Virginia Journal of Science
Volume 59, Number 1
Spring 2008

Topographic Factors Affecting the Tree Species Composition of Forests in the Upper Piedmont of Virginia

Rachael C. Brown, School of Natural Sciences and Mathematics, Ferrum College, Ferrum VA, 24088. Current Affiliation: Northern Arizona University, Flagstaff, AZ 86001 and
Todd S. Fredericksen[1], School of Natural Sciences and Mathematics, 212 Garber Hall, Ferrum College, Ferrum VA, 24088

ABSTRACT

There are many factors that influence forest species composition and many are linked to topographical features. This study, conducted on the Ferrum College campus in the Upper Piedmont Physiographic Province of Virginia revealed three major forest types associated with topographic factors using cluster analysis and detrended correspondence analysis. The first type of forest occurred mostly on northeastern slopes on toe slope topographic positions and was mainly composed of tulip tree (*Liriodendron tulipifera*) and red maple (*Acer rubrum*). The second type of forest was found on shoulder and side slope positions and was composed mostly of high densities of sourwood (*Oxydendrum arboreum*), red maple and chestnut oak (*Quercus prinus*) species. The final forest type was located mostly on ridgetops and shoulder slope positions with a southwestern aspect and was composed mostly of white pine (*Pinus strobus*), sourwood, chestnut oak and scarlet oak (*Quercus coccinea*). In general, tree density increased with ascending slope position while DBH decreased. Species richness did not differ significantly by topographic position or aspect.

INTRODUCTION

There are many variables that influence forest species composition including soil moisture and nutrients, air temperature, light and disturbance regime. These variables are often strongly linked to topographic features such as aspect, slope position, inclination and elevation (Desta et al. 2004). Edaphic and topographic factors exert important influences along the upper Piedmont and Blue Ridge physiographic provinces of Virginia (Stephenson 1982, Harrison et al. 1989, Farrell and Ware 1991, Copenheaver et al. 2006). These forests, however, also have a long and complex disturbance history that has affected forest species composition.

The forests in this region of Virginia were once dominated by American chestnut (*Castanea dentata*) until the invasion of the chestnut blight fungus (*Endothia parasitica*) in the 1920s (Johnson and Ware 1982). Following this event, highest rankings of density and basal area have been shared by a number of tree species,

---

[1] corresponding author; tfredericksen@ferrum.edu

predominately oaks (*Quercus*) and hickories (*Carya*) (Johnson and Ware 1982). A wide range of other natural and anthropogenic factors including recent ice storms (Stueve et al. 2007) and gypsy moth defoliation (Whitmire and Tobin 2006) also influence the species composition of Appalachian and Piedmont forests in Virginia. In addition, selective logging, deer browsing and the spread of invasive plant species, particularly ailanthus (*Ailanthus altissima*), continue to impact the structure and composition of these forests (Carter and Fredericksen 2007).

This study characterized the species composition of the forests on the property of Ferrum College located on the Upper Piedmont Physiographic Province close to the Blue Ridge Escarpment in Franklin County, Virginia. Data were collected on topographic position and aspect in order to interpret the species composition in relation to topographic variables.

MATERIALS AND METHODS

During 2006 and 2007, 19 permanent plots were established in forested areas of the 700-acre Ferrum College campus (N 36.5°, W 80.1°). Plantation forests were not included in this study. Plots were 20 x 20 m in size and were initially established randomly from a topographical map. After selection of the first eight plots, however, an effort was made to select plot locations based on representation of possible aspect and slope position combinations, with each individual slope position and aspect being represented at least twice, except for northwest slope positions which had n = 1. The stands chosen for this study had not been subjected to recent logging; however, all of the stands had most likely been subjected to light selective logging during the 1970s, mostly for oak species and tulip tree (*Liriodendron tulipifera*). The elevation of the plots ranged from approximately 300-400 m.

Each tree in the plot with diameter at breast height (DBH) of $\geq$ 10cm was identified to species, tagged, and evaluated for crown class, crown condition, stem quality and stem condition. Each plot location was marked and recorded with a GPS mapping system, and aspect and slope position in the topography were recorded. Aspect was measured with a compass and slope position was categorically determined as ridge top, slope shoulder, side slope, toe slope, or valley bottom.

