National Park Service
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Northeast Region
Philadelphia, Pennsylvania

Rimrock Pine Communities at New River Gorge National River

Technical Report NPS/NER/NRTR—2007/081

ON THE COVER
A rimrock pine community located along the Endless Wall at New River Gorge National River, WV.
Photograph by: R. Stockton Maxwell

Rimrock Pine Communities at the New River Gorge National River

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Executive Summary

In 2003, the National Park Service (NPS) at New River Gorge National River (NERI) hosted a workshop to identify significant forest issues, resources, and processes occurring within the park (National Park Service 2003b). Several forest communities of concern were identified by the panel of scientists and resource managers. One such community, the rimrock pine forest lining the rim of the gorge, was chosen due to the importance of the community to wildlife and recreation. The rimrock pines also were thought to be a historically significant feature of the northern section of the gorge as evidenced by historic photographs from the 1940s and 1950s. The panel suggested an investigation be conducted to better understand the establishment and maintenance of the rimrock pine forest.

The workshop was followed by the Natural Resource Assessment for New River Gorge National River (Mahan 2004). In this report, Mahan provided information on the current status and significance of, threats to, and gaps in knowledge about the natural resources at NERI. The rimrock pine community was identified again as a valued resource that may be in decline due to lack of disturbance. Vanderhorst (2001) reported that plant communities including the rimrock pines, old fields, seeps, and herbaceous wetlands occupy approximately 1% of the land area at NERI. Despite the small area forested by rimrock communities they have been deemed valuable by the NPS and warrant further research.

The Natural Resource Assessment has served as a primer for the development of a new General Management Plan (GMP) for the park. Suggested management recommendations for the rimrock pine community include forest health monitoring, dendrochronological analysis, and forest restoration through the use of prescribed burning. The GMP is presently under revision; however, management of niche communities may require research before implementation of management and restoration activities. Thus, both qualitative and quantitative descriptions of the rimrock are crucial to the preservation of this resource for the use of wildlife and the enjoyment of future generations of park visitors.

The present study was designed to meet the following research objectives of the NPS:

Objective 1. An inventory and description of all strata of vegetation was conducted to evaluate the current stand condition including species composition, stand structure, vigor, and potential for regeneration. Understanding the current condition of the rimrock community is necessary to establish whether or not the ecosystem is in the desired state which will affect future management decisions regarding these valued habitat and recreation areas.

Objective 2. A dendroecological analysis of Virginia pine, as well as other dominant species present in the rimrock community, was used to determine the age structure, growth trends, and disturbance regime (i.e., fire history) of the forest. This investigation required the collection of increment cores from live canopy trees and cross sections from fire-scarred Virginia pines.

Objective 3. An array of historic evidence was collected and reviewed to aid in the interpretation of the current condition of the rimrock forest and to determine the historic range of the Virginia pine forest type. Materials such as past land use records, mining activities, and historic maps and

photographs were essential in the development of a clearer understanding of the establishment and maintenance of the rimrock community.

Acknowledgements

I would like to thank the National Park Service at the New River Gorge National River, West Virginia for funding the study. A special thanks to John Perez, NERI resource manager, for his support of the project and help in the field. Thank you to my advisor, Ray R. Hicks, for taking me as a student and the many opportunities he afforded me during my master's research. Thanks to Jim Rentch for letting me occupy his office for months while I measured tree rings. Thanks to Amy Hessl for igniting my interest in fire history and the excellent feedback on my fire history literature review. Thanks to Gary Miller for joining my graduate committee, reviewing my thesis, and stimulating discussion.

Introduction

New River Gorge National River

New River Gorge National River (NERI) was formed in 1978 for "the purpose of conserving and interpreting outstanding natural, scenic, and historic values and objects in and around the New River Gorge and preserving as a free-flowing stream an important segment of the New River in West Virginia for the benefit and enjoyment of present and future generations" (Public Law 95-625). With this mandate and subsequent legislation, the National Park Service (NPS) has protected and managed the cultural, recreational, and ecological resources located along the 85.3-km stretch of the New River in southern West Virginia between the towns of Hinton and Fayetteville. There are 28,636 ha of land, spreading through Summers, Fayette, and Raleigh counties, within the park boundary. While the NPS owns 73% (20,828 ha) of this land, private landowners and companies control the remaining hectares zoned within the boundary.

The New River Gorge is a significant physical feature on the landscape of the southern Allegheny Plateau, reaching over 300 m in depth and 1.6 km in width. The northwestern flow of the New River cuts across the Appalachian Mountains allowing for a mix of northern and southern forest communities. Braun (1950) classified this area of the Allegheny Plateau as a mixed mesophytic hardwood forest. Grafton (1982) and Suiter (1995) documented the occurrence of several hundred species of plants native to West Virginia as well as many species rare to NERI. Currently, species of oak (*Quercus spp.*), yellow-poplar (*Liriodendron tulipifera* L.), red maple (*Acer rubrum* L.), eastern hemlock (*Tsuga canadensis* [L.] Carr.), and other mesic species predominate within the park. However, unique forest communities, such as the rimrock pine forest, exist throughout NERI. Several factors are responsible for the establishment and maintenance of the diversity at NERI, including past and present land use, disturbance regimes, differences in aspect and elevation, and a mosaic of soil types.

Rimrock Pine Communities

The rimrock pine communities are most common on the southern and southwestern aspects of the northern section of the gorge, occurring on shallow, xeric soils. In Brooks' (1910) description of the original forest of Fayette County, he stated that scattered clumps of pitch pine (*Pinus rigida* Mill.) and Virginia pine (*Pinus virginiana* Mill.) grew on dry ridges and along the sandstone outcrops. Vanderhorst (2002) classified these linear communities as Virginia pine forests with lesser amounts of pitch pine, black gum (*Nyssa sylvatica* Marsh.), sourwood (*Oxydendrum arboreum* [L.] DC), and oak species in the upper canopy. However, this description was based on an ocular estimation of species composition of the rimrock community rather than on sample plot data of the canopy. The Society of American Foresters (1980) list *P. virginiana* as a major species of the Virginia pine-oak (type 78) and Virginia pine (type 79) forest cover types. Also, *P. virginiana* is associated with chestnut oak (*Quercus prinus* L.; type 44), pitch pine (type 75), eastern redcedar (*Juniperus virginiana* L.; type 46), and several other forest cover types.

Carter and Snow (1990) describe *Pinus virginiana* as a small to medium-sized tree growing best on clay, loam, or sandy loam soils that are moderately well drained to well drained. The range of

P. virginiana extends from the Piedmont north to the lower elevations (760 m) of the Appalachian Mountains in central Pennsylvania. Also, it is found along the Atlantic Coastal Plain and scattered into areas of Ohio, southern Indiana, and Tennessee. *Pinus virginiana* is a colonizer of old fields, burned areas, and other disturbed sites such as surface mines. Successful establishment of *P. virginiana* is dependent on the exposure of mineral soil (Carter and Snow 1990). In a study conducted in the southern Appalachians, Barden (1976) found that all regeneration of *P. virginiana* over a 120-year period was related to site disturbances such as fire and logging. Additionally, Sucoff (1961) found that areas disturbed by either logging or fire resulted in 2 to 4 times the rate of germination than undisturbed areas and four-fold the survival rate at 2 years post-germination. One issue of concern is the ability of *P. virginiana* to regenerate on the rimrock. It remains unknown how much *P. virginiana* regeneration is present in the community and how much is necessary to maintain the historic range of the rimrock forest type.

Burkman and Bechtold (1998) used Forest Health Monitoring and Forest Inventory and Analysis (FIA) data from the USDA Forest Service to determine whether or not *Pinus virginiana* was in decline. They found that *P. virginiana* experienced significant crown dieback and reduced crown density during the 1991-1997 period. In addition, the FIA data showed that mortality of the species was 48% and removals (i.e., timber) were 92% of the net annual growth for this same time period. They concluded that these reductions in health and population were due to the shade intolerance and short-lived nature of *P. virginiana*. Throughout the central and southern Appalachians, other ridgetop pine species such as pitch and Table Mountain (*Pinus pungens* Lamb.) pines are also in decline (Brose and Waldrop 2000; Waldrop and others 2003). Researchers have identified several reasons for the decline including fire suppression (Abrams 1992; Delcourt and Delcourt 1997; Harmon 1982) and southern pine beetle (*Dendroctonus frontalis*; SPB) outbreaks (Zobel 1969). Similar to pitch and Table Mountain pines, regeneration of Virginia pine is thought to require fire or other disturbances to expose mineral soil and suppress deciduous competitors (Carter and Snow 1990). However, it is unclear if the rimrock pine communities are dependent on fire for regeneration or if they are an edaphic climax species on the rimrock sites.

It is known that older Virginia pine trees are susceptible to SPB attack. Veysey et al. (2003) investigated the relative suitability of *Pinus virginiana* and *Pinus taeda* L. (loblolly pine) as host species for southern pine beetle. They found that while *P. virginiana* was readily attacked and killed, it supported poor reproduction of SPB, suggesting that while outbreaks along the rimrock may occur in isolated locations, the spread of SPB is not a severe threat. Nonetheless, monitoring of NERI and surrounding NPS land should be ongoing in order to identify susceptible areas and protect valued habitats in the event of an outbreak. Other damaging agents that could affect *P. virginiana* communities include wind, snow, and ice damage, particularly in opened stands with shallow soils (Warrillow and Mou 1999). Additional threats to the health of the Virginia pine come from rodents, pine sawflies, and canker diseases (Fenton and Bond 1964).

Land Use History

Pre-European Settlement

Native American land use practices have had lasting impacts on the structure and composition of forest ecosystems in the eastern United States (Abrams 1992). Archeological evidence dating from 10,000 b.p. (before present) documents the presence of Native Americans along the New River through North Carolina, Virginia, and West Virginia. In 1965, the first official archeological survey of the upper New River uncovered 20 sites of Paleo-Indian habitation including several rock shelters (Johnson 1983). Marshall and Fuerst (1982) conducted an archeological survey of prehistoric cultures in the New River Gorge National River to aid in the collection and synthesis of cultural data and to predict the occurrence of archeological sites in the future. The authors found 248 new sites within the study area with some sites dating to 8,000 b.p. These sites were described as multi-activity rockshelters, base camps, villages, and burial mounds with varying degrees of usage. Seventy-six percent of sites were found in upland settings and were primarily rock overhangs or streamside sites. More recent evidence of Native American activity was documented by petroglyphs and pictographs representing human figures and animals. Rice (1985) mentioned the discovery of these drawings throughout West Virginia, citing Beards Fork in Fayette County as an example of the work of late prehistoric village farmers.

Other archeological investigations in the Bluestone Reservation have revealed 58 prehistoric Native American sites spanning 12,000 years (Maslowski 1982). Marwitt (1982) conducted test excavations of three sites at the Bluestone Reservation to determine the extent and nature of archeological deposits and to gather data and artifacts of prehistoric inhabitants. The excavations produced a collection of stone tools, specimens of worked bone, and shell and ceramic artifacts. Such evidence confirms the presence of Native Americans on the landscape of the southern Allegheny Plateau and the potential influence of pre-settlement land use on the forest ecosystem.

It is likely that Native American habitation in southern West Virginia was reduced significantly by the late 1600's due to campaigns by the Iroquois to dominate the region as well as the introduction of foreign diseases. The late seventeenth century saw the influence of Dutch and British traders spread into the area. One of the first documented accounts of the New River by western explorers came from a British expedition headed by Thomas Batts and Robert Fallam in 1671 (Rice 1985). The group came across a river flowing northwest near the present day West Virginia-Virginia border and named it Wood's River (a.k.a. New River) in honor of early plant-trader, Abraham Wood. England used this journey to lay claim to the region and attempted to set up a direct fur trade with remaining tribes along the New River. However, a claim by French explorers that they had penetrated the Ohio Valley two years earlier sparked an international feud and possession of southern West Virginia was in dispute until after the French and Indian War.

The earliest and largest recorded land survey in Fayette County of the Commonwealth of Virginia occurred in 1785, granting 40,680 acres along the New River to Henry Banks. In subsequent years, land was granted to hundreds of individuals along prominent branches of the New River with the more fertile land being claimed first (Peters and Carden 1926). By the time West Virginia became an official state in 1863, settlers occupying land in Fayette County were clearing forests for agriculture, raising of livestock, and probing the surface of New River Gorge for salt and coal.

Railroads, Coal, and Timber

Prior to the development of the railroad industry in the New River Gorge, coal operators faced great challenges moving coal out of the region. The first coal mine in the region was opened in 1873 by Joesph L. Buery following the completion of the Chesapeake and Ohio (C&O) Railroad. In the following decades, an extensive array of mines opened throughout the New River Gorge, becoming the dominant industry in southern West Virginia. Coal from the New River field was known internationally to be clean-burning, high-quality, and low-sulfur, making it highly suitable for metallurgic uses (Unrau 1996). By 1900, Fayette and Mercer counties had 8,287 coal employees and 1,845 associated manufacturing jobs (Unrau 1996).

One prominent coal operator, John Nuttall, became the second to ship coal out of the gorge in 1873. The Nuttallburg Coal Company consisted of two mine sites located on Keeneys Creek and Short Creek. Seventeen two-family dwellings, 80 one-family residences, 80 coke ovens, and 4 two-car monitors were erected within the first two years of operation. The Nuttallburg mine, located on the slope of the gorge just below the Endless Wall, had a scalehouse, scales, a headhouse, a blacksmith shop, a carpenter shop, a slate dump, and a tipple extending up the slope of the gorge (Figure 1). To access Nuttall's Keeneys Creek mine and his extensive landholdings on the plateau, he constructed a four-mile railroad subdivision connecting to the C&O railroad. By 1880, the Nuttallburg Coal Company was the largest producer of coal in the New River Gorge (Unrau 1996).

Figure 1. Photo of the Nuttallburg tipple below the present day study site.

To support the industry, coal companies purchased additional acreage to meet the timber requirements of the mines and mining towns. For example, Nuttall acquired 5.6 km of riverfront property as well as a 10,000-ha estate on the plateau to meet his timber needs. Brooks (1910) noted that the commercial timber industry in Fayette County did not begin until 1885. The land surrounding the approximately 150 mines in the New River Gorge was harvested by the early 1900s, leaving about 21,450 ha of virgin forests in the county. While 90% of the county grew back into forestland, the woodlot forests owned by the coal and timber industries became dominated by less valuable timber species such as black gum, American beech (*Fagus grandifolia* Ehrh.), birch (*Betula spp*.), sugar maple (*Acer saccharum* Marsh.), and red maple (Brooks 1910).

The mine at Nuttallburg was sold several times through the first half of the 20th century, and continued to produce coal until it finally closed in 1958. The town of Nuttallburg became a ghost town following the closing of the mine and the remnant mine structures became slowly covered by kudzu vines (Maddex 1992). The coal industry operated within the New River Gorge into the 1960s, producing a significant portion of the total coal for the entire country for many years. Though timber cutting and coal mining are no longer allowed within park boundaries, the impact on the landscape of decades of extraction remains, particularly through changes in species composition and forest structure.

Fire History in the Central Hardwood Region

Introduction

After decades of fire suppression in the United States, agencies such as the USDA Forest Service and the NPS have recognized the role of fire in the development and maintenance of our forestlands. Much of the current research in the US has focused on western (Agee 1993) and southeastern (Van Lear 1984; Wade and others 2000) forest ecosystems. Fire research activities have concentrated in these regions because of the high fire frequency and extent, damage to significant resources (e.g., timber, residential areas, and wildlife habitat), and availability of evidence [i.e., fire-scarred trees and stand-age data; (Agee 1993; Pyne and others 1996)]. Fire regimes in eastern deciduous forests have not been studied as extensively, yet, the importance of reintroducing fire to the eastern landscape has been discussed (Abrams 1992; Brose and others 2001; Schuler and McClain 2003) and is occurring in many locations (Brose and Waldrop 2000; Ruffner and Groninger 2006; Shifley and Brookshire 2000; Van Lear 1984). In particular, some have emphasized the role of fire in the regeneration of mixed-oak forests (Abrams 2000; Brose and others 2001; Elliott and others 2004) while others have studied fire effects on eastern pine ecosystems (Brose and others 2002; Sutherland and others 1993).

Like much of the eastern US, the role of fire in the Central Hardwood Region (Figure 2; CHR) is not clearly understood. A regime of frequent, low-intensity fires has been suggested for the majority of the region (Abrams 1992; Brose and others 2001; Lorimer 1985; Pyne 1982). However, the management of the different vegetation types present in the CHR requires specific knowledge of fire regimes in order to achieve forest regeneration and ecosystem restoration objectives. The goals of this chapter are to: 1) synthesize available fire-scar data in order to characterize the fire regime and its variability in this region, 2) address management implications, 3) discuss why there is a dearth of fire history research, and 4) help focus future research of fire history in the region.

In this review, I will focus on dendrochronological (tree-ring) evidence of fire. It is important to understand the characteristics of past fire regimes (e.g., fire frequency) if we are to determine whether or not fire is an integral part of the establishment and maintenance of forest ecosystems (Stokes 1980). While other methods of investigation (e.g., monitoring prescribed burning) have been useful in learning the effects of fire on current forest conditions (e.g., Brose and Van Lear 2004; Elliott and others 2004), restoring a historic fire regime will require accurately dated evidence of past fire frequency, intensity, seasonality, and extent. An analysis of fire scars is not without its drawbacks. Much of the evidence of historic fires has been destroyed through the extensive land clearing and logging of the 19th and 20th centuries. Yet, understanding the effects of fire in our forests will require more than evidence of the presence of fire alone (Agee 1993). We must investigate how fire has behaved over time and space to gain a better understanding of the role of fire in the CHR, and dendrochronology may be one of the best tools to accomplish this goal.

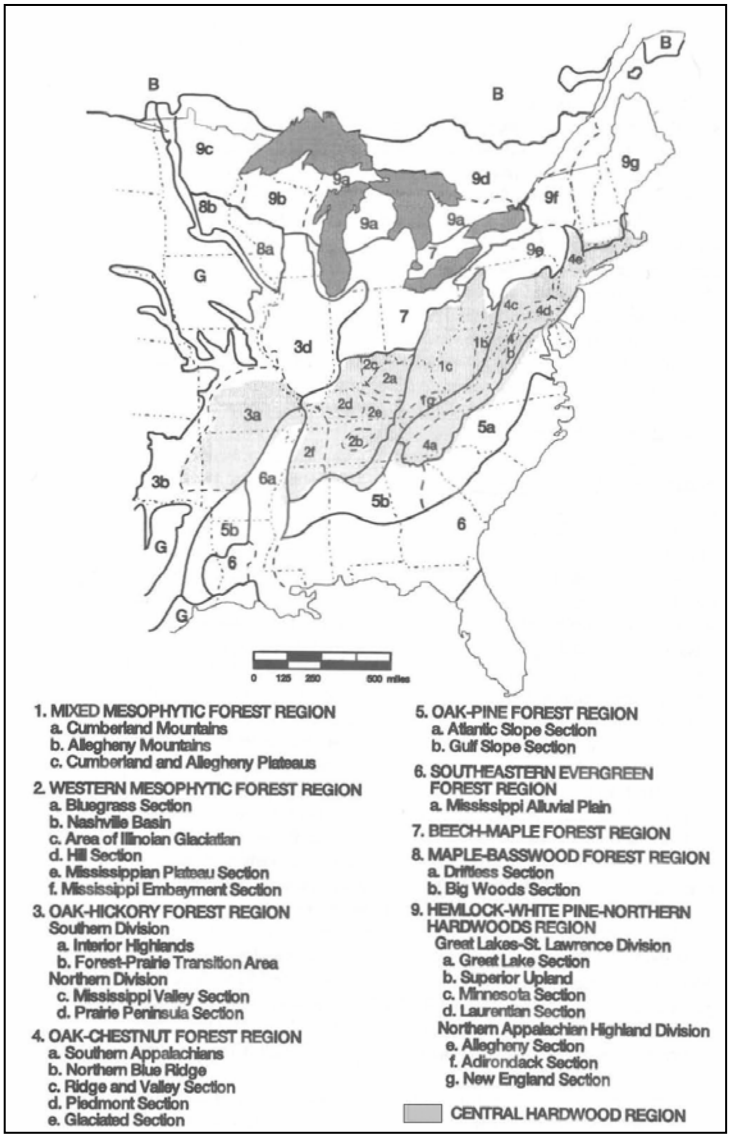

Figure 2. Braun’s (1950) vegetation regions that comprise the Central Hardwood Region (reproduced from Hicks 1998).

Central Hardwood Region

The Central Hardwood Region (Figure 2) encompasses the largest contiguous forest on Earth that is composed primarily of deciduous tree species. Hicks (1998) broadly defines the CHR as the area south of the beech-maple forests, east of the Great Plains, and northwest of the southern pine forests. It extends from New York to Georgia and from Maryland to Missouri covering approximately 609,000 km^2.

Four major vegetation types are represented in the region including the Oak-Chestnut, Oak-Hickory, Western Mesophytic, and Mixed Mesophytic (see Braun 1950). Though deciduous angiosperms predominate in the CHR, a variety of gymnosperms, such as Virginia, shortleaf (*Pinus echinata* Mill.), eastern white (*Pinus strobus* L.), and pitch pines, as well as eastern hemlock and species of spruce (*Picea spp.*), are locally important across the region. The majority of the CHR is located within the highland regions of the Ridge and Valley, Blue Ridge, Appalachian Plateau, and Ozark/Ouachita provinces with lowland areas situated in the Interior Low Plateau and New England provinces (see Fenneman 1938). The dominant climate of the region is classified as humid and continental. Total annual precipitation ranges from 100-127 cm with locally lower and higher amounts recorded in mountainous sections (National Oceanic and Atmospheric Administration 2005). Primary soil orders for the CHR include inceptisols, ultisols, and alfisols with an array of modifiers (Natural Resources Conservation Service 2005). For a complete treatment of the ecology and management of Central Hardwood Region consult Hicks (1998).

The current forests of the eastern US are the product of climate, soils, and a suite of disturbance factors such as land clearing for agriculture, logging, insect and disease outbreaks, and fires. Prior to European settlement, Native American land use was thought to significantly alter forests in the eastern US (Abrams 1992; Denevan 1992; Hicks 2000). Native Americans used fire to clear land for subsistence agriculture, drive game, create browse for game species, and create a walkable forest clear of underbrush (Pyne 1982). However, it has been difficult to determine the extent and frequency of Native burning in this region because much of the evidence supporting Native American use of fire has been from anecdotal reports of surveyors, explorers, and Native American elders. Paleoecological studies have provided the best evidence of the historic fire regime in the CHR linking pollen abundance of fire-adapted species (e.g., *Quercus spp.*) with the presence of charcoal in pond and bog core samples (Davis 1985; Delcourt and Delcourt 1997; Watts 1980). While such evidence is valuable in documenting general trends in fire frequency on the historic landscape, charcoal records have low temporal resolution and must rely on charcoal particle size to infer fire extent. A more precise method of dating fire events is dendrochronology or tree-ring analysis (Stokes 1980). The application of dendrochronology to the analysis of fire scars has allowed researchers to assess the frequency (e.g., Grissino-Mayer and Swetnam 1997), extent (e.g., Heyerdahl and others 2001), and seasonality of fire events (e.g., Grissino-Mayer and Swetnam 2000) with accuracy not possible in other methods of investigation.

In contrast to the Native American uses of fire, the impact of European settlement on the CHR landscape is better understood. Settlers utilized fire to clear land for farming and cut trees for fuel and building materials. In the mid-1800's, the iron industry began to develop in the region. Firing stone furnaces required repeated clearing large patches of forestland on very short rotations and burning the wood to produce charcoal (Clatterbuck 1991; Hicks 2000). Luther (1977) estimated that the pig-iron industry of the highland rim of middle Tennessee required approximately 97,000 hectares of timber to support 11 furnaces. In the late-1800's and early-1900's, the timber industry followed the iron industry cutting much of the remaining forests. Similar land use changes were common across Pennsylvania, Maryland, and West Virginia.

