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1. Please substitute the attached Figure 2 for the one in the report.

2. Please substitute the attached Table 2 for the one in the report.

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# Understory Density Characteristics in Several Midlatitude Temperate Forests

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# Preface

This report was prepared under Work Item No. 0060K7, "Vegetation/Soil Modeling," sponsored by Headquarters, U.S. Army Corps of Engineers. This work was conducted under Army RDT&E Management Structure No. 62278485500.

This research was conducted during the period February 2001 through September 2002 by Dr. Paul F. Krause and Messrs. Harry B. Puffenberger and Brian J. Graff, Information Generation and Management Branch, and Christopher D. Gard, Data Representation Branch, Topographic Research Division, Topographic Engineering Center (TEC), Alexandria, VA, U.S. Army Engineer Research and Development Center (ERDC). The work was performed under the supervision of Dr. Kevin R. Slocum, Team Leader, Information Generation and Management Branch; Ms. Debra L. Kabinier, Branch Chief, Information Generation and Management Branch; and Mr. William Z. Clark, Jr., Chief, Topographic Research Division.

Mr. Robert W. Burkhardt was Director and Mr. Laslo Greczy was Deputy Director of the TEC at the time of report publication.

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At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

# 1 Introduction

## Background

Classical military terrain analysis typically includes an interpretation and evaluation of numerous biophysical and geophysical characteristics of the surface of the earth within some specific area of interest. Geophysical elements include surface materials (including both soils and surficial geology), surface configuration (i.e., slope and aspect), surface drainage (i.e., landform class), and water resources. A primary biophysical parameter is a detailed description of the unique vegetation cover types. The interaction and spatial dependencies of adjacent or overlapping geophysical and biophysical parameters can result in highly complex terrain, potentially requiring extensive reconnaissance to define and delineate accurately and precisely. Remotely sensed data sources offer a most cost-effective method for large-area classification of most geophysical elements. However, identifying and delineating physical phenomena that are subordinate to (i.e., beneath) taller and wider dominant feature classes are difficult in airborne and space imagery acquired from overhead. Subordinate features and their attributes, such as understory features beneath a forest canopy, may be unattainable. Even radar and lidar, which have some canopy penetration capability, have problems discerning and measuring the understory constituents.

Terrain analysis database specifications list desired "overlay" information for a variety of geophysical parameters (Defense Mapping Agency (DMA) 1982). There are several critical vegetation structural and compositional variables as well:

- Vegetation type.
- Canopy closure percentage.
- Tree spacing.
- Vegetation height.
- Vegetation roughness factors.
- Tree stem diameter.
- Understory density.

Each of these vegetation characteristics is identified as a critical terrain element to be delineated onto hard-copy and digital map overlays. Each overlay is the product of some level of detailed manual interpretation of one or more remotely sensed images. The quality of the overlays relies on the interpreter's ability to identify the dominant landscape theme (e.g., forest type, shrub community, grass species association) accurately and then to infer the subordinate landscape themes (e.g., understory vegetation, soil conditions, water class) accurately.

This research effort examines the empirical relationship between (a) species composition and physical structure of the dominant vegetation layer and (b) density of the subordinate (i.e., understory) vegetation layers. Current military terrain analysis methods employ subjective procedures for estimating the nature and extent of understory vegetation strata. Tactical database specifications assign understory vegetation density estimates to only two possible classes: (a) greater than 50 percent understory density, and (b) less than 50 percent density or undetermined. These extremely broad class definitions provide only limited input to the various tactical terrain models, including cross-country mobility, cover and concealment, line-of-sight, and bivouac sights. Furthermore, the characteristic of "50 percent understory density" can be interpreted in a variety of ways. It does not represent a truly empirical measure of the biomass of woody and herbaceous vegetation below the dominant woody overstory. Figures 1a and 1b illustrate the wide variety of understory densities that are encountered in typical midlatitude forest settings. Therefore, there is a need to improve on the definitions of understory and understory density relevant to tactical military terrain database generation protocols, and enhance the analyst's ability to estimate understory vegetation physical and compositional characteristics accurately and precisely through the interpretation of the dominant overstory characteristics.

## Objectives

The ability to observe, record, and quantify dominant vegetation features over large areas has been developed and refined over the last 60 years following the widespread use of both large- and small-scale aerial photography and imagery. In the last 30 years, digital technologies have been employed to create vegetation type maps. However, the ability to observe understory vegetation directly remains a predictive procedure for typical passive, optical remote sensing devices. Some applications with active sensors, such as airborne radar and lidar systems, have attempted to quantify understory vegetation densities directly with marginal accuracy (Caetano et al. 1997).

Therefore, the purpose of this project is to develop some preliminary predictive relationships between forest overstory characteristics and forest understory densities. The specific objectives include the following:

*a.* Development of a field sampling strategy that ensures accurate and precise quantification of both forest overstory and woody understory species composition and vertical structure.

*b.* Examination of the understory in terms of structural patterns.

*c.* Generation of predictive relationships using forest overstory parameters as the independent variables and woody understory plant density as the dependent variable.

a. Sparse understory: ~1,000 understory plants $ha^{-1}$

b. Dense understory: ~10,000 understory plants $ha^{-1}$

Figure 1. Variety of understory densities encountered in typical midlatitude forest settings

## Scope of Study

The study of the relative quantities of vegetation biomass within multilayered or multistoried forest types has been applied to a wide variety of ecological arenas. Examples of studies that have investigated the differences in the horizontal distributions of the vertically arranged composition and structure of multilayered forest canopies include wildlife habitat evaluations, forest succession research, and vertical species diversity studies.

The characteristics that define each individual layer in a multitiered forest canopy differ drastically from one forest type to another. Past site disturbances, whether natural (e.g., fire, flood, storm event) or anthropogenic (land clearing, controlled burn, pollution impacts), likely play the greatest role in determining the current forest stand dynamic conditions. After the impacts from disturbance, local and regional landscape characteristics typically control the number of species within a specific forest type and their vertical placement in the perennial vegetated canopy. Some of the site-specific factors associated with landform that directly influence forest understory development include climate, landform position (e.g., slope and aspect), and soil moisture.

This study collected overstory and understory data within midlatitude, temperate forest ecosystems. The sample sites have been impacted by man-made disturbances for roughly 350 years. Two of the study sites, however, show little anthropogenic impacts over the last 250-300 years. The forests sampled in the study exhibited mixed deciduous, deciduous/coniferous, or pure coniferous species composition. Stand structures included both uneven-aged and even-aged canopies. Uneven-aged canopies are multilayered and include distinct dominant stems, a layer of codominant stems, and one or more layers of intermediate and suppressed stems. The understory layers ranged from a few widely scattered plants to fairly dense stands of seedlings, saplings, and woody shrubs. The pure pine plantations that were examined were unmanaged; hence the understory density of these sites was quite substantial.

This work builds upon the research described in Krause, Campbell, and Puffenberger (2001) (hereafter KCP01). Overstory and understory data were collected at fifty-six 10-m-radius circular plots, and predictive models to estimate understory density were generated. In this current research, the authors utilize linear forestry transects to reexamine the overstory and understory relationships, and examine the structure of the understory in terms of species composition, diversity, and density characteristics. Ancillary variables such as slope, soil and moisture are also analyzed in regard to their relationship to understory density and structure.

# 2 Methodology

## Field Data Collection Sites

Sample sites were selected based on prior forest sampling knowledge and experience within and around central Virginia. While an attempt was made to select transect locations randomly, consideration was given to ease of access. In addition, an effort was made to obtain samples from a wide variety of forest types (young and old-age stands, variable species composition, etc.).

The field data collection sites were located in northern and north-central Virginia on the eastern fringes of the Piedmont and Coastal Plain boundary. The topography of the areas generally consists of flat fields to gently rolling slopes. Local relief is generally less than 30 m (100 ft). In several data collect areas, the landscape was more dissected as streams cut through forested areas. Soils of the region are generally Ultisols, largely restricted to the southeastern quarter of the United States. Ultisols are typically reddish and generally have a distinctive subsurface clay accumulation. The soil is acidic, fairly infertile, and is the most weathered of all soils in the conterminous United States (McKnight 1990).

Thirty model-building transects (T) and four validation transects (V) were conducted at six separate locations in central Virginia between February 2001 and September 2002 (Figure 2). A description of the transect locations, respective number of transects at each location, and transect designations are as follows:

*a.* *Fort A.P. Hill, Bowling Green, Virginia.* Fort A.P. Hill is a U.S. Army training installation located approximately 24-32 km (15-20 miles) south of Fredericksburg, VA. The topography is generally flat, with numerous bottomlands and marshy areas. Locations on the fort present a more dissected landscape where creeks cut through forested areas [21 transects: T1-T6, T8, T10-T13, T17-T26, V1-V4].

*b.* *Caledon Natural Area, King George, Virginia.* This location is a special area set aside by the State of Virginia and managed by Virginia's Department of Conservation and Recreation. It is located approximately 40 km (25 miles) east of Fredericksburg, VA. The land, donated by a wealthy family, consists of forested hills and wetlands adjacent to the Potomac River. The forests on the property are described as second-growth stands [1 transect: T7].

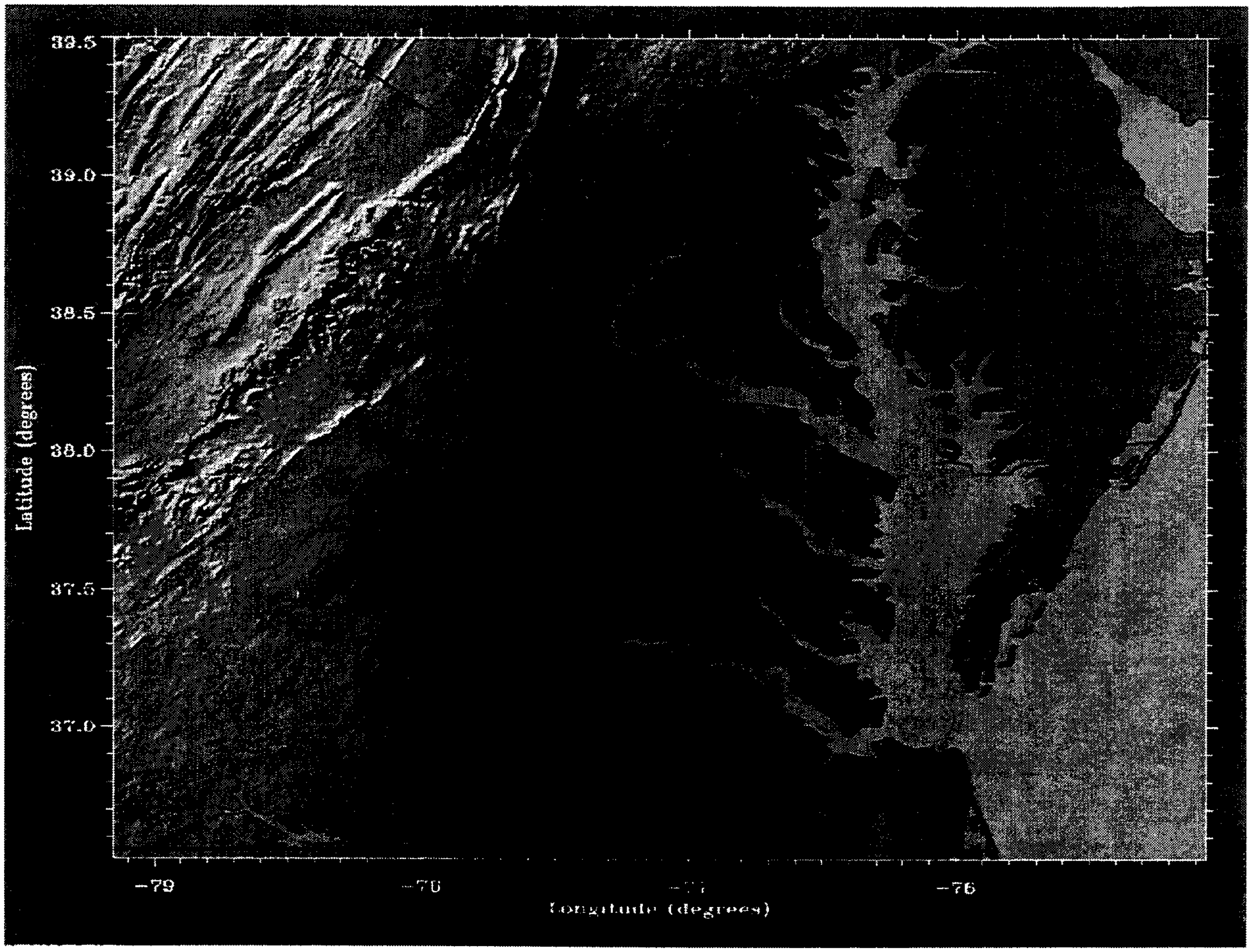



Figure 2. Data collection sites (Copyright 1995 by Ray Sterner, Applied Physics Laboratory, The Johns Hopkins University. Map used with permission. Available at http://fermi.jhuapl.edu/states/

c. *Montpelier.* Montpelier is located approximately 64 km (40 miles) west-southwest of Fredericksburg, VA. It is the former estate of President James Madison, and the grounds are managed by an historical foundation. The topography is generally rolling. Numerous areas on the estate contain old-growth specimens in what could be considered a climax forest setting [2 transects: T15, T16].

d. *Fredericksburg Battlefield.* This battlefield, located about a mile from downtown Fredericksburg, VA, is maintained by the National Park Service. The topography is flat to gently rolling. Pre-Civil War photographs of this site show hardly any woody vegetation and dominance by agricultural fields [1 transect: T9].

e. *Spotsylvania Courthouse Battlefield.* This site is located about 16 km (10 miles) southwest of Fredericksburg, VA. The topography is flat to gently rolling. As with the Fredericksburg Battlefield, this area had been agricultural fields during the Civil War. The woody vegetation that existed was cut down during this time for fuel and fortifications. [1 transect: T14].

