CLIFF ECOLOGY OF THE BIG SOUTH FORK NATIONAL RIVER AND RECREATION AREA

A Thesis
by
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Department of Biology

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Abstract

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Most of the world's cliff ecosystems remain unexplored by biologists, and little is known about patterns in the community structure of cliff vegetation. There is, however, a growing concern that biodiversity on cliffs may be threatened by impacts from recreational activities like hiking and rock climbing. Because cliffs support unique and diverse flora, including many rare and endemic species, conservation of cliff habitat should be a high priority for land managers. This study characterized the vascular plants, bryophytes, and lichens along 50 vertical transects in 18 cliff sites (cliff faces within 1 km^2) of the Big South Fork National River and Recreation Area (BISO)—in Kentucky and Tennessee—to determine which factors, including rock climbing, influenced the distribution of cliff vegetation. Throughout the sampled cliff systems, *Lepraria* was the most dominant lichen genus, *Rhododendron maximum* was the dominant vascular plant, and *Brotherella recurvans* was the dominant bryophyte. On cliff faces the dominant lichen was, again, *Lepraria*; but *Dennstaedtia punctilobula* was the dominant vascular plant; and *Dicranum montanum* was the dominant bryophyte. Several rare species were found including *Cladonia pocillum*, a boreal disjunct lichen; *Vittaria appalachiana*, Appalachian shoestring fern; and *Cynodontium schisti*, a rare bryophyte. Linear regressions of abiotic factors with species diversity indicated that no single factor dictates community composition for all vegetation. However, when taxa were divided into three taxanomic groups—vascular plants, bryophytes and lichens—each taxon was influenced by different environmental drivers. West-facing slopes supported high vascular plant diversity, gentler slopes supported high bryophyte diversity, and high surface heterogeneity supported high lichen diversity. Multivariate analyses indicated that plant and lichen communities varied widely by transect within and across cliff sites. In addition, cliffs with forested edges support higher diversity of all taxa than did those with exposed edges. Rock climbing did not appear to influence community structure; however, this result could be due to low levels of climbing traffic. Rock climbing is predicted to increase in the park, and understanding patterns in plant and lichen composition will be essential for park managers to develop management plans. Based on this study, guidelines for planning include: surveying each cliff individually if climbing is proposed; assigning conservation priority to cliffs with forested edges over those with open edges; and focusing conservation efforts on preserving vegetation above cliff faces. With these community data and management recommendations in mind, I have created a spatial model to predict vegetative diversity and potential for climbing development on BISO's cliffs. This model will provide a tool to aid park managers in determining where climbing should be permitted and where more in-depth surveys are necessary. With the increasing popularity of rock climbing, understanding plant community dynamics on cliff faces is increasingly important for developing sound management practices.

Dedication

I would like to dedicate this work foremost to my parents who have encouraged me in all of my academic pursuits. They listened to my crazy ideas and enthusiasm at the beginning of the project and stuck with me through the ups and downs, reading drafts with patience and insight. I would not be where I am without them.

Second, I want to acknowledge that this thesis would not have been possible without the support of Eric Purdy, my fellow graduate student. We've worked and played together for almost three years, through off-roading mishaps, poison-ivy rappels, maddening data foibles, and gallons of Texas Pete. Purdy, this one is for you.

Eric Purdy at Cumberland Gap, Summer 2011. Photo: Mike Madritch.

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Funding for this project was provided by a grant from the National Park Service through the Southern Appalachian Cooperative Ecosystem Studies Unit. Marie Tackett, the botanist at the Big South Fork National River and Recreation Area provided cheerful and consistent technical support. My advisors Dr. Gary Walker and Dr. Mike Madritch provided the perfect combination of advice, expertise, and encouragement, not to mention countless delicious meals and the opportunity to sleep in an RV and drive an ATV. My committee member Dr. Howie Neufeld also provided valuable input throughout and taught me basic biostatistics, for which I will always be grateful. Derick Poindexter, Keith Bowman, and Coleman McCleneghan helped with identifications of vascular plants, bryophytes, and lichens, respectively. Peter Smith helped identify state records for vascular plants and provided critical stress relief by donating his climbing holds.

Team BaLSACC (Bryophytologists and Lichenologists of the Southern Appalachian Cliff Coalition), our intrepid field crew, managed to remain hard-working, good-natured and hilarious through all sorts of trials. The team was: Justin Harkey, Tim Whitby, Kelen Dowdy, Marcus Funston, and Eric Purdy. My climbing buddies Adam Tripp and Brian Taylor set up anchors on routes when the climbing was too difficult for me. Finally, many of my fellow graduate students kept my chin up when things were not going according to plan. Carra Parker and Michael Perkins, in particular, were always willing to eat Thai curry and commiserate.

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Foreword

The research presented in chapter 2 of this thesis will be submitted to a scientific journal and has been prepared in accordance with the submission guidelines for this journal. Chapter 1 provides a brief introduction to the field of cliff research and puts the following chapter in context.

**Stuart Cowles (r) trains Justin Harkey (l) in the art of anchor building.
Summer 2011. Table Rock, NC.**

Training for Cliff Research in the Big South Fork. Summer 2012.
Pictured: Mike Madritch above; l to r, Kelen Dowdy, Marcus Funston, and Laura Boggess.

CHAPTER 1: INTRODUCTION TO CLIFF ECOSYSTEMS

Cliffs are found in virtually every environment around the world. Historically, biologists considered cliff faces too difficult to sample or too limited in biota to be worth the expense and effort of studying. However, over the last twenty years, scientists have become increasingly interested in cliff ecosystems (Larson et al. 2000). One major challenge for cliff ecology research has been the difficulty of reaching cliff faces in order to study them. At the same time that cliffs were becoming more interesting to scientists, rock climbing was gaining popularity as a recreational sport. Climbing is related to cliff research in several ways. The development of specialized equipment for climbers has facilitated the work of researchers by making field study safer and more effective. However, an unforeseen outcome of the increasing popularity of rock climbing is its potential for negative effects on the environment. Rock climbing is one of the few ways that humans directly impact cliff-face flora. The presence of more climbers in recreation areas increases the need for careful scientific study in order to better understand how disturbance affects cliff communities.

Why cliffs are important

Cliffs are unique ecosystems that can harbor rare and endemic species, glacial relicts, and ancient forests. Most work in the fledgling field of cliff ecology has been conducted by the Cliff Ecology Research Group (CERG), based at the University of Guelph and headed by Dr. Douglas Larson. In 1988, Larson and a high school student, Ceddy Nash, cored an eastern white cedar (*Thuja occidentalis* L.) growing at the edge of the Niagara Escarpment in Ontario, Canada. They expected the tree to be 40 or 50 years old, typical of secondary growth forests in southern Ontario. Instead, they counted 400 growth rings (Kelly and Larson 2007). This tree and its neighbors had persisted on the cliff faces of the escarpment for hundreds of years, within sight of Toronto, the largest metropolis in Canada. As the CERG went on to characterize the ancient forests, they found trees over 1000 years old (Kelly and Larson 2007). The trees grow extremely slowly and have persisted, in part, because human disturbance is limited (Larson et al. 2000). Because of their age, these trees offer valuable information regarding historic climate change and represent the unique ecology of cliff ecosystems.

In addition to white cedars, other rare and disjunct plant species have been found on cliffs, including species thought to have been stranded following repeated glacial advance and retreat cycles (Oosting and Hess 1956, Walker 1987, Clebsch and Walker 1988, Wiser 1994, Hart and Shankman 2005). Because cliffs are relatively disturbance-free and provide a release from interspecific competition, relict flora can persist long after other members of their species have been locally extirpated. These relict plants also contain levels of genetic variation far higher than those in their main range, potentially representing a genetic reservoir during interglacial periods (Walker 1987). Populations of cliff plants in the Southeastern United States are particularly important reservoirs of genetic diversity for many northern plant species, allowing these species to better adapt to climate change or exotic diseases (Davis and Shaw 2001, Jump and Peñuelas 2005). The Southern Appalachian Cliff Coalition at Appalachian State University has recently found disjunct boreal lichen assemblages in Cumberland Gap National Historic Park (Ballinger 2007, Harkey 2013). The genetic distinctiveness and biogeographical significance of these northern disjunct species, many of which persist only on cliffs, make them high priorities for conservation.

Disturbance on cliffs

Disturbance from natural sources is usually low on cliffs. Cliffs are inaccessible to most herbivores in the southeastern United States; deer, the most destructive grazers in many North American habitats, do not graze along cliff edges (Larson et al. 2000). Furthermore, fire is rare due to the absence of fuel load. Litter does not accumulate on a vertical surface, and the patchy distribution of vegetation makes it difficult for fire to spread (Larson et al. 2000). In fact, certain species persist on cliffs mainly due to the absence of fire, such as *Widdringtonia cedarbergensis* Marsh (Clanwilliam Cedar), which is restricted to rock outcrops and cliffs of South Africa (Manders 1986).

Human disturbance on cliffs has traditionally been low, but increased development is currently encroaching on cliff habitats. The expanding human population consumes more construction materials; cliffs and rock outcrops are prime sites for quarries (Ursic et al. 1997). Increasing demand for electricity has increased the incidences of flooding in gorges for hydroelectric power. The scenic nature of cliffs also makes them desirable sites for high-end real estate. The corresponding increase in property values makes cliff sites difficult to acquire for conservation (Larson et al. 2000).

Recreation also threatens cliff habitats. Hiking and backpacking can have negative effects on cliff edge vegetation, and sites exposed to heavy trampling have less diverse species composition than do untrampled cliffs (Cole 1995, Parikesit et al. 1995). Trail use by ATVs and horses exacerbates this decrease in diversity (Larson et al. 2000). On a small scale, bonsai collecting can threaten cliff trees, and extreme sports such as hang gliding and wingsuit flying increase trampling on cliff edges (Ota and Gun 1988, Larson et al. 2000).

Recreational rock climbing is known to affect cliff-face populations, but not always in intuitive ways. For example, richness and diversity of cliff face vegetation is generally expected to decrease with increases in climbing activity. However, several studies have found that crustose lichen richness and diversity actually increased with climbing activity (McMillan and Larson 2002, Hill 2009). More data are necessary to adequately describe and predict the long-term and varied impact climbing will have on cliff systems.

Conclusion

Cliffs should be studied because they often harbor rare and ancient species, can act as genetic reservoirs, and are threatened by increased human disturbance. Having the tools to study cliffs safely and effectively facilitates our understanding of the ecology of cliffs and how disturbance affects them. This understanding will form the basis for appropriate management plans that maintain access for climbers and recreationalists while protecting cliff resources and their fragile ecosystems.

The current study adds to cliff ecology research by describing community composition, as well as the effects of climbing disturbance on cliffs in the Big South Fork National River and Recreation Area (BISO) and creating a model to predict plant diversity and potential for climbing on the park's cliffs. This model can be adapted to other cliff systems in order to aid land managers in deciding, for example, which cliffs to close to recreational climbing and which can remain open. Chapter two is prepared as a manuscript for submission to a scientific journal. The chapter characterizes the vegetation on the cliffs of BISO and examines the effect of climbing disturbance on these communities. It then outlines how I used the data collected in the vegetation study to develop a predictive spatial model of cliff diversity and attractiveness to climbers. The research presented in this study will give ecologists and land managers a clearer understanding of plant community structure on cliff faces and provide tools to protect these important ecosystems.

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Eric Purdy being shown the ropes at Table Rock, Linville Gorge Wilderness Area.

CHAPTER 2: COMMUNITY STRUCTURE OF CLIFF VEGETATION IN THE BIG SOUTH FORK

Introduction

Most ecological research has focused on the major biomes: forests, deserts, oceans, tundra, wetlands, and grasslands, while ignoring cliff systems (Larson et al. 2000a). Cliff systems are generally considered either ecotones—transition areas between two biomes—or geological features lacking diversity (Ursic et al. 1997). In the past twenty years, however, cliffs are increasingly considered distinct and important ecosystems in their own right, ones that can support ancient forests, endangered biota, and high levels of biodiversity (Larson et al. 2000a, Kuntz and Larson 2006a). Ancient forests have been discovered on the cliffs of the Niagara Escarpment and elsewhere (Larson et al. 2000b). Additionally, cliffs harbor large numbers of rare species, many of which are restricted exclusively to cliffs (Ellenberg 1988). Many of these rare plants are remnants of an earlier boreal flora that followed the glacial margin at the peak of the Pleistocene glaciation. These plants persist due to limited disturbance, buffered temperatures, and a lack of competitive exclusion. Cliff faces can also sustain high floral diversity, which stems from having many microhabitats formed by numerous cracks and crevices in the rock. The presence of ancient forests, rare and disjunct species, and high biodiversity make cliffs important ecosystems that deserve high conservation priority.

