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Age, forest structure, and disturbance history of five potential old-growth forests in eastern Kentucky's Cumberland Plateau

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Age, forest structure, and disturbance history of five potential old-growth forests in eastern Kentucky's Cumberland Plateau

By

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Bachelor of Science

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ABSTRACT

The Cumberland Plateau (CP) is an ecoregion of global importance, yet its extent of old-growth forest (OG) is not well known. Due to its rarity and importance, understanding what OG remains is needed to deduce the region's health. This study described five potential OG forests in eastern Kentucky. Sites possessing >5 trees/ha established prior to 1780, and being similar in disturbance history and forest structure to other regional OG were to be considered OG. Shillalah Creek (SC) and Hensley-Pine Mountain (HP) possess no in plot trees established prior to 1780, show evidence of stand-wide disturbance during the 1930's, are denser than average eastern OG, and possess little coarse woody debris (CWD). SC and HP likely were altered by Chestnut Blight; in addition SC appears to have been logged around the time of chestnut loss. Angel Hollow (AH) exhibits continual disturbance often seen in eastern OG due to tree-fall gaps and is similar to average OG density, volume of CWD, snags and pre-European trees/ha. A change in establishment environment during the mid-1800's suggests AH might have been selectively logged. Gladie Creek (GC) and Natural Bridge (NB) exhibit disturbance during the 1890's likely the result of human land use. GC possesses low amounts of CWD while NB approaches ranges found in previously studied old-growth forest. Results suggest no site meets study standards of OG and underscore a need for further study regarding locating and quantifying OG on the CP.

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1. INTRODUCTION

Due to extensive human land use, old-growth forests have become increasingly rare in eastern North America. Current knowledge suggests old-growth forests play an important ecological role. For example, some species prefer the structural characteristics of old-growth forest, including many lichens, soil bacteria, amphibians, arthropods, and carnivores (Selva 1994, Meier et al. 1996, Pelton 1996, Greenberg et al. 1997, Winchester 1997). Many of these organisms are likely important for ecosystem functions (Frelich and Reich 2003) and might be important to pharmaceutical or biotechnological industries in the future (Hunter 1999, Thompson and Angelstam 1999, Frelich and Reich 2003). The ultimate value and ecological services provided by old-growth forest are not fully understood. As such, it is important that old-growth forest be preserved due to its rarity and structural characteristics.

In addition to their importance ecologically, old-growth forests are integral to the sustainability of some human ventures. For instance, old-growth forests are "benchmarks" or references to which harvested lands should be compared (Sarr et al. 2004). Without such monitoring, we might fail to recognize what changes are taking place in forested systems or have trouble deducing their causes (Kenific et al. 2005). Comparing effects of silviculture with unmanaged forests is especially important over long time scales because potential declines in productivity, soil fertility, and biodiversity might occur slowly over generations (Frelich and Reich 2003). Furthermore, old-growth forest might exhibit considerable ecological inertia, which may increase ecosystem resistance and resilience (Noss 2001). Old-growth forests are invaluable for dendrochronologists who can use ring-width data from old trees to reconstruct past climate and forest processes (Sheppard and Cook 1988), thereby providing insight into current processes. Considering the ecological and scientific value of old-growth forests, it is important to research their extent and structural attributes.

Forests of the Cumberland Plateau region of eastern Kentucky have not been excluded from the effects of human land use (Druckenbrod et al. 2006). The region is the center of the diverse mixed-mesophytic forest in the eastern United States (Braun 1950) and has a long history of logging, mining, and agricultural clearing. Due to high species diversity and extensive human land use, the plateau is considered to be of global importance and in need of immediate protection and restoration (Ricketts et al. 1999). No single reserve can represent the entire region, so a landscape scale approach is needed to conserve Cumberland Plateau forests (Schmalzar 1989). The preservation of old-growth forest is important to the landscape approach to conservation (Druckenbrod et al. 2006). Remnant old-growth forests should serve as centers for recovery across the region. Unfortunately, as is the case in much of the eastern United States, Cumberland Plateau forests have been heavily altered and a relatively small amount of old-growth forest is documented to persist.

Recent research in the eastern U.S. suggests that there is more old-growth forest across the landscape than was previously thought (e.g. Stahle and Chaney 1994, Orwig et al. 2001). There has been little systematic research to re-discover such forests in eastern Kentucky's Cumberland Plateau region. According to *The Land and Resource Management Plan* for the Daniel Boone National Forest, old-growth forest "has not been adequately documented and may be under-represented" (USDA FS 2004). If eastern Kentucky is like much of the eastern U.S., the Cumberland Plateau ought to have more old-growth forest than is currently known.

The objectives of this study were to determine the age structure, disturbance history, and stand structural characteristics of five potential old-growth forests in eastern Kentucky's Cumberland Plateau region. These are important attributes when attempting to classify forests as either old-growth or second growth. Forests selected for study were considered potential old-growth sites by the Kentucky State Nature Preserves Commission (KSNPC). Sites were selected subjectively using descriptions provided in the KSNPC's old-growth database; which included estimates of stand age, size, and species composition. The KSNPC bases its old-growth designation on observations from citizens or state agency workers and these sites had not been systematically studied with respect to their age and stand structures.

For study purposes, forests containing > 5 trees/ha recruited prior to European settlement of the area (~1780), showing limited evidence of stand-wide disturbance, and having structural attributes similar to previously studied old-growth forests in the area were to be considered old-growth. Structural attributes included tree and snag density, tree basal area, and a volume of Coarse Woody Debris (CWD) between 46-132 m^3/ha. Definition parameters were based on structural data regarding tree density, CWD volume, and snags provided by McComb and Muller (1983), Muller and Liu (1991), Goodburn and Lorimer (1998), Runkle (2000), and Galbraith and Martin (2005) (see Tables 1 and 2). Additionally, D'amato, Orwig, and Foster's (2008) study in which the criteria of >5 pre-European settlement trees/ha was used. Although possible that no forest is completely free from post-European human land use, guidelines presented by these authors are important to consider when deducing the maturity state of a forest. Additionally, each forest might be part of a continuum of disturbance on a larger scale; therefore, these parameters have the potential to vary widely between sites. Even so, results from previously studied regional old-growth forest should provide a workable guideline for study purposes.

2. MATERIALS AND METHODS

2.1 Sites

Sites were chosen for investigation in Bell, Laurel, Letcher, Menifee, and Powell counties based on descriptions in The Kentucky State Nature Preserves Commission's (KSNPC) old-growth database (Figure 1). KSNPC site descriptions often included estimates of stand size, age, and species composition. Based on KSNPC descriptions, sites were subjectively chosen for study. Most important to selection were stand size and geographic location. It seemed more likely for a large stand (e.g., 50 ha) to contain true old-growth structure than a small stand (e.g., 2 ha) and it was thought that investigating sites in a wide range of latitudes and forest types might expand the documented range of old-growth forest in Kentucky and bolster what is known about various forest types' structural characteristics. It also seemed important to choose larger stands that might contain true old-growth characteristics because it was possible that they would be more likely to provide ecological benefit to a surrounding area and less likely to be lost due to natural disturbance. For instance, a wind storm might have a greater impact on a 2 ha stand than one of 50 ha. Hence, sites were subjectively chosen for study based on descriptions provided by the KSNPC's old-growth database.

Due to variation in aspect and elevation, various forest types exist among sites including hemlock-hardwood, mixed- mesophytic, and sub-xeric communities (Anonymous 1995). These differences in site conditions provided a chance at documenting old-growth forest in communities were relatively small amounts are known to exist in the region. In addition, site distribution on the landscape presented an opportunity to expand the range of documented old-growth in Kentucky. Appendix I provides a general description of the Cumberland Plateau region and Appendix II a detailed species compositions for each study site.

