CHARACTERIZATION OF THE VEGETATIONAL COMMUNITIES ASSOCIATED WITH ANCIENT *JUNIPERUS VIRGINIANA* L. STANDS IN THE OBED WILD AND SCENIC RIVER GORGE.

A Thesis
by
BAL KRISHNA NEPAL

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ABSTRACT

CHARACTERIZATION OF THE VEGETATIONAL COMMUNITIES ASSOCIATED WITH ANCIENT *JUNIPERUS VIRGINIANA* L. STANDS IN THE OBED WILD AND SCENIC RIVER GORGE.

(August 2010)

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A vegetational survey of ancient red cedar (*Juniperus virginiana* L.) stands in the talus areas of the Obed Wall and North Clear Creek (NCC) in the Obed Wild and Scenic River Gorge was conducted during the summers of 2008 and 2009. Altogether, 161 vascular plants, 37 lichens, and 21 bryophytes were recorded from both the Obed Wall and NCC sites. The diversity and abundance of vascular plants were found to be higher at the Obed Wall site than that at the NCC site, while the reverse was true for lichens and bryophytes. Statistical analysis of percent coverage and frequency of vascular plants from systematic sampling revealed significant variations in species composition between the Obed and NCC sites. Thirty-five living red cedar trees were sampled, and their vegetational communities (vascular and non-vascular) in the vicinity were examined. Also, species accumulation curves (SAC) were determined for vascular plants, lichens and bryophytes found in association with red cedars. To determine the species richness of lichen epiphytes associated with red cedars 28 trees were surveyed, where an asymptote was observed in terms of increasing species diversity. However, a minimum of 12 trees were sampled before an asymptote was reached for bryophytes. During the study, an asymptote was not observed for vascular plant diversity even though 35 red cedar trees (a nearly complete census) were surveyed.

In December 2007, a dendroecological survey of ancient red cedars was carried out at the Obed Wall and NCC sites. The age-class structure of red cedars showed an inverse J-shaped curve, which represents continuous, balanced recruitment and mortality of these stands. Of the 36 living trees cored, the oldest-living red cedar was found to be 767 years old. A general climatic history of the Obed area was reconstructed back to 1246 A.D. but this is not a precise reconstruction because of the prevalence of false rings.

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The thirty-two months I lived and learned in Boone have been unforgettable. Sharing a house with Teri Reddick and Carlton Pendley in the final year has been an incredible experience. I would like to thank both of them for their tireless help and hospitality. Also, while writing this thesis, the University Writing Center helped me with my writing.

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DEDICATION

I would like to dedicate this thesis to my father, Kabi Raj Nepal, and mother, Shiva Kumari Nepal. Despite the distance, your support and encouragement helped to keep me motivated throughout all the challenges I faced.

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INTRODUCTION

Research on cliff systems, especially following the late 1980s, has revealed that cliffs may harbor long-lived trees and may also act as refugia for glacial-relict plant species in the Southern Appalachians. Plants migrated southward in advance of ice sheets and were established in the southern Appalachians during the time of the Wisconsin glaciations. As temperatures ameliorated after glacial maximum the north-facing cliff systems of the southern Appalachians were favorable sites (refugia) for those boreal plants left behind (Oosting and Hess 1956, Walker 1987). For instance, the main range of northern white cedar (*Thuja occidentalis* L.) presently surrounds the Great Lakes Region, but disjunct glacial-relict populations of these long-lived species are found on north-facing cliffs in the southern Appalachians (Walker 1987). Further, *Cypripedium reginae* Walter an orchid associated with the northern white cedars (Kennedy 2003), and some boreal lichens on the Cumberland Plateau rock outcrops (Ballinger 2007) support the idea that these species are an assemblage of glacial relics rather than having been established by long-distance dispersal (Parisher 2009).

Community structure on the cliff systems

Cliff edges show higher species richness than the cliff face and talus (Nuzzo 1996). But increased fractures in horizontal as well as vertical sites on a cliff face are related to an increase of vegetation density on those sites. In most cliff systems, ledges are where the greatest accumulation of soil is found on a face, providing the best habitat for vascular plants, including woody trees. A study of cliff vegetation structure in northeast Illinois by Nuzzo (1996) determined that different community groups were found in a very short distance from each other. 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 species to colonize on newly-formed cliffs (Maycock & Fahselt 1992, Larson et al. 1989), and when fractures develop in cliffs over time they accumulate soil and nutrients, leading to establishment of vascular plants (Nuzzo 1996).

Microtopography and geology of cliffs also determine plant community structure (Coates & Kirkpatrick 1992, Farris 1998). A study of 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 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 lichens.

Vegetation communities of cliff faces on the Niagara Escarpment showed distinct differences that were correlated with microtopography (Kuntz & Larson 2006b). It was found that an increase in the depth of soil increases the richness and frequency of vascular plants but decreases bryophyte richness and lichen frequency. This study also reported that microclimate was not the main factor influencing bryophyte richness and frequency, but was for lichen richness. In addition, increases in the number of rock crevices and pocket frequency corresponded with increases in lichen richness.

Vegetational communities on the limestone cliffs of the Niagara Escarpment (Cox & Larson 1993a,b, Gerrath et al. 1995) remain similar along its 725 km length (Larson et al. 2000a). Moreover, many genera like *Campanula*, *Asplenium*, *Sedum*, *Pellaea* and

Polypodium that are characteristic of tropical cliffs are also found on cliffs of the temperate zone. However, studies on the Niagara Escarpment have shown that aspect did not impact the number, shape, size and age of *T. occidentalis* individuals (Larson & Kelly 1991, Kelly et al. 1994).

Vegetation on the cliff systems

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

An 18-year long study of *T. occidentalis* on the Niagara Escarpment showed that seedling growth and survival of newly-regenerated plants depended upon climate and microsites (Matthes-Sears & Larson 2006). It was found that drought was the main cause of seedling mortality and rock fall the most frequent cause of death on cliff faces. Furthermore, with increased rockclimbing activities, cliff vegetation has been impacted more heavily (McMillan & Larson 2002, Parisher 2009).

A few studies have linked increased visitation to rock outcrops and cliff faces and increases in introductions of exotic species in these systems. Furthermore, increases of invasive species on cliffs are directly linked with increasing sizes of ledges and numbers of crevices (Kuntz & Larson 2006b). This relates to the notion that a large number of invasive or exotic species can be found on disturbed/climbed cliff faces (McMillan & Larson 2002), and that the number of exotic species correlates with the number of visitors/hikers on cliff sites (Lonsdale 1999). Umbilicate, fruticose and foliose lichens are more sensitive to disturbance, while crustose lichens become dominant on climbed cliff surfaces (Farris 1998). Moreover, disturbance in cliff-edge and talus regions facilitates the introduction of exotic and weedy species, and therefore it is necessary to conserve surrounding vegetation so that exotic species will not impede the survival of native cliff species.

Species accumulation curves

The species accumulation curve (SAC) was not formalized until the twentieth century (Cain 1938). However, the concept of SAC came after the work of de Candolle (1855), who stated that if sample area increases then the total number of species will increase. Subsequently, Cain (1938) proposed the SAC as an intuitive tool for community descriptions, which is used to determine the least number of quadrats needed to represent the larger community. Scheiner (2003) argues that there are two ways of obtaining more species in sampling regions. First, as more individuals are sampled, the chance of encountering additional species increases, especially if species are not randomly distributed. Second, a larger area is likely to be more environmentally heterogeneous, thus containing additional species.

Sample size and sampling intensity usually depend on the degree of accuracy and overall quality of the required information, time, financial and other constraints, and human resources as well (Ravindranath & Premnath 1997). The equilibrium among financial resources, time, and precision of the required information is considered crucial. Sometimes, it is very difficult to design cost-effective inventories, and also it is an important challenge when funding is limited and the rate of detecting new species is extremely low (Keating et al. 1998).

Old-aged cliff-associated trees

The longest-lived individuals of most conifer trees grow in adverse and rocky sites and have extremely slow growth rates (Schulman 1954, Ward 1982, Matthes-Sears et al. 1995). These are generally in the genera *Pinus*, *Cupressus*, and *Juniperus*, whose individuals also frequently show a distortion of morphology and asymmetric radial growth (Larson et al. 1993). It has been found that the mean maximum age of angiosperm trees is 248.4 years, while the mean maximum age for 55 gymnosperm species is 595.6 years (Schweingruber 1993). Among the gymnosperms, there are six species that live more than 1000 years but there is no angiosperm tree known which has lived that long. A study on ancient forests of Osage County, Oklahoma showed that eastern red cedar (*Juniperus virginiana* L.) is common on sandstone cliffs and large rock outcrops and some individuals exceed 500 yrs in age (Therrel & Stahle 1998).

A study of 65 different cliffs of the 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 distribution and growth-rates (Larson et al. 2000a). Kelly & Larson (1997a) observed that *T. occidentalis* can reach a maximum age of 1653 years, and produce reliable annual tree-rings which may be used to reconstruct past climatic conditions. A dendroecological study of *T. occidentalis* revealed that populations of this species sharply increased between 1780 and 1850 and declined until the 1940s, while after the 1950s the population had increased gradually on the Niagara Escarpment (Kelly & Larson 1997b). The present day stem densities, age structure and growth rates are used to infer past fluctuations in population dynamics and are 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 great longevity when they are living but also considerable decay resistance when dead (Schweingruber 1989). The high degree of cedar wood preservation is caused by either wet, anoxic conditions (Hoffmann & Jones 1990) or very dry conditions (Nilsson & Daniel 1990). Loehle (1996) mentioned that exceptionally long-lived trees have extremely effective defense systems which limit mortality by fungi and insects.

Stem-stripping

Stem-stripping is the death of sections of stem caused by partial mortality of the cambium. It is generally found in angiosperms and gymnosperms but is most common in the family Cupressaceae (Matthes-Sears et al. 2002). Species that exhibit stem-stripping often grow in adverse climatic conditions, are long-lived (LaMarche 1969), and very slow and asymmetric growth (Matthes-Sears et al. 2002). However, the cause of stem-stripping is still unclear. Some gymnosperm trees that show partial stem-stripping are *Pinus longaeva* (Schulman 1954, LaMarche 1969); *P. aristata* (Schauer et al. 2001); *T. occidentalis* (Larson et al. 1993, Matthes-Sears et al. 2002); *J. 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 was found in trees older than 1500 years of age with large diameters (LaMarche 1969). Kelly et al. (1992) sampled several populations of northern white cedar from the Niagara Escarpment, and found that almost half of the cambium had been lost between the ages of 130 and 280 years. Up until about 390 years of age, surviving white cedar trees generally had only 25% of its potential circumference in living cambium. Eastern red cedars when growing with cliff systems generally show symmetric shapes through young age classes, but are very deformed and asymmetric in old age (Kelly et al. 1992). However, stem-stripping also occurs in young trees. This may be due to external factors like root exposure or 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). 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 also 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, causing partial cambial mortality, but uninjured roots would continue to feed certain portions of the stem cambium, resulting in sectorial water transport to the crown.

Age-class structure

Age-class structure analysis of tree populations allows for the development of population parameters that can be used in analyses of species change in forest ecosystems (Hett and Loucks 1976). Larson and Kelly (1991) studied the age and size class structures of *T. occidentalis* in nine different sites of the Niagara Escarpment. Population densities of 666-1773 individuals per hectare on vertical cliff faces were observed and were uneven-aged. However, the older trees were more prevalent on 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 because little human disturbance and little evidence of fire were observed. Only 1.5% 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, < 3 cm diameter at breast height (dbh) (the smallest size classes) had the highest values, but high frequency values were observed between 6 and 10 cm in diameter in disturbed sites.

Previous studies in the Obed River Gorge found several old-aged red cedar trees in the talus. Walker and Parisher (2004) found a red cedar snag in the talus area to have about 863 annual rings. With this information, the Park Service decided to conduct research on red cedar growth patterns (age-class structure) and its community structure. 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. This information will be useful for the Park Service to implement climbing regulations toward the conservation of these ancient red cedar populations.

Objectives

The objectives of my study were to:

- characterize the vegetational community associated with ancient red cedar trees in the talus areas of the Obed Wall and North Clear Creek sites of the Obed Wild and Scenic River Gorge, since this is the region of the cliff system in which these ancient cedar stands occur

- determine the species accumulation curves for vascular and non-vascular plants associated with ancient red cedars
- determine the age-class structure of red cedars using a dendrochronological investigation, and to identify past and present reproductive patterns
- reconstruct the past climatic conditions of the Obed region using dendrochronological investigations of red cedar trees

MATERIALS AND METHODS

Study area

This study was conducted in the talus areas of the Obed Wall and North Clear Creek (NCC) sites (36.094°N and -84.7° W; 36.09°N and -84.71°W) of the Obed Wild and Scenic River Gorge (OWSRG), Tennessee. This area is recognized for recreational activities such as rock climbing, hiking, fishing, and white-water paddling. More than 300 sport climbing routes in the Park suggest that the area is popular among rock climbers (Parisher 2009). Most of the red cedar trees are growing at the base of sandstone cliffs and cliff edges.

The Obed River flows over 72 kilometers through rugged terrain across the Cumberland Plateau in eastern Tennessee. The Cumberland Plateau is a physiographic province of the southern Appalachian region, and extends northward from its Tennessee section across Kentucky and into West Virginia and Pennsylvania, and into Alabama to the southwest. The annual total precipitation varies from 130-153 cm (Mayfield 1984).

Vegetation analysis

In the summer of 2008 a vegetational survey and community composition description of the red cedar stands in the talus was conducted at the Obed Wall and NCC sites of OWSRG (Figure 1). This process involved a listing of bryophytes, lichens and vascular plants in the vicinity of red cedar trees (1 m radius for vascular plants, and about < 25 cm radius for lichens and bryophytes). A total of 35 red cedar trees were sampled, and their girths were measured as diameter at breast height except for seedlings. However, the tree height was not taken because of the deformed and convoluted shape of the trees. Lichen epiphytes were also noted on every red cedar tree.