The unique vertical environment of a cliff face affects plant communities and provides an important refuge from interspecific competition for stress-tolerant species (Larson et al. 1989). For example, *Thuja occidentalis* L., which has a main range in boreal forests of North America, uses cliff faces as retreats from competitively dominant species, especially as a glacial relict in its southern, disjunct range (Walker 1987). Cliff communities harbor other glacial relict and disjunct species, along with many rare and endemic species that may be absent from the surrounding landscape (Clebsch and Walker 1988). These cliff populations often act as genetic reservoirs, containing levels of genetic variation far greater than those populations in the species' main range (Walker 1987, Clebsch and Walker 1988). The high concentration of endemics, combined with the high levels of genetic variation for rare and common species, indicates that cliff systems should be high-priority targets for conservation efforts.

Abiotic factors that drive diversity of cliff flora

A cliff can be defined as a high, steep, or overhanging mass of rock (Larson et al. 2000a). Typically, a cliff system includes edge, face, and talus habitats. The cliff edge is the area of relatively level ground above the cliff face, while the talus is the area below, which often contains rocks that have fallen from the face (Figure 1).

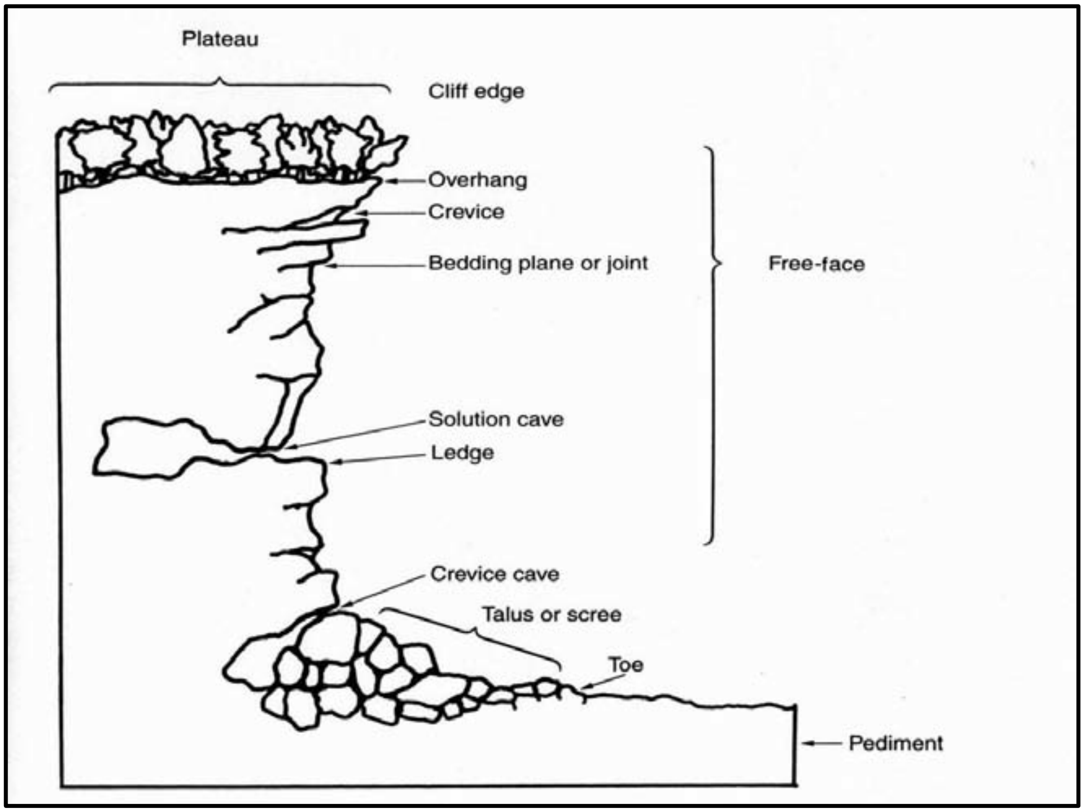

Figure 1. Diagram of a cliff system. (Larson et al. 2000a)

Physical factors vary greatly at the microsite scale on cliff faces and other rock outcrops, resulting in widely divergent habitat conditions across short spatial distances (Hora 1947, Wiser et al. 1996, Kuntz and Larson 2006a). Light, moisture, vertical zonation (height on the face), surface heterogeneity, slope, and aspect all have the potential to affect floristic diversity.

Light and moisture

Baskin and Baskin (1988) found that a requirement for high light levels was the most important characteristic common to endemic herbaceous rock outcrop species in the eastern United States. In addition, variation in light levels among microsites on cliff faces is correlated with the presence or absence of plant species in Tasmania (Coates and Kirkpatrick 1992). However, there are exceptions to the high light requirement. For example, a southern Appalachian endemic*, Hymenophyllum tayloriae*, Farrar & Raine, (gorges filmy fern) grows only in extremely low light, high moisture environments such as spray cliffs and caves near waterfalls (Weakley 2007). Moisture gradients also impact plant community composition and distribution in cliff sites. Moisture availability on cliffs is determined by a number of factors including climate, the presence of perennial seeps, surface heterogeneity of the rock, and exposure to incident radiation. Higher surface temperatures and windy conditions on exposed rocks may increase evaporative rates, resulting in dry conditions and a strong selection for desiccation-tolerant species (Phillips 1982), however, some cliff habitats actually buffer plants from drought because they retain moisture in deep cracks in the rock and provide habitats that experience no direct insolation (Kelly and Larson 1997).

Vertical zonation and surface heterogeneity

Vertical zonation also affects plant community structure on cliffs; communities often vary with their position on the cliff face. The lower portions of cliff faces, particularly those in narrow river gorges, are less exposed, and thus less likely to experience stressful wind, temperature and moisture regimes than are cliff habitats near the top edge. For instance, Smith (1998) determined that species composition varied along a vertical gradient in the Linville Gorge Wilderness Area, NC, an area characterized by steep slopes in a narrow river gorge. Light levels, in combination with other physical gradients, can also drive vertical zonation of vegetation in some cliff systems (Yarranton and Green 1966, Smith 1998). On cliff faces and abandoned quarry walls along the Niagara Escarpment, the canopy beyond the talus shades the lower cliff face, resulting in a community shift to shade-tolerant plants near the base (Ursic et al. 1997).

Surface heterogeneity—the variation in the rock surface caused by bumps, cracks, pockets and ledges—can also drive the composition of cliff flora and was the most important determinant of vegetation on the Niagara Escarpment (Kuntz and Larson 2006a). Additionally, Ursic et al. (1997) demonstrated that the presence of ledges on the vertical walls of abandoned quarries significantly increased plant species richness. Vegetation formed communities in pockets and along joint crevices but was absent from dry, smooth faces on sandstone cliffs in Tasmania (Coates and Kirkpatrick 1992). Likewise, woody vegetation establishment was strongly associated with rock joints along granite outcrops at Wilson's Promontory in Victoria, Australia (Ashton and Webb 1977), probably due to increased soil accumulation and water availability from seeps in the cracks.

Aspect and slope

Aspect can also influence the distribution of mountain and cliff vegetation. For example, north- and south-facing cliffs can have marked differences in species composition (Walker 1987, Ursic et al. 1997, Larson et al. 2000a) and in overall vegetation cover (Ashton and Webb 1977). Walker (1987) found that *T. occidentalis* on north-facing cliffs grew faster than those on south-facing cliffs in the Southern Appalachian Mountains. A similar pattern occurs in *Tilia cordata* L. in France, where trees are restricted to north-facing cliffs in the southern part of their range. However, these trees do not have an affinity for a particular aspect in the central and northern parts of their range (Pigott and Pigott 1993).

Slope is also an important abiotic driver of community composition that can act as a proxy for moisture. The steeper the slope, the less water is retained by vegetation; thus steep slopes generally harbor more desiccation-tolerant flora (Larson 2000a). Slope also affects species recruitment, since shallower slopes are more likely to accumulate debris that can trap propagules, while steep slopes do not. Slope also affects incident radiation. Steep slopes have lower flux densities of radiation, especially near solar noon, whereas shallower ones have higher solar radiation either in the morning or evening, depending on their aspect.

Of the six abiotic factors discussed, vertical zonation, slope, aspect, and surface heterogeneity are directly addressed in the current study. Light and moisture are difficult to measure accurately in the cliff environment as they are temporally and spatially variable. Consequently, slope and aspect were used as proxies for light and moisture, respectively, since aspect affects insolation (south-facing cliffs receive more light than north-facing cliffs) and slope affects moisture availability. Additionally, light can be easily modeled given slope, aspect and height on the cliff face (McCune and Keon 2002).

Climbing impact

Climbing can negatively affect cliff vegetation (Kelly and Larson 1997, Camp and Knight 1998). Farris (1998) and Nuzzo (1996) found that the total percent cover of vegetation on climbed faces was significantly lower on climbed than on unclimbed faces in Minnesota and Illinois, respectively. In Canada, the Cliff Ecology Research Group found that vegetation and land snail populations of the Niagara Escarpment were reduced by climbing activity (McMillan and Larson 2002, McMillan et al. 2003). In Michigan, climbing decreased richness and cover of lichens (Adams and Zaniewski 2012). However, climbing does not always reduce diversity and can, in fact, increase the diversity of some lichen communities. For instance, small, disturbance-tolerant species, such as crustose lichens increased in diversity on climbed cliffs along the Niagara Escarpment (Pampang et al. 1995). Similarly, climbing activity in the Linville Gorge

Wilderness Area, NC, reduced the diversity and abundance of vascular plants, mosses, and both foliose and fruticose lichens. Crustose lichens, however, increased in both abundance and diversity (Smith 1998). Hill (2009) also found that the diversity of crustose lichens increased on climbed faces in the Obed River Gorge, TN. This increase in crustose lichen richness may be caused by a release from competition when competing vascular plants, mosses and other lichen taxa are destroyed or disturbed by climbers (Smith 1998). Alternatively, climbers, in seeking challenging routes, may be choosing overhanging or relatively smooth rock that is already lower in abundance and diversity of vegetation. Therefore, the differences in community structure may not have been due to climbing disturbance, but rather the fact that climbed routes had lower plant diversity and richness before they were developed for climbing. These disparate results imply that we are only beginning to understand the effects of climbing disturbance on cliff vegetation and that additional studies are needed before drafting definitive climbing management plans. Long-term studies, in particular, are needed to investigate community changes on climbed faces over time. The popularity of sport climbing in the United States has increased substantially over the last two decades (U.S. Department of the Interior 2004), and the Big South Fork is predicted to see an increase in climbing activity in the coming years (U.S. Department of the Interior 2005). Thus, an understanding of climbing impact on vegetation is necessary to inform sound management decisions for the park.

Objectives of the current study

The current study was conducted between May 2012 and August 2013 by researchers at Appalachian State University. The objectives were to 1) characterize vegetation on 18 cliff sites in the Big South Fork National River and Recreation Area (BISO), 2) determine how abiotic factors influence plant and lichen communities on those sites, 3) examine the effects of rock climbing on plant communities, and 4) develop a model to predict cliff floral diversity and attractiveness to climbers.

Methods

Site description

The Big South Fork National River and Recreation Area (BISO) encompasses 50,586 hectares (125,000 acres) of the Upper Cumberland Plateau, protecting the Big South Fork of the Cumberland River and its tributaries. The park spans Kentucky (McCreary County) and Tennessee (Scott, Fentress, Morgan and Pickett Counties) (Figure 2).