Fire History Terminology

In reviewing the studies of fire history in the CHR, several key characteristics of fire regimes should be clarified in order to correctly interpret existing studies. The level of analysis has become more complex as the science of tree-ring dating and its application to studying past fire regimes has developed. Initially, researchers calculated simple mean fire intervals. Now, more precise descriptions of fire regimes are determined with new standards for sampling designs, statistical procedures, and data on seasonality and fire extent.

Though fire is considered to have been a ubiquitous disturbance in the CHR, local disturbances may be altered by climate, topography, structure and composition of the forest, and humans (White and Jentsch 2001). It is important to consider the generality of fire regimes and their applicability to other regions because the description of a fire regime may change depending at which spatial and temporal scale they are measured (Morgan and others 2001). For example, a fire frequency measure can be estimated for one point in a stand (i.e., point fire return interval) or for the forest as a whole [(i.e., composite fire return interval; (Arno and Peterson 1983)]. Knowing the vegetation type, size of the study area, time period, sample size, and whether or not fire scar dates have been crossdated is critical in the interpretation of fire intervals. The following list of definitions commonly used in fire scar analysis literature were adapted from Romme (1980):

Fire Interval (a.k.a. Fire Free Interval or Fire Return Interval)- the number of years between two successive fires that have been recorded (i.e., produced a fire scar) by one or more trees.

Mean Fire Interval (a.k.a. Mean Fire Free Interval, Mean Fire Return Interval, or MFI)- the arithmetic average of all fire intervals in a defined study area of a defined period of time; also, Weibull probability distributions are used to determine median (WMFI) and modal fire intervals (WModFI).

Fire Intensity- a relative term used to describe the magnitude of ecological effects of fire (e.g., a fire that results in low mortality is referred to as a low-intensity fire while a stand-replacing fire produces high mortality); also, percent of scarred trees has been used to describe intensity.

Fire extent- the area of an individual burn (in hectares or square kilometers); while not often discussed in fire history literature in the eastern US, several authors infer fire extent from the number and location of fire-scarred trees of a given fire year.

Seasonality- the time of year when a fire occurred; position of the fire scar within the tree ring is typically used to determine seasonality and fires are typically classified as early-growing season, late-growing season, and dormant season fires.

Crossdating- used to establish synchroneity between the ring patterns of one sample with another; crossdating allows fire scars to be absolutely dated by correcting individual specimens with a master chronology.

Fire Histories by Forest Type

The first goal of this paper is to review available fire history research conducted in the CHR. Several databases were searched to compile a list of references to be reviewed (Table 1). In the past, forest types have been used to summarize fire regimes due to the similarity of vegetation and environmental effects of fire on these communities (Abrams 1992; Agee 1993; Brown and Smith 2000). I have chosen to organize the data by Braun's (1950) forest regions: Oak-Chestnut, Oak-Hickory, Western Mesophytic, and Mixed Mesophytic. Study locations are displayed in Figure 3 and Table 2 provides a summary of the fire history data collected for the review. For each study I have reported the vegetation region, sub-region, species, fire interval, chronology dates, frequency computation method, size of study area, number of fires or scars, sample size, type of data, and whether or not the authors crossdated specimens and addressed fire extent, seasonality, and intensity.

In the Oak-Chestnut forest type that extends along the Appalachian Mountains, researchers have constructed fire history chronologies for *Quercus* (oak) and *Pinus* (pine) species. Buell (1954) dated an old-growth white oak (*Quercus alba* L.) in central New Jersey that recorded 6 fires between 1611 and 1711 with a fire interval of 14 years (calculated by author based on fire dates). Though this represented one of the first published examinations of fire history using tree rings in the east, these data are not replicated and must be interpreted cautiously. More recently, Schuler and McClain (2003) seized the opportunity to collect red oak (*Quercus rubra* L.) cross sections following an illegal timber cut on land owned by The Nature Conservancy in the Ridge and Valley province. The authors developed a 156-year chronology with fire intervals ranging from 7 to 32 years (MFI = 15.5 years). However, the limited sample area (0.6 ha) and xeric site conditions make generalizations to other sites in the Oak-Chestnut forest type tenuous.

Table 1. Databases searched for fire history literature with internet addresses and search word(s) used. All databases were last accessed December, 2005.

Database	Internet Address	Search Word(s)
AGRICOLA	http://agricola.nal.usda.gov	fire history
Google Scholar	www.scholar.google.com	fire history
EbscoHost	www.ebscohost.com	fire history
The Nature Conservancy	www.conserveonline.org	fire management
USDA Forest Service TreeSearch	www.treesearch.fs.fed.us	fire, fire history
Bibliography of Dendrochronology	http://www01.wsl.ch/dendrobiblio/	fire
Tall Timbers Fire Ecology Database	www.talltimbers.org	fire history

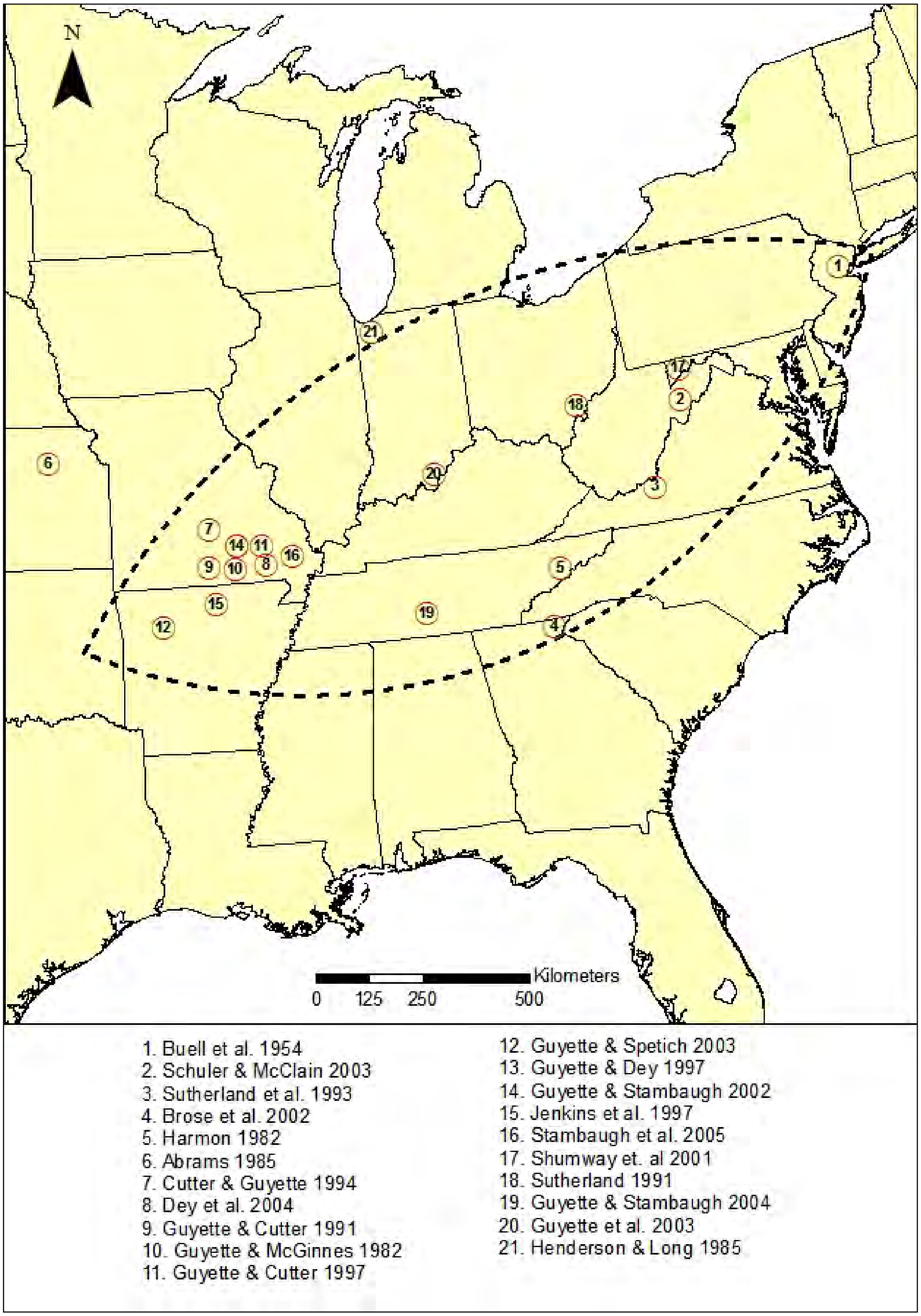

Figure 3. Fire history study locations (red circles) of the Central Hardwood Region (dashed line).

Table 2. Summary of the fire history studies conducted in the Central Hardwood Region. * - MFI calculated by author. ** - MFI is the Mean Fire-free Interval. WModFI is the Weibull Modal Probability Interval. WMFI is the Weibull Median Probability Interval.

Sub-region	Study Location	Species	Fire Interval (years)	Chronology	Interval Method**	Size of Study Area	Number of Fire Scars	Sample Size	Cross-dated? (Y/N)***	Fire Extent? (Y/N)	Seasonality? (Y/N)	Intensity/ Severity? (Y/N)	Reference
Oak Chestnut:													
Piedmont Section	Somerset County, New Jersey	*Quercus alba*	14.0*	1641-1711	MFI	N/A	6	1	N	N	N	N	Buell et al. 1954
Ridge and Valley Section	North Fork Mountian, Circelville, West Virginia	*Quercus rubra*	15.5 14.8	1846-2002	MFI WMFI	0.6 ha	17	17	Y	N	N	Y	Schuler & McClain 2003
Ridge and Valley Section	Brush Mountain, Montgomery County, Virginia	*Pinus pungens*	9.0-11.0	1765-1993	MFI	N/A	81	14	Y	N	Y	Y	Sutherland et al. 1993
Southern Appalachian Mountains	Chattahoochee National Forest, Northern Georgia	*Pinus pungens*	16.7*	1946-1996	MFI	3, 10-ha sites	12	30	N	N	N	N	Brose et al. 2002
Southern Appalachian Mountains	Great Smoky Mountains National Park, Tennessee/ North Carolina	*Pinus spp.*	12.7	1856-1940	MFI	9100 ha	115	43	N	Y	N	N	Harmon 1982
Forest-Prairie Transition Area	Konza Prairie, NE Kansas	*Quercus macrocarpa, Quercus muehlenbergii*	11.2-19.7	1862-1983	MFI	3, 1-ha sites	47	19	N	N	N	N	Abrams 1985
Interior Highlands	Mark Twain National Forest, Missouri	*Quercus stellata*	2.8 24	1740-1850 1851-1975	MFI	240 ha	84	24	Y	Y	N	Y	Cutter & Guyette 1994
Interior Highlands	White Ranch State Forest, Missouri	*Quercus stellata*	3.7 7.6 3.6	1705-1830 1831-1960 1961-1997	MFI	100 ha	135	35	Y	N	N	Y	Dey et al. 2004
Interior Highlands	Caney Mountain Wildlife Refuge, Missouri	*Quercus stellata, Pinus echinata, Juniperus virginiana*	4.3 6.4	1710-1810 1810-1990	MFI	600 ha	175	43	Y	Y	N	Y	Guyette & Cutter 1991
Interior Highlands	Buttram Hollow, Ava Ranger District, Missouri	*Juniperus virginiana*	3.2 22.0	1730-1870 1870-1980	MFI	259 ha	96	21	Y	N	N	Y	Guyette & McGinnes 1982
Interior Highlands	Current River Watershed, Van Buren, Missouri	*Pinus echinata*	17.7 12.4 3.7	1580-1700 1701-1820 1821-1940	MFI	431,600 ha	2,004	150	Y	N	N	Y	Guyette & Cutter 1997; Batek et al. 1999; Guyette et al. 2002
Interior Highlands	Boston Mountains, Pope County, Arkansas	*Pinus echinata*	4.6-13.0 2.0-3.1 1.4-5.0 62-80+	1680-1820 1821-1880 1881-1920 1921-2000	MFI	3, 50-200 ha sites	309	45	Y	Y	Y	Y	Guyette & Spetich 2003
Interior Highlands	Huckleberry Hollow, Shannon County, Missouri	*Pinus echinata*	7.1 2.2	1700-1820 1821-1930	MFI	930 ha	N/A	9	Y	N	N	Y	Guyette & Dey 1997

Table 2. Summary of the fire history studies conducted in the Central Hardwood Region. * - MFI calculated by author. ** - MFI is the Mean Fire-free Interval. WModFI is the Weibull Modal Probability Interval. WMFI is the Weibull Median Probability Interval (continued).

Sub-region	Study Location	Species	Fire Interval (years)	Chronology	Interval Method**	Size of Study Area	Number of Fire Scars	Sample Size	Cross-dated? (Y/N)***	Fire Extent? (Y/N)	Seasonality? (Y/N)	Intensity/ Severity? (Y/N)	Reference
Oak Chestnut (continued):													
Interior Highlands	Panther Cave, Carter County, Missouri	*Pinus echinata*	4.4 3.75	1604-1996	MFI WMFI	100 ha	106	12	Y	Y	N	Y	Guyette & Stambaugh 2002
Interior Highlands	Turkey Mountain, Buffalo National River, Arkansas	*Pinus echinata*	5.7	1770-1993	MFI	700 ha	54	9	Y	Y	N	Y	Jenkins et al. 1997
Interior Highlands	Big Spring Pines Natural Area, Missouri	*Pinus echinata*	2.8	1634-1974	MFI	80 ha	193	19	Y	Y	Y	Y	Stambaugh et al. 2005
Allegheny Plateau	Racoon Ecological Management Area, Vinton County, Ohio	*Quercus spp.*	5.4 3.6	1856-1995	MFI WMFI	8 ha	48	14	Y	Y	Y	Y	Sutherland 1997
Cumberland Plateau	Arnold Air Force Base, Coffee County, Tennessee	*Quercus stellata*	7.7	1850-1950	MFI	3 ha	18	20	Y	N	N	Y	Guyette & Stambaugh 2004
Western Mesophytic Beech-Maple													
Hill Section	Hoosier National Forest, Indiana	*Quercus stellata*	8.4	1656-1992	MFI	75 ha	84	27	Y	Y	N	N	Guyette et al. 2003
Beech-Maple													
(Though considered Beech-Maple Forest, this region contains significant patches of Oak-Hickory forest)	Indiana Dunes National Lakeshore, Lake Michigan, Indiana	*Quercus velutina, Quercus alba*	5.2-11.1	1929-1979	MFI	2, 160-ha sites	171	38	N	Y	N	Y	Henderson & Long 1985

While the genus *Pinus* is less abundant in the Oak-Chestnut forest type, it is locally significant on ridges, rock outcrops, and south-facing aspects. Sutherland et al. (1993) researched the linkage between fire exclusion on Brush Mountain, VA and recent regeneration failures of Table Mountain pine (*Pinus pungens* Lamb.). They found mean fire intervals (MFIs) of 9 to 11 years prior to 1944 with few pines established after 1950. Other studies using pine species in the southern Appalachians have indicated MFIs of 12.7 (Harmon 1982) and 16.7 years (Brose and others 2002). Finally, Lafon and colleagues (2005) investigated the relationship between climate and the contemporary fire regime (1970-2003) on federal lands located in the Ridge and Valley province. The primary objective of the study was not to determine fire return intervals, rather they focused on size, intensity, and seasonality of fire events. They found that that majority of fires occurring in this region were small acreage, low-intensity fires burning in the spring and fall (dry seasons) and that these fires were ignited by humans most of the time. The authors are continuing their investigation of fire regimes in this region using fire scars on Table Mountain, pitch, and Virginia pine stands (personal communication). Though studies located in the oak-pine interface of the Oak-Chestnut community do not represent the forest type as a whole, this research has provided valuable data for managing stands on dry, southern aspects.

The Oak-Hickory forests of Interior Highlands of Arkansas and Missouri have been the most intensely studied area of the CHR. Researchers have constructed fire history chronologies using shortleaf pine, post oak (*Quercus stellata* Wang.) and eastern redcedar. Guyette and Cutter (1991) utilized all three species to create a fire chronology with MFIs of 4.3 years during Native American habitation (1710-1810) and 6.4 years following the decline of tribal warfare (1811-1990). Similarly, fire intervals differed when chronologies were broken down into periods of human history and land use at other sites located in the Interior Highlands. Prior to European settlement, MFIs of 2.8 to 13 years were calculated for nearby study sites (Dey and others 2004; Guyette and Cutter 1997; Guyette and Dey 1997; Guyette and Spetich 2003; Stambaugh and others 2005). Following European settlement, Guyette and McGinnes (1982) and Cutter and Guyette (1994) found an increase in the MFI from ~3 years to ~24 years. The studies reviewed above highlight the importance of land use and human habitation patterns on fire regime characteristics in the Oak-Hickory forest type.

However, not all studies in the Oak-Hickory forests have focused on the effect of humans. Jenkins et al. (1997) found a MFI of 5.7 years in an oak-pine savanna-glade-woodland and noted that the percentage of fire-scarred trees was positively correlated with elevation ($r = 0.83$, $p < 0.001$, $n = 18$). These results confirmed the hypothesis that fire intensity would increase as the fire moved upslope. Other studies conducted outside the typical range of the Oak-Hickory forest type have explored the role of fire in oak communities. Henderson and Long (1984) investigated two black oak sites on the shore of Lake Michigan in Indiana and found fire intervals of 5.2 and 11.1 years. They attributed current differences in stand structure between the two sites to differences in fire frequency.

In the Mixed-Mesophytic forests of the Allegheny Mountains, Shumway and others (2001) examined 20 oak cross sections (~325 ha) obtained from a previous shelterwood cut to document the fire history and associated ecological changes in an old-growth forest in western Maryland. They found a MFI of 7.6 years from 1615-1958 and increased recruitment of shade tolerant species following fire suppression in 1930. Such evidence supports the hypothesis that periodic fire played a significant role in the historical development and perpetuation of oak in this region.

In an even-aged, second-growth oak stand in southern Ohio, Sutherland (1997) analyzed 14 cross sections to determine the frequency and seasonality of fire following Euro-American settlement. The author developed a fire chronology that revealed mostly dormant season fires (69%) occurring every 3.6 years (1856-1995) and concluded that ignitions were primarily human-caused because the area had been extensively cleared for agriculture and the iron industry. Additionally, shorter fire return intervals documented prior to the implementation of fire suppression would have favored the continued dominance of oak species.

On a different note, Guyette and Stambaugh (2004) researched the biological and statistical characteristics of fire-scarring of post oak along the Highland Rim, Tennessee to aid in the prediction of the effects of prescribed fire on trees and in the historical interpretation of past fire occurrences. They found a MFI of 7.7 years (1850-1950) and concluded that post oak were more likely to be scarred and survive when they were small in diameter and had slow radial growth. Also, this study highlights the challenges of reconstructing fire histories from fire scars because of the danger of misinterpreting wounding events when charcoal is not present. Falsely interpreting a wounding event may misrepresent the historic fire regime and lead to incorrect management of prescribed burning programs.

While other researchers have documented fire as a frequent disturbance of the CHR, the data presented in these studies was not sufficient to establish key temporal and spatial characteristics of the fire regime. Typically, these studies focused on other ecological applications of tree-ring data such as the role of historic fires on forest stand dynamics. For example, Abrams (1995) investigated the disturbance history and successional dynamics of a *Quercus alba - Castanea dentata* Marsh. - *Carya spp*. - *Pinus strobus* forest in southern West Virginia. The radial growth chronologies of these species showed regular release events every 20-30 years. The author hypothesized that these release events, and the continued dominance of oak and pine in the stand until the era of fire suppression, were caused by small-scale, periodic fires. Similarly, Soucy et al. (2005) researched the establishment and development of oak forests in the Ozark Mountains of Arkansas. Using tree-rings and fire-scar analysis, they determined that forests established following timber and fire events in the 1900's. Again, the advent of fire suppression changed the succession dynamics of the forests and shade tolerant, fire-intolerant species began replacing oak in the understory. The authors suggested that prescribed fire may be an important management tool to aid in the regeneration of oak forests in this region.

In summary, mean fire return intervals range from 2 to 20 years for the CHR. There are variations in the fire intervals that may be dependent on land-use history, local vegetation composition, topography, and climate. For instance, Schuler and McClain (2003) found a WMFI of 14.8 years in the Oak-Chestnut forests of the Ridge and Valley while Guyette and Stambaugh (2002) established a 3.75-year WMFI for the Oak-Hickory forest of the Interior Highlands. Despite our current knowledge of fire regimes in the CHR, it is uncertain if fire behaved uniformly across the landscape because much of the existing research on fire regimes has been concentrated in small pockets of the region, was limited in temporal scale, and complicated by human influence (e.g., changes in land use).

Impact on Management

The era of fire suppression in the eastern US has had lasting impacts on the structure and composition of the forests (Brose and others 2001). As fire management on public and private lands becomes more active, an understanding the historic and modern trends in the fire regimes of the Central Hardwood Region is needed (Yaussy 2000). The general acceptance that fire played a role in the CHR has led forest managers to implement prescribed burning programs on federal and state lands without a thorough understanding of the fire regime including frequency, extent, intensity, and seasonality. Given our current knowledge of the fire regimes of the CHR, how has the fire history data affected forest management practices?

In some areas of the CHR, management may have proceeded ahead of science. Prescribed burning programs have been approved and implemented prior to an understanding of the past fire regime. Such actions may have resulted from federal mandates, public opinion, or the lack of adequate information. Regardless, these programs may be ignoring key aspects of the past fire regime that helped establish and maintain present forest conditions. For example, in oak forests, burning in the wrong season or when advanced seedlings are too small may not promote regeneration of oak species because the fire did not adequately prepare the seedbed for germination and reduce competition from shade-tolerant, fire-intolerant species (Lorimer 1985; Van Lear and Watt 1993). Knowledge of the seasonality of historic fires can help managers schedule prescribed burns during the season when natural and/or anthropogenic wildfires burned in the past and aid them in achieving management objectives. However, determining the seasonality of the historic fire regime can be difficult due to different species' response to injury (Hengst and Dawson 1994), the effects of cutting and burning (Guyette and Spetich 2003), and the influence of changing climate over time (Grissino-Mayer and Swetnam 2000).

In other areas of the CHR, application of fire regime data has been successful. For instance, the Missouri Ozark Forest Ecosystem Project (MOFEP) has been compiling information and designing studies to address land use and disturbance history along with an array of other ecosystem processes (Shifley and Brookshire 2000). Fire history studies (Dey and others 2004; e.g., Guyette and Dey 1997; Guyette and Stambaugh 2002) have established fire intervals for the region and provided needed data to monitor the effects of prescribed burning and natural fires on the ecosystem. Other federal and state lands have not been able to fund projects of such magnitude and rely upon the best available information. Historic fire reports and silvical characteristics may indicate the past presence of fire; however, accurate data of fire regimes is still lacking.

Currently, public land managers are using prescribed burns to achieve resource management objectives such as fuel load reduction and regeneration of oak species. Smoke management issues, presence of threatened and endangered species, and protection from damage to adjacent private property often determine the timing and size of burn areas. For example, the New River Gorge National River proposed in their Wildland Fire Management Plan (2005) to utilize prescribed fire to reduce fuel loads, maintain native vegetation, preserve the historic scene, and maintain fire-adapted ecosystems. The Fire Plan recognized the value of fire history data to establish and maintain forest ecosystems. However, the linear nature of the park and its proximity to towns and interstates may govern future burn prescriptions. Though managers must consider the social, political, and economic impacts of prescribed fire, it is essential that fire management plans actively seek data on local fire regimes and understand how fire can meet management goals prior to burning extensive areas.

The use of prescribed burns may be helpful in determining the effects of fire on forest regeneration, species composition, and other ecosystem processes. Researchers at the USDA Forest Service Southern Research Station Coweeta Hydrologic Laboratory have conducted numerous studies investigating the effects of prescribed fire on hardwood survival in pine-oak forests, understory vegetation, nutrient cycling, and Table Mountain pine regeneration (Brose and others 2002; Elliott and others 2004; Van Lear and Waldrop 1989). These studies provide valuable information that allow researchers and managers to assess specific changes following prescribed fire, but they do not reveal characteristics of the historic fire regime. Therefore, the use of prescribed fire should be informed by an understanding of the frequency, extent, intensity, and seasonality of the past fire regime.