*f.* *Chancellorsville Battlefield.* This site is located approximately 16 km (10 miles) west of Fredericksburg, VA. The topography is primarily flat. Its history mirrors that of the previous two sites [4 transects: T27-T30].

## Transect Design

Variable-area rectangular transects were established to sample the overstory and understory layers accurately. The length of the transects ranged from 76 to 183 m (250 to 600 ft), with the majority being 91 m (300 ft). The width of the transects was variable, ranging from 6 m (20 ft) in dense forest stands to 18-24 m (60-80 ft) in older growth stands where overstory specimens were farther apart. The data collect team surveyed the area and selected a width that would allow a representative sample of the overstory stems to be measured. Figure 3 shows a sample 12- by 91-m (40- by 300-ft) transect. In KCP01, 10-m-radius circular plots were used. The authors felt that the circular plot method did not show the full extent of the variability in understory density. It was surmised that a straight-line transect would better uncover understory variability characteristics.

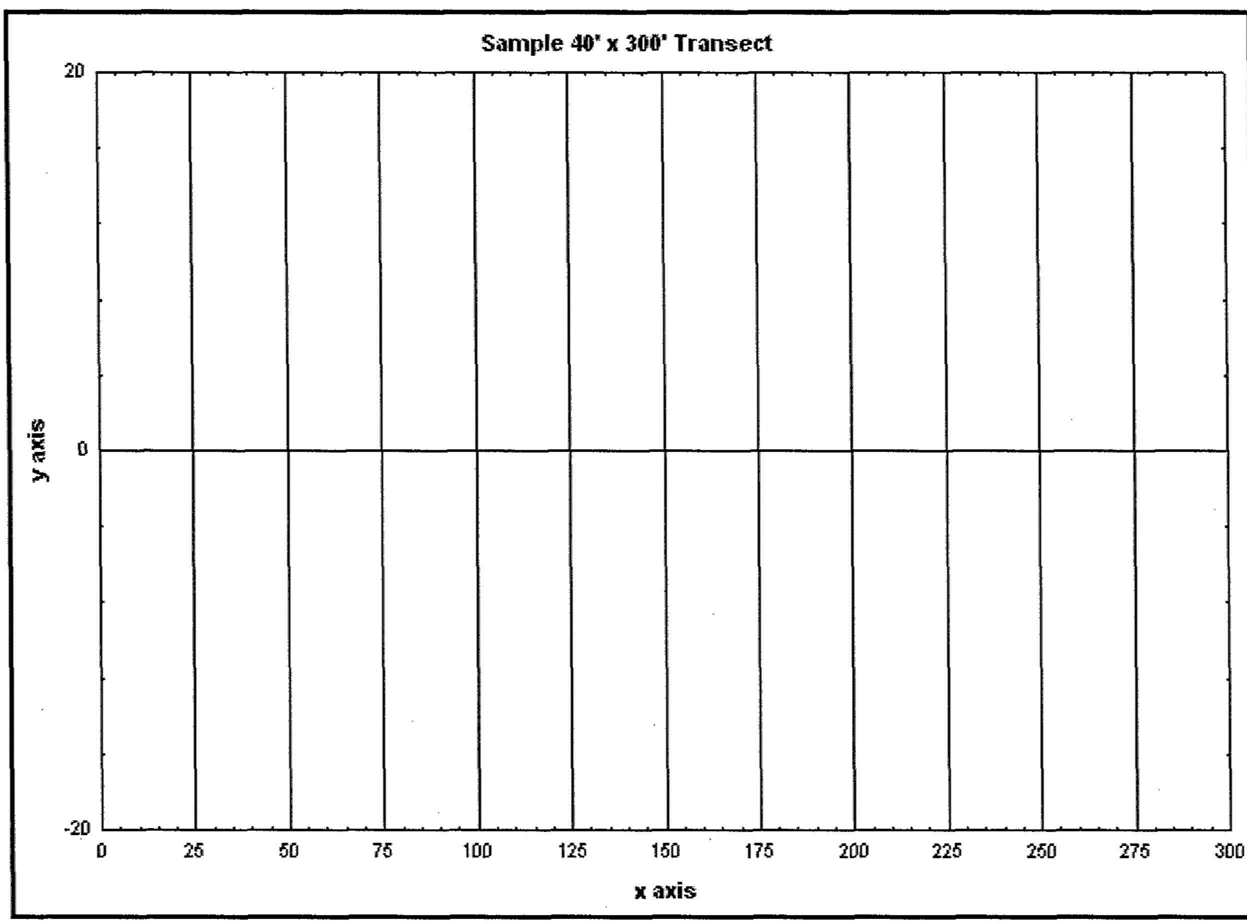



Figure 3. Sample transect

The transect origin was established at a representative location within the selected forest stand. A small wire flag was placed in the ground to mark the origin of the transect. An azimuth was then selected so that the transect ran through a representative stand of trees. A tape was then run along the ground to the end point–usually 91 m (300 ft). Wire flags were placed every 15 m (50 ft) along the transect length. To outline the width of the plot, flagging was then tied to branches or stems every 8 to 15 m (25 to 50 ft) along the transect length at the selected width distance. Coordinates of plot origin and endpoint were obtained using a Trimble GeoExplorer3 (Global Positioning System (GPS) receiver).

## Data Collection Procedures

Working from the origin, all overstory and understory woody plants were measured. The following attributes were recorded for each overstory tree using standard measurement techniques (Avery and Burkhart 1994):

- Distance along the transect (x-axis), ft.
- Offset distance from the transect (y-axis), ft.
- Species.
- Diameter at breast height (d.b.h.), in.
- Height, ft.
- Mean crown diameter, ft.

Overstory individuals were defined as all woody stems with a d.b.h. ≥4 in. (~10 cm). The d.b.h. measurements were collected using a diameter tape. Trunk diameter was consistently measured at approximately 1.37 m (4.5 ft) above the ground to the nearest 2.54 mm (0.1 in.). Tree height was measured using a clinometer. Mean crown diameter required two measurements, one representing the major crown axis and the other the minor crown axis. Crown axes were determined by estimating the drip line of the crown. These values were then summed and divided by 2 to obtain an average crown diameter.

For the purpose of this study, understory plants were defined as all woody individuals with d.b.h. less than ~100 mm (4 in.) and total height ≥ ~1.8 m (~6 ft). A value of 1.8 m (6 ft) was selected as a plant of this height would impede the vision of an individual standing on the forest floor. Using these criteria, measured understory specimens consisted of saplings and taller shrubs. Intermediate and suppressed trees were also considered to be part of the understory as they cannot be seen by airborne sensors. Species, d.b.h., and x-, y-location were measured and recorded for all understory plants. In KCP01, all individual stems were measured. Therefore, a woody understory shrub possessing six individual stems was counted as six plants. For this report, the same shrub is counted as a single plant (i.e., all plants were given equal weight regardless of number of stems). Standing dead trees (termed snags), dead shrubs, and dead saplings were also counted as long as they met the ≥ ~6-ft height criterion.

## Ancillary Information

Plant material that was < ~1.8 m (~6 ft) in total height consisted of tree seedlings, small shrubs, and the herbaceous layer (grasses, forbs, and ferns). No direct measurements of this vegetation stratum were recorded. However, information on species and relative density was noted in the plot logs.

Other ancillary transect attributes recorded at each plot location included the following:

- Slope, percent.
- Aspect, degrees.
- General topography.
- General soil description.
- Surface drainage.
- Deadfall.
- General forest health.

## Defining the Overstory Canopy

Canopy class describes the vertical position of each overstory crown with respect to the surrounding individuals. Definitions of each of the following four crown canopy classes are provided by Smith (1962):

- *Dominant:* Trees with crowns extending above the general level of the crown cover and receiving full light from above and partially from the side; larger than average trees in the stand, and with crowns well developed but possibly somewhat crowded on the sides.
- *Codominant:* Trees with crowns forming the general level of the crown cover and receiving full light from above but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.
- *Intermediate:* Trees shorter than the dominant and codominant with crowns pushing into the crown cover; receiving little light from above and none from the sides; usually with small crowns considerably crowded on the sides.
- *Suppressed:* Also known as overtopped, these trees have crowns that fall entirely below the general level of the crown cover, receiving no direct light either from above or from the sides.

For statistical analysis in this study, the overstory was deemed to be dominant and codominant stems. The crowns of these stems can be readily seen by airborne platforms.

## Preliminary Data Management

All of the acquired transect information was entered into an Excel spreadsheet and imported into Statistica (StatSoft, Inc., 1999) for manipulation and analysis. Summary statistics were then generated for each transect, including means, standard deviations and variances for overstory height, crown diameter, d.b.h., and understory d.b.h. Overstory and understory plant densities were computed and reported as the total number of woody plants per hectare ($ha^{-1}$).[1] Mean minimum distance (MMD) between the dominant and codominant stems was computed for each transect and served as an additional predictor variable. MMD is computed using an extension to ArcView (Environmental Systems Research Institute, Inc. (ESRI), 2000), a Geographic Information System software package. The distance from each tree in the overstory to its nearest neighbor is computed, summed, and averaged. Other measures, including basal area, eight different diversity indices, and dominant species, were computed or derived to provide an ensemble of continuous nominal and ordinal independent variables for exploratory data analysis (EDA).

## Statistical Analysis

Due to the paucity of previous work on this subject found in the literature, the authors had only the findings of KCP01 concerning the relationships between the overstory characteristics and understory plant density. Therefore, all measured variables (plant characteristics and transect attributes) were included in the analysis. The initial approach to uncovering relationships was through employment of EDA techniques. EDA is an approach to data analysis that postpones the usual assumptions about what kind of model the data follow and takes the more direct approach of allowing the data itself to reveal its underlying structure and model. Most EDA techniques are graphical in nature. Graphics provide analysts with open-minded exploration using their intuitive pattern-recognition capabilities. Primary EDA techniques include scatterplots, histograms, residual plots, probability plots, and plots of simple statistics such as means and standard deviations. The data, therefore, are used to suggest the appropriate model(s) that fit the data itself.

The data were also stratified into classes by height, crown, overstory density, and species; and subsequent patterns were examined further. The full data set also underwent such techniques as discriminant analysis, cluster analysis, and factor analysis to look for natural breaks and groupings within the data.

[1] To convert to plants per acre divide by 2.471.

# 3 Results

## Transect Description and Summary Statistics

A total of 7,221 individual woody plants were measured–776 overstory trees and 6,445 understory trees and woody shrubs. Table 1 shows the species found in the overstory and understory and gives both their Latin and common names. Table 2 presents the number of overstory trees by species in each transect. Of the 21 different species encountered in the overstory, five species account for slightly over 75 percent of all overstory trees measured: white oak (*Quercus alba*), black oak (*Quercus velutina*), yellow-poplar (*liriodendron tulipifera*), loblolly pine (*Pinus taeda*), and Virginia pine (*Pinus virginiana*). *Q. alba* is found in 28 of 30 transects and *Q. velutina* in 24 of the 30 transects.

Table 3 shows the number of understory trees and woody shrubs by species in each transect. Of the 39 different species that were encountered, nine species account for over 75 percent of all measured understory members: American holly (*Ilex opaca*), flowering dogwood (*Cornus florida*), red maple (*Acer rubrum*), highbush blueberry (*Vaccinium corymbosum*), black gum (*Nyssa sylvatica*), white oak (*Q. alba*), mockernut hickory (*Carya tomentosa*), American beech (*Fagus grandifolia*), and sweetgum (*Liquidambar styraciflua*). *C. florida* is found in 29 of 30 transects and *I. opaca* and *C. tomentosa* in 27 of 30 transects.