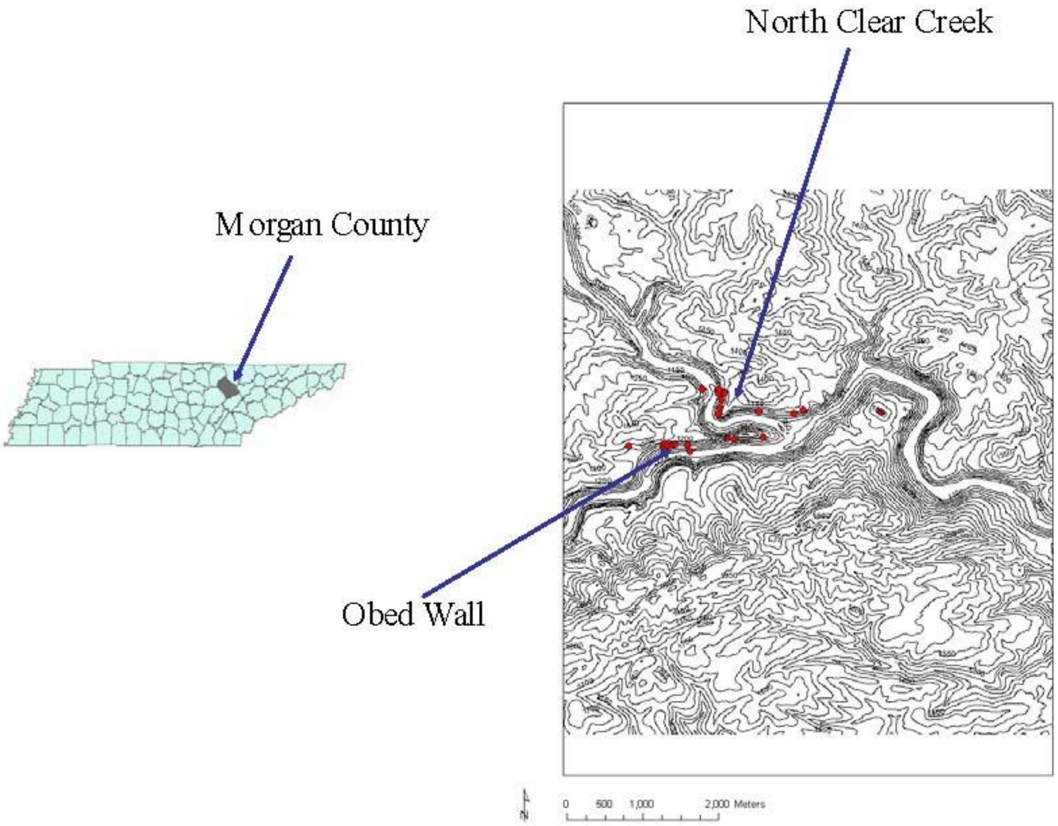

Figure 1. Map of the study area (Obed Wild and Scenic River Gorge, Tennessee). The red points are the red cedar tree cores collection sites.

In addition, a systematic field survey was conducted from 15-17 May 2009 in the talus area (Figure 2) of ancient red cedar communities of the Obed Wall and NCC sites of OWSRG. I stretched out a tape 20 m parallel to the cliff system extending from the first red cedar tree encountered in the talus region (Figures 2 & 3). Then within the 20 m distance, I laid down 3 transects perpendicular to the cliff positioned using a random number table. In each transect I laid out 1 m^2 plots on either side of the transect (Figure 3). Contiguous plots were laid down every 3 m until the exposed rock of a talus area ended. Altogether, three transects (12 plots) were laid down at each site. In each plot, I recorded the percent coverage of vascular plants, bryophytes, and lichens. Most of the vascular plants inside the plots were identified in the field. Unidentified specimens were brought to Appalachian State University (ASU) and later identified using the ASU herbarium. However, most of the specimens were identified by Derick Pointdexter, Assistant Herbarium curator, following the nomenclature of Weakley (2010). The USDA plant database was also used for scientific names of vascular plants sampled in this study.

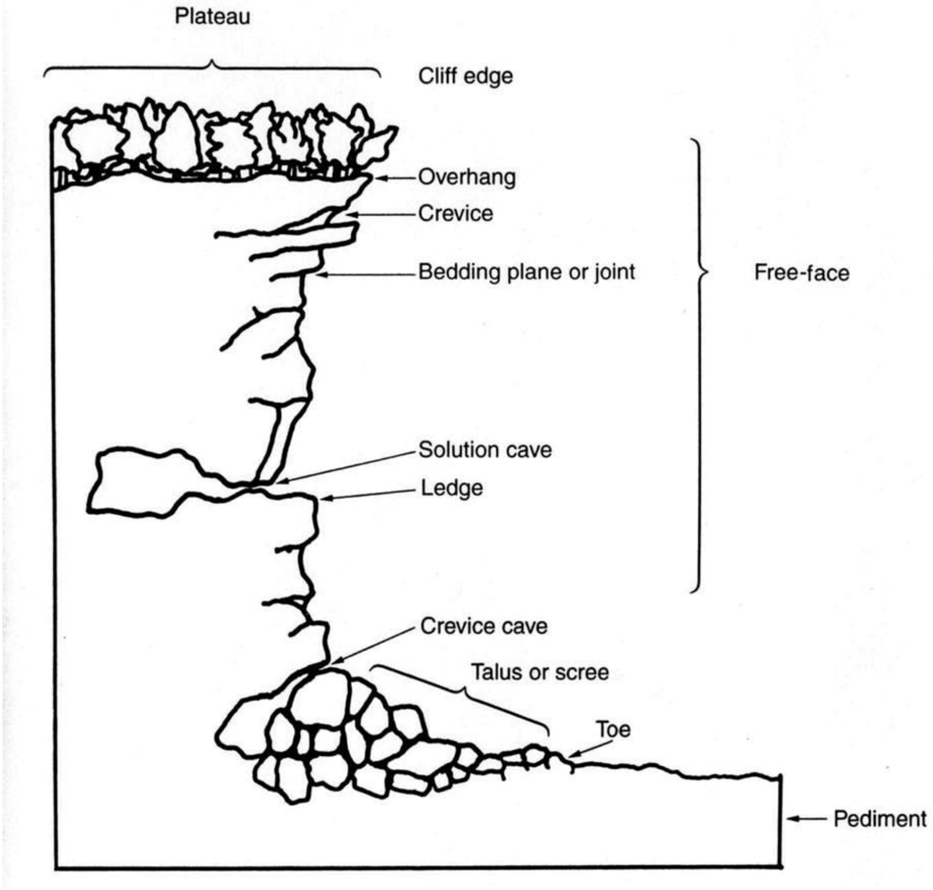

Figure 2. Cliff system (Larson et al. 2000b).

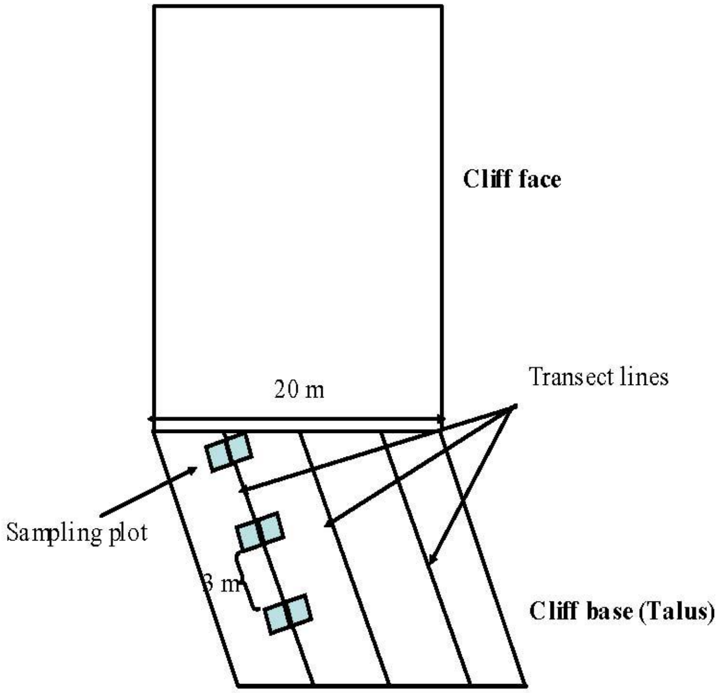

Figure 3. Sampling design to collect vascular and non vascular plants in the talus area.

Lichen specimens were collected from the rock surface very carefully. Most of the crustose lichens were attached tightly to the rock surface, so blades and sharp knives were used to remove them. In some cases a chisel was used to remove lichens from the surrounding substrate. After removal, all specimens of lichens and bryophytes were put in paper bags, labeled according to plot number and brought to ASU. The specimens were dried in a drying cabinet. Bryophytes were identified by Keith Bowman, SUNY Syracuse using the nomenclature of Crum and Anderson (1981) for mosses, and Hicks (1992) for liverworts. All the lichen specimens were identified by Dr. S. Coleman McCleneghan according to the nomenclature of Brodo et al. (2001).

Coefficient of community similarity

To calculate the community similarity between the sites, a coefficient of community was calculated using Whittaker (1975):

$$\text{Coefficient of community (CC)} = 2SAB*100/(SA + SB) \qquad (1)$$

where:

SA = number of species in sample A

SB = number of species in sample B, and

SAB = number of species common to both samples.

This index can range from 0 when there are no species common to either community, to 100% when both communities have the exact same species.

GIS map

Using latitude and longitude recorded by GPS for every red cedar tree, a GIS location map with lichen and bryophytes collection sites was constructed for the ancient red cedar trees found in the talus and ledge areas of the cliffs of the Obed Wall and NCC.

Statistical analysis

Analysis of variance (ANOVA) was performed on species coverage and frequency to determine differences between values at the Obed Wall and NCC sites using SAS 9.1 (SAS Inc., Cary, NC). Average percent cover was taken for every species present in the respective transect. Also, based on the presence or absence of each species in the plot, average percent frequency was calculated for each transect. Differences were considered significant for all p-values < 0.05. Transformations of the data were not necessary. It was not possible to do ANOVAs for non-vascular plants because of the large number of zero values in the plots.

Dendrochronology of red cedar

A dendrochronological analysis of ancient red cedar stands was conducted by the research team of Dr. Pete Soulé, Department of Geography and Planning, ASU. In 2007, the dendroecological field study occurred in two different locations (36.094°N and -84.7° W; 36.09°N and -84.71°W) of the Obed cliff systems. The majority of the red cedars were found growing in the talus and cliff edge habitats. Aspect, slope and position were recorded for each tree. The sampling design was selective, and a total of 68 samples (tree cores) were collected from a total of 36 live trees. The increment borer is a threaded hollow bit used to take out cores of 4-5 mm diameter from a tree (Lafon 2005). The process is thought to be harmless to live trees although it makes a lesion. In the case of conifers, the exuded resin coming from the tree seals the wound immediately (Fritts 1976). Measurements of basal area at breast height, dbh of each tree sampled and other information about the tree (e.g., evidence of fire scars, and stem strips) were also recorded. Height measurement was not taken because most of the red cedar trees were found to be convoluted in shape. The age and diameter of the trees were used to develop regression analyses and to determine the age-class structure of red cedar stands.

The collected core samples were brought to the Dendroecology Laboratory of the Department of Geography and Planning at ASU. The samples were dried, glued, mounted, and then sanded to smooth surface using sequentially finer grit sandpapers so that the ring structures of the stem were clearly visible in order to count the annual rings.

Crossdating is a means of matching ring-widths across different samples (Fritts 1976). It is a very important part of dendrochronology because trees growing in extreme climates like cliff systems may not produce a ring on all portions of the stem annually. These are referred to as missing rings. Sometimes, because of the changes in cell structure within an annual growth ring, two or more false rings may appear (Fritts 1976). Uniformally wide rings or complacent rings (lack of width variability) are produced where the climate significantly limits the growth of trees. But when trees grow in harsh climates they produce variable ring widths from year to year (Fritts 1976). So, the trees which produce sensitive rings are very useful in reconstructing past climatic history because it tells how severely climate has limited growth of such trees.

The dendrochronology program COFECHA (Holmes 1983) was used for the process of cross-dating and also for searching for signature years, which are the years that consistently produce narrow or wide rings. Also, the skeleton plot technique, which provides a visual representation of the radial growth arrangement, was performed to compare ring growth patterns among the samples. Unfortunately, because red cedar produce many false and missing rings, as well as extremely narrow rings, cross-dating among samples was not successful. So, only one core sample, the oldest-living tree cored (sample no. 17a) was used for the generalized but not publishable reconstruction of past climatic history of the Obed region.

Radial growth was standardized using a conservative technique (negative exponential) (Biondi & Qeadan 2008, modified by Fritts 1976) as follows:

$$W_t = ae^{-bt} + k \qquad (2)$$

where:

W_t is ring width at year t

a is the ring-width at year zero

e is the base of natural logarithms

b is the slope of the decrease in ring width, and

k is the minimum ring width.

The Palmer Drought Severity Index (PDSI) is a soil-water balance model (Palmer 1965) or meteorological drought index that integrates weather conditions. The soil moisture algorithm is calibrated for relatively homogeneous areas. Negative values indicate relative drought and positive values indicate relative wetness. The values from 0 to ± 0.99 are near normal; ± 1 to ± 1.99 are mild; ± 2 to ± 2.99 are moderate, and values beyond ± 3 represent worst conditions. The relationship between red cedar radial growth rates and climatic conditions were determined using Cumberland Plateau, TN climatic data (1895 to 2007).

RESULTS

Species richness

Altogether 161 vascular plant species were found at both the Obed Wall and NCC surrounding areas (Appendix A & B). The Obed Wall site had 117 species while only 69 different species were recorded at the NCC site (Appendix B). Twenty-five vascular plant taxa were common to both sites. Altogether 37 lichen species were recorded; 25 were from the NCC site and 14 from the Obed Wall site, while only 5 lichen taxa were found to be common to both sites. Ten lichens were observed in the vicinity of red cedars at both sites. In the case of bryophytes, a total of 21 species were found associated with red cedar. Out of 21 bryophytes, 16 were from the NCC site; only 6 were from the Obed Wall site, while 3 bryophyte taxa were common to both sites (Appendix A).

Systematic sampling in the talus areas of the Obed Wall and NCC sites resulted in a total of 44 vascular plants; 35 at the Obed Wall site, and 15 at the NCC site, while only 6 species were common to both sites (Table 1; Appendix A). A total of 14 lichens were at the NCC site but only 5 were at the Obed Wall site, and 2 species were common to both. Likewise, out of the 14 different bryophytes, the NCC site constituted almost 80% of all bryophytes observed (Table 1).

Vascular plants were also collected in the vicinity (1 m) of red cedars in the talus area of the Obed Wall and NCC sites, and a total of 59 different vascular plants were found. Ten mosses and 10 lichens were also observed (Appendix A). The sampling of 35 red cedar trees in the talus region showed 22 epiphytic lichens, with 10 in their vicinity (Table 2). The red cedar trees at the cliff base at the Obed Wall were relatively less abundant than at the North Clear Creek site. Therefore, only 2 trees on the ledge at the Obed Wall site were sampled but they had a high diversity of lichen epiphytes compared to NCC where 33 red cedars were sampled. By systematic sampling of the talus I recorded 7 lichen species common to both red cedar sites and those found in their vicinity (Appendix A).

Table 1. Comparison of vascular, non-vascular plants, and lichens in a systematic sampling of the talus area of the Obed and NCC sites.

Groups	Obed	NCC	Total	Species common to both sites
Vascular plants	35	15	44	6
Lichens	5	14	17	2
Bryophytes	4	11	14	1

Table 2. Comparison of epiphytic lichens and bryophytes between the Obed and NCC sites.

	Obed	NCC	Total	Species common to both sites
Epiphytic lichens	11	13	22	2
Lichens in the vicinity of red cedar	0	0	10	0
Bryophytes in the vicinity of red cedar	3	8	10	1

Table 3. Total number of species found in the cliff systems of the Obed and NCC sites.