The State of Research

The study of fire regimes has been active throughout the 20th century even during the time of fire suppression (Pyne and others 1996); however, research has concentrated in the southeastern and western US. Fire regimes of longleaf pine (*Pinus palustris* Mill.) of the southeast (Hermann 1993), ponderosa pine (*Pinus Ponderosa* Dougl.) forests of the Rocky Mountains (Allen and others 2002; Ehle and Baker 2003; Veblen and others 2000) and southwest (Grissino-Mayer and Swetnam 1997; Swetnam 1990; Swetnam and Baisan 1996), and the chaparral of the California coastline (Keeley 2002; Moritz 2003) have been studied in detail and results have had major implications for fire management. Why has less attention been given to the Central Hardwood Region? Is there a lack of physical evidence (e.g., old-growth forests) due to past land use history? Does species longevity or how species record fire events in the eastern US play a role?

It has been suggested that a historic fire regime of frequent, low-intensity fires predominated in the CHR prior to the land-use practices of Euro-Americans in the late 1800’s (Abrams 1992; Brose and others 2001; Lorimer 1985; Pyne 1982). However, the research reviewed above shows substantial variation among the fire regimes of forests types in the CHR and many areas lack data. Differences in dominant tree species, land use history, and topography may have influenced fire regimes across the eastern US, and a single fire return interval will not be sufficient for the complex management requirements of public and private forests. Though the western states have an intense fire season nearly every year, large fires in the east have had significant impacts on forestland as well. For example, in southern West Virginia, the third most forested state, ten counties reported fires in 1986, 1987, and 1991. These counties averaged 3.39% to 32.74% of land area burned each year (Hicks and Mudrick 1993).

One impediment to studying fire history in the CHR may be the lack of physical evidence. In the late 19th century and early 20th century, the majority of the region was harvested for timber. Remaining refugia of old-growth stands remain but due to the ecological sensitivity of these areas, obtaining appropriate sample sizes of intact specimens may be difficult. Similar to the methods of Schuler and McClain (2003) and Shumway and others (2001), opportunistic sampling of lands disturbed by logging or other activities can provide valuable and, otherwise, unobtainable data. Species longevity may limit the ability of researchers to extend fire chronologies longer than two or three hundred years. However, species such as eastern hemlock, are reported to live almost 1000 years (Hough 1960). Additionally, identifying fire-scarred trees in central hardwoods may be difficult because of the avoidance of injury through constitutive protection and induced defenses (Smith and Sutherland 2001). Smith and Sutherland (1999) dissected chestnut and black (*Quercus velutina* Lam.) oaks present during two prescribed burns during the 1990's in southeastern Ohio and found that trees exposed to single fires did not have outward signs of scarring (e.g., charred bark and scorched wood).

Future Research

The Central Hardwood Region encompasses roughly 609,000 km^2 of Oak-Chestnut, Oak-Hickory, Mixed Mesophytic and Western Mesophytic forests in the eastern US. Thirteen of the twenty-four fire history studies listed on Table 1 occurred in the Oak-Hickory forests. Of those thirteen, eleven studies were conducted in the highlands of Arkansas or Missouri, making it the most studied area in the CHR. While this is a significant step toward a better understanding of the role of fire in Oak-Hickory forest of the CHR, these data are not representative of the CHR as a whole.

In the remaining forest types, many studies have been conducted in unusual stands (Abrams 1985), have limited sample sizes (Buell and others 1954), or insufficient sample area (Schuler and McClain 2003), making it difficult to generalize results to the region. Further research concentrated in representative stands is needed to confirm and broaden the applicability of past research to other areas of the CHR. Given the extent of the Mesophytic forests of the Mississippi and Allegheny Plateaus and the Oak-Chestnut forests of the Appalachian Mountains, considerable gaps in our understanding of the historic role of fire in the CHR still remain.

Old-growth forests of the region that have undergone little or no anthropogenic disturbance in the past centuries represent a unique opportunity for fire ecologist to investigate historic and contemporary fire regimes (Abrams and others 1995). Stands of post oak in the Ozarks, white oak on the Allegheny Plateau, and Table Mountain pine in the Ridge and Valley may be our best recorders of past disturbances. Difficulty arises when these stands are located on private lands, for much of the CHR is owned by non-industrial private landowners. However, some of these forests exist on federal lands such as Monongahela National Forest, Great Smoky Mountains National Park, and Ozark National Scenic Riverways. Other potential study sites are located on state parks and forests, gamelands and conservation lands. While obtaining permission to sample on some public forests may be difficult, these are the areas that we will have the best chance to affect change in management prescriptions with the backing of sound scientific data.

The application of dendrochronology to fire history studies also has been useful in understanding the effects of fire on species and communities of special concern. Hessl and Spackman (1995) highlighted the importance of fire in the management of threatened and endangered plants [e.g., Peter's Mountain Mallow (*Iliamna corei*)] in the US. Mahan (2004) emphasized the utility of tree-ring analysis to understand the development and maintenance of valued rimrock pine communities in New River Gorge National River, WV. These unique communities may be very sensitive to even small changes in frequency and seasonality. Understanding the role of fire in the development and maintenance of herbaceous and understory woody vegetation of the CHR will require additional fire history research that describes spatial and temporal characteristics of fire regimes.

Conclusions

Central Hardwood Region is the product of a long history of natural and anthropogenic disturbances including insect and disease epidemics, logging, agriculture, and burning. The influence of fire in the development and regeneration of the eastern forests is widely accepted. Yet, this acceptance of fire is not supported by quantitative data on frequency, extent, and variability of fire in the region. In this chapter, I have reviewed literature addressing fire history from a dendrochronological perspective. Mean fire intervals ranged from 2 to greater than 20 years across the CHR with fire history chronologies evidencing changes in fire regimes with land use across the past few centuries. While the papers presented here provide valuable knowledge of the characteristics of fire regimes in the eastern deciduous forests, these studies have concentrated in pockets of the region that may not be representative of the entire area. Future research is needed to describe the fire regimes of much of our federal, state, and private lands and to aid managers who are charged with the task of restoring and maintaining desired forest conditions.

Study Area

The study area consists of a linear stand (~100 ha) located 4 km east of Fayetteville, WV along the “Endless Wall” in the New River Gorge National River (38°03′15″N, 81°03′32″W; Fayetteville 7.5-min. quadrangle; Figure 4). The Endless Wall is a 15-35 m sandstone cliff that extends approximately 6 km (3.7 miles) along the northern section of the gorge (Figure 5). This site was chosen because it is the largest contiguous segment of the rimrock pine forest type within the park.

Geologically, the site is composed of the coal-bearing New River Formation of the Pottsville group. This formation contains the Fire Creek, Beckley, and Sewell coal seams as well as siltstone, shale, and sandstone components. The Nuttall sandstone layer tops the formation creating the highly erosion-resistant cliffs that are prominent along the Endless Wall (Lessing 1986). The very stony soils along the Endless Wall are characterized by the Dekalb and Gilpin series derived from Nuttall sandstone parent material (United States Department of Agriculture 1975). Jenkins (2005) described the forest floor on top of the south-facing cliffs as having a thin O horizon (2 to 7 cm thick) and shallow A horizon (usually less than 50 cm) that is coarse, well-drained, drought prone, and having low fertility. Due primarily to foot travel along popular hiking trails and overlooks, significant portions of the rimrock have experienced compaction, erosion, and limited plant colonization.

The study site is located along a south-facing aspect of the gorge at an elevation of 580 m (1900 ft) with slope inclination ranging from 0 to 40%. The mean annual temperature is 10.5°C (50.9°F) with the high and low mean monthly temperatures of 20.9°C (69.7°F) and -1.6°C (29.2°F) recorded in July and January, respectively. The growing season extends from mid-April to mid-October. A nearby weather station (Beckely, WV) reported an average of 104.2 cm (41.0 in) of precipitation per year with snowfall, ice pellets, and hail averaging 48.8 cm (19.2 in) of the total. While more precipitation occurs during the summer season than the winter season, there is no defined dry period for the area (Suiter and Evans 1995).

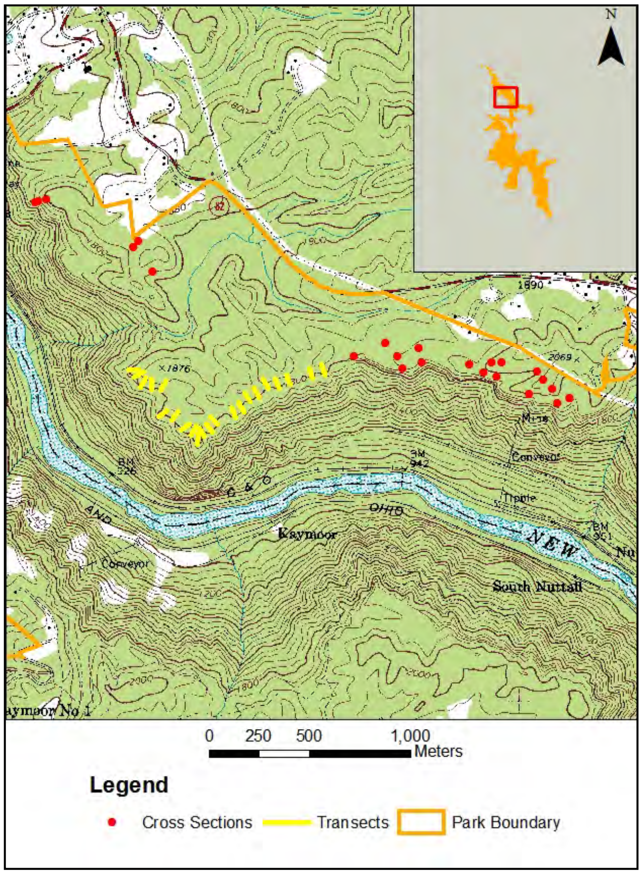

Figure 4. Location of sample transects and cross sections along the Endless Wall.

Figure 5. Photo of the sandstone cliffs that compose the Endless Wall.

Methods

Vegetation Survey

Twenty-two transects (50 m x 6 m), broken into 5 adjacent 10 m x 6 m sections for data collection and analysis purposes, were used to sample the rimrock pine community (Figure 6). Each transect originated at the cliff edge in the predominately pine cover type and was oriented perpendicular to the cliff extending into the hardwood community. While a spacing of at least 60 m between transects was used, the location of an individual transect depended upon the presence of overstory *P. virginiana* and the ability to safely sample the vegetation. All trees, with any portion of the stem falling within a transect and greater than 2.54 cm (1 in) diameter at breast height (DBH), were identified to species. Total height, crown class, vigor, longevity, and time since tree death (for standing dead) were collected. Specifically, crown class was separated into dominant, codominant, intermediate, and overtopped (Smith and others 1997). A vigor rating of 1 to 7 was assigned for each tree: 1) healthy crown, 2) minor dieback, 3) some dieback but >50% alive, 4) >50% of crown dead with some live branches, 5) crown completely dead with some stem and basal sprouts, 6) crown completely dead with some basal sprouts, or 7) dead tree. Longevity was estimated in addition to the vigor rating: 1) >20 yrs to live (for vigor ratings 1 and 2), 2) 10-20 yrs to live (for vigor ratings 3 and 4), or 3) <10 yrs to live (for vigor ratings 5 and 6). Time since tree death was ranked: 1) <5 yrs since death (fine limbs and tight bark), 2) 5-10 yrs since death (large limbs and bole with substantial bark), or 3) >10 yrs since death (no bark only stem remains). Individual species characteristics were taken into account for vigor, longevity, and percent dead ratings.

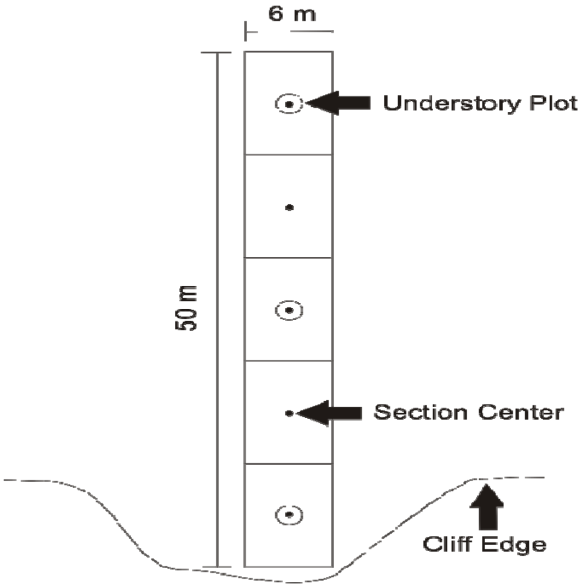

Figure 6. Diagram of sample transect layout.

Three circular understory plots (2-m diameter) were established in each transect, with one plot each in the pine, ecotone, and hardwood portions of the forest. These zones were subjectively identified in the field for each transect, however, plots were typically located at 5 m (pine), 25 m (ecotone), and 45 m (hardwood). In each plot, percent cover of herbaceous plants and shrubs was estimated and dominant species were identified. Woody vegetation was identified to species, counted, and assigned a size class: 1) germinals (<15 cm), 2) 1 year+ but not established (15 cm - 1.23 m), or 3) established (>1.23 m and <2.54 cm DBH).

Vegetation Data Analysis

Average ratings of total height, crown class, vigor, and longevity, as well as percent dead were calculated for each species to provide a subjective snapshot of the overstory structure and health of the rimrock community. Percent of understory woody vegetation assigned to each size class was averaged for each species in the pine, ecotone, and hardwood plots. Percent cover of shrubs and herbaceous plants were averaged for each portion of the forest.

For each 6 m x 10 m overstory section, density, dominance (i.e., basal area), and importance values were calculated for each species. Density was calculated as the number of individuals per hectare. Dominance was estimated as the total basal area per hectare. Species importance value (IV) indices were calculated as one-half the sum of the relative density and relative dominance for each species (Smith and others 1997). Additionally, frequency was determined as the number of sections occupied by a given species and was used as a measure of species distribution across the site. Understory data were analyzed with similar methods except species IV utilized relative frequency and relative density.

Community composition patterns were assessed using cluster analysis of the overstory trees using the program PC-ORD (McCune and Mefford 1999). A main matrix of species IVs for each transect section was constructed. This method was chosen to determine if sections at each distance were similar throughout the study site. Following the initial cluster analysis, a second matrix was developed to identify a pine group (sections 1 and 2) and a hardwood group (sections 3, 4, and 5) across the study area. These groupings were based on field observations and preliminary data analysis of the dominant vegetation type in each section of the sample transects. The Sorenson (Bray-Curtis) distance was used as the mathematical distance measure in the cluster analysis and the farthest neighbor as the method of linkage. To reduce the number of null values in the data set, species occurring in fewer than 6 plots were removed from the analysis. Analysis of understory species IVs followed a similar procedure except the second matrix defined 3 *a priori* groups at 5 m (pine), 25 m (ecotone), and 45 m (hardwood). However, this method of understory grouping was insufficient to identify meaningful groups and a second matrix was constructed using to 2 groups, pine (5 m) and hardwood (25 m and 45 m).

A multi-response permutation procedure (MRPP, McCune and Mefford 1999) was conducted to assess the strength of the cluster analysis and to determine within-group homogeneity of *a priori* overstory section groups. MRPP is a nonparametric technique used to test the hypothesis of no difference between two or more groups of entities (McCune and others 2002). In the procedure, an average Sorenson distance within each group is calculated from a distance matrix. Observed and expected weighted mean within-group distances (δ) are determined and a test statistic (T) is generated to describe the separation between the groups. Stronger separations between groups are represented by more negative *T* values. A *p* value is then used to evaluate the likelihood that the observed difference (*T*) is due to chance. The size of the effect is described by the chance-corrected within-group agreement (*A*), with an observed $\delta = 0$ and $A = 1$ returned when all items are identical within groups. In community ecology, *A* values below 0.1 are common, even when observed δ differs significantly from the expected value (McCune and others 2002).

Dendrochronological Sampling

Following preliminary data analysis of species composition and distribution within the study site, a total of 50 representative overstory and understory trees were cored to determine the age structure of the community and construct master chronologies of dominant species (Table 3). Samples were taken from three representative overstory transects and were selectively chosen to target *Pinus virginiana*, *Quercus spp.*, *Oxydendrum arboreum*, *Nyssa sylvatica*, and *Acer rubrum*. Thus, the cored trees do no represent a random sample. Two cores were removed from opposite sides of each tree at 0.5 m above the ground. Cores were extracted perpendicular to slope direction to avoid sampling of compression or reaction wood (Phipps 1985).

To assess the fire history of the rimrock community, 23 cross sections were collected from fire-scared live and dead *P. virginiana* (n = 22) and *P. rigida* (n = 1) throughout the study area. During sampling, an effort was made to sample hazard trees and preserve the ecological integrity of the forest.

Dendrochronological Analysis

Increment cores and cross sections were returned to the laboratory to be dried, mounted (cores only), and sanded according to standard dendrochronological techniques (Stokes and Smiley 1968). Cores were skeleton plotted and visually crossdated by matching narrow tree-ring widths to accurately assign a year to each ring. Tree rings of *Oxydendrum arboreum* and *Nyssa sylvatica* samples could not be crossdated due to the difficulty identifying boundaries between annual rings, but rings were counted to estimate year of establishment. Annual radial growth

Table 1. Species composition and canopy position of trees sampled for age structure.

Species	Overstory	Understory	Total
Pinus virginiana	14	0	14
Pinus rigida	3	0	3
Quercus coccinea	4	0	4
Quercus alba	3	0	3
Quercus velutina	2	0	2
Carya spp.	0	2	2
Nyssa sylvatica	0	7	7
Oxydendrum arboreum	0	7	7
Acer rubrum	4	4	8
TOTAL			50

was measured to the nearest 0.001 mm using a Velmex measuring system in conjunction with Measure J2X® software. The accuracy of crossdating was assessed by statistically comparing the raw ring widths using the computer program COFECHA (Grissino-Mayer 2001a). Discrepancies in crossdating were corrected and 4 cores that did not crossdate were removed from the analysis.

Raw ring widths from 18 pines and 10 oaks were used to identify moderate and major releases (Lorimer and Frehlich 1989). A moderate release was defined as a 25% increase in radial growth sustained for a minimum of 10 years. A major release was defined as at least a 50% increase in radial growth sustained for a minimum of 10 years (Nowacki and Abrams 1997). The first year of the 10-year span was identified as the release year.

The ARSTAN program (Cook and Holmes 1990) was used to detrend each series with a negative exponential curve or a negative linear function. This standardization procedure removed the effects of tree aging, bole geometry, and microsite conditions in order to develop a standardized ring-width series (Fritts and Swetnam 1989). The procedure was used to detrend ring-width measurements and create master chronologies for *Pinus*, *Quercus,* and *Acer* genera.

All fire scars from each cross section were then crossdated against the *Pinus* master chronology and a *Pinus pungens* chronology from the Ridge and Valley province (Sutherland and others 1993). Seasonality of each fire scar was determined by noting the position of the scar within the annual tree ring (Dieterich and Swetnam 1984). Fire scars located between the latewood of one growth ring and the earlywood of the next growth ring were identified as dormant season events. Dormant season events were assigned to the year of the last full growth ring. Thus, a fire burning during the dormant season of 1953 may have occurred in fall of 1953 or the spring of 1954.

Distributions of fire scar dates may not be adequately described by symmetrical measures of central tendency because there is no upper bound to fire-free periods and the lower bound may never be negative (Schuler and McClain 2003). Grissino-Mayer (2001b) suggested that a two-parameter Weibull distribution would be more appropriate to characterize such distributions because fire scar dates tend to be positively skewed. With the Weibull distribution, a 0.50 exceedance probability is the 50th percentile, or the central tendency, of the distribution. Fire scar dates, seasonality, and inner and outer dates of each samples were entered into the software program FHX2® to evaluate the goodness of fit between the fire intervals and the empirical and Weibull distributions using a one-sample Kolmogorov-Smirnov (K-S) test (Grissino-Mayer 2001b). Following the methods of Schuler and McClain (2003), two criteria (conservative and liberal) were used to estimate composite fire intervals. The conservative criterion was a year when 2 or more trees recorded a fire event. The liberal criterion was a year when only 1 tree had a fire scar. Additionally, box plots were created to display the median, quartile, and minimum and maximum fire interval values for each sample location and both site combined.

Results

Overstory Vegetation

Overstory Structure and Composition

The rimrock pine forest type was composed of *Pinus virginiana*, *Nyssa sylvatica*, *Oxydendrum arboreum*, *Acer rubrum*, *Quercus spp*., and other hardwoods (Figure 7). Though *P. virginiana* was the dominant species in the overstory, its abundance was not equally spread throughout the sample area. Its prevalence in the canopy decreased from approximately 64% of the stems in the first 10-m section of transects to less than 5% in the last section. As distance from the rim of the gorge increased, the decrease in percentage of *P. virginiana* stems was compensated by an increase in *N. sylvatica*, *O. arboreum*, *A. rubrum*, and other deciduous stems. *Quercus spp*. stems were present in modest amounts ranging from 9-16% of the total number of stems in each section.

A modified inverse J-shaped diameter distribution curve was observed with more trees in the smaller diameter classes and fewer trees in the larger diameter classes (Figure 8). In general, smaller diameter trees were found near the rim of the gorge with the exception of several large-diameter (>30 cm) oaks and pines. Intermediate and overtopped species, such as black gum, sourwood, and red maple, composed the majority (58%) of the smallest diameter classes (0-10 cm). When examining the diameter distribution of Virginia pine alone, a skewed normal distribution curve was present which may indicate that this component was approximately even-aged.

The most important canopy species, in descending order, were *Pinus virginiana*, *Nyssa sylvatica*, *Oxydendrum arboreum*, *Quercus coccinea*, *Acer rubrum*, *Quercus prinus*, and *Quercus alba* (Table 4). Of these species, the dominant and codominant crown classes were occupied by *P. virginiana* and *Quercus spp.* with the *N. sylvatica*, *O. arboreum*, and *A. rubrum* in the intermediate and overtopped classes. Height of *P. virginiana* averaged 6.85 m compared to a mean of 11.11 m for *Quercus spp.*, but the majority of pines were located near the cliff edge where all trees were shorter. *P. virginiana* had the highest density and basal area of all rimrock species; however, it did not have the greatest frequency. The *Quercus spp.* composed the second greatest basal area despite having a lower density and frequency than other prominent species. *N. sylvatica*, *O. arboreum,* and *A. rubrum* had the greatest distributions (i.e., frequency) across the study area with corresponding high densities and low dominance.

Most species present on the rimrock showed some signs of crown dieback (Table 4). Mean vigor (1-7 scale, with 1 being a healthy tree and 7 being a dead tree) of canopy species ranged from 2.82 for *Quercus prinus* to 3.62 for *Quercus coccinea*. Despite signs of dieback, expected longevity of canopy species is greater than 20 years based on overall tree health and silvical characteristics. Percent dead (i.e., count of standing dead trees/count of living trees x 100) for the most important species ranged from 6.9% for *N. sylvatica* to 20% for *Q. coccinea*.