Table 4 presents the summary statistics for all 30 transects. The transect that covered the most area (2,230 sq m (24,000 sq ft)) was Transect 15 (T15), which was in a mature forest stand at Montpelier. The greatest overstory densities were in two pine plantations: T5 (673 trees $ha^{-1}$) and T6 (723 trees $ha^{-1}$). The smallest overstory densities occurred in T4 (63 trees $ha^{-1}$) and T7 (72 trees $ha^{-1}$). T4 is an approximately 100-year-old mixed-oak stand in the Wildlife Refuge at Fort A.P. Hill, and T7 is in an old, second-growth stand at Caledon Natural Area. The greatest MMD of overstory trees occurred at T9, a white oak stand on Fredericksburg National Military Park, and T16, an old, second-growth stand at Montpelier. The MMDs were 10.5 and 9.6 m (34.4 ft and 31.6 ft), respectively.

The two greatest understory transect densities occurred at T21 (3,653 $ha^{-1}$) and T6 (3,598 $ha^{-1}$). T21 was in an upland forest setting with an inordinate number of holly (*I. opaca*). T6 is an unmanaged pine plantation. The sparsest understory occurred in T7 (951 $ha^{-1}$). T7 is located in the old second-growth stands at Caledon Natural Area.

## Table 1
## Species Composing the Overstory and Understory, Transects 1-30

| Common Name | Latin Name | Local Name(s) | Overstory (O) Understory (U) |
|---|---|---|---|
| American Beech | *Fagus grandifolia* | Beech | O,U |
| American Chestnut | *Castanea dentata* | Chestnut | U |
| American Elm | *Ulmus americana* | White Elm | U |
| American Holly | *Ilex opaca* | Holly, White Holly | O,U |
| American Hornbeam | *Carpinus caroliniana* | Blue-beech, Water-beech | U |
| Bigtooth Aspen | *Populus grandidentata* | Largetooth Aspen, Poplar | O,U |
| Black Cherry | *Prunus serotina* | Wild Cherry | U |
| Black Oak | *Quercus velutina* | Yellow Oak | O,U |
| Black Gum | *Nyssa sylvatica* | Black Tupelo | O,U |
| Chestnut Oak | *Quercus prinus* | Rock Oak | O,U |
| Common Alder | *Alnus serrulata* | Hazel Alder | U |
| Devil's Walking Stick | *Aralia spinosa* | Hercules-club | U |
| Dogwood | *Cornus florida* | Flowering Dogwood | U |
| Downy Serviceberry | *Amelanchier arborea* | Shadbush, June berry | U |
| Eastern Hemlock | *Tsuga canadensis* | Canada Hemlock | O |
| Eastern Hophornbeam | *Ostrya virginiana* | Ironwood | U |
| Eastern Redbud | *Cercis canadensis* | Judas-tree | O,U |
| Eastern Red Cedar | *Juniperis virginiana* | Red Juniper | U |
| Fraser Magnolia | *Magnolia fraseri* | Umbrella-tree | U |
| Highbush Blueberry | *Vaccinium corymbosum* | Unkn. | U |
| Loblolly Pine | *Pinus taeda* | Oldfield Pine | O,U |
| Maple Leaf Viburnum | *Viburnum acerifolium* | Flowering Maple | U |
| Mockernut Hickory | *Carya tomentosa* | White Hickory | O,U |
| Mountain Laurel | *Kalmia latifolia* | Calico-bush, Ivybush | U |
| Northern Red Oak | *Quercus rubra* | Red Oak | O,U |
| Pin Oak | *Quercus palustris* | Swamp Oak | O |
| Post Oak | *Quercus stellata* | Iron Oak | U |
| Red Maple | *Acer rubrum* | Scarlet Maple | O,U |
| River Birch | *Betula nigra* | Red Birch, Black Birch | O,U |
| Sassafras | *Sassafras albidum* | White Sassafras | U |
| Scarlet Oak | *Quercus coccinea* | Red Oak, Black Oak | O,U |
| Sourwood | *Oxydendrum arboreum* | Lily-of-the-valley-tree | U |
| Southern Red Oak | *Quercus falcata* | Spanish Oak | O,U |
| Spicebush | *Lindera benzoin* | Unkn. | U |
| Sweet Pepperbush | *Clethra alnifolia* | Summersweet | U |
| Sweetgum | *Liquidambar styraciflua* | Redgum, Sapgum | O,U |
| Virginia Pine | *Pinus virginiana* | Scrub Pine | O,U |
| White Ash | *Fraxinus americana* | Biltmore Ash | U |
| White Oak | *Quercus alba* | Stave Oak | O,U |
| Willow Oak | *Quercus phellos* | Pin Oak, Peach Oak | O,U |
| Yellow-Poplar | *Liriodendron tulipifera* | Tulip Poplar, Tulip-tree | O,U |

**Table 2**
**Overstory Species Counts**

| Species | Transect | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Tot. | PCT | Cum. PCT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | | |
| White Oak | 13 | 12 | 9 | 4 | 1 | 0 | 5 | 8 | 6 | 1 | 3 | 10 | 18 | 16 | 6 | 0 | 12 | 1 | 10 | 7 | 6 | 1 | 1 | 0 | 1 | 9 | 20 | 1 | 1 | 3 | 178 | 22.94 | 22.94 |
| Black Oak | 9 | 2 | 1 | 8 | 2 | 0 | 2 | 2 | 2 | 4 | 0 | 1 | 4 | 3 | 21 | 2 | 0 | 5 | 3 | 1 | 3 | 3 | 6 | 14 | 8 | 1 | 3 | 0 | 0 | 11 | 120 | 15.46 | 38.40 |
| Yellow-Poplar | 2 | 6 | 1 | 3 | 0 | 0 | 0 | 6 | 1 | 7 | 4 | 4 | 2 | 0 | 13 | 9 | 1 | 2 | 3 | 5 | 1 | 1 | 10 | 5 | 1 | 3 | 0 | 2 | 6 | 18 | 116 | 14.95 | 53.35 |
| Loblolly Pine | 0 | 0 | 10 | 2 | 38 | 44 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 106 | 13.66 | 67.01 |
| Virginia Pine | 0 | 0 | 3 | 1 | 32 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 9 | 0 | 0 | 6 | 1 | 0 | 0 | 0 | 0 | 0 | 66 | 8.51 | 75.52 |
| Southern Red Oak | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 5 | 1 | 1 | 5 | 8 | 1 | 7 | 2 | 4 | 0 | 0 | 0 | 4 | 52 | 6.70 | 82.22 |
| River Birch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 | 15 | 0 | 43 | 5.54 | 87.76 |
| Red Maple | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 13 | 0 | 32 | 4.12 | 91.88 |
| Mockernut Hickory | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 19 | 2.45 | 94.33 |
| Black Gum | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 11 | 1.42 | 95.75 |
| Scarlet Oak | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 8 | 1.03 | 96.78 |
| Chestnut Oak | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0.64 | 97.42 |
| Sweetgum | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 5 | 0.64 | 98.07 |
| Beech | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.52 | 98.58 |
| Northern Red Oak | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0.39 | 98.97 |
| Bigtooth Aspen | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.26 | 99.23 |
| Holly | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.26 | 99.49 |
| Hemlock | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0.13 | 99.62 |
| Pin Oak | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0.13 | 99.74 |
| Redbud | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.13 | 99.87 |
| Willow Oak | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.13 | 100.00 |
| TOTAL | 24 | 23 | 28 | 21 | 76 | 45 | 9 | 17 | 9 | 18 | 20 | 18 | 25 | 22 | 42 | 15 | 21 | 34 | 18 | 17 | 26 | 16 | 23 | 33 | 15 | 18 | 23 | 48 | 39 | 39 | 776 | 100 | |

## Table 3
## Understory Species Counts

| Species | Transect | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Tot. | Pct. | Cum. Pct. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | | |
| American Holly | 62 | 56 | 42 | 45 | 19 | 26 | 16 | 101 | 1 | 29 | 40 | 35 | 24 | 7 | 0 | 0 | 29 | 28 | 59 | 91 | 200 | 216 | 61 | 103 | 106 | 73 | 2 | 1 | 0 | 5 | 1,477 | 22.92 | 22.10 |
| Dogwood | 6 | 12 | 6 | 2 | 0 | 37 | 1 | 15 | 46 | 29 | 21 | 22 | 11 | 47 | 182 | 87 | 6 | 1 | 5 | 10 | 18 | 4 | 21 | 28 | 6 | 22 | 11 | 3 | 3 | 30 | 692 | 10.74 | 32.84 |
| Red Maple | 0 | 0 | 0 | 0 | 71 | 0 | 5 | 0 | 6 | 13 | 17 | 1 | 3 | 0 | 20 | 1 | 3 | 42 | 0 | 0 | 1 | 5 | 9 | 10 | 0 | 0 | 19 | 61 | 165 | 83 | 535 | 8.30 | 41.14 |
| Highbush Blueberry | 12 | 5 | 8 | 13 | 18 | 4 | 1 | 21 | 4 | 0 | 0 | 13 | 21 | 0 | 0 | 0 | 36 | 52 | 42 | 70 | 33 | 57 | 56 | 11 | 15 | 22 | 0 | 0 | 29 | 3 | 546 | 8.47 | 49.61 |
| Black Gum | 6 | 0 | 0 | 3 | 2 | 2 | 41 | 5 | 79 | 6 | 3 | 1 | 0 | 70 | 26 | 14 | 6 | 1 | 1 | 5 | 2 | 54 | 10 | 34 | 2 | 2 | 0 | 22 | 51 | 18 | 466 | 7.23 | 56.84 |
| White Oak | 21 | 17 | 11 | 11 | 7 | 3 | 5 | 6 | 0 | 3 | 3 | 11 | 15 | 0 | 1 | 0 | 15 | 15 | 11 | 14 | 26 | 2 | 0 | 12 | 3 | 9 | 163 | 2 | 2 | 14 | 402 | 6.24 | 63.08 |
| Mockernut Hickory | 3 | 4 | 5 | 1 | 1 | 0 | 0 | 8 | 40 | 6 | 11 | 8 | 6 | 9 | 95 | 130 | 2 | 1 | 14 | 3 | 2 | 3 | 8 | 4 | 0 | 5 | 1 | 1 | 1 | 3 | 375 | 5.82 | 68.90 |
| American Beech | 1 | 9 | 5 | 11 | 22 | 0 | 31 | 3 | 0 | 23 | 70 | 4 | 17 | 14 | 0 | 0 | 2 | 1 | 7 | 1 | 5 | 0 | 0 | 13 | 0 | 0 | 4 | 0 | 3 | 0 | 246 | 3.82 | 72.71 |
| Sweetgum | 1 | 0 | 38 | 12 | 50 | 3 | 4 | 1 | 8 | 5 | 10 | 12 | 6 | 2 | 0 | 0 | 0 | 21 | 11 | 1 | 0 | 3 | 11 | 2 | 0 | 0 | 1 | 11 | 10 | 6 | 229 | 3.55 | 76.27 |
| Yellow-Poplar | 1 | 1 | 13 | 1 | 18 | 26 | 0 | 2 | 3 | 3 | 10 | 4 | 3 | 4 | 20 | 1 | 0 | 5 | 4 | 8 | 0 | 0 | 5 | 5 | 0 | 0 | 5 | 3 | 27 | 46 | 218 | 3.38 | 79.65 |
| Black Oak | 0 | 0 | 0 | 0 | 38 | 0 | 1 | 1 | 7 | 3 | 0 | 0 | 3 | 6 | 7 | 6 | 10 | 7 | 1 | 2 | 13 | 1 | 2 | 10 | 3 | 0 | 9 | 0 | 3 | 25 | 158 | 2.45 | 82.10 |
| Sweet Pepperbush | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 31 | 0 | 0 | 0 | 0 | 49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 155 | 2.40 | 84.50 |
| Mountain Laurel | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 49 | 16 | 0 | 7 | 1 | 0 | 4 | 1 | 0 | 0 | 7 | 0 | 7 | 43 | 147 | 2.28 | 86.79 |
| American Hornbeam | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 38 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 87 | 9 | 5 | 144 | 2.23 | 89.02 |
| Sassafras | 0 | 0 | 0 | 0 | 1 | 8 | 0 | 0 | 26 | 0 | 0 | 1 | 2 | 0 | 10 | 1 | 8 | 7 | 0 | 3 | 1 | 1 | 1 | 0 | 2 | 2 | 13 | 0 | 5 | 14 | 106 | 1.64 | 90.66 |
| Southern Red Oak | 0 | 0 | 2 | 0 | 78 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 4 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 100 | 1.55 | 92.22 |
| Bigtooth Aspen | 0 | 0 | 0 | 0 | 0 | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 88 | 1.37 | 93.58 |
| Virginia Pine | 0 | 1 | 2 | 1 | 30 | 3 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 2 | 1 | 1 | 0 | 6 | 2 | 0 | 0 | 0 | 0 | 0 | 57 | 0.88 | 94.47 |
| Willow Oak | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 22 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 50 | 0.78 | 95.24 |
| Redbud | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 14 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 41 | 0.64 | 95.88 |