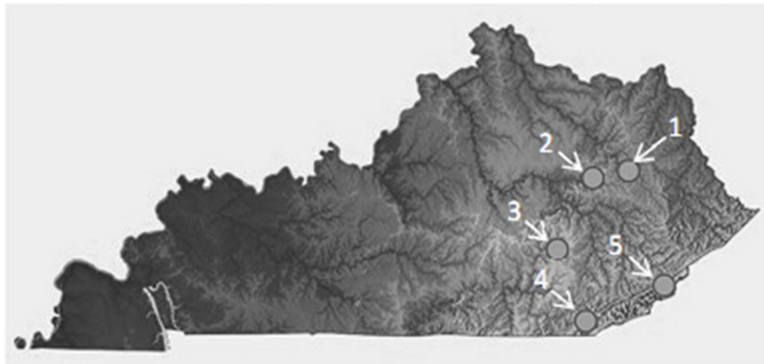

Figure 1: General location of study sites thought to be old-growth forest on eastern Kentucky's Cumberland Plateau. 1 Gladie Creek, 2 Natural Bridge, 3 Angel Hollow, 4 Shillalah Creek, 5 Hensley Pine Mountain

2.2 Data Acquisition and Analysis

Forest structural parameters including volume of Coarse Woody Debris (CWD), age, and disturbance history were quantified to determine if each forest was in an old-growth condition according to study standards. To this end, point quarter transects (PCQM) were used (Mitchell 2007). Transects were initiated 25 m from the edge of areas that seemed most likely to be old-growth at each site and subjectively directed. This study design was meant to maximize chances of investigating areas likely to exhibit old-growth forest characteristics. For each transect, five points were established every 20 m along a set azimuth. Species and diameter at breast height (DBH) were recorded for one tree (≥10 cm DBH) and sapling (2.5-9.99 cm DBH) in each quadrant. With these data, tree density and basal area of each forest was determined and importance values were calculated for each species by summing their relative cover, relative density, and relative frequency (Mitchell 2007).

To obtain further information regarding forest structure, CWD greater than 1 m in length and 20 cm DBH was measured for length, diameter, and decay class within a 10 x 10 m^2 plot located at the center of each point on a transect in order to calculate volume of CWD (m^3/ha). Additionally, snags >25 cm DBH were recorded in each 10 X 10 m^2 plot to obtain number of snags/ha. CWD volume was considered independent of snags and four decay classes were implemented. For instance, Decay Class I included pieces with sound bark and minimal decay while Decay Class IV had no bark and rot extended well into the piece of debris (Muller and Liu 1991). Three diameter measurements were taken per debris piece and Newton's formula,

$$V = h/6\ (A_1 + (Am*4) + A_2),$$

where V = volume, h = length, A_1 is the area of one end of the piece, A_2 is the area of the opposite end, and A_m is the area of each log's midpoint, was used to obtain volume of CWD within and among decay classes (Fraver et. al. 2007).

At each point in a PCQM transect, two trees were cored in alternating quadrants for age structure and disturbance history analysis. Trees were cored parallel to relief contours to avoid reaction wood and between 1.1 and 1.5 meters above the ground. Most trees were cored at 1.3 m, variation in placement occurred due to inaccessibility and rot. Fifty trees were randomly selected at each site. Additionally, ten trees per site which possessed characteristics suggesting great age (sensu Pederson 2010) were cored outside of PCQM transects to increase sample replication, aid in crossdating, and fill out forest age structure. Out-of-plot trees were included in disturbance history, but not in analyzing structural parameters such as trees/ha, trees established prior to 1780/ha, basal area, and species importance values. Age structure, disturbance history, and forest structure provide three lines of evidence useful to the delineation of old-growth forests. Visible signs of human land use, such as skid roads and stumps, also aided in designation. Taken together, these forest attributes provided an indication of each sites' stage of development.

All core samples were analyzed using standard dendrochronological procedures (Stokes and Smiley 1968). Two cores were taken per tree. After drying and mounting, cores were progressively sanded to show ring structure. This allowed for crossdating, and calendar dates were assigned to each ring through the identification of wide and narrow rings common to cores from each tree and between trees of the same species in a population. External factors such as drought cause variation in ring widths through time. Often these variations can be seen regionally (Fritts 1976, Cook and Kairiukstis 1990). Thus, some trees collected in different study areas and tree-ring records in the region made by prior investigators were useful for crossdating in this study (N. Pederson, K. Tackett, unpublished data). Visual crossdating was validated using the statistical program COFECHA (Holmes 1983, Grissino-Mayer et al. 1997). In this program, as trees are satisfactorily crossdated within species at a site, a master chronology is formed and correlations between 50 year segments are output. If higher correlations are possible in a given segment they are provided, indicating where up to 10 extra or missing rings might be located in a sample (Holmes 1983, Grissino-Mayer et al. 1997). Although in many cases visual crossdating is sufficient for age structure analysis, inputting ring width data into COFECHA is a key quality control step that aids in further statistical analysis.

After crossdating, disturbance history was analyzed for each of the five study sites. Because more resources are available to trees after a disturbance, they often exhibit releases in ring width. Depending on the amount of canopy lost and a tree's proximity to a disturbance, these releases will be greater or lesser in magnitude. A high proportion of trees exhibiting major release in ring width in any one or two decades suggests that a major canopy disturbance has occurred in a forest (Lorimer and Frelich 1989). Since the prevailing disturbance regime of eastern forests is canopy gap caused by tree-fall, large canopy disturbances are infrequent (Runkle 1982). Although there are natural events such as fire, insect outbreak, or tornadoes that can cause canopy wide disturbances, large canopy events away from major hurricane tracks are often associated with human land use in eastern forests. As such, analyzing a site's disturbance history is useful in attempting to distinguish its maturity status

To determine the disturbance history of each forest, the equation,

$$\%GC = \frac{(M_2 - M_1)}{M_1} \times 100,$$

where %GC is percent growth change, M_1 is the average radial growth during the 15 years prior to a given year, and M_2 is the subsequent 15 years, was used to determine the presence of possible events based on releases in ring width. This equation uses two 15-year means to quantify differences in average ring-width in a 30 year time period encompassing each ring on a core. For study purposes, releases were described as minor if a 50-99.9% increase in ring-width occurred (relative to a ring's previous 15 years) and as major if a ≥ 100% increase occurred (Lorimer and Frelich 1989). Potential disturbances were validated visually and years with peak %GC were chosen as the most likely year of disturbance. Only those decades in which ≥ 10 trees were available for analysis were considered.

Trees established in a canopy position often have notably wide early rings as they are able to access more resources than those established under a full canopy. To provide further evidence of canopy disturbance, trees were classified as open grown or suppressed at time of reaching coring height. Trees exhibiting a general decline in ring width through time, signifying an abundance of resources at establishment and thus an open position which gradually closed through time, as well as those exhibiting a constant rate of growth are considered open grown (Lorimer and Frelich 1989, Nowaki and Abrams 1997, Parish and Antos 2004). When a high proportion of trees exhibit patterns of disturbance during periods of time encompassing one or two decades, especially if followed by an influx of open grown trees, the forest was considered to have had a major canopy disturbance. Although large canopy disturbances can suggest human land use, other criteria (i.e. volume of CWD, snags, presence of man-made structures) are taken into account to indicate the land-use history and maturity status of each forest.

