

Characterization of Ancient Red Cedar Communities in the Obed Wild and Scenic River Gorge

Dr. Gary Walker
Professor of Biology, Appalachian State University
Cliff-Face Ecology

Dr. Peter Soule'
Professor of Geography, Appalachian State University
Dendroecology

Mr. Bal Krishna Nepal
M.S. Candidate, Appalachian State University
Plant Ecologist

Dr. Coleman McCleneghan
Shrooms Inc.
Mycologist

Mr. Derick Poindexter
Research Assistant, Appalachian State University
Plant Systematist

Mr. Keith Bowman
Ph.D. Candidate, SUNY ESF
Syracuse
Bryologist

Mr. Brandon Saunders
M.S. Candidate, Appalachian State University
Geography and Planning, GIS

INTRODUCTION

Recent ecological research on cliff faces in the eastern United States and Canada suggest that cliff-face habitats harbor old-growth trees, serve as refugia for glacial relict plant populations, and act as genetic reservoirs. Studies of the Niagara Escarpment in Ontario, Canada and the southern Appalachian mountains in Tennessee have demonstrated that cliff-face plant communities represent ancient forests, with trees dated in excess of 1000 years of age (Kelly et al. 1994; Larson et al. 2000; Walker 1987). Additionally, many rare and disjunct plant species have been found on cliffs, including species thought to have been stranded in these habitats following glacial advance and retreat cycles (Oosting and Hess 1956; Walker 1987; Hart and Shankman 2005; Wiser 1994; Kennedy 2003).

Plant species adapted to cool, moist conditions migrated south in advance of the Wisconsin glaciation of the last ice age and colonized the southern Appalachians (Ramseur 1960; Delcourt and Delcourt 1987). As the climate warmed and the glacier retreated, the cool, moist micro-climates of north-facing cliffs in the south provided isolated refugia with favorable conditions for these species (Oosting and Hess 1956; Walker 1987; Hart and Shankman 2005). North-facing cliffs in the southern latitudes of the northern hemisphere receive less insolation and have lower temperatures and higher moisture than cliffs with eastern, western, or southern aspects (Larson et al. 2000b).

Walker (1987) found old-growth disjunct populations of *Thuja occidentalis* L. on north-facing cliffs in the southern Appalachians. The main range of this species encompasses the northeastern U.S. and southeastern Canada, where it occurs in flat, swampy areas as well as on cliffs. Subsequent research by Walker and his students have found other rare northern disjunct plant and lichen species, such as the boreal lichen assemblages recently discovered on the White Rocks Cliff system of Cumberland Gap National Historic Park (Ballinger 2007) and *Cypripedium reginae* Walter, associated with *Thuja occidentalis*, on north-facing cliffs in the southern Appalachians (Kennedy 2003). The presence of multiple northern disjunct species in these communities supports the theory that they are present as glacial relicts, rather than as long-distance dispersers.

Such relict plant populations may represent genetic reservoirs. Disjunct populations are typically thought to have less genetic variation than their main range counterparts, due to genetic bottleneck effect and inbreeding depression. However, some northern disjunct plant and animal populations in the southern Appalachians, including *Thuja occidentalis* and Northern Saw-whet Owls (*Aegolius acadicus*), were found to have far greater genetic variability than the populations sampled in the glaciated main range (Walker 1987; Tamishiro 1996). In the case of *T. occidentalis* in the southern Appalachians, long-lived, asexually reproducing populations may have preserved a diversity of alleles, while inbreeding in sexually reproducing populations that migrated north following glacial retreat resulted in a loss of diversity through founder effect. This is supported by the greater genetic diversity observed in southern Appalachian *T. occidentalis* populations compared to those of the Niagara Escarpment (Walker 1987). Southern Appalachian cliff-face populations may, therefore, be important reservoirs of genetic diversity for many northern plant species, which may allow these species to better adapt to future climate

changes or exotic diseases (Davis and Shaw 2001; Jump and Penuelas 2005; Hammond-Kosack and Jones 1996).

Fire on cliff faces is rare because there is no accumulation of litter and the patchy distribution of vegetation impedes the movement of fire. The pre- and post- fire study on population density of microarthropod in cliff system of Linville Gorge, NC showed no significant changes in microarthropod density on the cliff face, although differences were found in the cliff edge and bottom (Pleszewski, 2003), which suggests that cliff-face areas are safeguarded from natural fire. This study further supports the notion that the cliff face itself can preserve habitats for cliff-dwelling animals and flora.

Given what we know about cliff habitats as reservoirs of biodiversity and genetic diversity, and given the increasing popularity of recreational rock climbing in the United States, vegetation surveys for areas with heavy rock climbing use, such as the Obed River Gorge in Tennessee, are crucial for sound resource management practices. As researchers discover new species on cliff faces, it is becoming apparent that cliff-face forests may represent the remnants of old-growth forests undisturbed by fire and humans for thousands of years, and that cliff-face communities have been species and genetic refugia since the last ice age. Their study and protection then becomes of immediate concern to scientists, conservationists, land managers, and environmentally concerned members of the rock-climbing community.

Park Description and Rock Climbing History

Recognized for its free-flowing condition, rugged terrain, and pristine waters, the Obed River was included in the Wild and Scenic Rivers System in 1976 and established as a unit of the National Park Service. The Obed is one of only nine Wild and Scenic Rivers authorized in the

Southeastern United States. It flows over 45 miles through some of the most rugged and undeveloped terrain in eastern Tennessee. It offers a vast array of both cultural and natural resources. A complex network of streams drain the Park and adjacent lands supporting diverse flora and fauna, as well as providing numerous recreational opportunities including hiking, backpacking, fishing, white-water paddling, and rock climbing.

The popularity of sport climbing in the United States has increased substantially over the last two decades (U.S. Department of Interior 2004). Sport climbing routes, which consist of fixed anchors drilled into the rock faces of the cliffs, were first developed along the Obed River and Clear Creek in the early 1990s. Currently, more than 300 sport climbing routes exist within the Park, and managers continue to get requests for additional route development. Due to the occurrence of rare plant species and old-growth trees in and around climbing areas, and the increasing popularity of rock climbing in the Obed River Gorge, Park managers determined that a comprehensive study of the vegetation, ecology, and impacts of climbing in these areas was needed in order to make sound resource management decisions.

Geomorphology of the Cumberland Plateau

The Obed River flows across the Cumberland Plateau in east Tennessee. The Cumberland Plateau is a physiographic province of the southern Appalachian region that lies east of the eastern Highland Rim and west of the Ridge and Valley physiographic provinces. It is a broad upland that extends northeast from its Tennessee portion across Kentucky and into West Virginia and Pennsylvania where it is known as the Allegheny Plateau, and to the southwest into Alabama. The Cumberland Plateau of Tennessee is the southern extension of the Appalachian Plateaus Province (Fenneman 1938). In Tennessee it is recognized as a true tableland, with

gently sloping uplands throughout most of its extent. In its Tennessee portion it averages 55 to 65 km in breadth with upland elevations from 460 m above mean sea level near Kentucky to nearly 610 m above mean sea level in the south. The two large river systems of the Plateau are the Clear Fork-Big South Fork drainages of the Cumberland River basin and the Obed-Emory, which exhibit similar morphologies. Unlike many stream channels these systems flow in shallow gorges in their upper reaches and are increasingly entrenched downstream. The lower reaches of these rivers have cut down 90 to 120 m below the surface of the Plateau. Much of this vertical depth is accounted for by bluffs, which comprise up to 30 m of the basin depth. While the larger tributaries join the stream at grade, the smaller ones often enter as waterfalls and seeps (Mayfield 1984). The bluffs of these two river systems are attractive as rock-climbing destinations, particularly in the Obed-Emory basin.

Geology of the Emory Basin

Because the rock strata of the Cumberland Plateau dip northeastward while its surface elevations are generally constant, the older Mississippian limestone rock units are exposed in the valley walls of entrenched streams in these areas. The lithology of the Emory basin is primarily comprised of near-horizontal sedimentary strata of Pennsylvanian age with alternate layers of sandstone, siltstone, and shale composing the bed rock. The Rockcastle Sandstone-Conglomerate is the most commonly exposed outcrop at the surface, while older shales and sandstones are exposed in the cliff faces of the gorges. This conglomerate has a very low intergranular permeability that is somewhat enhanced by fractures in the unit (Newcombe and Smith 1958). Springs are commonly formed where sandstone layers contact shale beds (Newcombe and Smith 1958).

Hydrology of the Obed Basin

It has been established that the streamflow of the Obed basin is able to move water rapidly through shallow but highly permeable soils with runoff occurring over a short period of time (Mayfield 1979). This results in a streamflow regime that consists of great extremes, which is anomalous when compared to other watersheds in the Cumberland Plateau. Although the watershed of the Obed has low-drainage density, gentle to moderate slopes, heavy forest cover, permeable soils and less-intense rainfall than other watersheds that are found in its vicinity, the impermeable bedrock and shallow soils of the basin provide minimal water storage. Therefore water exits the watershed rapidly as stream flow.

Soils of the Obed-Emory Basin

The natural fertility of the Cumberland Plateau soils is low. Soil depths range from 2-4 feet deep, are well-drained, loamy, and relatively acidic (Springer and Elder 1980). Most of these soils are formed from sandstone and shale parent material on gentle slopes and are the most favorable soils of the Plateau for agricultural use (Springer and Elder 1980). The steeper slopes, such as those in the Obed-Emory basin range from deep, stony colluvium, to rocky, shallow soils. Permeability is moderately rapid to rapid (Springer and Elder 1980). The majority of the soils in the Obed basin are Ultisols and Inceptisols (Hubbard et al 1950, USDA Soil Conservation Service 1978).

Climate of the Obed-Emory Basin

The Obed River basin climate is humid and mesothermal (Thorntwaite 1948). Because of the higher elevations of the Cumberland Plateau in its Tennessee portion relative to adjacent physiographic regions, it experiences relatively lower temperatures and higher amounts of precipitation, which results in a greater water surplus. For example, in Crossville, the surplus is 63 cm of water, while in Knoxville the surplus is 45 cm. Most of the precipitation within the Plateau is received during the winter months, with significantly less precipitation occurring during the fall. Total precipitation varies from about 130 cm to 153 cm annually (Mayfield 1984).

Obed Natural Communities

Vegetative community types listed by Schmalzer et al. (1985) that are pertinent to the present study are xeric upland oak or oak-pine forests, sandstone cliffs and rockhouses, sandstone boulder fields, wet sandstone or shale cliffs, and sandstone outcrops. The community descriptions below follow Schmalzer et al. (1985). Species names cited by Schmalzer et al. have been updated to reflect recent taxonomic and nomenclature changes, per Weakley (2007).