Average DBH, average basal area, average density and species richness were calculated by site according to aspect and also by slope position. Cluster analysis and detrended correspondence analysis (DCA) were used to determine similarities among plots with respect to species composition. Rare species were down-weighted in the analyses because they can exert an effect on ordinations that is disproportionate to their abundance. All ordination analyses were carried out using PC-ORD (Version 5, MJM Software, Gleneden Beach, Oregon). Kruskal-Wallis (K-W) non-parametric tests were conducted to determine if species richness, tree density, or mean tree diameter varied among slope position, aspect, or plot groupings generated by DCA and cluster analysis. Differences were considered statistically significant at $p \leq 0.05$. Analyses were carried out using SYSTAT 10.2 (SYSTAT Software, Inc., San Jose, CA).

RESULTS

The study plots contained 498 trees and 23 tree species. In these plots, the most abundant species were tulip tree, sourwood (*Oxydendrum arboreum*), and red maple (*Acer rubrum*). Red maple was found in every plot and sourwood appeared in all but three of the plots. Tulip tree was found in slightly over half of the plots, but it was abundant in the plots in which it was located. White pine (*Pinus strobus*), and chestnut oak (*Quercus prinus*) were also common in plots of this study.

Some trends were observed with respect to tree density and DBH by the topographic slope classification. In general, tree density increased with ascending topographic position while DBH decreased. Valley plots had a larger mean tree DBH than all other positions (Table 1) and toe slope positions had a significantly higher mean tree DBH than shoulder or ridge top topographic positions. Tree density tended to increase with topographic position (Table 1). Species richness did not differ significantly by topographic position (Table 1). No significant differences were observed for aspect in mean tree diameter, species richness, or tree density (Table 2).

Cluster analysis (Figure 1), revealed three main types of forest tree communities. The attributes of these groups with respect to DBH, tree density, species richness, and

TABLE 1. Number of plots (N), average diameter at breast height (DBH), tree density, species richness, and top three most abundant species by topographic position in forested plots on the property of Ferrum College, Franklin County, VA. Means with the same letter are not significantly different at $p \leq 0.05$. LiTu = *Liriodendron tulipifera*, OxAr = *Oxydendrum arboreum*, AcRu = *Acer rubrum*, PiSt = *Pinus strobus*, QuPr = *Quercus prinus*, QuCo = *Quercus coccinea*, AiAl = *Ailanthus altissima*.

Topographic Position	N	DBH (cm)	Density (#/ha)	Species Richness	Most abundant species
Valley	2	33.7 a	238 b	3.0 a	LiTu, AcRu, AiAl
Toe	4	24.6 b	600 ab	5.5 a	LiTu, AcRu, OxAr
Side	5	22.0 bc	725 a	6.4 a	LiTu, AcRu, OxAr
Shoulder	5	20.0 c	670 ab	5.4 a	QuPr, OxAr, PiSt
Ridge	3	20.0 c	800 a	5.7 a	PiSt, OxAr, QuCo

TABLE 2. Number of plots (N), average diameter at breast height (DBH), tree density, species richness, and top three most abundant species by aspect in forested plots on the property of Ferrum College, Franklin County, VA. Means with the same letter are not significantly different at $p \leq 0.05$. LiTu = *Liriodendron tulipifera*, OxAr = *Oxydendrum arboreum*, AcRu = *Acer rubrum*, PiSt = *Pinus strobus*, QuPr = *Quercus prinus*, AiAl = *Ailanthus altissima*, QuAl = *Quercus alba*.