*(Continued)*

| Table 3 (Concluded) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Transect | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Species | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | Tot. | Pct. | Cum. Pct. |
| Loblolly Pine | 0 | 0 | 1 | 0 | 11 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 37 | 0.57 | 96.45 |
| River Birch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 10 | 1 | 35 | 0.54 | 97.00 |
| Chestnut Oak | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 18 | 1 | 1 | 0 | 0 | 0 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 0.45 | 97.45 |
| Fraser Magnolia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27 | 0.42 | 97.86 |
| Sourwood | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 18 | 0.28 | 98.14 |
| Maple Leaf Viburnum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0.22 | 98.36 |
| Eastern Red Cedar | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0.14 | 98.50 |
| Serviceberry | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0.12 | 98.62 |
| American Chestnut | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0.11 | 98.73 |
| Devil's Walking Stick | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0.11 | 98.84 |
| Spicebush | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0.11 | 98.95 |
| Hazel Alder | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 5 | 0.08 | 99.03 |
| Scarlet Oak | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.05 | 99.07 |
| Northern Red Oak | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.03 | 99.11 |
| White Ash | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.02 | 99.12 |
| Black Cherry | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.02 | 99.14 |
| American Elm | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.02 | 99.15 |
| Eastern Hophornbeam | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0.02 | 99.17 |
| Post Oak | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.02 | 100 |
| TOTAL | 115 | 105 | 135 | 100 | 378 | 231 | 106 | 177 | 239 | 159 | 191 | 112 | 111 | 171 | 396 | 266 | 288 | 244 | 157 | 219 | 307 | 351 | 268 | 241 | 159 | 143 | 235 | 215 | 329 | 299 | 6,445 | 100 | |

## Table 4
## Transect Specifications

| Variable | Transect | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Transect Dimensions ft | 300 x 20 | 300 x 20 | 300 x 20 | 300 x 20 | 600 x 20 | 350 x 20 | 300 x 40 | 300 x 30 | 300 x 40 | 300 x 40 | 250 x 40 | 300 x 40 | 300 x 40 | 300 x 40 | 300 x 80 |
| Dominant/Codominant Trees $ha^{-1}$ | 90 | 98 | 81 | 63 | 673 | 723 | 72 | 204 | 81 | 180 | 237 | 161 | 233 | 197 | 108 |
| Intermediate/Suppressed Trees $ha^{-1}$ | 117 | 179 | 179 | 170 | 206 | 308 | 278 | 250 | 188 | 224 | 323 | 188 | 251 | 99 | 220 |
| Mean Minimum Distance of Overstory Trees, ft | 17.7 | 15.2 | 17.5 | 16.1 | 8.8 | 8.3 | 31.3 | 14.5 | 34.4 | 17.4 | 15.4 | 17.2 | 15.1 | 17.9 | 18.74 |
| Overstory Mean Height ft | 118.8 | 113.0 | 100.2 | 107.3 | 40.4 | 57.9 | 114.8 | 113.0 | 110.2 | 112.5 | 108.5 | 110.0 | 99.4 | 98.0 | 113.3 |
| Variance of Overstory Height, ft | 121.0 | 225.2 | 81.3 | 121.5 | 100.7 | 16.4 | 168.7 | 117.2 | 62.5 | 98.7 | 268.0 | 35.3 | 86.1 | 163.2 | 208 |
| Overstory Mean Crown Diameter, ft | 38.8 | 31.4 | 23.2 | 38.8 | 15.2 | 13.2 | 41.7 | 39.0 | 34.8 | 31.1 | 27.6 | 32.4 | 29.3 | 34.8 | 45.5 |
| Variance of Overstory Crown Diameter | 121.2 | 120.8 | 36.2 | 99.8 | 25.4 | 16.5 | 24.8 | 160.3 | 44.2 | 118.9 | 188.4 | 81.0 | 46.4 | 104.8 | 302.0 |
| Overstory Mean d.b.h. in. | 18.8 | 16.4 | 14.5 | 18.3 | 8.9 | 9.6 | 21.3 | 19.8 | 22.7 | 18.5 | 16.0 | 17.6 | 13.6 | 17.5 | 25.0 |
| Variance of Overstory Mean d.b.h. | 35.9 | 8.8 | 9.2 | 16.3 | 9.4 | 4.1 | 25.5 | 21.2 | 14.2 | 21.3 | 28.7 | 9.65 | 5.2 | 18.2 | 64.8 |
| Understory Plants $ha^{-1}$ | 2076 | 1880 | 2417 | 1808 | 3391 | 3598 | 951 | 2106 | 2144 | 1426 | 2055 | 1005 | 1014 | 1534 | 1782 |
| Mean Minimum Distance of Understory Plants, ft | 3.2 | 4.53 | 4.11 | 3.58 | 2.1 | 2.1 | 5.14 | 2.63 | 3.48 | 4.16 | 3.64 | 3.65 | 4.37 | 4.47 | 3.68 |
| Overstory Species Count | 4 | 4 | 7 | 7 | 6 | 3 | 3 | 4 | 3 | 8 | 9 | 5 | 4 | 4 | 4 |
| Understory Species Count | 12 | 8 | 12 | 11 | 18 | 16 | 10 | 15 | 12 | 12 | 11 | 11 | 11 | 12 | 14 |

*(Continued)*

**Table 4 (Concluded)**

| Variable | Transect | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| Transect Dimensions, ft | 300 x 60 | 300 x 30 | 300 x 30 | 300 x 30 | 300 x 40 | 300 x 30 | 300 x 40 | 300 x 40 | 300 x 30 | 300 x 30 | 300 x 40 | 300 x 40 | 300 x 30 | 300 x 30 | 300 x 30 |
| Dominant/Codominant Trees $ha^{-1}$ | 96 | 252 | 419 | 214 | 152 | 311 | 144 | 206 | 407 | 179 | 161 | 179 | 586 | 466 | 466 |
| Intermediate/Suppressed Trees $ha^{-1}$ | 221 | 179 | 275 | 298 | 260 | 203 | 466 | 350 | 359 | 395 | 224 | 251 | 287 | 299 | 466 |
| Mean Minimum Distance of Overstory Trees, ft | 31.6 | 12.3 | 10.3 | 16.4 | 18.8 | 14.1 | 16.3 | 16.0 | 10.0 | 17.9 | 17.1 | 18.9 | 8.6 | 8.7 | 10.3 |
| Overstory Mean Height, ft | 114.7 | 72.1 | 66.7 | 109.4 | 112.9 | 94.3 | 93.4 | 101.7 | 84.1 | 107.1 | 102.1 | 78.0 | 57.2 | 50.1 | 59.7 |
| Variance of Overstory Height, ft | 269.5 | 156.4 | 73.4 | 5.6 | 125.2 | 79.7 | 75.7 | 159.2 | 91.6 | 520.0 | 183.1 | 219.5 | 84.9 | 240.5 | 98.0 |
| Overstory Mean Crown Diameter, ft | 44.5 | 26.8 | 20.6 | 33 | 35.4 | 26.1 | 34.8 | 34.7 | 24.1 | 30.5 | 34.4 | 34.2 | 14.1 | 16.4 | 16.9 |
| Variance of Overstory Crown Diameter | 180.3 | 56.3 | 62.7 | 125.5 | 114.7 | 118.4 | 90.3 | 114.1 | 61.8 | 76.9 | 37.8 | 56.4 | 26.5 | 25.0 | 23.0 |
| Overstory Mean d.b.h. in. | 24.9 | 12.9 | 10.7 | 16.0 | 17.7 | 13.5 | 15.5 | 17.5 | 11.6 | 16.1 | 18.2 | 16.7 | 7.3 | 7.4 | 8.2 |
| Variance of Overstory Mean d.b.h. | 68.0 | 11.5 | 10.9 | 11.7 | 13.4 | 19.4 | 17.1 | 20.9 | 9.2 | 24.8 | 18.1 | 11.0 | 6.1 | 6.3 | 5.8 |
| Understory Plants $ha^{-1}$ | 1591 | 3427 | 2904 | 1868 | 1964 | 3653 | 2251 | 2404 | 2868 | 1916 | 1319 | 2108 | 2559 | 3915 | 3558 |
| Mean Minimum Distance of Understory Plants, ft | 4.1 | 2.25 | 2.48 | 3.44 | 2.91 | 2.02 | 2.07 | 2.83 | 2.39 | 2.42 | 2.99 | 3.86 | 2.34 | 2.33 | 2.5 |
| Overstory Species Count | 4 | 7 | 12 | 5 | 6 | 7 | 2 | 8 | 6 | 7 | 5 | 2 | 9 | 7 | 6 |
| Understory Species Count | 14 | 15 | 22 | 12 | 14 | 13 | 19 | 16 | 14 | 11 | 9 | 11 | 11 | 15 | 16 |

The greatest overstory mean height was 36 m (118+ ft) and occurred in T1, an approximately 100-year-old mixed oak site. The shortest overstory mean height (12.3 m (40.4 ft)) was in T5, a 20- to 25-year-old unmanaged pine plantation. The largest mean crown diameters came from the two Montpelier sites: T15 (13.9 m (45.5 ft)) and T16 (13.6 m (44.5 ft)). The largest mean d.b.h. also came from the two Montpelier sites: T15 (0.6 m (25.0 in.)) and T16 (0.63 m (24.9 in)).

The transect with the most overstory species (12) was T18 located on Fort A.P. Hill. This transect ran from a stream floodplain (river birch, maple, sweetgum) to a drier upland forest (white, southern red, and chestnut oaks). Two transects had the fewest number of species in the overstory. Both T22 and T27 had only two species. T22 is an old pine plantation and T27 is a stand of 70 percent white oak and 30 percent black oak at Chancellorsville Battlefield.

The most understory species found, 22, occurred in T18, a transect that ran from a stream floodplain to an upland forest. T5, a 20- to 25-year-old unmanaged pine plantation on Fort A.P. Hill, had 18 different understory species. The least number of different understory species was eight and occurred in T2, an approximately 100-year-old mixed-oak stand in the Wildlife Refuge at Fort A.P. Hill.

## Regression Analysis

To estimate the understory plant density, linear regression was used with understory plant density as the dependent variable. The eight independent predictor variables included the following:

- Overstory stems $ha^{-1}$.
- Mean minimum distance of the overstory stems.
- Overstory mean height.
- Variance of the overstory mean height.
- Overstory mean crown diameter.
- Variance of the overstory mean crown diameter.
- Overstory mean d.b.h.
- Variance of the overstory mean d.b.h.