Although age structure and disturbance history were major factors in old-growth determination for each site investigated in this study, forest structure was compared to that typically found in mixed-mesophytic, old-growth forests. Tree density in these forests averages 250 trees/ha while basal area ranges from 25 to 64 m^2/ha (Galbraith and Martin 2005). Due to the nature of the region's predominate disturbance regime (i.e. gap creation by tree-fall), the amount of CWD present in temperate forests can fluctuate through time (Runkle 1982, Muller 2003). However, old-growth forests generally have more CWD present in a wider range of sizes and decay classes than second-growth forests. For instance, Muller and Liu (1991) found almost half of the CWD volume at Lilley-Cornet Woods to be in later stages of decay. Webster and Jenkins (2005) found large diameter (>40 cm DBH) debris comprised > 50% of CWD volume in primary forests of the Great Smokey Mountains National Park, while in forests that were anthropogenically disturbed smaller diameter wood contributed the majority. Although these structural attributes vary widely depending on species composition and site characteristics (Greenberg et al. 1997), they provide a workable guideline for a variety of forest types

3. RESULTS

Each site was found to have different combinations of dominant tree species (Appendix II). Angel Hollow is dominated by *Tsuga canadensis* (L.) Carriere. *Liriodendron tulipifera* L. and *Betula lenta* L. are the next most important canopy species, respectively. *Tsuga canadensis* is also the most important species found in Gladie Creek, with *Fagus grandifolia* Ehrh. and *Pinus strobus* L. being second and third in importance. Hensley-Pine Mountain's three most important canopy species are *Quercus montana* Willd., *Acer rubrum* L., and *Liriodendron tulipifera*. *Liriodendron tulipifera*, *Tsuga canadensis*, and *Acer saccharum* Marsh. are Natural Bridge's most important species while *Quercus coccinea* Munchh., *Acer rubrum*, and *Quercus montana* are the dominate species at Shillalah Creek. Although present in the canopy and seedling layers at each site, no *Quercus* saplings were documented during the course of this study (Appendix II).

All forests investigated contain trees that reached coring height prior to 1780 (Figure 2). Several were out-of-plot and not included in analysis of structural parameters. Angel Hollow has the most trees established prior to European settlement, 21.3 pre-1780 trees/ha including 3.0 pre-1780 *Quercus montana*/ha, 12.2 pre-1780 *Q. alba* L./ha, and 6.1 pre-1780 *Tsuga canadensis*/ha (Figure 2a, Table 1). Gladie Creek possesses 14.5 pre-1780 trees/ha: 4.8 *Aesculus flava* Aiton/ha and 4.8 pre- 1780 trees/ha each of *Fagus grandifolia* and *Tsuga canadensis* (Figure 2b, Table 1). The oldest tree documented in this study was found at Gladie Creek, an *Aesculus flava* with a ring count putting the inner ring date as 1601 (not crossdated prior to 1774 due to low species replication). Interestingly, no *Quercus* were found to have established at Angel Hollow since the 1740's and no *Aesculus* were established after the 1760's at Gladie Creek.

Natural Bridge contains considerably fewer pre-1780 trees when compared with Angel Hollow or Gladie Creek. With only one *Liriodendron tulipifera* established prior to 1780, Natural Bridge has the fewest cored pre-European trees of any study site (2.8/ha, Figure 2d).

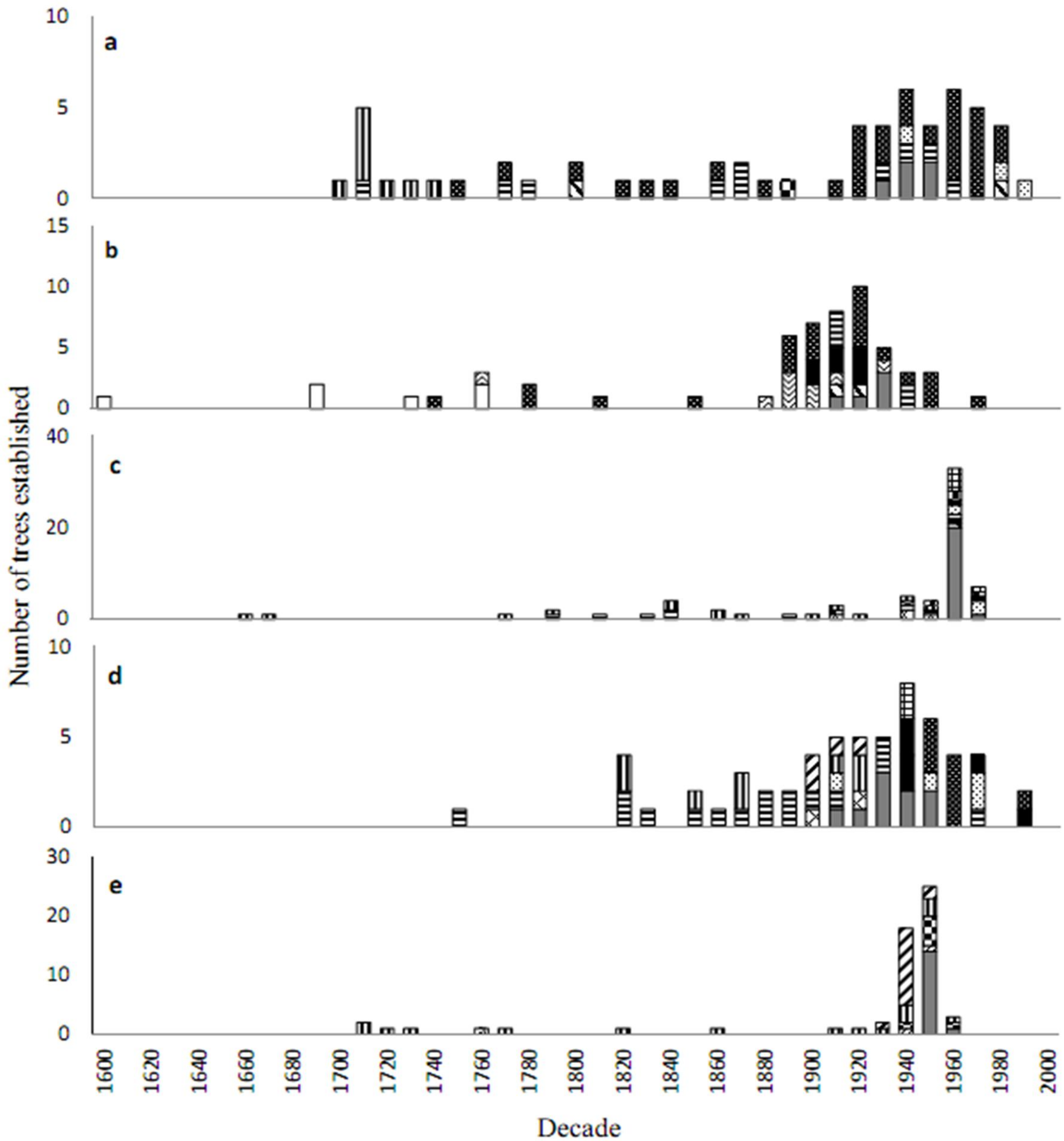

Figure 2: Number of trees established per decade at five sites thought to be old-growth forest in eastern Kentucky*. (a) Angel Hollow (b) Gladie Creek (c) Hensley Pine Mtn. (d) Natural Bridge (e) Shillalah Creek. *Acer species* *Aesculus flava,* *Betula lenta,* *Carya spp.,* *Fagus grandifolia,* *Liriodendron tulipifera,* *Magnolia spp.,* *Oxydendrum arboretum,* *Quercus alba/Montana,* *Quercus rubra/coccinea,* *Sassafras albidum,* *Tsuga canadensis* Other: *Ilex opaca, Juglans nigra, Nyssa sylvatica, Tilia americana, Pinus strobus, Cornus florida*.

*y-axes differ between plots

Table 1: Tree density, basal area and density of snags >25 cm DBH of five sites thought to be old-growth forest on eastern Kentucky's Cumberland Plateau. Pre-1780 trees are expressed as trees/ha in parenthesis. Values typical of eastern old-growth are shown for comparison.

	Trees/ha	Basal Area (m^2 /ha)	Snags/ha
Angel Hollow	304 (21.3)	41	12
Gladie Creek	484 (14.5)	52	4
Hensley Pine Mtn.	479 (0)	34	4
Natural Bridge	287 (2.9)	33	4
Shillalah Creek	783 (0)	36	0
Typical values*	250[†] (>5)[§]	25-64[†]	5.9-20[‡]

*Sources: [†] Galbraith, S.L. and Martin, W.H., 2005. Three decades of overstory and species change in a mixed-mesophytic forest in eastern Kentucky. Castanea 70(2): 115-128.

[§] D'amato, A.W., Orwig, D.A, Foster, D.R., 2008. The influence of successional processes and disturbance on the structure of *Tsuga Canadensis* forests. Ecological Applications, 18(5): 1182-1199.