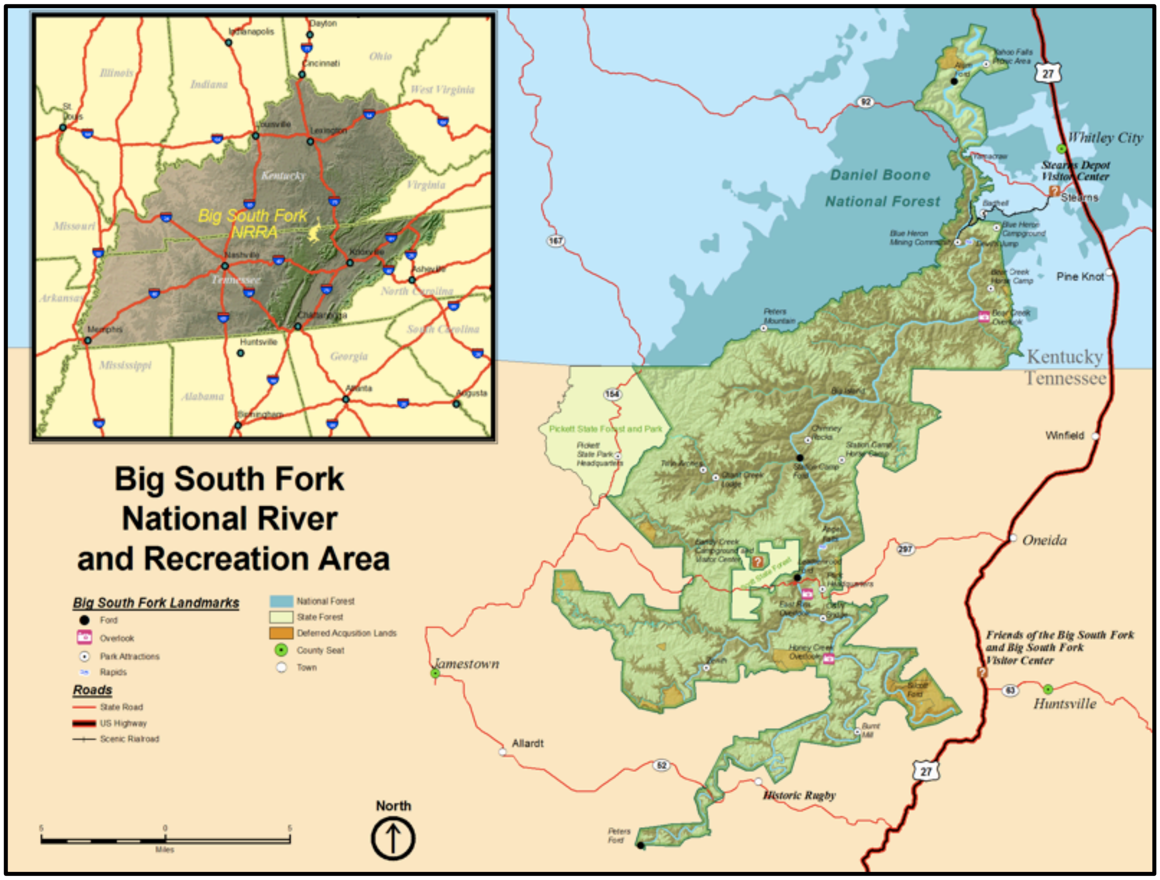

Figure 2. Location of the Big South Fork National River and Recreation Area. (NPS 2013)

Geology of BISO

The rock of the Big South Fork is sedimentary from the Pennsylvanian and Mississippian periods. The Pennsylvanian rock is predominantly sandstone and shale, but also includes siltstone, conglomerate, and coal. The sandstone weathers easily and has produced an array of cliffs suitable for rock climbing. The park's unique formations, including arches, chimneys, cracks, and rockhouses are also formed predominantly from Pennsylvanian sandstone. The Mississippian rock is limestone, containing oil and gas deposits, that underlies the sandstone (Shaw and Wofford 2003). Elevations range from 236 m in the river basin to over 488 m on the ridges. Most of the park is elevated tableland, but erosion by the Big South Fork of the Cumberland River and its tributaries has created deep gorges in the soft sandstone bedrock. This erosion has produced approximately 1207 km (750 miles) of cliff but very little bottomland. The relatively soft sandstone cliffs have also eroded horizontally at the base forming thousands of ledges and rockhouses (Smith and Des Jean 2012).

Field collection methods

Fifty transects were surveyed in 18 sites throughout BISO (see Appendix 1 for a map of transect and site locations). A cliff site was designated as cliff faces within 1 km^2. Twenty transects were climbed/unclimbed pairs made up of a climbed transect and an adjacent unclimbed transect. Routes were designated as climbed either by appearing in the climbing guide for Tennessee, the *Dixie Cragger's Atlas* (Watford 2005), or by the presence of fixed gear on the route such as bolts or anchors. A 1 m^2 quadrat was sampled on each side of the rappel rope (one plot to the left and one to the right), at 3 m intervals along the face of the cliff. The number of face plots sampled varied with the height of the cliff.

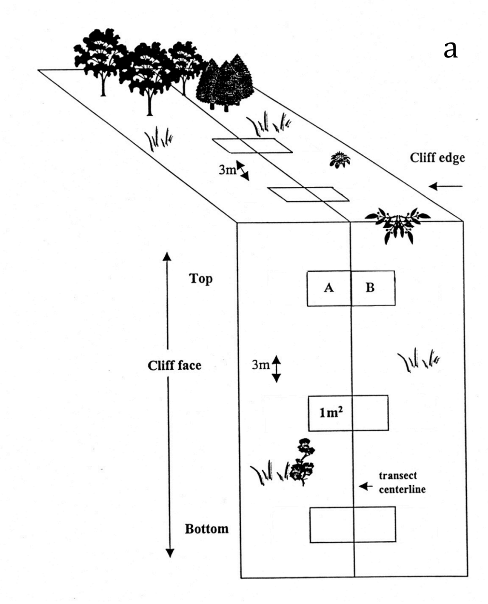

Figure 3a. Diagram of the sampling design (Smith 1998). **Figure 3b.** Photograph of 1 m^2 quadrats used on either side of the rappel line (photo: Mike Madritch).

Samples of vascular plants, lichens, and bryophytes were collected from these paired plots along each transect beginning three meters from the cliff edge and every three meters thereafter. Paired plots were also sampled on the cliff edge and in the talus area. Aspect, slope, surface heterogeneity, and percent cover of each species were recorded in all plots. Percent cover was visually estimated within each quadrat. Surface heterogeneity was visually estimated and assigned a value between one (low heterogeneity: smooth rock) and ten (high heterogeneity: cracked, pocketed or pitted rock). Aspect and slope were measured with a compass and inclinometer, respectively.

Vegetation samples were temporarily placed in paper bags or envelopes and labeled with transect and plot numbers. Vascular samples were then transferred to a plant press in the field. Upon return to the Appalachian State University herbarium, all samples were placed in a dryer for at least one week. Vascular samples were identified by Derick Poindexter, a consulting botanist, using the nomenclature of Weakley (2007). Bryophyte samples were identified by Dr. Keith Bowman, bryologist, SUNY Syracuse, using the nomenclature of Anderson et al. (1990) for mosses and Hicks (1992) for liverworts. When sampling crustose lichens, it was often necessary to remove a small portion of the rock. This was done with a hammer and chisel in a manner which minimized impact and scarring. Lichen samples were identified to genus by the author and by Dr. Coleman McCleneghan, mycologist, using the nomenclature of Brodo et al. (2001).

Statistical methods

Species richness and species diversity were calculated for individual plots within transects then summed to find the total for each transect. Species richness for each vegetation type (vascular plants, bryophytes, and lichens) was recorded for every 1 m^2 plot then combined to determine total transect richness. Shannon's Diversity Index (H') was used to represent species diversity for each plot, then combined to determine total transect richness. Shannon's index accounts for both abundance and evenness of the species present and is calculated as follows: $H' = -\sum_{i=1}^{R} p_i \ln p_i$, where R is the total number of species in the population (richness) and p_i is the proportion of individuals of species *i* relative to the total number of individuals for all species.

Species abundance curves

Relative species abundance describes how common or how rare a species is in relation to other species in a given community. Species abundance curves were constructed using PC-ORD (V6, MjM Software, Gleneden Beach, Oregon) to determine the most abundant species for all sampled taxa as well as for each vegetation group. Species abundance curves were also constructed for each site to determine if different cliff sites had the same dominant species.

Species-effort curves

Nested species effort curves were constructed in PC-ORD (V6, MjM Software, Gleneden Beach, Oregon). Because observed species richness is usually less than the actual species richness in a given area, I applied first-order jackknife estimates using PC-ORD (Palmer 1990, Smith and Pontius 2006). The jackknife estimator is a nonparametric resampling procedure that adjusts richness based on different ratios of the number of species that occur only once or twice in the matrix relative to sample size (Peck 2010), and provides estimated values of total species richness.

Linear regressions

I performed linear regressions of species diversity with the various abiotic factors measured using JMP (V10, SAS Institute, Cary, NC). Using transect diversity data, I regressed H' for each vegetation type (vascular plants, bryophytes, lichens) with cliff height, slope, aspect, and the coefficient of variation (CV) of the surface heterogeneity.

Multi Response Permutation (MRPP)

I employed multi-response permutation procedures (MRPP) with Sørenson distance measures to test for differences in species composition of vegetation (PC-ORD V6, MjM Software, Gelenden Beach, Oregon). A p value of < .05 was considered significant. The A statistic represents chance-corrected within-group agreement or more simply put, the effect size. A small effect size ($A \rightarrow 0$) indicates that heterogeneity within groups equals that expected by chance; a large effect size ($A \rightarrow 1$) indicates that all values within a group are identical. An A value greater than 0.3 is considered high; ecological data commonly have A values around 0.1 (McCune and Grace 2002). The test statistic, T, describes the separation between groups, with more negative values indicating greater separation (McCune and Grace 2002).

Adjacent transects that covered continuous cliff sites were grouped and MRPPs were employed to determine if plant communities differ by cliff site (cliff site effect). MRPP was also employed to determine if communities differ depending on whether trees and shrubs grow within three meters of the cliff edge (edge cover effect). Finally MRPPs were performed to determine if climbed transects differ from unclimbed (climbing effect).

Non-metric Multidimensional Scaling (NMS)

Community data are typically complex and require ordination procedures to distill multivariate data into more tangible datasets. Non-metric Multidimensional Scaling (NMS) makes no assumptions regarding sample distribution and is often best suited for highly skewed, non-normal, and sparse ecological data (McCune and Grace 2002). I used NMS to describe variation in plant communities. I grouped visual representations of Sørenson distance between data points by site, edge cover, and climbed/unclimbed.

Spatial Model

A predictive model was constructed based on a Partial Least Squares (PLS) regression of five physical variables: cliff height, slope, aspect, latitude, and longitude. These variables were chosen because they are easily derived from a Digital Elevation Model. PLS finds a linear regression by projecting the predicted variables into a new space. PLS combines features from Principal Component Analysis (PCA) and multiple regression (Wold 1985). Aspect was transformed to northness and eastness (Beers et al. 1966). Physical attribute data including slope and aspect were extracted from a 10-m resolution digital elevation model (DEM). Slope was restricted to "cliff" areas, defined as slopes greater than 72°. Aspect was color-coded red (N-facing), yellow (E-facing), teal (S-facing), and dark blue (W-facing) (Figure 9). Predicted species diversity for the three vegetation types (vascular plants, bryophytes, and lichens) were the outputs of the model based on these physical attributes. I then selected cliffs that may be attractive to climbers; that is, cliffs that are higher than 10 m, have a slope of at least 90 degrees and are within 2 km of a road. I also included the World Topographic Map Base Terrain Layer (ESRI 2010) as well as a Trails and Roads layer provided by the park to give geographic context and enhance visual appeal for users (Figure 11).

