A GIS-BASED APPROACH TO STAND VISUALIZATION AND SPATIAL PATTERN ANALYSIS IN A MIXED HARDWOOD FOREST IN WEST VIRGINIA

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Abstract.—Tree spatial patterns were characterized for a 75-year-old mixed hardwood forest dominated by northern red oak, chestnut oak, red maple and yellow-poplar. All trees ≥5 inches diameter at breast height (d.b.h.) were measured for diameter, total height, crown height, and crown width along with their locations in the field over an area of 8 acres. The spatial patterns of trees were analyzed using Ripley's *L(d)*. The stand map was projected using a geographic information system with measured tree attributes for visual representation of the stand in the spatial context. The result indicated that the forest represented a random spatial pattern, but spatial patterns varied by species and size classes. For example, among the dominant species, red maple species represented a random spatial pattern while red oak, chestnut oak and yellow-poplar had clustered spatial patterns. Larger trees(d.b.h. >18 inches) were found to be uniformly dispersed while smaller trees had random patterns. We suggest that shade tolerance of trees can be used as an indicator variable in generalizing random spatial pattern. This generalization could be helpful in planning silvicultural activities in a stand.

INTRODUCTION

Spatial patterns of trees in forests are important elements for understanding ecosystem dynamics (Veblen and others 1979). However, the potential for improved ecological understanding afforded by spatially explicit analysis has not been fully recognized (Franklin and others 2002). The existing spatial structure of the stand may be viewed as resulting from species adaptation to a particular ecological niche as a deterministic process and localized dispersal events as a stochastic process (Hubbell 2001). The mainstream approach to community ecology has been to search for deterministic processes that explain the particular adaptations of each species to abiotic factors, or interactions among species (Hardy and Sonke 2004). The existing tree spatial patterns can be used to infer intra- and interspecific interactions among plants (Pielou 1977, Greg-Smith 1979), and explain certain stand attributes. For example, Leopold and others (1985) explained that the existing random spatial pattern in smaller trees may be the result of shade tolerance, seed production, and available growing space. Based on these insights, we hypothesized that tree characteristics can be used to generalize stand spatial patterns.

Geographic information systems (GIS) provide a framework within which large spatial databases can be stored, retrieved, and manipulated quickly and easily, allowing efficient data analysis and statistical inference techniques (Cressie and Kornak 2002). Location of individual trees can be accurately mapped in GIS and tree records can be identified by addresses in established spatial units. These spatial data can be analyzed in a visual interface and such visual representation of stand spatial pattern can aid in interpreting various spatial statistical tests that can be calculated using most GIS software packages. For example, Ripley's *K* function uses distance between all possible pairs of points by increasing the search radius to detect pattern at multiple scales (Ripley 1977, Moeur 1993).

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In this study, we used GIS to characterize the tree spatial patterns in a mixed hardwood forest stand in West Virginia and explored the possibility of identifying stand characteristics such as d.b.h., height, crown width, and shade tolerance as indicator variables for particular spatial patterns in the stand. The generalized spatial patterns can be helpful in reconstructing stand disturbance history as the existing spatial patterns reflect primarily disturbance history, such as fire (Rebertus and others 1989, Skarpe 1991, Woods 2004), edaphic factors, or weather patterns, e.g. droughts (Couteron and Kokou 1997). Similarly, knowledge of pattern can be used to select efficient and economical harvesting techniques and equipment. For example, drive-to-tree machines used in forest harvesting are less expensive to purchase and operate and are more productive in scattered stands (i.e., for random or regular spatial patterns). Swing-to-tree type machines, which are expensive to purchase and operate, are productive in clustered stands (Green and Reisinger 1999).

STUDY AREAS

The study area was a 75-year-old, second-growth mixed hardwood forest stand located in the 2800-ha West Virginia University Forest. The forest is located approximately at 39.66°N, 79.78° W. The elevation of the field study sites ranged between 2001 ft and 2310 ft. The major species at the forest are northern red oak (*Quercus rubra*), yellow-poplar (*Liriodendron tulipifera*), red maple (*Acer rubrum*), and chestnut oak (*Q. montana*).

METHODS

Twenty 0.4-acre square plots were laid out to the northwest and southeast of Glade Run Stream. Diameter at breast height (d.b.h.), total height, crown height, crown length, and crown diameter were recorded for all living trees with d.b.h. ≥5.0 in. A subsample of smaller trees (2 - 5 in d.b.h.) was measured in one plot to analyze the spatial patterns of smaller trees.