Xeric upland oak or oak-pine forests are dominated by *Quercus alba* Linnaeus, *Q. montana* Willdenow, and *Pinus strobus* Linnaeus with *Carya spp.* and other taxa occurring on middle to upper slopes. Typical herbs in this forest community include *Geranium maculatum* Linnaeus, *Solidago caesia* Linnaeus var. *zedia* R.E. Cook & Semple, *Bromus pubescens* Muhlenberg ex Willdenow, and *Agrostis perennans* (Walter) Tuckerman.

Sandstone cliffs and rockhouses (shallow caves) form plant habitats that are unique and distinct from the surrounding communities. Plants restricted to these communities in the Obed include *Heuchera parviflora* Bartling and *Silene rotundifolia* Nuttall.

Sandstone boulder fields have developed on gorge slopes and are extensive in certain areas. Where they occur on south-facing slopes, the canopy vegetation is composed of *Q. montana* and *Q. alba*. Herbaceous plants restricted to these sites include *A. fungosa* and *P. laevigata*.

Wet sandstone or shale cliffs are kept moist by seepage and contain species assemblages that are distinct from the more common dry sandstone cliffs. Plants restricted to these sites include *Thalictrum clavatum* A.P. de Candolle and *Cystopteris protrusa* (Weatherby) Blasdel.

Horizontal sandstone outcrops occur where sandstone bedrock is exposed near cliff-edges. Deeper pockets of soil on the outcrop support dwarf *Pinus virginiana* P. Miller, shrubs (e.g., *Gaylussacia baccata* (Wangenheim) K. Koch, *Kalmia latifolia* Linnaeus, *Aronia arbutifolia* (Linnaeus) Persoon), grasses (e.g., *Chasmanthium laxum* (Linnaeus) Yates, *Danthonia compressa* Austin ex Peck, *D. sericea* Nuttall), and forbs (e.g., *Liatriis microcephala* (Small) K. Schumann). Shallow pockets of soil support the rare outcrop plants *Minuartia glabra* (Michaux) Mattfeld and *Phemeranthus teretifolius*.

Old-Growth Cliff-Associated Trees

The longest-lived individuals of most conifer trees grow on adverse and rocky sites and have extremely slow growth rates (Schulman, 1954; Ward, 1982; Matthes-Sears *et al.*, 1995). These are generally the genera of *Pinus*, *Cupressus*, and *Juniperus*, which also frequently show the distortion of morphology and asymmetric radial growth (Larson *et al.*, 1993). It has been

found that mean maximum age of angiosperm trees is 248.4, while the mean maximum age for 55 gymnosperms is 595.6 years (Schweingruber, 1993), and among the gymnosperms, there are six species that live more than 1000 years but there is no angiosperm tree which live 1000 years. A study on ancient forests of Osage County, Oklahoma showed that *Juniperus virginiana* L. is common on sandstone cliffs and large rock outcrops and exceed 500 yrs in age (Therrel & Stahle, 1998).

A study in sixty-five different cliffs of temperate climatic zone revealed that some stems of *T. occidentalis*, *J. virginiana*, and *Taxus baccata* L. attained ages of more than 1,000 years, and all these species showed general similarities in age and growth-rate distributions (Larson *et al.*, 2000a). Kelly & Larson (1997a) mentioned that *T. occidentalis* (northern white cedar) can reach maximum ages of 1653 years, and produces annual tree-rings, which may be used to reconstruct the past climatic conditions. The dendroecological study of *T. occidentalis* revealed that populations of this species sharply increased between 1780 and 1850 and declined until 1940s, while after the 1950s the population had increased gradually (Kelly & Larson, 1997b). The present day stem densities of cedar, age structure and growth rates are used to infer past fluctuations in population dynamics and also used to make predictions of future trends (Hiebert & Hamrick, 1984). Dynamic life tables are the sole method of determining how recruitment and mortality rates affect age structure (Veblen, 1986).

Most of the conifers like *Pinus*, *Cupressus*, and *Juniperus* when grown under adverse conditions on cliffs and rock outcrops show extremely slow growth, and thus great longevity. Furthermore, the genera of *Cupressus*, *Juniperus*, *Chamaecyparis*, and *Thuja* show not only the greatest longevity when they are living but also considerable decay resistance when dead (Schweingruber, 1989). The greater degree of cedar wood preservation is exerted by either wet

anoxic conditions (Hoffmann & Jones, 1990) or very dry conditions (Nilsson & Daniel, 1990). Loehle (1996) mentioned that the exceptionally long-lived trees have extremely effective defense systems which limit pathology imposed by fungi and insects.

Several old-aged trees have been discovered within the climbing areas of the Obed Wild and Scenic River. In 1999, four red cedars (*Juniperus virginiana* Linnaeus var. *virginiana*) were cored to determine age. These trees ranged in age from 287 years to 381 years. Several other trees that had been cut at the bases of climbing routes were studied. Their ages ranged from 150 to 200 years old (Nancy Keohane, personal communication). In light of this information, the National Park Service determined that an in-depth study of the vegetation on the cliff face, cliff base, and cliff edges was necessary to assist in managing climbing activities within the Obed Wild and Scenic River area.

Two stands of ancient eastern red cedar trees (*J. virginiana*) were found in the talus areas of both the North Clear Creek climbing area and the Obed Wall climbing area. Preliminary sampling of the North Clear Creek stand consisted of the removal of a section of a large, dead snag using a small pruning saw. The section was sanded and the rings were counted in the field using a 10x hand lens, yielding approximately 800 annual rings. The snag section was then brought to the dendrochronology lab at Appalachian State University, Department of Geography and Planning, and was found to have 863 annual rings. That finding prompted subsequent increment coring of five different living trees, two from the Obed Wall talus and three from the North Clear Creek talus. The extracted cores were placed in plastic drinking straws and brought to the dendrochronology lab at Appalachian State University.

Dendrochronological analysis was performed by Ms. Leslie Morefield. Each core was mounted in a core tray with wood glue, which was then placed in a vice for sanding. Cores were

sanded down using at least three grades of sand paper: coarse (320), fine (P400), and extra fine (15 μ). Core samples were then rubbed with natural wool, which leaves a film of lanolin on the wood, which in turn renders the annual growth rings more easily distinguishable. Next, the rings were counted by hand using a National® brand biocular dissecting microscope. Years for each core were placed in a spreadsheet and especially wide or narrow ring years were noted. During manual counting, dots were placed on the wood using a pencil to indicate decade, 50 year, and 100 year increments of annual growth rings. After manual counting, the cores were cross-dated and their annual growth-rings measured using a dissecting microscope connected to a computer equipped with Measure J2X © software (Voortech Consulting, Holderness, NH). This computer program recorded ring widths, could cross-reference the different trees, and calculate the variance in ring.

Stem-stripping and Red Cedar

Stem stripping is generally found in angiosperms and gymnosperms but is most commonly observed in the family Cupressaceae (Matthes-Sears *et al.* 2002). The species which exhibit stem-stripping grow in adverse climatic conditions, and show greater longevity (LaMarche, 1969), and very slow and asymmetric growth (Matthes-Sears *et al.*, 2002). Although, the formation of stem stripping occurs in most of the long-lived trees, mainly on gymnosperms, its cause is still unclear. Some of the gymnosperm trees that show partial stem stripping are *Pinus longaeva* (Schulman, 1954; LaMarche, 1969); *P. aristata* (Schauer *et al.*, 2001); *Thuja occidentalis* (Larson *et al.*, 1993; Matthes-Sears *et al.*, 2002); *Juniperus communis* (Ward, 1982) and *Juniperus* spp. (Ward, 1982; Larson *et al.*, 1999). Schauer *et al.* (2001) found a close relationship between cambial mortality and diameter of *P. aristata* i.e., more cambial mortality

with an increase of diameter. In the case of bristlecone pine, stem stripping (cambium mortality) was found in older than 1500 year aged trees with large diameters (LaMarche, 1969). Kelly *et al.* (1992) sampled several populations of northern white cedar from the Niagara Escarpment, Canada and found that almost half of the cambium had been lost at the age of 130 and 280 years, and up until 390 years of age white cedar survived only having 25% of its potential circumference. It was an interesting observation that a few trees survived with only 2% of cambium remaining at the time of death. Eastern red cedars when growing on cliff systems generally show symmetric shapes during young age classes, but they are very deformed and asymmetric in old age (Kelly *et al.*, 1992). Although the reasons for reduction of cambium have not been identified so far, external factors like drought, snow-loading, abrasion by rock fall, and fire could have a great role (Matthes-Sears & Larson, 1990). However, Kelly *et al.* (1992) observed that stem stripping also occurs in young trees. This may be due to external factors like root exposure by rock fall in cliff systems, which initiates water deficiency (Larson *et al.*, 1993) or poor microsite conditions for young trees (Matthes-Sears *et al.*, 2002). In most cases tree size and stem stripping is found to be closely related (Beasley and Klemmedson, 1980; Schauer *et al.*, 2001). In *T. occidentalis* partial cambial death was found mainly associated with slope (Kelly *et al.*, 1992). Similar evidence was obtained in *P. longaeva*, where movable soil particles scratch the root surface (LaMarche, 1969). Schauer *et al.* (2001) observed a strong relation between cambium mortality and wind, and found more cambial death on the windward side. Severe tree swaying can cause exposure of roots towards the windward side resulting in root injury, which could initiate partial cambial dieback. In either case, the flow of water could be blocked and result in partial stem mortality.

Reasons for stem stripping to occur could be a sectored hydraulic architecture. The plant divides internally as a distinct xylem component in which each component carries at least one root, a stem part and a branch (Larson *et al.*, 1993). The loss of hydraulic conductance in this sector would be the cause of stem stripping initiation. When a root dies, then transportation of water to the particular stem and branch would stop and starts to stem strip (Larson *et al.*, 1993). Further, Matthes-Sears *et al.* (2002) observed larger pits in tracheids with greater cavitations in older trees than younger ones. This results in the blockage of water supply, and then starts stem strip formation.

Age-class Structure

Larson and Kelly (1991) studied a relation of age and size class structure of *T. occidentalis* in nine different sites of the Niagara Escarpment. Population density of 666-1773 ha⁻¹ on vertical cliff-faces was observed to have an uneven-aged population. However, the older trees were more prevalent on the northern reaches of the Escarpment. An inverse relation between age-classes (> 250 yrs) and number of stems was observed. Apparently, the cliff ecosystem was intact and undisturbed even though little human disturbance (absence of seedlings in two sites) and fire were observed. Only 1.49% of sampled cores showed the dark bands of fire scars.