Groups	No. of associates of red cedar in the talus area of Obed and NCC	No. of associates of red cedar in the cliff systems of the Obed and NCC
Lichens	37	0
Bryophytes	21	0
Vascular plants	80	161

In the systematic sampling of sites, dominant taxa were identified based on the number of times the species were present in the plots. Fourteen vascular plants were considered dominant at the Obed Wall site with the most frequent being *Chasmanthium laxum, Pityopsis graminifolia,* and *Solidago arguta* var. *caroliniana* (Table 4a), while only 5 species dominated the NCC site (Table 4b) where *Acer rubrum* was the most dominate taxa. The most noteworthy results were found for lichens. None of the lichens were notably dominant at the Obed Wall site, while *Aspicilia cinerea*, *Leparia lobificans* and *Rhizocarpon geographicum* were observed as dominants at the NCC site (Table 4c). This is also validated by the average cover percentage of lichens. Almost 50% of plots area was covered by lichens at the NCC site, while negligible coverage was observed at the Obed Wall site (Figure 4). NCC had higher species richness in the case of bryophyte populations (Table 1) with *Leucobryum glaucum*, as the most frequently observed species, but the overall percent coverage was not higher than that at the Obed Wall site (Figure 4). The reason was that a single species, *Polytrichum* cf. *commune,* had covered most of the plots at the Obed Wall site.

Table 4. List of dominant taxa. Species were considered as dominant if they were present in at least 3 plots out of 12 (25% of the sampled area) in a systematic sampling of the talus area of the Obed and NCC.

(a) Obed Wall: Dominant vascular plants.

Species	Presence/12 plots	Growth habit	Group
Acer rubrum	4	Tree	Dicot
Betula lenta	4	Tree	Dicot
Chasmanthium laxum	9	Graminoid	Monocot
Danthonia sericea	3	Graminoid	Monocot
Dennstaedtia punctilobula	4	Forb/herb	Fern
Dichanthelium commutatum	4	Graminoid	Monocot
Hypericum prolificum	3	Shrub	Dicot
Lysimachia quadrifolia	3	Forb/herb	Dicot
Minuartia glabra	7	Forb/herb	Dicot
Pinus virginiana	8	Tree	Gymnosperm
Pityopsis graminifolia	9	Forb/herb	Dicot
Solidago arguta var. *caroliniana*	9	Forb/herb	Dicot
Solidago odora	3	Forb/herb	Dicot
Solidago sp.	3	Forb/herb	Dicot

(b) North Clear Creek: Dominant vascular plants.

Species	Presence/12 plots	Growth habit	Group
Acer rubrum	7	Tree	Dicot
Carex emmonsii	5	Graminoid	Monocot
Hamamelis virginiana	3	Tree/shrub	Dicot
Minuartia glabra	4	Forb/herb	Dicot
Nyssa sylvatica	4	Tree	Dicot

(c) Dominant lichens.

Obed Wall		North Clear Creek	
Species	Presence/12 plots	Species	Presence/12 plots
None	0	*Aspicilia cinerea*	9
		Cladonia apodocarpa	3
		Cladonia caespiticia	5
		Leparia lobificans	6
		Rhizocarpon geographicum	6

(d) Dominant bryophytes.

Obed Wall		North Clear Creek	
Species	Presence/12 plots	Species	Presence/12 plots
Polytrichum cf. *commune*	5	*Leucobryum glaucum*	5
		Odontoschisma cf. denudatum	3
		Polytrichum ohioense	3
		Racomitrium heterostichum	3

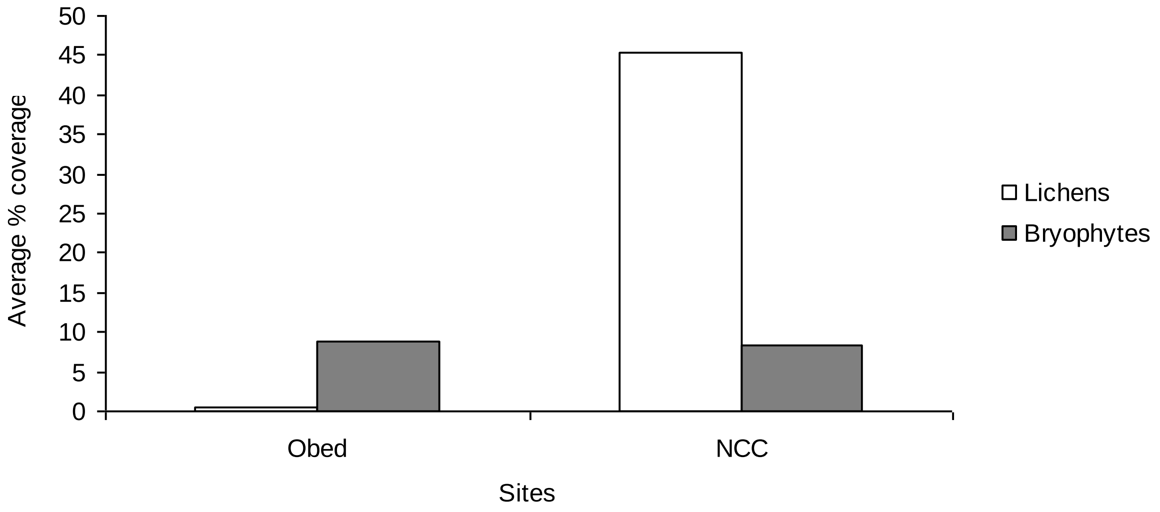

Figure 4. Percent coverage of lichens and bryophytes.

Species accumulation curves

It is very interesting that the species accumulation curve for vascular plants did not show any asymptote when plotted as a function of the number (35) of cedars sampled (Figure 5). This indicates that more than 35 red cedar trees should be sampled to determine the vascular plant associates of red cedars. However, asymptotes were observed for non-vascular plants. In the case of lichens, there were no unique epiphytic lichens observed after sampling the 28th red cedar tree (Figure 5). Likewise, the bryophytes showed an asymptote after the 12th tree (Figure 5).

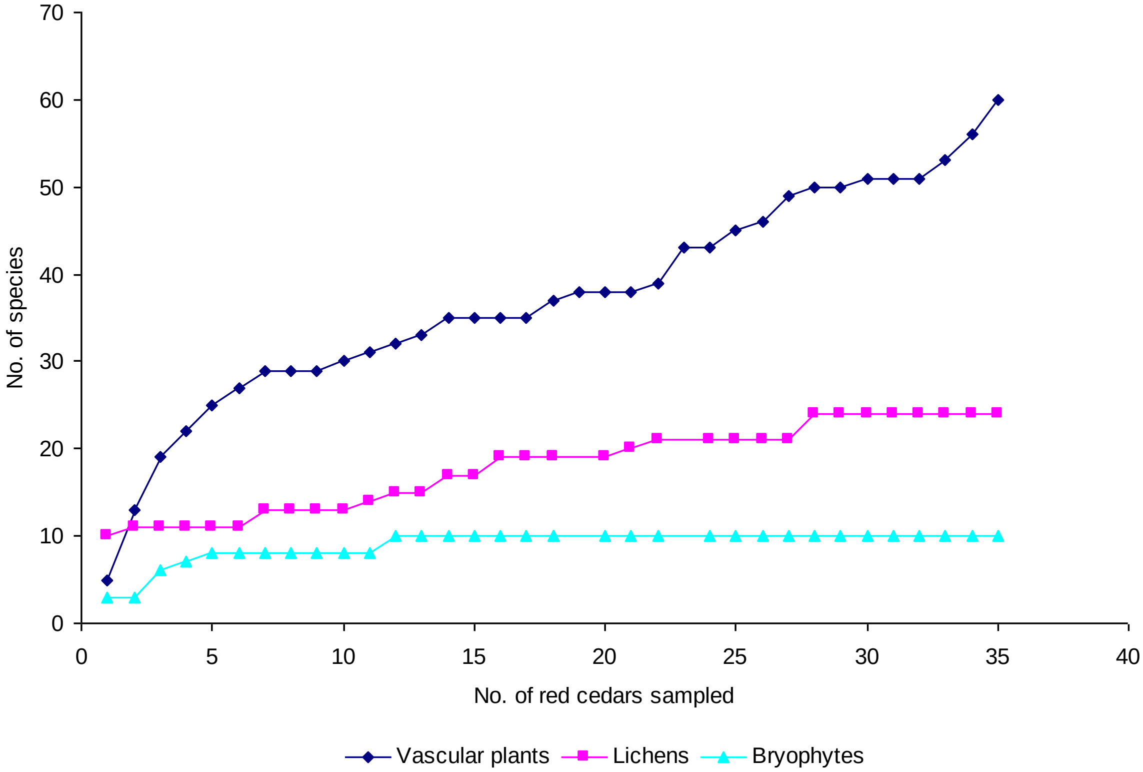

Figure 5. Species accumulation curves for the sampling of vascular plants, bryophytes and lichens in the vicinity of red cedar.

A regression curve between red cedar diameter and number of vascular plants in the vicinity showed no relationship (Figure 6). However, it did show a very strong relationship with tree diameter and age (see dendrochronology section). Figure 7 shows the ten most frequently occurring vascular plants in the vicinity of red cedars, of which *Acer rubrum* was the most frequent species observed. Likewise, *Lepraria lobificans, Canoparmelia caroliniana,* and *Physcia americana* are lichen epiphytes found to be the most frequent (Figure 8). *Leucobryum glaucum, Pohlia* sp., and *Polytrichum ohioense* were the most frequently occurring bryophytes in the vicinity of red cedars (Figure 9).

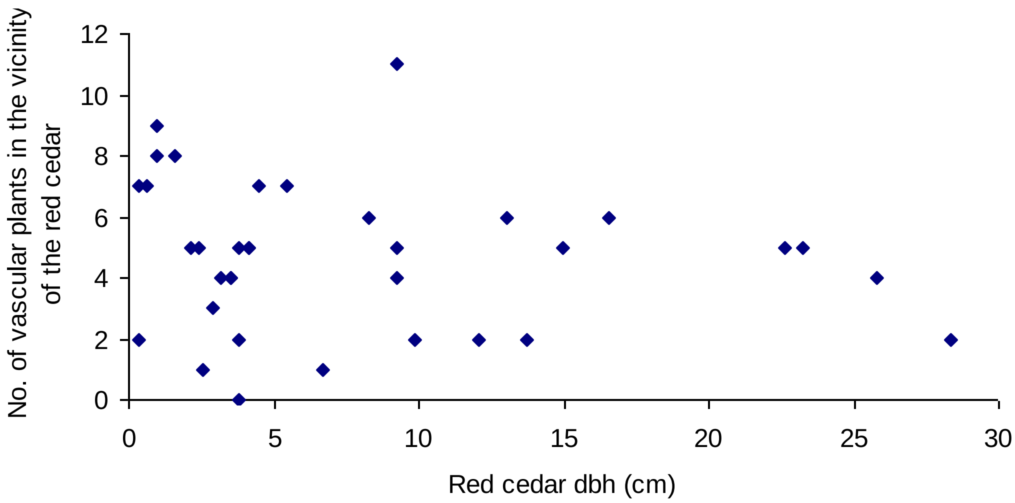

Figure 6. Lack of significant relationship (p = 0.3798) between red cedar diameter at breast height (dbh) and number of vascular plant associates.

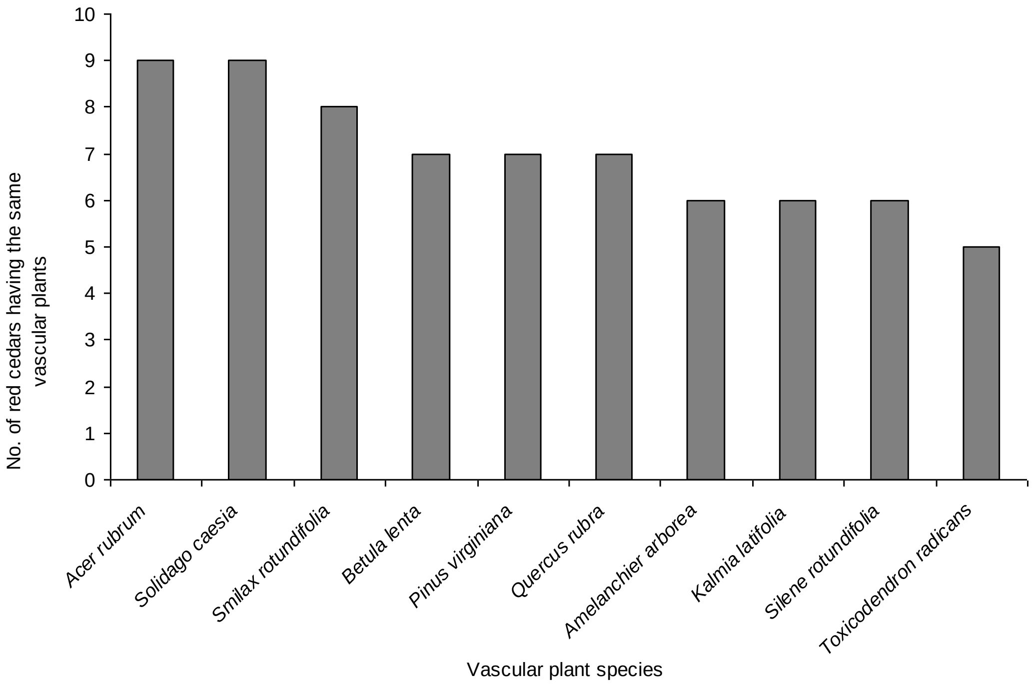

Figure 7. Top ten dominant vascular plants in the vicinity of the red cedar as determined by the number of red cedars each species was associated with.

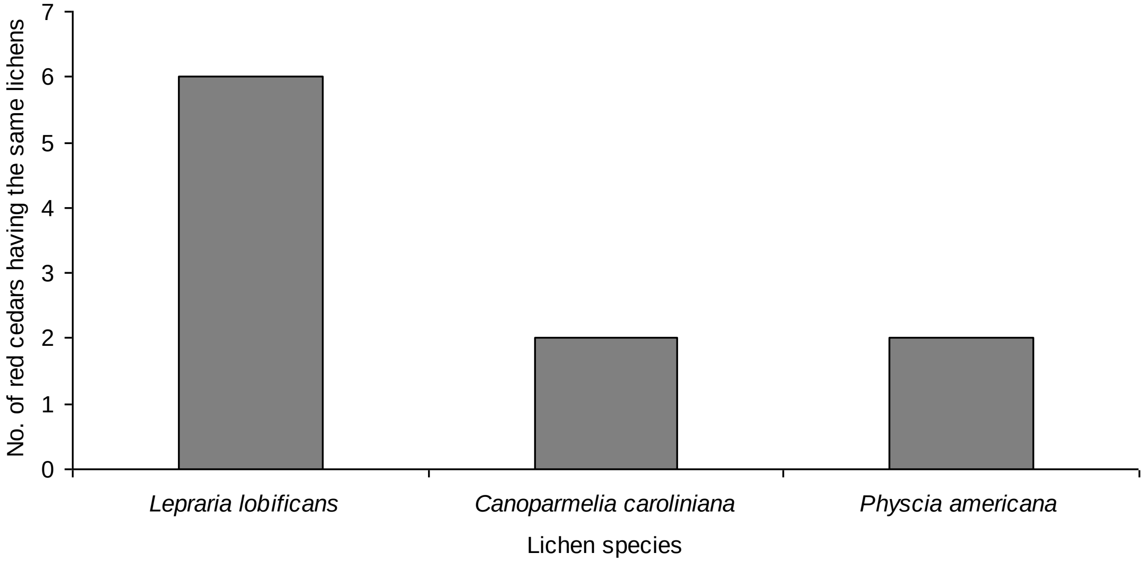

Figure 8. Top three dominant lichens in the vicinity of the red cedar as determined by the number of red cedars each species was associated with.

