piedmont Lowlands (Table 1). The abundance of *Castanea dentata, Q. prinus,* and to a lesser extent *Q. coccinea* (scarlet oak) and *Q. rubra* (northern red oak), increased with topographic relief. Calculation of corrected standardized residuals indicated that *Castanea dentata* and *Quercus prinus* were positively associated with the Piedmont Uplands, somewhat negatively associated with the Triassic–Jurassic Lowlands, and strongly negatively associated with the Piedmont Lowlands (Table 1, Fig. 5). *Quercus coccinea* and *Q. rubra* exhibited a similar, but weaker, response to physiographic section. In contrast, *Carya* spp. was most abundant on the Piedmont Lowlands, but was negatively associated with the Piedmont Uplands and Triassic–Jurassic Lowlands. *Quercus velutina* was also negatively associated with the Piedmont Uplands, but positively associated with both the Triassic–Jurassic Low-

TABLE 1. Presettlement forest species percentages and witness-tree counts of three physiographic sections in the Piedmont of Lancaster County, Pennsylvania, USA.

	Physiographic section		
Trees	Triassic–Jurassic Lowlands	Piedmont Lowlands	Piedmont Uplands
Acer spp.	0.97	0.47	1.96
Betula spp.	0.18	0.47	0.50
Carpinus caroliniana	0.03	0.29	0.00
Carya spp.	15.16	28.09	11.76
Castanea dentata	8.39	0.41	17.96
Cornus florida	0.15	0.12	0.04
Fagus grandifolia	0.65	0.58	0.11
Fraxinus spp.	0.70	0.87	0.34
Juglans spp.	0.21	0.64	0.21
Lindera benzoin	0.00	0.06	0.00
Liriodendron tulipifera	0.62	0.41	0.48
Morus spp.	0.03	0.00	0.00
Nyssa sylvatica	1.29	0.47	1.35
Ostrya virginiana	0.00	0.06	0.00
Pinus spp.	0.09	0.00	0.21
Platanus occidentalis	0.03	0.00	0.02
Populus spp.	0.00	0.00	0.02
Prunus serotina	0.03	0.06	0.06
Pyrus spp.	0.03	0.06	0.02
Quercus alba	29.35	29.55	26.59
Quercus bicolor	0.09	0.06	0.00
Quercus coccinea	5.84	3.32	6.42
Quercus palustris	0.03	0.00	0.00
Quercus prinus	2.99	0.12	5.99
Quercus rubra	0.12	0.06	1.26
Quercus velutina	32.67	32.75	24.15
Robinia pseudoacacia	0.00	0.41	0.46
Sassafras albidum	0.06	0.00	0.04
Tilia americana	0.09	0.00	0.00
Tsuga canadensis	0.06	0.06	0.00
Ulmus spp.	0.18	0.47	0.02
Lightwood	0.00	0.06	0.00
Tree count	3410	1716	4754