The size and age class distribution of *T. occidentalis* in disturbed and undisturbed sites of the Niagara Escarpment showed the greatest differences in the smallest size classes (Larson, 1990). In undisturbed sites the smallest size classes (< 3 cm diameter) had the highest values, but high frequency values were observed between 6 and 10 cm in diameter in disturbed sites. However, size classes greater than 12 cm were almost equal in both disturbed and undisturbed

sites. Further, the study confirmed that due to the very poor representation of young trees in disturbed sites, the highest frequency was found in 80-100 yr age class, and then it declined until 200 yr age class, after which the frequency seemed quite stable up to 410 yrs. While high frequencies of individuals occurred in 20-60 yr age classes, and the highest was in 100 year age classes, it declined drastically.

Dendroecological Study:

Introduction

The objective of the dendroecological aspect of the present study was designed to allow investigators to reconstruct the Park's climate history (dendroclimatology), fire history (dendropyrochronology) and to measure periods of environmental change (dendrochronology) in Park vegetation through the examination of tree rings found in living trees and dead snags of ancient red cedars. This information, along with the community and age-class structure of these stands, would be helpful in providing Park management with the information needed to further protect these stands and to hopefully formulate fire prescriptions for Park vegetation that coincide with natural or historic fire regimes.

Climatic reconstructions can potentially help play a role in interpreting the natural history of an area that date back prior to European settlement. Similarly, a dendropyrochronology can provide information toward fire frequency on the Cumberland Plateau, information crucial to determining management practices involving controlled burns and maintenance of fire-released plant communities. A dendrochronological record of this length could also address archeological questions such as whether this area experienced a mini-ice age such as that recorded in Europe

and whether such an event influenced early Native American populations. Questions about climatic change predating the industrial revolution can be similarly obtained from such a record and can contribute to our understanding of present climatic change and that of the future.

A section taken from the top third of a snag during the course of the climbing impact study conducted in the Obed Wild and Scenic River Gorge had been sanded, polished and analyzed in the dendrochronology lab at Appalachian State University. This section, which is only 8 inches in diameter, was dated to be 863 year of age. This indicates that the snag itself is likely of a much older age. Other similar snags in the same area that have not yet been sectioned are of much larger diameters. This aspect of the project endeavored to determine the community and age-class structure of these existing stands, ensuring Park management has the information necessary to further protect this valuable resource.

In a preliminary study included in the climbing impact investigations a few cores taken from living trees were dated in excess of two hundred years and both cores from living trees and snags show a high degree of “sensitivity”. This refers to varying ring widths that may correspond to environmental conditions such as rainfall and temperature. A very preliminary comparison of these varying ring widths to the Palmer Drought Sensitivity Index (PDSI) show some correspondence of narrow ring width to periods of extended drought from that region of the Cumberland Plateau. In addition, such sensitivity bodes well for cross-dating of the increment cores from living trees with the sections from the ancient red cedar snags indicating the likely potential for dendrochronological reconstructions of great time spans.

Some of these ancient red cedar stands had already showed evidence of human impact. All were found in the talus region of cliff faces frequented by the rock climbing community.

Some had been hacked by axes, others used as tie-offs for climbing and still others burned by fires. In 2005 several areas of the Park were burned by wildfires, including some of the young red cedar saplings and even some cliff faces, areas usually thought to be buffered from natural disasters such as fire.

Methods and Materials:

Fieldwork:

In December 2007, Dr. Pete Soulé and graduate assistants Justin Maxwell and Daniel Griggs completed dendroecological fieldwork on the ancient red cedar communities within the Obed Wild and Scenic River. They sampled red cedar trees (*Juniperus virginiana*) in two different locations. On December 17th, they concentrated on trees growing near 36.094°N and 84.7° W. On December 18th, they concentrated on trees growing near 36.09°N and 84.71°N. The majority of trees were growing at the base of sandstone cliffs (Fig. 1, 2), but some were growing on the plateau areas above the cliffs. On both days they were guided by a National Park Service Ranger from the Obed Wild and Scenic River.



Figure 1. Photograph of red cedar growing at cliff base within the Obed Wild and Scenic River Gorge.



Figure 2. Photograph of the study locale showing the sandstone cliffs.

While their sampling protocol was designed to be selective in nature, they ended up sampling virtually every red cedar encountered. Thus, they ended up with more of a population census than a sample. We took 68 core samples from a total of 36 trees. Most were alive, but some samples were taken from dead trees. We also obtained two “slab” samples from the base of dead snags. All core sampling was non-destructive (Fig. 3). That is, they used increment borers to obtain core samples from trees, a process that does not harm live specimens. Wherever possible, they obtained at least two core samples from each tree. For each tree sampled they recorded the latitude and longitude using a hand-held GPS unit. We also measured the basal area of each tree sampled and recorded information about the tree (e.g., evidence of fire scars, strip bark, position

of tree relative to cliff). Because of the convoluted shape of most trees (e.g., some were growing essentially horizontally), it was decided that recording tree height was not useful.



Figure 3. Graduate student Justin Maxwell using an increment borer to take a core sample from the base of a red cedar tree. By using increment borers, all of the sampling was non-destructive (no harm to the tree).

Laboratory Work

In December 2007 and January 2008 processing of the collected core samples began in the Dendroecology Laboratory of the Department of Geography and Planning at Appalachian State

University. The process involves gluing the collected samples to wood mounts, then sanding the samples progressively, using finer grit sandpaper each step, until the cellular structure of the samples becomes visible under magnification.

Next the process of crossdating the samples began. Crossdating is an iterative process with a goal of accurately assigning a calendar year date to each ring of each collected samples. Crossdating is a critical element of dendroclimatology because if the exact calendar year of each ring cannot be determined with a high level of confidence, accurate climatic reconstructions cannot be completed for the site. Crossdating is necessary because trees, especially trees growing in stressed locales like Obed, will often produce false rings (i.e., a given calendar year will have what appears to be two or more growth rings) and/or not produce an annual ring at all (known as a missing ring). If the false rings and missing rings are not identified, then a simple ring count of the core sample may be off by many years. In the process of this aspect of the study Dr. Soulé contacted his dendroecological colleagues who have developed or attempted to develop tree-ring chronologies from this species of tree and the consensus was that red cedar is extremely difficult and often impossible to crossdate, especially using core samples as opposed to slabs because core sampling only provides information on tree growth for an extremely small portion of the tree's total diameter. Because most of the trees in this study were living obtaining slabs from living trees was impossible.

Crossdating began in early January 2008. Using funds from the grant, Justin Maxwell, an ASU student, was hired for 100 hours of work. These 100 hours included the hours needed for sample preparation (i.e., mounting and sanding). Justin continued working on crossdating throughout Spring Semester 2008 using hours allocated to Dr. Soulé for graduate assistant work

from the Department of Geography and Planning. Justin worked 10 hours/week on crossdating during the 15-week semester, thus resulting in an in-kind contribution to the grant of \$1500. In August 2008 Philip White was hired for 50 hours of crossdating and measuring, and 45 hours of Philip's assistantship hours for fall semester 2008 from the Department of Geography and Planning were dedicated to this project (in-kind contribution of \$450). In addition, Dr. Soulé assisted in and supervised all of the laboratory work. The total person hours invested in their attempt to accurately crossdate the collected samples was in excess of 500 hours. As the crossdating technique (the list method) used by Justin Maxwell and Dr. Soulé had been unsuccessful, Philip employed a different technique known as skeleton plotting. Skeleton plotting provides a visual representation of the radial growth pattern that can be compared easily among multiple samples. Unfortunately, the skeleton plot technique likewise did not reveal any consistency in the radial growth patterns among trees. The samples contain multiple false rings and contained many missing rings. After multiple iterations their dating techniques were unable to develop a consistent pattern among the trees sampled. To confirm the accuracy of crossdating the computer program COFECHA was used. The process works in this fashion: 1) each core was examined and dated multiple times, searching for "signature years", i.e., years that always produce narrow or wide rings, 2) once the samples have been crossdated to a temporal pattern of growth that is thought to represent growth across the sites, each ring is measured from each dated core and then the COFECHA program is used to determine if dating is accurate. The diagnostics showed that there was simply very little agreement in the patterns of radial growth among the sampled trees. There are likely multiple reasons for the lack of agreement. First are microenvironmental factors. Most of the trees sampled were at the cliff base, and many trees were actually underneath rock overhangs (Fig. 4). Because of their topographic position, it was

assumed that access to water by the tree roots is extremely variable from tree to tree. Some trees are in such a position that they would have immediate access to water from infiltration via precipitation, while for others this would be delayed after a precipitation event. Other individuals positioned deep under the rock overhangs are likely only receiving water through seepage, thus there is likely a considerable delay between a precipitation event and availability of water (Fig 5). Because most of the trees are growing at the cliff base and have a southerly exposure, the microenvironment is extremely stressful for tree growth. While stressful environments often support some of the oldest-lived trees on the planet, radial growth is extremely slow or sometimes non-existent in a given calendar year. This produces an overall mean ring width that is very narrow, and is conducive for the production of false rings. Extremely narrow rings, missing rings, and false rings make the process of crossdating trees difficult or impossible. In addition to collecting live samples, dendroecologists were also able to collect two slab samples from dead trees using a pruning saw. A careful inspection of the growth patterns from the slabs gave them insight as to why the process of crossdating was so difficult. In many cases an individual tree ring would be wide relative to surrounding rings on one side of the tree but narrow on the other sides. The slabs also revealed missing rings, where the ring or multiple rings were present on one side of the tree but disappeared on the other side. Unfortunately, when non-destructive core samples were taken from a tree they were likely missing many of the intricacies of tree growth that a slab sample may reveal.



Figure 4. Red cedar tree growing horizontally underneath overhanging rock.

The second major reason for the variable growth between trees was believed to be physiological. Specifically, red cedar “radial growth is extremely irregular”:

(<http://www.fpl.fs.fed.us/documnts/usda/amwood/260eredc.pdf>, p. 3) as the apical meristems on one side of the tree may be more active than on the other. In many of the trees sampled, evidence of live growth was often on only one side of the tree in a narrow band (Fig. 6).



Figure 5. Obtaining a core sample from a red cedar growing at cliff base. Note the dark stains on the rock behind the park ranger, evidence of water seeping through the cliff face.

Without agreement among the samples, it was not possible to use the collected data for a formal climate reconstruction from the site, as the work would not be able to pass through a peer-review process. Upon consultation with Dr. Walker, we made a decision to stop investing any more resources from the grant on crossdating and to proceed with work on other deliverables.