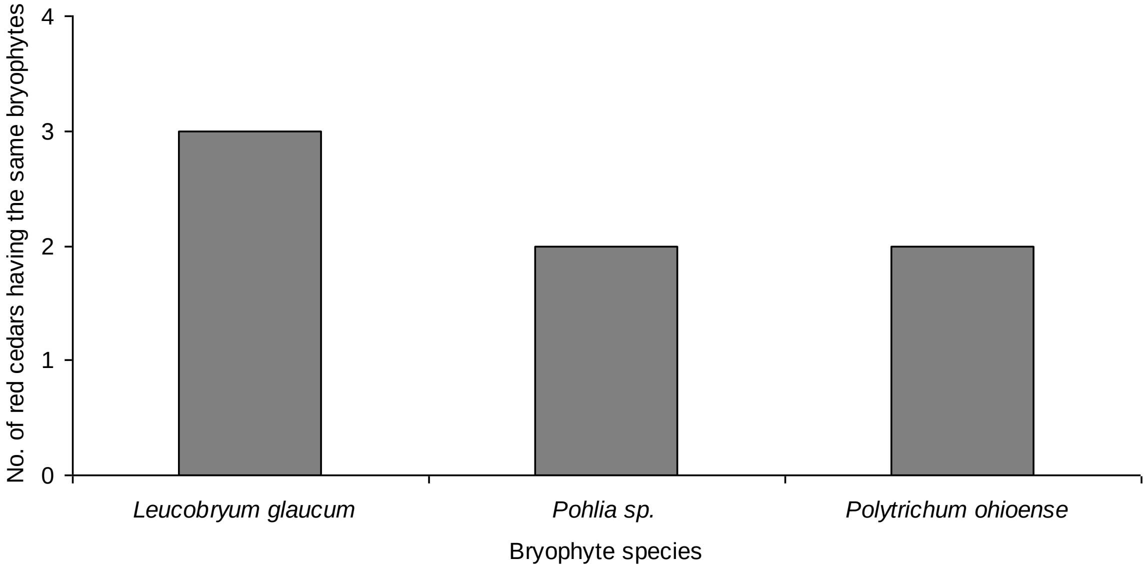

Figure 9. Top three dominant bryophytes in the vicinity of the red cedar as determined by the number of red cedars each species was associated with.

Analysis of the red cedar community in the talus area

Statistical analysis on species coverage and frequency showed that the two sites, Obed Wall and NCC are significantly different ($p < 0.05$) in terms of red cedar community structure. In this regard, the most notable species distinct to a particular site are *Betula lenta, Chasmanthium laxum, Danthonia sericea, Dennstaedtia punctilobula, Dichanthelium commutatum, Hamamelis virginiana, Pinus virginiana, Pityopsis graminifolia, and Solidago arguta var. caroliniana* (Tables 5 & 6). Furthermore, the coefficient of community similarity between the two sites (Obed Wall & NCC) shows that none of the groups (vascular & non-vascular) exceed 24% (Table 7). Thus, there is a low probability that both sites share the same species. This is even more evident for the lichens (CC = 21%) and bryophytes (CC = 13%).

Table 5. Mean percent coverage of vascular plants in the Obed and the NCC sites. Species in bold are significantly different in coverage ($p < 0.05$).

	mean +/- se		P value
Species	Obed	NCC	
Acer rubrum	2.41 ± 1.09	0.23 ± 0.10	0.1840
Amelanchier laevis	0.16 ± 0.16	0.17 ± 0.17	1.0000
Aralia spinosa	0.16 ± 0.16	0	0.3173
Betula lenta	**0.54 ± 0.11**	**0**	**0.0369**
Bignonia capreolata	0.25 ± 0.25	0	0.3173
Carex emmonsii	0.16 ± 0.16	1.20 ± 0.91	0.2463
Chasmanthium latifolium	0.08 ± 0.08	0	0.3173
Chasmanthium laxum	**2.83 ± 0.41**	**0.29 ± 0.23**	**0.0463**
Commelina communis	0	0.41 ± 0.41	0.3173
Danthonia compressa	0.08 ± 0.08	0	0.3173
Danthonia sericea	**0.83 ± 0.58**	**0**	**0.0339**
Dennstaedtia punctilobula	**1.25 ± 0.57**	**0**	**0.0369**
Dichanthelium commutatum	**1 ± 0.38**	**0**	**0.0369**
Dichanthelium tenue	0.16 ± 0.16	0	0.3173
Hamamelis virginiana	**0**	**0.83 + 0.22**	**0.0369**
Heuchera parviflora	0	0.02 ± 0.02	0.9020

Table 5. Continued.

Species	mean +/- se		P value
	Obed	NCC	
Hypericum densiflorum	0.04 ± 0.04	0	0.3173
Hypericum gentianoides	0.12 ± 0.07	0	0.1213
Hypericum prolificum	0.41 ± 0.41	0	0.1213
Kalmia latifolia	0	0.04 ± 0.04	0.3173
Liriodendron tulipifera	0.58 ± 0.36	0	0.1213
Lysimachia quadrifolia	0.41 ± 0.30	0	0.1213
Minuartia glabra	1.25 ± 0.45	0.13 ± 0.12	0.0765
Mitchella repens	0	0.25 ± 0.14	0.1213
Nyssa sylvatica	0	0.91 ± 0.58	0.1213
Oxalis violacea	0	0.33 ± 0.33	0.3173
Oxydendrum arboreum	0.25 ± 0.14	0	0.1213
Pinus virginiana	**1.79 ± 0.15**	**0**	**0.0369**
Pityopsis graminifolia	**4.41 ± 0.46**	**0**	**0.0369**
Quercus alba	0.41 ± 0.41	0	0.3173
Quercus coccinea	0.66 ± 0.66	0	0.3173
Quercus prinus	0.08 ± 0.08	0	0.3173
Rhododendron cumberlandense	0	0.17 ± 0.17	0.3173
Rhus copallinum	3 ± 2.87	0	0.1213
Rubus allegheniensis	0.58 ± 0.36	0	0.1213
Smilax glauca	0.04 ± 0.04	0	0.3173
Smilax rotundifolia L.	0.08 ± 0.08	2.25 ± 2.25	0.7963
Solidago arguta var. caroliniana	**2.83 ± 0.36**	**0**	**0.0369**
Solidago odora	0.66 ± 0.44	0	0.1213
Solidago spp.	0.83 ± 0.83	0	0.3173
Ulmus alata	0.04 ± 0.04	0	0.3173
Vaccinium corymbosum	0	0.42 ± 0.42	0.3173
Viburnum acerifolium	0.41 ± 0.41	0	0.3173
Vitis rotundifolia	0.25 ± 0.25	0	0.3173

Table 6. Mean percent frequency of vascular plants in the Obed and the NCC sites. Species in bold are significantly different in frequency ($p < 0.05$).

	Frequency +/- se		P value
Species	Obed	NCC	
Acer rubrum	33.33 ± 8.33	58.33 ± 8.33	0.099
Amelanchier laevis	8.33 ± 8.33	8.33 ± 8.33	1
Aralia spinosa	8.33 ± 8.33	0	0.3173
Betula lenta	**33.33 ± 8.33**	**0**	**0.0339**
Bignonia capreolata	16.16 ± 16.16	0	0.3173
Carex emmonsii	8.33 ± 8.33	41.66 ± 22.04	0.2463
Chasmanthium latifolium	8.33 ± 8.33	0	0.3173
Chasmanthium laxum	**75 ± 0**	**16.66 ± 8.33**	**0.0339**
Commelina communis	0	16.66 ± 16.66	0.3173
Danthonia compressa	8.33 ± 8.33	0	0.3173
Danthonia sericea	**25 ± 0**	**0**	**0.0253**
Dennstaedtia punctilobula	**33.33 ± 8.33**	**0**	**0.0339**
Dichanthelium commutatum	**33.33 ± 8.33**	**0**	**0.0339**
Dichanthelium tenue	8.33 ± 8.33	0	0.3173
Hamamelis virginiana	**0**	**25 + 0**	**0.0253**
Heuchera parviflora	0	4.16 ± 4.16	0.902
Hypericum densiflorum	8.33 ± 8.33	0	0.3173
Hypericum gentianoides	16.66 ± 8.33	0	0.1138
Hypericum prolificum	12.5 ± 12.5	0	0.3173
Kalmia latifolia	0	8.33± 8.33	0.3173
Liriodendron tulipifera	16.66 ± 8.33	0	0.1138
Lysimachia quadrifolia	25 ± 14.43	0	0.1213
Minuartia glabra	58.33 ± 8.33	33.33 ± 22.02	0.3687
Mitchella repens	0	16.66± 8.33	0.1138
Nyssa sylvatica	0	33.33 ± 16.66	0.1138
Oxalis violacea	0	8.33 ± 8.33	0.3173
Oxydendrum arboreum	16.66 ± 8.33	0	0.1138
Pinus virginiana	**66.66 ± 8.33**	**0**	**0.0339**
Pityopsis graminifolia	**75 ± 0**	**0**	**0.0253**
Quercus alba	8.33 ± 8.33	0	0.3173
Quercus coccinea	16.66 ± 16.66	0	0.3173
Quercus prinus	8.33 ± 8.33	0	0.3173
Rhododendron cumberlandense	0	8.33 ± 8.33	0.3173
Rhus copallinum	16.66 ± 8.33	0	0.1138
Rubus allegheniensis	16.66 ± 8.33	0	0.1138
Smilax glauca	8.33 ± 8.33	0	0.3173

Table 6. Continued.

Species	Frequency +/- se		P value
	Obed	NCC	
Smilax rotundifolia L.	8.33 + 8.33	16.66 + 16.66	0.7963
Solidago arguta var. caroliniana	**75 + 14.43**	**0**	**0.0369**
Solidago odora	25 + 14.43	0	0.1213
Solidago spp.	25 + 25	0	0.3173
Ulmus alata	8.33 + 8.33	0	0.3173
Vaccinium corymbosum	0	8.33 + 8.33	0.3173
Viburnum acerifolium	16.66 + 16.66	0	0.3173
Vitis rotundifolia	8.33 + 8.33	0	0.3173

Table 7. Coefficient of community similarity (in percent) between the Obed Wall and NCC sites.

	Vascular plants	Lichens	Bryophytes
Coefficient of Community (CC)	24	21	13

Red cedars locations

The locations of red cedars as well as bryophyte and lichen collection sites were indicated using GPS coordinates from both Obed and NCC cliff systems (Figure 10).

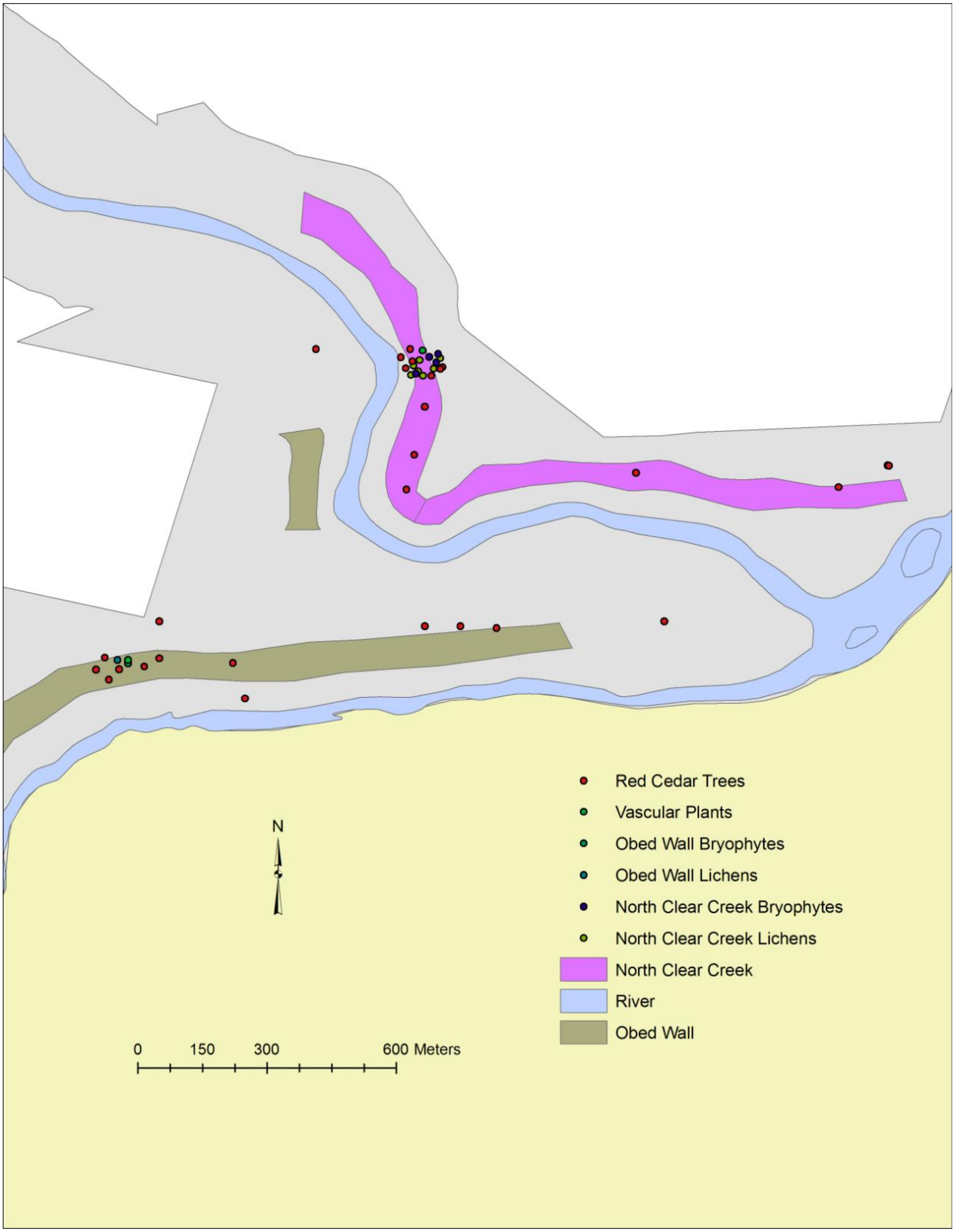

Figure 10. Locations of red cedars, and collection sites of bryophytes and lichens.