Each plot was converted to a planar coordinate system by transforming to the northwest corner of each plot as origin (0,0). Plots were randomized in the analysis framework to avoid plot-level bias. Tree locations were measured using a laser hypsometer and digital compass. Precise tree centers were obtained by adding stem radius to the horizontal distance from laser location to tree stem. Tree locations were projected to Universal Transverse Mercator (UTM) upon registering the locations into corresponding geographical units (Snyder 1987) in GIS. The spatial pattern of trees (by species, d.b.h., crown width, and total height) was determined by using the Ripley's *L* function (standardized Ripley's *K* function) (Ripley 1976, 1981, Besag 1977) as in equation (1). Ripley's *L* function computes the overall mean number of points lying within a circular search window of radius d and stabilizes and linearizes the variances and edge corrections:

$$\hat{L}(d) = \sqrt{\left(A \sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} k_{ij} \right) / \left(\Pi (n-1) \right)} \quad (1)$$

where A is area, N is the number of points, d is the distance and k_{ij} is the weight, which is 1 when the distance between i and j is less than or equal to d and if there is no edge correction, and when the distance between i and j is greater than d. When the edge correction is applied, the weight of k_{ij} is modified slightly.

The expected value of $\hat{L}(d)$ under a Poisson process (i.e., Complete Spatial Randomness or CSR) is 0, positive values indicate clustering, and negative values indicate spatial segregation. We used Monte Carlo simulations of Poisson process to provide a 95 percent confidence envelope (Burrough and McDonnel 1998) by randomly relocating each tree 99 times over the study area. The maximum and minimum simulated *K* values of these random patterns corresponded to the maximum and minimum of the

Table 1.—Stand characteristics by species. Figures represent mean value and figures in parenthesis represent associated standard deviation.

	Trees per acre	DBH (inch)		Height (ft)		Crown height (ft)		Crown width (ft)		Basal area (ft^2/acre)
For all trees larger than 5 inches d.b.h										
American beech	0.1	5.2	(-)	25	0	16	(-)	22	(-)	0.02
Black cherry	9	12.8	-4.1	65.8	-17.7	50.4	-16.9	25.3	-11.3	8.06
Black gum	2.3	6.4	-1.1	29.6	-8.9	20.1	-8	13.9	-4.5	0.5
Black oak	1.4	12.3	-2.8	72	-6.9	53.5	-13.8	28.4	-11.3	1.14
Blue beech	0.6	11.3	-3.5	59.4	-8.8	46.8	-8.9	26.6	-5.5	0.44
Chestnut oak	14.4	11.3	-3.4	65.1	-16.8	51	-15.8	23.4	-9.7	9.96
Cucumber tree	4	11.1	-3.3	61.8	-18.1	49.5	-18.8	19.4	-7	2.7
Elm	0.1	5.8	(-)	36	0	18	(-)	22	(-)	0.02
Hickory	0.9	12.3	-3.9	61.1	-18.2	41.3	-14.8	27.6	-14.5	0.72
Red maple	42.3	8.3	-3	43	-15.3	30.5	-13.6	20.2	-6.8	15.72
Red oak	24.8	15.2	-5.2	72.5	-14.5	54.8	-15.3	32.7	-11.9	31.2
Sassafras	4.8	12.1	-3.2	54.7	-15.1	39.7	-10.6	17.8	-6.9	3.78
Sourwood	3.4	14.6	-4.9	71.3	-16.8	54.4	-18.3	35.5	-12.7	3.92
Sweet birch	0.3	5.6	-0.3	23.5	-1.5	17	-1.4	18.5	-0.7	0.04
White ash	0.3	19.7	-7.1	83.5	-0.5	70	0	41	-7.1	0.53
White oak	6.6	13.8	-5.1	68.7	-15.1	53.3	-15.2	28.3	-13.5	6.84
Yellow-poplar	22	16.7	-4.7	79	-15	64.4	-13.8	31.4	-11.1	33.61
Total	137	12.2	-5.2	61.1	-21.1	46.6	-19.5	25.7	-11.3	110.99
For trees in 2 – 5 inches d.b.h. (from one sample plot)										
Black cherry	0.6	2.9	-1	20.6	-5.1					0.2
Black gum	0.1	2.5	(-)	18.6	(-)					0
Red maple	1	4.1	-0.6	36.3	-8.7					0.7
Total	1.8	3.6	-0.9	29.4	-10.8					1

confidence envelope at each d. If observed *L(d)* values are inside the confidence envelope, the observed spatial distribution is likely to be random. If values are larger than the upper confidence envelope, then distribution is significantly clustered and if less, significantly uniform.