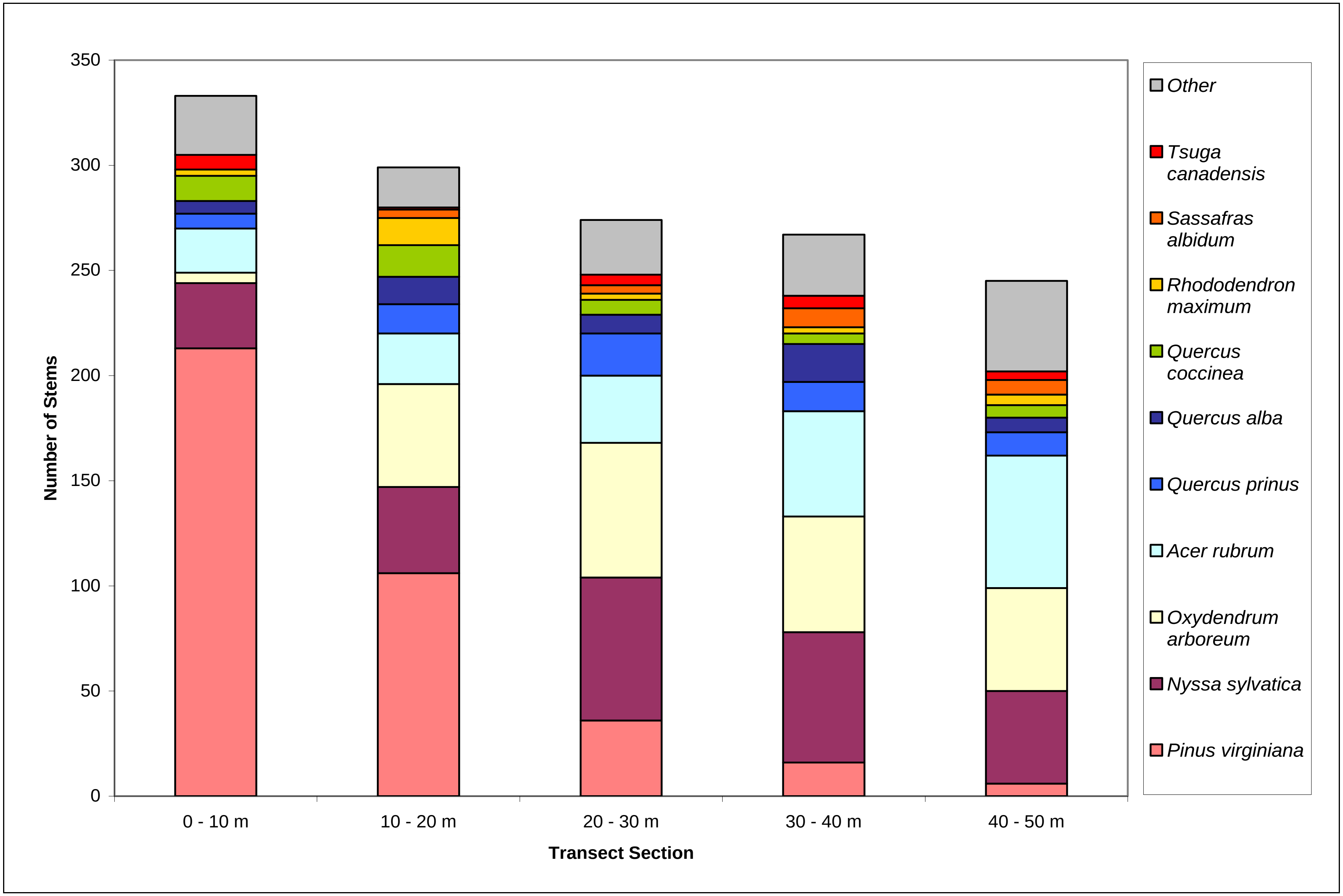

Figure 7. Number of stems by species for each section of sample transects.

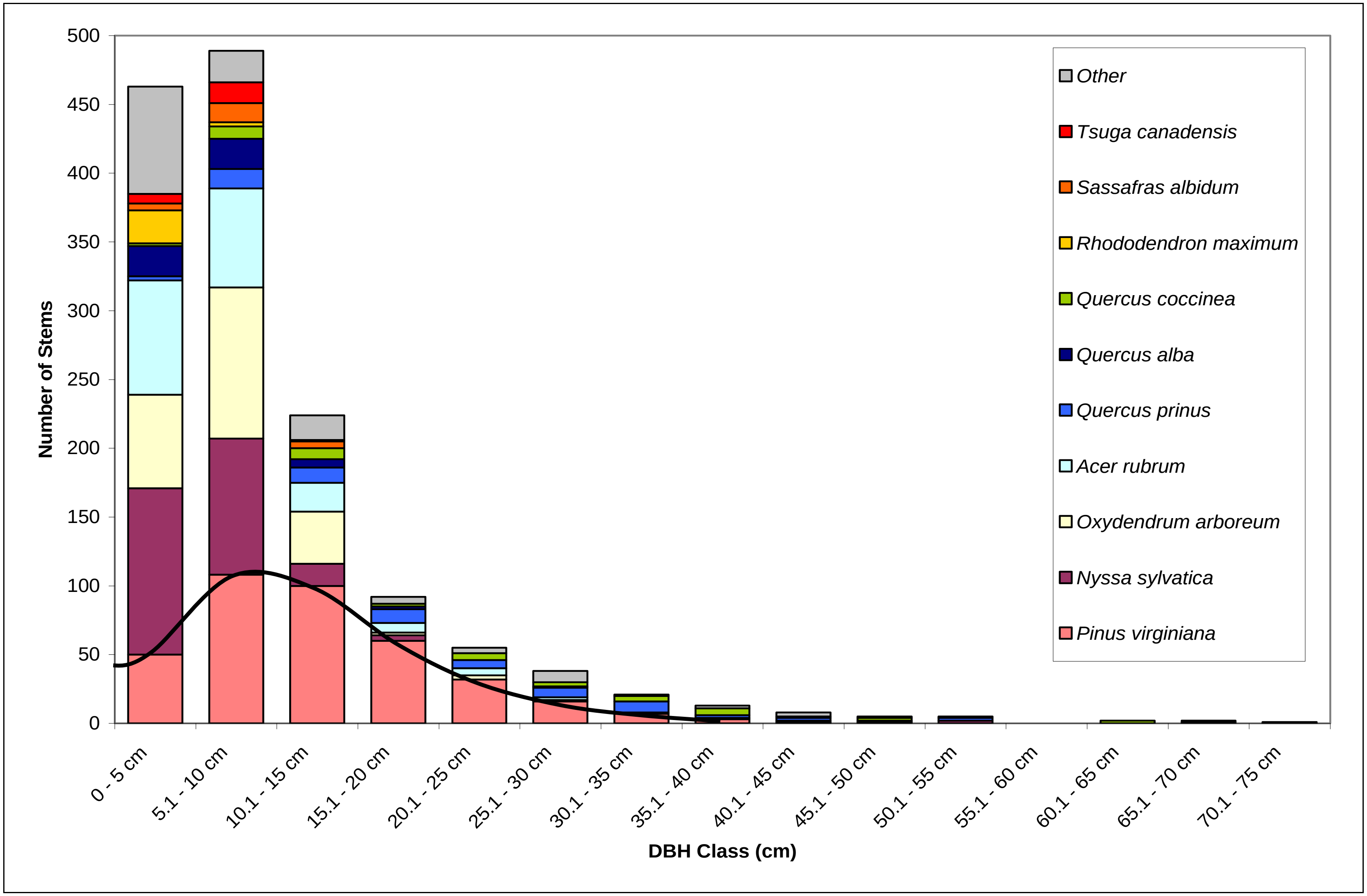

Figure 8. Diameter distribution by species from 22 sample transects along the "Endless Wall" portion of the rimrock pine forest. The bold curve represents the skewed normal distribution of *Pinus virginiana* DBH.

Table 2. Overstory species present in the rimrock forest with descriptive variables. *Crown Class*: 1 = dominant, 2 = codominant, 3 = intermediate, 4 = overtopped; *Vigor*: 1 = healthy crown, 2 = minor dieback, 3 = some dieback but >50% alive, 4 = >50% of crown dead with some live branches, 5 = crown completely dead with some stem and basal sprouts, 6 = crown completely dead with some basal sprouts, 7 = dead tree; *Longevity*: 1 = >20 yrs to live (for vigor ratings 1 and 2), 2 = 10-20 yrs to live (for vigor ratings 3 and 4), 3 = <10 yrs to live (for vigor ratings 5 and 6); *Importance Value* = (relative density + relative dominance)/2.

Species	Average DBH (cm)	Average Height (m)	Average Class	Average Vigor	Average Longevity	Percent Dead	Frequency (# sections)	Density (Stems/HA)	Dominance (BA in m^2)	Relative Frequency	Relative Density	Relative Dominance	Importance Value
Pinus virginiana	12.76	6.85	2.38	3.19	1.40	11.14	54.00	876.74	6.45	11.79	26.61	29.89	28.25
Nyssa sylvatica	6.60	4.85	3.63	3.14	1.56	6.91	68.00	572.09	1.66	14.85	17.36	7.68	12.52
Oxydendrum arboreum	7.35	5.73	3.44	3.45	1.68	9.91	63.00	516.28	1.26	13.76	15.67	5.83	10.75
Quercus coccinea	25.26	11.33	2.16	3.62	1.24	20.00	28.00	104.65	3.37	6.11	3.18	15.61	9.39
Acer rubrum	7.09	6.94	3.51	3.02	1.23	12.63	54.00	441.86	1.11	11.79	13.41	5.14	9.28
Quercus prinus	20.16	10.25	2.30	2.83	1.21	9.09	35.00	153.49	2.88	7.64	4.66	13.37	9.01
Quercus alba	17.76	11.03	2.42	3.13	0.96	18.87	34.00	123.26	1.93	7.42	3.74	8.94	6.34
Quercus velutina	16.12	8.27	2.71	3.12	1.88	0.00	9.00	39.53	0.79	1.97	1.20	3.68	2.44
Pinus rigida	22.89	9.36	2.00	3.00	1.47	6.67	9.00	34.88	0.78	1.97	1.06	3.63	2.34
Quercus rubrum	16.99	11.81	2.45	2.95	1.30	10.00	16.00	46.51	0.66	3.49	1.41	3.04	2.23
Sassafras albidum	7.42	6.30	3.42	3.04	1.71	4.17	16.00	55.81	0.12	3.49	1.69	0.55	1.12
Rhododendron catawbiense	3.93	2.96	3.89	2.11	1.07	0.00	8.00	62.79	0.03	1.75	1.91	0.16	1.03
Carya spp.	14.35	11.64	3.20	2.20	1.20	0.00	5.00	23.26	0.29	1.09	0.71	1.35	1.03
Tsuga canadensis	6.35	4.43	3.57	2.26	1.57	0.00	8.00	53.49	0.08	1.75	1.62	0.37	1.00
Kalmia latifolia	3.10	2.44	4.00	2.38	1.44	0.00	12.00	37.21	0.01	2.62	1.13	0.06	0.59
Betula lenta	4.23	3.57	3.50	3.64	1.29	21.43	9.00	32.56	0.03	1.97	0.99	0.12	0.55
Hamamelis virginiana	3.16	3.33	3.79	3.14	1.36	14.29	7.00	32.56	0.01	1.53	0.99	0.05	0.52
Magnolia fraseri	7.95	8.16	3.60	2.00	1.00	0.00	4.00	23.26	0.07	0.87	0.71	0.32	0.51
Amelanchier arborea	4.80	3.60	2.90	2.10	1.10	0.00	3.00	23.26	0.02	0.66	0.71	0.09	0.40
Ilex opaca	3.18	2.77	3.90	2.80	1.70	0.00	10.00	23.26	0.01	2.18	0.71	0.04	0.37
Rhododendron maximum	4.06	2.78	4.00	2.00	1.00	0.00	1.00	9.30	0.01	0.22	0.28	0.02	0.15
Fagus grandifolia	2.79	2.65	3.50	4.00	2.50	0.00	2.00	4.65	0.00	0.44	0.14	0.01	0.07
Cercis canadensis	7.37	3.05	3.00	2.00	1.00	0.00	1.00	2.33	0.00	0.22	0.07	0.02	0.05
Cornus florida	7.11	6.10	4.00	2.00	1.00	0.00	1.00	2.33	0.00	0.22	0.07	0.02	0.04
Liriodendron tulipifera	2.54	4.61	4.00	3.00	2.00	0.00	1.00	2.33	0.00	0.22	0.07	0.00	0.04

Overstory Grouping

A cluster analysis was conducted to separate transect sections into pine (sections 1 and 2) and hardwood (sections 3, 4, and 5) groupings that were previously defined by field observations and preliminary data analysis. The resulting dendrogram (Figure 9) showed grouping of transect sections with a low percentage of chaining (3.13%). Two section-1 groups and six section-2 groups did not cluster into the pine component and were replaced by hardwood sections. The MRPP results confirm the presence of pine and hardwood components with a negative T-statistic ($T = -25.832$) that was highly significant ($p < 0.001$). The A-statistic was acceptable ($A = 0.105$) for studies of community ecology (McCune and others 2002).

Understory Vegetation

Understory Structure and Composition

The understory regeneration of the rimrock pine forest type was dominated by *Acer rubrum*, *Sassafras albidum*, *Nyssa sylvatica*, *Oxydendrum arboreum*, *Pinus virginiana*, and *Quercus spp*. of varying size classes. The "germinal" class was 55% *A. rubrum*, 17% *Quercus spp*., 8% *Hamamelis virginiana*, and 2-3% each for *O. arboreum*, *N. sylvatica*, and *P. Virginiana* (Figure 10). The most abundant saplings in the "1 year+ but not established" class were *S. albidum* (39%), *A. rubrum* (23%), and *Quercus spp.* (14%). Though red maple (29%) was the most prevalent species in the "established" class, a substantial percentage of *P. virginiana* (13%) and *N. sylvatica* (9%) saplings were present.

Pinus virginiana regeneration was present in 38% of plots (25 of 66) with a density of approximately 4,200 stems/ha compared to *A. rubrum* presence in 78% of plots and a density of approximately 30,000 stems/ha (Table 5). Nearly half of the *P. virginiana* regeneration was found in the pine plots located at 5 m from the cliff edge.

Greenbrier, blueberry, mountain laurel, and rhododendron were present in 97%, 57%, 62%, and 17% of plots, respectively (Figure 11). The pine plots had abundant amounts of *Vaccinium pallidum* (lowbush blueberry) between 15 cm - 1.23 m in height with lesser amounts of *Smilax rotundifolia* (common greenbrier). In the ecotone and hardwood plots, *Kalmia latifolia* and *Rhododendron spp.* were common, covering 28-64% of plot area, with substantial amounts of greenbrier (16-50% of plot area) as well.

Percent herbaceous cover for plot locations averaged 11%, 10%, 6% for the pine, ecotone, and hardwood plots, respectively. While the percent of herbaceous cover was similar for these locations on average, bare soil and rock was common in the pine plots and leaf litter was common in the ecotone and hardwood plots. Noted species included teaberry (*Gaultheria procumbens*), spotted wintergreen (*Climaphila maculate*), pink lady's slipper (*Cypripedium acaule*), and several unidentified grass species.

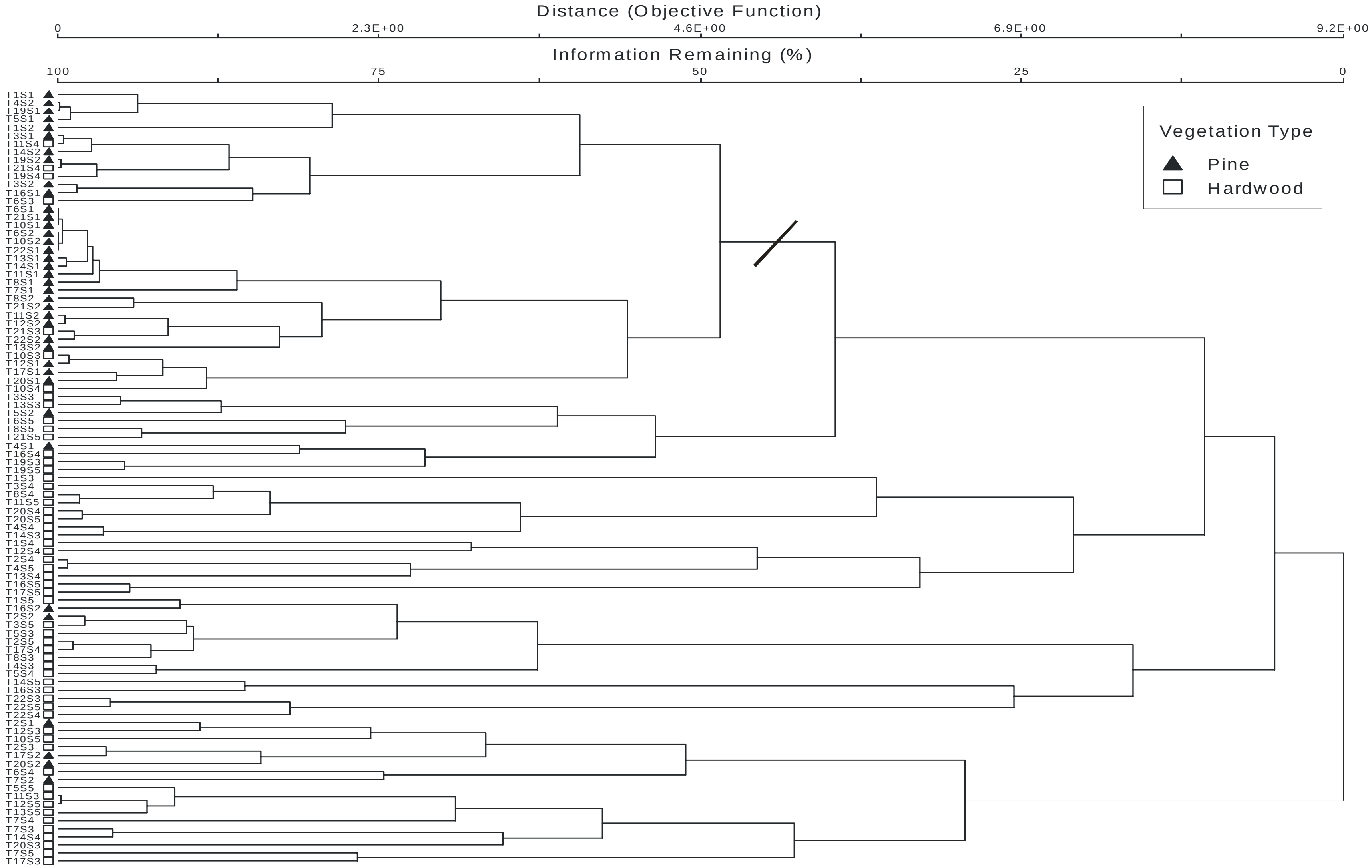

Figure 9. Cluster analysis of 85 10 m x 6 m transect sections using overstory tree (DBH > 2.54 cm) species IV as input data. Each section is labeled on the left and subjectively identified as either pine (solid triangle) or hardwood (open square). The diagonal line shows the separation between groups. Sorenson distance was the distance measure and sections were linked using the farthest neighbor method.

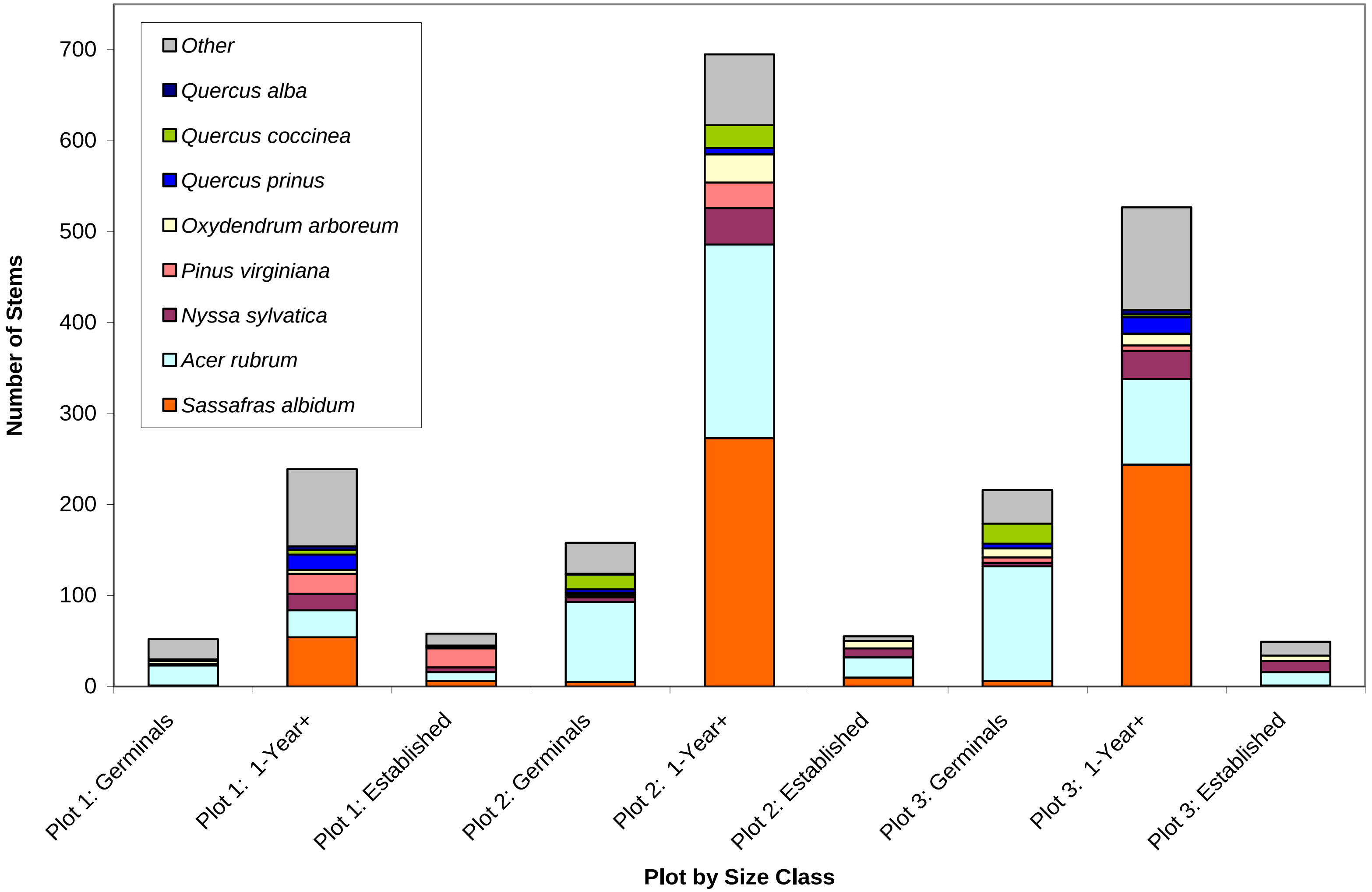

Figure 10. Number of understory stems by species for each plot and size class. Plot locations were 5 m (plot 1), 25 m (plot 2), and 45 m (plot 3) from cliff edge. Size classes were: 1) germinals (<15 cm), 2) 1 year+ but not established (15 cm - 1.23 m), or 3) established (>1.23 m and <2.54 cm DBH).

Table 3. Understory species present in the sample transects with descriptive variables. Importance values were calculated as one-half the sum of the relative frequency and relative density.