Figure 6. Obtaining a core sample from a red cedar where only one lobe of the tree was producing live growth. Note the side of the tree facing the camera appears dead.

Results

File Core_Dates.xls is an Excel spreadsheet containing the estimated (via ring count) interior dates of the 36 live trees (68 cores total) that were sampled. While a few of these trees were on the plateau and collected to aid in the process of crossdating, most were at the cliff-face base and

as every live tree that was encountered was sampled, these investigators were confident in saying that this data set represents a population census from the two cliff base areas sampled.

Figure 7 shows the distribution of tree ages for the 36 live trees sampled. In response to the question of whether there are ancient and live red cedar growing within OBED, this was certainly found to be the case. The oldest live tree sampled in this data set had an estimated interior age of 1241 ad, or 767 years of age. Given that the oldest live *Juniperus virginiana* that has been accurately crossdated is 860 years (<http://people.eku.edu/pedersonn/OLDLISTeast/>), it is clear that the study locale contains remarkably old-aged individuals.

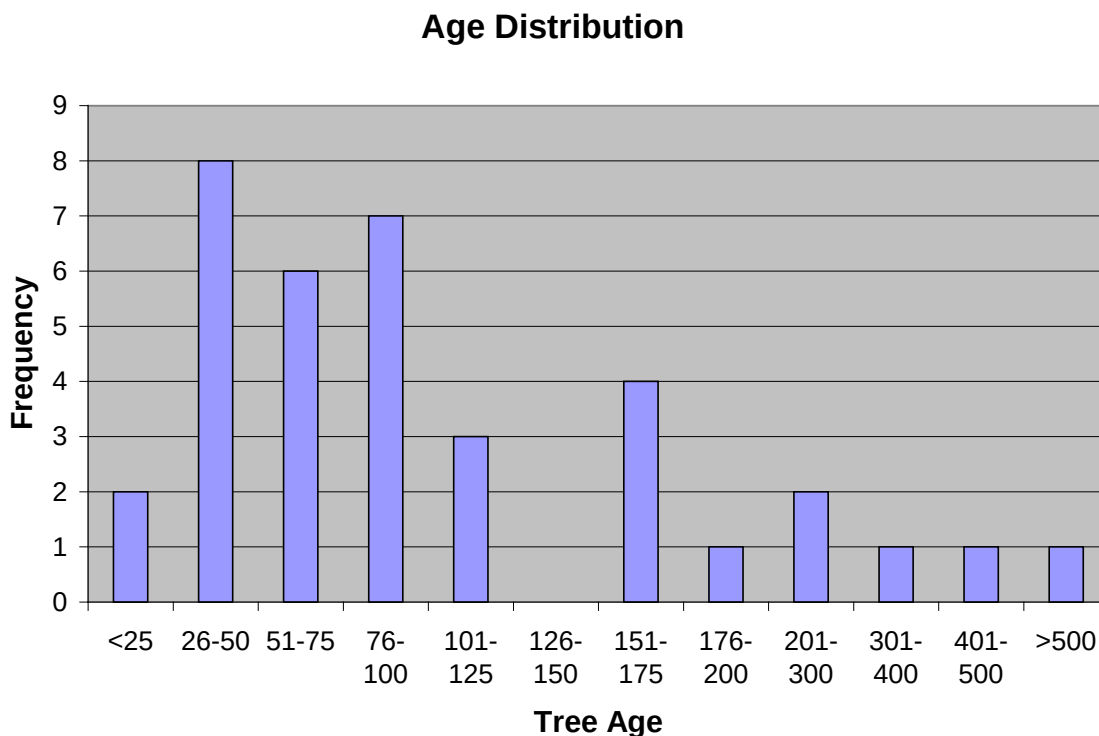


Figure 7. Age distribution of the 36 live trees sampled

File Individual_tree_GPS.xls is an Excel spreadsheet containing information about each tree sampled. This includes the lat/long coordinates recorded using a hand-held Garmin GPS unit, basal area of each tree, the aspect of where the tree was located and the slope (flat if not indicated), and information about the physical characteristics of each tree. As shown in Figure 8, we sampled largely at the base of the two prominent south-facing cliff faces along North Clear Creek and the Obed Wall.

From the information collected on individual trees, one of the relationships we investigated was between basal diameter and tree age. We found this to be a highly significant, positive relationship (Spearman $r_s = 0.80$, $p < 0.001$; Fig. 9).

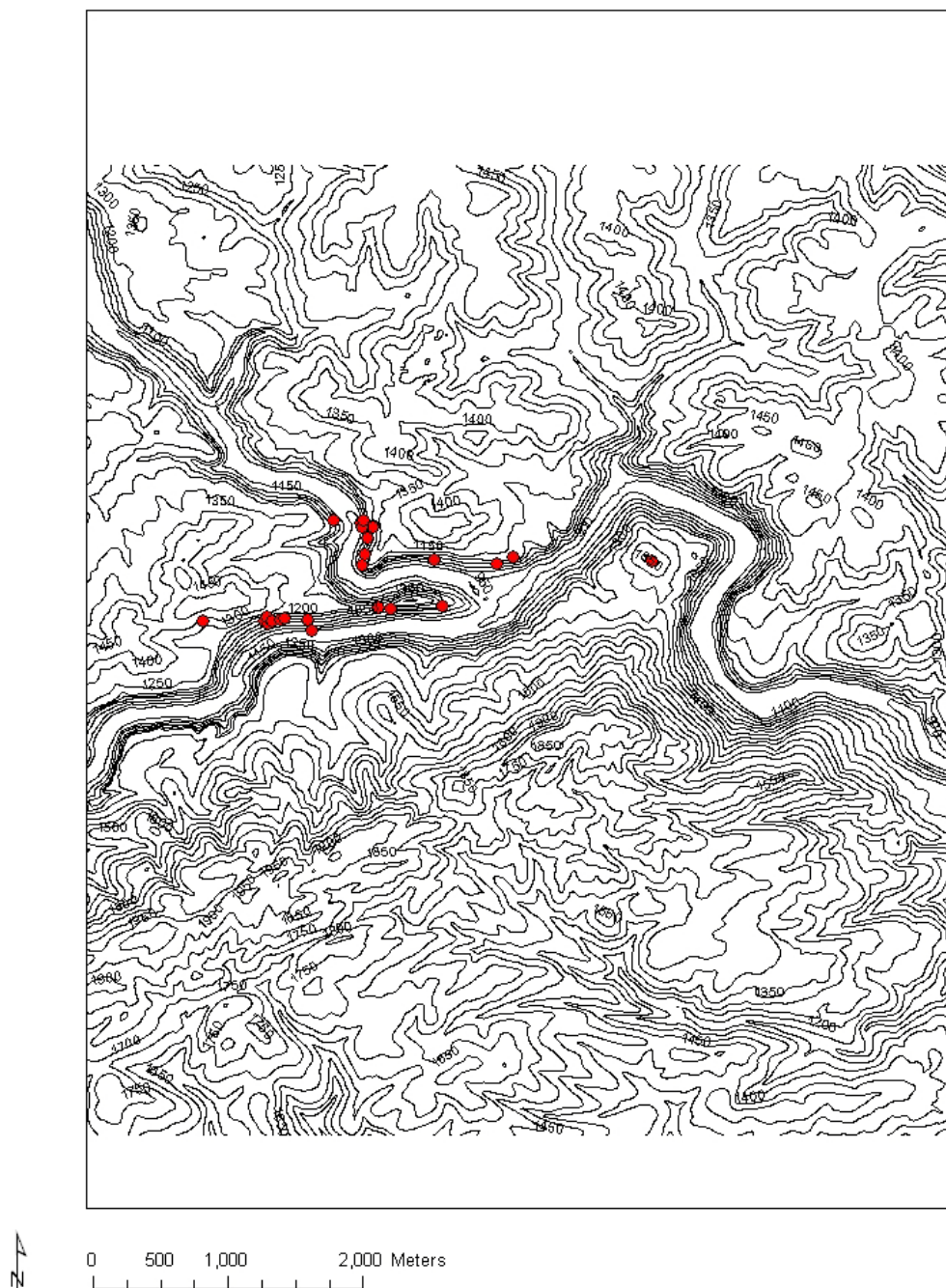


Figure 8. Location of trees sampled (note, some trees are essentially in the same spot, thus some of the red circles showing tree position are obscured)

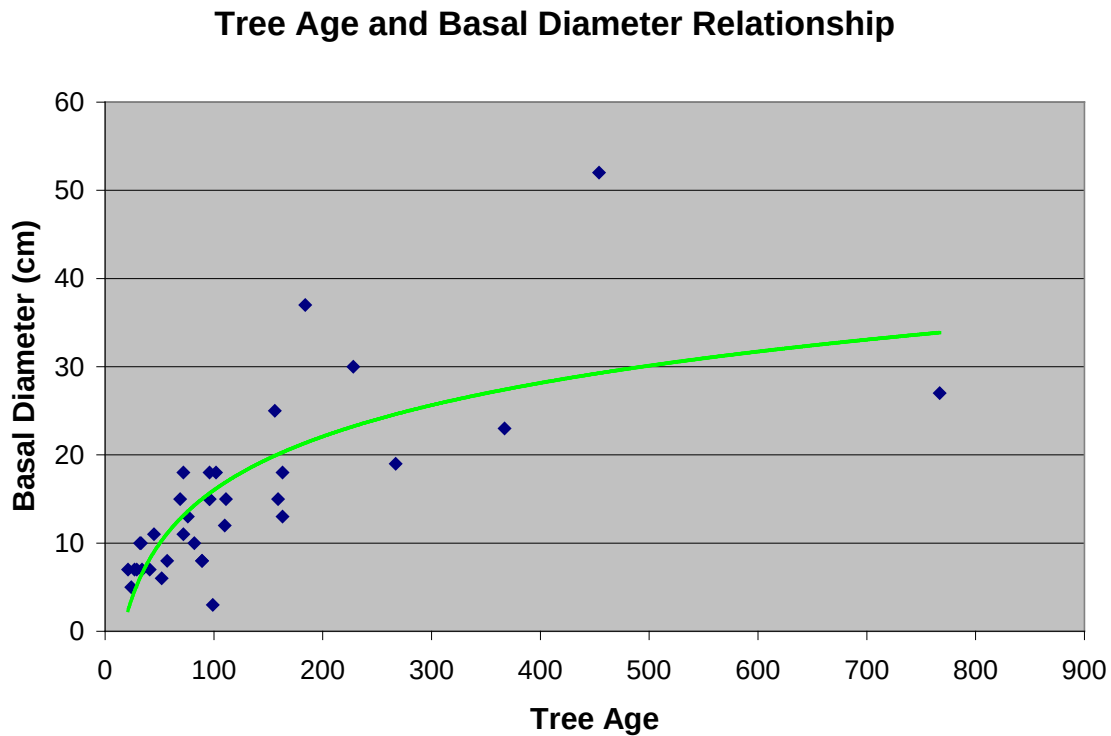


Figure 9. Relationship between tree size (measured via basal diameter) and tree age for the 36 trees sampled.