Dendrochronology of red cedar

Age-class distribution

A total of 36 red cedars were sampled, and the resulting frequency distribution showed most individuals were below 100 years of age (Figure 11). The ages of trees varied from as young as 25 years to as old as 767 years; the majority (75%) were between 26 to 200 years old. Only 13.8% of trees were over 200 years old. This study showed a low frequency of trees less than 26 years old. The oldest living tree (27 cm diameter) was found to have 767 annual rings, in which the innermost ring is estimated to have been established ~1241 A.D. The age and basal diameter curve suggested a highly significant positive relationship between these two parameters (Spearman $r_s = 0.80$, $p < 0.001$) (Figure 12). A large proportion of trees had diameters ranging from 7-18 cm, whereas the average diameter was 16.15 cm with a mean age of 120 years.

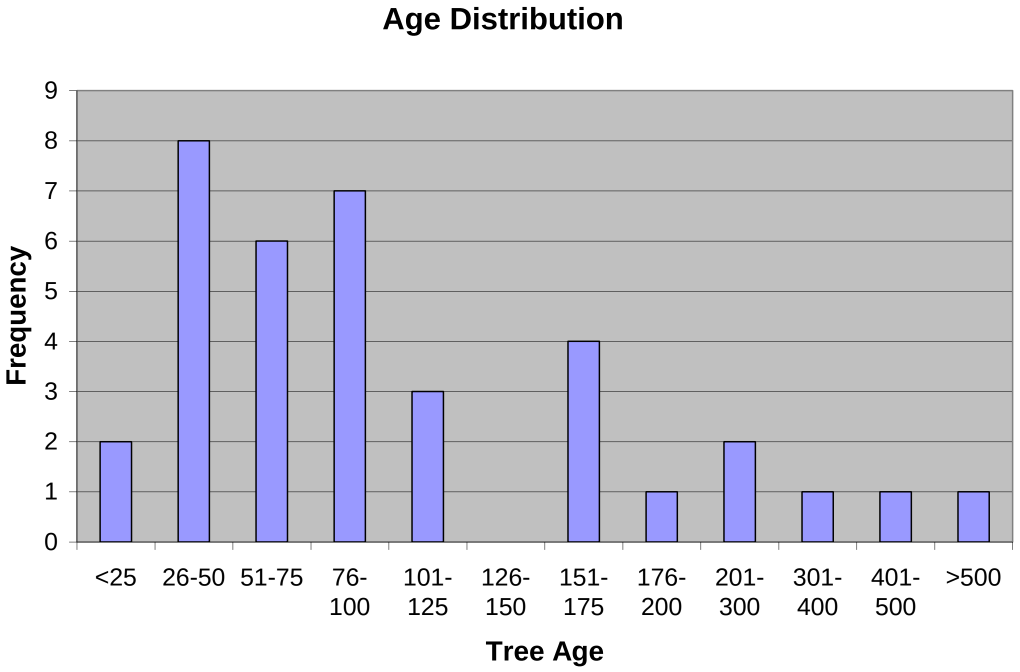

Figure 11. Age distribution of the 36 living red cedar trees sampled.

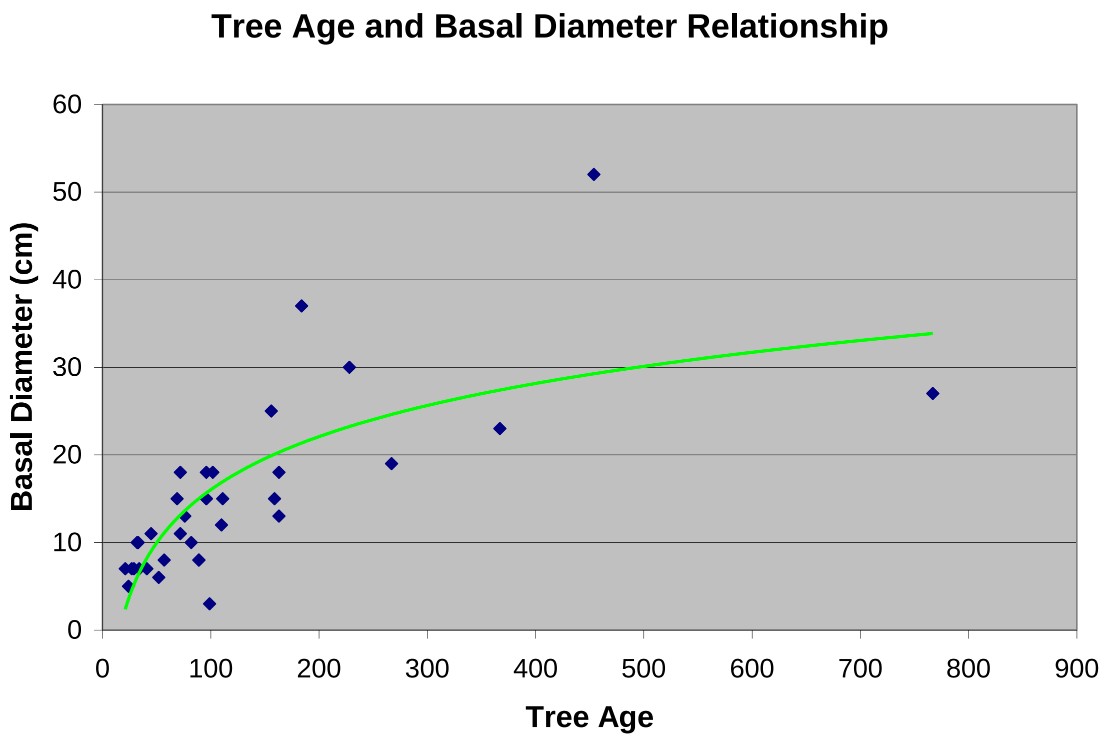

Figure 12. Relationship between tree size (measured via basal diameter) and tree age for the 36 trees sampled.

A large number of growth functions are used for curve-fitting processes, such as parabolas, hyperbolas, logarithmic functions, polynomials, and moving averages. Among them, the polynomials and moving averages are applied to a variety of situations (Fritts 1976). A dendroclimatic reconstruction of the Obed region was projected using the oldest-living tree (sample no. 17a). The pattern of radial growth for this tree is shown in Figure 13. The ring widths of a tree can vary by many factors, such as environmental fluctuations, systematic changes of tree age, height, and the productivity of the site. Also, larger variability in ring widths generally occurs for younger and fast-growing portions of trees, whereas lesser variability is often observed for older and slow-growing portions of the trees (Fritts 1976). Therefore, standardization, and correction of variable ring widths for the changing age portions of the trees are necessary, and can be obtained by dividing ring width by the value of the fitted curve for a particular year. Radial growth was standardized to a 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. Figure 13 shows that the two longest periods of sustained above-normal radial growth were from approximately 1400-1600 A.D. and in the more recent past, post 1940. However, below-normal growth occurred in the late 1200s through the 1300s. It continues again from the early 1600s to mid 1900s except for some intermittent normal growth periods.

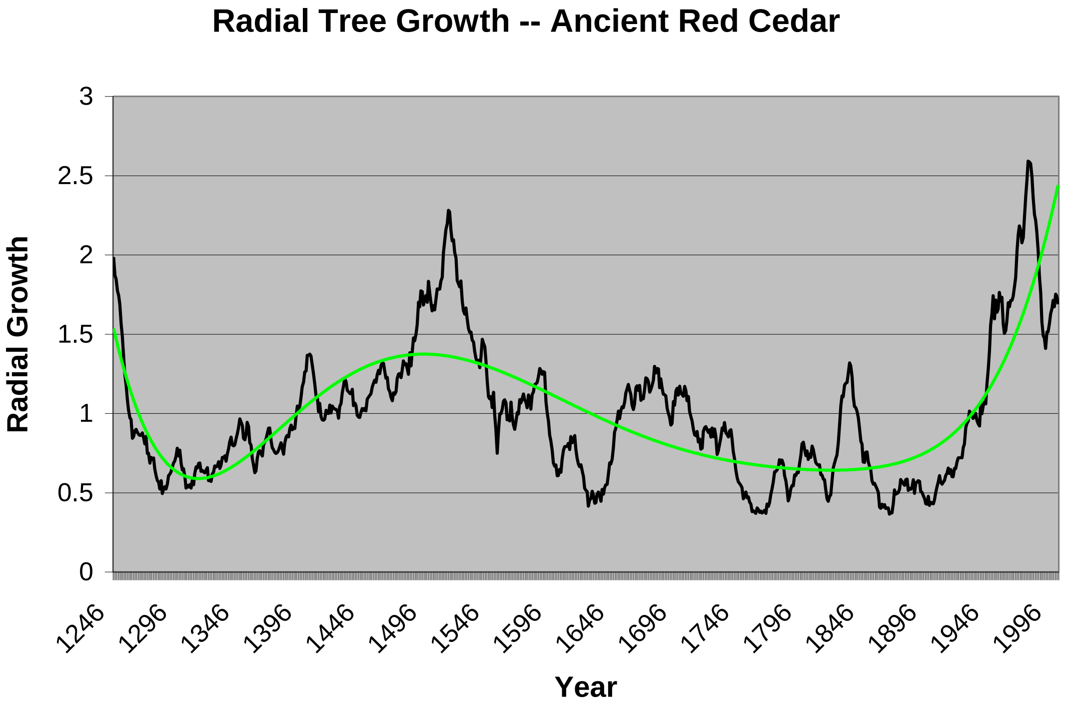

Figure 13. Standardized radial growth rates of the oldest tree sampled, normalized to a value of one. Values presented represent an 11-year running mean. The curved line is a 6th order polynomial fit of the growth trend.

Correlations between annual radial growth and monthly PDSI values were established, but the closest relationship was obtained for November (Figure 14). Without taking running means, the Pearson correlation between PDSI and radial growth for the single oldest tree (sample no. 17a) was 0.224 ($p = 0.017$). To remove year to year variations in the ring width, moving averages or running means can be applied for dendroclimatic studies. They are the ring-width averages for a given number of successive rings/years, and the sequence is moved by one ring (year) each time the successive means are applied (Fritts 1976). For instance, for an eleven-year running mean, the first is a mean of 1 to 11; the second is 2 to 12, the third is 3 to 13, and the last is 11 to 21. The mean values are then weighted by a low-pass filter. The low-pass filter is used if the weighted means hold long-term or low-frequency variations. Five, seven and eleven-year running means were calculated for radial growth and PDSI values, but a significant relationship ($r = 0.726$; $p < 0.001$) was obtained for the 11-year running mean (Figures 13 and 14). Finally, the relationship between radial tree growth of the oldest tree and November drought severity was used to reconstruct November drought conditions of the Cumberland Plateau back to 1246 A.D. (Figures 15 and 16).

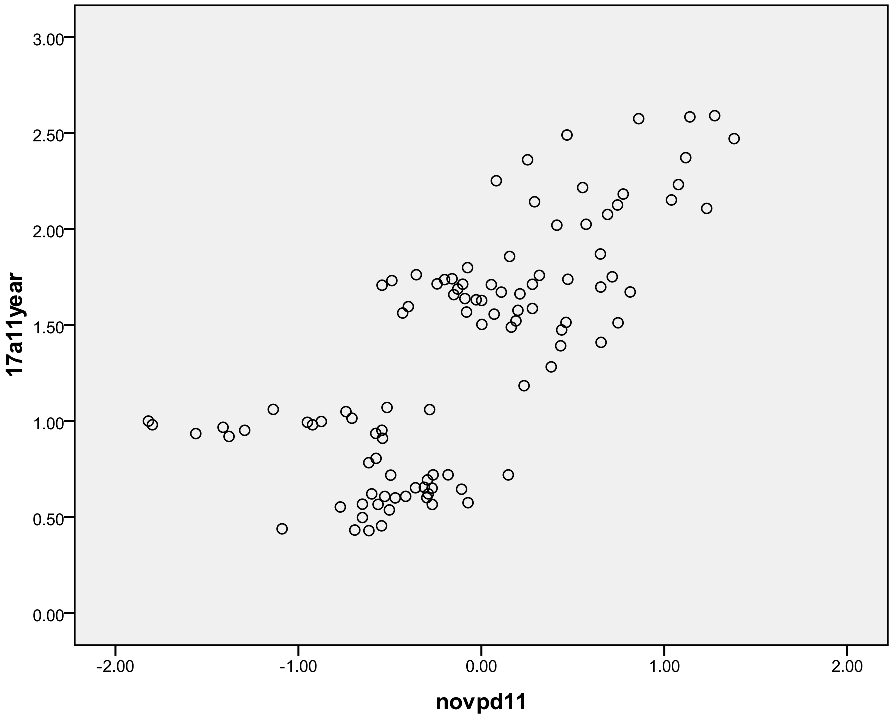

Figure 14. The relationship between radial growth and November PDSI using an 11-year running mean.

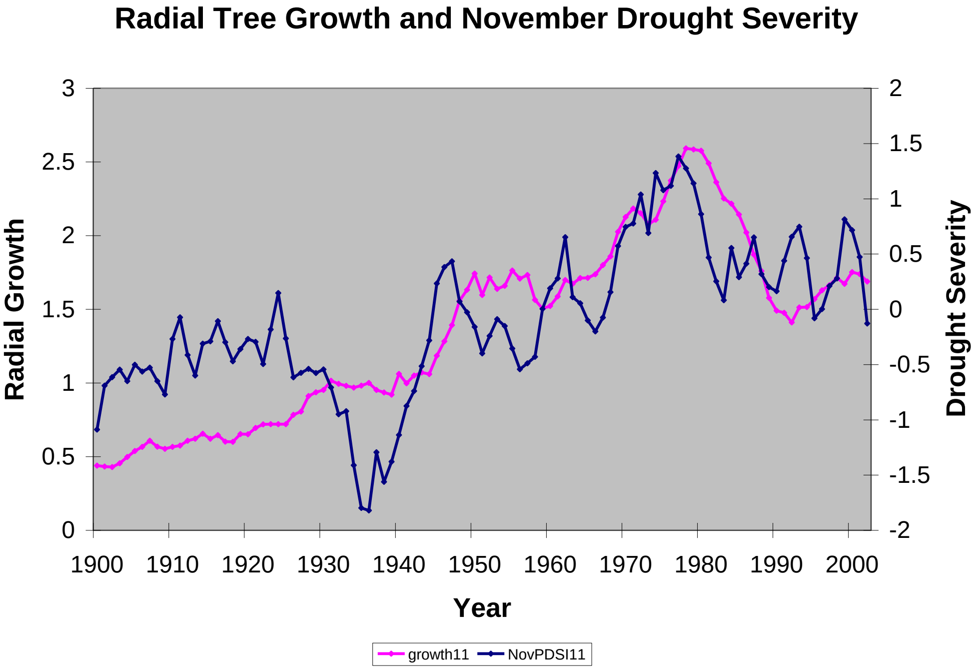

Figure 15. Time series of radial growth (pink line) and November PDSI (blue line) using an 11-year running mean.