Species	Frequency (# sections)	Density (Stems/ha)	Relative Frequency	Relative Density	Importance Value
Acer rubrum	51	29917.00	14.53	30.24	22.39
Sassafras albidum	52	28951.94	14.81	29.27	22.04
Nyssa sylvatica	38	6031.65	10.83	6.10	8.46
Oxydendrum arboreum	31	3763.75	8.83	3.80	6.32
Pinus virginiana	25	4246.28	7.12	4.29	5.71
Quercus rubra	20	4487.55	5.70	4.54	5.12
Quercus coccinea	21	3570.74	5.98	3.61	4.80
Quercus velutina	21	3136.46	5.98	3.17	4.58
Quercus prinus	19	2509.17	5.41	2.54	3.97
Hamamelis virginiana	10	2653.93	2.85	2.68	2.77
Magnolia fraseri	12	1302.84	3.42	1.32	2.37
Viburnum acerifolium	5	3136.46	1.42	3.17	2.30
Amelanchier arborea	7	1302.84	1.99	1.32	1.66
Ilex opaca	8	530.79	2.28	0.54	1.41
Carya spp.	6	965.06	1.71	0.98	1.34
Betula lenta	6	723.80	1.71	0.73	1.22
Quercus alba	5	482.53	1.42	0.49	0.96
Lonicera spp.	2	434.28	0.57	0.44	0.50
Fagus grandifolia	3	144.76	0.85	0.15	0.50
Liriodendron tulipifera	2	193.01	0.57	0.20	0.38
Magnolia acuminata	2	96.51	0.57	0.10	0.33
Castanea dentata	1	96.51	0.28	0.10	0.19
Robinia pseudoacacia	1	96.51	0.28	0.10	0.19
Cercis canadensis	1	48.25	0.28	0.05	0.17
Cornus florida	1	48.25	0.28	0.05	0.17
Tsuga canadensis	1	48.25	0.28	0.05	0.17

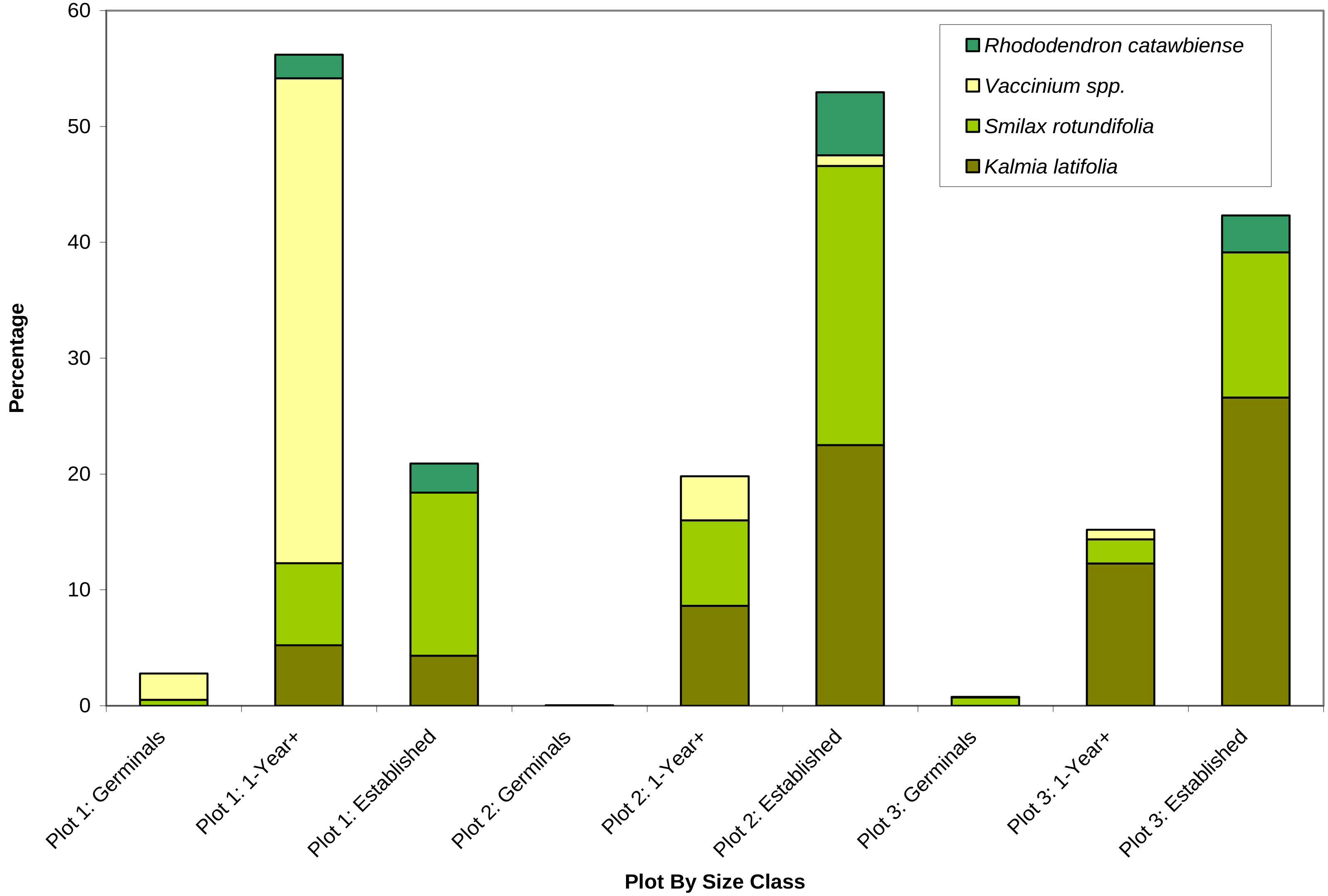

Figure 11. Percentage of shrub cover in understory plots by species for each plot location (based on distance from the cliff edge) and size class.

Understory Grouping

An understory cluster analysis was conducted to separate circular plots into pine (plot 1) and hardwood (plots 2 and 3) groupings. These groupings were subjectively defined and based on field observations and preliminary data analysis. The resulting dendrogram (Figure 12) showed groupings of understory plots with a greater percentage of chaining (14.04%) than the overstory transect sections. Understory plots clustered into 4 larger groups composed of 25-m and 45-m hardwood plots and 9 of 20 pine plots. Eleven pine plots clustered into smaller groups of two or three plots without forming a larger cohesive group. The MRPP results confirm the lack of pine and hardwood grouping despite a negative T-statistic ($T = -8.066$) that was highly significant ($p < 0.001$). Average distance for the 20 pine plots was large (0.818). The A-statistic was low ($A = 0.042$) for studies of community ecology (McCune and others 2002).

Age Structure and Growth Trends

Pinus rigida was the largest diameter and oldest species on the rimrock site with establishment dates of 1830, 1840, and 1861 for cored trees (Figure 13). The oldest *Pinus virginiana* established in 1900, and two periods of *P. virginiana* establishment were noted in between the periods 1900-1909 and 1943-1946. Similar periods of establishment for the *Quercus spp*. were observed, however, the largest and oldest oak established in 1861. A lack of establishment was seen for the period of 1911-1937 for all species. Then, small diameter, shade tolerant species (i.e., *Acer rubrum*, *Nyssa sylvatica*, and *Oxydendrum arboreum*) invaded the understory in the 1940s and early 1950s. It is important to note that only surviving stems were sampled. Therefore, the diameter-age distribution in Figure 13 does not depict earlier successional species that may have established during the 1911-1937 period and were subsequently killed by fire, logging, or competition prior to sampling.

The master chronologies developed for pine, oak, and maple show highly variable growth rates over time (Figures 14, 15, and 16). For each chronology, the standardized ring-width indices had mean value of one. Periods of above-average growth occurred when the index rose above one while periods of below average growth occurred when the index fell below one. Using the criteria of Nowacki and Abrams (1997), growth releases were calculated from raw ring-widths for pine and oak species. Four pines experienced minor releases in 1939, 1964, 1971, and a major release in 1923. Two oaks recorded 2 minor releases in 1925 and 1964.

Fire History

A 108-year fire chronology (1897-2005) was constructed from 51 fire scars recorded by 23 trees along the “Endless Wall” in New River Gorge National River, WV (Figure 17). Forty-eight of these fires occurred in the dormant season and seasonality was undetermined for the remaining 3 fires. Pith dates from cross sections ranged from 1897 to 1961. Origin dates could not be established on 2 cross sections due to decay. Fires were detected by at least one sample in 1914, 1922, 1930, 1932, 1934, 1938, 1939, 1940, 1941, 1945, 1946, 1948, 1952, 1953, 1954, 1956, 1963, 1965, 1970, 1972, and 1976 (Table 6). The largest fires (≥ 5 fire-scarred trees) occurred in 1938, 1946, 1953, and 1970. It must be noted that, due to the young age of some sample trees, dating of cross sections may be inaccurate. Error in crossdating may have the effect of increasing the number of fire intervals reported in the composite chronology; however, fire

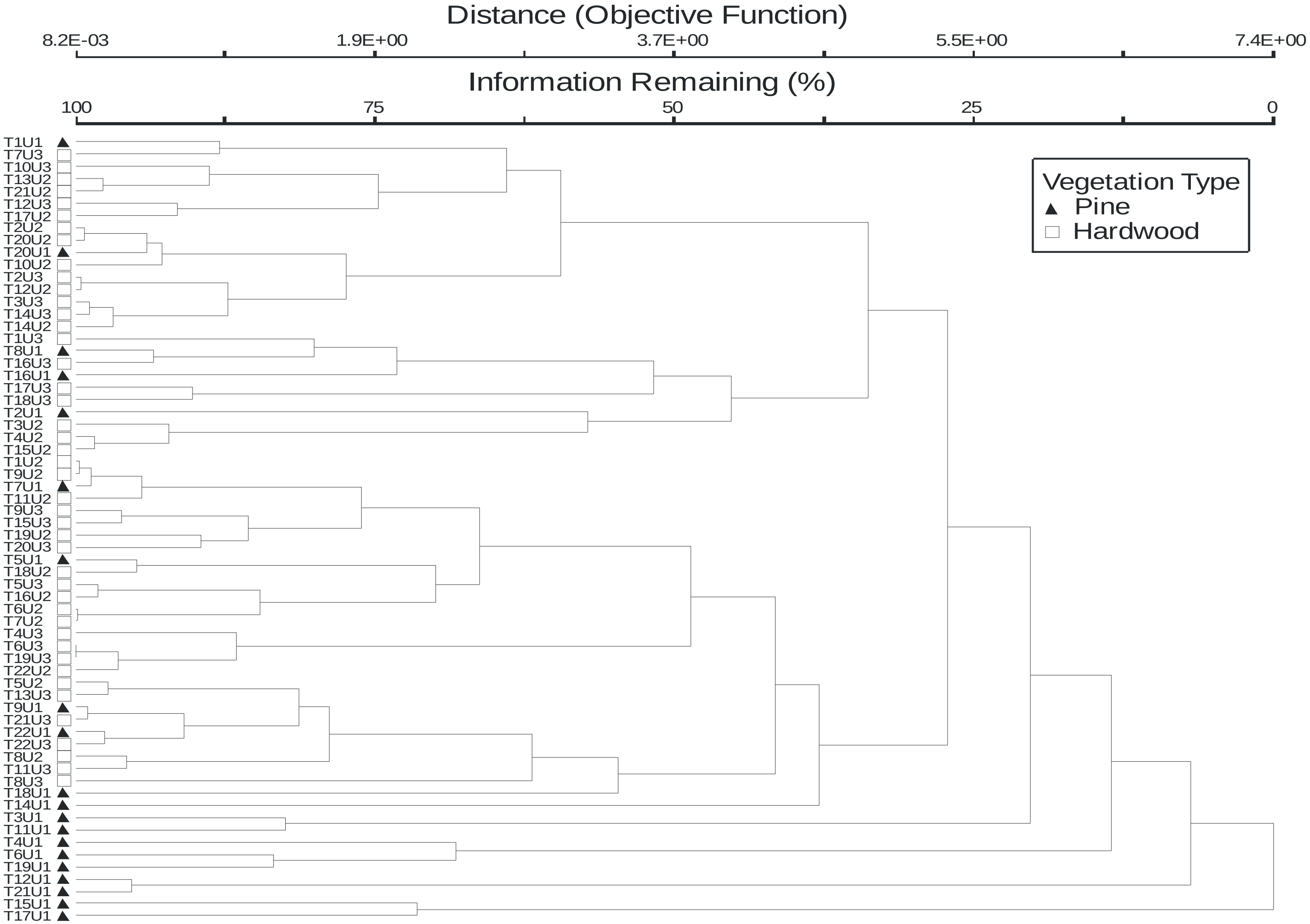

Figure 12. Cluster analysis of 64 understory plots using understory woody vegetation (DBH < 2.54 cm) species IV as input data. Each plot is labeled on the left and subjectively identified as either pine (solid triangle) or hardwood (open square). Sorenson distance was the distance measure and sections were linked using the farthest neighbor method.

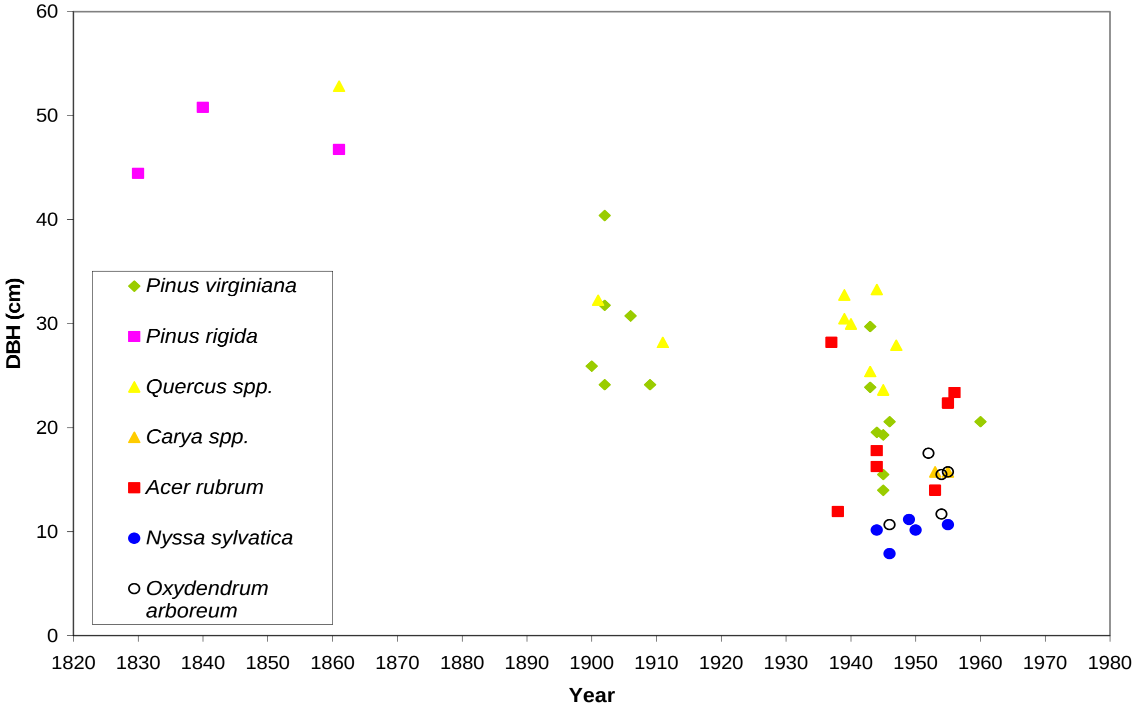

Figure 13. Age-diameter distribution of species sampled along the “Endless Wall” in New River Gorge National River, WV.

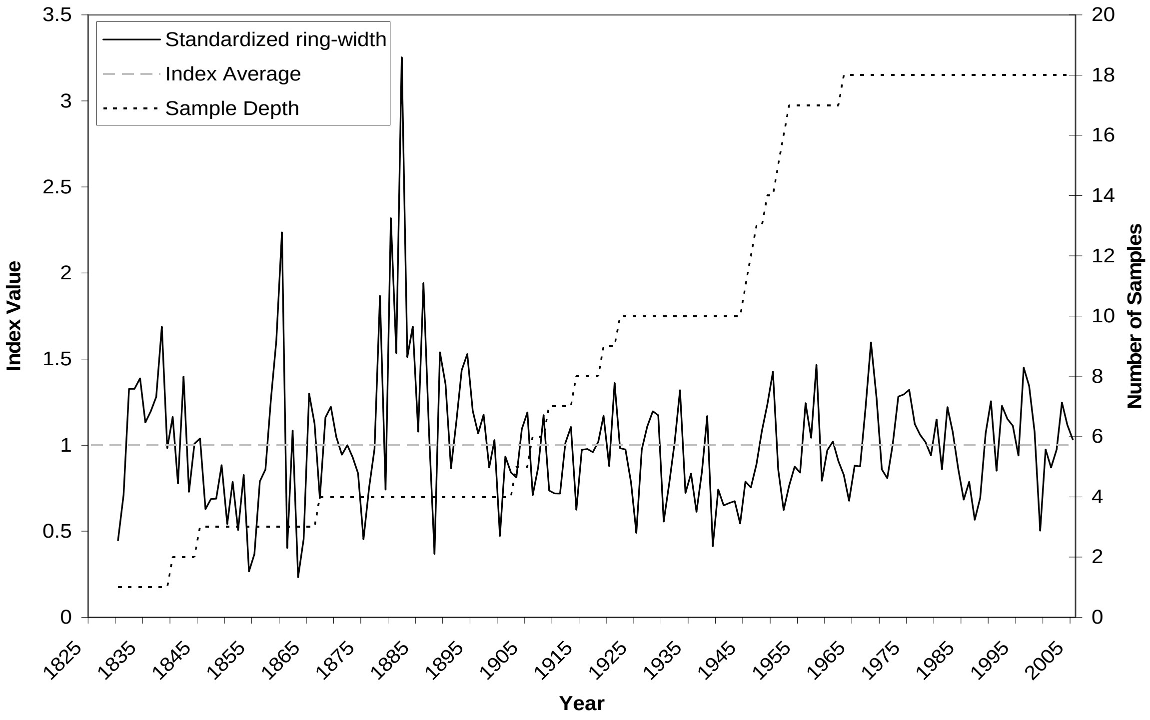

Figure 14. Master chronology for *Pinus* species (N = 18).

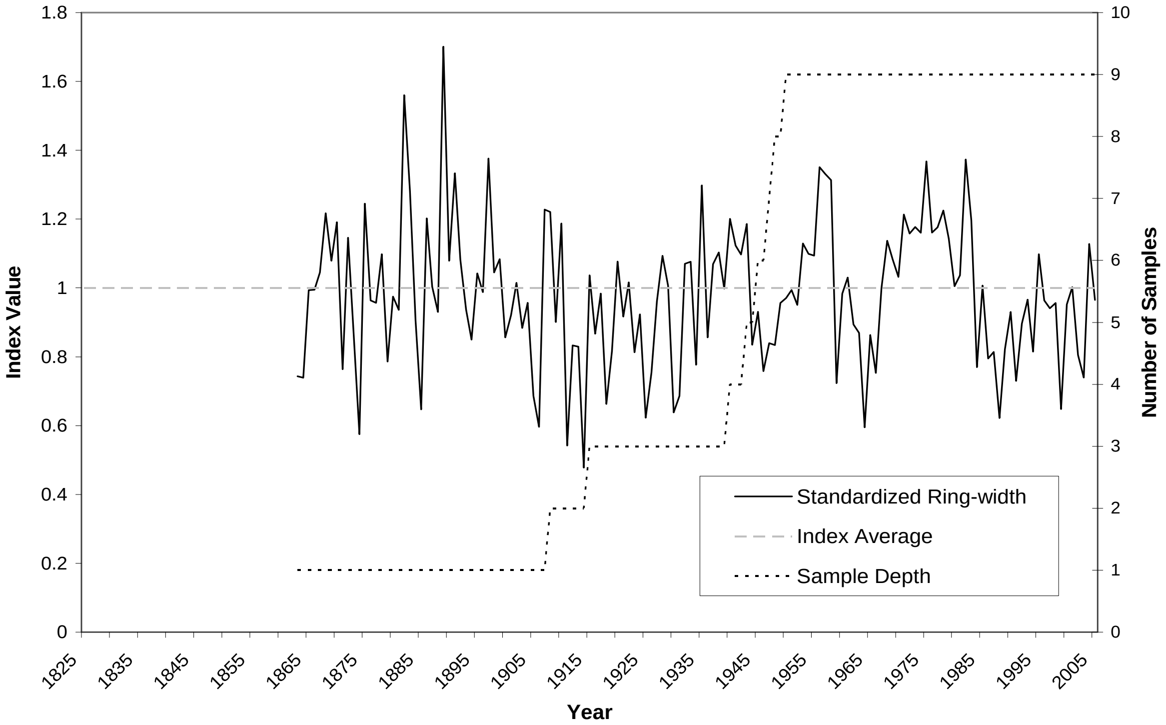

Figure 15. Master chronology for *Quercus* species (N = 9).

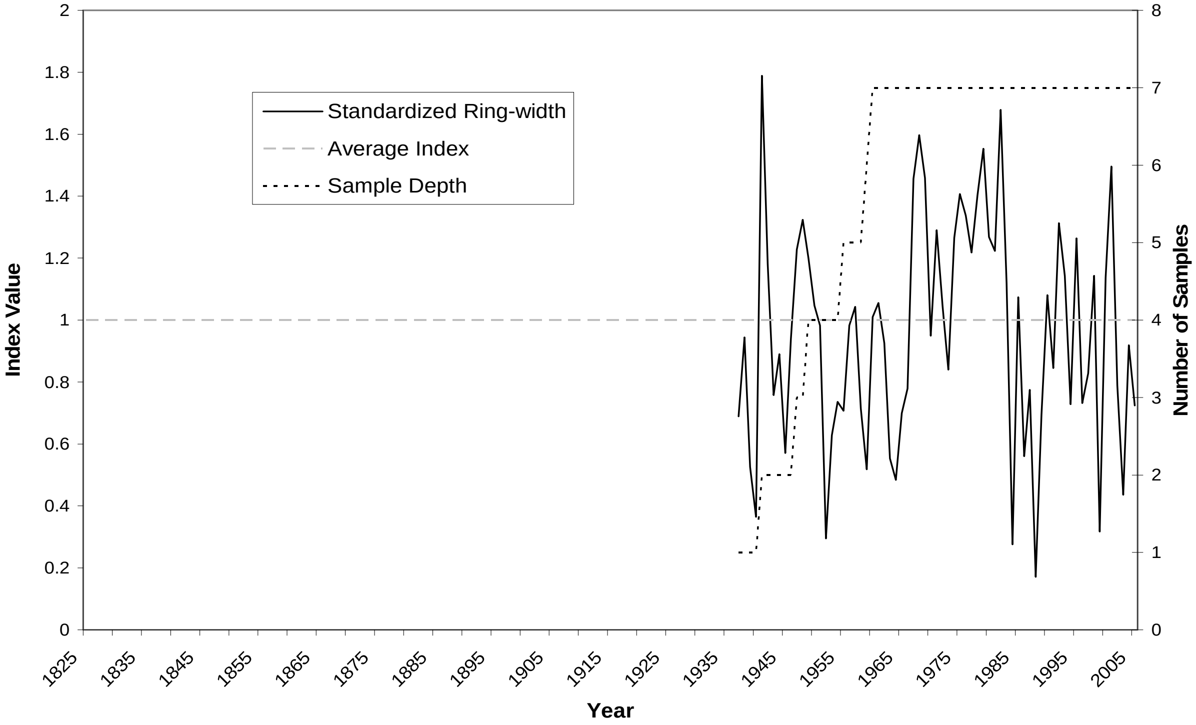

Figure 16. Master chronology for *Acer rubrum* (N = 7).