Aspect	N	DBH (cm)	Density (# / ha)	Species Richness	Most abundant species
NE	7	21.6 a	685 a	6.3 a	LiTu, OxAr, AcRu
NW	1	22.4 a	650 a	4.0 a	OxAr, PiSt, AcRu
SE	3	23.4 a	633 a	6.0 a	AcRu, LiTu, QuAl
SW	3	21.6 a	675 a	5.0 a	PiSt, QuPr, OxAr

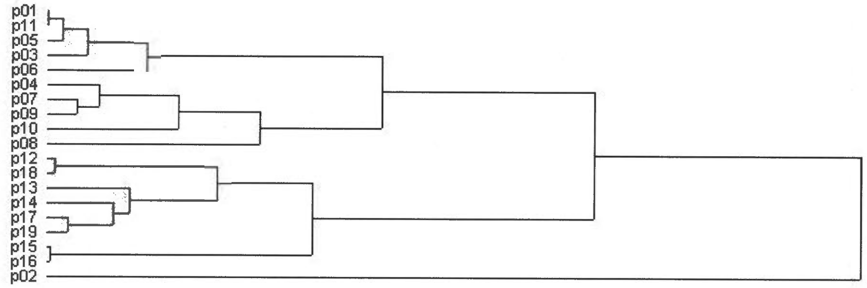

FIGURE 1. Cluster analysis of the plots within forests on the property of Ferrum College, Franklin County, Virginia. The first cluster of plots 1, 11, 5, 3 and 6 were plots with a modal tendency for toeslope positions and northeastern aspects. Cluster two of plots 4, 7, 8, 9 and 10 represented mostly shoulder and sideslope plots. Plots 12-19 made up the third cluster occurring most often on southwestern aspects and ridgetop or shoulder. The main outlier plot identified from the cluster analysis was plot 2, a plot with a very high density (80%) of tuliptree.

TABLE 3. Number of plots (N), average diameter at breast height (DBH), tree density, species richness, highest mode(s) for topographic position (Mode TP), and aspect (Mode aspect), and top three most abundant species by major species groups identified in cluster analysis of forested plots on the property of Ferrum College, Franklin County, VA. Means with the same letter are not significantly different at $p \leq 0.05$. LiTu = *Liriodendron tulipifera*, OxAr = *Oxydendrum arboreum*, AcRu = *Acer rubrum*, PiSt = *Pinus strobus*, QuPr = *Quercus prinus*, AiAl = *Ailanthus altissima*, QuCu = *Quercus coccinea*.

Species Group	N	DBH (cm)	Density (# / ha)	Species Richness	Mode TP	Mode Aspect	Most abundant species
1	5	26.2 a	540 a	5.4 a	Toeslope	NE	LiTu, AcRu, OxAr
2	5	24.4 ab	495 a	6.0 a	Sideslope Shoulder	NE SE	OxAr, AcRu, QuPr
3	8	20.2 b	756 b	5.1 a	Ridgetop Shoulder	SW	PiSt, QuCo, QuPr

most abundant species is summarized in Table 3. According to cluster analysis (Figure 1), the first cluster of plots 1, 11, 5, 3 and 6 were plots with a modal tendency for toe slope positions and northeastern aspects (Table 3). All but one of the plots contained in this cluster had an easterly aspect and the plots in this cluster were dominated by tulip tree and red maple. Cluster two of plots 4, 7, 8, 9 and 10 represented mostly shoulder and side slope plots. These plots were characterized by eastern aspects and relatively high densities of sourwood, red maple, and chestnut oak. Plots 12-19 made up the third cluster. Cluster three occurred most often on southwestern aspects and ridgetop or shoulder positions. Plots in cluster three contained relatively high densities