Radial Tree Growth and Climate:

One of the goals of this project was to provide information on climatic conditions in the region, particularly drought conditions, prior to the instrumental record which begins in 1895. Ideally, climatic reconstructions are based on a formal tree ring chronology, which shows the average rate of radial growth across a site developed using a large sample of trees. For this project, the level of inter-series correlation among trees was extremely small, again suggesting that individual trees may have been responding to the driving forces for growth in different ways. Rather than present results based on a flawed tree ring chronology, presented here are results

based on the oldest living tree sampled, tree #17, core A. For this live tree there were 767 rings, placing the innermost ring at 1241 ad. The pattern of radial growth for this tree is presented in Figure 10. To create this time line, radial growth was first standardized using a conservative technique (negative exponential) that accounts for the natural decline in tree growth with age. Radial growth was standardized to value of 1.0, with anything >1.0 representing greater than normal growth. To remove some of the year to year variation, the radial growth rates were smoothed using an 11-year low pass filter. The figure shows that the two longest periods of sustained above-normal radial growth were from approximately 1400-1600 ad and in the more recent past, post 1940. Sustained periods of below-normal growth occurred in the late 1200s through the 1300s, in the early 1600s, in the mid 1700s through early 1800s, and again in the late 1800s through early 1900s.

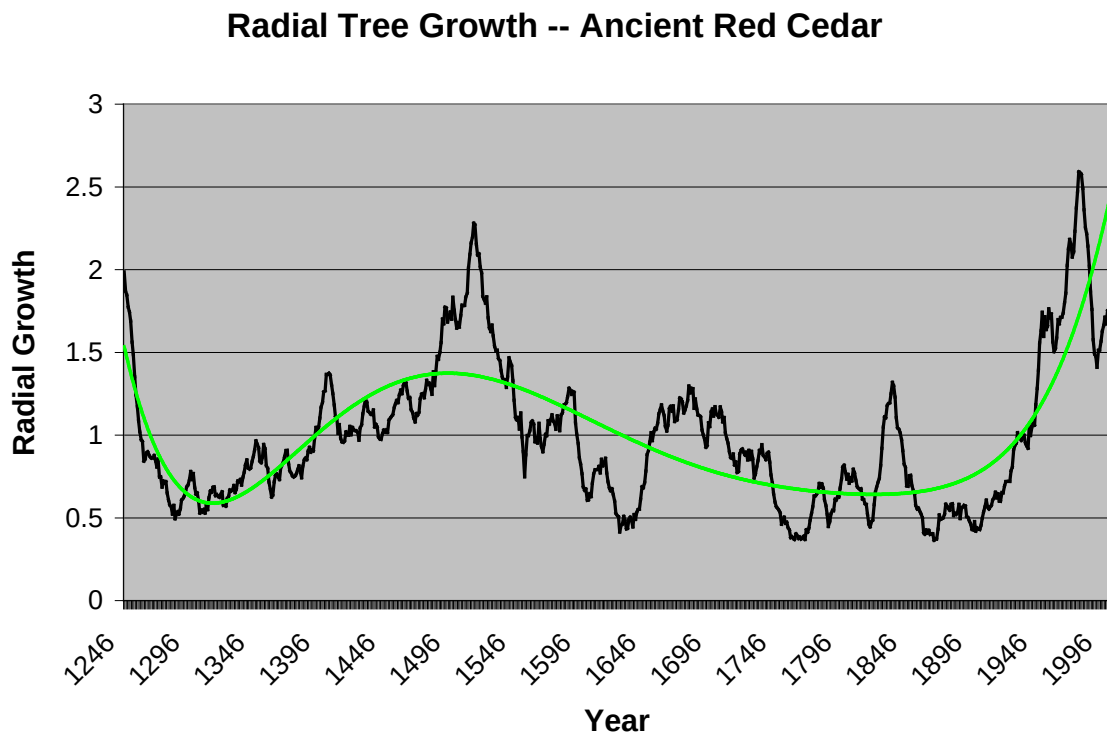


Figure 10. Standardized radial growth rate of the oldest tree sampled, normalized to a value of one. Values presented represent an 11-year running mean. The curved line is a 6th order polynomial fit to the growth trend.

The relationship between the radial growth rates and climatic conditions were determined using monthly climatic division-level data from Tennessee climatic division 2 (Cumberland Plateau). Monthly temperature, precipitation, and Palmer Drought Severity Index (PDSI) data were examined from 1895-2007 (2007 being the last year of radial growth from our collected samples). The PDSI is a commonly used measure of drought severity based on the climatic water balance. The PDSI is centered on zero, with negative numbers representing drought conditions and positive numbers wetter conditions. Values from -0.5 to +0.5 are “near normal”, values -1.0 to -2.0 represent “mild drought,” and values <-2.0 represent “moderate drought” or

worse. The PDSI is influenced by antecedent moisture conditions in that supply and demand for moisture (i.e., evapotranspiration) of prior months can impact conditions in a current month.

The best relationship between a climatic variable and annual radial growth was with November PDSI values. With no modification, the Pearson correlation between PDSI and radial growth for tree sample 17a was 0.224 ($p = 0.017$). Given the likelihood of missing and/or false rings causing the dating to not be exact, running means of 5, 7, and 11-years were calculated for radial growth and PDSI values and again simple correlation was used to examine the relationships. For the 11-year running mean the relationship was significant at $p < 0.001$ ($r = 0.726$) (Fig. 11, 12). Thus, it appears that one of the driving forces for radial growth of the red cedar sampled is moisture conditions of the late summer through autumn months, as captured by November PDSI values.

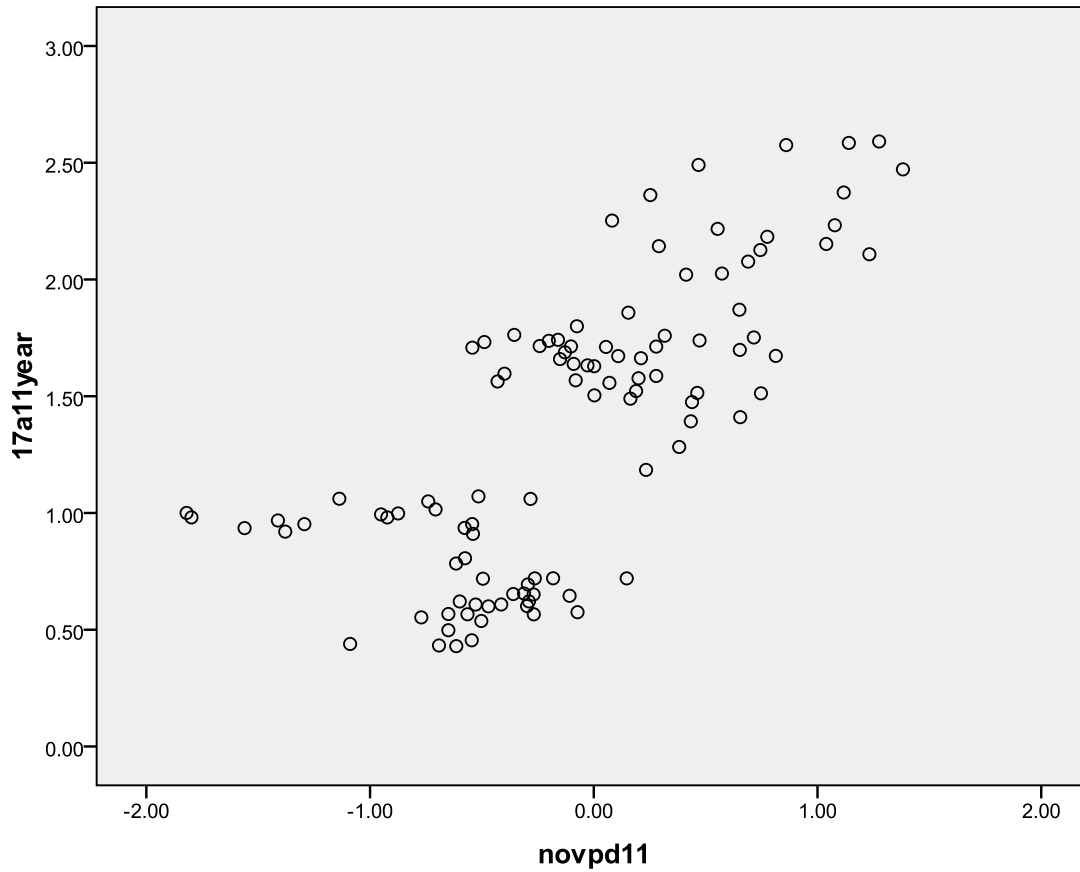


Figure 11. Relationship between radial growth and November PDSI using an 11-year running mean.