Results

Species richness and diversity

Two hundred and sixty-five total species were found on the sampled cliffs. Eighty-one species were vascular plants, including *Carex cumberlandensis* Nazci, Kral and Bryson, a grass that has not been previously found in the park. Sixty-four bryophyte and 120 lichen taxa were found on the cliffs including *Cynodontium schisti* (Web. & Mohr) Lindb., a rare moss, and *Cladonia pocillum* (Ach.) Grognot, a boreal and Rocky Mountain disjunct. Shannon's Diversity (H') values (by transect) ranged from 0.774 to 3.03 and averaged 2.33. These data were normally distributed. Overall species richness ranged from 5 species to 45 species per transect and were not normally distributed. The geometric mean for species richness was 18.8. Table 1 illustrates that the Big South Fork contains high levels of overall species richness when compared to other cliffs on the Cumberland Plateau. Bryophyte and lichen richness was higher at BISO than any other park and BISO vascular plant richness was second only to CUGA.

Table 1. Comparison of Species Richness in Four Protected Areas of the Cumberland Plateau

	Obed River Gorge	**White Rocks (CUGA)**	**Cumberland Gap (CUGA)**	**Big South Fork**
Total Vascular Species	58	14	111	81
Total Bryophyte Species	65	9	37	64
Total Lichen Species	47	48	83	120
Overall (combined)	170	71	231	265

Species abundance distributions

I used species rank abundance plots to represent relative abundance of BISO cliff vegetation. Abundance was measured by the total percent area covered by a species on all sampled cliffs. Figure 4a-d illustrates species dominance for combined taxa and for each vegetation type (vascular plants, bryophytes, and lichens). The most abundant taxon on sampled cliffs was a gray powdery crustose lichen, genus *Lepraria.*

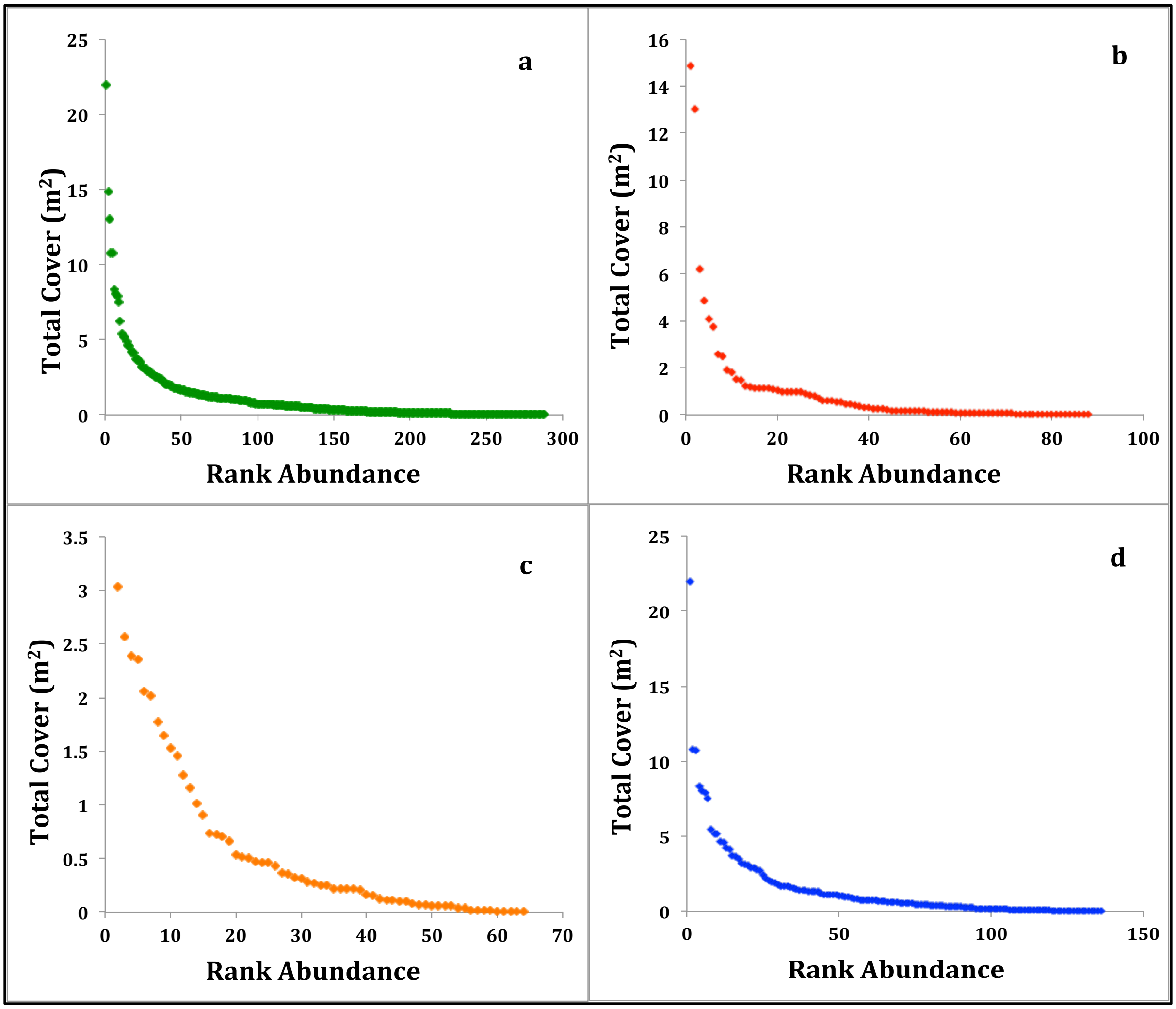

Figure 4a-d. Rank abundance curves for vegetation. Panel a: all vegetation; panel b: vascular plants, panel c: bryophytes; panel c: lichens. Each point is a species (or morphospecies for lichens).

Six to ten species dominate and many others occur only once or twice in the dataset. Table 2 illustrates this trend by listing the five most abundant species for each vegetation type as well as the total percent cover in sampled plots. The four most abundant species overall are lichens and none of the bryophyte species occur in the top ten.

Table 2. Species with the Five Highest Rank Abundances

All Taxa:	Rank	Taxon	Total Cover (m^2)
	1	*Lepraria gray*	22.99
	2	*Rhododendron maximum*	14.89
	3	*Cladonia gray*	13.02
	4	*Parmelia green*	10.77
	5	*Cladonia green*	10.75

Vascular:	Rank	Species	Total Cover (m^2)
	1	*Rhododendron maximum*	14.89
	2	*Kalmia latifolia*	13.02
	3	*Acer rubrum*	6.230
	4	*Vaccinium sp.*	4.880
	5	*Ilex opaca*	4.090

Bryophytes:	Rank	Species	Total Cover (m^2)
	1	*Brotherella recurvans*	3.03
	2	*Dicranum montanum*	2.57
	3	*Dicranum scoparium*	2.39
	4	*Andreaea rothii*	2.35
	5	*Racometrium heterostichum*	2.06

Lichens:	Rank	Taxon	Total Cover (m^2)
	1	*Lepraria gray*	22.99
	2	*Cladonia gray*	13.02
	3	*Parmelia green*	10.77
	4	*Cladonia green*	10.75
	5	*Tan crustose*	8.070

Species-effort curves

I used species-effort curves, which show species accumulation per sampling effort, to estimate total species richness in the Big South Fork using the first-order jackknife estimator in PC-ORD (Table 3) (Palmer 1990, Smith and Pontius 2006).

Table 3. Sampled Species and Estimated Species Calculated by First-Order Jackknife Estimates.

	Total Sampled Species	**Total Estimated Species**
All Taxa	286	388
Vascular	88	123
Bryophyte	62	88
Lichen	135	173

Species-effort curves all approach an asymptote, but more sampling is probably needed to document all species on BISO cliffs (Figure 5).

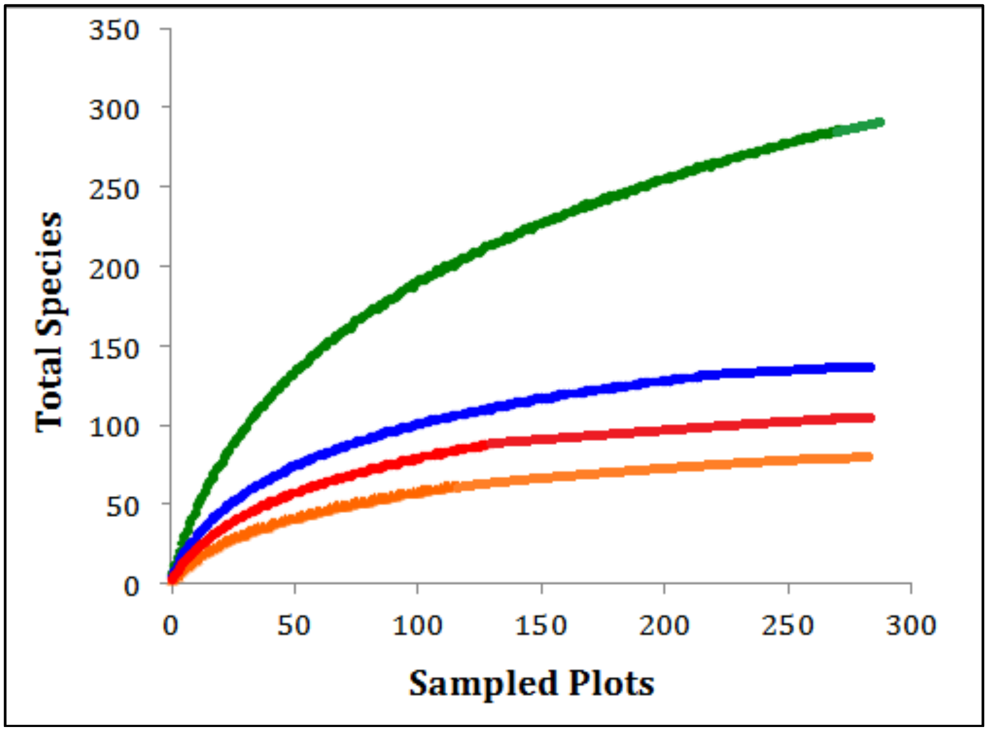

Figure 5. Species-effort curves for all sampled taxa. Green: all taxa, Blue: lichens, Red: vascular plants, Orange: bryophytes.

Linear regressions

No significant relationships were detected when regressing diversity of all taxa with abiotic variables. But when separated by vegetation type, significant relationships were detected. Vascular plants responded weakly to aspect (r^2 = .16 and p = < .0001); west-facing slopes had the highest diversity of vascular plants. Bryophyte diversity responded to variation in slope (r^2 = .20 and p = .0001); gentler slopes supported higher bryophyte diversity. Lichens showed a weak relationship with variation in surface heterogeneity (r^2 = .08 and p = .0001); higher surface heterogeneity supported higher lichen diversity.

MRPP analysis

I used Multi-Response Permutation Procedure (MRPP) tests to determine if plant communities differed by cliff site (site effect), edge cover (edge cover effect), and climbed versus unclimbed (climbing effect). The results indicated several important relationships. First, all vegetation types—vascular plants, bryophytes, and lichens—varied by cliff site (Table 4a). Bryophyte communities were most strongly driven by cliff site (Table 4a). Second, bryophyte communities on transects with canopy cover along the edge differed from those on transects that were bare within three meters of the edge (see Figure 3 for cliff edge definition). The effect size for bryophytes was small despite a significant result (Table 4b). Edge cover has a marginal impact on the community composition of vascular plant species with some separation between groups. Analysis of lichens showed little to no edge effect (Table 4b). None of the vegetation groups varied according to whether transects were climbed or unclimbed, which indicated that cliff communities were not different as a result of climbing activity or disturbance. Bryophytes were the closest to showing significant effects (Table 4c) and some separation between groups.