Initially, both forward and backward multiple linear regression was used with all of the predictor variables. For multiple regression, overstory mean height proved to be the only variable that was statistically significant at the 0.05 level. When considered individually, five of the variables were statistically significant at the 0.05 level. Table 5 shows the regression results for the five variables. The table presents (a) the correlation coefficient $r$, which measures the strength and direction of a linear relationship between the dependent and independent variables; (b) the coefficient of determination $r^2$, which is a measure of the proportion of variability in the dependent variable that is explained by the

**Table 5**
**Regression Results**

| Independent Variable | $r$ | $r^2$ | Equation | Standard Error of the Estimate (SEE) |
|---|---|---|---|---|
| Overstory Mean Height | -0.814 | 0.662 | $y = 4887.0 - 28.487x$ | 470 |
| Overstory Density $ha^{-1}$ | 0.733 | 0.538 | $y = 1409.3 + 3.24x$ | 549 |
| Overstory Mean d.b.h. | -0.727 | 0.529 | $y = 4133.9 - 121.79x$ | 555 |
| Overstory Mean Crown | -0.723 | 0.522 | $y = 4107.9 - 62.292x$ | 558 |
| Mean Minimum Distance | -0.617 | 0.381 | $y = 3740.0 - 76.41x$ | 636 |

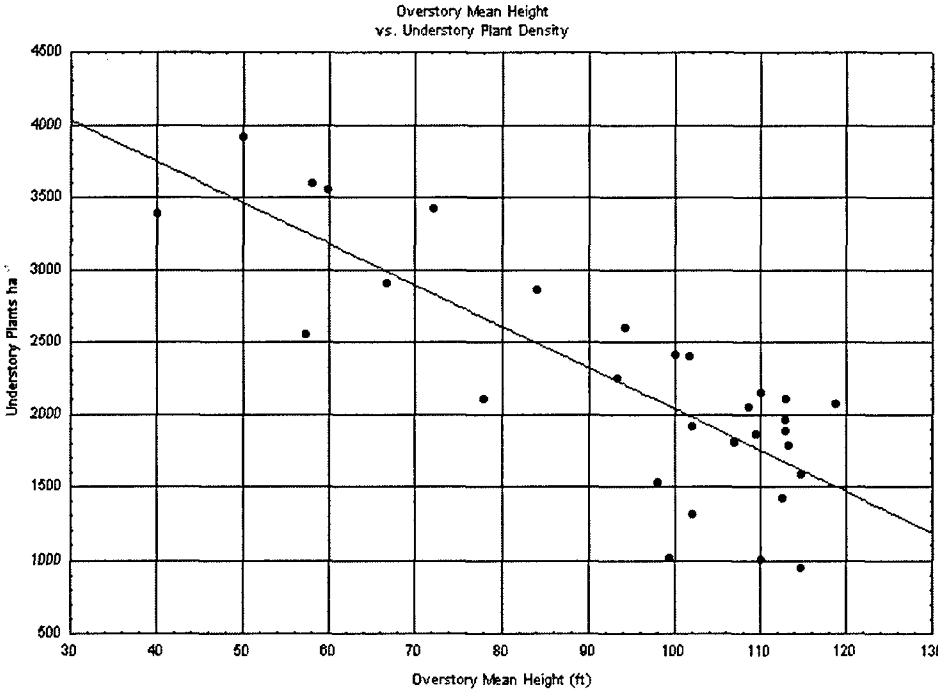
independent (predictor) variable; (c) the regression equation in the form $y = a + bx$, where $y$ is the estimate of the understory density, $a$ is the $y$-intercept, $b$ is the regression coefficient, and $x$ is the independent variable; and (d) the standard error of the estimate (SEE), which is the estimated standard deviation of the residuals around the regression line.

**Overstory mean height has the strongest relationship with the understory plant density.** Its SEE was the smallest (470) and $r^2$ was the greatest–0.662; $p = 0.0000$. Overstory mean height explains slightly over 66 percent of the variability in understory plant density. This is slightly better than the results found in KCP01. In that report, overstory mean crown diameter was the best predictor variable and yielded an SEE of 520 and an $r^2$ of 0.56.

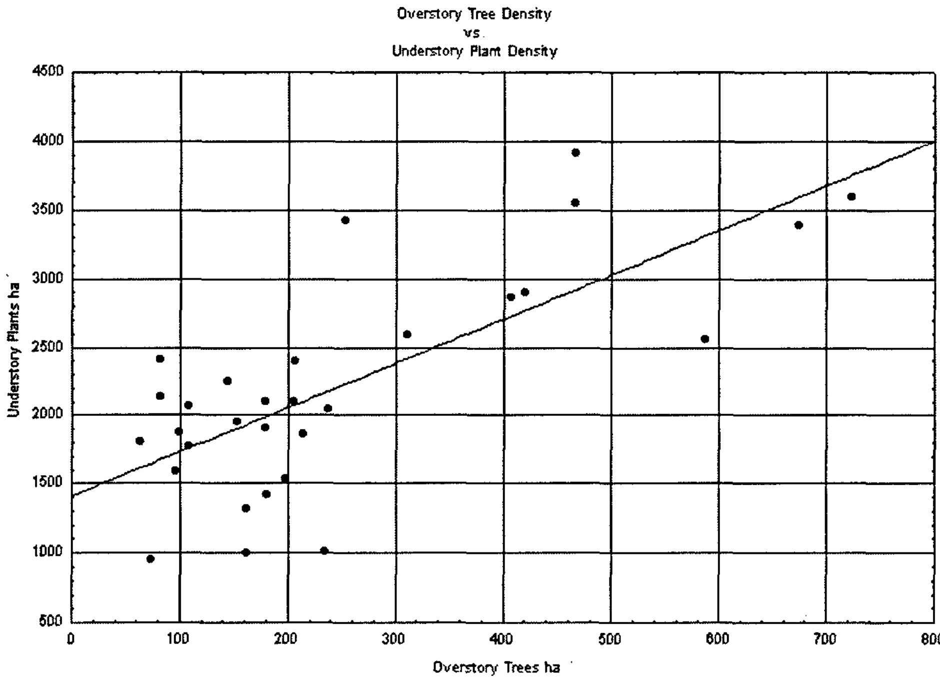
The sign of the correlation coefficient $r$ shows the direction of the relationship. Overstory height, crown diameter, d.b.h., and MMD are all negatively correlated with understory plant density. As these values increase, the understory density decreases. As a forest matures, there is an increasing competition for light, water, and nutrients. Some codominant trees may die, increasing the tree spacing of the overstory. Crowns of the remaining overstory grow to fill in the gaps. Light conditions become such that many of the seedlings and saplings of the overstory cannot survive. Only highly shade-tolerant understory species will be capable of survival. In other words, as the forest grows older there are fewer understory stems. Overstory stem density is positively correlated with understory stem density. There are more understory members in younger forests and fewer understory members in older forests.

Additionally, the same predictor variables were used in stepwise discriminant analysis in conjunction with K-means clustering. This was attempted under the assumption that the created discriminant groups would have similar understory densities. But the results showed that statistically significant groups could not be created. The generated groupings showed much overlap so that discriminant functions would be incapable of assigning any new transect into a correct group with a high degree of confidence.

Figures 4a–4e show the relationship between understory plant density and five of the predictor variables for the 30 transects. They are presented in the order of decreasing correlation.

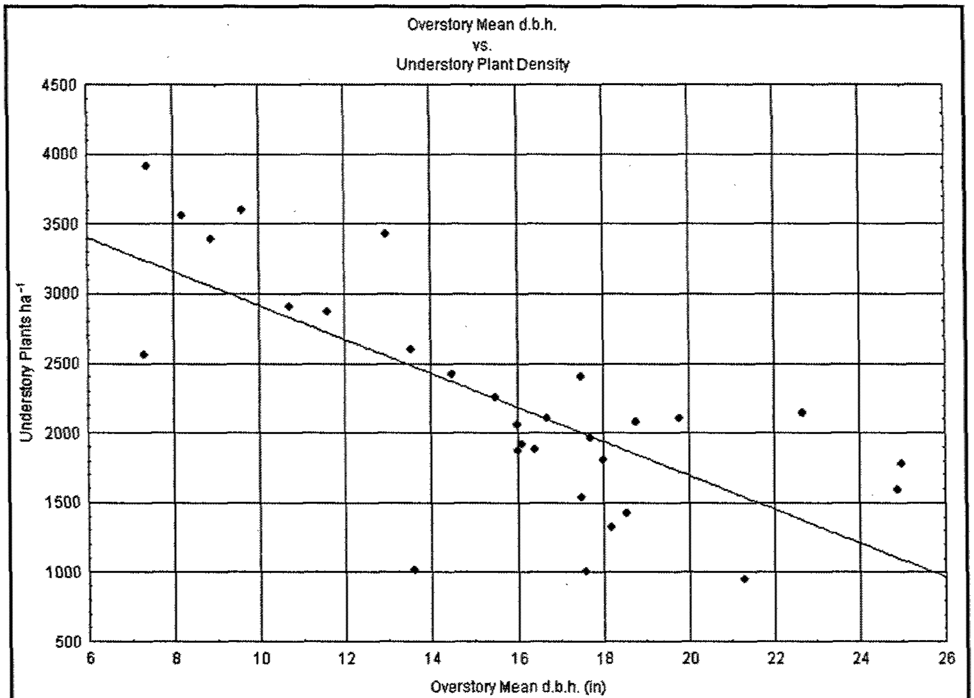



a. Overstory mean height versus understory plant density

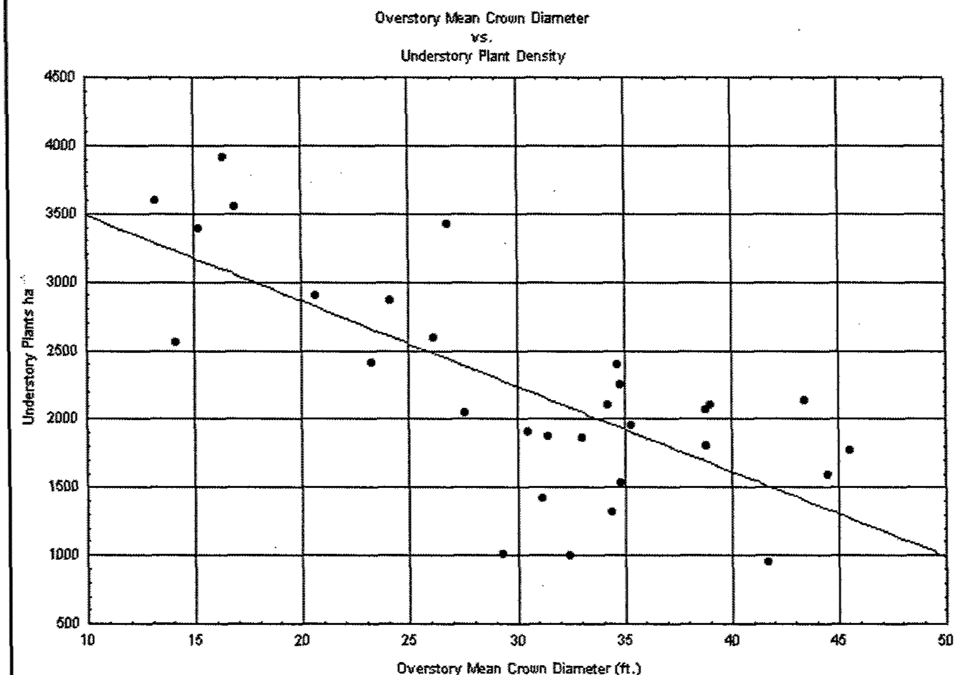



b. Overstory tree density versus understory plant density

Figure 4. Relationship between understory plant density and five of the predictor variables for the 30 transects (Sheet 1 of 3)

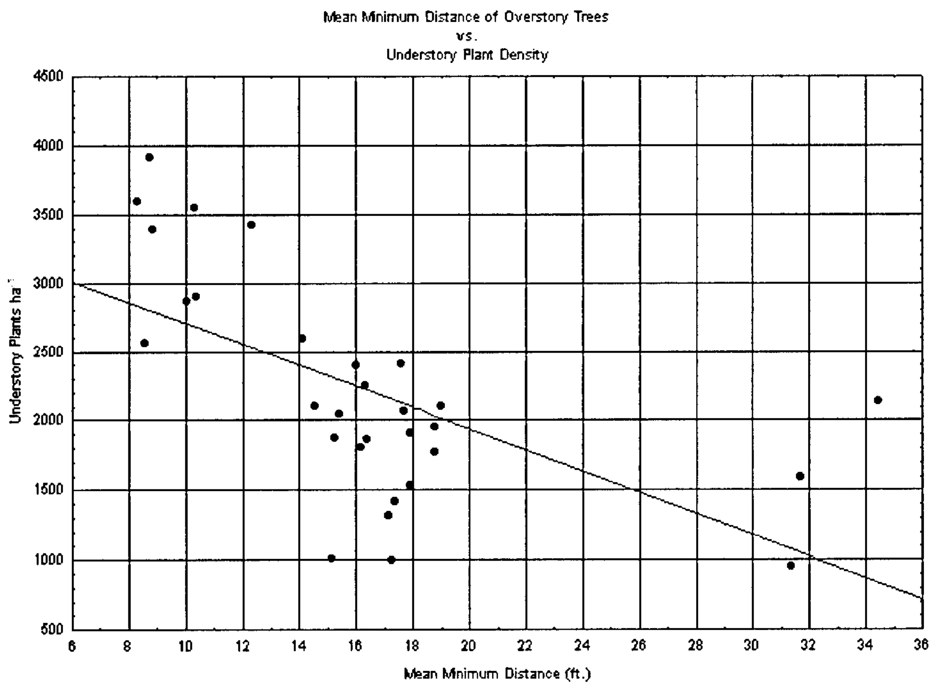



c. Overstory mean d.b.h. versus understory plant density




d. Overstory mean crown diameter versus understory plant density

Figure 4. (Sheet 2 of 3)




e. Overstory mean minimum distance versus understory plant density

Figure 4. (Sheet 3 of 3)

## Validation Transects

In order to test the developed predictive model, a series of validation transects were performed at Fort A.P. Hill. One hundred sets of random northing and easting coordinates were generated for Fort A.P. Hill using the randomization algorithm available at the Web site http://www.random.org. These 100 coordinate pairs were then plotted on a map. Points were then discarded if they fell on, or very close to, man-made objects (roads, parking lots, etc.), on open fields, or near ponds and streams, etc. This paring away yielded 32 candidate sites from the 100 generated pairs. Once at the random transect site, a set of 100 random compass bearings was used to provide a random transect direction. On several occasions, the field data collect team found that the random transect sites showed evidence of disturbance by man. This could not be discerned beforehand from available imagery. These sites were excluded from consideration.