RESULTS

Stand Description

Stand density was 137 trees per acre with four species comprising more than 75 percent of total tree density: red maple (RM), northern red oak (RO), chestnut oak (CO), and yellow-poplar (YP). Total basal area was 111 square feet per acre (Table 1). Average stand d.b.h. was 12.2 in., average height was 61.54 ft, average crown height was 46.60 ft, and average crown width was 25.7 ft.

The smaller diameter classes were composed mainly of red maple; yellow-poplar and northern red oak made up the majority of trees in larger diameter classes (Fig. 1). Of the four major species, red maple was found in the understory, and its height distribution was shortest. Yellow-poplar and northern red oak dominated the canopy of the stand (Fig. 2). Among the four dominant species analyzed, northern red oak and yellow-poplar tended to have wider crowns while red maple and chestnut oak had smaller crowns (Fig. 3).

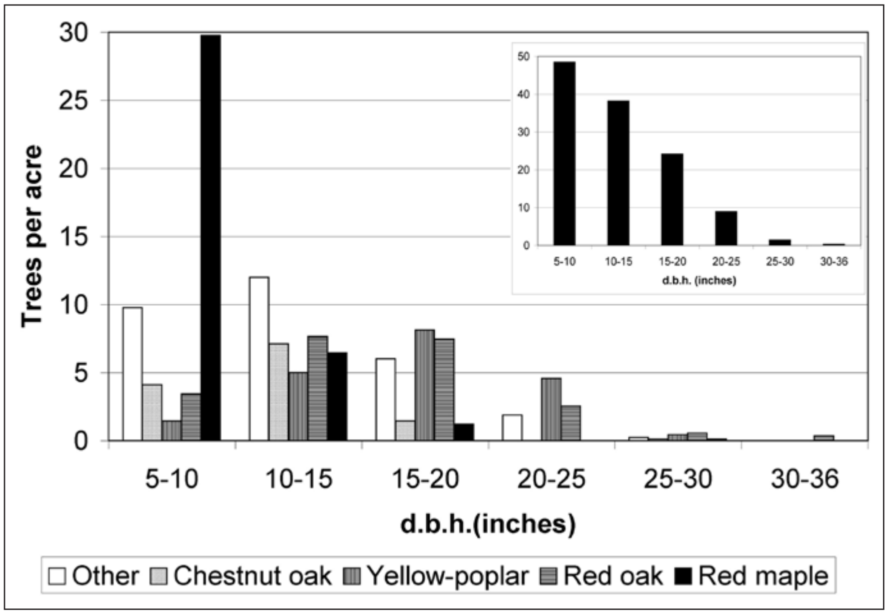

Figure 1.—Stand diameter distribution of four major species and for all species combined (in inset). The estimated stand age is 75 years and it is a mixed hardwood stand.