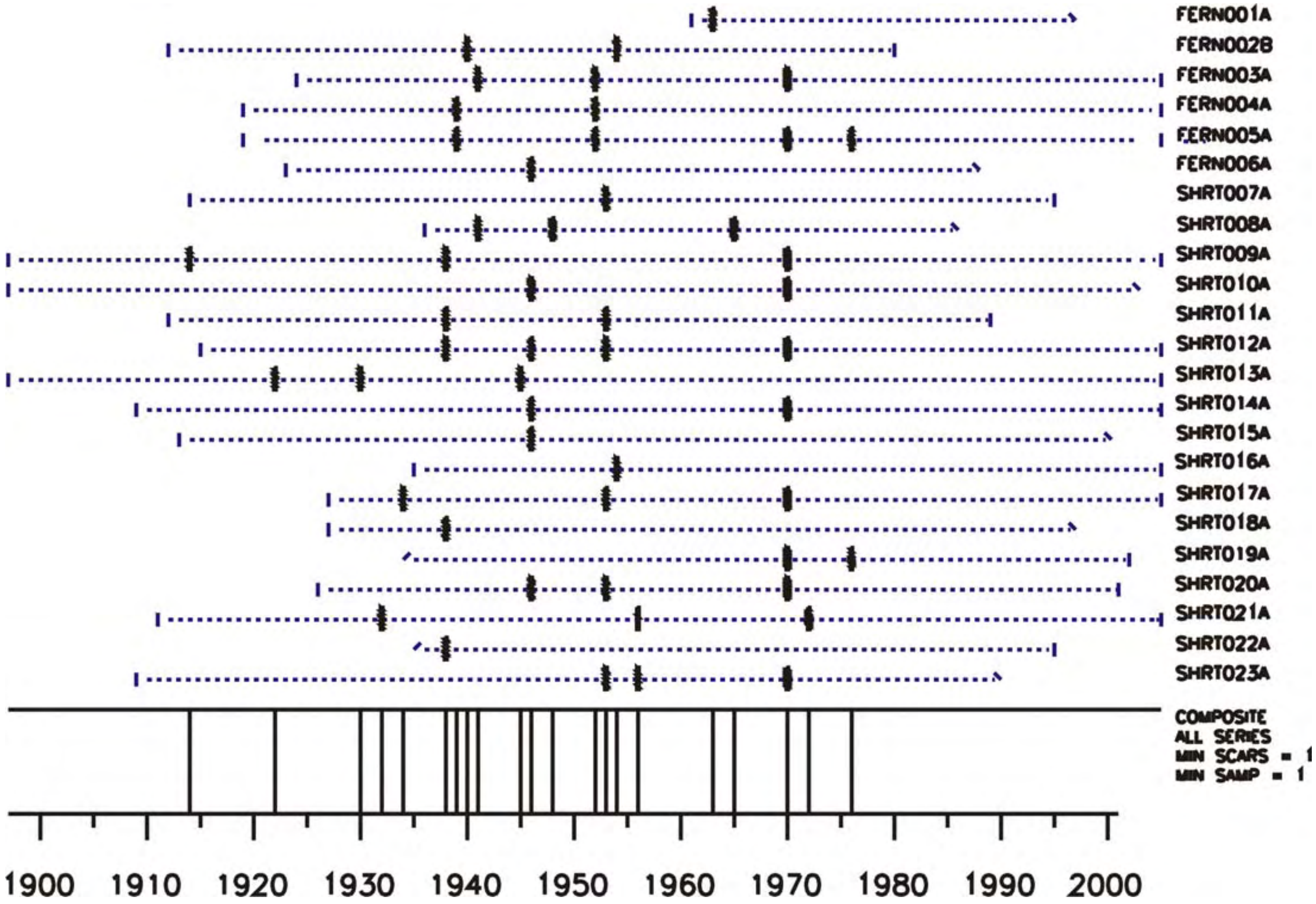

Figure 17. Fire scar chronology from 22 Virginia pines and 1 pitch pine cut from the “Endless Wall” in the northern section of New River Gorge National River, WV. Each horizontal line (dashed) represents the annual rings of one sample cross section. Vertical lines represent pith dates (left) or outer ring dates (right). Forward slashes represent earliest dated annual rings when pith was not present. Back slashes represent outermost ring of samples without bark. Bold vertical bars represent fire events.

Table 4. Summary of fire information for both sites combined. Sample depth represents the number of trees alive in the sample for the fire year. Fire intervals must be bounded by two fire events. There was no evidence of fire after 1976; however, several trees recorded scars from unknown sources following the last fire.

Year	Same depth	Total fire scars	Fire interval
1914	9	1	0
1922	12	1	8
1930	18	1	8
1932	18	1	2
1934	19	1	2
1938	22	5	4
1939	22	2	1
1940	22	1	1
1941	22	2	1
1945	22	1	1
1946	22	6	2
1948	22	1	1
1952	22	3	1
1953	22	6	1
1954	22	2	1
1956	22	2	4
1963	23	1	1
1965	23	1	2
1970	23	10	1
1972	23	1	6
1976	23	2	2

intervals within each sample remain relatively accurate. Median point fire interval values ranged from 3.5 to 5.5 years with minimum and maximum values of 1 and 9 years for two sites, respectively (Figure 18). These values may be taken as point estimates of fire frequency. Other injuries from unknown sources occurred in 1940, 1943, 1944, 1953, 1954, 1957, 1966, 1983, 1989, 1990, 1993, 1997, 1998, and 2002, and were not used in the fire interval analysis.

Fire interval data for each site was analyzed separately prior to performing a stand-wide analysis. Six cross sections were collected from the Fern Creek site and 8 fire intervals were recorded in the site chronology. Using a liberal criterion (at least 1 tree recording a fire event), the K-S test indicated that the fire intervals could be described by either the empirical (p = 0.957) or Weibull (p = .951) distributions. Schuler and McClain (2003) noted that the K-S test lacks robustness when the number of intervals being evaluated is small; therefore, the empirical and Weibull summary statistics are reported for each site (Tables 7, 8, and 9). Both distributions yielded about a 4 year return interval for the Fern Creek site. The Weibull exceedance probabilities of 0.875 and 0.125 indicated that fire intervals were unusual when less than 1.5 years and greater than 8 years occurred between fires, respectively. A conservative criterion (at least 2 trees recording a fire event) was not used to evaluate the intervals between fires for the Fern Creek site due to the small sample size.

Seventeen trees were sampled from the Short Creek site and 16 fire intervals were recorded in the site chronology using the liberal criterion (Table 8). The K-S test indicated that both the empirical (p = 0.241) and Weibull (p = 0.554) distributions adequately described the intervals between fires with mean and median values between 3.5 and 4 years. Using at least two recorder trees to define a fire event, the K-S test returned p-values of 0.964 and 0.992 for the empirical and Weibull distributions, respectively. The WMFI was 7.7 years for the conservative analysis and lower and upper exceedance values were 3.6 years and 12.6 years. The mean fire interval (MFI) was 8 years. The MFI and WMFI both increased by approximately 4 years using the conservative criterion.

When data from the two sites were combined, the empirical distribution did not adequately model the intervals between fires for either criterion (Table 9). Individual fire intervals from the stand-wide fire chronology ranged from 1 to 14 years when using two or more trees as an indicator of a past fire. The WMFI and MFI were 3.2 and 4.2 years, respectively. The 1970 fire resulted in the greatest percentage of fire-scarred trees (43%) with evidence from both sites. Because an interval must be bounded by two fires, the 29-year fire-free period from 1976-2005 was not included in the calculation of fire intervals. However, this period was not characteristic of the period modeled from 1897-2005.

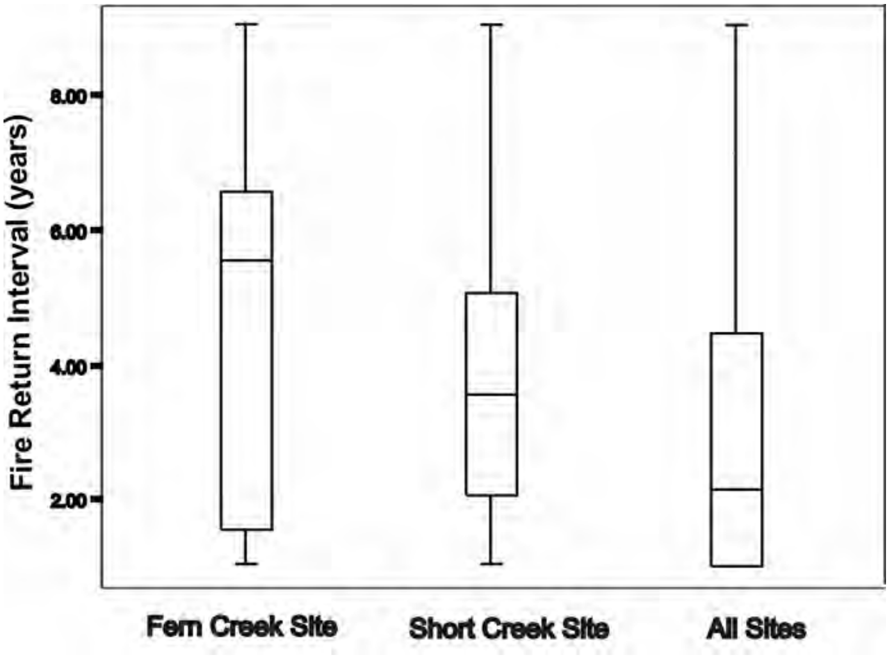

Figure 18. Fire return interval boxplots for Fern Creek, Short Creek, and both sites combined. Boxplots include median, quartiles, and minimum and maximum return intervals.

Table 5. Fire interval analysis for the Fern Creek site using a liberal criterion (at least 1 tree recording a fire event). A conservative analysis (at least 2 trees recording a fire event) was not used due to the small sample size.

	Liberal Criteria
Total intervals	8.00
Mean fire interval (yrs)	4.63
Standard deviation (yrs)	2.97
Median fire interval (yrs)	5.50
Weibull modal interval (yrs)	2.87
Weibull median interval (yrs)	4.11
Weibull scale parameter	5.15
Weibull shape parameter	1.63
Minimum fire interval (yrs)	1.00
Maximum fire interval (yrs)	9.00
Empirical K-S	0.181 (p = 0.957)
Weibull K-S	0.183 (p = 0.951)

Table 6. Fire interval analysis for the Short Creek site using liberal (at least 1 tree recording a fire event) and conservative (at least 2 trees recording a fire event) criteria.

	Liberal Criteria	Conservative Criteria
Total intervals	16.00	4.00
Mean fire interval (yrs)	3.88	8.00
Standard deviation (yrs)	2.55	4.55
Median fire interval (yrs)	3.50	7.50
Weibull modal interval (yrs)	2.51	6.84
Weibull median interval (yrs)	3.50	7.66
Weibull scale parameter	4.36	9.07
Weibull shape parameter	1.66	2.18
Minimum fire interval (yrs)	1.00	3.00
Maximum fire interval (yrs)	9.00	14.00
Empirical K-S	0.257 (p = 0.241)	0.250 (p = 0.964)
Weibull K-S	0.199 (p = 0.554)	0.217 (p = 0.992)

Table 7. Fire interval analysis for all sites using liberal (at least 1 tree recording a fire event) and conservative (at least 2 trees recording a fire event) criteria.

	Liberal Criteria	Conservative Criteria
Total intervals	20.00	9.00
Mean fire interval (yrs)	3.10	4.22
Standard deviation (yrs)	2.34	4.24
Median fire interval (yrs)	2.00	2.00
Weibull modal interval (yrs)	1.55	0.68
Weibull median interval (yrs)	2.68	3.21
Weibull scale parameter	3.45	4.44
Weibull shape parameter	1.46	1.13
Minimum fire interval (yrs)	1.00	1.00
Maximum fire interval (yrs)	8.00	14.00
Empirical K-S	0.350 (p = 0.015)	0.460 (p = 0.044)
Weibull K-S	0.236 (p = 0.215)	0.223 (p = 0.764)

Discussion

Vegetation Classification

The rimrock pine forest type is characterized by a canopy of Virginia pine, black gum, sourwood, red maple, and oak species. The importance of Virginia pine decreases as distance from the cliff edge increases. In fact, the frequency of Virginia pine decreases by at least 50% every 10 m until it becomes marginal at 40 – 50 m. The cluster analysis of canopy species confirmed that the pine component was concentrated within the first 20 m from the cliff edge. However, suitable growing conditions exist up to 300 m from the cliff edge for drier, south-facing aspects which may explain the grouping of some pine and hardwood transect sections. Regeneration of Virginia pine is relatively sparse when compared to the number of stems/ha of competing deciduous species. Those stems surviving to the sapling size classes are suppressed under a closed canopy except for individuals established within the first 20 m from the cliff edge that may receive more direct light due to the southern exposure and the sparse canopy of Virginia pine.

The understory cluster analysis did not confirm the subjectively defined pine (5-m plots) and hardwood (25-m and 45-m plots) groupings. One explanation for the lack of clustering is the use of species IV as the input data for the analysis. This variable may not be suitable because it does not include a measure of unvegetated areas (bare rock and soil) that were common in the 5-m plots. The understory shrub layer of the forest is dominated by greenbrier, blueberry, mountain laurel and rhododendron. The herbaceous layer is sparse within the first 10m because of soil compaction and the presence of bare rock. Farther from the cliff edge, thick leaf litter may prevent some herbs from growing in larger numbers.

These results confirm Vanderhorst's (2002) classification of the rimrock pine forest as a linear Virginia pine-(oak)/blackgum/teaberry forest when selectively sampling within the pine component. The species composition of this forest type is present within the first 20 m from the cliff edge with the dominant vegetation quickly changing to hardwood species after 20 m. It is likely that the rimrock will become increasingly dominated by hardwood species except for the cliff edge and larger rock outcrops (e.g., Diamond Point) that receive direct sunlight throughout the day. In theses areas, Virginia pine is an edaphic climax species as evidenced by the harsh site conditions created by the soil type and orientation of the cliff face, the high density and low basal area of overstory pine, and continuous recruitment of pine saplings. Whittaker (1956) discussed the characteristics of climax theory and hypothesized that topographic and edaphic climaxes occurred in areas with a distinct soil parent-material, steepness of slope, and dryness as affected by direction of exposure. Throughout the Appalachian Mountains, edaphic pine (Abrams and Orwig 1995) and oak communities (Nowacki and Abrams 1991) have persisted due to site factors.

One issue of concern is the threat of decline due to the aging of Virginia pine in the canopy. Fenton and Bond (1964) reported an estimated longevity of 90 years for Virginia pine growing on poor sites in southern Maryland. Of the Virginia pines cored for the present study, half of the sample dated approximately 100 years old while the other half dated 60 years old. As mentioned above, understory sapling and seedling classes are dominated by hardwood species. Ohmand

and Buell (1968) report that these size classes are the best indicator of future species composition in communities without disturbance. This suggests that the older cohort of dominant and codominant pines in the canopy will senesce in the next 10-15 years leaving a younger cohort to compete with a host of deciduous competitors established in the 1940s as well as the present hardwood regeneration (Figure 13). Table Mountain pine communities located in the Ridge and Valley (Sutherland and others 1993; Williams and Johnson 1990) and southern Appalachian (Harmon 1982; Zobel 1969) physiographic provinces are experiencing similar successional trends in the absence of fire.

Disturbance Regime

Virginia pine requires a disturbance, such as logging or fire, to regenerate (Carter and Snow 1990; Fenton and Bond 1964). These disturbances prepare the seedbed by exposing mineral soil and opening the canopy to provide direct sunlight for seedling establishment. In the present study, fires were found to occur every 1 to 9 years. This estimation of fire frequency is based on point fire return intervals at each site due to the small sample size and difficulty dating cross sections taken from dead pines. The WMFI at each site was approximately 4 years when using one tree as an indicator of a past fire. Major fire events, injuring at least 5 trees, were recorded in 1938, 1946, 1953, and 1970. Despite the size of these major fires, the presence of a large number of fire-scarred survivors indicates low-intensity events (Romme 1980). Compared to other xeric forest types in the central Appalachians, fires occurred more frequently along the rimrock than in other areas. For instance, Schuler and McClain (2003) found a MFI of 15.5 years for red oak growing on a poor site in southeastern West Virginia and Sutherland and colleagues (1993) reported MFIs of 9 to 11 years for a Table Mountain pine stand in the Ridge and Valley province of southwestern Virginia.

A primary reason for the discrepancy in fire frequency between the rimrock pine communities of the New River Gorge and other forest types of the central Appalachians may be due to differences in past land use. In Appalachian mixed-oak forests, steam-driven locomotives and mining activities have been identified as potential ignition sources (Brose and others 2001; Shumway and others 2001). Brooks (1910) cited locomotives (71%), saw mills and campers (20%), improving rangeland (3%), arson (2%), and other causes (4%) as ignition sources in West Virginia for the 1908 fire year. While natural fires caused by lightening do occur in the eastern US, the majority of historic fires have been caused by human ignition sources (Abrams 1992). Fires in the New River Gorge would likely have been ignited by locomotives, mining activities, and land clearing. The operation of more than 150 mines and continuous traffic on the C&O railroad running along the bottom of the gorge provided ample ignition sources. These ignitions would have produced fires that burned quickly up the slope of the gorge with increasing intensity and flame length. To reach the rimrock above the 15-35 m sandstone cliffs, the fire had to travel up vegetated gaps or ignite from burning debris landing on the top of the cliff. The presence of fire-scarred Virginia and pitch pine tells us that the fires were of low to moderate intensity once burning began along the rimrock community. The linear form of the rimrock pine forest may have allowed only small sections of the rimrock to burn during each event. This is evidenced by the greater number of short fire return intervals (< 2 years) calculated from the composite fire chronologies for the entire study area. A fire regime of this type would have allowed dominant pines to survive while creating patches of even-aged regeneration.

Studies of Table Mountain/pitch pine stands in the southern Appalachian Mountains have found fire to be an important disturbance maintaining these xeric ridgetop communities (Brose and others 2002; Brose and Waldrop 2000; Waldrop and others 2003). In these studies, pine and oak dominated the canopy, more shade tolerant black gum and red maple occupied the midstory, and mountain laurel covered the majority of the understory. They found that major disturbances, presumably fire or logging, were followed by pulses of regeneration of pine and oak seedlings as well as increased radial growth of surviving Table Mountain pine. Based on the growth release criteria of Nowacki and Abrams (1997), pines and oaks in the present study did not experience any minor or major releases in the 1940s or 1950s. However, a visual examination of the tree-ring index values from the pine and oak master chronologies show a trend of increased growth following major fire events. While precise dating of fire-scarred samples taken from dead trees was difficult, the occurrence of fire on the rimrock and the reaction to disturbance is evident. Frequent fires, throughout the 1940s and early 1950s, led to the establishment of a host of species following these disturbances. It could be argued that the regeneration during the period of 1937-1960 was caused by one stand-replacing fire occurring in the 1930s. This scenario is unlikely because a sufficient number of samples (N = 18) were present during this time period and did not record such an extensive fire event. Also, historical records indicate that the period of pine and oak establishment from 1900-1910 was probably due to harvesting and fire. Brooks (1910) reported fire statistics for West Virginia citing 710 fires and 1.7 million acres burned in the fall season of 1908.

More recent fire records from 1939-present were collected by the West Virginia Division of Forestry (2005) for each county in the state. The WVDOF reported a greater number of fires occurring in Fayette County during the spring fire season with the average year in the 1940s and 1950s having 50 fires. Though spring fires burn more often, fall fires have historically accounted for the largest fire years in the county with an average of 6,000 acres burned in each year in the 1950s. The largest fire year happened in 1952 when 118 fall fires burned over 39,000 acres. The present study found 94% of fires occurred during the dormant season that includes the period of the spring prior to budbreak.

It is possible that other types of disturbances aided in the establishment and maintenance of rimrock pine communities in the New River Gorge. Mining operations and railroad construction fueled the timber industry in the late 19th and early 20th centuries. However, it is unlikely that large portions of the rimrock forest were cut because of the poor quality of timber. Other events such as windthrow, ice storms, and insect outbreaks may have resulted in pulses of regeneration that coincided with the pine establishment following fires.

Management Suggestions

Restoring the disturbance regime that has established and maintained the rimrock pine community presents a number of challenges. First, we must ask the question, "Do we want to restore the rimrock pine community to its past dominance or do we want to keep the community within its current range?" The present-day pine component of the rimrock exists largely within the first 20 m of the cliff edge. However, historic photographs of the rimrock and the presence of dominant Virginia pines up to 300 m from the cliff edge suggest that the rimrock pine community was, in the first half of the 20th century, a thicker band along the rim of the gorge. For Virginia pine to become a dominant in the canopy away from the cliff edge, disturbances that created suitable growing conditions (i.e., mineral soil and direct sunlight) must have occurred in the past.

A management plan directed at restoring Virginia pine to its prior extent would include periodic prescribed burning to prepare the seedbed for pine regeneration and suppress deciduous competitors. As previously suggested by Vanderhorst (2002), burning could occur adjacent to the current pine communities (>20 m from cliff edge) to preserve a seed source. Mimicking past fires ignited on the slope of the gorge would not be feasible due to fire control issues and the risk of combusting exposed coal. There has been no research regarding the intensity of prescribed fire needed to regenerate Virginia pine. Research on prescribed burning conducted in Table Mountain pine stands located in the southern Appalachians suggests that multiple low-intensity fires may provide the best conditions for regeneration (Waldrop and others 2003). Because Virginia pine is considered a thin-barked species that is vulnerable to fire, the survival of fire-scarred pines confirms a regime of low-intensity burning (Carter and Snow 1990). Fires should occur during the dormant season prior to budbreak to follow the fire regime of the 20th century; however, fall fires may be more successful at promoting regeneration. A Virginia pine seed dispersal study found that dispersal began between mid-October and early November, and 60-90% of seed fell before January (Church and Sucoff 1960). Thus, burning prior to seedfall may be more effective in establishing pine seedlings in the following growing season. A second prescribed burning method could involve burning patches of the rimrock community to simulate a fire traveling up narrow breaks and low points along the Endless Wall. Initially, burning should occur in non-pine areas that have succeeded into more mesic hardwoods and eastern hemlock. This method would preserve the existing pine seed source adjacent to these areas while suppressing competitors and destroying the hardwood seedbank lying dormant in the soil.

Some questions must be taken into consideration when conducting a prescribed burn within a rimrock community. Is the area accessible to fire personnel and equipment? Is the area used often by visitors? Is the area safely within the park boundary? Is there a risk of the fire escaping to private land? Is smoke management a problem? How will other forest communities and wildlife be impacted? Some of the rimrock communities within the park boundary will be more suitable than others for conducting prescribed burning programs based on the answers to these questions. Resource managers may find that a combination of linear burns adjacent to the existing community and patch burns within community will satisfy the restoration objectives of the park.

Other methods to encourage regeneration of Virginia pine may complement prescribed fire. For instance, herbicide treatments could be used to target hardwood competitors while the seedbed was prepared by mechanical scarification. The amount of herbicides and extent of mechanical disturbance necessary to prepare the seedbed introduce additional concerns about the impacts on the ecosystem. Clearcutting strips of forest adjacent to the rimrock community, crop tree management, and other methods of canopy manipulation are more intensive options. While these methods may be highly successful at regenerating pine, they can be expensive, aesthetically unappealing to visitors, and increases susceptibility of residual pines to windthrow. Less intensive management actions could be implemented in addition to prescribed burning. These could involve voluntary and/or mandatory trail closings to halt soil compaction and trampling of pine regeneration and restrictions against using trees as anchors for rock climbing.

Finally, there is the option of no action. The rimrock community could be left to succeed into a hardwood dominated forest with Virginia pine existing on the cliff edges and rock outcrops.

Future Research

Implementing a prescribed burning program to restore and maintain the rimrock pine community will require much preparation to ensure management objectives are achieved. The NPS has developed a methodology outlined in the New River Gorge National River Wildland Fire Management Plan (2005) and in the NPS Fire Monitoring Handbook (2003a) that standardizes data collection procedures for fire effects research. Minimum research variables would measure pre- and post-burn vegetation data, leaf litter/duff measurements, soil moisture, consumption of woody debris, flame temperature, and flame height. While much is known about the effects of prescribed fire in mixed-oak (Brose and Van Lear 1998; Brose and Van Lear 2004; Elliott and others 2004; Yaussy 2000) and ridgetop pine stands (Brose and Waldrop 2000; Waldrop and others 2003; Welch and Waldrop 2001) of the Central Hardwood Region, their has been little research investigating the effects of prescribed fire on xeric, cliff-edge Virginia pine communities.

Another issue of concern is the impact of recreational use on cliff-edge forest structure and establishment of tree regeneration (Farris 1998; Larson and others 2000; Parikesit and others 1995). The rimrock pine community, located along the Endless Wall, is a popular area for hiking and rock climbing. Increased visitor usage will likely speed the rate of decline of the Virginia pine due to soil compaction, trampling of regeneration, and damage to the existing boles and roots that are used as anchors for rock climbing. In many areas along the gorge, the park boundary extends less than 100 m from the cliff edge, restricting the ability of the NPS to effectively restore and manage the rimrock pine community. Additionally, NERI faces the new challenge of preserving threatened ecological communities as the surrounding area becomes more desirable for residential development. A future research project investigating the impacts of visitor usage and residential development on the rimrock pine community would be valuable in determining management prescriptions and park policy regarding the location of developments near the park boundary.

The rimrock pine community is not separate from the surrounding ecosystem. The vegetation of the New River Gorge is a mosaic of forest communities and the management of each community will impact the others. For example, the hemlock wholly adelgid (*Adelges tsugae*) threatens to kill the neighboring eastern hemlock forest that buffers the streams flowing into the rimrock community. The loss of this evergreen species may hasten the hardwood succession near the cliff edge. Also, little is known about the vegetation on the vertical faces of the Endless Wall. Lichens, bryophytes, and canopy species such as Virginia pine, exist along this expansive substrate and may require a different management strategy from the surrounding ecosystems. Canadian researchers have conducted investigations along the Niagara Escarpment in southern Canada studying the effects of rock climbing of cliff vegetation (McMillan and Larson 2002), the impact of trails on cliff-edge vegetation structure (Parikesit and others 1995), and the effects of disturbance on old growth growing on cliff edges (Larson 1991). Similar projects would be beneficial in the description and management of cliff communities within the New River Gorge.