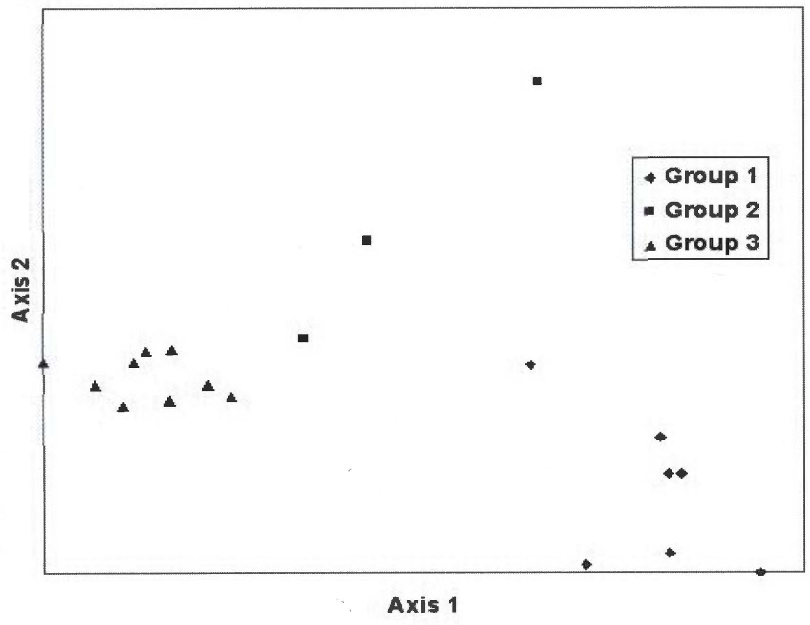

FIGURE 2. Plot of the first two axes of a detrended correspondence analysis (DCA) showing stand scores on plots within forests on the property of Ferrum College, Franklin County, Virginia. DCA results are similar to those of cluster analysis, except that more stands in the intermediate group 2 were placed in the ordination with mesic stands (group 1) and more xeric stands (group 3). The first group included plots 1-6, and 11. The second group included plots 7-9. The third group included plots 10 and 12-19.

of white pine, scarlet oak, and chestnut oak. The main outlier plot identified from the cluster analysis was plot 2, a plot with an 80% relative density of tulip tree.

Detrended correspondence analysis (Figure 2) ordered stands along the principal axis (eigenvalue = 0.70) from moist (lower slope positions and northern and eastern aspects) to drier sites (upper slope positions and southern and western aspects). The second axis had an eigenvalue of 0.20 and, despite down-weighting of rare species, appeared to be driven by appearances of relatively rare species in certain plots. DCA groups stands somewhat similarly to the cluster analysis except that it grouped plots 2, 4, 6, and 11 with the stands in cluster group 1 and included plot 10 with cluster group 3.

DISCUSSION

Topographic factors did not have a definitive influence on species composition in this study, although it was possible to differentiate three different species groupings that appeared to be influenced by topographic position and, to a lesser extent, by aspect. The lack of strong relationships between topographical variables and species composition is possibly attributable to a range of factors including a relatively large number of common species in this study considered to be generalists with respect to environmental variation (e.g., red maple, white oak, sourwood, white pine), a lack of extremes in topographic variation (low variation in altitude and slope percentage), and offsetting effects of topographic variables with respect to moisture and soil fertility (e.g., plots on southwestern slopes on lower slope positions).

DCA and cluster analysis isolated species more common on mesic, toe slope positions, such as tulip tree, red maple, and ailanthus. Tulip tree is one of the most common forest tree species on mesic locations in Franklin County (Carter and Fredericksen 2007), often forming almost pure stands on lower slopes with north and east aspects. Many of these trees probably became established following logging operations early in the 20^{th} century. Ware (1998) did not find an abundance of tuliptree in a study of Blue Ridge forests, but these were probably avoided because that study avoided post-cultivation stands and therefore may have been under represented. Red maple was an abundant canopy and understory species in a study of Blue Ridge Forests by Farrell and Ware (1988). Braun (1950) described red maple as a species with wide ecological amplitude being present on all but the most mesic cove forests and dry ridges. White pine occurred on many plots in this study, but tended to reach its highest abundance on upper slopes, where it often shared dominance with oak species. Scarlet oak was also common in these same stands. White pine and scarlet oak were not common in the studies by Ware (1998) or Farrell and Ware (1988). Chestnut oak was observed mostly on stands on shoulder and ridge top positions in this study.

Aspect did not exert a strong influence in this study, perhaps because of its interaction with topographic position and percent slope. Stephenson (1982) studied exposure-induced differences of north- and south-facing slopes in southwestern Virginia and found that while some species were found on both aspects, most species were more specific to one exposure than the other (Stephenson 1982). In our study plots, red maple and sourwood were often found in plots of both east- and west-facing aspects. Most other trees, however, were found primarily in plots with an eastern or western aspect. Tulip tree and other mesophytic tree species were found primarily in plots with an eastern aspect, while plots with a western aspect had more oak and pine.