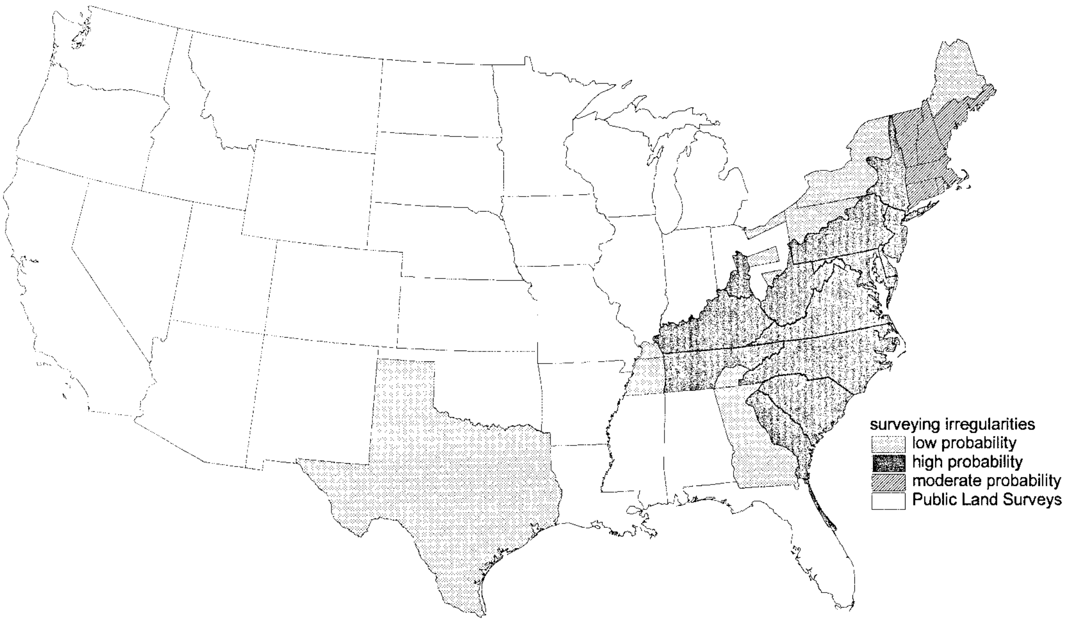

FIG. 4. Distribution of metes and bounds and public land surveys in the eastern United States. The probability of irregularities in witness-tree data is indicated for metes and bounds surveys.

lands and the Piedmont Lowlands (Fig. 5). *Acer* (maplc) spp., *Nyssa sylvatica* (black gum), and *Fraxinus* spp., were weakly associated with specific physiographic sections (Fig. 5), and *Q. alba* was not significantly associated with any physiographic section, suggesting an even distribution (no significant relationships; data not shown).

Landform analysis revealed consistent species–site relationships among the three physiographic sections (Fig. 6). *Acer* spp. and *Quercus alba* were strongly associated with stream valleys and coves (Fig. 6). Indeed, *Q. alba* constituted 44% of the presettlement forests in the stream valleys of the Piedmont Uplands and Triassic–Jurassic Lowlands (Black 1998). *Fraxinus* spp., *Fagus grandifolia, Juglans* spp., *Robinia pseudoacacia, Betula* (birch) spp., and *Ulmus americana* were also most common in the stream valleys and, to a lesser extent, in the coves (Black 1998). On the sideslopes and hilltops, *Castanea dentata, Q. prinus, Q. velutina,* and *Carya* spp. attained their greatest frequencies (Fig. 6). In the Piedmont Uplands and Triassic–Jurassic Lowlands *Castanea dentata* and *Q. prinus* were strongly associated with north-side slopes, *Carya* spp. and *Q. velutina* were associated with south-