The relationship between radial tree growth of sample 17a and November drought severity was used to reconstruct November drought conditions in the region. First, we created a linear regression model with November PDSI values (11-year mean) as the dependent variable and radial tree growth (11-year mean) as the independent variable. The model takes the form:

$$\text{Nov. PDSI} = -1.183 + (0.799 \times \text{Radial tree growth}) \quad R^2 = 0.53, p < 0.001$$

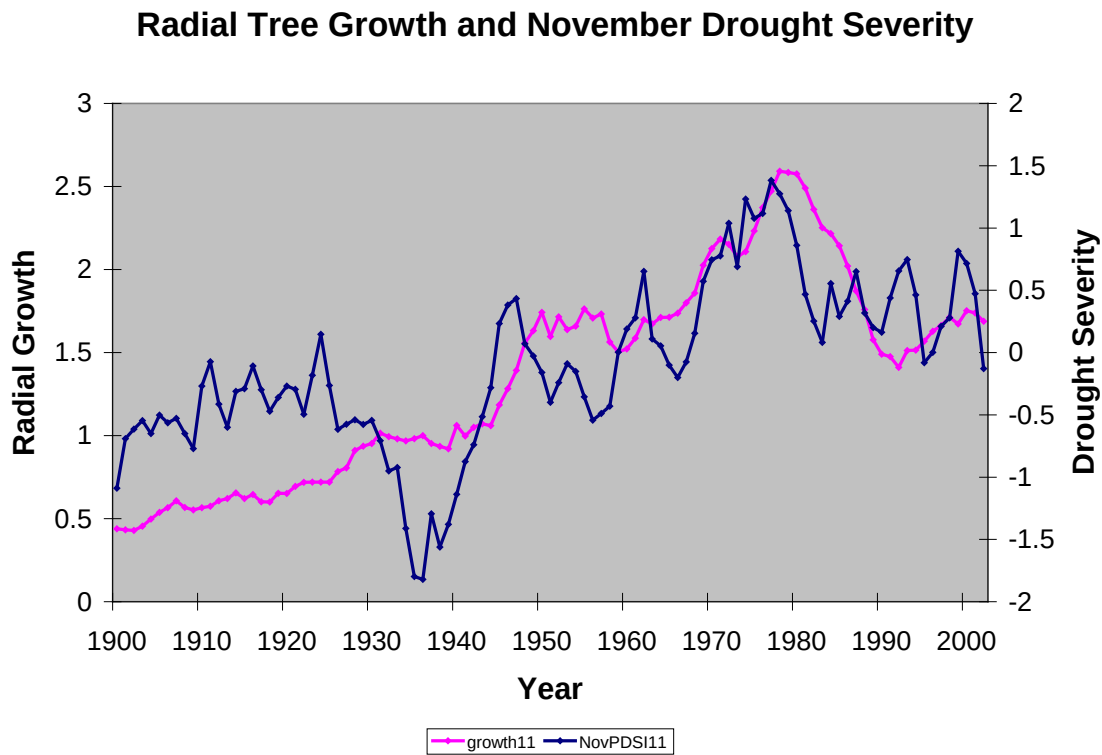


Figure 12. Time series of radial growth (pink line) and November PDSI (blue line) using an 11-year running mean.

The temporal pattern of November drought severity back to 1246 ad, both actual (post 1900) and reconstructed by this process is displayed in Figure 13. With the exception of the 1930s, most of instrumental record of November drought shows conditions either near normal (PDSI -0.5 to 0.5) or above normal (> 0) (Fig. 12), although the first three decades of the 20th century generally had consistently, slightly below normal moisture conditions and below normal radial growth (Fig. 12). As reconstructed, drought conditions in the region prevailed in the mid to late 1800s, in the mid to late 1700s, and in the early 1600s. A significant wet period occurred in the early 1500s (Fig. 13). However, nothing in the reconstructed record of drought suggests that the region

experienced any extended, unprecedented droughts in the time period prior to the advent of climatic instrumentation. Again, all of these results are presented cautiously, as they are based upon the record of one tree sampled, and the level of agreement among the group of trees we sampled was not sufficient for the standards used in peer-review of dendroecological work.

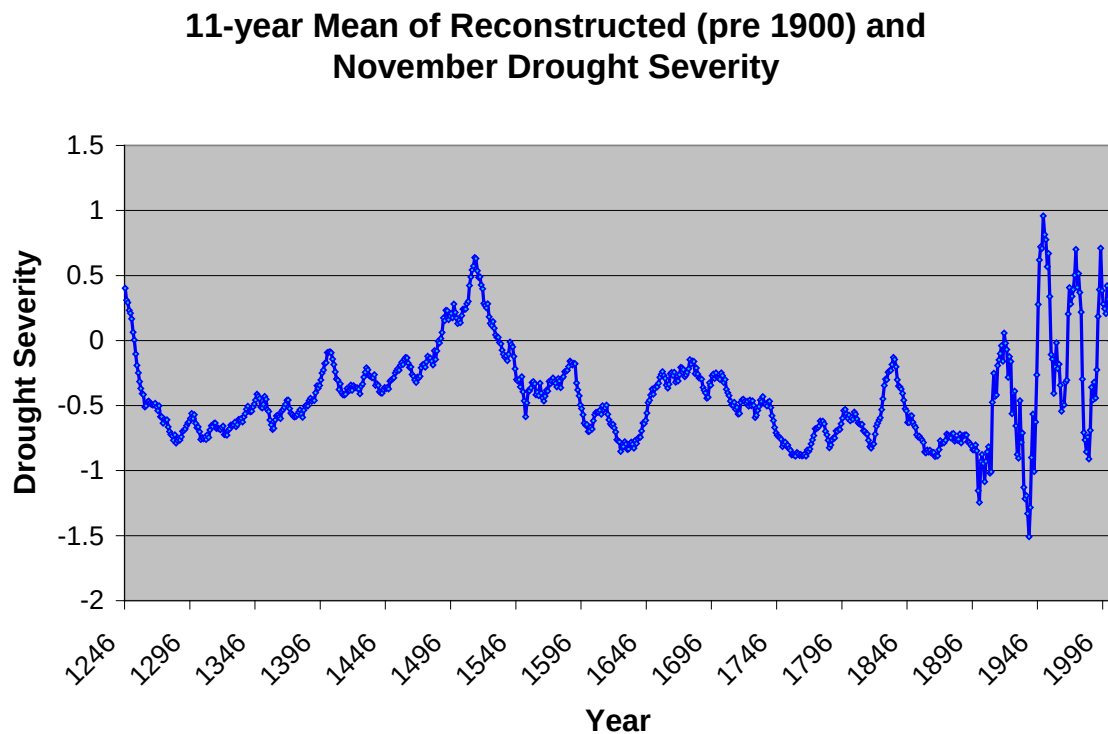


Figure 13. November drought severity (PDSI values) as reconstructed from red cedar (tree sample 17a) (pre-1900) and actual drought severity (1900-2002). All values represent 11-year running means.

Discussion

Although the data obtained from the dendroecological portion of this investigation is not publishable in peer-reviewed journals due to lack of congruence among a significant number of increment cores, it does provide some valuable insight into the past climatic history of the region

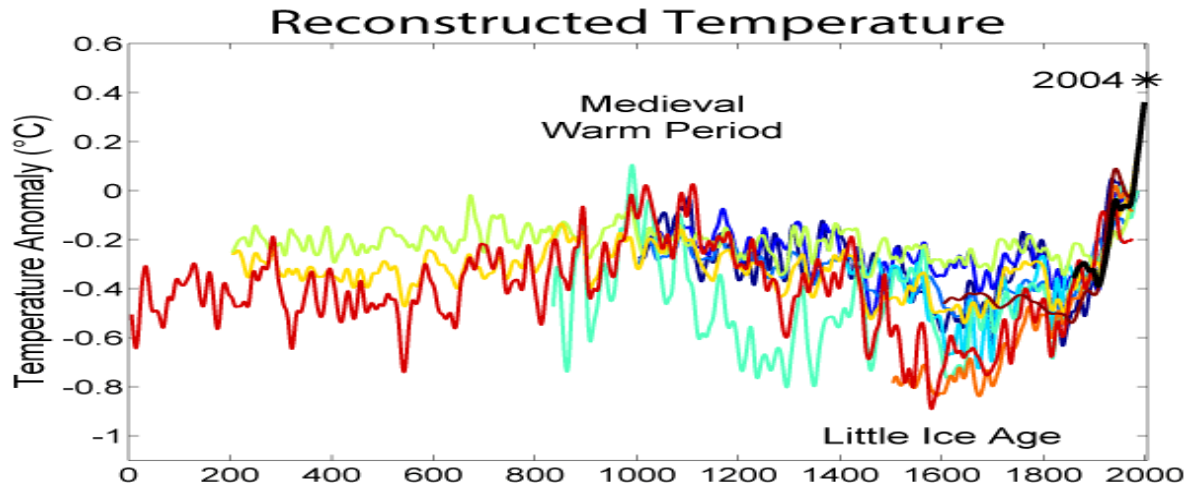
that might be applied to such areas as archeological investigations and for management and interpretation of the natural history and future sustained growth and reproduction of these stands of ancient red cedars. It may also be possible to use carbon-14 dating to confirm some of the long-term climatic patterns suggested in this study in future investigations. All of this data should be useful in the interpretative process of the natural history of the Park.

The age-class distribution data is particularly useful in revealing the past history of the ancient red cedar stands in the Park and for making predictions of their future growth and reproduction. In Figure 7 the age-class structure of the stands reveals an inverse J-shaped curve of age distributions. Populations represented by an inverse J-shaped curve have been associated with continuous, balanced recruitment and mortality (Whipple and Dix, 1979, Walker 1989). Red cedar populations with this age structure are likely producing moderate to high numbers of seedlings, particularly following years of mast seed production and high levels of precipitation. Seedlings likely exhibit high rates of mortality resulting in lower representation in subsequently higher diameter classes. Such stands are often associated with cliff systems with canopy openings, with some source of moisture present (Walker 1989). Several seedlings and saplings of red cedars were observed that were not included in this age-class distribution in the flood plain of North Clear Creek and the Obed. With regular fire intervals, surrounding competitive vegetation would be removed allowing recruitment, growth and reproduction of these young individuals. From the results of this aspect of the study it appears that these stands are undergoing balanced recruitment through seedling survival and mortality. In the absence of mitigating factors such as human disturbance such as cutting and fire, these stands should continue on for millennia.

Although fire scars were not observed in cores or snag sections of the ancient red cedar stands, this is likely indicative of the buffering effect afforded by association with cliff systems. Cliff systems have been described as natural buffers affording a refuge for associated species from both natural and man-made disturbances such as fire and logging (Larson et. al 2000). The noticeable lack of fire scars in these ancient red cedars coupled with the observation of the recent fires that reached some of these populations in 2005 may be indicative of a changing fire regime for the Park, perhaps owing to fire suppression with protection of the surrounding lands and a subsequent buildup of a fuel load. The absence of old-aged red cedars on the plateau and cliff-edge habitats of these sites may also be interpreted as a result of the lack of protection from natural and human-related disturbances in this habitat as opposed to the cliff face and cliff talus habitats of these systems.

The radial growth records taken from the long-lived core, 17a (Figure 10) show an apparent congruence to reconstructed temperatures from the Little-Ice Age with minimal radial growth periods that coincide with the three minima of that period. Some investigators confine the duration of this climatic period from the 16th century to the mid-19th century. It is generally agreed that there were three minima, beginning about 1650, about 1770, and 1850, each separated by intervals of slight warming. Again, this is based on a single core, but it does provide interesting insight into what the conditions on the Cumberland Plateau may have been like dating back to 1241 ad and should provide information toward natural history interpretation

for the Park.