[‡] McComb, W.C. and Muller, R.N., 1983. Snag densities in old-growth and second-growth Appalachian forests. Journal of Wildlife Management 47(2) 376-382.

[‡] Muller, R.N. and Liu, Y., 1991. Coarse woody debris in an old-growth deciduous forest on the Cumberland Plateau, southeastern Kentucky. Can. J. For. Res. 21: 1567-1572.

[‡] Goodburn, J.M. and Lorimer, C.G., 1998. Cavity trees and coarse woody debris in old-growth and managed northern hardwood forests in Wisconsin and Michigan. Can. J. For. Res. 28: 427-438.

[‡] Runkle, J.R., 2000. Canopy tree turnover in Old-Growth mesic forests of eastern North America. Ecology, 81(2): 554-567.

Conspicuous in Natural Bridge's age structure is a large gap in recruitment from the 1750's to the 1820's and an influx of multiple species after the 1910's (Figure 2d). *Quercus* spp. have failed to establish after the 1920's at Natural Bridge.

Both Hensley-Pine Mountain and Shillalah Creek are more or less even aged due to cohort establishment during the mid-1900's. Although trees established prior to 1780 at the two sites none older than 1780 were found in transects (Table 1, Figures 2c and 2e). Forty-eight percent of trees sampled at Hensley-Pine Mountain obtained coring height during the 1960's: of these, 63% are *Acer* spp. As at Natural Bridge, *Quercus* spp. failed to establish after the 1920's at Hensley-Pine Mountain. Seventy-two percent of trees sampled at Shillalah Creek established during the 1940's and 1950's. *Quercus coccinea* composes 72% of Shillalah Creeks 1940's cohort while *Acer rubrum* comprises 56% of the sites' 1950's recruitment spike. No *Acer* spp. seem to have been present at Hensley-Pine Mountain or Shillalah Creek prior to the 1960's and 1950's at each site respectively (Figures 2c and 2e). Shillalah Creek is the only site of any studied where oaks succeeded in establishing after what seems to be an *Acer* influx.

When compared to previously studied, eastern old-growth forest, all sites were found to be within typical ranges for basal area, but not tree or snag density (ranges provided or discussed by McComb and Muller 1983, Muller and Liu 1991, Goodburn and Lorimer 1998, Runkle 2000, and Galbraith and Martin 2005). At 783 trees/ha, 484 trees/ha, and 479 trees/ha respectively, Shillalah Creek, Gladie Creek, and Hensley-Pine Mountain are denser than average (250 trees/ha) for eastern old-growth forests (Table 1, Martin 1992). Angel Hollow and Natural Bridge are most comparable in density with 304 and 287 trees/ha respectively. With 12 snags/ha, only Angel Hollow possesses a number of snags >25 cm/ha approaching that often documented in eastern old-growth forest (Table 1, McComb and Muller 1983).

With 65.8 m^3/ha, Angel Hollow is the only site falling within typical ranges for CWD (Table 2). After Angel Hollow, Natural Bridge (35.1 m^3/ha) and Hensley-Pine Mountain (29.8 m^3/ha) respectively possess the highest volumes of CWD. Each of these three sites contain

Table 2: Volume of coarse woody debris (CWD) > 20 cm DBH within and among decay class in five sites thought to be old-growth forest on eastern Kentucky's Cumberland Plateau. Volume of an example old-growth forest is provided along with typical ranges of CWD volumes.

Decay Class	Angel Hollow	Gladie Creek	Hensley Pine Mtn.	Natural Bridge	Shillalah Creek
1	0.7	1.8	0.2	3.1	0
2	12.7	0	1.5	7.2	0
3	33.7	4.9	20.2	11.3	0
4	18.7	4.4	7.9	13.5	2.5
Total CWD Volume (m^3/ha)	65.8	11.1	29.8	35.1	2.5
Typical Values*	LCW[†]~65m^3/ha			Range of CWD:	46-132 m^3/ha

*Source: Muller, R.N. and Liu, Y., 1991. Coarse woody debris in an old-growth deciduous forest on the Cumberland Plateau, southeastern Kentucky. Can. J. For. Res. 21: 1567-1572.

CWD in decay classes three and four; 79.6%, 70.9%, and 94.3%, respectively. Gladie Creek and Shillalah Creek possess the least amount of CWD documented in this study. With 11.1 and 2.5 m^3/ha, they fall well below typical ranges for eastern old-growth forest (Muller and Liu 1991). Shillalah Creek only has CWD in decay class four. Gladie Creek's volume is distributed among decay classes, but lacks class two (Table 2).

When looking at the size distribution of CWD it becomes apparent that volume and decay class distribution are not the only aspects of downed wood that differ between these sites. Angel Hollow, Natural Bridge, and Hensley-Pine Mountain possess greater amounts of large diameter CWD than do Gladie Creek and Shillalah Creek. Angel Hollow, Natural Bridge, and Hensley-Pine Mountain are the only sites with CWD > 50 cm DBH with 38.9 m^3, 15.8 m^3, and 9.9 m^3 respectively. Only Angel Hollow has > 50% of its CWD volume composed of pieces >50 cm

DBH. Hensley-Pine Mountain has no documented CWD > 60 cm DBH and Angel Hollow is the only site possessing CWD > 90 cm DBH.

Forest disturbance histories are found in Figures 3-7. Angel Hollow does not exhibit decades of synchronous release, but the abundance of open grown trees after the 1860's at this site is notable (Figure 3). Prominent at Gladie Creek are the decades of 1880 and 1900 in which 36.4% and 40.9% of trees respectively exhibit release, after which 61.5% of trees establish in an open grown setting (Figure 4). Additionally the 1970's and 1980's are decades in which a high percentage of trees exhibit disturbance at Gladie Creek. During these decades, 24.5% and 26.4% of trees exhibit patterns of release, respectively. At Hensley-Pine Mtn. 60% of trees exhibit a disturbance during the 1930's after which 33 of 41 trees established in an open grown setting (Figure 5). Just over 31% of Natural Bridge's trees exhibit patterns of release during the 1890's. Of the following 39 trees established, 31 established in an open setting (Figure 6). Twenty-five percent of trees exhibit release during the 1930's at Shillalah Creek, after which all of the 47 subsequent trees established in an open-grown setting (Figure 7).

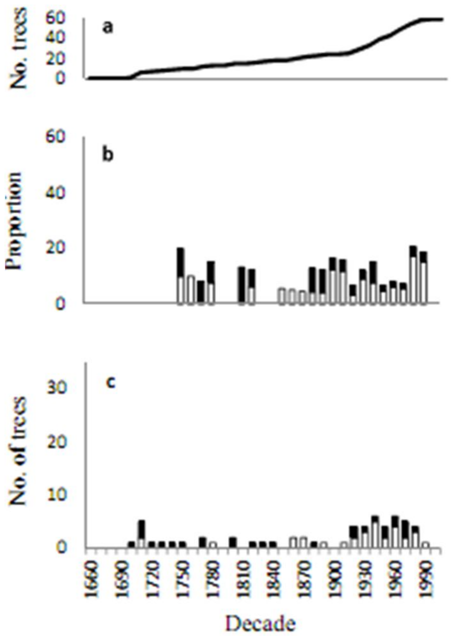

Figure 3: (a) Sample size, (b) proportion of trees exhibiting ☐ major or ■ minor disturbances, and (c) number of ☐ open grown or ■ suppressed trees per decade at Angel Hollow, Laurel Co., KY.