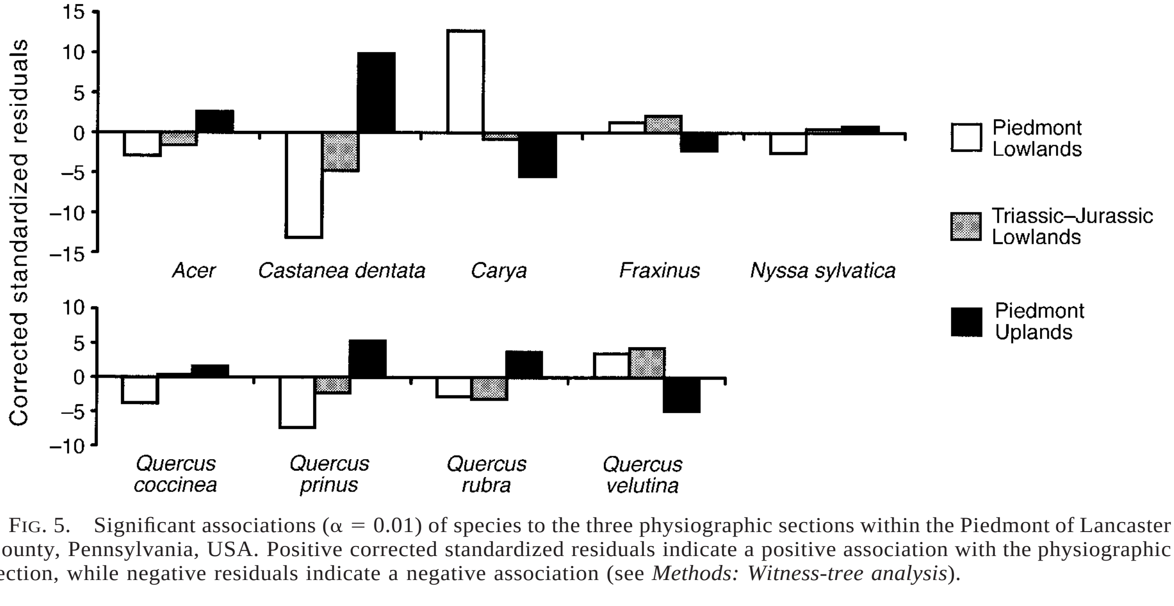

FIG. 5. Significant associations (α = 0.01) of species to the three physiographic sections within the Piedmont of Lancaster County, Pennsylvania, USA. Positive corrected standardized residuals indicate a positive association with the physiographic section, while negative residuals indicate a negative association (see *Methods: Witness-tree analysis*).

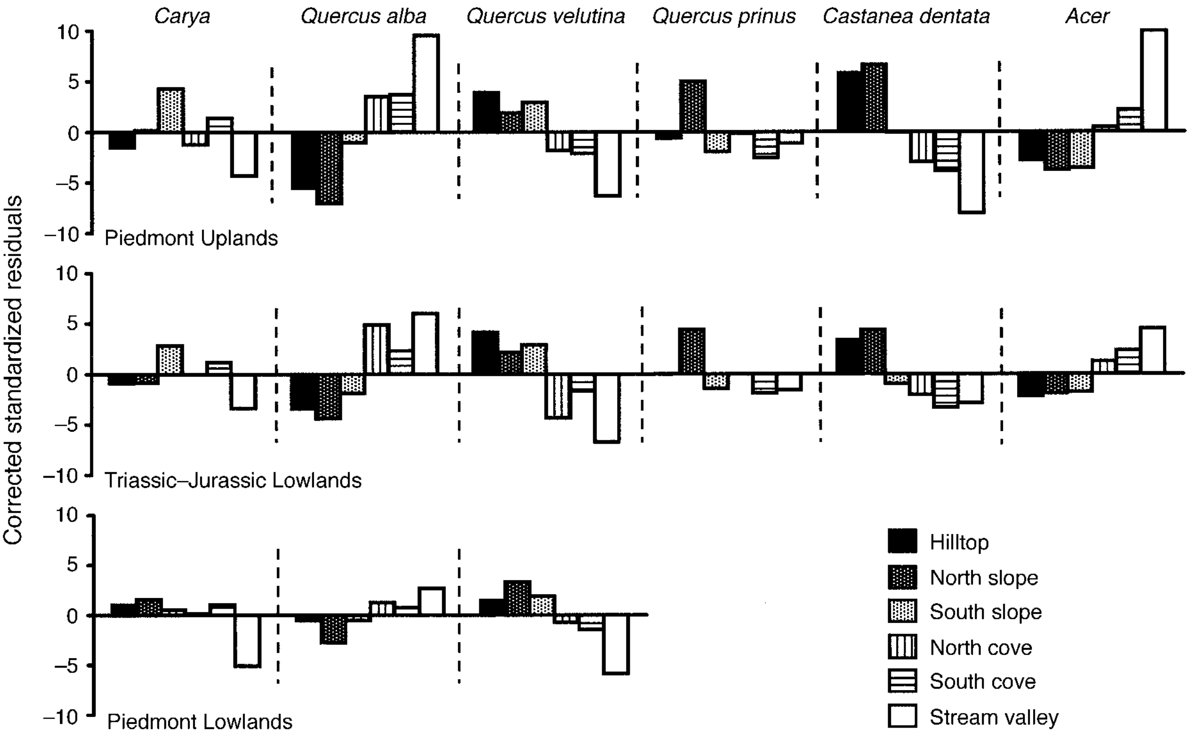

FIG. 6. Significant associations of species to landform classes (α = 0.01) within the Piedmont of Lancaster County, Pennsylvania, USA. Positive corrected standardized residuals indicate a positive association with the landform classes, while negative residuals indicate a negative association.