Six validation transects were performed. Data for the overstory consisted of the species and height of the dominant and codominant trees. Overstory height was the best predictor variable based on the regression analysis. Understory information consisted of a tally of the woody plants and shrubs that were ≥ 6.0 ft. Two of the six random validation transects were located in extremely wet areas. When the data from these two transects were run against the model, understory densities were severely underpredicted. This is not surprising, however, inasmuch as the model was developed from transect sites that were, in general, located in drier more upland locations. These two "wetter area" transects were removed from consideration. **The model, therefore, has applicability only to drier sites.** Using the model containing overstory mean height found in Table 5, understory plant density was computed for the four remaining validation transects. The results appear in Table 6. The mean absolute mean error is 220 understory plants ha$^{-1}$. The mean percent error is 8.53.

**Table 6**
**Predictive Model Results**

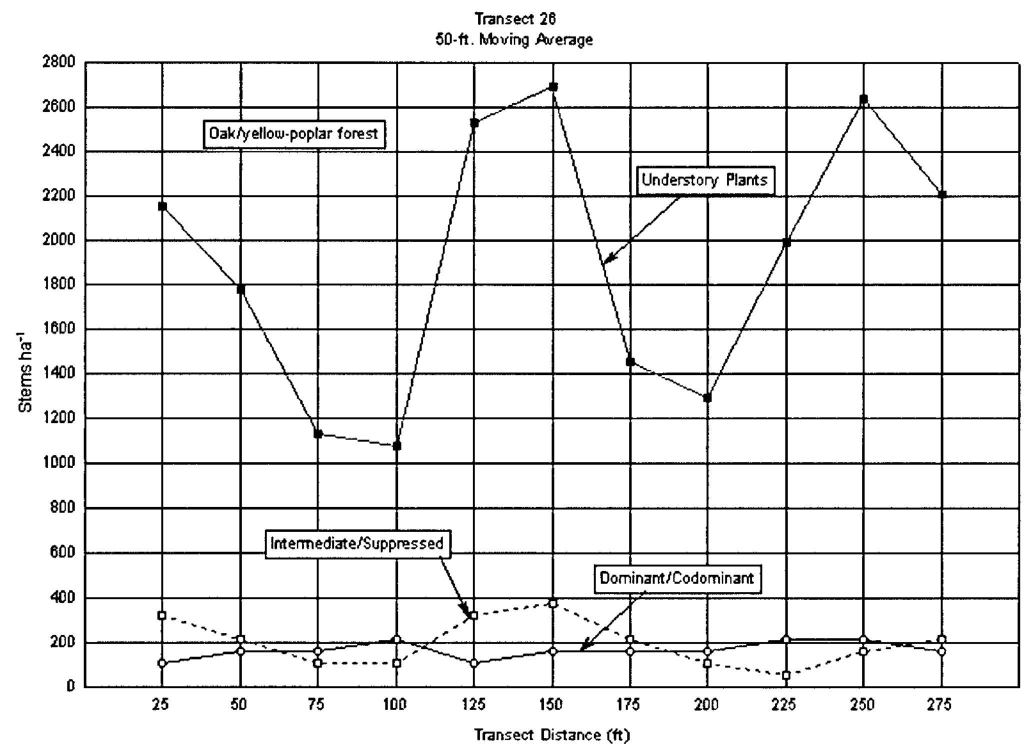
| Validation Transects | Actual Understory Plants ha$^{-1}$ | Predicted Understory Plants ha$^{-1}$ | (Predicted – Actual) |
|---|---|---|---|
| 1 | 2930 | 3026 | 96 |
| 2 | 2476 | 2257 | -219 |
| 3 | 2551 | 2093 | -458 |
| 4 | 2397 | 2502 | 105 |

## Understory Density Characteristics

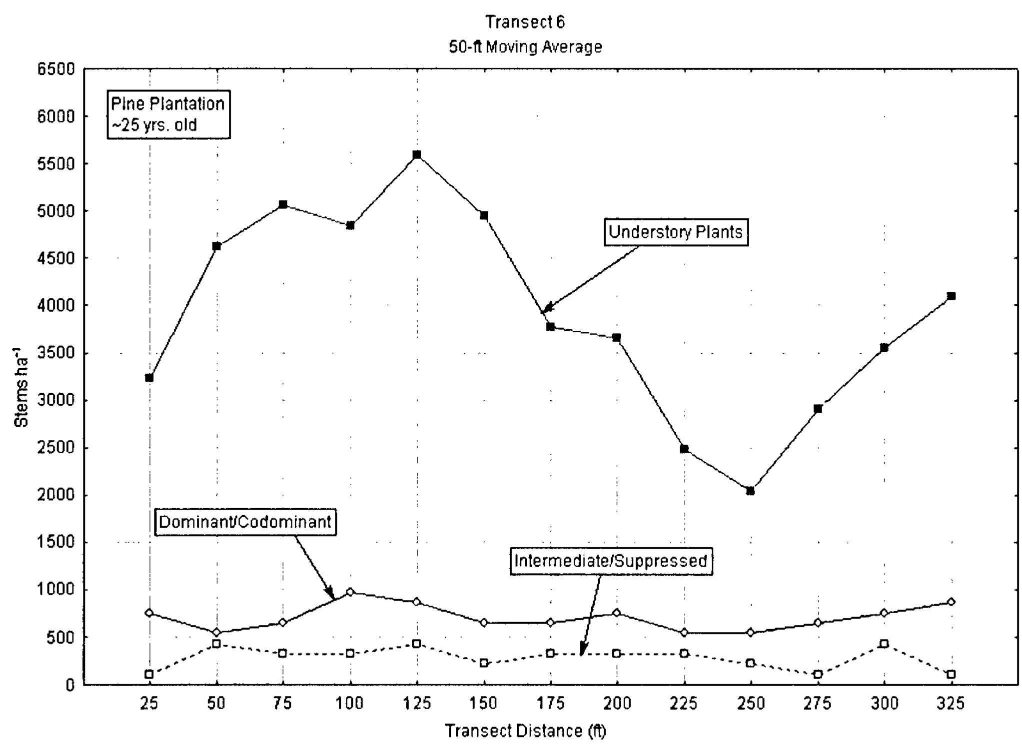
This section focuses on an examination of the understory in terms of its density characteristics. Initially, the transect data were subdivided into small 3- × 3-m (10- × 10-ft) squares. Understory plants were counted and converted into plants ha$^{-1}$. The center x-, y-coordinate of each square was then obtained. Thus, every coordinate pair had a density value. These data were then processed by a kriging algorithm that looked for spatial patterns and spatial dependence. This, however, proved unsuccessful. The algorithm could not find any spatial trends or patterns in the understory density. This method was discarded and others were attempted in its place.

Within the transects the understory plant densities changed dramatically along the main transect axis. Figures 5a-5c are several examples of plant density computed as 15-m (50-ft) moving averages. The examples are from three different forest biomes. Figure 5a represents a typical upland mixed hardwood forest stand. Figure 5b is an approximately 25-year-old loblolly pine plantation, and Figure 5c represents a transition from a wet creek floodplain to a drier upland forest. Vertical relief in Figure 5c is 15 m (50 ft) from creek floodplain to the upland forest. It was readily apparent that the understory plant density varied widely over a short distance. All 30 of the transects mirror these three examples. The understory curves are sinuous and undulating. Curves of the dominant and codominant trees remain rather flat throughout the transects.

While the specific species of understory cannot be predicted, the density of the understory can. The authors noted while collecting the data that the understory stems exhibited "clumpy" pattern dispersal. There existed areas of high understory density and areas with very few understory stems. Using the linear 90-m- (300-ft-) long plots averaged out this clumpy nature. This clumpy nature also did not seem to correlate directly with gaps in the overstory.

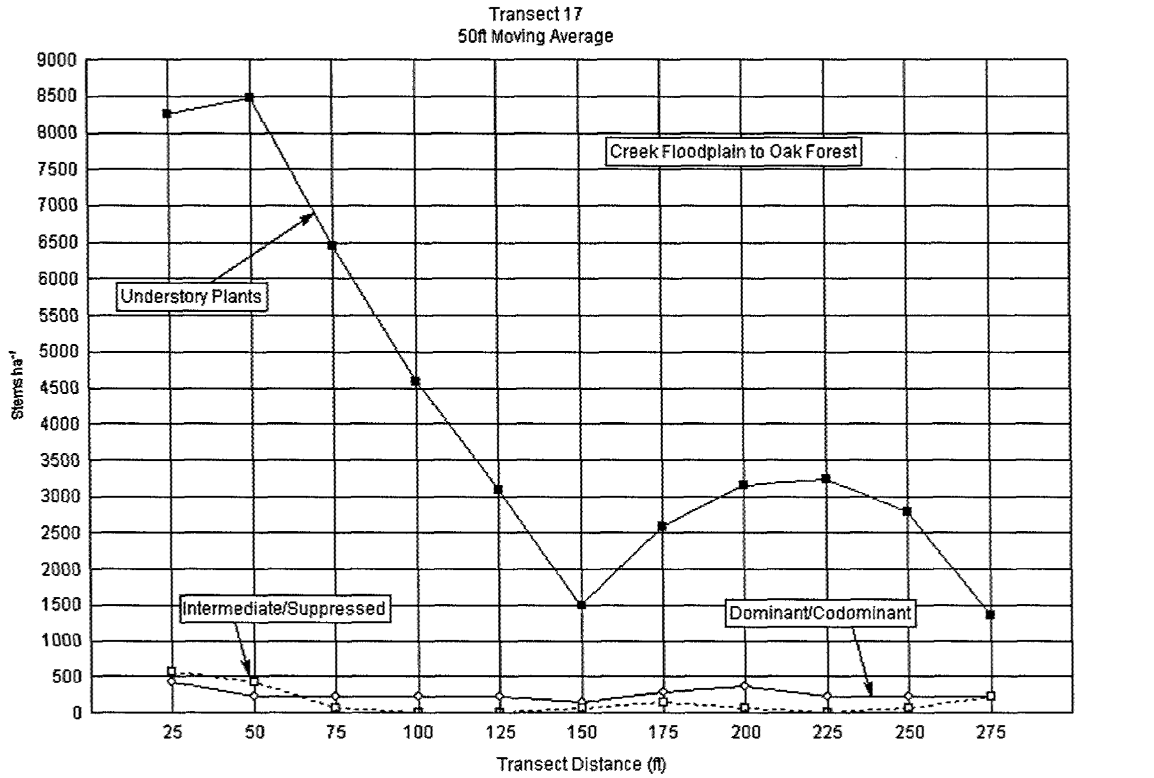



a. Transect 26, typical upland mixed hardwood forest stand




b. Transect 6, an ~25-year-old loblolly pine plantation

Figure 5. Examples of plant density computed as 15-m (50-ft) moving averages from three different forest biomes (Continued)



c. Transect 17, transition from a wet creek floodplain to a drier upland forest

Figure 5. (Concluded)

The transects were next subdivided into consecutive 8-m (25-ft) plots (termed quadrats). The understory plants were then counted for each of these 8-m (25-ft) quadrats and converted to plants $ha^{-1}$. Figure 6 shows the relationship between the understory density of the entire transect and the maximum 8-m (25-ft) quadrat density. A moderately strong positive relationship exists. The SEE is 745 plants $ha^{-1}$ ($r^2 = 0.80, p = 0.0000$).

Figure 7 shows the relationship between the maximum 8-m (25-ft) quadrat density and the range in quadrat densities for the transects. An extremely strong positive correlation exists between these two variables ($r^2 = 0.94; p = 0.0000$; SEE = 398 plants $ha^{-1}$). Thus, if it were eventually possible to estimate the maximum density with a high degree of accuracy, then it would be possible to estimate the full range of densities that would be encountered in a forest stand.

Table 7 presents the results of the equations found in Figures 6 and 7 applied to the validation transects. The actual measured understory density for the entire transect was used in the initial equation appearing in Figure 6. The mean absolute error in estimating the maximum understory quadrat density was 1,045 understory plants $ha^{-1}$. The mean absolute error in predicting the range in quadrat density was 442 understory plants $ha^{-1}$.