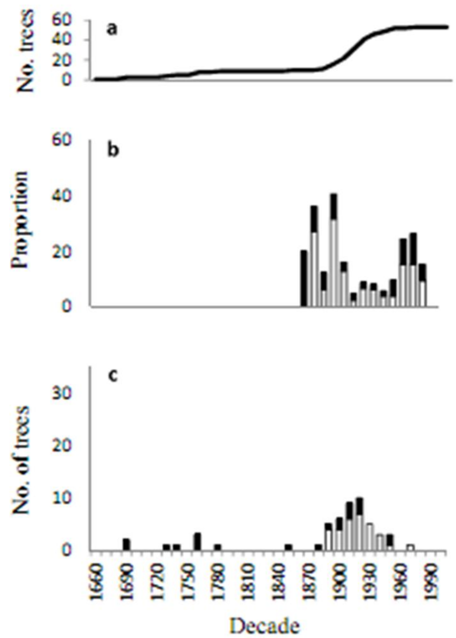

Figure 4: (a) Sample size, (b) proportion of trees exhibiting ☐ major or ■ minor disturbances, and (c) number of ☐ open grown or ■ suppressed trees per decade at Gladie Creek, Meniffe Co., KY

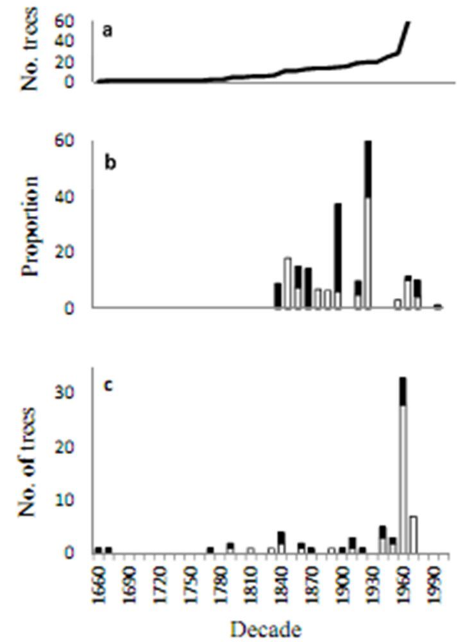

Figure 5: (a) Sample size, (b) proportion of trees exhibiting ☐ major or ■ minor disturbances, and (c) number of ☐ open grown or ■ suppressed trees per decade at Hensley- Pine Mtn., Letcher Co., KY.

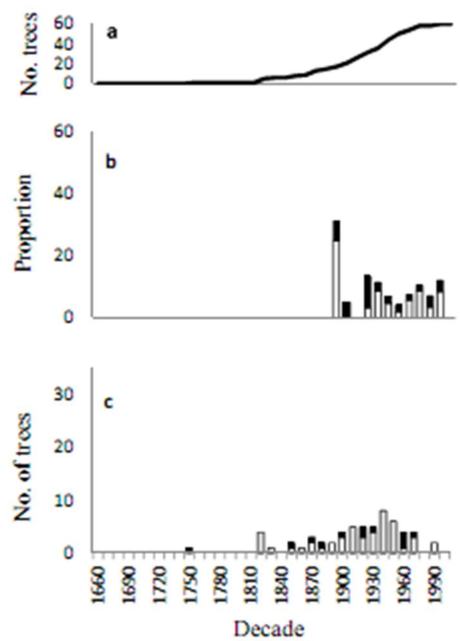

Figure 6: (a) Sample size, (b) proportion of trees exhibiting ☐ major or ■ minor disturbances, and (c) number of ☐ open grown or ■ suppressed trees per decade at Natural Bridge, Powel Co., KY.

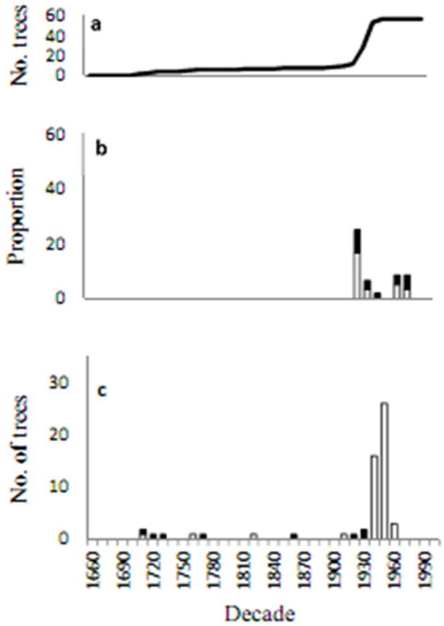

Figure 7: (a) Sample size, (b) proportion of trees exhibiting ☐ major or ■ minor disturbances, and (c) number of ☐ open grown or ■ suppressed trees per decade at Shillalah Creek, Bell Co., KY

4. DISCUSSION

4.1 General

Despite investigating areas purported to be old-growth and subjectively sampling within areas that appeared to exhibit old-growth characteristics, none of the areas studied seem to be classic old-growth forest. Among study sites, Angel Hollow seems closest structurally to eastern old-growth mixed-mesophytic forest, but a man-made structure and an apparent change in forest process as indicated by a preponderance of open grown trees after the 1860's suggest that it might not be an old-growth forest by study standards. Furthermore, when compared to structural characteristics of *Tsuga* dominated old-growth forest, such as those studied by Tyrrell and Crow (1994) and Goodburn and Lorimer (1998), Angel Hollow seems quite different with regards to tree density (400-600 trees/ha vs. 304 trees/ha in this study) and volume of CWD (100-200 m^3/ha vs. 65.8 m^3/ha in this study). Discrepancies in CWD volume could be attributable to differing decay rates between sites (Busing 2005). Structural differences between regional old-growth forest and direct evidence of post-European human land use suggest Angel Hollow to not be old-growth forest. Considering the site exhibits an uneven age structure and no decades of canopy wide disturbance, it is possible that it was selectively logged.

Since Gladie Creek has several pre-European settlement trees, it seems similar in age structure to eastern old growth forest but is denser than average and is generally lacking in CWD. These differences could be attributed to major disturbance which occurred around 1900. The 1890's would have been about the time that the Mountain Central Railway was built in The Red River Gorge and thus, would have been a time of extensive land use in the area. It is likely, based on a network of old roads, that Gladie Creek was not excluded from logging. The site was designated a wilderness area during the 1980's. An apparent disturbance which occurred immediately prior to this time suggests that the site experienced natural thinning or management of the influx of trees that entered the forest after the 1890's. Gladie Creek's structural attributes might continue to be altered in part due to illegal recreational use of the area (Appendix III).

Hensley-Pine Mountain is quite different structurally from regional old-growth forest. This change in characteristics seems to follow an alteration of species composition that might be partially attributable to chestnut blight. Many trees exhibit disturbance in the 1930's which is about the time *Castanea dentata* (Marsh.) Borkh. was decimated by blight in eastern Kentucky (Muller 1982). This could have enabled an *Acer* spp. cohort to establish, concomitantly altering Hensley-Pine Mountain's structural characteristics (Appendix III).

Although Natural Bridge seems close structurally to previously studied eastern old-growth forest, it has relatively low CWD volume. The site's CWD volume is largely attributable to a lack of large downed wood and its cause seems evident in the site's disturbance history. Many trees exhibit disturbance during the 1890's, which is about the time that the Mountain Central Railway was built in the vicinity of Natural Bridge (KYSP 2010). It is likely that trees were taken out of the forest during that time and thus, current forest structure is different from that generally observed in old-growth forest (Hansen et al 1991, McGee et al. 1999).

In addition to CWD volume and size distribution, how a sites downed wood is distributed among decay classes is important to analyzing a forest's state of development (Muller and Liu 1991). Angel Hollow, Hensley-Pine Mountain and Natural Bridge are sites that are at or near volumes of CWD found in previously studied old-growth forest (McComb and Muller 1983). Although Hensley-Pine Mountain and Natural Bridge's volumes fall short of ranges proposed, these sites' decay class distributions might be suggestive of old-growth forest, as >70% of CWD is found in decay classes three and four. In light of this information, these sites seem closer to previously studied eastern old-growth forest than when only taking into consideration volume of CWD. Given a new disturbance (e.g. a blow-down) in either Hensley-Pine Mountain or Natural Bridge, these sites could be on par with volume ranges suggested for eastern old-growth forest. Due to current decay class distributions at these sites, it is likely that later stages of decay would still possess > 50% of either of the site's CWD even after such an event. These considerations are indicative of the region's predominate disturbance regime and underscore how the amount and decay class distribution of CWD present at a temperate forest can fluctuate through time (Runkle 1982, Muller 2003).