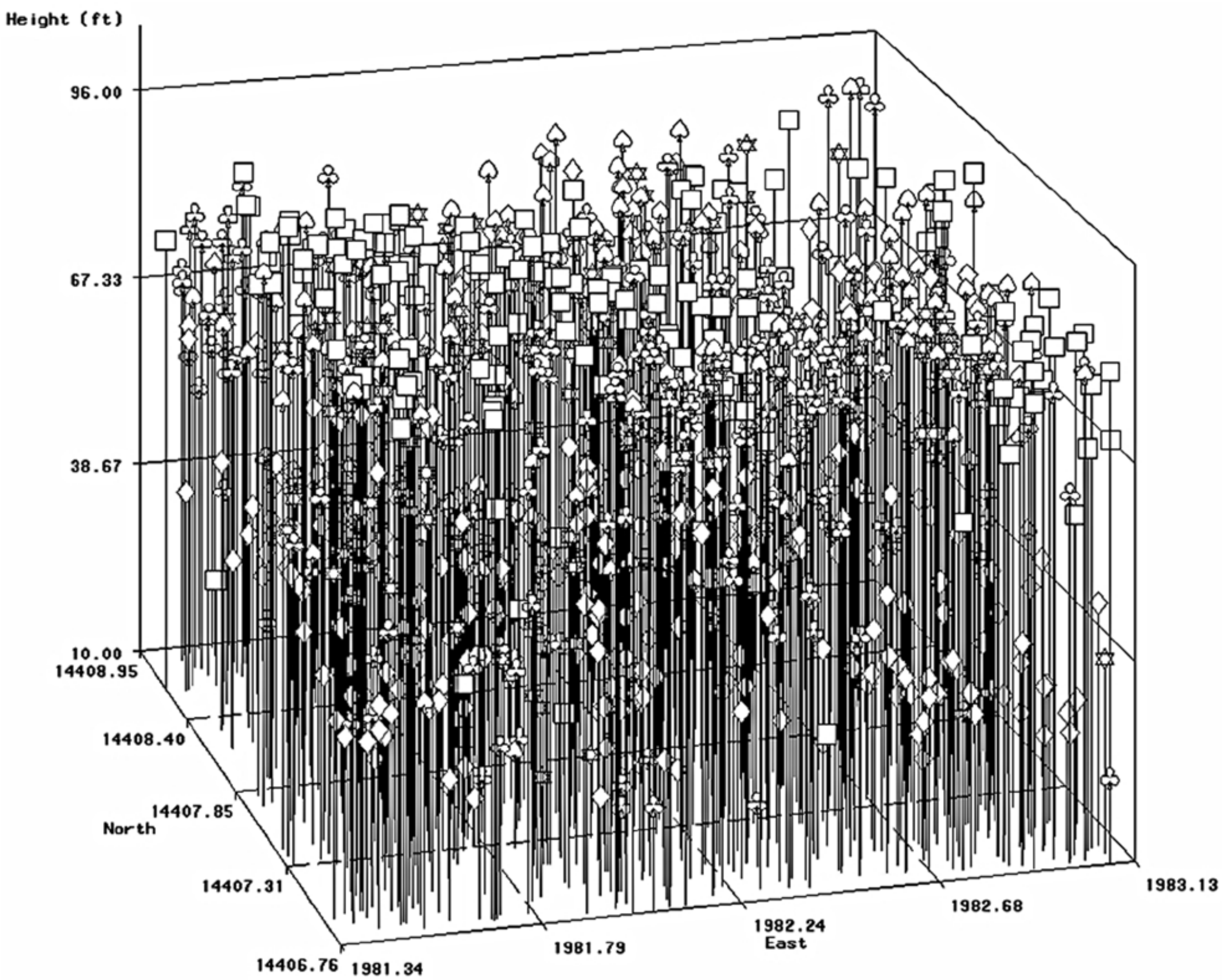

Figure 2.—Height profile of trees in the study area. The North and East coordinate systems (i.e. Y and X) are drawn to Universal Transverse Mercator (UTM) and represent UTM equivalent to ’000 feet distance. The coordinate has a false easting component of 1,640,000 ft. (Legend: spade for red oak, square for yellow poplar, diamond for red maple, star for chestnut oak, and club for all other species).