TABLE 2. Edaphic characteristics of control and catchment areas.

Characteristic	Control	Village
Elevation (m)		
Mean	117	106
Max.	154	117
Min.	51	52
1 SD	19	17
Parent-material classes area (%)		
Alluvial limestone	7.7	3.1
Limestone	75.4	58.5
Limestone and siltstone	4.1	3.3
Schist and limestone	12.8	35.1
Soil series area (%)		
Clarksburg	3.4	2.5
Conestoga	3.2	7.3
Duffield	38.1	50.6
Hagerstown	35.2	5.1
Hollinger	2.1	2.8
Letort	7.4	12.1
Lindside	3.4	1.1
Newark	4.3	2.0
Nolin	0.7	0.8
Penlaw	0.2	0.1
Pequea	2.1	15.6
Landform sampling (%)		
Hilltop	13.9	10.3
North slope	21.6	24.3
South slope	25.0	17.8
North cove	5.5	9.2
South cove	7.9	9.2
Stream valley	26.2	29.2

side slopes, and *Q. velutina* and *Castanea dentata* were positively associated with hilltops (Fig. 6). *Carya* spp. was affiliated with southern aspects throughout the Triassic–Jurassic Lowlands and Piedmont Uplands, but was slightly more common on north slopes in the Piedmont Lowlands (Fig. 6). Although *Quercus alba* was less abundant on sideslopes and hilltops relative to stream valleys and coves, it was almost always more common than *Carya* spp., *Castanea dentata,* or *Q. prinus* on these landforms throughout the county (Black 1998). Despite the degree of association of *Q. alba, Carya* spp., or *Castanea dentata, Quercus velutina* dominated all sideslopes and hilltops of Lancaster County (Black 1998).

Catchment analysis

Village and control catchment areas contain roughly similar proportions of each soil series and parent-material class (Table 2). There is a slightly higher component of ''limestone'' and lower component of ''schist and limestone'' in the control catchments. Also, the control catchments contain a greater proportion of Hagerstown and a lower proportion of Duffield and Pequea soil series. However, Duffield and Hagerstown, both of limestone origins, had very similar species compositions. On these soil types, *Quercus velutina, Q. alba,* and *Carya* frequencies were each within 5% of one another (Black 1998). Pequea, of limestone and schist

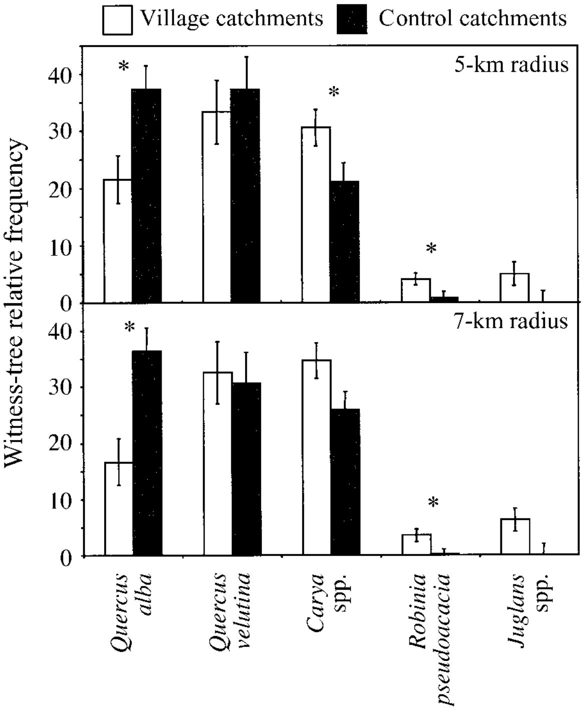

FIG. 7. Relative frequencies of witness trees in village catchments and control catchments (means ± 1 SE). Asterisks (*) denote significant ($P < 0.05$) differences between control and village catchments.