Conclusion

The goal of the present study was to evaluate the current and past condition of a rimrock pine community at the New River Gorge National River through a descriptive analysis of the vegetation, a tree-ring analysis of the age structure and disturbance regime, and the investigation of land use history. It is intended that with this information the NPS will be better able to manage valuable forest resources that are in danger of decline. The management suggestions written above will require modification to meet the multi-faceted goals of preserving the rimrock for future generations. However, the results of the study confirm the need of some type of restoration activity to aid regeneration of rimrock pines and to maintain the historic prevalence of the forest. Without action, the rimrock community will be succeeded by deciduous competitors on all but the poorest sites on the cliff edges and rock outcrops.

The present study is not without limitations and many questions were raised that were beyond the scope of the project. For example, would a spatial analysis of historic photographs taken throughout the 20th century provide evidence to confirm the frequency of disturbance and past abundance of Virginia pine? Is there evidence of wildfire in historic newspapers, magazines, journals, or mining and timber industry documents? Was fire a ubiquitous presence in the park or was it confined to the forests on the slopes of the gorge and rimrock areas? To better understand the disturbance regime (i.e., fire frequency, intensity, and extent), additional sampling must occur along the rimrock as well as down the slope of the gorge. Also, sampling in other rimrock pine communities within the park will help determine the impact of anthropogenic fires across the park. It is plausible that the frequency of fires differed in other cliff communities in the park and that the historic prevalence of Virginia pine along the Endless Wall is driven more by its disturbance regime than the edaphic site conditions.

The current rimrock pine community is a valued resource in threat of decline in the New River Gorge National River. Under the mandate of the National Park Service to conserve and interpret the natural, scenic, and historic character of this stretch of the New River Gorge, restoration of the rimrock pine community is necessary. The present project is only a snapshot of an ever-changing ecosystem and the maintenance of the rimrock forest will require some type of disturbance (i.e., fire) if it is to be preserved for the enjoyment of future generations.

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Appendix A: Raw tree-ring widths for Virginia and pitch pine species.

NERI001A1963	1632	1193	1706	1795	2436	2192	1556			
NERI001A1970	480	310	417	603	858	904	815	779	1034	1032
NERI001A1980	1515	467	598	401	268	462	377	478	253	484
NERI001A1990	669	344	737	497	754	509	762	602	596	176
NERI001A2000	514	274	383	359	418	544	-9999			
NERI001B1963	1815	1297	2106	2771	3539	3411	2611			
NERI001B1970	1536	475	1389	1673	1316	1832	1654	1866	1910	1695
NERI001B1980	1651	851	808	589	799	467	509	263	448	500
NERI001B1990	937	644	900	496	674	478	1375	1201	824	180
NERI001B2000	806	735	548	567	451	607	-9999			
NERI002A1909	1746									
NERI002A1910	2181	1294	2257	2834	1499	2692	3003	3918	3514	3078
NERI002A1920	1656	2683	2394	2514	1502	935	1728	2267	2010	1803
NERI002A1930	799	884	1517	1640	635	1069	676	1067	1897	80
NERI002A1940	587	446	751	715	435	883	661	719	647	720
NERI002A1950	639	460	272	757	780	582	837	608	821	248
NERI002A1960	416	413	308	160	88	335	412	672	1343	1062
NERI002A1970	653	534	946	916	831	781	467	466	584	515
NERI002A1980	514	601	584	546	563	409	305	286	212	491
NERI002A1990	608	236	704	659	659	457	472	453	457	137
NERI002A2000	490	254	412	444	587	340	-9999			
NERI002B1919	3007									
NERI002B1920	2089	2872	2264	1556	1464	951	1609	2591	4159	2651
NERI002B1930	796	174	1092	1875	900	1168	1004	1000	872	10
NERI002B1940	450	433	312	441	337	609	851	485	918	664
NERI002B1950	854	623	418	711	763	590	871	608	1106	718
NERI002B1960	790	692	492	389	268	459	490	562	883	649
NERI002B1970	428	698	817	1059	903	694	630	396	697	548
NERI002B1980	857	705	1109	831	627	354	405	305	304	786
NERI002B1990	689	426	897	824	843	657	1083	935	1022	428
NERI002B2000	1017	761	648	983	1034	688	-9999			
NERI003A1946	986	1205	2065	2707						
NERI003A1950	2670	1650	412	772	1171	1162	2212	1918	1986	1158
NERI003A1960	1756	1776	1337	1151	969	1451	1529	1985	2104	1590
NERI003A1970	1059	618	1557	1148	1363	1332	1693	1555	1781	1339
NERI003A1980	1531	808	1053	657	678	577	581	364	421	920
NERI003A1990	1257	1000	1772	1305	1018	853	1869	1231	1154	303
NERI003A2000	936	505	488	541	247	772	-9999			
NERI003B1955	1603	2137	2136	2706	1026					
NERI003B1960	1796	1516	1691	1301	1080	1598	1509	2167	2399	1816
NERI003B1970	1214	663	1629	1364	1321	1160	1300	1547	1754	1467
NERI003B1980	1606	785	1232	928	749	567	383	198	366	632
NERI003B1990	1454	1056	2155	1576	1138	878	2084	1317	1205	323
NERI003B2000	1071	455	836	892	380	647	-9999			
NERI004A1903	2047	2621	2669	837	1615	2373	1468			
NERI004A1910	922	1016	1775	1760	925	1909	1626	1345	1973	2602
NERI004A1920	1376	2506	1775	2329	1397	906	1894	2609	2272	1769
NERI004A1930	883	1997	2003	2451	1360	1821	1077	1239	1960	360

NERI004A1940	1179	886	860	1050	815	965	735	1174	1414	1656
NERI004A1950	1358	873	831	916	1080	754	1097	1318	2282	1469
NERI004A1960	1412	1452	989	714	979	897	1156	1337	1494	1044
NERI004A1970	771	952	1069	1070	1711	1663	1201	1018	690	458
NERI004A1980	677	489	802	968	777	479	526	330	608	732
NERI004A1990	793	519	865	1059	643	870	1629	1310	1060	546
NERI004A2000	805	859	1182	1641	1390	762	-9999			
NERI004B1905	2912	708	1786	2451	1473					
NERI004B1910	1200	1295	1839	1865	1037	1534	1732	1515	2087	2097
NERI004B1920	1371	2198	1693	1894	1385	858	1668	2378	2698	1986
NERI004B1930	876	1765	1764	2205	1230	1531	881	861	1476	1120
NERI004B1940	1197	880	1184	1137	628	1069	916	1150	1155	1180
NERI004B1950	1347	856	880	767	968	656	988	945	1664	1149
NERI004B1960	666	1054	673	306	364	412	506	652	1358	1314
NERI004B1970	1391	908	1066	1253	1075	1286	887	1260	818	710
NERI004B1980	904	722	892	1249	775	430	687	496	563	1006
NERI004B1990	1305	616	1056	1253	850	819	1252	1264	1056	461
NERI004B2000	594	700	813	1263	956	571	-9999			
NERI005A1914	2422	2894	3606	4095	2794	4458				
NERI005A1920	2642	3230	2584	3763	2245	1339	2458	2436	2982	1885
NERI005A1930	967	1936	1965	2281	1336	1275	1249	1886	3629	871
NERI005A1940	1703	1370	1162	1023	642	1596	1610	2245	1969	1875
NERI005A1950	2005	1683	1055	1112	1391	1215	2207	1189	1781	751
NERI005A1960	931	1080	906	842	768	639	553	653	1340	1356
NERI005A1970	902	827	966	1128	1625	2145	1831	1306	517	479
NERI005A1980	488	558	1008	1014	829	675	660	578	563	853
NERI005A1990	838	748	1059	1390	793	773	1075	1568	1157	709
NERI005A2000	910	747	963	1024	776	604	-9999			
NERI005B1905	4541	833	2082	2185	2521					
NERI005B1910	3189	2319	2762	3031	1641	1926	2633	2800	2648	3273
NERI005B1920	2061	3181	2740	3051	2062	1326	3425	3287	2151	1791
NERI005B1930	882	1101	898	1447	778	629	845	1391	1844	448
NERI005B1940	910	445	484	869	1141	1407	1063	1539	2474	3361
NERI005B1950	2820	944	1026	1191	1367	1247	1753	1344	2246	1086
NERI005B1960	1073	1340	892	954	692	568	838	826	1910	1674
NERI005B1970	1092	903	661	1089	1192	1076	1189	631	713	691
NERI005B1980	1404	883	1257	1598	1352	1144	867	597	689	860
NERI005B1990	1024	564	887	1002	777	522	643	799	687	326
NERI005B2000	478	532	647	1239	865	656	-9999			
NERI006A1906	2341	3565	3640	281						
NERI006A1910	733	1149	1889	1948	1081	1829	1544	1793	2098	2465
NERI006A1920	2348	2588	2063	1875	2112	1757	2824	2961	2610	2367
NERI006A1930	1274	799	1047	1703	852	779	904	926	1538	584
NERI006A1940	984	761	938	908	815	794	875	974	1044	1565
NERI006A1950	1888	1067	621	746	909	1204	1194	1147	1247	668
NERI006A1960	670	1092	837	649	546	698	696	1083	1593	1304
NERI006A1970	952	1396	1274	1744	1631	1382	1258	998	1122	984
NERI006A1980	963	901	1161	725	678	664	763	487	499	739
NERI006A1990	925	546	677	718	669	697	895	800	612	312
NERI006A2000	802	922	905	969	970	794	-9999			
NERI006B1915	2634	2622	1493	2335	2796					

NERI006B1920	3174	3814	3103	2282	2692	3216	2912	2543	2154	3289
NERI006B1930	3322	3411	3352	3759	2152	2430	2009	1931	2596	474
NERI006B1940	673	623	841	1116	642	670	667	980	1009	1451
NERI006B1950	1677	947	595	776	737	789	952	809	1276	711
NERI006B1960	622	1350	1306	1048	893	1059	1094	1737	1976	1639
NERI006B1970	1040	1110	1327	1933	1619	1123	1104	978	1178	874
NERI006B1980	1101	994	1635	1285	1009	895	958	664	669	1103
NERI006B1990	1381	924	928	959	992	991	1088	782	771	165
NERI006B2000	631	782	727	813	898	815	-9999			
NERI007A1947	5534	5815	3897							
NERI007A1950	4085	1869	1105	1678	1178	1192	1629	1831	2998	2958
NERI007A1960	2180	2820	1204	1274	738	1321	1343	1450	2087	2090
NERI007A1970	1465	1858	1610	2084	1807	1312	1006	1023	1092	1088
NERI007A1980	1163	929	1160	983	940	451	734	294	513	883
NERI007A1990	1033	629	1380	1025	1034	498	1363	1116	1191	437
NERI007A2000	1081	666	484	1284	1064	936	-9999			
NERI007B1953	2073	1760	1692	2490	2227	3429	2113			
NERI007B1960	2438	1941	1175	1327	761	1218	1042	1747	2066	1772
NERI007B1970	1061	1226	1226	2104	1990	1798	1003	1249	1563	1400
NERI007B1980	1161	1014	1709	1545	1479	1014	878	685	808	899
NERI007B1990	1030	406	1064	1017	1051	597	1271	985	899	191
NERI007B2000	857	881	929	1790	956	978	-9999			
NERI008A1840	3127	1827	2747	1763	2613	2415	1447	1685	1416	2083
NERI008A1850	937	1612	1192	1845	527	856	1755	1499	2520	3300
NERI008A1860	3457	533	1813	182	727	1982	1488	1323	1991	2163
NERI008A1870	1894	1734	2344	1574	1323	523	1366	1668	2479	830
NERI008A1880	2421	1295	5020	2683	2245	1457	2586	2225	1662	4122
NERI008A1890	2533	1412	1330	1703	2001	2475	1587	1352	927	833
NERI008A1900	328	1069	1010	822	956	818	960	1044	778	715
NERI008A1910	476	539	1033	1079	224	484	693	687	666	719
NERI008A1920	416	360	370	360	103	1	451	107	576	608
NERI008A1930	337	346	735	978	332	350	187	531	728	374
NERI008A1940	534	768	576	386	212	445	319	457	816	1196
NERI008A1950	1261	848	719	751	964	756	1045	763	1007	591
NERI008A1960	589	738	515	451	387	709	591	795	1039	617
NERI008A1970	631	631	916	1729	1325	1587	1410	1103	871	652
NERI008A1980	1360	1040	1287	1189	739	558	833	889	802	1281
NERI008A1990	1484	1026	1238	1337	1003	1025	1769	1274	1004	419
NERI008A2000	646	849	811	1085	1155	852	-9999			
NERI008B1830	1727	2671	4826	4685	4758	3765	3869	4018	5144	2910
NERI008B1840	2759	2088	4238	1728	2077	2365	1385	1332	1579	1654
NERI008B1850	1344	1610	828	1400	503	532	1180	1636	2012	2361
NERI008B1860	4248	826	1799	570	737	2115	1878	602	1524	1492
NERI008B1870	1626	1825	1566	1352	1278	675	1145	1240	2318	1658
NERI008B1880	2837	1984	4757	1695	1745	938	1719	1107	398	2107
NERI008B1890	2083	1313	1119	1480	1718	1255	1093	1041	693	695
NERI008B1900	222	481	305	486	765	563	422	421	516	498
NERI008B1910	268	264	533	482	105	204	277	251	104	278
NERI008B1920	271	124	165	113	70	1	66	162	254	512
NERI008B1930	328	258	681	1359	581	490	250	315	599	348
NERI008B1940	515	614	517	336	320	143	201	265	624	839

NERI008B1950	1064	364	471	553	484	501	706	618	613	203
NERI008B1960	319	446	463	411	212	470	368	647	628	643
NERI008B1970	504	841	825	1115	892	1050	826	920	457	411
NERI008B1980	439	533	832	753	539	515	648	650	520	933
NERI008B1990	1012	849	977	1225	1308	940	879	640	1157	449
NERI008B2000	631	748	536	675	526	484	-9999			
NERI010A1867	2072	3731	1946							
NERI010A1870	2275	1337	1936	1970	1853	331	1294	1986	3538	984
NERI010A1880	4466	3974	5771	2275	3300	2047	3650	1886	319	1585
NERI010A1890	1179	1085	2206	2578	2437	1625	948	1867	1492	2090
NERI010A1900	1060	1492	1261	1391	1943	1599	1740	2294	2108	1604
NERI010A1910	1549	1436	1888	1731	908	1334	1322	975	698	985
NERI010A1920	814	735	789	336	362	177	579	647	1276	1595
NERI010A1930	921	730	1455	1540	570	805	473	1414	1378	957
NERI010A1940	892	793	783	682	358	547	427	567	747	867
NERI010A1950	1114	852	553	909	1401	1292	1304	1107	1514	922
NERI010A1960	854	1238	1384	1356	1091	1110	921	866	903	1082
NERI010A1970	714	524	409	982	1223	1409	1920	2000	1380	1093
NERI010A1980	1834	1689	2447	2006	1867	1288	1859	1519	1459	2200
NERI010A1990	2519	2211	2043	2505	2355	1766	2921	2240	1759	1070
NERI010A2000	1145	1443	1325	2048	1635	1508	-9999			
NERI010B1866	3130	1698	2210	3743						
NERI010B1870	1453	1859	1052	1747	1379	1676	282	1720	4910	1770
NERI010B1880	4781	2342	2699	2532	3104	2008	5947	1286	522	1224
NERI010B1890	1120	881	634	1304	1844	1233	1195	1731	1394	1591
NERI010B1900	948	1337	1231	1214	1760	1410	1205	1059	1036	885
NERI010B1910	719	772	1199	1421	925	994	874	970	810	1155
NERI010B1920	977	902	946	509	356	168	511	417	694	766
NERI010B1930	441	321	819	858	566	276	212	330	317	234
NERI010B1940	293	225	164	239	167	125	288	311	646	1053
NERI010B1950	1779	878	367	517	635	671	551	845	849	520
NERI010B1960	511	617	940	1033	718	1157	921	1092	1340	872
NERI010B1970	852	514	946	1125	799	1042	846	592	470	248
NERI010B1980	528	441	694	600	628	666	1145	1008	1058	1506
NERI010B1990	1199	708	818	1005	1036	822	1372	1159	1304	671
NERI010B2000	694	1410	1450	2684	1739	1113	-9999			
NERI011A1922	2534	1540	1178	627	1320	1869	2022	2366		
NERI011A1930	1135	2066	2216	3312	1831	2090	1446	1715	2118	998
NERI011A1940	2087	1357	1393	2194	1478	1926	1848	1934	1803	1599
NERI011A1950	1847	764	815	1062	1045	941	1296	1320	1222	1044
NERI011A1960	933	1401	1114	1239	1160	1061	769	1255	1772	1496
NERI011A1970	934	1439	1428	1129	1258	1749	1605	1237	998	1038
NERI011A1980	838	1074	971	922	709	808	723	688	716	890
NERI011A1990	1267	965	1028	1082	1018	890	997	1203	672	533
NERI011A2000	687	534	835	984	887	662	-9999			
NERI011B1913	2859	1630	2682	2192	1917	1945	2409			
NERI011B1920	1924	2538	1662	1815	1063	667	987	1024	1199	1131
NERI011B1930	923	1698	1378	2042	1266	1496	1221	1784	2013	703
NERI011B1940	974	791	706	843	1079	1273	1418	1299	1884	2913
NERI011B1950	2664	1677	1574	1502	1485	1728	1708	2205	1798	1230
NERI011B1960	1520	1717	1168	1105	1157	1012	938	1502	2629	1626

NERI011B1970	1092	1196	1874	1404	1723	1735	1359	1277	879	803
NERI011B1980	904	875	963	1145	930	712	805	468	725	943
NERI011B1990	1032	581	874	1028	880	960	1019	1119	592	161
NERI011B2000	665	490	864	969	726	793	-9999			
NERI012A1919	2229									
NERI012A1920	1394	2275	1415	1226	970	488	754	1296	1895	1528
NERI012A1930	337	109	113	909	531	404	495	611	1348	314
NERI012A1940	900	456	851	1139	599	1095	1179	1303	1203	774
NERI012A1950	618	251	166	547	391	506	741	897	1452	820
NERI012A1960	682	875	766	747	803	834	847	1523	1645	1200
NERI012A1970	766	453	198	865	996	1513	1014	856	911	912
NERI012A1980	940	793	1113	755	582	526	332	490	536	1039
NERI012A1990	1032	911	890	521	822	630	497	882	243	85
NERI012A2000	335	490	319	325	232	147	-9999			
NERI012B1904	2686	3416	1783	2095	3222	1530				
NERI012B1910	2081	1845	1964	2172	1001	1723	1655	1548	2052	1510
NERI012B1920	1185	1518	1263	1236	1235	815	814	1029	785	1178
NERI012B1930	621	595	435	876	338	361	296	722	1176	180
NERI012B1940	456	798	494	827	500	803	1174	1073	931	1464
NERI012B1950	2019	1314	1009	798	735	595	935	742	1220	788
NERI012B1960	942	1075	1183	1097	978	1094	973	1555	1693	1700
NERI012B1970	1061	572	692	2114	1802	2012	1803	1168	1043	932
NERI012B1980	1660	1379	1659	1222	1071	712	706	470	891	1392
NERI012B1990	1305	1190	1286	907	1128	954	698	1166	326	263
NERI012B2000	237	342	429	570	675	453	-9999			
NERI014A1951	1775	1093	890	2162	2323	3244	1943	2644	1548	
NERI014A1960	1938	1774	1867	1363	1053	1509	1504	2159	2428	1804
NERI014A1970	813	1058	1330	1699	1697	1714	1071	1059	932	1021
NERI014A1980	1092	530	902	1100	1182	786	991	584	854	972
NERI014A1990	690	1409	1313	993	832	818	1868	1826	972	834
NERI014A2000	1489	1474	1565	1363	1671	1179	-9999			
NERI014B1947	1836	2408	2576							
NERI014B1950	2679	1875	1086	1145	1832	2278	3450	2182	2768	1838
NERI014B1960	2419	2283	2295	1681	1230	2164	2037	2815	2926	2357
NERI014B1970	1459	1730	1629	2001	1871	1854	1540	1619	1169	1304
NERI014B1980	2131	1320	1700	1491	1322	866	1217	679	1002	1550
NERI014B1990	1488	901	2230	1408	1236	905	1609	1631	1377	398
NERI014B2000	1340	1078	1237	1847	1717	1588	-9999			
NERI015A1953	1056	1603	1890	4164	2215	3440	1523			
NERI015A1960	1695	1714	1590	2618	977	985	864	1378	2608	1748
NERI015A1970	975	1227	788	1015	1413	1330	1418	1698	1151	830
NERI015A1980	987	645	1484	1818	1123	655	1114	887	936	1208
NERI015A1990	1409	974	1356	1138	1199	903	1933	1619	1210	508
NERI015A2000	1169	1093	943	1521	1209	1386	-9999			
NERI015B1945	1556	1962	2959	2927	2473					
NERI015B1950	3074	2170	1262	1346	1303	1263	3247	2089	2773	1326
NERI015B1960	2169	2125	1948	1461	1080	1698	1344	2168	2176	2117
NERI015B1970	1022	1082	1271	1717	1671	1460	1506	1333	1755	1911
NERI015B1980	1848	1096	2318	1854	1036	940	1109	734	890	1351
NERI015B1990	1866	1156	1721	1434	1770	1235	2298	2339	1374	756
NERI015B2000	1310	1108	1258	1816	1477	1636	-9999			

NERI016A1949	2362									
NERI016A1950	2911	2533	1253	1307	1820	1814	2575	2319	2442	1371
NERI016A1960	1498	1902	1311	1357	1151	1360	1159	1934	1912	1405
NERI016A1970	808	1167	1072	1969	2152	1780	1416	1301	1302	1053
NERI016A1980	1123	780	904	661	588	365	411	349	329	558
NERI016A1990	429	357	431	193	416	279	268	342	254	276
NERI016A2000	225	199	400	281	90	80	-9999			
NERI016B1947	2889	2931	2694							
NERI016B1950	3112	2810	1166	994	1166	1350	2252	1596	2544	1764
NERI016B1960	1838	1685	1278	1291	962	1328	1662	1956	1868	1533
NERI016B1970	1200	1460	1151	1137	1126	1087	1081	951	866	894
NERI016B1980	949	379	391	359	97	97	190	287	262	266
NERI016B1990	194	246	306	269	277	414	165	55	134	35
NERI016B2000	43	37	98	132	100	97	-9999			
NERI017A1952	2327	1910	1371	1368	2488	1928	3018	1622		
NERI017A1960	1965	1577	1842	1412	1277	1587	1533	2029	2619	1805
NERI017A1970	1085	1075	1570	1668	1953	1614	1780	1520	1801	1681
NERI017A1980	1959	1189	2205	1568	1339	956	1203	916	1924	2104
NERI017A1990	2112	1641	2016	1862	2382	1812	2317	1964	1791	1269
NERI017A2000	1635	1282	1664	2017	1490	1516	-9999			
NERI017B1949	4659									
NERI017B1950	4636	3614	2748	2666	1483	1209	2188	1825	3049	1396
NERI017B1960	1813	1434	1605	1401	722	1090	1417	1994	3052	2284
NERI017B1970	1490	1235	1346	1895	1739	1605	1570	1648	1887	1797
NERI017B1980	2588	1335	2395	1837	1350	1066	1700	1153	1468	2203
NERI017B1990	2669	1656	2293	2161	2665	1877	2569	2465	1858	1432
NERI017B2000	1430	1189	1421	1940	2010	2028	-9999			
NERI021A1903	2493	3822	4787	2684	3242	4429	2029			
NERI021A1910	4396	3639	4202	3834	2857	4132	3946	3903	3544	3487
NERI021A1920	2463	4021	2112	2958	2068	1581	3986	3531	3882	2990
NERI021A1930	1487	3526	3160	2860	2151	3397	1309	1694	1661	1394
NERI021A1940	1861	1610	1405	1369	1052	2636	1264	1796	1834	2661
NERI021A1950	2790	1259	1	471	1847	1578	2640	1938	2858	1339
NERI021A1960	2057	1354	815	1405	1631	1660	1325	1306	2710	2329
NERI021A1970	1446	764	1019	1946	1862	1965	1272	1020	1320	1346
NERI021A1980	1210	901	1109	1004	1112	546	745	423	873	1198
NERI021A1990	1027	540	915	638	925	871	1203	1276	766	830
NERI021A2000	1167	898	872	976	925	1030	-9999			
NERI021B1907	3980	4287	440							
NERI021B1910	1200	2449	2169	1779	1087	3221	2535	2847	2940	3242
NERI021B1920	2405	3820	1996	3126	2620	1815	4543	2762	2684	2991
NERI021B1930	1448	2770	4239	3264	1966	2811	1740	2250	1828	1067
NERI021B1940	2194	2306	2211	2446	1819	1862	1693	2367	2538	3260
NERI021B1950	4061	2500	1318	1670	3020	2720	4055	2325	2886	1113
NERI021B1960	2584	1934	1698	1828	1686	2963	2825	2728	2486	1773
NERI021B1970	1305	1348	1822	1793	1631	1217	1400	838	996	1666
NERI021B1980	1904	1470	1591	1098	974	656	1227	461	562	1191
NERI021B1990	886	355	590	338	346	243	439	471	341	292
NERI021B2000	610	521	730	1082	1121	1081	-9999			

Appendix B: Raw tree-ring widths for oak species.