Forest composition in this study was invariably affected by light selective logging that took place approximately 30 years ago. Three of the main beneficiaries of this logging included red maple, sourwood, and ailanthus. Red maple is increasing in abundance in eastern forests for a number of reasons including its wide ecological amplitude and the reduced influence of fire (Abrams 1998). Sourwood is a species that normally occupies intermediate positions in the canopy and was not subjected to logging. Ailanthus probably invaded stands after logging, becoming established in gaps where logging equipment exposed mineral soil (Carter and Fredericksen 2007). Finally, the influence of topographical features on species composition may be confounded with historical patterns of forest clearing and farmland abandonment. With their higher soil fertility, valley and toe slope positions were probably cleared earlier and abandoned later than ridge top and shoulder positions. Steeper slopes were probably also abandoned earlier than more moderate slopes.

Although the effects of topographic position were not pronounced in this study, we were able to detect some associations of species groupings with topographic position and aspect in the stands studied in the upper Piedmont. A relationship was also observed for a general increase in tree density with ascending slope position while mean tree DBH decreased. Species richness did not differ significantly by topographic position or aspect.

ACKNOWLEDGMENTS

This study was conducted on the campus of Ferrum College and supported with material and logistic support by the School of Natural Sciences and Mathematics and the Ferrum College Watershed Project. We thank Drs. Bob Pohlad, Carolyn Thomas, and Greg Turner for their guidance and support and JD Fiore, Kyle Carter, and Porter Knight for help with field data collection.

LITERATURE CITED

Abrams, M.D. 1998. The red maple paradox. Bioscience 48:355-364.

Braun, E.L. 1950. Deciduous forests of Eastern North America. The Blakiston Company, Philadelphia, 595pp.

Carter, W.K. and T.S. Fredericksen. 2007. Tree seedling and sapling density and deer browsing incidence on recently-logged and mature non-industrial private forestlands in Virginia, USA. Forest Ecology and Management. 242:671-677.

Copenheaver, C.A., J.M. Matthews, J.M. Showalter, and W.E. Auch. 2006. Forest stand development in the southern Appalachians. Northeastern Naturalist 13:477-494.

Desta, F., J.J. Colbert, J.S. Rentch, and K.W.Gottschalk. 2004. Aspect induced differences in vegetation, soil, and microclimatic characteristics of an Appalachian watershed. Castanea 69:92-108.

Farrell, M.M. and S.Ware. 1988. Forest composition of the southern Blue Ridge escarpment in Virginia. Virginia Journal of Science 39:250-257.

Farrell, M.M. and S.Ware. 1991. Edaphic factors and forest vegetation in the Piedmont of Virginia. Bulletin of the Torrey Botanical Club. 118:161-169.

Harrison, E.A., B.M. McIntyre, and R.D. Dueser. 1989. Community dynamics and topographic controls on forest pattern in Shenandoah National Park, Virginia. Bulletin of the Torrey Botanical Club 116:1-14.

Johnson, G.G. and S. Ware. 1982. Post-chestnut forests in the central Blue Ridge of Virginia. Castanea 47:329-243.

Stephenson, S. 1982. Exposure-induced differences in the vegetation, soils, and microclimate of north- and south-facing slopes in southwestern Virginia. Virginia Journal of Science 33:36-50.

Stueve, K.M., C.W. Lafon, and R.E. Isaacs. 2007. Spatial patterns of ice storm disturbance on a forested landscape in the Appalachian Mountains, Virginia. Area 39:20-30.

Ware, S.A. 1998. Hardwood Forests of Virginia's Southern Blue Ridge: A Second Look. Virginia Journal of Science 49:3-9.

Whitmire, S.L. and P.C. Tobin. 2006. Persistence of invading gypsy moth populations in the United States. Oecologia 147:230-237.