There is much evidence suggesting that oak populations are contracting in eastern forests, while more generalist or mesophytic species such as red maple seem to be expanding (Lorimer 1984, McCarthy et al. 1987, Goebel and Hix 1996, McEwan and Muller 2006). Although an abundance of oak seedlings was observed at Shillalah Creek and Hensley-Pine Mountain (data not shown), no oak saplings were recorded by transects at any site (Table A-2.1). Collins and Carson's (2004) and McEwan and Muller's (2006) findings provide insight into our study results, as current site conditions might not be favorable to *Quercus* saplings. According to their results, Shillalah Creek, a ridge-top site previously dominated by *Quercus montana* was most likely of any site studied here to support oak regeneration due to dry site conditions. Contrary to this likelihood, no *Quercus* saplings were found on the ridge-top above Shillalah Creek. Although, of the sites which contain a major oak component, Shillalah Creek is the only one in which *Quercus* was recorded to have successfully established after an *Acer* influx.

There is evidence of extensive anthropogenic disturbance at Shillalah Creek, which might have provided a foothold for major compositional change despite favorable xeric site conditions. As was found at Hensley-Pine Mountain, patterns of release during the 1930's and an influx of open grown trees afterwards correspond with loss of *Castanea* due to blight (Muller 1982). However, the site's cohort of *Quercus coccinea* is important to deducing its disturbance history, as that species is a fast growing, shade intolerant tree that is often associated with human land use (Martin 1992). Thus, in addition to sweeping changes brought on by chestnut blight, Shillalah Creek seems to have undergone a major logging event that might have been the result of salvage logging of *Castanea dentata*. Additional evidence of post-European land use is provided by the vertical structure of the *Q. coccinea* stand. Canopy height is lower and density higher in the

1940's cohort when compared to an adjacent area that includes the site's old trees (personal. obs.). Hensley-Pine Mountain possesses *Castanea* woody debris while none was documented at Shillalah Creek. In fact, the area surveyed at Shillalah Creek is practically devoid of any CWD. This evidence suggests a major event occurred here, possibly salvage logging and clear-cutting.

4.2 Implications

Based on recent research in the eastern U.S. (e.g., Stahle and Chaney 1994, Orwig et al. 2001), this study investigated the possibility that there might to be more old-growth forest in Kentucky than was previously thought. The long-term preservation of such forests could help insure the persistence of structural characteristics that are not fully understood, some of which might be important to ecosystem function. Contrary to expectations and the methodology of this work, this study suggests that eastern Kentucky might not have more old-growth forest on its landscape than previously thought. Due to limited sample size this study is far from comprehensive. More research of this type is needed in eastern Kentucky.

Angel Hollow, Gladie Creek, Hensley-Pine Mountain, Natural Bridge, and Shillalah Creek might not be old-growth forest according to study standards, but their importance should not be overlooked. For instance all of the forests have old trees and may contain plants that are threatened or rare in Kentucky. Gladie Creek possesses what is possibly the oldest documented *Aesculus flava:* at >400 years old it may be the oldest documented tree of any species in Kentucky (Eastern OLDLIST 2010). Additionally this site contains the glacial relict *Taxus canadensis* (Clark and Weckman 2008). Natural processes have been allowed to proceed for such a long time in forests like Angel Hollow that they look and might be functionally similar to "classical" old-growth forests. In the absence of forests free of post-European settlement disturbance, these old second-growth forests or marginally disturbed forests are our best replacements (Kenific et al. 2005).

4.3 Conclusions

Although each forest investigated in this study contains trees established prior to European settlement of eastern Kentucky, they do not seem to be old-growth forest according to the standards of this study. Several lines of evidence were used to deduce the maturity state of each forest, including analysis of age structure and disturbance history, CWD volume, decay class and size distribution, forest structure, and direct evidence of human alteration (e.g. roads, stumps). Forest attributes were compared to previously studied, regional old-growth forest. In each case, to some degree, sites studied here did not compare favorably to regional old-growth forests. However, because of great variability in site conditions across the region and other ecological phenomena (e.g. the loss of *Castanea dentata*, lack of oak regeneration) these lines of evidence are challenging to interpret. Even so, they are some of the best indicators available in deducing whether or not a site is in fact old-growth forest.

Even though these study sites might not be old-growth forest, data obtained here provide a baseline for more detailed dendrochronological, structural, and ecological comparisons with other forests in the region. Future research in this area should increase our understanding of the state of Cumberland Plateau forests. Since the area studied here only represents a small fraction of the region's forested landscape, it is possible that further study of different sections of eastern Kentucky will reveal old-growth forest. Ultimately, a comprehensive understanding based on a larger network of rigorous field study, dendrochronological analysis and historical information is needed to evaluate the extent of old-growth forest in Kentucky.

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APPENDIX I

DESCRIPTION OF STUDY REGION

Research was conducted in eastern Kentucky's Cumberland Plateau region of the southern Appalachian Plateau province. This region encompasses about 63,840 sq. km (USDA NRCS 1981) and includes much of eastern Kentucky and Tennessee, northeastern Alabama, and lesser parts of West Virginia, Virginia, and Georgia. Elevations range from 366 meters above sea level (msl) to 610 msl. Southern portions of the region generally have higher precipitation and temperatures than northern areas. Mean annual precipitation is about 1,175 mm/yr. with about 525 mm falling during the growing season. The region has a freeze-free period of around 175 days and temperatures average from 1°C in January to 23°C in July near its geographic center (Smalley 1986).

Sedimentary rocks underlie the Cumberland Plateau province in eastern Kentucky. A cap of hard Pennsylvanian sandstone is often found on ridges while outcrops of Mississippian limestone, chert, shale, conglomerates, and sandstones occur on lower slopes and in streambeds. Ridges and slopes characteristically have soils derived from sandstone and shale and are typically loamy to clayey, well drained, acidic, and low in fertility (Jones 2005). Since being uplifted by the Alleghany Orogeny in Paleozoic times, the Cumberland Plateau has become deeply incised by streams. The dissected terrain is rugged and differential weathering of varying rock types create many caves, arches, rock shelters, chimneys, and sinks.

Braun (1950) and Kuchler (1964) classified the forests of eastern Kentucky's Cumberland Plateau as mixed-mesophytic. These forests are characterized by their canopy species and structural diversity (Muller 1982). *Aesculus flava* and *Tilia americana* are indicators of mixed-mesophytic forests. Other common canopy species include *Quercus alba, Q. rubra, Fraxinus americana, Fagus grandifolia, Acer saccharum, Liriodendron tulipifera,* and *Tsuga canadensis* (Jones 2005). High species richness is typical of all forest layers, and at the community level, mixed-mesophytic forests may contain over 30 canopy tree species (Hinkle *et al.* 1993). Because the Cumberland Plateau is such a varied landscape, it possesses many different forest communities. Differing slope position, aspect, and form create microclimates and edaphic conditions suitable for great diversity at the landscape scale. As this is the case, true mixed-mesophytic forests are found only in protected mesic sites such as gorges and coves on the plateau (Martin 1992).