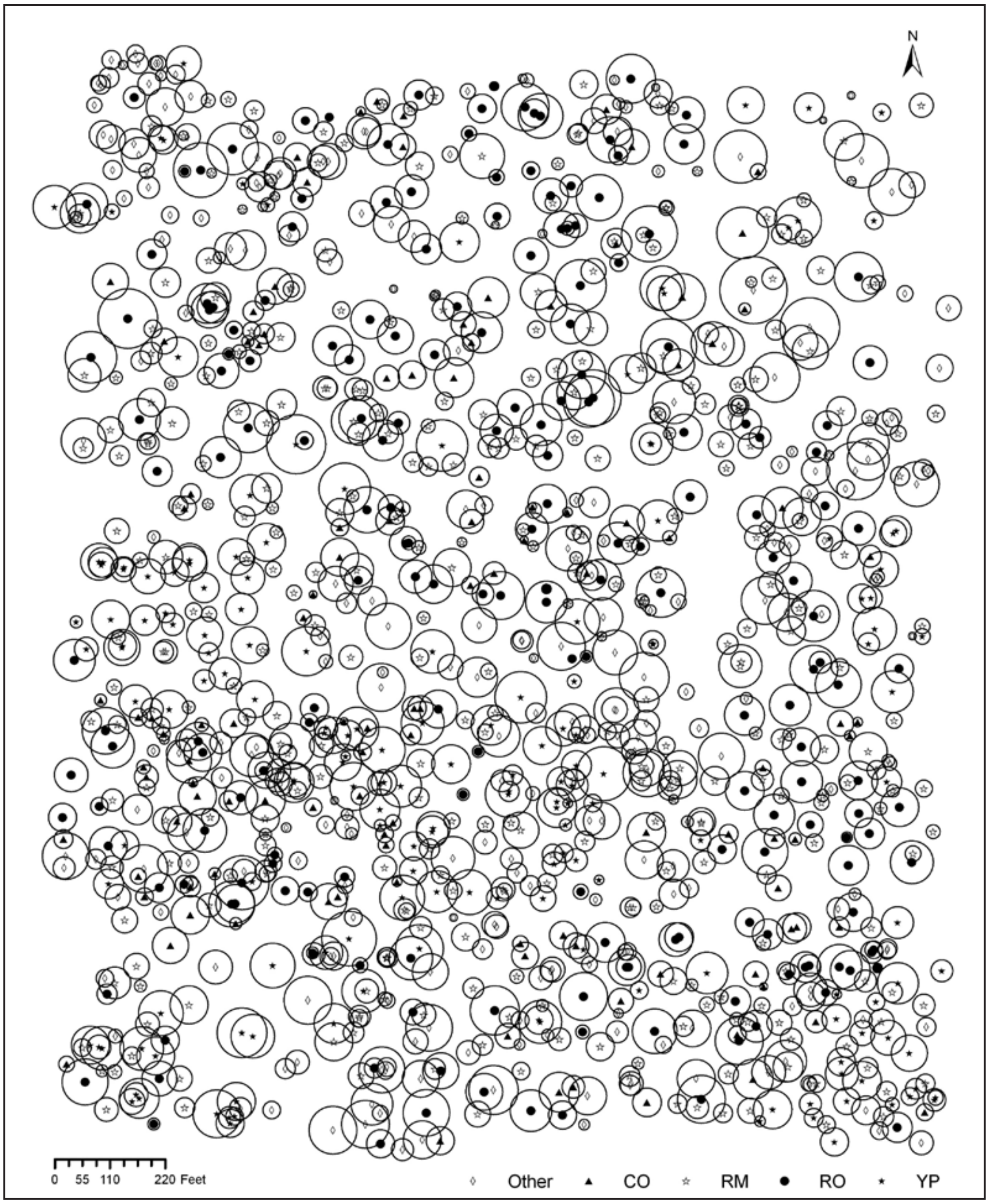

Figure 3.—Spatial distribution of trees with individual tree crown width drawn to scale. The circle diameter represents the crown width. The gaps within the stand are either smaller trees which were not measured during the study or natural gaps in the stand.

Spatial Pattern

L(d) plots indicated that overall the stand's tree distribution was not significantly different from random or CSR (Fig. 4b). However, this pattern was not uniform for all species. Among the four major species, red maple showed a random spatial pattern while northern red oak, chestnut oak, and yellow-poplar each showed a clustered pattern (Fig. 4c-f). The spatial pattern tended to vary by distance (i.e., scale of observation). For example, yellow-poplar tended to become more clustered at a distance of 48 to 112 ft and tended to come closer to random pattern at broader scales (i.e., >160 ft). On the other hand, red oak's distribution pattern was random at finer scales and clustered when distance increased. The spatial pattern analyzed for smaller trees (d.b.h. 2 to 5 in.) in a randomly selected plot showed that the existing pattern was random for all distances (Fig. 4a).