Table 4. MRPP Results for Cliff Site, Edge Cover, and Climbing Effects. P values less than .05 were considered significant and are indicated in bold. P values refer to both the T and A test statistics.

a. Cliff site effect

	P	T	A
All	**<0.0001**	-9.29	0.117
Vascular	**<0.0001**	-6.82	0.184
Bryophytes	**<0.0001**	-9.98	0.269
Lichens	**<0.0001**	-6.79	0.010

b. Edge cover effect

	p	T	A
All	**0.0493**	-1.81	0.004
Vascular	0.2200	-0.65	0.003
Bryophytes	**0.0099**	-3.06	0.016
Lichens	0.1889	-0.84	0.002

c. Climbing effect

	p	T	A
All	0.1470	-1.043	0.003
Vascular	0.2520	-0.528	0.003
Bryophytes	**0.0350**	-2.160	0.012
Lichens	0.1067	-1.286	0.004

NMS ordination

Non-metric Multidimensional Scaling (NMS) analyses were complementary to the MRPP analyses and provide a visual representation of community differences. The NMS ordination of transects grouped by site demonstrates that communities vary by cliff site (Figure 6. See Appendix 2 for a list of site names and characteristics.) For example, the green triangles representing plant communities in different transects within site 2 can be connected to form a convex hull that is distinct from the hull formed by connecting the orange triangles from site 6, thus indicating that the plant communities of the two sites are distinct from each other.

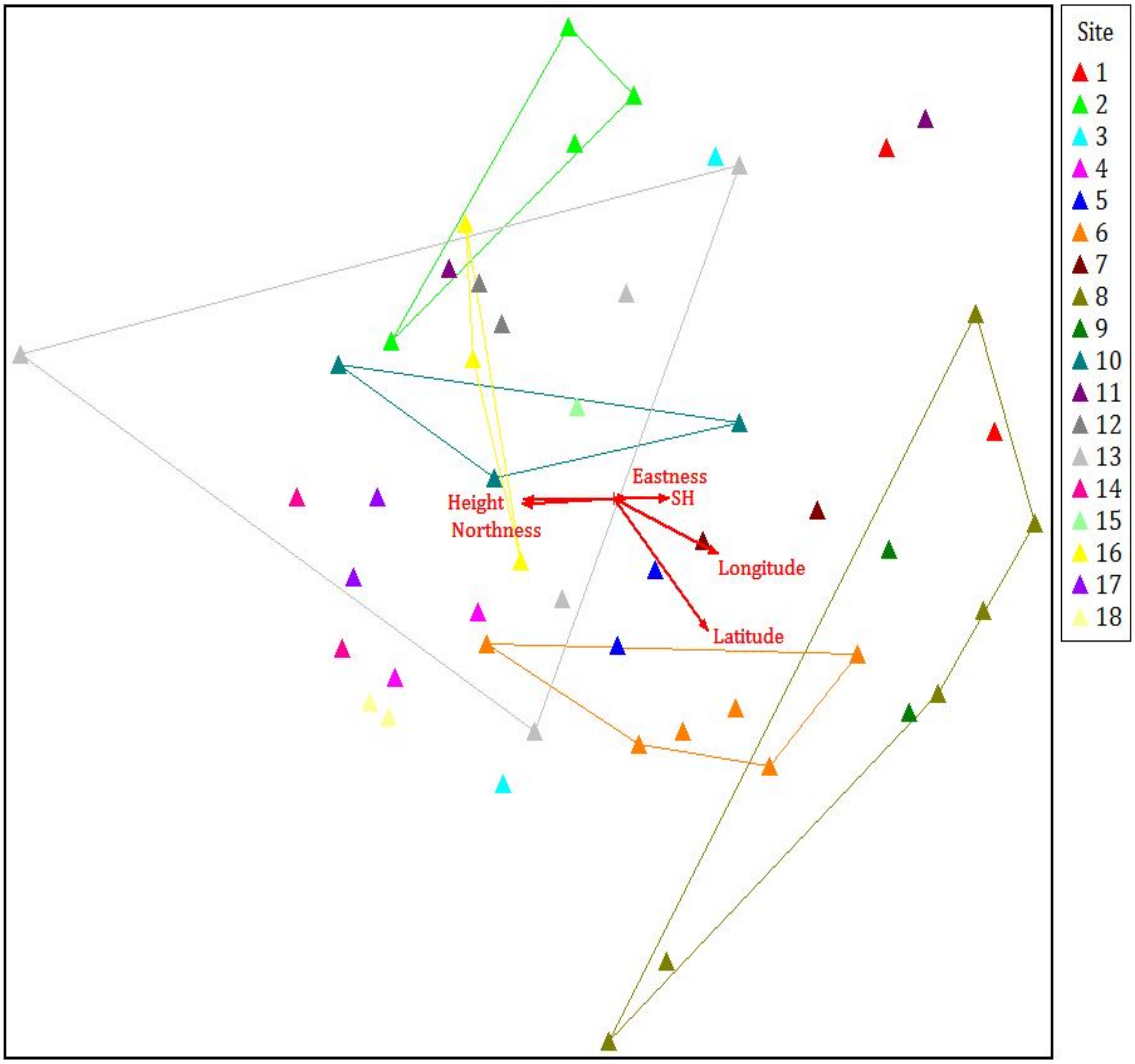

Figure 6. NMS Ordination of transects grouped by site. Numbers indicate transects and colors indicate sites. If a site included only two transects, no convex hull was drawn.

Some overlap of convex hulls is acceptable in sites that vary, especially when MRPP values corroborate differences between groups (Table 4). The red vectors in Figure 6 represent the relative importance of abiotic factors in driving differences between sites. The length of the arrow corresponds to the strength of the effect. Latitude and longitude have the greatest effect on differences in community composition between sites on BISO cliffs (Figure 6).

The NMS ordination compares transects with edge cover to those without cover and illustrates that transects on faces with closed edge canopy differ marginally from transects with no canopy (Figure 7).

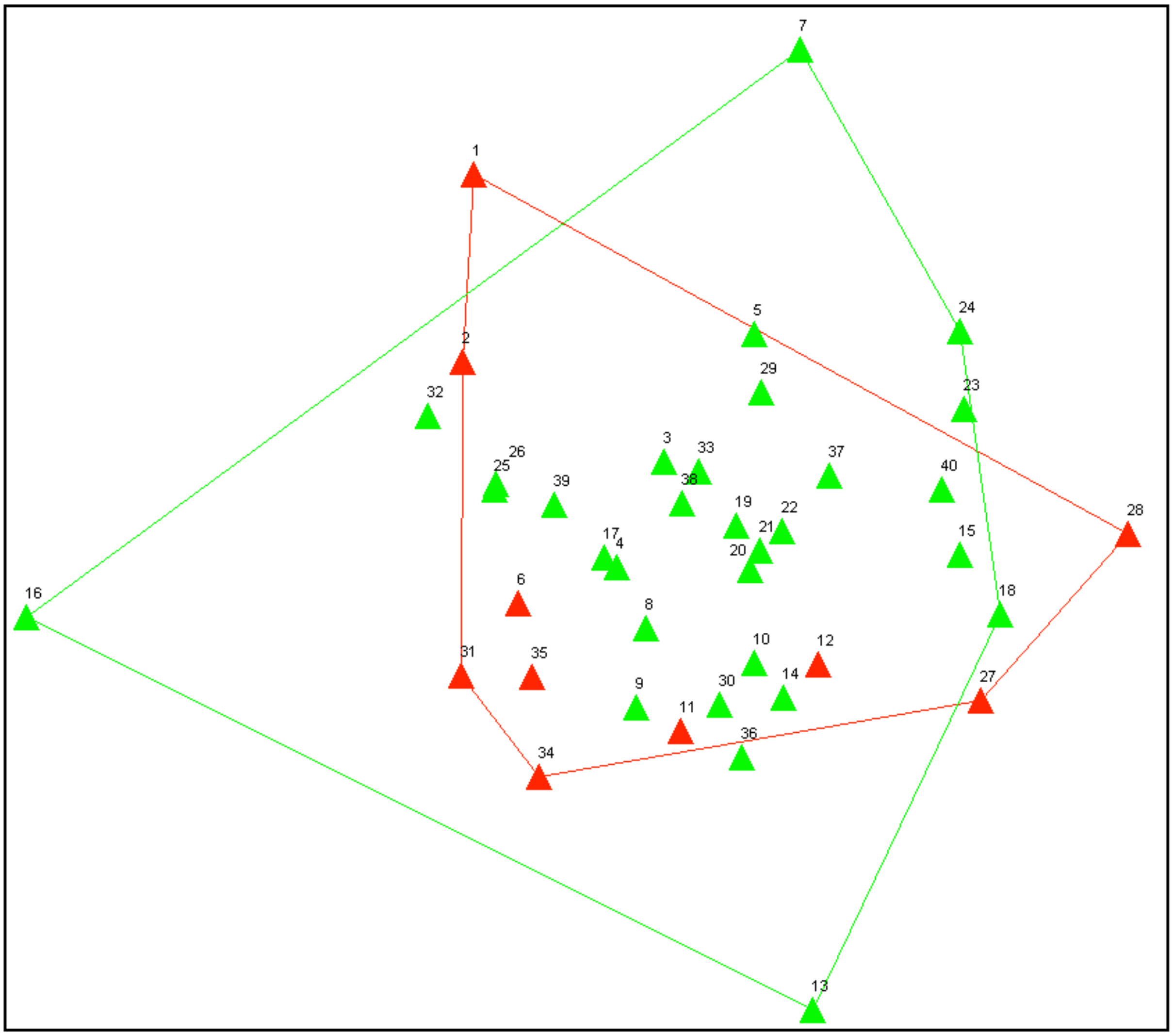

Figure 7. NMS Ordination of transects grouped by presence or absence of edge cover. Red triangles indicate cliff edges that had no canopy within 3 m of the cliff edge, and green ones indicate edge plots that were covered by a canopy.

Plant communities do not vary according to whether or not transects are climbed (Figure 8). The leftmost red triangle is transect 16, a climbed transect that did not contain any vascular plants or bryophytes. The absence of bryophytes and vascular plants likely accounts for its position outside the main group in Figure 8.

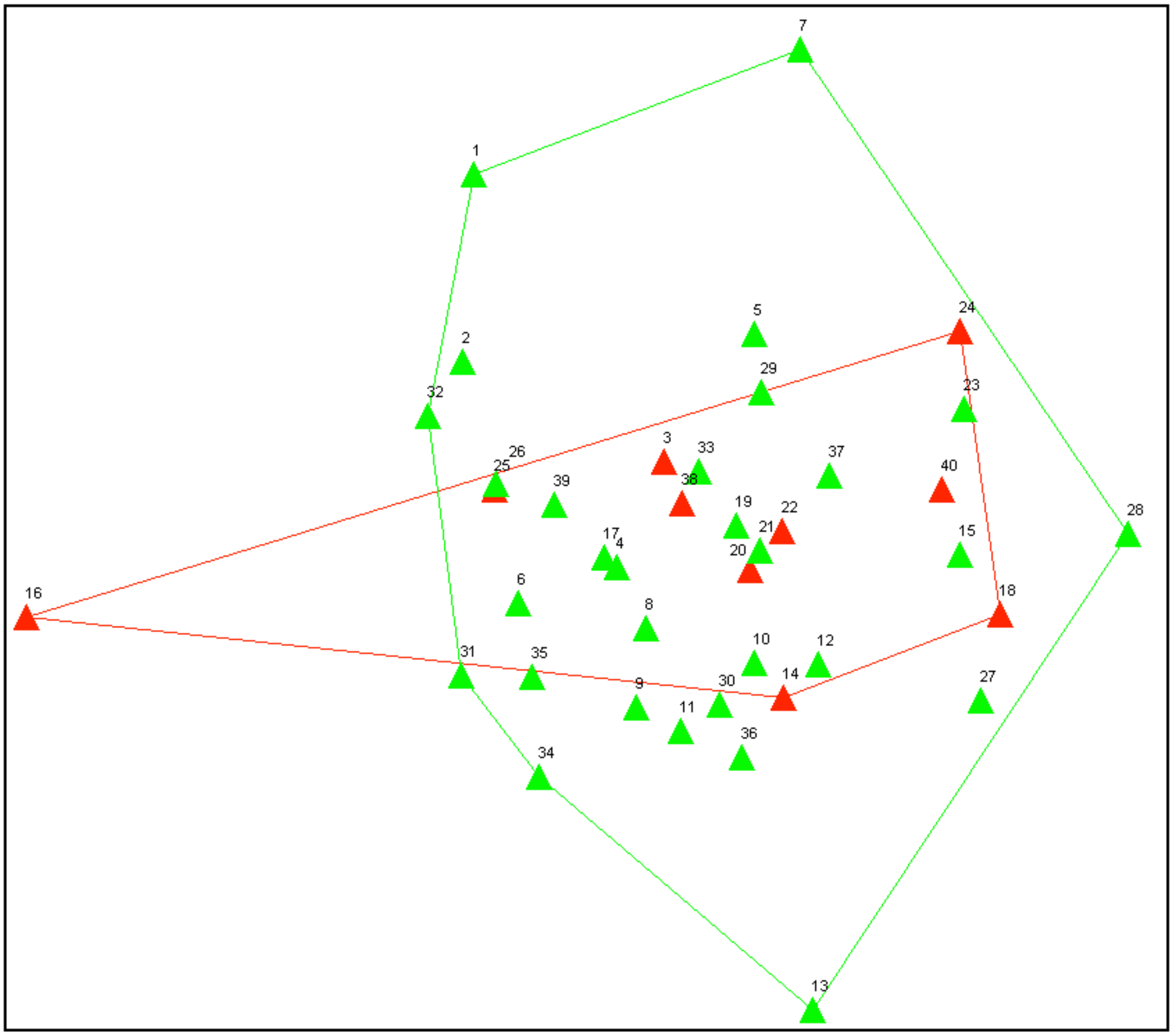

Figure 8. NMS Ordination of transects grouped by climbed or unclimbed. Red triangles indicate climbed transects and green triangles, unclimbed.