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APPENDIX II

SPECIES COMPOSITION AND DESCRIPTION OF STUDY SITES

Table A-2.1 shows the species composition of each study site. Angel Hollow is part of the Daniel Boone National Forest (DBNF) and is situated along a tributary to Pine Creek in Laurel County. With 16 species in the canopy, this site is dominated by *Tsuga canadensis* with *Liriodendron tulipifera* and *Betula lenta* being the next most important canopy species, respectively. *Tsuga canadensis* is also the most important species found Gladie Creek with *Fagus grandifolia* and *Pinus strobus* being the next most important. This site is located in the Red River Gorge area of Menifee County and 14 species were found in its canopy, including *Aesculus flava* and *Tilia americana* L., two indicators of true mixed-mesophytic forest. Gladie Creek is part of the Clifty Wilderness Area located in DBNF. Hensley-Pine Mountain is part of a Wildlife Management Area (WMA) that is in a protected high elevation location found in Letcher Co., its three most important canopy species are *Quercus montana*, *Acer rubrum*, and *Liriodendron tulipifera*. Seventeen canopy species were documented at Hensley-Pine Mountain, much of this species richness was likely due to the protected nature and high elevation of the site, which combined allowed for such species as *Acer pensylvanicum* L. and *Magnolia fraseri* Walter (personal obs.). With 20 canopy species, Natural Bridge State Resort Park had the highest canopy species richness, making it most similar to a true mixed-mesophytic forest, though the site lacked *Aesculus* in its canopy. Natural Bridge is located in Powel County's Red River Gorge area and *Liriodendron tulipifera*, *Tsuga canadensis*, and *Acer saccharum* are its three most important species. *Quercus coccinea*, *Acer rubrum*, and *Quercus montana* are the three dominant species at Shillalah Creek WMA, a ridge-top site located in Bell County. The dry conditions at Shillalah are likely a contributing factor in the site's low canopy species richness: it had only seven canopy species.

Table A-2.1 Species importance values for five study sites thought to be old-growth forest in Eastern Kentucky's Cumberland Plateau and mountain regions.

Species		Angel Hollow	Gladie Creek	Natural Bridge	Pine Mtn.	Shillalah Creek
Acer pensylvanicum L. (ACPE)	Trees	0	0	0	5.9	0
	saplings	0	0	0	7.4	0
Acer rubrum (ACRU)	Trees	12.3	11.9	16.5	51.1	81.4
	saplings	19.6	6.6	44.1	111	190.3
Acer saccharum (ACSA)	trees	10.7	17.8	38.2	24.7	0
	saplings	14.4	24.4	67.3	26.1	0
Aesculus flava (AEFL)	trees	0	6.4	0	0	0
	saplings	0	3.3	0	0	0
Asimina triloba (ASTR)	trees	2.6	0	0	0	0
	saplings	8.6	13.0	4.0	0	0
Betula lenta (BELE)	trees	30.1	10.5	8.2	3.1	0
	saplings	45.4	3.7	5.6	10.9	0
Carpinus caroliniana (CACA)	trees	0	0	0	0	0
	saplings	3.8	0	0	0	0
Castanea dentata (CADE)	trees	0	0	0	0	0
	saplings	0	0	0	0	5.7

Table A-2.1 (continued)

Species		Angel Hollow	Gladie Creek	Natural Bridge	Pine Mtn.	Shillalah Creek
Carya glabra						
(CAGL)	trees	0	0	0	10.6	0
	saplings	0	0	0	3.5	0
C. tomentosa						
(CATO)	trees	0	0	6.1	3.5	0
	saplings	0	0	3.0	0	0
Cornus florida						
(COFL)	trees	0	0	7.4	0	0
	saplings	0	0	8.4	3.6	0
Fagus grandifolia						
(FAGR)	trees	2.7	46.4	18.8	0	0
	saplings	8.6	38.9	22.4	0	0
Fraxinus americana						
(FRAM)	trees	1.5	0	0	0	0
	saplings	0	0	0	0	0
Ilex opaca						
(ILOP)	trees	0	5.5	0	0	0
	saplings	21.8	6.5	0	0	0
Juglans nigra						
(JUNI)	Trees	0	0	0	3.5	0
	saplings	0	0	0	0	0
Liriodendron						
tulipifera (LITU)	Trees	47.5	25.9	67.9	27.1	0
	saplings	6.3	0	0	11.3	0
Magnolia						
accuminata						
(MAAC)	Trees	2.7	0	2.8	7.2	0
	saplings	8.9	5.8	3.1	4.6	0

Table A-2.1 (continued)

Species		Angel Hollow	Gladie Creek	Natural Bridge	Pine Mtn.	Shillalah Creek
M. frazieri						
(MAFR)	Trees	0	0	0	3.2	0
	saplings	0	0	0	3.8	0
M. macrocarpa						
(MAMA)	trees	5.7	5.6	2.6	7.0	0
	saplings	12.5	13.5	7.8	17.1	0
M. tripetala						
(MATR)	trees	7.7	0	5.2	0	0
	saplings	35.0	7.3	16.5	0	0
Nyssa sylvatica						
(NYSY)	trees	2.6	0	7.1	14.9	10.3
	saplings	0	0	19.7	31.0	53.0
Oxydendrum						
arboreum (OXAR)	trees	3.3	0	4.1	19.6	47.8
	saplings	9.8	0	5.8	17.2	51.0
Pinus strobus						
(PIST)	trees	0	42.8	11.0	0	0
	saplings	0	0	3.3	0	0
Prunus serotina						
(PRSE)	trees	0	0	0	0	0
	saplings	0	0	4.3	0	0
Quercus alba						
(QUAL)	trees	21.8	6.4	4.2	20.2	26.9
	saplings	0	0	0	0	0
Q. coccinea						
(QUCO)	trees	0	0	3.5	0	57.3
	saplings	0	0	0	0	0

Table A-2.1 (continued)

Species		Angel Hollow	Gladie Creek	Natural Bridge	Pine Mtn.	Shillalah Creek
Q. montana						
(QUMO)						
	trees	4.5	3.5	27.2	50.0	44.7
	saplings	0	0	0	0	0
Q. rubra						
(QURU)	trees	2.8	6.7	18.6	26.3	31.7
	saplings	0	0	0	0	0
Sassafras albidum						
(SAAL)	trees	0	0	4.8	25.4	0
	saplings	2.9	0	10.2	39.8	0
Tilia americana						
(TIAM)	trees	0	4.6	10.3	0	0
	saplings	4.4	0	17.9	0	0
Tsuga canadensis						
(TSCA)	trees	141.8	106.0	35.6	0	0
	saplings	98.0	170.9	53.4	17.5	0
Ulmus rubra						
(ULRU)	trees	0	0	0	0	0
	saplings	0	0	2.9	0	0

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APPENDIX III

SUPPLEMENTAL DISCUSSION

Each forest has direct evidence of human disturbance. Angel Hollow has the remains of a weir or a similar structure on its north drainage. Less pointed evidence at this site includes a lack of oak establishment after the 1740's and a hemlock stand situated around the weir. Although there is currently a pipeline running through a section of Angel Hollow, no old roads, skids, coppiced trees, or stumps were noted. In contrast, the remaining forests possess these man-made attributes. Shillalah Creek is the only forest (other than Angel Hollow) in which old roads were not observed, although it exhibits a different sort of direct evidence of human disturbance. A stand of *Quercus coccinea*, which reached coring height in the 1940's abruptly flanks an area with old *Quercus alba* and *Q. montana*.

Although Angel Hollow is closest to study standards of old-growth forest structurally, it is heavily dominated by *Tsuga canadensis.* Thus, it differs somewhat in composition from that of mixed-mesophytic forests on which this study's standards are based and it seems relevant to compare Angel Hollow with other forests of similar composition. Hemlock is one of the smallest components at Lilley-Cornet Woods (LCW) but it makes up a significant community type. At 321 and 478 trees >12.5 cm DBH/ha respectively, Martin (1975) found tree densities to be the highest in LCW's hemlock communities. Tyrrell and Crow (1994) documented densities in 25 old-growth hemlock-hardwood stands to range between 1200 trees > 10 cm DBH/ha in the youngest stands and 400 trees > 10 cm DBH/ha in the oldest. With only 304 trees >10 cm DBH/ha Angel Hollow falls below densities estimated by Martin (1975) and Tyrrell and Crow (1994). This suggests that, although it is close to study standards, it differs structurally from previously studied old-growth hemlock communities.