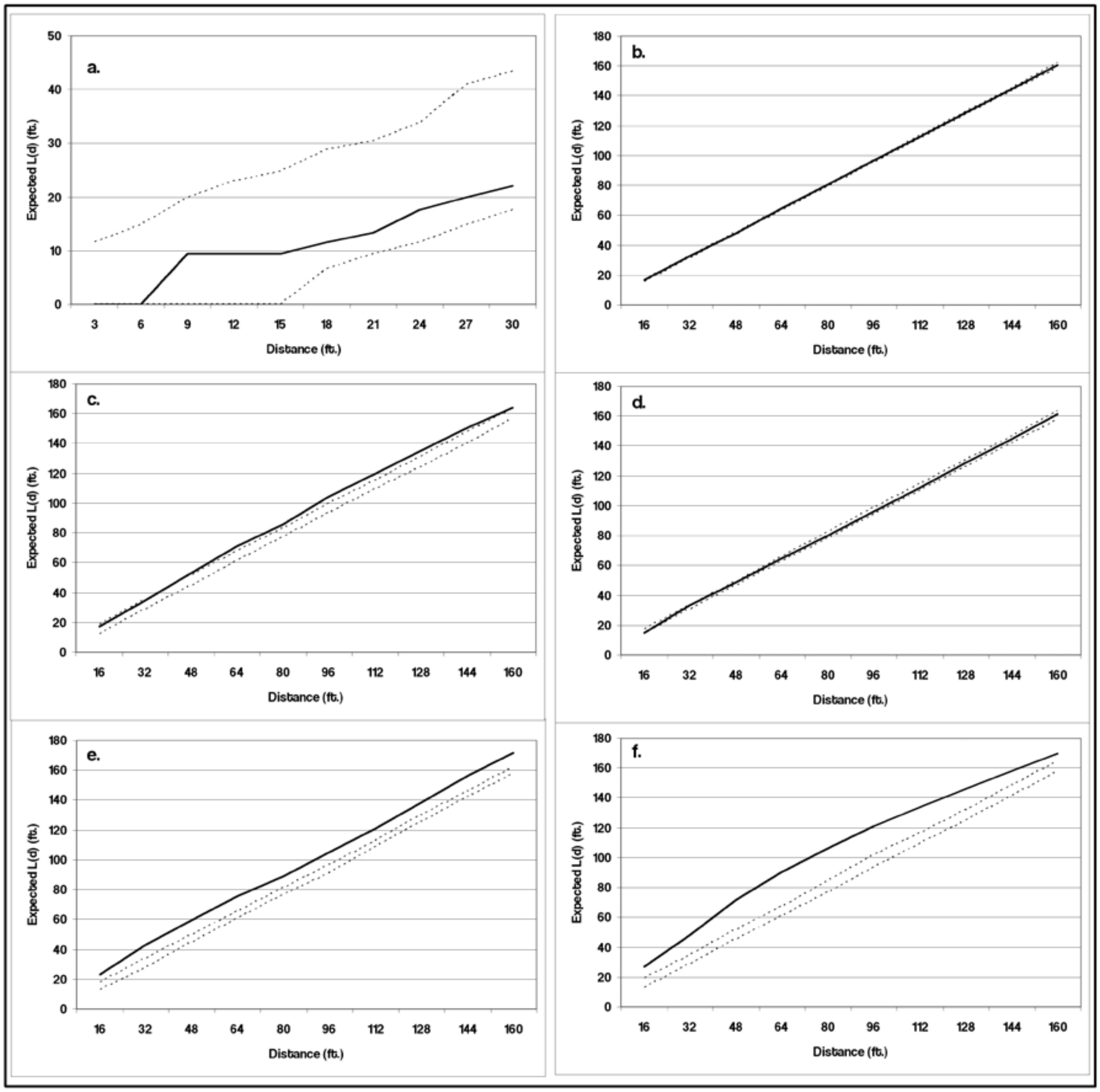

Figure 4.—Spatial pattern as function of L(d) of smaller trees (a.), for all the species (b.) and for major species red oak (c.), red maple (d.), chestnut oak (e.) and yellow poplar (f.). The dotted lines are the 95 percent confidence envelopes for spatial randomness and the solid line is the existing spatial pattern. A solid line above the confidence envelope indicates a significant clustered pattern while a line below the envelope indicates a significant regular (dispersed) pattern.

We also analyzed the spatial pattern of trees based on d.b.h., height, and crown width (Fig. 5). The distribution of larger trees (d.b.h. >18 in.) was regular while smaller trees (d.b.h. <18 in.) were distributed randomly at shorter distances and showed a clustered pattern at larger reference distance. Taller trees had a clustered pattern while shorter trees had a random pattern. Trees with larger crown width (>20 ft) had random distribution at reference distances up to 40 ft and were clustered at higher reference distances. Trees with smaller crowns (<20 ft) had a random spatial pattern.