Vascular Plant, Nonvascular Plant (Bryophytes) and Moss Surveys

Introduction

Community Structure on Cliffs

The cliff edge shows higher species richness than cliff face and talus. This may be due to the higher accumulation of water and seepage from the fractured rock (Nuzzo, 1996), but the increase of fracture in horizontal as well as vertical sites on a cliff face shows an increase of vegetation density and coverage. In most cliff systems, ledges, where the greatest accumulation of soil is found on a face, provides the best habitat for vascular plants including woody trees. Cliff vegetation structure in northeast Illinois determined that different community groups were found in a very short distance from each other (Nuzzo, 1996). He concluded that differential weathering processes, slope of cliff, rock fracturing, and seepage were some of the variables that determined community structure. Lichens are the first colonized species in newly-formed cliffs (Maycock & Fahselt, 1992; Larson *et al.*, 1989), and when fractures develop in cliffs over time

they accumulate soil and nutrients, which result in the growth of vascular plants (Nuzzo, 1996). Microtopography and geology of cliffs also determine plant community structure (Coates & Kirkpatrick, 1992; Farris, 1998). A study on the White Rocks cliff system in the Cumberland Gap National Historic Park showed that surface heterogeneity, amount of soil, and steepness of cliff face all directly affected the vegetational composition (Ballinger, 2007). This research showed that the greater the surface heterogeneity and accumulation of soil, the higher the occurrence of vascular plants, whereas the reverse was observed for non-vascular plants.

A study on the effects of microtopography on the vegetation community on cliff faces on the Niagara Escarpment showed distinct and different vegetational communities were found to be correlated with microtopography (Kuntz & Larson, 2006). It was found that an increase in the level of soil increases the richness and frequency of vascular plants but decreases bryophyte richness and percentage of lichen frequency. This study also reported that the local microclimate was not the main influencing factor for bryophyte richness and frequency, but correlated with lichen richness instead, as increases in the number of rock crevices and pocket frequency corresponded with the increases in lichen richness. A distinct vegetational community of higher plants, mosses, lichens and terrestrial algae was found in limestone cliffs of the Niagara Escarpment (Cox & Larson, 1993a, b; Gerrath *et al.*, 1995), and the floristic composition remained the same along the 725 km length of the escarpment, which extends from north to south (Larson *et al.*, 2000a). Moreover, many genera like *Campanula*, *Asplenium*, *Sedum*, *Pellaea* and *Polypodium* that are characteristics of tropical cliffs are also found on the cliffs of the temperate zone. However, studies on the Niagara escarpment have shown that the aspect did not impact the number, shape, size and age of *Thuja occidentalis* L. individuals (Larson & Kelly,

1991; Kelly *et al.*, 1994). Likewise, moisture was not found to be a limiting factor of the growth of *T. occidentalis* (Matthes-Sears *et al.*, 1995).

Previous Floristic Studies

The areas within the southern extent of the Cumberland Plateau of Tennessee have been the subject of several floristic studies including Fall Creek Falls State Park (Caplenor 1955, Bowman 2003, Fleming and Wofford 2004), Fiery Gizzard Gorge (Clark 1966), Savage Gulf Natural Area (Wofford *et al.*, 1979), Frozen Head State Natural Area (Holtzclaw 1977), and several areas in the Upper Cumberland River Basin (Patrick 1979). The vegetation of Cumberland Plateau sandstone outcrops has been studied in detail by Perkins (1981). A survey of vegetation associated with the cliff systems of the Obed Wild and Scenic River was conducted in 1999-2003 by Emily Parisher and a similar floristic survey of a Cumberland Plateau cliff system was conducted by David Ballinger of the White Rocks Cliff System at Cumberland Gap National Historic Park in 2005-2006.

Limited studies of the vegetational communities in the Obed have been completed (Schmalzer and DeSelm 1982, Schmalzer *et al.* 1985, Schmalzer 1989). Within the Obed River gorge Schmalzer *et al.* (1985) reported 734 vascular plant taxa within 393 genera and 122 families. Asteraceae was the most highly represented family, with 102 taxa, followed by Poaceae with 82 taxa. They also reported 59 introduced taxa that comprised eight percent of the total species list. Sixteen taxa reported from that study were on the Tennessee list of rare plants (Tennessee Natural Heritage Program 1982) or have been proposed for Federal listing (U.S. Dept. of the Interior 1980). One species of grass collected, *Sporobolus junceus* (Palisot de

Beauvois) Kunth, was a state record for Tennessee (Patrick et al. 1983). Among those species listed as of special concern or threatened in the Schmalzer study are *Adlumia fungosa* (Aiton) Greene ex Britton, Sterns, & Poggenburg and *Polymnia laevigata* Beadle, each from single populations found in boulder fields along the Obed River, and *Phemeranthus teretifolius* (Pursh) Rafinesque, from a sandstone outcrop above Clear Creek. The relevance of the presence of these species for the present study is that they are in areas that could potentially be subject to impacts by rock-climbing activities. Although they included descriptions of some of the boulder field, cliff edge, and talus vegetation, these studies did not systematically sample the cliff-face vegetation of the Obed Gorge.

Recently a short study of the cliff face and cliff base area was completed. This study revealed that numerous bryophyte species occur along the cliff face and cliff base. A large number of these bryophytes have not been reported in other areas of the Cumberland Plateau (Risk 1999). A new species of lichen, *Canoparmelia amabilis*, was discovered in 1999. *C. amabilis* was discovered within the climbing area and at this time, likely due to its recent discovery, is the only known location for this lichen (Nancy Keohane, personal communication).

In 1999-2003 a systematic sampling of cliff systems in climbing areas of the Obed River Gorge was conducted by Emily Parisher and Gary Walker of the Department of Biology of Appalachian State University. That study included cliff edge, cliff face and talus regions of cliff systems and compared climbed and unclimbed faces, including a number of physical and biological variables that were described using multivariate statistical analyses. In the course of that study two populations of ancient red cedars were discovered in the talus slopes of North Clear Creek and the Obed Wall climbing areas. A preliminary investigation of the age of some dead snags that were sectioned was conducted revealing very old red cedars.

Vegetation on Cliffs

The harsh environment in semi-arid and sub-arctic regions sometimes hinders tree growth and therefore such trees can be used to describe long dendrochronological sequences (Archambault & Bergeron, 1992). Living bald cypress trees, *Taxodium disticum* (L.) Rich. have been used to reconstruct up to 1614-year long chronologies for North Carolina (Stahle *et al.* 1988). Previous studies, mainly on *Thuja occidentalis* L., revealed that a multi-century-long tree ring chronology can be obtained from gymnosperm trees mainly growing in cliff systems. Northern white cedar (*Thuja occidentalis*) can grow in extreme environmental conditions and can reach relatively old ages (Sheppard & Cook, 1988; Larson & Kelly, 1991; Kelly *et al.*, 1994).

The 18-year long study of *T. occidentalis* in the Niagara Escarpment shows that seedling growth and survival of newly regenerated plants depends upon the climate and microsite (Matthes & Larson, 2006). It is found that drought is the main cause of seedling mortality in early stages of regeneration, while rock fall is the most frequent cause of death on cliff faces, while pathogens are the most frequent in horizontal habitats. The study further identified that the cliff-face habitats are sites of poor seedling emergence but safe for the best survival, whereas it is just the opposite on large ledges and shelves.

Differences in species richness, abundance and coverage of vascular plants or bryophytes on climbed and unclimbed cliffs were based on the effects of microsites rather than climbing

impacts in some studies (Kuntz & Larson, 2006b; Nuzzo, 1996; Farris, 1998), and that climbers select cliff faces that are specific for microsite characteristics. They also avoid cliffs that are heavily vegetated (Farris, 1998). These findings can strongly influence the commonly accepted concepts of climbing impacts on vegetation composition and richness (McMillan & Larson, 2002; McMillan et al., 2003). Further, the increase of alien species on cliffs is directly linked with the increasing sizes of ledges, and numbers of crevices, and pollution (Kuntz & Larson, 2006b). This relates the notion that a large number of alien species will be found on disturbed/climbed cliff faces (McMillan & Larson, 2002), and that the number of alien species correlates with the number of visitors/hikers on cliff sites (Lonsdale, 1999). The umbilicate, fructose and foliose lichens are more sensitive to disturbance, and finally, the crustose lichens become dominant on climbed cliff surfaces (Farris, 1998). Moreover, disturbance on cliff-edge and talus regions promotes the introduction of alien and weedy species (Farris, 1998), and therefore it is necessary to conserve surrounding vegetation so that alien species would not impede native cliff species survival.