Spatial Model

I constructed a spatial model for climbing management by combining attribute layers (cliff location, height, slope, aspect, and location) using a geographical information system (ESRI 2010). An example of the cliff aspect layer is shown below (Figure 9).

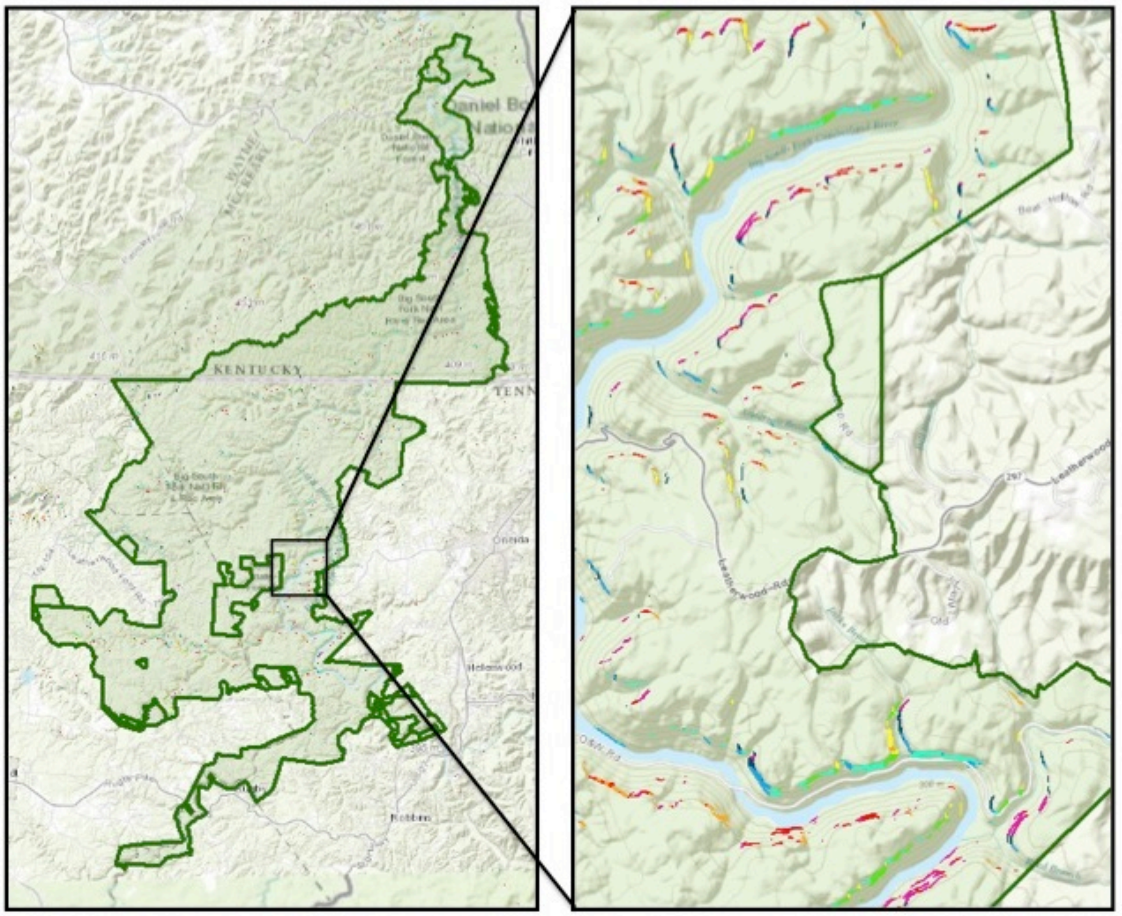

Figure 9. Map showing cliff aspect by color. The left panel shows the BISO park boundary and the right panel shows site four in greater detail.

Partial Least Squares (PLS) analysis of Shannon's diversity index as predicted by the five abiotic factors (cliff height, slope, aspect, latitude, and longitude) was compared to actual Shannon's diversity as determined by field collection. The PLS regression had an R^2 value of .30 and p value of .0020.

The weighting factors for each abiotic variable (height, slope, aspect, and location) were multiplied by each corresponding GIS layer and the resulting layer was restricted to cliff sites, producing a final map depicting predicted Shannon's diversity for cliff vegetation (Figure 10).

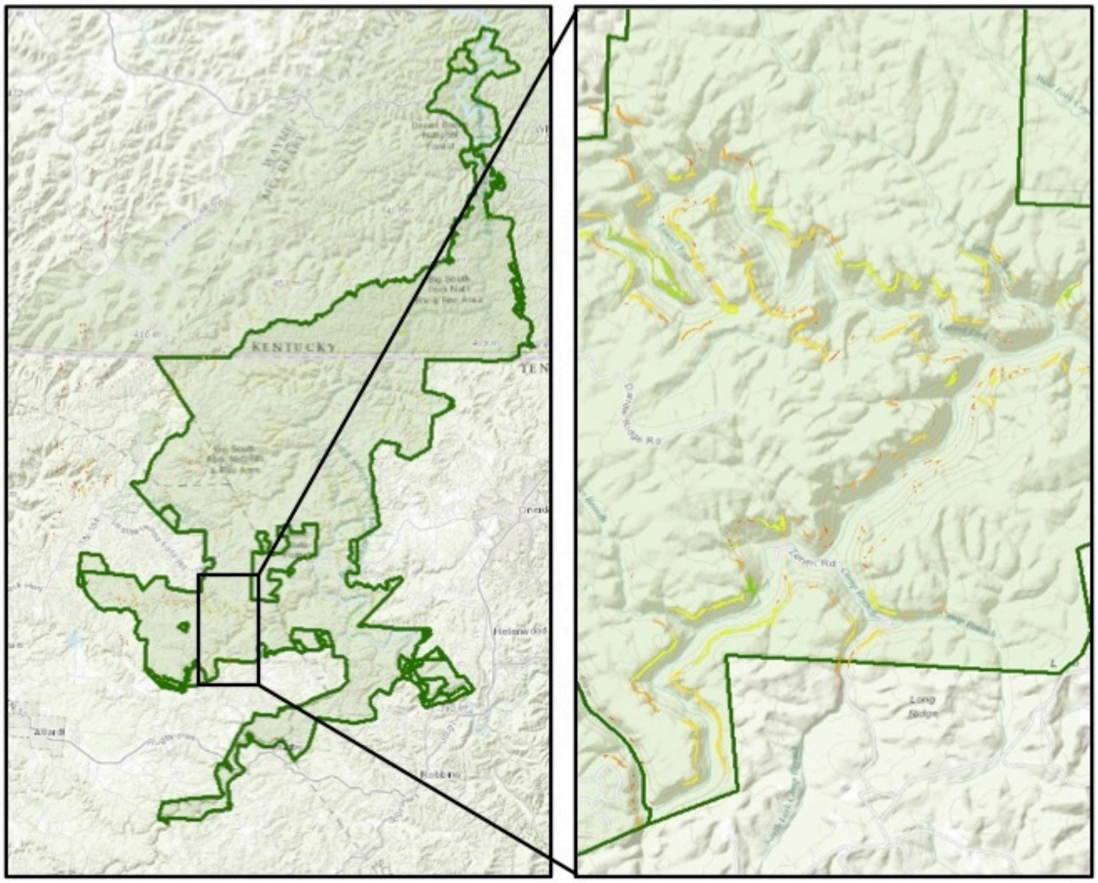

Figure 10. Map of predicted Shannon's diversity (H'). Site 3 is shown in greater detail on the right. Areas of higher diversity are shown in red and areas of lower diversity are shown in green.

Cliffs that are 10 m or higher, have a slope of at least 90 degrees and are within 2 km of a road are displayed in the climbing suitability portion of the model (Figure 11).

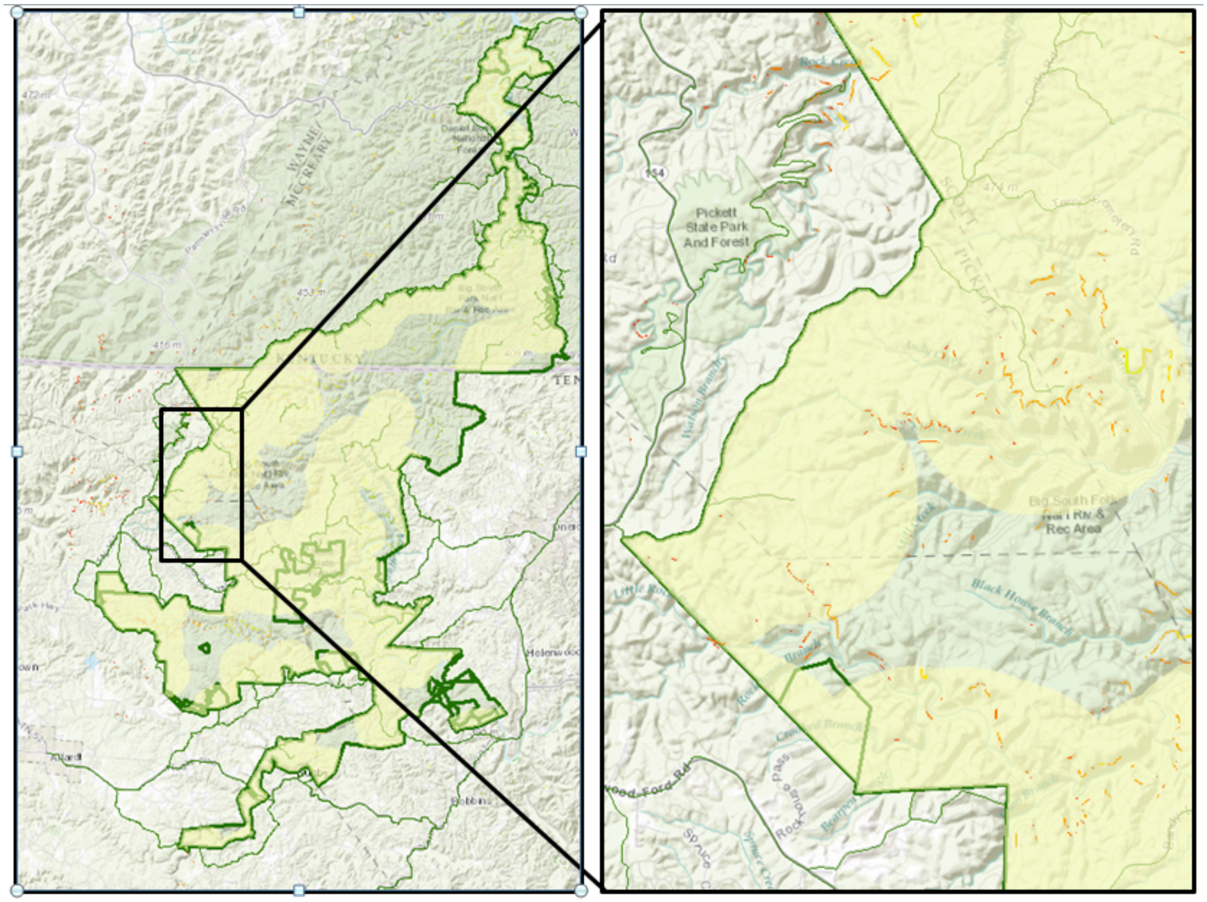

Figure 11. Map highlighting cliffs that are likely to be climbed. Red cliffs within the light yellow buffer zone (2 km from park roads) have high diversity and are likely to be climbed.