While conducting species-level analysis of the four major species, we found that only red maple showed a random spatial pattern. A review of silvical characteristics of all the major species showed that red maple differs from other species only in its ability to tolerate shade. Shade-tolerant species including maple were randomly distributed in the stand (Fig. 6).

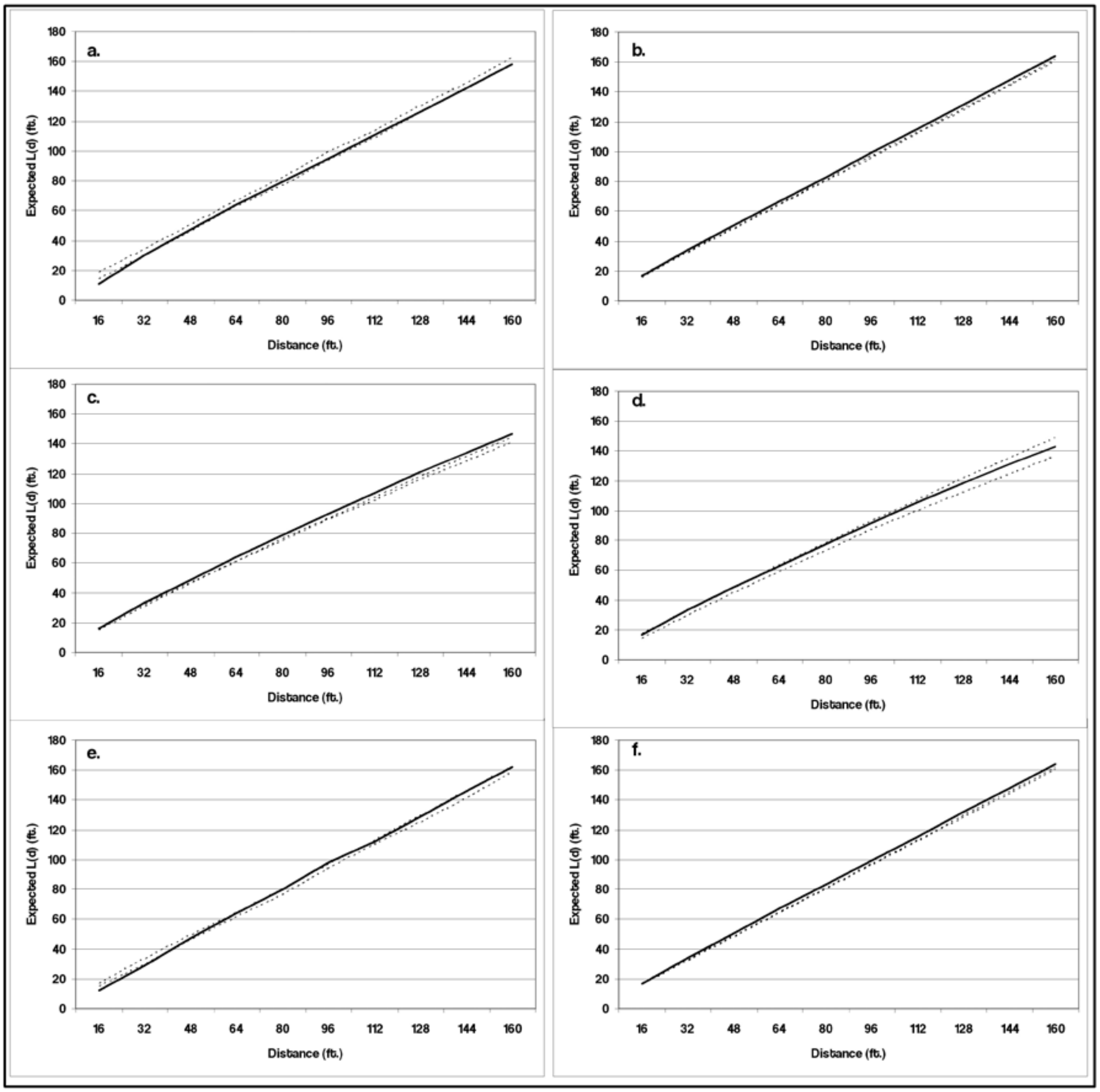

Figure 5.—Spatial pattern as function of *L(d)* by different size attributes (d.b.h., total height, and crown width). Spatial pattern of trees with d.b.h. >18 inches (a.); d.b.h. <18 inches (b.); height >33 ft (c.); height <33 ft. (d.); crown width >20 ft (bottom left) and crown width <20 ft (e.).