Angel Hollow's volume of coarse woody debris (CWD) and number of snags/ha also seem to deviate from eastern hemlock forests, but this may be due to differing site conditions and decay rates. Tyrrell and Crow's (1994) CWD findings are a great deal higher than that of Angel Hollow. Goodburn and Lorimer (1998) calculated a volume of CWD close to 100 m^3/ha in a hemlock-hardwood forest in Michigan and Wisconsin. They also documented almost 41 snags >45 cm DBH/ha. Considering Goodburn and Lorimer's (1998) study also found more CWD and snags in hardwood communities than would be expected in corresponding southern forests, differing decay rates between these northern sites and Angel Hollow might partially explain disparity in CWD volume and snag density. Decay rates of 0.07 and 0.11 are common for mixed forests in Tennessee, whereas Tyrrell and Crow's (1994) Michigan and Wisconsin forests' decay rate averages only 0.021 (Busing 2005). Although Angel Hollow does not possess as much CWD or as many snags/ha as more northerly sites, it may be up to par with more regional old-growth Hemlock forests, due to relatively high rates of decay.

Angel Hollow is similar to study standards structurally but there are indicators that suggest the site has been directly altered by modern humans to some degree. For instance, the remains of a weir or a similar structure are present on the site's north drainage. The structure is surrounded by essentially a pure stand of *Tsuga canadensis*. Excepting a short stint as an important tanbark tree, *Tsuga* has historically been of low importance to the timber industry, and stands were often left following selective logging of more valuable trees such as *Quercus spp.* and *Liriodendron tulipifera* (Kelty and D'Amato 2005). Furthermore, a lack of oak establishment since the 1740's is striking in Angel Hollow's age structure and possibly indicates human activity. Though it seems unlikely that loggers would have left such a high number of old trees at this site, all of them are located in draws and ridges away from the hemlock stand and might have been inaccessible to loggers.

There are no decades in which a high percentage of trees exhibit release in Angel Hollow's disturbance history but establishment environment indirectly sheds light as to when selective logging might have occurred. Angel Hollow's disturbance history might reflect natural disturbance due to tree fall (Runkle 1982), but it is interesting to note that after the 1860's, 27 of 42 trees established in an open grown setting whereas only 3 of 17 were open grown prior to that time. Coincidentally, this seeming shift in canopy setting is accompanied by accelerated incidence of major disturbance since the 1850's. This might indicate a change in forest processes during the mid-1800's at Angel Hollow, possibly attributable to human activity during this time (Canham 1985, Orwig and Abrams 1999). Although disturbance history is somewhat inconclusive at Angel Hollow, based on structural discrepancies with regional old-growth hemlock communities and observations such as man-made structures, this site is not old-growth by study standards.

Although there are no obvious cohorts causing Gladie Creek to appear even-aged, it differs from previously studied old-growth forest structurally, especially in CWD volume. Like Angel Hollow, Gladie has a strong component of *Tsuga canadensis* (IV = 106). It is actually more comparable in density to other *Tsuga* dominated eastern old growth forests than is Angel Hollow (Martin 1975, Tyrrell and Crow 1994), but its volume of CWD is far below regional expectations. Horse and ATV trails along with campsites complete with fire-rings and trash piles are present. Thus, heavy recreational use at Gladie Creek might account for a portion of this lack of CWD.

Gladie Creek's disturbance history suggests that changes in forest process took place during the late 1800's which might be attributable to human land use practices (Canham 1985, Orwig and Abrams 1999). After the 1890's trees began establishing in an open canopy position, whereas before this time all documented trees established under a closed canopy. Species diversity began to increase during this time as well and ~36% of trees exhibit crown release during the 1870's while ~41% release during the decade of 1900. The timing of these apparent changes in forest process coincides with documented logging activity in the area (KYSP 2010).

Hensley-Pine Mountain seems to be diverging from the structural characteristics of previously studied eastern old-growth forest. Although there are certainly other factors involved, as indicated by a lack of old trees documented in transects as well as by the presence of coppiced trees and old roads, this divergence could be partially due to a drastic shift from oak dominance to one of maple dominance. No oak saplings were documented in any forest in this study (Table A-2.1) which suggests that all sites are experiencing compositional shift, a phenomena that seems to be occurring throughout eastern North America (Lorimer 1984, McCarthy et al. 1987, Goebel and Hix 1996, McEwan and Muller 2006). Red maple composes 60% of Hensley-Pine Mountain's 1960's cohort. This mass of maples greatly contributes to Hensley's relatively high density of 479 trees/ha as well as to the site's cohort establishment, attributes which seem to diverge from this study's definition of eastern old-growth forest (Martin 1992, Orwig and Abrams 1999).

There are indicators of canopy wide disturbance evident in Hensley-Pine Mountain's trees. Sixty percent of trees exhibit release during the 1930's (40% major) after which 33 of 41 trees established in an open grown setting. The 1930's are about the time that chestnut blight (*Cryphonectria parasitica*) swept through eastern Kentucky (Muller 1982, Delcourt et al. 1998). Coppiced *Castanea dentata* were found at Hensley-Pine Mountain, along with remnants of fallen trees of that species. Possibly humans altered this forest through logging but it is apparent that the site has been affected by the introduction of the chestnut blight into North America. This loss, along with contributing factors, may well have facilitated the influx of *Acer rubrum* into Hensley-Pine Mountain and the site's seemingly concomitant divergence from eastern old-growth characteristics.

Similar to Angel Hollow, Natural Bridge appears to be a mature forest that might be converging with old-growth characteristics. Although this forest is similar structurally and compositionally to previously studied old-growth mixed-mesophytic forest (Martin 1992), CWD volume, snag density, and reports of logging in the area are not consistent with study standards. Natural Bridge is documented to possess only two pieces of CWD >50 cm DBH and none > 90 cm. The site's lack of large diameter CWD might reflect logging events noted along Natural Bridge State Resort Park's trails as well as the park's website (KYSP 2010). Additionally, only one snag >25 cm DBH was encountered in transects. As is the case in all sites studied here, the paucity of snags might be indicative of post-European anthropogenic land use (Muller and Liu 1991, Runkle 2000). Logging events would likely have taken larger trees out of the site's dead-wood resource bank, altering its current CWD volume and forest structural characteristics (Hansen et al 1991, McGee et al. 1999).

Natural Bridge exhibits some synchronous decades of disturbance and trees established in an open grown setting as well as a 60 year gap in recruitment, attributes which might provide further record of area logging. Evidence of disturbance is present in the 1890's with 31% of trees exhibiting release. This is about the time that the Mountain Central Railway was built in the vicinity of Natural Bridge (KYSP 2010). Natural Bridge's gap in recruitment might be a relic of 1890's logging activity. As it is unlikely that loggers took every tree out of the forest that recruited between the 1760's and the 1820's, the gap might represent an earlier natural disturbance or reflect the relatively short longevity of species (e.g. *Acer rubrum*, *Cornus florida* L., *Sassafras albidum* (Nutt.) Nees and *Magnolia* spp.) that seem to have only recently entered into the forest (Eastern OLDLIST 2010). Ten of the fifteen trees recruited in eight decades following this gap are open grown *Liriodendron,* which indicates natural disturbance as the recruitment gap's cause, as these trees are valuable timber. Although the gap's cause is difficult to discern, Natural Bridge's disturbance history suggests that it was in fact altered by human land use since the times of European settlement, specifically in the late 1800's.

The area of Shillalah Creek investigated here does not seem to be comparable to previously studied eastern old-growth forest. It exhibits strong cohort establishment and has direct signs of human disturbance, including an abrupt demarcation between an area containing pre-European *Quercus alba* L. and *Q. montana* from a stand composed of *Q. coccinea* and *Q. rubra* L. that reached coring height in the 1940's. These trees, along with an *Acer* cohort in the 1950's, contribute to the site's high density. A lack of CWD of all sizes and decay classes is apparent at Shillalah Creek. Slash left from logging could easily have decayed since the early 1900's (Mattson et al. 1987). Shillalah Creek's disturbance history suggests release during the 1930's. As at Hensley-Pine Mountain, chestnut sprouts are common here. Since no downed chestnut logs were evident it seems likely that Shillalah Creek's chestnut was salvaged and the area was logged sometime during or just after the chestnut blight.

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