The map of diversity and attractiveness to climbers is available at:

www.BISOmodel/madritchlab/appstate.edu.

Discussion

Community structure

The Big South Fork has higher overall floral richness than do other cliff sites in the Cumberland Plateau (Table 1). It is possible that these higher species numbers are due to more thorough sampling in the current study than has occurred in previous studies. For example, the Cumberland Gap study sampled 27 transects in 11 sites, whereas this study of BISO sampled 50 transects in 18 sites. However, jackknife estimates take into account total area sampled, which mitigates the problem of sampling effort inequality. The jackknife estimates for Cumberland Gap predicted 315 total cliff species, but the Big South Fork was predicted to have 388 total species.

Several factors may be contributing to high vegetative richness in the Big South Fork. BISO's large area including many cliffs, low human disturbance, and high microclimatic variability could all contribute to the unusually high levels of cliff-based biodiversity. The Obed Wild and Scenic River is located 80 km south of BISO, and data are reported for six extensively climbed, mainly south-facing cliff sites (Hill 2009). Cumberland Gap National Historical Park (CUGA) is located 134 km west of BISO, and data are reported for eleven cliff sites (Harkey 2013). White Rocks is one large cliff system within Cumberland Gap (Ballinger 2011). These four protected areas share certain similarities, including geographic location and geology, but the following characteristics set the Big South Fork apart: BISO encompasses a larger area, sees fewer visitors, and subsequently experiences lower levels of human disturbance than do the other sampled parks. The Big South Fork also has the highest total cliff area, thus providing habitat for more species. Shaw and Wofford (2003) report that the park exhibits high microclimatic variability, especially in north-facing drainages along tributaries and near rockhouses. This climatic variability could explain the high levels of observed species diversity since changes in microclimate create optimal growth opportunities for a larger number of species. The Cumberland Plateau has gained a reputation as a center of biodiversity in the Southeast (Shaw and Wofford 2003). Even when compared to other cliffs of the Cumberland Plateau, Big South Fork's cliffs support high species richness. Understanding plant community dynamics will help managers preserve this hotspot of biodiversity through development of sound management strategies.

Abiotic drivers

Total diversity across all taxa was not related to any measured abiotic factor. The lack of a relationship between total diversity and abiotic factors could be a result of each vegetation type having its own distinct driver. For example, vascular plant diversity responded more to aspect than to other abiotic drivers while lichen diversity responded to more surface heterogeneity than other drivers. When all data are combined, the patterns are too variable to show a strong influence of one single factor. But when separated by vegetation type, clear patterns do emerge. For example, west-facing slopes had the highest diversity of vascular plants. This could be a result of differences in insolation between east- and west-facing slopes. West-facing slopes warm by way of the ambient temperature during the morning, and then by direct sun in the afternoon, leading to higher average temperatures than those on east-facing slopes. In other words, west-facing slopes are hotter because they receive direct sunlight during the hotter part of the day. Bryophyte diversity, on the other hand, responded most strongly to variation in slope; gentler slopes supported higher bryophyte diversity. Gentler slopes tend to collect more particulate matter and water than do steep slopes. Since most bryophytes thrive in moist environments, moister, more moderate slopes are likely to harbor higher bryophyte diversity. Finally, lichens responded most strongly to variation in surface heterogeneity. The variety of microhabitats created by cracks, crevices, and pockets in the rocks provides niches for more distinct species. In addition, many lichens propagate by fragmentation, and a cliff with high heterogeneity will likely have more ideal habitats for propagules than will a cliff with low heterogeneity. Lichens may be responding more strongly to heterogeneity than other vegetation types because they are the most abundant vegetation on the cliff face. Additionally, responses of plant diversity to surface heterogeneity may be masked by more immediate needs in bryophytes and vascular plants: bryophytes generally require high moisture levels and vascular plants require soil. The fact that vegetation types respond to different abiotic factors means that no single factor can be examined in order to gain an idea of what is controlling community composition.

Climbing impact

MRPP and NMS analyses indicate that climbing does not affect overall community composition on BISO cliffs; however, our sample size of climbed routes was relatively small. Only 10 of 50 total transects were climbed; of those, many appeared not to have been climbed within the last climbing season. Several of the "climbed" routes showed little or no evidence of recent climbing activity such as trampled talus vegetation, chalk residue on the face, or clear trails leading to the base of the route. There are few established routes and those that are established are not heavily climbed. Results could be interpreted one of two ways: either climbing has little to no effect on cliff vegetation or climbing in BISO has not become well enough established to allow researchers to detect evidence of climbing disturbance.

My observation was that even the most popular routes in the park see less climbing traffic than other climbing areas on the Cumberland Plateau. Several factors likely account for the lower levels of climbing activity in the park. First, many of the cliffs in BISO are remote and undeveloped. The established routes are tall and must be climbed in the traditional style (see the glossary of climbing terms) without fixed protection, a style that is riskier, more expensive, and requires more experience than do sport climbing and bouldering. Second, BISO is located between the Obed River Gorge and the Red River Gorge. The Obed, one hour south, has hundreds of steep sandstone routes similar to those at BISO, and is more developed, concentrated, accessible, and publicized. The Red River Gorge, two hours north in Kentucky, is an international climbing destination that attracts thousands of visitors per year and contains some of the best steep sport routes in the world. BISO's location between these two areas may explain why all but a few intrepid climbers ignore its vast potential. The park presents a good opportunity for a long term climbing-impact study because climbing is just becoming established. The baseline vegetation data provided in this study could serve as a starting point to gauge shifts in community structure caused by climbing or other human disturbance.

Spatial model

The time and cost of conducting thorough field surveys over wide and remote areas is usually prohibitive. This problem is compounded in cliff systems where sampling requires skilled personnel and specialized equipment. In these cases, models based on GIS data and the predictions derived from them can provide useful tools and insights into conservation planning (Vaughan and Ormerod 2003). As this study shows, cliff vegetation in the Big South Fork varies by site, meaning management must be tailored to the individual cliff system. The 1207 km of cliffs in the park make it virtually impossible for park managers to survey all cliff vegetation for management purposes. To my knowledge, spatial models like the one presented here have never before been developed for cliff vegetation. My hope is that this model will prove useful in predicting which climbable cliff sites have high floral diversity so that they may be prioritized for conservation. While the model will not substitute for monitoring, it can help managers narrow their pool of cliff sites that may require further investigation. For example, a cliff with high diversity (displayed in red or orange on the map) which also appeals to climbers (in the light yellow buffer zone on the map) should be prioritized for sampling. This spatial model is designed to bring the attention of land managers to areas that may need special consideration for conservation.

Conservation implications

Several management strategies can be implemented easily and should be of interest to BISO management. First, because cliff vegetation varies by site, each potential climbing area must be surveyed before management decisions are made. Communities can vary significantly depending on aspect, slope or surface heterogeneity; for this reason, a blanket management plan for the whole park will not be sufficient to protect all community types. Second, sites with canopied edges may have more diverse and heterogeneous plant communities than those with bare edges; therefore, cliffs with tree cover could be considered candidates for higher conservation priority. Third, cliff edge vegetation is distinct from face vegetation, and many rare plants are found only on the edges and in the talus rather than on the face (Ellenberg 1988). For example, in this study *C. cumberlandensis*, a park record, was found only in edge plots. These fragile edge habitats should be protected via appropriate trail routing. Hiking and horse trails should not run along the edge but instead should access overlooks via trails perpendicular to the cliff edge. Horses should be kept away from cliff edges both for conservation and safety. Similarly, *C. schisti*, a rare moss was found in the talus. Talus vegetation should be protected by constructing climbing access trails perpendicular rather than parallel to the base of the cliff.

A no topping-out policy also protects fragile cliff edge communities (Hill 2009). When climbers reach the top of a climb, if no fixed anchors are present (see the glossary of climbing terms), they must climb up and over the cliff edge and walk back down, or run a sling around a tree to rappel to the ground. Both practices are detrimental to vegetation and can be time-consuming and unsafe for the climber. Prohibiting topping-out and encouraging fixed anchors at the top of every climb protects edge habitats and increases safety as well as convenience for climbers. A similar policy has been successful in maintaining edge habitats in the Obed River Gorge (NPS 2004).

Conclusion

This study analyzes and synthesizes the largest set of cliff community data collected in the southeastern United States. It is also the first study of the extensive cliff systems of the Big South Fork National River and Recreation Area. Vegetation was identified on 18 cliff sites (50 transects), including three rare species and one park record. The cliff flora of the Big South Fork is diverse and interesting, even when compared to other cliffs in the Cumberland Plateau, a region that has a reputation as a center of biodiversity. The community composition of vegetation on cliffs in the Big South Fork is driven by complex interactions of ecological variables, but when vegetation is divided into groups, useful relationships between abiotic factors and diversity can be detected. The effect of climbing disturbance on these cliffs was not as strong as expected. Yet because climbing is predicted to increase in the area, the results of this survey can provide valuable baseline data for a long-term study of the effects of human disturbance on well-managed cliffs. Finally, the work has resulted in a predictive model that will help managers decide which areas can be opened and developed for rock climbing. The BISO cliffs warrant more in-depth study and careful management. My hope is that the patterns discovered in this study and the model we have developed will be important and useful tools for future work of cliff ecologists and land managers.

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Team BaLSACC and our trusty ATV at the Big South Fork. Summer 2012. Pictured l to r: Laura Boggess, Kelen Dowdy, Marcus Funston, and Eric Purdy

Angel Falls Overlook in the Big South Fork National River and Recreation Area.

GLOSSARY OF CLIMBING TERMS

Anchor. An arrangement of one or (usually) more pieces of gear set up to support the weight of a belay or top rope. Fixed anchors are permanent arrangements of two bolts.

Belay. To protect roped climber from falling by passing the rope through, or around, any type of friction enhancing belay device. All rope climbers need a belayer who stands beneath them in the talus area of the cliff system

Bolt. A point of protection permanently drilled into the rock, to which a metal hanger is attached to clip a quickdraw.

Choss. Poor quality or loose rock that will flake off when pressure is applied**.**

Dihedral. An inside corner of rock, with more than a 90-degree angle between the faces.

Face climbing. To ascend a vertical rock face using finger holds, and small edges.

Overhang. A section of rock with a slope of 100 degrees or greater.

Pitch. The portion of a climb between two belay points.

Slab. A relatively low-angle (significantly less than vertical) section of rock.

Sport Climbing. Any bolt-protected climbing.

Traditional Climbing. Climbing that requires natural protection placements.

Top-out. To complete a route by ascending over the top of the wall or boulder being climbed.

APPENDIX 1. SITE DESCRIPTIONS

Below are cliff site descriptions of the 18 sites surveyed within BISO (site = cliffs within 1 km^2). Shannon's Diversity (H') values ranged from 0.774 to 3.03 and averaged 2.33 with Mill Creek North (T34) containing the highest diversity and the Honey Creek (T40) containing the lowest. Overall species richness ranged from 5 species (T25 at Springfield) to 45 species per transect (T34 at Mill Creek North) and the geometric mean was 18.8.

1. Leatherwood Overlook. T1 and T2. Unclimbed

Located just west of the Leatherwood Ford, these cliffs are northeast-facing, shaded and damp. No climbing would be possible on these cliffs due to wetness, short height, and poor rock quality. Several seeps were present and the talus had areas of standing water. Diversity and richness were relatively high. *Thalictrum* was abundant as were lichens of the *Lepraria* genus.