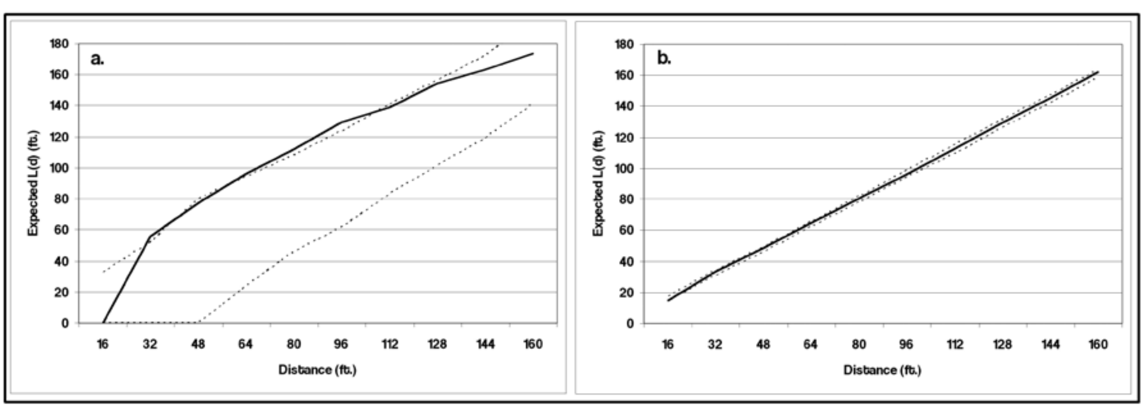

Figure 6.—Tree spatial pattern as function of *L(d)* in shade-tolerant species excluding red maple (a.), and including red maple (b.).

DISCUSSION AND CONCLUSIONS

The stand explored in this study represents a central hardwood stand for West Virginia based on the characteristics described by Hicks (1998). The spatial pattern of trees across the study area was random. This pattern was consistent with studies conducted in similar hardwood regions (e.g., Chokkalingam and White 2001).

In our stand, red maple comprised of about one-third of stem density. This species is considered adapted to a broad spectrum of environmental conditions, and in the central hardwood region, emerges as both pioneer and climax species (Hicks 1998). In our analysis, we found that red maple had a random spatial pattern. The existing pattern of these species can be related to their ecological role and silviculture. For example, red maple's shade tolerance enables it to persist on a range of sites. In our stand, site availability could be a function of tree mortality, which creates canopy gaps. In the absence of anthropogenic disturbance, gap creation often is a spatially random phenomenon and, in younger stands, gap sizes are generally small. Red maple can opportunistically establish in small, randomly distributed gaps and thus approximate a random spatial pattern.

Large trees with wide crowns affect the distribution of smaller trees in the forest understory. Crown-width mapping, together with the height profile, gives insights into the existing stand structure. For example, red maple, which was mostly found in the understory (Fig. 2), also exhibited smaller crowns (Fig. 3) in this stand. The shorter trees, trees with smaller diameters, and those with smaller crown widths growing in the understory were able to persist under shady conditions and had random spatial patterns. The shade-intolerant species—northern red oak, chestnut oak, and yellow-poplar—exhibited clustered spatial patterns.

Although several processes are involved in stand spatial pattern including past disturbances, life history strategy, ecological role, species regeneration guilds, differential resource use, dispersal and germination mechanisms or reproductive strategies (Agren and Fagerstrom 1984, Bazzaz 1990, Sutherland and others 2000), it is possible that trees growing in shade are affected by those processes and can be used as an indicator variable to generalize the existing spatial pattern in the stand as a quick assessment of random spatial distribution in the stand. Although our analysis was able to detect the linkage between shade tolerance and random spatial distribution, it could be possible that this was a result of a random chance event. Future research with different datasets from comparable stands could give further insights into predicting spatial pattern and validate this research. Similarly, the spatial pattern analysis conducted in different size classes can be extended to temporal measurements to understand the spatial pattern of forest turnover. Once we obtain acceptable predictive ability based on indicator variables like shade tolerance in regards to spatial pattern, stand simulation using a desktop system may be more accurate for silvicultural prescriptions and harvest scheduling.

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