origins, exhibited forest composition consistent with the rest of the parent-material class (Black 1998). Mean elevation differs by 11 m and the standard deviation of elevation, a measure of topographic roughness, differs by 2 m (Table 2). Landforms are equally represented in the village and control sample sets (Table 2).

The soils differences between village and control catchments could potentially affect the abundance of tree species. Given the higher frequencies of *Carya* on limestone soils than on limestone and schist soils, and the greater proportion of limestone to limestone and schist soils in the control catchments, *Carya* should be less abundant in the village catchments. *Quercus alba* was evenly distributed across the soils of the Piedmont Lowlands (Black 1998) and should be equally represented in the control and village catchments. But despite these expectations, village catchments contained significantly more *Carya,* and significantly less *Q. alba* (Fig. 7). *Juglans* and *Robinia pseudoacacia* were also more abundant in village catchments, but sample sizes were too low to evaluate the effects of soils on their distributions.

Such differences in forest composition may be the result of Native American activity. In Lancaster County, Susquehannocks maintained palisaded villages with populations as large as 2900 individuals (Kent 1984). They cultivated subtropical crop plants, including maize, beans, and squash. As reported by early settlers and travelers the Native Americans including Susquehannocks often set forest fires, which may have increased browse for game, facilitated growth of berries and mast, cleared agricultural fields, or improved hunting (Ellis and Evans 1883, Day 1953, Mellars 1976, Chapman et al. 1982, Pyne 1983). Together, agriculture, fire, and collection of wood for construction and fuel may have impacted forest composition. For example, *Carya* spp., a genus that responds well to disturbance in southeastern Pennsylvania, could have become more abundant as a result of Native American activity. High frequencies of the early successional species *Robinia pseudoacacia* and *Juglans* spp. in the village catchments also suggest high levels of disturbance.

Susquehannocks may have engaged in activities that more directly increased the abundance of edible nut-producing species, particularly *Carya* spp. and *Juglans* spp. Evidence suggests other cultures may have actively fostered these species. Iroquois may have introduced *Juglans nigra* to New York by planting it at several sites throughout the state (Wykoff 1991). At Hunter Island, New York City, Native Americans appear to have planted *Carya* spp. in fields (Loeb 1998). In the Midwest, Native Americans may have girdled trees near *Carya* in a type of swidden silviculture that could have increased mast production 500% in five to ten years (Munson 1986). Although there are no historical accounts of Susquehannocks girdling or planting trees, such practices could have been advantageous. Susquehannocks remained at their village sites for 20–25 yr, and would have been able to reap the benefits of their efforts (Kent 1984). Furthermore, new villages were often located close enough to previous village sites to allow continued exploitation of established *Carya* orchards. Indeed, three of the six known Susquehannock Village sites were located in the Washington Boro region.

In contrast to *Carya, Quercus alba* was consistently less common in village catchments (Fig. 7), which may be the result of human disturbance. In several comparisons of presettlement and modern forest cover throughout the mid-Atlantic region, *Q. alba* exhibited substantial declines following heavy logging or catastrophic wildfires. For example, *Q. alba* declined by as much as 30% in the Hudson River Valley of New York, 25% in the Ridge and Valley province of Pennsylvania, 20% in the Ridge and Valley province of eastern West Virginia, and by as much as 15% in the Piedmont and Coastal Plain of northern Virginia (Abrams and Downs 1990, Glitzenstein et al. 1990, Abrams and Nowacki 1992, Orwig and Abrams 1994, Abrams and McCay 1996). When compared to other members of the *Quercus* genus, decreases in *Q. alba* since the time of European settlement are often most dramatic (Abrams and McCay 1996). Native American land uses appear to have had similar effects on *Quercus.* Indeed, *Q. velutina* and *Q. coccinea* did not significantly differ in frequency between village and control catchments, while *Q. alba* was as much as 20% less abundant in village catchments.