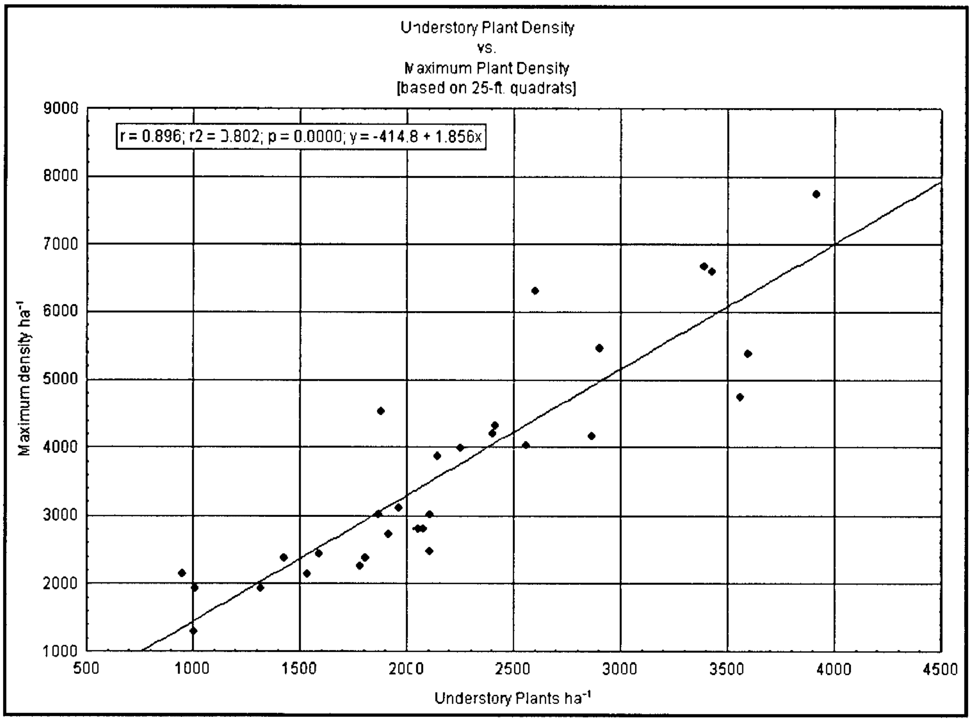



Figure 6. Plant density/maximum density relationship

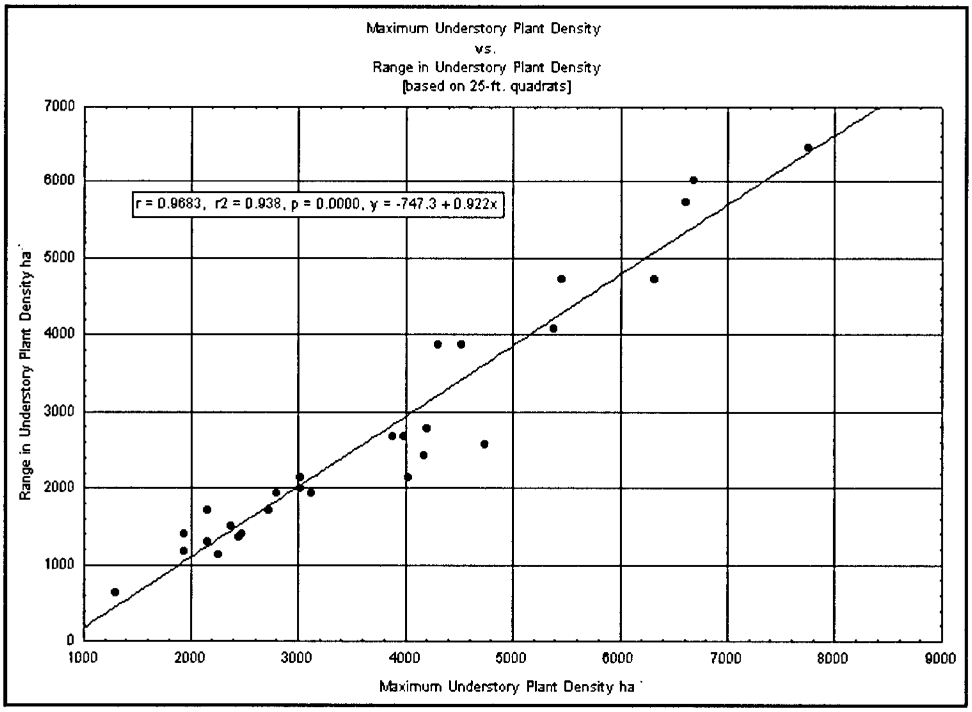



Figure 7. Maximum density/range in density relationship

| Table 7<br>Predicting Quadrat Densities from Actual and Predicted Transect Density | | | | | | |
|---|---|---|---|---|---|---|
| Validation Transect | (a) Maximum Quadrat Density | (b) Predicted Maximum Quadrat Density | (b-a) | (c) Range in Quadrat Density | (d) Predicted Range in Quadrat Density | (d-c) |
| Actual Transect Density | | | | | | |
| 1 | 5884 | 5023 | -801 | 4162 | 4549 | 387 |
| 2 | 5023 | 4177 | -846 | 3731 | 3884 | 153 |
| 3 | 6171 | 4320 | -1941 | 5883 | 4943 | -940 |
| 4 | 3444 | 4034 | 590 | 2152 | 2421 | 289 |
| Predicted Transect Density | | | | | | |
| 1 | 5884 | 5198 | -686 | 4162 | 4046 | -116 |
| 2 | 5023 | 3772 | -1251 | 3731 | 2731 | -1000 |
| 3 | 6171 | 3468 | -2703 | 5883 | 2450 | -3433 |
| 4 | 3444 | 4226 | 782 | 2152 | 3149 | 997 |

Table 7 uses the predicted understory density from Table 6 as computed from the equation appearing in Figure 6 as the initial density value for computation of the maximum quadrat density. The predicted maximum quadrat density is then used to predict the range in quadrat density. The absolute mean error in estimating the maximum understory quadrat density was 1,355 understory plants $ha^{-1}$. The mean absolute error in predicting the range in quadrat density was 1,387 understory plants $ha^{-1}$.

Using the predicted transect density instead of the actual increased the error in estimating the maximum quadrat density by 310 understory plants $ha^{-1}$. There was a threefold increase in mean absolute error when estimating the range in density using the estimated maximum quadrat density–442 to 1,387. It is obvious that the initial estimation of the overall transect density is too gross to predict the internal transect density structure adequately. By themselves, the models perform reasonably well. When generating estimations and then using these estimations as independent variables to predict additional variables, the estimates can be considered gross at best.

# Observations of Field Data Collect Team

During the collection of data at the 30 model-building forest transect sites, the field data collect team observed and recorded many additional attributes of the transect sites. The following generalizations are based on these observations:

- *Slope and aspect.* These variables appeared to have little correlation to understory plant densities. Both high and low densities of woody as well as herbaceous plant material were found on steeper slopes as well as on flatter areas and also both north- and south-facing slopes. In the western United States, relief is great enough that it has impact on which species of plants can exist at a particular location. In the study areas for this report, relief plays a fairly insignificant role. Many examples of tree species that are affected by slope and aspect situations can be found in Burns and Honkala (1990).

- *Soil.* Soils were measured every 15 m (50 ft) along the main transect axis. The soils at the Fort A.P. Hill are generally sandy, silty loams. The humus layer ranged from nonexistent to approximately 100 mm (4 in). When it did exist, the A horizon was sandy and silty and gray. Lower levels were generally clay or sandy clay and tan. Soils appeared to be fairly uniform throughout the full length of the transects and did not appear to play a significant role in the variation of understory density.
- *Canopy closure.* This variable appeared to have little or no effect on understory plant densities. High understory densities could be found in stands with 95-100 percent canopy closure; conversely, sparse understory counts could be found in areas with fairly open overstory canopies. Since the sun is never at zenith at the latitudes where the transects were conducted (approximately 38.5°N), perhaps what is more important is the amount of crown closure to the southeast through southwest of the transect. (Note: At 38.5°N the maximum elevation of the sun on the summer solstice is ~75°.)
- *Soil moisture.* This variable appeared to be highly correlated with understory plant density. In areas that are permanently or semipermanently moist to damp year-round, understory plant abundances were greater than at the drier sites. The areas in which the transects were performed have been under what could be termed drought conditions since 2001. Yet, there were several transect sites at which the soils were moist and the vegetation was thick and lush, showing no signs of drought-induced stress.
- *Seedlings, herbaceous shrubs, and ground cover.* Seedlings of the dominant and codominant species were more numerous in younger growth stands. As the stands mature, the amount of available light may reach such low levels that most of the seedlings and saplings cannot survive. Some of the more common plants and shrubs include ferns (many species), lowbush blueberry (*Vaccinium augustifolium*), southern running-pine (*Lycopodium digitatum*), poison ivy (*Toxicodendron (rhus) radicans*), roundleaf greenbrier (*Smilax rotundifolia*), virginia creeper (*Parthenocissus quinquefolia*), mosses (many species), and numerous mushrooms and wildflowers.
- *Man-made disturbances.* All of the areas visited, with the exception of Montpelier, Caledon Natural Area, and selected portions of the Fredericksburg and Spotsylvania Battlefields, have been disturbed by man within the last 100 or so years. Anthropogenic disturbance is quite pronounced at Fort A.P. Hill. Training has been conducted on the fort for approximately 50 years. In addition, commercial lumbering companies plant and harvest loblolly pines on the base. The disturbances can be quite noticeable (foxholes, berms, revetments, and understory thinning) or quite subtle. During exploratory data analysis, three sites at Fort A.P. Hill were consistently outliers in scatterplots and in regression analyses. Two of the three sites had a severe paucity of understory plants. Members of the field team returned to the sites at Fort A.P. Hill

to analyze these sites more closely. At one site the subtle remnants of an old logging road crossing the transect at an oblique angle became apparent. At another transect site, the remains of old, cut-off fence posts were found surrounding the transect area at some distance from it. The area may have once served as an animal paddock prior to World War II when most of the fort was covered with various types of farms. The area may also have more recently been a bivouac area, with most of the smaller understory vegetation having been trampled by soldiers along with the compaction of the soil. These two transects were replaced with new transects from different locations. At the third transect site, it was obvious that within approximately the last 5-10 years some commercial loblolly pine harvesting had taken place within the last 46 m (150 ft) of the 91-m (300-ft) transect. There was a practically impenetrable wall of loblolly seedlings and saplings. This transect was also replaced.

- *Forest health.* While it is not uncommon to encounter standing dead saplings and shrubs in the understory, their fate can be readily explained. Competition for nutrients, disease, and reduced ambient light levels can be the causes of much of these deaths. Table 8 shows the dead standing understory members for each transect. The data are presented as the percent of all standing understory members that are dead and as dead plants $ha^{-1}$ in order to allow comparison between transects with different areal extents.

**Table 8**
**Understory Mortality Counts**

| Transect | Percent Dead | Dead $ha^{-1}$ | Transect | Percent Dead | Dead $ha^{-1}$ | Transect | Percent Dead | Dead $ha^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.7 | 36 | 11 | 12.7 | 248 | 21 | 5.6 | 153 |
| 2 | 6.7 | 125 | 12 | 7.1 | 72 | 22 | 9.5 | 216 |
| 3 | 7.4 | 179 | 13 | 7.1 | 72 | 23 | 9.6 | 230 |
| 4 | 10.9 | 197 | 14 | 14.0 | 215 | 24 | 3.0 | 86 |
| 5 | 3.4 | 117 | 15 | 27.2 | 484 | 25 | 7.9 | 152 |
| 6 | 11.1 | 400 | 16 | 16.9 | 269 | 26 | 4.4 | 58 |
| 7 | 3.8 | 62 | 17 | 2.8 | 96 | 27 | 2.0 | 43 |
| 8 | 5.1 | 138 | 18 | 4.5 | 132 | 28 | 4.7 | 120 |
| 9 | 7.9 | 170 | 19 | 1.3 | 24 | 29 | 0.9 | 37 |
| 10 | 15.7 | 224 | 20 | 1.8 | 36 | 30 | 10.1 | 359 |

The greatest mortality rates occur at T15 and T16, old-growth deciduous stands at Montpelier; T14, a white oak-hickory forest stand on the Spotsylvania Courthouse Battlefield; and T10, an oak-hickory-yellow-poplar forest site at Fort A.P. Hill. If all transects are considered, 533 understory plants were dead. This represents 8.27 percent of all understory woody plants that were measured. T6, an approximately 22-year-old unmanaged pine plantation, has the second largest count in terms of dead $ha^{-1}$. The vast bulk of the dead individuals at this site were bigtooth aspen (*Populus grandidentata*). *P. grandidentata* is a short-lived but fast-growing tree that quickly reforests disturbed sites. The species is very intolerant of shade, and once overtopped, the mortality is quite high.