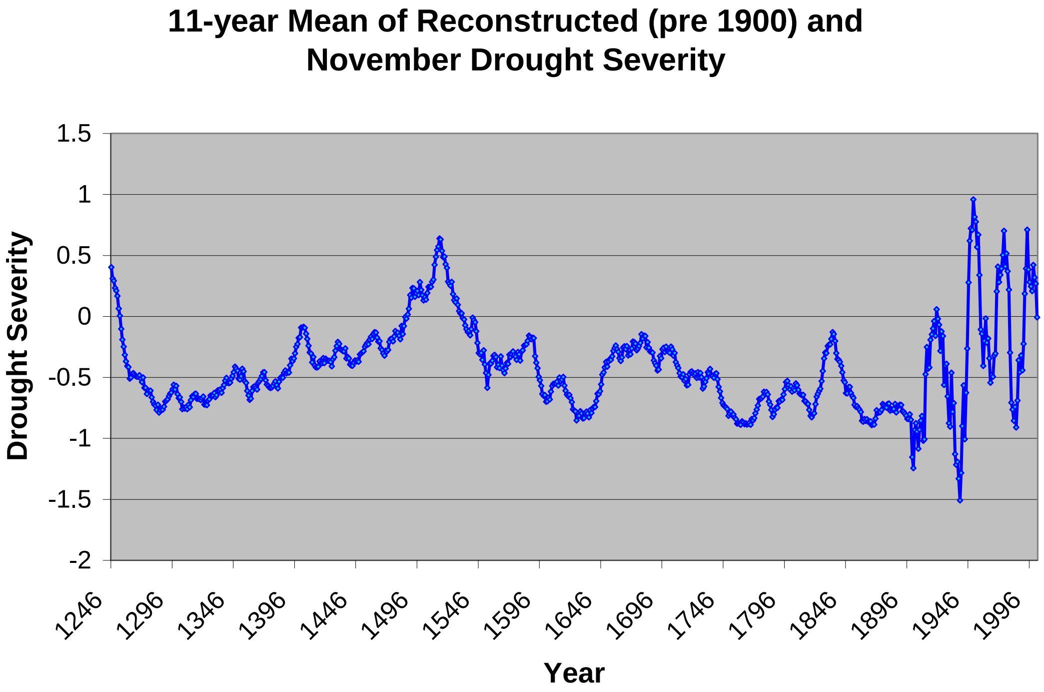

Figure 16. November drought severity (PDSI values) as reconstructed from a red cedar tree (tree sample 17a) (pre-1900) and actual drought severity (1900-2002). All values represent 11-year running means.

DISCUSSION

Community structure

Cliff-faces harbor ancient trees and disturbance-sensitive plants in eastern North America, and are often dominated by stunted, deformed, and slow-growing trees such as *T. occidentalis* and sometimes *Betula papyrifera* (Booth & Larson 2000). These ancient, undisturbed ecosystems are also found on tall cliff faces in other parts of the world (Larson et al. 1999). *J. virginiana* is also an extremely slow-growing tree when found in harsh conditions such as those associated with cliff systems. Red cedars are frequently found at the cliff base, ledges, and edges of the OWSRG. However, unlike *T. occidentalis*, *J. virginiana* populations are rarely observed on cliff faces of OWSRG.

The ancient red cedar stands of the OWSRG 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 vegetational surveys of climbed and unclimbed cliffs in a previous study. In the vascular plant survey of this study, a species new to the Park, *Carex emmonsii* (sensu Schmalzer et al. 1985) was discovered. Interestingly, this species was common on rock faces at both the Obed Wall and NCC ancient red cedar sites. It may be that this species was previously misidentified as *Carex pensylvanica*. 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 at the time of 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 were epiphytic upon red cedars. Several of the lichens, including *Cladonia symphycarpia*, *Lecanora albellula*, and *Punctelia subrudecta* were found outside of their normal ranges as southern disjuncts. *Usnea amblyoclada* was found here at the northern boundary of its range. These disjuncts confirm general assumptions regarding the Cumberland Plateau as a refugium for species with normally more northerly or southerly ranges. Some lichens such as *Physcia americana* and *Loxospora pustulata* are normally found on the bark of deciduous trees and as such represent habitat disjunctions.

In old-growth forests, epiphytic mosses make thick mats that store water, accumulate humus, and form a spongy surface that can either promote or inhibit lichens (Sillett et al. 2000). Based on my field observations, I did not find any such thick mats in red cedar stands except at the Obed Wall ledge. There, a thick mat of moss was found at the bottom of a red cedar trunk. In my observations, no lichens were found at that location. The colonization of epiphytic macro-lichens is also often associated with the old branches of trees with rough bark (Sillett et al. 2000). This was observed in the case of red cedars in this study, in which the old trees had many lichens. However, no direct comparisons were made in this study between the lichen community structures on older trees and younger ones.

There may be several reasons for the abundance of vascular plants at the Obed Wall ancient red cedar site as compared to the NCC site. There is a more heterogeneous topography at the Obed site that would facilitate a higher level of colonization. Because the cliff system is of greater height there, there is more surface area for species as well. There were big ledges at a few cliff sites at the Obed Wall which had dense vegetation at the base, differing from the bedrock found in most of the talus areas of the NCC site. This might explain why I found greater vascular plant richness at the Obed site and a decrease of non-vascular plants. This observation also supports the results found on the Niagara Escarpment (Kuntz and Larson 2006b), where bryophytes species richness and frequency of lichens were found to decrease with an increase of soil volume.

Another important factor is the remoteness of the site, particularly where the ancient red cedar populations were located. The NCC site, being more accessible, may have encountered more disturbances from climbing and hiking activities, thereby reducing vegetation cover. 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 the NCC site the talus slope declines more gradually. The NCC 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 listing of vascular flora of the cliff systems in the Obed and NCC surrounding areas showed remarkably few exotic species, exceptions being *Cardamine hirsuta, Chenopodium album,* and *Poa annua*. The former two species are forbs/herbs while the latter one is graminoid. Lonsdale (1999) reported a positive correlation between the number of visitors and the number of exotic species in natural forests. Although, this study was not focused on the relationship between visitors and exotic/alien species, it was observed that rock climbers and hikers have impacted the talus vegetation. It is obvious that during the course of climbing (before and after climbing), all these activities occur at the cliff base.

During data collection, I saw many trampled and abraded plants and even fire logs in some sites of NCC.

The abundance and diversity of mosses and lichens are higher at the NCC site and this may be related to lower levels of abundance of vascular plant vegetation at that site. Competitive release of lichens and mosses has been observed in other cliff systems where vascular plant abundance was lower, e.g. at the White Rocks cliff system at Cumberland Gap National Historic Park (Ballinger 2007). This was also noted on Linville Gorge climbing routes where removal of mosses and vascular plants resulted in an increased abundance and diversity of lichen flora (Smith 1998). Other reasons might include microtopogrphy of rock surfaces, rock size, moisture, and shade.

Moss and Nickling (1980) showed that blocks of rock in talus areas provide a stable substrate in which plants establish faster than in similar structures where the talus area has smaller rocks. In this study, however, I did not measure talus rock size between the two sites, Obed and NCC. But it was obvious that most of the talus sites at NCC have accumulated big blocks of rocks with large numbers of fissures among them. It was also found that the talus area experiences a large amount of shade from big trees that are growing slightly outside the talus area. Furthermore, few permanent seeps were observed at the NCC site where water oozes out as droplets. Pentecost (1980) suggested that rough surfaces play a key role for colonization of bryophytes and lichens. Surfaces having many crevices preserve moisture and also provide shelter from radiation, airflow, and herbivores. Pentecost also showed that smooth and polished rock surfaces rarely harbor bryophytes and lichens. Kuntz and Larson (2006b) also observed the positive relationship between lichen richness and microtopography; and found that the higher the crevice and pocket frequencies on the Niagara Escarpment, the greater the number of lichen species.

This study also shows that community structure in the talus area of the Obed Wall is different than at NCC, even though both sites have similar physical structures. Larson et al. (1989) found a homogeneous and single predictable vegetation community in the Niagara Escarpment. Cox and Larson (1993a) and Haig et al. (2000), however, found that small amounts of variation in plant communities in the talus area of the Niagara Escarpment was correlated with latitude. A possible reason might be glaciation. The Niagara Escarpment was completely covered by an ice sheet during the last ice age and after glacial retreat, about 12,000 years ago, many boreal plants started to return. In contrast, the southern Appalachians were not glaciated during the last ice age (Parisher 2009), and therefore remained intact and have had the chance to accumulate many plant taxa.

The vegetation types and their percent coverages at the cliff bases of the Obed Wall and NCC sites were found to be significantly different (Table 5). The coefficient of community analysis further supports the observed differences in community structure between the two sites. None of the groups, vascular and non-vascular (bryophytes and lichens), show more than 24% similarity (Table 7). The crustose lichens were found to cover most of the sampling plots at the NCC site, while a negligible percent coverage was observed for lichens at the Obed Wall site. Besides human disturbances, as mentioned earlier, other microtopographic conditions such as slope, aspect, and temperature would facilitate these observed differences in the vegetation types and structures. The most frequent woody species in the talus region included *Pinus virginiana, Acer rubrum, Betula lenta, Hamamelis virginiana,* and *Nyssa sylvatica.*

Species accumulation curves

Species accumulation curves are used to determine the minimal area needed to be surveyed in order to get an accurate count of species for a particular habitat. The point on the curve when it flattens and becomes an asymptote with the x-axis gives the minimum area required for a particular community (Cain 1938). The results of such studies are specific for the particular groups of plants and the landscape (the talus) in which they are conducted. Lichens, bryophytes, and red cedars are key components of this ecosystem. To find the minimal sample number it is necessary to determine species accumulation curves for the talus community. Many ecological papers deal with species-area relationships (SAR) and species accumulation curves. Both of these methods are used to estimate the adequacy of sampling. SAR is used to evaluate adequacy of sampling size for each sample while the accumulation curve deals with the adequacy of numbers of samples taken (Zhao et al. 2010).

The talus area of the Obed Wall is not fragmented, except for some variations in the micro-topography as mentioned above. The curve for vascular plants did not reach an asymptote even though 35 trees were sampled (Figure 5). A probable reason might be the heterogeneous surface with some variations in micro-topography, which supports diverse vascular plant communities. This makes sense ecologically because few red cedars were found growing in permanent seeps; few were in rock crevices, while others were on flat surfaces. It indicates that more red cedars should be sampled to determine the precise structure of red cedar vascular plant communities. In contrast, curves flattened immediately after the 12th and the 28th sample tree for bryophytes and lichens, respectively. This makes sense in the case of lichens because the diversity of lichens is higher than that of bryophytes. Stohlgren et al. (1998) found that the nested scale design is the most effective method in forested and mountainous landscapes when linked to remotely-sensed data. Stohlgren and Chong (1997) described species-area curves as cost-efficient, information rich, and easy to use. They estimated almost half the number of plants recorded in the Rocky Mountain National Park with a sampling intensity of just 0.29% out of their 754 hectare study site.

Age-class distributions of red cedar

The age-class distributions of red cedar trees revealed past histories such as disturbances (natural and/or anthropogenic) faced by these stands. It was also useful in order to predict future growth and reproduction patterns in the Obed cliff systems. The age-class distribution graph (Figure 11) shows a typical inverse J-shaped curve. Populations represented by such a curve have been associated with continuous, balanced recruitment and mortality (Whipple & Dix 1979, Walker 1987). 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 1987). However, in this study, several seedlings, saplings and even small red cedar trees were not included in the analysis of age-class structure because such sampling would involve destruction of small diameter individuals. However, many small trees and saplings of red cedars were observed, especially at the NCC site and fewer in the Obed flood plain. It appears that these stands are undergoing balanced recruitment through seedling survival and mortality. In the absence of mitigating factors such as human disturbance (cutting, trampling and fire), these stands should continue on for the foreseeable future.

Dendrochronology

A few long chronologies were developed in eastern North America for *T. occidentalis;* a 1032-year chronology from the Niagara Escarpment (Larson and Kelly 1991), an 802-year chronology from the shores and islands of Lake Duparquet in western Quebec (Archambault and Bergeron 1992), and a 1397-year chronology from the Niagara Escarpment (Kelly et al. 1994). The longest chronology, 1614-years, was developed by Stahle et al. (1988) from *Taxodium distichum* in North Carolina. However, in the case of *J. virginiana* very few studies have been conducted to establish a chronology. In Osage County, Oklahoma, Therrel et al. (1998) found red cedar trees over 500 years old. Walker and Parisher (2004) found an 863-year old red cedar snag from the Obed. The present study was able to reconstruct a general natural history of the area back 767 years (to 1241 A.D.) although cross-dating was not possible because of the many false and missing rings. These long chronologies reveal that eastern red cedar is third compared to *T. distichum* and *T. occidentalis* in longevity in eastern North America. However, dendrochronologists have avoided some of the more troublesome species, including *Juniperus*, which are thought to produce several false rings in a single growing season (Schulman 1954).

Tree-ring growth of ancient red cedar trees in talus areas of the Obed cliff systems showed correlations with moisture conditions as shown by November PDSI values, but this has not been observed for northern white cedars on the cliff face of the Niagara Escarpment. Kelly et al. (1994) found a weak correlation between tree-ring growth and summer precipitation. It was argued that these limestone cliffs retain enough water to support tree growth even during periods of little surface precipitation. This may be true on cliff faces because of the lack of competitors and lower evapotranspiration rates experienced by white cedars. In contrast, most of the red cedars in talus areas of the OWSRG are associated with other flora. In this case the inter-specific competition may cause cliff surfaces to be drier. Fraser (1962) also observed the need for adequate soil moisture during formation of tree-rings. However, Kelly et al. (1994) found an inhibition of tree-ring growth of northern white cedar during hot July and August temperatures on the Niagara Escarpment. Although, the physiological responses of high temperature on white cedars are not well known, they are interpreted as increases of respiration and lowering photosynthetic rates, which might lead to the loss of photosynthetic reserves which eventually may lead to reduced growth.

The sharp decrease in ring widths between the late 1200s and the 1300s indicates drought during these time periods (Figure 13). Stahle et al. (1988) also found several prolonged droughts within the 1614-year reconstruction of *T. distichum* in North Carolina from 1000 to 1300 A.D. The prolonged radial growth of red cedars between the 1400s and the 1500s could signify wet conditions (Figure 13). This could be the effects of the onset of the Little Ice Age (from 1300 to 1600) (Stahle et al. 1988).

Red cedar trees are fire sensitive (Batek et al. 1999). However, fire scars were not observed in the red cedar cores, which is likely an indication of the buffering effect afforded by their 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. 2000b).

The absence of old-aged red cedars on the plateau and the 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. Larson (1990) found on cliff edges of the Niagara Escarpment the lowest age-class structure for the youngest and smallest northern white cedars in these disturbed sites, and also that the forests are in decline, while forests at undisturbed cliff-edge sites are self-maintaining.