NERI013A1908	2107	1568								
NERI013A1910	2244	1070	1374	1244	652	1978	1535	1819	1426	1814
NERI013A1920	1652	1706	1497	923	1028	831	1074	1671	2330	1571
NERI013A1930	917	847	1216	1190	852	1321	1128	1955	2260	3034
NERI013A1940	1932	1639	2408	1985	1636	1014	896	797	893	892
NERI013A1950	779	1129	964	1007	816	758	809	1008	785	899
NERI013A1960	612	815	732	750	444	550	519	578	542	521
NERI013A1970	772	1004	908	775	641	712	670	619	884	842
NERI013A1980	854	745	879	787	607	861	714	855	606	545
NERI013A1990	715	613	575	737	607	822	728	727	501	518
NERI013A2000	653	876	-9999							
NERI013B1904	1895	2108	2363	3078	2998	1829				
NERI013B1910	2718	1009	1182	1190	778	1908	1535	1364	1156	1928
NERI013B1920	1840	2262	1880	1614	1674	1048	1358	1716	2245	2151
NERI013B1930	1302	1111	1615	1486	1117	1881	1248	1716	1827	2348
NERI013B1940	2095	2991	2878	2011	1710	876	762	736	702	791
NERI013B1950	663	798	848	869	708	643	525	913	777	825
NERI013B1960	480	555	557	474	475	655	558	607	682	573
NERI013B1970	667	1325	828	799	622	873	590	633	695	663
NERI013B1980	673	788	1018	859	672	680	564	695	593	618
NERI013B1990	835	575	586	496	544	701	606	591	463	284
NERI013B2000	370	546	509	562	493	698	-9999			
NERI018A1947	2139	1896	1685							
NERI018A1950	1237	1520	2847	3142	3158	2890	4260	3806	2913	1146
NERI018A1960	1958	1586	1333	1558	1129	1851	1157	1380	1815	1621
NERI018A1970	998	1347	2118	2823	3744	3386	3404	2722	2910	2595
NERI018A1980	2852	2581	3282	2768	1553	2412	1818	1662	1009	1822
NERI018A1990	2136	1504	1613	1919	1343	1702	1505	1446	1521	893
NERI018A2000	1487	836	797	727	824	-9999				
NERI018B1952	1552	1771	1549	8536	5881	5104	5162	2659		
NERI018B1960	3597	2510	1720	2514	1874	2577	1491	2088	2460	1951
NERI018B1970	1746	2126	2611	2765	3265	3286	2699	2525	3072	2867
NERI018B1980	2565	2129	3181	2825	1804	2234	1607	1304	963	1743
NERI018B1990	1933	1439	1267	1548	1061	1462	1420	1435	1209	838
NERI018B2000	1197	579	779	544	890	631	-9999			
NERI019A1941	1945	1705	2142	2104	2556	1967	2237	3523	3350	
NERI019A1950	3073	2528	3038	4731	5107	4266	4964	5086	5465	2835
NERI019A1960	3463	3636	3562	3035	2023	3703	3019	3250	3664	3517
NERI019A1970	2587	3103	2439	3162	2533	3047	2362	1724	2061	2036
NERI019A1980	1967	1909	2366	2199	1048	1729	973	1350	928	1253
NERI019A1990	1406	1172	1404	1676	1154	1562	1126	1049	667	584
NERI019A2000	1125	847	976	728	1279	868	-9999			
NERI019B1942	2194	2566	2767	3708	1965	2210	3244	3451		
NERI019B1950	4242	3350	3544	4856	4716	3585	5420	5115	6101	3692
NERI019B1960	4768	3369	3381	3402	2479	3366	3450	4033	3911	3403
NERI019B1970	3086	2151	2974	3108	2521	3507	3083	2333	2418	2264
NERI019B1980	2126	2097	2371	2575	1620	1780	862	1290	792	1117

NERI019B1990	1133	1199	1397	1690	1045	1200	732	1040	714	555
NERI019B2000	833	672	895	512	1078	769	-9999			
NERI020A1950	2354	1556	1349	2379	1444	1934	1720	1942	2487	1369
NERI020A1960	1536	2526	1639	1534	837	1176	854	1554	2072	2591
NERI020A1970	2072	3403	2747	3530	2641	3606	2721	3583	4359	3908
NERI020A1980	2429	2685	4390	2909	1550	2285	1976	1807	1203	1750
NERI020A1990	1620	1477	2116	2213	1470	2176	1959	1355	1914	983
NERI020A2000	1514	1524	1098	1013	1594	1326	-9999			
NERI020B1964	1157	2005	1886	3853	5113	4900				
NERI020B1970	3127	4117	3958	4284	3798	6615	5501	5727	7023	6566
NERI020B1980	3376	4080	5672	2755	2034	2340	2815	2458	1834	3027
NERI020B1990	3124	2330	2603	2464	1847	3336	3010	2321	2653	1703
NERI020B2000	2441	2707	1827	1591	2998	1961	-9999			
NERI022A1875	2692	2158	1810	1913	1225					
NERI022A1880	1468	1472	2223	1722	1278	856	1532	1396	1254	1747
NERI022A1890	1289	1664	1234	1164	1222	1557	1096	1493	1122	1325
NERI022A1900	1097	1269	1331	1107	1120	797	547	1424	1008	733
NERI022A1910	988	561	952	1077	679	1197	1001	1291	974	941
NERI022A1920	1426	1057	1425	1433	1780	1021	913	1108	1452	1413
NERI022A1930	893	1010	1486	1598	1239	1787	1706	1265	1390	1353
NERI022A1940	1368	1209	969	1422	895	965	1277	861	1066	1241
NERI022A1950	1416	1521	1426	1534	992	1350	1513	1457	1302	1084
NERI022A1960	884	1229	1090	1081	910	1377	964	1281	1082	1033
NERI022A1970	964	1412	1162	1006	1210	1587	1054	1303	1319	1250
NERI022A1980	1083	1301	1722	1441	782	1257	986	990	749	840
NERI022A1990	1120	847	904	924	892	1277	987	974	1001	754
NERI022A2000	879	1057	826	820	1076	768	-9999			
NERI022B1863	3031	2953	3893	3826	3941	4507	3920			
NERI022B1870	4252	2679	3947	2932	1914	4396	3005	3227	3697	2717
NERI022B1880	3269	2851	4921	4051	2618	1909	3533	2614	2417	5411
NERI022B1890	2981	3442	2970	2324	1725	1944	2579	3607	2722	2461
NERI022B1900	1815	1752	2038	1855	1533	1470	1312	2658	2518	1811
NERI022B1910	2110	1145	1761	1815	1086	1516	1417	1986	1109	1318
NERI022B1920	1448	1243	1456	1579	1781	1195	1257	1568	1747	1769
NERI022B1930	1043	1514	2218	2509	1508	2571	1876	1945	1908	1662
NERI022B1940	1932	1947	1918	2502	1677	1365	1897	1545	1890	2119
NERI022B1950	2238	2333	2711	3023	1892	1990	2023	2283	2578	1743
NERI022B1960	1556	2386	1665	1816	1292	1858	1614	2220	2074	1878
NERI022B1970	2176	2169	2321	2427	2312	2714	1793	1821	1979	1846
NERI022B1980	1649	1614	2104	2049	1095	1572	1149	1381	1035	1248
NERI022B1990	1530	1218	1374	1716	1333	1599	1110	1206	1271	888
NERI022B2000	1302	1291	1191	1134	1234	1392	-9999			
NERI024A1945	1195	805	1455	1341	1486					
NERI024A1950	1581	2047	2751	2217	1529	6368	5198	3635	3142	1291
NERI024A1960	2665	1883	2312	2656	1458	1677	1737	1658	2353	2094
NERI024A1970	1799	2253	1416	1847	1996	2061	2116	1860	1875	1478
NERI024A1980	1287	1509	2295	2267	1568	1867	1354	1157	974	1262
NERI024A1990	1194	1014	1320	1316	944	1305	975	928	899	535
NERI024A2000	932	860	666	717	774	661	-9999			
NERI024B1962	2884	2258	1346	2375	2145	2479	3454	2847		

NERI024B1970	2457	2782	2831	2986	2852	2751	2159	1994	2197	1513
NERI024B1980	1592	1507	1953	2331	1532	1676	1739	1313	1293	1372
NERI024B1990	1196	905	1409	1187	1279	1561	1179	1037	1086	861
NERI024B2000	1100	864	825	671	1140	861	-9999			
NERI025A1940	2181	1608	1802	1524	993	1236	944	1428	1177	1383
NERI025A1950	1751	1544	2498	3233	3580	2833	3569	3784	4394	2069
NERI025A1960	3719	3221	3296	2833	1635	2856	3508	3501	3934	3288
NERI025A1970	2791	4391	3520	2429	3042	3678	3139	3711	4085	3843
NERI025A1980	1968	2213	4135	2826	2248	2887	2674	2680	1665	1993
NERI025A1990	2651	1920	2286	2813	2804	4090	5776	3828	4117	1964
NERI025A2000	4419	4302	3207	3126	5078	3472	-9999			
NERI025B1942	1240	1179	819	1198	913	1696	944	1079		
NERI025B1950	1088	1270	2168	3280	4243	2860	3399	2767	3720	1365
NERI025B1960	3287	2646	2712	2227	1494	2842	2620	2822	3078	2762
NERI025B1970	2441	3599	3291	2314	2800	3836	3046	3621	3609	3786
NERI025B1980	2164	2977	4601	3201	2135	2213	2397	2383	2191	2113
NERI025B1990	2637	1705	2275	2622	2712	3129	3508	2373	2462	1222
NERI025B2000	3038	3325	2673	2964	3280	2710	-9999			
NERI026A1943	2359	1424	2256	1419	2115	1521	1211			
NERI026A1950	1378	1637	1343	1751	1462	1642	2604	2571	3178	1709
NERI026A1960	2387	2841	1247	1077	1044	1483	1358	1581	2037	2237
NERI026A1970	2689	2876	3477	3447	2754	3963	2629	2836	3387	3194
NERI026A1980	2646	2503	3915	2899	2107	2717	2930	3298	2519	2731
NERI026A1990	3395	2636	3576	3396	3149	4483	4299	3028	4378	2658
NERI026A2000	4215	4192	3312	3607	4619	4056	-9999			
NERI026B1939	1858									
NERI026B1940	1422	2526	3499	2651	1798	4020	2014	3542	3030	3316
NERI026B1950	2361	2464	2019	2506	2085	2692	3679	3736	3451	1502
NERI026B1960	2627	2931	1813	1829	1269	1634	1554	1858	2375	2855
NERI026B1970	2830	3852	3459	3233	3261	3990	4269	3260	3102	3105
NERI026B1980	2249	2318	3414	2691	1866	2558	2365	2383	1474	1813
NERI026B1990	1950	1532	1816	1692	1487	2116	2148	2237	2253	1231
NERI026B2000	1463	1558	1431	1708	2973	2685	-9999			
NERI030A1915	997	2061	1101	597	632					
NERI030A1920	919	788	902	867	980	474	1086	1824	1442	1472
NERI030A1930	964	1002	2074	1917	1486	2649	1531	1342	1347	1221
NERI030A1940	2716	3263	3739	3378	3499	3091	2398	1925	2560	2924
NERI030A1950	2814	2890	2460	2420	2043	3018	2462	2802	2096	1202
NERI030A1960	2027	2467	1971	1599	1130	1928	1280	2495	1976	1536
NERI030A1970	2197	1807	1419	1129	1276	1425	960	940	1352	1027
NERI030A1980	1085	1074	1464	1383	811	877	584	780	583	767
NERI030A1990	721	615	748	658	478	740	567	378	325	388
NERI030A2000	395	567	396	460	587	584	-9999			
NERI030B1928	1307	1349								
NERI030B1930	1199	1329	2009	1935	1629	2471	1463	1869	1332	1347
NERI030B1940	2333	2172	1795	2950	1957	3068	2334	2997	2942	2886
NERI030B1950	3448	3205	2061	3020	2476	2752	3153	3128	2806	1223
NERI030B1960	2204	2938	1469	1348	1178	2157	1380	2103	2125	2317
NERI030B1970	2093	2253	1932	1443	1724	2415	1979	1888	2348	2028
NERI030B1980	1505	1562	2609	2003	1352	1377	926	1183	903	993

NERI030B1990	1006	667	883	976	756	801	783	716	563	412
NERI030B2000	738	885	606	515	953	783	-9999			
NERI036A1948	2831	5916								
NERI036A1950	6135	6715	4465	4524	4724	4886	6422	5922	6248	2947
NERI036A1960	4074	4116	3766	5127	2491	2999	2426	3044	4259	2688
NERI036A1970	2643	2741	2966	3286	3560	3520	2997	3120	3255	2883
NERI036A1980	3329	2862	3745	2778	1735	1646	1015	1384	1103	1580
NERI036A1990	2332	1895	2066	2415	2097	2541	2259	2216	1604	1441
NERI036A2000	1469	2034	1452	1001	1731	1891	-9999			
NERI036B1948	2691	5642								
NERI036B1950	5298	5224	2727	3443	3485	3784	4194	3692	4909	2015
NERI036B1960	2423	2510	2363	2049	1383	1850	1876	1940	2463	1701
NERI036B1970	2260	2109	1970	2196	2702	3198	2793	2843	3180	2369
NERI036B1980	2243	1988	2581	2193	1524	1995	896	1060	689	1006
NERI036B1990	1213	1068	1166	1514	1398	1520	1553	1388	1163	866
NERI036B2000	937	1470	914	804	1383	1514	-9999			
NERI042A1953	1966	5387	2342	2073	2206	1862	1001			
NERI042A1960	1299	1176	1445	1314	1016	1153	1008	1973	1999	1990
NERI042A1970	2065	1560	2194	2062	1889	1810	1598	1404	1208	1290
NERI042A1980	1284	1167	1026	1014	586	1017	707	751	436	594
NERI042A1990	646	480	486	530	420	528	395	486	474	436
NERI042A2000	413	630	639	383	422	498	-9999			
NERI042B1953	1915	4653	2959	2151	2316	2392	1283			
NERI042B1960	1841	1599	1909	1521	1077	1136	986	2323	2112	2129
NERI042B1970	2074	2213	2519	1978	2034	1920	2077	1582	1388	1639
NERI042B1980	1312	1454	1375	1504	818	1201	733	742	463	959
NERI042B1990	1005	677	896	796	605	870	568	857	684	458
NERI042B2000	814	854	790	760	517	622	-9999			
NERI043A1958	1741	1358								
NERI043A1960	1645	2241	2475	2219	1575	1921	2089	2589	2704	2603
NERI043A1970	2580	2485	2123	3005	2058	1841	1688	2570	1730	1455
NERI043A1980	1469	1324	1300	1256	871	1112	898	959	816	1046
NERI043A1990	1158	783	949	828	809	943	627	732	710	559
NERI043A2000	700	770	629	720	642	687	-9999			
NERI043B1958	1841	1288								
NERI043B1960	1822	1868	1416	1635	1128	1289	1407	1805	2308	2420
NERI043B1970	2538	2388	2581	2689	2680	2181	2428	2973	2281	1697
NERI043B1980	2046	1968	1692	1697	1128	1543	1073	1012	916	1098
NERI043B1990	1227	986	1190	1064	993	1405	981	1338	1189	1008
NERI043B2000	1206	1230	1096	1300	1084	850	-9999			

Appendix C: Raw tree-ring widths for maples species.

NERI031A1947	1564	1490	1279							
NERI031A1950	812	1026	519	1456	998	1316	1153	502	1288	1186
NERI031A1960	1159	540	266	324	162	257	241	1698	1931	1894
NERI031A1970	1406	2101	1411	1234	1399	1280	2563	2036	1966	2379
NERI031A1980	2670	2536	2833	2055	433	2864	1699	2382	1	880
NERI031A1990	2251	1498	2549	2256	1331	2529	1505	1819	1574	413
NERI031A2000	2299	3615	1205	1422	1723	830	-9999			
NERI031B1947	1583	1453	1333							
NERI031B1950	891	1144	598	1451	774	1502	1411	667	1122	1078
NERI031B1960	1672	283	223	350	409	420	425	1983	1891	2103
NERI031B1970	1679	1719	1288	810	1408	1853	2052	1743	1426	2634
NERI031B1980	2544	2168	2584	1319	516	2235	489	1310	197	829
NERI031B1990	1698	1489	3052	2359	1505	2452	1040	1724	1556	481
NERI031B2000	1285	2123	898	736	1865	1088	-9999			
NERI033A1949	1376									
NERI033A1950	1233	838	532	284	778	157	461	696	407	208
NERI033A1960	937	373	407	258	731	328	681	1942	1898	1485
NERI033A1970	940	1574	1264	585	1399	1997	1920	2182	2232	2533
NERI033A1980	1936	2581	3861	2559	704	2396	2720	1718	241	743
NERI033A1990	1247	901	1731	1445	822	1692	1045	1037	1653	245
NERI033A2000	1202	2138	760	645	1544	665	-9999			
NERI033B1949	1122									
NERI033B1950	1092	1152	516	431	970	431	1125	1707	635	248
NERI033B1960	1818	1386	844	225	279	1187	626	2092	1841	1575
NERI033B1970	827	1136	869	176	708	1041	646	1202	1202	1533
NERI033B1980	1825	1676	1981	1503	340	1163	942	865	153	631
NERI033B1990	810	744	1701	1512	1141	2044	839	818	1409	253
NERI033B2000	1330	1794	842	500	1681	719	-9999			
NERI034B1941	2363	1221	698	801	364	646	743	944	890	
NERI034B1950	406	308	1	164	548	339	687	813	386	644
NERI034B1960	925	958	704	324	543	385	601	897	1102	1100
NERI034B1970	691	1195	910	577	1489	1578	1482	1604	1995	2414
NERI034B1980	1903	3134	737	226	1018	284	659	67	1	166
NERI034B1990	234	462	647	435	768	257	310	141	480	67
NERI034B2000	586	964	445	25	288	422	-9999			
NERI034A1941	2362	1232	843	831	276	580	827	780	826	
NERI034A1950	611	488	1	234	803	447	924	1337	557	644
NERI034A1960	1190	987	617	365	612	205	677	1058	1551	1408
NERI034A1970	843	1150	951	573	1350	1255	1106	1321	1799	1878
NERI034A1980	797	2264	2910	856	204	915	199	704	1	80
NERI034A1990	143	187	318	440	368	697	207	202	480	55
NERI034A2000	620	909	405	75	477	362	-9999			
NERI035A1937	1724	2195	1163							
NERI035A1940	949	2709	1856	1420	1967	1612	2514	2419	3123	2680
NERI035A1950	3546	2410	457	2262	1212	3296	3986	2702	2637	1214
NERI035A1960	2190	3365	2403	1737	885	1459	1314	2519	2975	2147
NERI035A1970	1132	2793	1700	2172	1467	1999	2068	1375	2486	2000

NERI035A1980	1960	2015	3283	1981	433	1088	570	1554	753	1867
NERI035A1990	2547	1592	2269	1843	1101	2304	1779	1767	2693	670
NERI035A2000	1399	2046	1426	667	2022	1743	-9999			
NERI035B1937	1560	2304	1340							
NERI035B1940	760	2200	2786	1853	2949	1947	3369	3668	3543	3161
NERI035B1950	3569	2518	1	1089	688	3276	3762	2813	2797	924
NERI035B1960	2214	2631	2319	2193	1221	1892	2287	3426	3480	2660
NERI035B1970	1476	2438	2382	3032	2479	3010	3614	1882	3007	2259
NERI035B1980	1822	2017	2417	1434	360	767	556	1096	553	1601
NERI035B1990	1932	1472	2431	2191	1181	2487	1747	1651	2815	622
NERI035B2000	2224	2515	1350	427	1351	1322	-9999			
NERI037A1959	1131									
NERI037A1960	2217	3616	3475	1823	1212	1880	1479	2448	2988	3607
NERI037A1970	1873	2661	2046	1491	2358	2542	2611	1967	2177	1833
NERI037A1980	2335	1656	2891	2333	792	2397	2089	1701	634	2550
NERI037A1990	3220	2029	2724	3453	1534	1982	1617	1532	2394	615
NERI037A2000	2442	2312	1569	1041	1773	1423	-9999			
NERI037B1958	1969	1073								
NERI037B1960	2457	2799	3204	1841	1438	2156	1929	2452	2901	3553
NERI037B1970	1742	2767	1828	1580	2904	3107	2681	1856	3321	3337
NERI037B1980	2246	2141	3552	3250	528	2575	1653	1752	849	3160
NERI037B1990	4488	3661	4882	3515	2159	3876	3715	3221	3708	923
NERI037B2000	4152	4176	2291	2714	2772	3444	-9999			
NERI038B1960	2128	2287	2291	1181	1843	1454	3198	4365	4302	3412
NERI038B1970	2986	2375	2708	3633	4016	3899	2313	1889	937	2823
NERI038B1980	3074	2243	3705	2059	654	1780	598	758	539	1392
NERI038B1990	2325	1774	2472	2035	1065	1996	1178	1544	1752	713
NERI038B2000	2947	1849	1571	848	1545	1454	-9999			
NERI038A1960	3588	5701	3811	1932	3183	1645	3286	4288	4113	4360
NERI038A1970	4065	3223	4058	4772	4628	3456	2579	2244	1425	2038
NERI038A1980	1755	1811	2735	2043	490	1866	555	883	573	1729
NERI038A1990	2066	1348	1742	1901	998	1610	816	959	921	534
NERI038A2000	1253	1042	913	470	481	866	-9999			
NERI039A1955	502	607	1821	137	366					
NERI039A1960	1176	1349	2220	1620	119	2148	1536	2380	3166	2544
NERI039A1970	1431	1673	1172	324	1520	1826	1292	1674	2213	2393
NERI039A1980	1426	1394	2544	1850	289	1491	865	893	1	685
NERI039A1990	866	775	1080	837	715	1130	507	678	1554	482
NERI039A2000	976	1480	798	108	240	307	-9999			
NERI039B1955	475	620	1625	117	332					
NERI039B1960	710	1701	1898	975	77	2521	1659	3174	4245	4111
NERI039B1970	3375	2694	2247	1697	2463	3124	2705	2308	2621	2426
NERI039B1980	1501	1317	2195	1437	152	1263	499	963	1	600
NERI039B1990	1275	1037	1347	963	748	1042	482	705	1101	385
NERI039B2000	902	1802	1293	241	421	658	-9999			

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