One noticeable feature in most of the transect areas was the high mortality rate of the flowering dogwood (*C. florida*). This is directly attributable to the disease termed dogwood anthracnose caused by the disease agent *Discula distructiva.* First encountered in the late-1970's in Connecticut and southern New York, the disease has spread southward to Georgia. Dogwoods especially susceptible are those in poorly ventilated forest stands where leaves may remain wet for extended periods. Currently there is no cure for this disease.

Table 9 presents the mortality rates for standing *C. florida* understory. Almost one-third of all *C. florida* encountered over the 30 transects was dead. Of the 182 *C. florida* in the understory of T15 at Montpelier, 85 are dead. This is approximately 47 percent of all *C. florida* at the site. The other Montpelier site, T16, exhibits the next highest percentage dead. The mortality rate for *C. florida* is approximately 45 percent, nearly equal to that of T15. The *C. florida* mortality rate at T10 is 33 percent. At T14, Spotsylvania Courthouse Battlefield, 36 percent of *C. florida* is deceased. Likewise, 38 percent of the *C. florida* at T11 is dead.

**Table 9**
**Dogwood Mortality**

| Transect | Dogwoods | Dead | Percent Dead | Transect | Dogwoods | Dead | Percent Dead |
|---|---|---|---|---|---|---|---|
| 1 | 6 | 0 | 0 | 16 | 87 | 39 | 44.8 |
| 2 | 12 | 2 | 16.7 | 17 | 6 | 1 | 16.7 |
| 3 | 6 | 1 | 16.7 | 18 | 1 | 0 | 0 |
| 4 | 2 | 1 | 50 | 19 | 5 | 1 | 20.0 |
| 5 | 0 | 0 | 0 | 20 | 10 | 1 | 10.0 |
| 6 | 37 | 7 | 18.9 | 21 | 18 | 2 | 11.1 |
| 7 | 1 | 0 | 0 | 22 | 4 | 0 | 0 |
| 8 | 15 | 2 | 13.3 | 23 | 21 | 3 | 14.3 |
| 9 | 46 | 7 | 15.2 | 24 | 28 | 5 | 17.9 |
| 10 | 29 | 14 | 48.3 | 25 | 6 | 1 | 16.7 |
| 11 | 21 | 8 | 38.1 | 26 | 22 | 1 | 4.5 |
| 12 | 22 | 0 | 0 | 27 | 11 | 8 | 72.7 |
| 13 | 11 | 1 | 9.1 | 28 | 3 | 1 | 33.3 |
| 14 | 47 | 15 | 31.9 | 29 | 3 | 0 | 0 |
| 15 | 182 | 85 | 46.7 | 30 | 30 | 12 | 40.0 |
| | | | | **Total** | **692** | **218** | **31.5** |

## Diversity

Since stem counts and species were gathered, it was decided to compute several diversity indices. The authors decided to examine if there was any correlation between the overstory and understory density and the diversity of species in the transects. Diversity may be defined as the variety and relative abundance of species within a biome. It can also be thought of as the variability within a natural community. Diversity measures take into account two primary factors: species richness, that is, number of species; and evenness (sometime know as equitability), that is, how equally abundant the species are (Magurran 1988). Forest diversity may be an element of interest to training area managers.

There is a myriad of diversity indices. Some of the more common are Shannon, Brillouin, McIntosh, Margalef, Berger-Parker, and Menhinick. Some, such as Brillouin's, are computationally difficult. Others, such as Berger-Parker, are quite simple. For the mathematical formulas see Magurran (1988) and Pielou (1975). All of these diversity indices were computed for the overstory and understory for the 30 transects. Besides the diversity values for the transects, the authors had an interest in how these indices were related. Table 10 contains the correlation matrix for these more common indices. It is readily apparent that there is a high linear correlation between many of the indices.

**Table 10**
**Correlation among Diversity Indices**

| Diversity Index | Shannon | Brillouin | Margalef | Menhinick | McIntosh Diversity | McIntosh Evenness | Berger-Parker (D-1) |
|---|---|---|---|---|---|---|---|
| Shannon | ---- | **1.00** | 0.61 | 0.49 | **0.97** | **0.94** | **0.94** |
| Brillouin | **1.00** | ---- | 0.61 | 0.45 | **0.96** | **0.92** | **0.94** |
| Margalef | 0.61 | 0.61 | ---- | 0.71 | 0.48 | 0.36 | 0.49 |
| Menhinick | 0.49 | .045 | 0.71 | ---- | 0.49 | 0.42 | 0.46 |
| McIntosh Diversity | **0.97** | **0.96** | 0.48 | 0.49 | ---- | **0.99** | **0.99** |
| McIntosh Evenness | **0.94** | **0.92** | 0.36 | 0.42 | **0.99** | ---- | **0.97** |
| Berger-Parker | **0.94** | **0.94** | 0.49 | 0.46 | **0.99** | 0.97 | ---- |

That being the case, the Shannon index of diversity was selected as a representative index, and the results for the 30 transects appear in Table 11. Shannon's index is based on the proportional abundances of species. Since $\log_{10}$ was used in the Shannon formula, its output values range from 0.0 to 1.0. Low values indicate low diversity and high values indicate high diversity. The transect with the most diversity, T18, is a transect that began in a stream flood-plain and ended in a drier upland forest setting. T18 has the highest number of different overstory species (12) and different understory species (22). T18 contains both species that prefer a wet environment and those that prefer a drier one. Other high understory diversities are found in T5, a young unmanaged pine plantation; T17, another floodplain to forest transect; T22, a pine plantation; and T23, an upland mixed deciduous stand. The lowest diversity, as expected, occurred in the overstory of pine plantations in T5, T6 and T22. T27 also has very low diversity. It contains an 85 percent white oak overstory and a 70 percent white oak understory.

All the generated diversity indices had no statistically significant correlation with the overstory and the understory density, maximum quadrat density, or range in quadrat density. If diversity had been a statistically significant predictor variable of understory plant density, then the photo analyst would have to be able to differentiate between all species–an extremely difficult task inasmuch as many species are spectrally similar.

**Table 11**
**Shannon Diversity Values for Transect Overstory (OS) and Understory (US)**

| Transect (T) | OS | US | Transect (T) | OS | US | Transect (T) | OS | US |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.473 | 0.654 | 11 | 0.899 | 0.819 | 21 | 0.716 | 0.516 |
| 2 | 0.507 | 0.628 | 12 | 0.532 | 0.848 | 22 | 0.289 | 0.949 |
| 3 | 0.681 | 0.840 | 13 | 0.374 | 0.911 | 23 | 0.698 | 0.935 |
| 4 | 0.738 | 0.732 | 14 | 0.374 | 0.749 | 24 | 0.645 | 0.760 |
| 5 | 0.424 | 1.000 | 15 | 0.477 | 0.724 | 25 | 0.654 | 0.449 |
| 6 | 0.121 | 0.852 | 16 | 0.468 | 0.597 | 26 | 0.565 | 0.560 |
| 7 | 0.432 | 0.695 | 17 | 0.591 | 0.978 | 27 | 0.184 | 0.536 |
| 8 | 0.495 | 0.693 | 18 | 0.986 | 1.000 | 28 | 0.573 | 0.629 |
| 9 | 0.369 | 0.840 | 19 | 0.773 | 0.716 | 29 | 0.632 | 0.773 |
| 10 | 0.738 | 0.895 | 20 | 0.641 | 0.720 | 30 | 0.604 | 0.941 |

# 4 Summary

Overstory and understory tree and woody plant measurements were gathered in a series of 30 forestry transects that were conducted at six midlatitude forest sites in central Virginia. Transect sites were selected to provide a wide range of forest types. Over 7,200 overstory and understory stems were measured. Overstory variables were tree height, mean crown diameter, d.b.h., species and x-, y-location within the transect. Variables gathered for the understory included d.b.h., species, and x-, y-location within the transect. Other transect information gathered included soils, slope and aspect, herbaceous layer species, canopy closure, and notes on the general health of the forest. Other ancillary variables were computed and derived such as basal area, diversity indices, and species counts.

Mean tree height of the dominant and codominant stems was the best predictor variable. It explained 66 percent of the variability in the understory density. The SEE of the regression equation was 470 plants ha $^{-1}$. This means that 95.45 percent of all understory plant estimations should be within $\pm 940$ plants $ha^{-1}$, or an estimation that is in error by one understory plant for every 10.6 $m^2$. The model was also applied to four validation transects. The mean absolute error in understory density estimation was 220 plants $ha^{-1}$, and the mean percent error was 8.53. This translates into an estimation that is in error by one understory plant for every 45.5 $m^2$. All of the other independent variables proved to be poorer predictors or totally uncorrelated with understory plant density.

The developed model performs best in drier upland locations. It severely underestimates understory densities at wetter transect sites. The model, however, has applicability to all forest types–pure coniferous, pure deciduous, and mixed.

Understory density was not uniform across the transects. It appeared as random, clumpy patterns when viewed on the ground. When plotted as a 15-m (50-ft) moving average, it exhibited a rolling, sinuous pattern (Figures 5a-5c). However, when broken up into 8-m (25-ft) quadrats, the understory exhibited a density structure. The maximum quadrat density and the range in densities were highly correlated.

One curious finding in KCP01 is that understory density was statistically shown to be best predicted by overstory mean crown diameter. In this study, the predictor variable is mean overstory height. Why is there a difference in predictor variables? This might be explained in the plot sampling method. In KCP01 the authors used a 10-m- (32-ft-) radius plot. The limited size of these plots then did not fully describe the overstory and understory characteristics. This study used 91-m (300-ft) linear transects of variable widths. These bigger plots more adequately represent the understory conditions and the clumpy nature of the understory distribution. The circular plots missed some of these sparse and some of the dense areas. The plots from this study were better able to record the varying degree of spatial distribution of the understory. Figure 5 shows how the understory densities vary along the plot while the overstory density remains relatively constant.

The ability to estimate understory density from overstory height enables the prediction of line-of-sight and cross-county mobility through forested areas without having to have extensive ground-truth data. This prediction model is based on data gathered only in central Virginia. The model needs to be tested in other regions of Virginia and then in other regions of the United States to see if they hold up under various vegetation ecological and climatic zones. For this study, there seems to be no difference in the estimation of understory between pine forests and deciduous forests. With height being the predictor variable, however, stereo imagery would be necessary.

# 5 Conclusions and Recommendations

There is a relationship between selected overstory properties and understory plant density. The relationship maintains a structure and is partially explainable. Although the understory plant density can vary widely along a transect, there is an inherent structure to the density. The maximum understory density for equal-area quadrats within the transect is highly correlated to the range in understory density.

Other ancillary variables such as soils, slope and aspect, species diversity, and canopy closure had no correlation to the understory density and to the pattern of understory plant dispersion.

One difficulty encountered by the authors was that even though there were 30 transects, there was difficulty in breaking up the data set into smaller groups by species, ranges in height, and mean crown diameter. When subdivided, it did not provide a sufficient number of data points with which to derive meaningful stable equations. Hence, the data set was treated as a whole.

Additional transects need to be performed at wetter sites such as forests adjacent to stream courses or lowland locations. Wetter sites did not fit the developed model. Transects should also be performed in different geographic and climatic locations to test the applicability of the models generated in this report. Locations with different overstory and understory species types should also be investigated.

Tree height was the best predictor variable in estimating understory stem density. This necessitates the acquisition of stereo imagery. In addition, since the species of the overstory is not a significant predictor of understory plant density, the identification of individual tree species or even type is not required by the analyst.

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Understory density can have impacts on such military activities as cross-country mobility, bivouac, cover and concealment, and line of sight. Airborne sensors provide a fairly good mechanism for measuring the overstory: crown diameter and tree height. The nature and characteristics of the understory, however, must be subjectively estimated by the analyst. This current work focused on the development of a model to predict understory plant densities from measurable overstory characteristics. Over 7,200 overstory and understory woody plants were measured in a series of 30 forestry transects conducted at six sites in central Virginia. Measurements included overstory height, mean crown diameter, diameter at breast height (d.b.h.), and species. Understory species and d.b.h. were gathered. For both overstory and understory, x-,y-location within the transect was also determined. Ancillary variables such as soils, slope, aspect, canopy closure, ground cover, and surface drainage were also measured or noted. The best-fit equation for estimating understory plant density was a simple linear model with overstory mean height being the most statistically significant relationship between the maximum understory density and the range in densities along the transect. Species diversity indices also were computed but showed no relationship to understory density. Understory mortality rates were noted with special interest given to the threatened flowering dogwood (*Cornus florida*).

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