Stem-stripping was observed in most of the red cedar trees sampled (Appendix C), which is typical of long-lived trees growing in extremely harsh habitats (LaMarche 1969) with asymmetric growth (Matthes-Sears et al. 2002). Matthes-Sears et al. (2002) argued that the formation of stem strips occurs through partial cambial dieback and appears to be associated with old age, slow growth, and habitat adversity. Kelly et al. (1992) observed that a few northern white cedars survived with only 2% of the cambium remaining at the time of death. Although the reasons for reduction of cambium have not been clearly identified yet, external factors like drought, snow-loading, abrasion by rock fall, and fire could have a significant role (Matthes-Sears & Larson 1990). Furthermore, the reason stem-stripping occurs could be a sectored hydraulic architecture. In this circumstance, the plant divides internally into distinct xylem components in which each component carries at least one root system, a stem part and a branch (Larson et al. 1993). The loss of hydraulic conductance in this sector could be the cause of stem-stripping initiation. When a root dies, the transportation of water to the particular stem and branch would stop and the stem starts to 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 may result in blockage of water supply, and lead to initiation of stem strip formation.

SUMMARY AND RECOMMENDATIONS

The cliff systems of the OWSRG are rich in biodiversity including several old-growth red cedar populations. The vegetation associated with red cedar trees 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 constitute a very fragile assemblage of unusual species. *Conradina verticillata* Jennison is a rare plant found at the Obed Wall site. *Silene rotundifolia* Nuttall is also a rare plant that was observed at the Obed Wall and NCC sites and is a threatened species in the state of Kentucky. The Obed Wall site has a higher population density of this plant than the NCC site. Similarly, *Avenella flexuosa* (L.) Drejer, *Heuchera parviflora* Bartling, and *Stewartia ovata* (Cavanilles) Weatherby are uncommon species found in the OWSRG. Parisher (2009) found *Phemeranthus teretifolius* (Pursh) Rafinesque, a Tennessee state-threatened plant, on the Lilly Bluffs edge of the Obed cliff system.

One of the most exciting results of this study is that the talus areas between the two sites are highly distinct, even though the sites are close to each other. This is supported by the results obtained for the species accumulation curve for vascular plants and the low coefficient of community similarity indices.

There are many studies that describe the impacts of human disturbance on rock-outcrop and cliff-system plant communities (McMillan & Larson 2002, Smith 1998, Kelly & Larson 1997a, Nuzzo 1995, Parisher 2009). In every study, humans have had a negative impact on such communities. The present study also supports the observation that cliff vegetation at the Obed Wall and NCC sites are severely affected by rock climbers and hikers although this study was not focused on anthropogenic impacts on vegetation. The signs of trampling and fire logs present at the NCC site would clearly indicate foot traffic is impacting the talus areas. The talus soils in climbing areas of the Obed are compacted, and vegetation is trampled because climbers and hikers like to walk along trails at the cliff base (Parisher 2009). Furthermore, climbers use talus as a platform for climbing. It still would be worth researching and quantifying the impacts of climbers on talus vegetation including lichens and bryophytes in the Obed.

Another fascinating aspect observed in this study is epiphytic lichens and their relationships to red cedar tree ages. There seems to be a positive correlation between a red cedar's age and the number of epiphytic lichens on it. Sillett et al. (2000) reported that epiphytic lichens often colonized in branches of old trees having rough bark texture in old-growth forests. So, it would be interesting to see in the red cedar trees of OWSRG if any relationship exists between tree age and number and types of epiphytes.

It was also found that *Physcia americana*, and *Loxospora pustulata* are lichens that prefer deciduous trees. However, these lichens also were found growing on red cedar trees. It would be worth researching why they are growing in these evergreen trees. One possibility is due to the high exfoliation of bark that occurs in this evergreen species which may simulate some aspect of deciduous trees that favors colonization of these species of lichens.

Ancient red cedar stands at the OWSRG include uniquely long-lived individual trees in populations that have likely persisted for many hundreds of years. The dendrochronological study of the red cedars revealed that the Obed system harbors ancient stand of red cedar. 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. The cross-dating of ring width with other samples was very difficult for red cedars because they had many false/missing rings and even some rings that were extremely narrow. So, the oldest-aged sample was taken into consideration for the climatic reconstruction, and the study was able to generally reconstruct climate back to 1241 A. D. for the Cumberland Plateau. The November PDSI values showed that the ring growth of this tree was found to correlate with precipitation. Red cedar trees bearing fire scars were not observed although a few scars have been noticed externally on the tree trunks. The absence of fire scars could be because of the lack of large fires in the past. Age-class structure suggests that red cedars are producing moderate number of seedlings at the base of cliffs. However, the absence of old-aged trees on cliff-edges and plateaus of the Obed and NCC sites suggest human induced disturbances have influenced the area.

It is likely that the Obed red cedars have been somewhat insulated from natural fires across the landscape, demonstrated by the lack of fire scars in snag sections taken from these trees. This insulation is likely because of their association with extensive cliff systems at both the Obed Wall and the NCC 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 constitute a very fragile assemblage of unusual species. An important consideration for management 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. 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 cedars should also be promoted 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 consciousness and with proper signage, explanations and natural history education of the area these sites may be better preserved for the enjoyment of future generations.

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Appendix A

List of plants and lichens associated with the red cedars in the talus area of the Obed Wall and North Clear Creek sites.

Vascular plants	Spp. in the Talus area		Spp. within 1 m radius of the red cedar
	Obed	NCC	
Acer rubrum L.	*	*	*
Amelanchier arborea (Michx. f.) Fernald			*
Amelanchier laevis Wiegand	*	*	
Aquilegia canadensis L.			*
Aralia spinosa L.	*		
Betula lenta L.	*		*
Bignonia capreolata L.	*		*
Campsis radicans (L.) Seem. ex Bureau			*
Carex cf. normalis			*
Carex emmonsii	*	*	
Carex muehlenbergii Schkuhr ex Willd. var. *enervis* Boott			*
Carex spp.			*
Carya glabra (Mill.) Sweet			*
Cercis canadensis L. var. *canadensis*			*
Chasmanthium latifolium (Michx.) Yates	*		
Chasmanthium laxum (L.) Yates	*	*	
Chenopodium album L.			*
Clethra acuminata Michx.			*
Commelina communis L.		*	
Danthonia compressa Austin ex Peck	*		*
Danthonia sericea Nutt.	*		*
Dennstaedtia punctilobula (Michx.) T. Moore	*		*
Dichanthelium cf. *tenue* (Muhl.) Freckmann & Lelong			*
Dichanthelium commutatum (Schult.) Gould var. *ashei* (T.G. Pearson ex Ashe) Mohlenbr.	*		
Dichanthelium spp.			*
Dichanthelium tenue (Muhl.) Freck. & Lelong	*		
Gaultheria spp.			*
Hamamelis virginiana L.		*	*
Heuchera parviflora Bartlett		*	*
Hypericum densiflorum Pursh	*		
Hypericum gentianoides (L.) Britton, Sterns & Poggenb.	*		*
Hypericum prolificum L.	*		
Hypoxis hirsuta (L.) Coville			*
Kalmia latifolia L.		*	*
Liatris spp.			*
Liquidambar styraciflua L.			*
Liriodendron tulipifera L.	*		*
Lysimachia quadrifolia L.	*		
Minuartia glabra (Michx.) Mattf.	*	*	*

Mitchella repens L.		*	*
Nyssa sylvatica Marsh.		*	
Osmunda regalis L.			*
Oxalis violacea L.		*	*
Oxydendrum arboreum (L.) DC.	*		*
Parthenocissus quinquefolia (L.) Planch.			*
Pellaea atropurpurea (L.) Link			*
Philadelphus hirsutus Nutt.			*
Pinus strobus L.			*
Pinus virginiana Mill.	*		*
Pityopsis graminifolia (Michx.) Nutt.	*		
Pteridium aquilinum (L.) Kuhn			*
Quercus alba L.	*		*
Quercus coccinea Münchh.	*		
Quercus prinus L.	*		
Quercus rubra L.			*
Rhododendron cumberlandense E.L. Braun		*	*
Rhus copallinum L.	*		
Robinia pseudoacacia L.			*
Rosa cf. carolina			*
Rubus allegheniensis Porter	*		
Silene rotundifolia Nutt.			*
Smilax glauca Walter	*		*
Smilax rotundifolia L.	*	*	*
Solidago arguta Aiton var. *caroliniana* A. Gray	*		
Solidago caesia L.			*
Solidago nemoralis Aiton			*
Solidago odora Aiton	*		
Solidago sp.	*		
Toxicodendron radicans (L.) Kuntze			*
Tsuga canadensis (L.) Carrière			*
Ulmus alata Michx.	*		
Unidentified			*
Unidentified			*
Unidentified			*
Unidentified			*
Vaccinium arboreum Marsh.			*
Vaccinium corymbosum L.		*	*
Viburnum acerifolium L.	*		*
Viburnum cassinoides L.			*
Vitis rotundifolia Michx.	*		*

Lichens	On the red cedar		In the vicinity of the red cedar	Spp. in the talus area	
	Obed	NCC		Obed	NCC
Aspicilia cinerea (L.) Körb.			*		*
Bacidia schweinitzii (Fr. ex E. Michener) A. Schneid.					*
Buellia spuria (Schaerer) Anzi				*	
Canoparmelia caroliniana (Nyl.) Elix & Hale	*	*			
Canoparmelia texana (Tuck.) Elix & Hale	*				
Chrysothrix candelaris (L.) J.R. Laundon		*			
Cladina mitis (Sandst.) Hustich				*	
Cladonia apodocarpa Robbins	*		*	*	*
Cladonia caespiticia (Pers.) Flörke	*		*	*	*
Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.	*		*		
Cladonia parasitica (Hoffm.) Hoffm.		*			
Cladonia squamosa (Scop.) Hoffm.					*
Cladonia strepsilis (Ach.) Grognot				*	
Cladonia symphycarpa (Flörke) Fr.					*
Diploschistes scruposus (Schreb.) Norman					*
Dirinaria aegialita (Afz.) B. Moore		*			
Lecanora albella (Pers.) Ach.	*				
Lepraria lobificans Nyl.	*	*	*		*
Lepraria neglecta (Nyl.) Erichsen		*			*
Lepraria spp.		*	*		
Loxospora pustulata (Brodo & W.L. Culb.) R.C. Harris	*				
Ochrolechia sp.		*			
Parmelia squarrosa Hale					*
Parmotrema tinctorum (Delise ex Nyl.) Hale	*				
Parmotrema ultralucens (Krog) Hale	*				
Pertusaria velata (Turner) Nyl.		*	*		
Physcia americana G. Merr.		*			
Physcia halei J.W. Thomson					*
Porpidia albocaerulescens (Wulfen) Hertel & Knoph			*		
Punctelia rudecta (Ach.) Krog		*			
Punctelia subrudecta (Nyl.) Krog		*			
Ramalina petrina Bowler & Rundel					*
Ramalina pollinaria (Westr.) Ach.		*	*		
Rhizocarpon geographicum (L.) DC.					*
Trapeliopsis granulosa (Hoffm.) Lumbsch	*				
Usnea amblyoclada (Müll. Arg.) Zahlbr.					*
Xanthoparmelia angustiphylla (Gyel.) Hale			*		

Mosses	In the vicinity of the red cedar		Spp. in the talus area	
	Obed	NCC	Obed	NCC
Andreaea rothii Weber & Mohr				*
Campylopus tallulensis Sull. & Lesq. ex Sull.	*	*	*	*
Cephaloziella byssacea var. *asperifolia* (Tayl.) Macv.	*			
Cephaloziella cf. *byssacea* (Roth.) Warnst.				*
cf. *Dicranella heteromalla* (Hedw.) Schimp.				*
Dicranum fulvum Hook.				*
Dicranum montanum Hedw.				*
Diphyscium foliosum (Hedw.) Mohr			*	
Frullania eboracensis Gottsche		*		
Homomalium adnatum (Hedw.) Broth.		*		
Isopterygium sp.			*	
Kurzia sylvatica (A. Evans) Grolle		*		
Leucobryum glaucum (Hedw.) Ångström		*		*
Odontoschisma cf. denudatum (Nees) Dum.				*
Odontoschisma denudatum (Nees) Dumort.		*		
Pohlia cf. *nutans* (Hedw.) Lindb.				*
Pohlia sp.	*			
Polytrichum cf. *commune* Hedw.			*	
Polytrichum ohioense Renauld & Cardot		*		*
Racomitrium heterostichum (Hedw.) Brid.				*
Tortella humilis Hedw.		*		

Appendix B

List of vascular plants in the cliff systems of the Obed Wall and North Clear Creek sites.

Species	Obed Wall site (including floodplain and forests)	North Clear Creek Site	Rare or Noteworthy	Exotic
Acer pensylvanicum L.	*			
Acer rubrum L. var. rubrum	*	*		
Amelanchier laevis Wiegand	*			
Anemonella thalictroides (L.) Spach	*			
Aralia spinosa L.	*			
Arnoglossum atriplicifolium (L.) H. Rob.	*			
Arundinaria gigantea (Walter) Muhl.	*			
Asimina triloba (L.) Dunal	*			
Asplenium montanum Willd.	*	*		
Betula lenta L. var. *lenta*	*			
Bignonia capreolata Linnaeus	*	*		
Calycanthus floridus L.	*			
Cardamine hirsuta Linnaeus	*			*
Carex emmonsii Dewey ex Torrey	*	*		
Carex muehlenbergii Schkuhr ex Willd. var. *enervis* W. Boott	*			
Carya cordiformis (Wangenheim) K. Koch		*		
Carya ovalis (Wangenheim) Sargent	*			
Chasmanthium laxum (Linnaeus) Yates	*	*		
Chenopodium album L.	*			*?
Chimaphila maculata (L.) Pursh	*			
Commelina communis L. var. *communis*		*		
Conradina verticillata Jennison	*		* (rare)	
Conyza canadensis (L.) Cronquist var. *canadensis*	*			
Coreopsis major Walter var. *rigida* (Nutt.) F.E. Boynton		*		
Danthonia compressa Austin ex Peck	*	*		
Danthonia sericea Nuttall	*	*		
Dendrolycopodium obscurum (Linnaeus) A. Haines	*			
Dennstaedtia punctilobula (Michaux) T. Moore	*			
Avenella flexuosa (L.) Drejer	*		*	
Desmodium glabellum (Michaux) A.P. de Candolle	*			
Dichanthelium commutatum (Schultes) Gould var. *ashei* (Pearson ex Ashe) Mohlenbrock	*			
Dichanthelium laxiflorum (Lamarck) Gould	*			
Dichanthelium tenue (Muhlenberg) Freckmann & Lelong	*			
Diphasiastrum digitatum (Dillenius ex A. Braun) Holub	*			
Elephantopus carolinianus Raeuschel	*			
Epifagus virginiana (Linnaeus) W. Barton	*			