In a similar study on the Allegheny Plateau of Northern Pennsylvania, witness-tree catchment analysis demonstrated unusual forest composition near Iroquois villages (Ruffner 1999). Forests within the village catchment areas were more characteristic of *Quercus–Carya–Castanea dentata* forests than the surrounding northern hardwood–conifer forests, despite a lack of soil or topographic differences (Ruffner 1999). The abundance of *Quercus, Carya,* and *Castanea dentata* has been attributed to Native American agriculture and use of fire near the villages (Ruffner 1999). Although witness-tree analysis revealed that there were significant differences between forests of high and low Native American activity on the Allegheny Plateau and in Lancaster County, cause-and-effect relationships between Native Americans and vegetation cannot be tested. We cannot determine whether forest composition of the study site was unique before Native American settlement, whether Native Americans directly altered forest composition using fire, agriculture, or silviculture, or whether there was some combination of these factors. Widespread application of catchment analysis may provide evidence to suggest that Native Americans directly influenced forest vegetation. Even cross-cultural studies may be possible in which the effects of various Native American cultures on forest composition could be compared. However, the exact nature of Native American and vegetation interactions may never be fully understood.

CONCLUSIONS

Scientists and natural-resource managers increasingly rely on estimates of pre-European-settlement forest composition and dynamics to maintain diversity, evaluate the influences of post-settlement disturbance, and restore severely altered ecosystems (Landres et al. 1999, Moore et al. 1999). Ideally, descriptions of reference conditions should include multiple spatial and temporal scales to capture community, landscape, and regional structure and variability (Swetnam et al. 1999). Witness-tree data may be used to describe several of these processes in natural systems. Although witness trees represent only a momentary glimpse of forest composition at the time of European settlement, they often contain indirect evidence of landscape-level disturbance regimes (Lorimer 1977, Grimm 1984). When coupled with palynology or dendroecology, the nature of the system's dynamics may be even more thoroughly addressed (Abrams and Downs 1990, Mikan et al. 1994). One of the most favorable attributes of witness-tree data is its extent, which allows for regional-level analyses. Already, ecologists have used witness-tree data to determine early-European-settlement forest cover on the state level, but these studies have taken place only in the Midwest using PLS survey data. Except for New England, regional-level historical analyses are still rare in the eastern United States (Marks et al. 1992, Russell et al. 1993, Foster et al. 1998). Application of our techniques to correct irregularities in metes and bounds witness-tree data should contribute to regional-level studies of colonial forests in mid-Atlantic and Southeastern states.

Witness trees have been used extensively to evaluate post-European-settlement influences on forest composition (Glitzenstein et al. 1990, Palik and Pregitzer 1992, Abrams and Ruffner 1995). However, catchment analysis using witness trees can also provide a data source for evaluating Native American influences on their environment. In contrast to fossil-pollen analysis, which can be ineffective at recording small-scale disturbances (Jackson 1997, Sugita et al. 1997), catchment analysis is well suited for detecting disturbances at the scale of those created by Native Americans. Thus, widespread use of catchment analysis may generate more data to support the growing body of evidence that Native Americans had a significant impact on local forests (Clark and Royall 1995, Delcourt et al. 1998, Loeb 1998, Ruffner 1999). Catchment analysis would be most effective in regions of high witness-tree density and low physiographic complexity, and, under these circumstances, not only the degree but also the boundaries of Native American influences may be better quantified. Evaluating the impacts of Native Americans will also help to better define the extent and character of truly natural forests free of human impacts. Future studies using metes and bounds witness-tree data and catchment analysis may provide new perspectives on the ecology of eastern forests and the role of pre- and post-European-settlement disturbance in forest change.

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