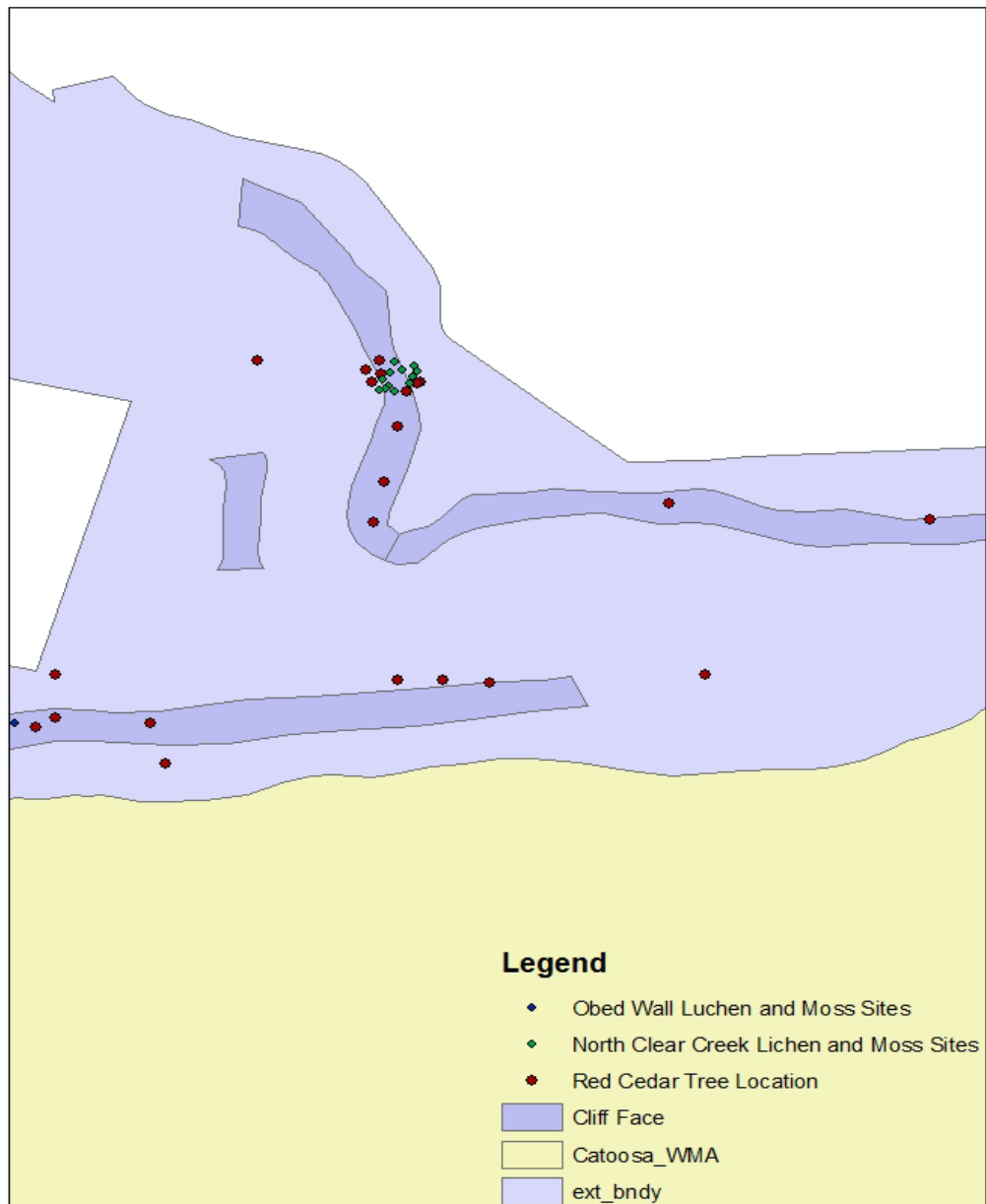


Figure 15. Collection sites for vascular plants, mosses, and lichens

Methods

In summer 2008, a vegetational survey and community composition description of red cedar stands in talus was conducted in two sites: Obed wall and Clear Creek of OWSRG under the guidance of Dr. Gary Walker. This process involved a listing of bryophytes, lichens and vascular plants in the vicinity of (1 m radius) of red cedar trees. Lichen and bryophyte species were also noted on every individual tree of red cedar in the Talus region.

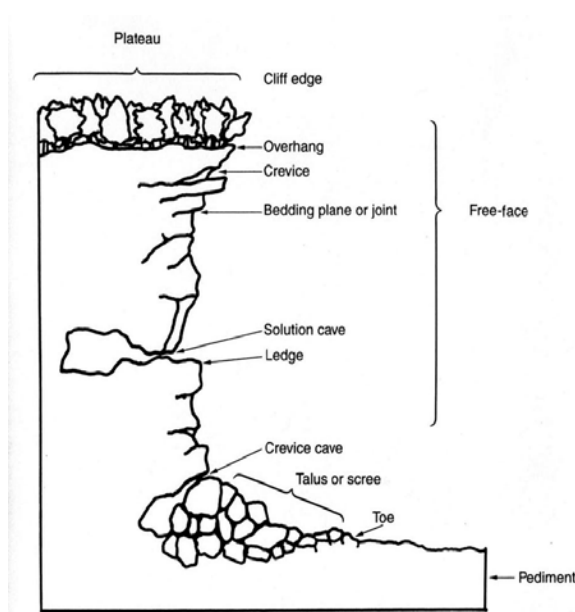


Figure 16. Cliff system habitats (Larson et al. 2000)

An additional systematic field survey was conducted from 15-17 May, 2009 in the talus area of ancient red cedar communities of the Obed Wall and Clear Creek of OWSRG. The vegetational sampling was done using a 1m x 1m quadrat size along transects. A tape measure was stretched out 20 m parallel to the cliff system extending from the first red cedar tree was encountered in the talus region. Then within the 20 m distance, 3 transects were laid down

perpendicular to the cliff system using a random number table. In each transect we laid 1m x 1m plot on either side of the transect, contiguous plots were laid down every 3 meters until the exposed rock of the talus area ended. Altogether, three transects (12 plots) total in each site were laid down. In each plot the percent coverage of vascular plants and non-vascular plants (bryophytes and lichens) were recorded. Most of the vascular plants inside the plots were identified in the field, and the unidentified species and all samples of mosses and lichens were collected and brought to Appalachian State University for identification. Mosses and liverworts were identified by Keith Bowman SUNY Syracuse while Dr. S. Coleman McCleneghan identified the lichen specimens.

Results

A total of 133 different vascular plant species were found to be associated with the Obed Wall and North Clear Creek Ancient Red Cedar Sites including forest and floodplains contiguous with the cliff systems at each of these sites. There were 43 different species observed at the North Clear Creek site and 111 different vascular plants observed at the Obed Wall site. Of the 133 vascular plants observed at both sites, 22 were unique to North Clear Creek, 88 were unique to the Obed Wall site, and 23 were found at both sites. 20 different bryophyte species were found during the two collection cycles associated with the two sites and one liverwort at the North Clear Creek site. Of these 20 bryophytes, 15 were associated with the North Clear Creek site and 5 were associated with the Obed site. 43 different species of lichens were observed and collected over the two collection cycles at the two sites. Of these 16 lichens were observed at the Obed site and 27 at the North Clear Creek site.

In a previous study, “Statistical Analysis of Cliff-face Vegetation in the Obed River Gorge,” (Walker and Parish 2004), 7 vascular plants were observed in quadrats along transects in the talus region of North Clear Creek and 11 were observed at the Obed Wall site. In the same study 16 bryophyte species were found in talus plots at the North Clear Creek site and 7 bryophyte species at the Obed Wall. Likewise, 16 lichen species were observed in plots at the North Clear Creek Site and 12 at the Obed Wall site. In both the present study and the 2004 study, the Obed Wall talus sites were more heavily vegetated with vascular plants, while the North Clear Creek talus site had a greater number of lichens and bryophyte species.

Discussion

The Ancient Red Cedar stands of the Obed Wild and Scenic River obviously contribute substantially to the species diversity of the Park. They have greatly increased the number of lichen, moss and vascular plant species first described in the vegetational survey of climbed and unclimbed cliffs in a previous study. In the vascular plant surveys a species new to the Park (sensu Schmalzer 1985) was discovered, *Carex emmonsii*. Interestingly, this species was common on rock faces at both the Obed Wall and the North Clear Creek ancient red cedar sites. It may be that species was misidentified as *Carex pensylvanica* in previous studies. Another addition to the species list for the Park is *Robinia hispida* var. *fertilis*. The likely reason for omission in Schmalzer’s survey was that different varieties of *Robinia hispida* were not separated in that publication. Other species of note include *Conradina verticillata*, a narrow endemic confined to Tennessee and Kentucky, *Silene rotundifolia*, which had a particularly robust population at the Obed Wall site, and *Stewartia ovata*, a fairly infrequent tree.

A number of both lichen and moss species are epiphytic upon the red cedars. Several of the lichens, including *Cladonia symphy carpia*, *Lecanora albellula*, and *Punctelia subrudecta* are found here outside of their normal ranges as southern disjunctions. *Usnea amblyoclada* is found here at the northern boundary of its range. These disjunctions confirm general assumptions regarding the Cumberland Plateau as a refugium for species with normally more northerly or southerly ranges. Some, such as *Phycia Americana* are normally found on the bark of deciduous trees and as such represent habitat disjunctions.

There may be several reasons for the abundance of vascular plants at the Obed Wall ancient red cedar site as compared to the North Clear Creek site. There is a more heterogeneous topography at the Obed site that would facilitate a higher level of colonization. As the cliff system is higher there, there is more surface area for species as well. Another important factor is the remoteness of the site, particularly where the ancient red cedar population is located. The North Clear Creek site, being more accessible, may have encountered more disturbance from climbing and hiking activity, reducing vegetation. The Obed site also has a higher diversity of ecotonal variation between its community types as it transitions more abruptly into riparian habitats while at North Clear Creek the talus slope declines gradually. The North Clear Creek site also has evidence of mass wasting and debris flows. Whether these are the result of natural processes or increased human visitation is unknown.

The abundance and diversity of mosses and lichens are higher at the North Clear Creek site and this may be related to the lower levels of abundance of vascular plant vegetation at that site. Competitive release of lichens and mosses has been observed in other cliff system where vascular plant abundance is lower. This has been observed at the White Rocks cliff system at

Cumberland Gap National Historic Park (Ballinger 2007). This was also noted in Linville Gorge climbing routes where removal of mosses and vascular plants resulted in an increased abundance and diversity of lichen flora (Smith 1998).

Summary and Management Implications

Ancient red cedar populations at the Obed Wild and Scenic River represent uniquely long-lived individuals in populations that have likely persisted for many hundreds of years. Their age-class structure indicates that they exhibit balanced recruitment and mortality, suggesting that they could potentially persist for many more hundreds of years in the absence of any severe natural disasters or human-induced disturbances. It is likely that they have been somewhat insulated from natural fires across the landscape, evidenced by the lack of fire scars in snag sections taken from these trees. This insulation is likely owing to their association with extensive cliff systems at both the Obed Wall and the North Clear Creek sites. Presently the greatest perceived threat to their continued existence is human-induced disturbance. They have been chopped, used as fire wood, and for anchors for climbing. The vegetation associated with these stands includes several uncommonly occurring species of lichens and vascular plants. The vegetation and lichens associated with these stands are rooted in extremely shallow soils, and constitutes a very fragile assemblage of a diversity of unusual species. There are many studies that describe the impacts of human disturbance on rock-outcrop and cliff system plant communities (McMillan, 2000, Smith P. 1998, Camp, R.J. and Knight, R.L. 1998, Larson, D.W. and Kelly, P.E. 1997, Nuzzo, V.A. 1995). In every study humans have had a negative impact on such communities. An important management consideration for such areas is to restrict access to such sites. This may be particularly effective for the Obed Wall site as the section containing the ancient red cedars

is relatively remote. One step would be to remove the ladder that provides access to the Saddam Hussein climbing route. The ledge from which this climb originates is made accessible by a crudely constructed ladder and the ledge itself supports a very diverse and fragile association of uncommon vascular plants, mosses and lichens as well as the old-aged cedars themselves. Interpretation of the uniqueness of these ancient cedar stands should also be employed to make climbers and hikers aware of the special nature and fragility of these sites. Also, trails that are used as approaches to both sites run along the talus sections of the cliff faces where many unusual species are located. There is a proliferation of side trails, especially at the Obed Wall site. Rerouting of the main trail, out of the talus area, through the less diverse oak-hickory communities toward the river, with access trails directly to the climbing routes would greatly lessen the foot traffic impact across the talus region of this site. Most hikers and climbers have an environmental conscience and with proper signage, explanations and natural history education regarding the uniqueness of the ancient red cedar communities of the Obed Wild and Scenic River these sites may well be better preserved for the enjoyment of future generations.

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