Species	Obed Wall site (including floodplain and forests)	North Clear Creek Site	Rare or Noteworthy	Exotic
Epigaea repens L.	*			
Erechtites hieraciifolius (L.) Raf. ex DC.				
Euonymus americanus L.		*		
Euphorbia mercurialina Michx.	*			
Eutrochium fistulosum (Barratt) E.E. Lamont		*		
Fagus grandifolia Ehrh. var. *caroliniana* (Loudon) Fernald & Rehder	*			
Galium circaezans Michx. var. *hypomalacum* Fernald	*			
Gaultheria procumbens Linnaeus	*			
Gaylussacia baccata (Wangenheim) K. Koch	*			
Geum species [*Waldsteinia fragarioides* (Michx.) Tratt. ssp. *doniana* (Tratt.) Teppner]	*			
Gillenia trifoliata (Linnaeus) Moench	*			
Hamamelis virginiana L. var. *virginiana*	*	*		
Hieracium venosum L.	*			
Heuchera parviflora Bartling	*	*	*	
Hexastylis arifolia (Michaux) Small var. *arifolia*	*			
Houstonia caerulea Linnaeus	*			
Hylodesmum nudiflorum (Linnaeus) H. Ahashi & R.R. Mill	*			
Hypericum gentianoides (Linnaeus) Britton, Sterns, & Poggenburg	*			
Hypericum prolificum Linnaeus	*			
Hypericum stragulum P. Adams & Robson	*			
Hypoxis hirsuta (Linnaeus) Coville		*		
Ilex montana Torrey & A. Gray ex A. Gray	*			
Ilex opaca Aiton var. opaca	*			
Iris verna L. var. *smalliana* Fernald ex M.E. Edwards		*		
Isotrema macrophyllum (Lam.) C.F. Reed	*			
Juncus tenuis Willdenow	*			
Juniperus virginiana L. var. *virginiana*	*	*		
Kalmia latifolia Linnaeus		*		
Krigia biflora (Walter) S.F. Blake var. biflora	*			
Krigia virginica (Linnaeus) Willdenow	*			
Lespedeza repens (Linnaeus) W. Barton	*			
Liquidambar styraciflua Linnaeus	*	*		
Lygodium palmatum (Bernhardi) Swartz	*			
Lysimachia quadrifolia Linnaeus	*			
Magnolia acuminata (L.) L. var. *acuminata*	*	*		
Magnolia macrophylla Michaux	*	*		

Species	Obed Wall site (including floodplain and forests)	North Clear Creek Site	Rare or Noteworthy	Exotic
Magnolia tripetala (Linnaeus) Linnaeus	*	*		
Melica mutica Walter	*			
Minuartia glabra (Michaux) Mattfeld	*	*		
Mitchella repens Linnaeus	*	*		
Nyssa sylvatica Marshall		*		
Osmunda regalis L. var. *spectabilis* (Willd.) A. Gray	*			
Osmundastrum cinnamomeum (L.) C. Presl	*			
Ostrya virginiana (P. Miller) K. Koch	*			
Oxalis grandis Small	*			
Oxalis stricta Linnaeus	*			
Oxalis violacea Linnaeus		*		
Oxydendrum arboreum (Linnaeus) A.P. de Candolle	*	*		
Packera anonyma (Wood) W.A. Weber & Á. Löve	*			
Packera aurea (Linnaeus) Á. & D. Löve	*			
Physocarpus opulifolius (L.) Maxim. var. *opulifolius*	*			
Pinus strobus Linnaeus	*			
Pinus virginiana P. Miller	*	*		
Piptochaetium avenaceum (Linnaeus) Parodi	*			
Pityopsis graminifolia (Michaux) Nuttall var. latifolia Fernald	*			
Poa annua Linnaeus	*			*
Podophyllum peltatum Linnaeus	*			
Potentilla canadensis L. var. *canadensis*	*			
Potentilla simplex Michaux	*			
Pteridium aquilinum (L.) Kuhn var. *latiusculum* (Desv.) Underw. ex A. Heller	*			
Quercus alba Linnaeus		*		
Quercus coccinea Muenchhausen	*			
Quercus montana Willd.		*		
Quercus rubra L. var. *rubra*	*	*		
Quercus velutina Lamarck	*	*		
Rhododendron cumberlandense E.L. Braun		*		
Rhus copallinum L. var. *latifolia* Engl.	*			
Robinia hispida Linnaeus var. *fertilis* (Ashe) Clausen	*			
Rubus argutus Link	*			
Rubus flagellaris Willdenow	*			
Sassafras albidum (Nuttall) Nees	*	*		
Silene rotundifolia Nuttall	*	*	* (rare)	

Species	Obed Wall site (including floodplain and forests)	North Clear Creek Site	Rare or Noteworthy	Exotic
Silene virginica Linnaeus	*			
Maianthemum racemosum (L.) Link ssp. *racemosum*	*			
Smilax glauca Walter	*			
Smilax rotundifolia Linnaeus		*		
Solidago arguta Aiton var. *caroliniana* A. Gray	*			
Solidago odora Aiton	*	*		
Stewartia ovata (Cavanilles) Weatherby	*		*	
Thelypteris noveboracensis (L.) Nieuwl.	*			
Toxicodendron radicans (L.) Kuntze var. *radicans*		*		
Triodanis perfoliata (Linnaeus) Nieuwland	*			
Tsuga canadensis (Linnaeus) Carrière	*			
Vaccinium arboreum Marshall	*			
Vaccinium corymbosum Linnaeus	*	*		
Vaccinium pallidum Aiton	*	*		
Viburnum acerifolium Linnaeus	*			
Viburnum cassinoides Linnaeus	*			
Viburnum dentatum L. var. *dentatum*	*	*		
Vicia caroliniana Walter	*			
Viola hastata Michaux	*			
Viola primulifolia Linnaeus		*		
Viola sororia Willdenow	*			
Vitis rotundifolia Michx. var. *rotundifolia*		*		
Vulpia octoflora (Walter) Rydberg var. *octoflora*	*			
Yucca filamentosa Linnaeus	*			

Appendix C

Location of red cedars sampled at the talus area of the Obed and North Clear Creek sites.

Tree/core no.	Site	Latitude	Longitude	Stem Strip (F/S)	Dbh (cm)	Aspect	Age (obtained by ring analysis)
OBD 1A	NCC	36.09635	-84.70827	S	25	SW	150-380
OBD 1B	NCC	36.09635	-84.70827	S	25	SW	150-380
OBD 2A	NCC	36.09635	-84.70827	F	30	SW	200-250
OBD 2B	NCC	36.09635	-84.70827	F	30	SW	200-250
OBD 2C	NCC	36.09635	-84.70827	F	30	SW	200-250
OBD 3A	NCC	36.09627	-84.70803	S	23	SW	150-380
OBD 3B	NCC	36.09627	-84.70803	S	23	SW	150-380
OBD 3C	NCC	36.09627	-84.70803	S	23	SW	150-380
OBD 3D	NCC	36.09627	-84.70803	S	23	SW	150-380
OBD 4A	NCC	36.09596	-84.70763	S	52	SW	~ 450
OBD 4B	NCC	36.09596	-84.70763	S	52	SW	
OBD 4C	NCC	36.09596	-84.70763	S	52	SW	
OBD 5A	NCC	36.09431	-84.70799	F	13	WSW	60-280
OBD 5B	NCC	36.09431	-84.70799	F	13	WSW	60-280
OBD 6A	NCC	36.09431	-84.70799	F	10	WSW	<100
OBD 6B	NCC	36.09431	-84.70799	F	10	WSW	
OBD 51A	NCC	36.09358	-84.70815	F	11	WSW	<100
OBD 51B	NCC	36.09358	-84.70815	F	11	WSW	
OBD 7A	NCC	36.09328	-84.70845	S	38	WSW	200-250
OBD 7B	NCC	36.09328	-84.70845	S	38	WSW	200-250
OBD 8A	NCC	36.09393	-84.70336	F	37	SSW	200-250
OBD 8B	NCC	36.09393	-84.70336	F	37	SSW	200-250
OBD 9A	NCC	36.09393	-84.70336	F	15	SSW	60-280
OBD 9B	NCC	36.09393	-84.70336	F	15	SSW	60-280
OBD 9C	NCC	36.09393	-84.70336	F	15	SSW	60-280
OBD 10A	NCC	36.09363	-84.69913	F	15	SSW	60-280
OBD 10B	NCC	36.09363	-84.69913	F	15	SSW	60-280
OBD 52 A	NCC	36.09408	-84.69807	F	5	S	<100
OBD 11A	NCC	36.09409	-84.6981	F	10	S	<100
OBD 11B	NCC	36.09409	-84.6981	F		S	
OBD 53A	NCC	36.09377	-84.69884	F	7	WSW	<100
OBD 53B	NCC	36.09377	-84.69884	F		WSW	
OBD 12A	NCC	36.09399	-84.70795	F	14	WSW	60-280
OBD 12B	NCC	36.09399	-84.70795	F		WSW	
OBD 13A	NCC	36.09562	-84.70777	F	7	WSW	<100
OBD 13B	NCC	36.09562	-84.70777	F		WSW	
OBD 14A	NCC	36.09614	-84.7074	F	12	WSW	60-280
OBD 14B	NCC	36.09614	-84.7074	F		WSW	
OBD 15A	NCC	36.0961	-84.70744	F	8	WSW	<100
OBD 15B	NCC	36.0961	-84.70744	F	8	WSW	<100
OBD 16A	NCC	36.09612	-84.70817	F	18	WSW	60-280
OBD 16B	NCC	36.09612	-84.70817	F	18	WSW	60-280
OBD 17A	NCC	36.09652	-84.70807	S	27	WSW	767
OBD 17B	NCC	36.09652	-84.70807	S	27	WSW	
OBD 54A	NCC	36.09992	-84.71004	F	18	WSW	60-280
OBD 54B	NCC	36.09992	-84.71004	F	18	WSW	60-280
OBD 55A	NCC	36.09992	-84.71004	F	11	WSW	<100
OBD 55B	NCC	36.09992	-84.71004	F	11	WSW	<100

Tree/core no.	Site	Latitude	Longitude	Stem Strip (F/S)	Dbh (cm)	Aspect	Age (obtained by ring analysis)
OBD 18A	Obed	36.08981	-84.71464	S	8	SSW	<100
OBD 18B	Obed	36.08981	-84.71464	S	8	SSW	<100
OBD 19A	Obed	36.08981	-84.71464	S	20	SSW	60-280
OBD 19B	Obed	36.08981	-84.71464	S	20	SSW	60-280
OBD 20A	Obed	36.08992	-84.08992	S	10	SSW	<100
OBD 20B	Obed	36.08992	-84.08992	S	10	SSW	<100
OBD 21A	Obed	36.0896	-84.71437	S	28	SSW	150-380
OBD 21B	Obed	36.0896	-84.71437	S	28	SSW	150-380
OBD 21C	Obed	36.0896	-84.71437	S	28	SSW	150-380
OBD 23A	Obed	36.09006	-84.71445	S	15	SSW	60-280
OBD 23B	Obed	36.09006	-84.71445	S	15	SSW	60-280
OBD 22A	Obed	36.09006	-84.71445	S	12	SSW	60-280
OBD 22B	Obed	36.09006	-84.71445	S	12	SSW	60-280
OBD 24A	Obed	36.08982	-84.71416	F	6	SSW	<100
OBD 24B	Obed	36.08982	-84.71416	F	6	SSW	<100
OBD 25A	Obed	36.09011	-84.71395	S	27	SSW	150-380
OBD 25B	Obed	36.09011	-84.71395	S	27	SSW	150-380
OBD 26A	Obed	36.08987	-84.71363	S	8	S	<100
OBD 26B	Obed	36.08987	-84.71363	S	8	S	<100
OBD 27A	Obed	36.08987	-84.71363		18	S	150-380
OBD 27B	Obed	36.08987	-84.71363		18	S	150-380
OBD 28A	Obed	36.08987	-84.71363	F	15	S	60-280
OBD 28B	Obed	36.08987	-84.71363	F	15	S	60-280
OBD 29A	Obed	36.08987	-84.71363	F	3	S	~100
OBD 29B	Obed	36.08987	-84.71363	F	3	S	
OBD 30A	Obed	36.08987	-84.71363	S	30	S	150-380
OBD 30B	Obed	36.08987	-84.71363	S	30	S	150-380
OBD 31A	Obed	36.09004	-84.71332	S	15	S	60-280
OBD 31B	Obed	36.09004	-84.71332	S	15	S	60-280
OBD 32A	Obed	36.09004	-84.71332	F	7	S	<100
OBD 32B	Obed	36.09004	-84.71332	F	7	S	<100
OBD 33A	Obed	36.08981	-84.7188	F	25	SSW	150-380
OBD 33B	Obed	36.08981	-84.7188	F	25	SSW	150-380
OBD 34A	Obed	36.0892	-84.71153	FS	18	S	150-380
OBD 34B	Obed	36.0892	-84.71153	FS	18	S	150-380
OBD 35A	Obed	36.08995	-84.71178	F	13	SSW	60-280
OBD 35B	Obed	36.08995	-84.71178	F	13	SSW	60-280
OBD 36A	Obed	36.08995	-84.71178	S	35	SSW	200-250
OBD 36B	Obed	36.08995	-84.71178	S	35	SSW	200-250
OBD 37A	Obed	36.08995	-84.71178	FS	17	SSW	60-280
OBD 37B	Obed	36.08995	-84.71178	FS	17	SSW	60-280
OBD 38A	Obed	36.08995	-84.71178	FS	11	SSW	<100
OBD 39A	Obed	36.08956	-84.71104	F	7	SSW	<100
OBD 40A	Obed	36.08956	-84.71104	S		SSW	
OBD 41A	Obed	36.08956	-84.71104	FS	6	SSW	<100
OBD 42A	Obed	36.09068	-84.70627	F	19	SSW	150-380
OBD 42B	Obed	36.09068	-84.70627	F	19	SSW	150-380
OBD 43A	Obed	36.09082	-84.70277	F	10	S	<100

Tree/core no.	Site	Latitude	Longitude	Stem Strip (F/S)	Dbh (cm)	Aspect	Age (obtained by ring analysis)
OBD 43B	Obed	36.09082	-84.70277	F	10	S	<100
OBD 44A	Obed	36.09072	-84.70702	F	7	SW	<100
OBD 44B	Obed	36.09072	-84.70702	F	7	SW	<100
OBD 45A	Obed	36.09072	-84.70702	F	7	SSW	<100
OBD 45B	Obed	36.09072	-84.70702	F	7	SSW	<100
OBD 46A	Obed	36.0907	-84.70892	F	7	N	<100

NCC= North Clear Creek; F = full bark; S = bark/stem strip

Tree no. 5 and 6 were on the cliff ledge, approx. 30 ft. above the base of the cliff.

BIOGRAPHICAL SKETCH

Bal Nepal obtained his Bachelor of Science degree in Biology from Amrit Science College, Kathmandu, Nepal. After graduating, he joined the Department of Botany at Tribhuvan University to pursue his Master of Science (M.Sc.), and earned the degree in 2001. He served several years as a free-lance consultant in Nepal for biodiversity management and conservation projects affiliated with various non-government organizations such as WWF Nepal Program, IUCN Nepal Program, and Center for Biological Conservation Nepal. With an earnest desire of receiving a higher education degree from a developed country, he joined ASU's Biology Masters Program in spring 2008. He is expected to graduate in August 2010.