2. O&W Wall: T3-6. Two Climbed Transects.

Located just east of the Oneida and Western Bridge, the O&W wall is a prominent headwall and the best-known climbing crag in the Park (although the Blue Heron site probably sees more climbing traffic). The *Dixie Cragger's Atlas* (Watford 2009) lists seven climbing routes here, all traditional style with some fixed anchors. The area has a lot of potential for climbing development thanks to its proximity to a road and the excellent rock quality. I sampled paired climbed and unclimbed transects along two pitches of a multi-pitch climbing route called Suicide Direct. No evidence of climbing activity was found on the third pitch such as chalk, fixed gear or trampled vegetation on the belay ledge. This pitch also followed a chimney feature that would be very hard to protect leading me to believe that it had not been climbed in a very long time, perhaps not at all beyond the first ascensionists. I, therefore, sampled one transect, unclimbed, along the final section of the climb. The belay ledge at the base of pitch three was a large shelf containing several large red cedars (*Juniperus virginiana*), and a variety of grasses and shrubs.

3. East Rim Overlook: T7 and T8. Unclimbed.

The East Rim Overlook site is located east of the river and just north of the viewing platform at the popular East Rim Overlook, near Park Headquarters. Transects on these southwest-facing cliffs were short (8m) and had high diversity and richness (T7 had an H' of 2.8 and 36 species).

4. Angel Falls: T9 and T10. Unclimbed.

The Angel Falls site is just west of the river and slightly south of the Angel Falls Overlook, accessed by the Grand Gap Loop Trail. The two transects were southwest facing and southeast-facing respectively. The edge was not vegetated and any trees were at least 10m from the cliff edge. Diversity and richness were high, especially in T10, the southeast-facing transect.

5. Bronco Overlook: T11 and T12. Unclimbed.

Bronco Overlook is on the north side of the park and was accessed via the Bronco Overlook equestrian trail. The cliffs were south facing and T11 was one of the longest surveyed (28m). These transects harbored relatively diverse plant communities especially along T10.

6. Blue Heron: T13-18. Three Climbed Transects.

Blue Heron is one of three sites sampled in Kentucky as well as the only area with established sport routes. With at least 56 established routes, this site sees more climbing traffic than anywhere in the park. This was the only area with obvious evidence of recent climbing. The sandstone is slightly softer and most of the routes were slab, with slopes less than 90 degrees.

7. Crack in the Rocks: T19 and T20. Two Climbed Transects.

Crack in the Rocks is also in Kentucky, just south of the Blue Heron area. Climbing routes are also sport routes though I noted fewer signs of climbing disturbance. Like Blue

Heron, the transects we sampled were low-angle slabs with low surface heterogeneity and very small holds. It is interesting to note that the park prohibited climbing on a section of cliffline in this area and chopped bolts and anchors on at least fours sport climbs in 1998 (Watford 2005). While we were not able to sample these routes, the vegetation seemed similar to that of other climbed and unclimbed routes in the area.

8. Springfield: T21-26. Three Climbed Transects.

Another Kentucky site, Springfield, is just north of Blue Heron. This site was unique in that cliffs and giant boulders formed corridors and shaded "rooms" that created distinct microclimates. These unique geological features provided the opportunity to sample many different aspects in close proximity. The area was shaded and seeps were abundant.

9. Honey Creek Overlook: T27 and T28. Unclimbed.

This site is located on the west side of the river just below the popular Honey Creek Overlook. The transects, which flanked the ladders leading down the Honey Creek Loop trail, were short (12m), damp, and high in diversity. T29, the north-facing transect, had very high richness (32 species) while T30 and T31, which were east-facing, were average (15 and 16 species, respectively). T31 had the lowest diversity of the three, at 1.83.

10. Hatfield Ridge: T29-31. Unclimbed.

Hatfield Ridge was the westernmost site sampled and was accessed via Hatfield Ridge multiuse trail from the western side of the park. These north-facing transects had average diversity and richness with the exception of T29 which was high for both.

11. Crackhouse: T32 and T33. One Climbed Transect.

The Crackhouse is east of the river and has several traditional routes and two sport routes established. This area will likely see more climbing development in the future thanks to easy access, proximity to the O&W Wall (site 2) and good rock quality.

12. Mill Creek North: T34 and T35. Unclimbed.

The Mill Creek North site, which is along the Mill Creek Drainage, was accessed via the River Trail East and included a long bushwhack to the anchor. There is some potential for climbing development but steep slopes and a long hike will keep the area from becoming a popular crag. The transects were long (T35 was the longest transect sampled, at 40 m), northwest facing and had intermediate diversity and richness.

13. Honey Creek East: T36-40. Three Climbed Transects.

Honey Creek East has several established traditional routes (seven listed in the guide) and the potential to be developed as a sport climbing area. Access is difficult (a long hike and a rappel are required to reach the base of the cliff), but the excellent rock quality and splitter cracks make this area worthwhile for climbers. These south-facing transects were low in both diversity and richness.

14. Laurel Fork: T41 and T42. Unclimbed.

The Laurel Fork site is west of the river and just northwest of the Laurel Fork Overlook. These southwest facing cliffs overlook the North White Oak Creek tributary.

15. Charit Creek: T43. Unclimbed.

The Charit Creek site is west of the river and accessed via a 1.5 mile hike. We classified the transect as unclimbed though T43 had a bolt midway up the route. This means the route was climbed at some point, but no evidence of recent disturbance was visible.

16. Sawtooth Ridge: T44-T46. Unclimbed.

Sawtooth Ridge is a unique assemblage of cliffs on the western edge of the park. The Laurel Fork tributary winds through steep canyons creating mesa-like features that support healthy and relatively undisturbed rock-outcrop communities at their summits. The ridge provides the opportunity for sampling cliffs with many different aspects in a small geographic area.

17. Sunset Overlook: T47 and T48. Unclimbed.

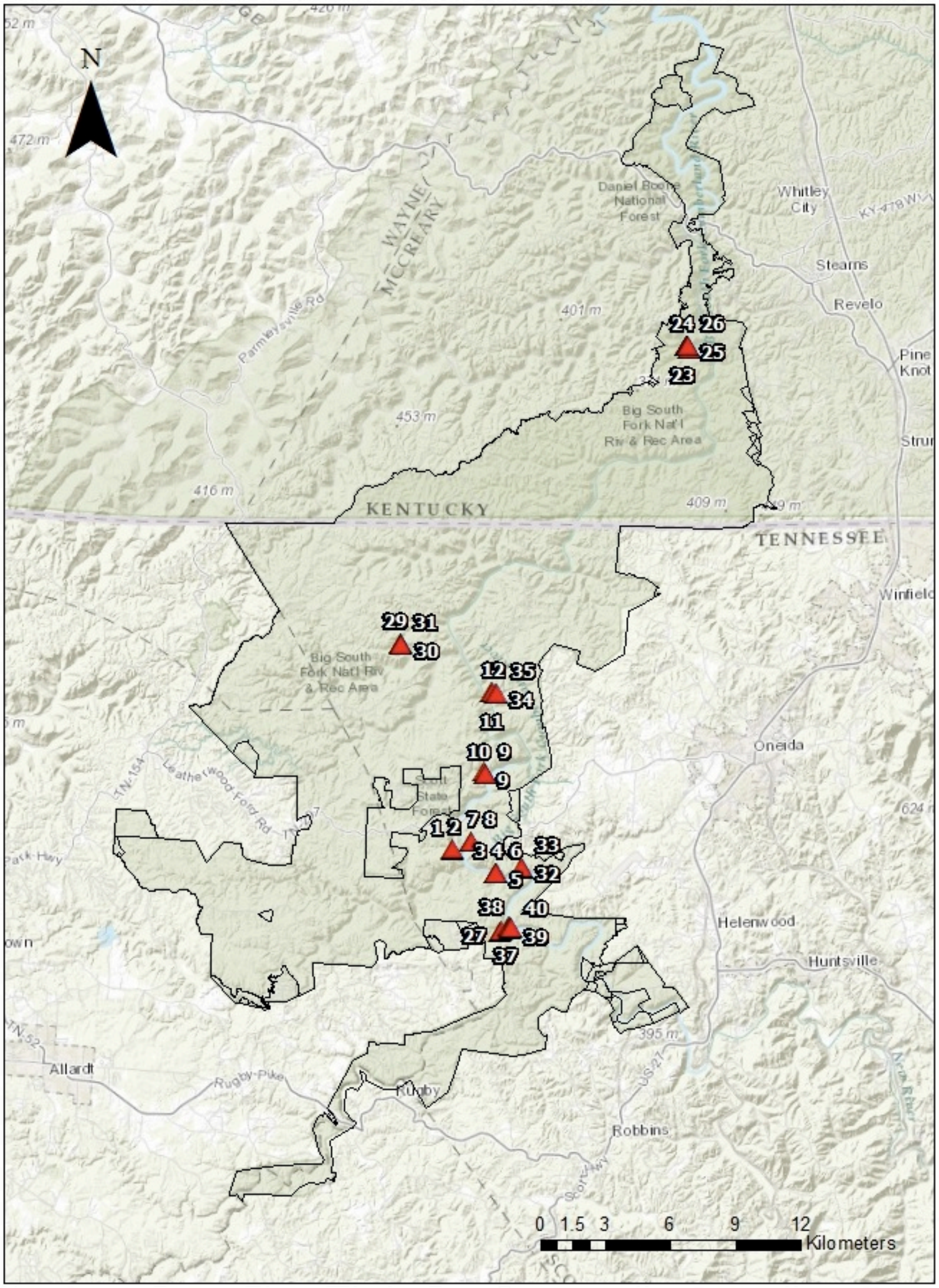
Sunset Overlook is just west of the river and accessed by a popular hiking trail that begins near the Park Headquarters. The sampled cliffs are very diverse, especially in crustose lichens.

18. Grand Gap: T49 and T50. Unclimbed.

The Grand Gap site is east of the river and accessed via the Grand Gap Loop Trail that leads to the popular Angel Falls Overlook. The transects were long and T49 was overhung enough to prevent sampling of the bottom third of the face.

Eric Purdy, Marcus Funston and Kelen Dowdy at Leatherwood Overlook (Site 1), a shaded, north-facing site with high overall diversity. Summer 2012.

APPENDIX 2. MAP OF SAMPLED TRANSECTS



APPENDIX 3. SPECIES OF INTEREST

Clockwise from left: *Vittaria appalachiana*, Appalachian shoestring fern. Southern Appalachian endemic. Photo: http://www.flickr.com/photos/alan_cressler.
Cynodontium schisti, rare moss. Photo: http://www.swissbryophytes.ch.
Carex cumberlandensis, park record. Photo: http://www.southeasternflora.com.
Cladonia pocillum, disjunct lichen assemblage. Photo: Sheri Hagwood @ USDA-NRCS PLANTS Database.

APPENDIX 4. VASCULAR SPECIES LIST

Acer rubrum L. var. rubrum

Amelanchier arborea (F. Michx.) Fernald

Asplenium montanum Willd.

*Asplenium pinnatifidum*Nutt.

Asplenium platyneuron (L.)Britton, Sterns, &Poggenb.

Avenella flexuosa (L.)Drejer

Betula lenta L. var. lenta

Carex sp

Carex cumberlandensis Nazci, Kral and Bryson

Chasmanthium laxum (L.) H.O. Yates

Clethra acuminata Michx.

Danthonia sericea Nutt.

Danthonia spicata (L.) P. Beauv. ex Roem. & Schult.

Dendrolycopodium obscurum (L.) A. Haines

Dennstaedtia punctilobula (Michx.) T. Moore

Deparia acrostichoides (Sw.) M. Kato

Dichanthelium depauperatum (Muhl.) Gould

Dichanthelium laxiflorum (Lam.) Gould

Dichanthelium meridionale (Ashe) Freckmann

Dichanthelium sphaerocarpon (Elliott) Gould

Dryopteris intermedia (Muhl. ex Willd.) A. Gray

Epigaea repens L.

Eupatorium serotinum Michx.

Eurybia divaricata (L.) G. L. Nesom

Gaultheria procumbens L.

Gaylussacia brachycera (Michx.) A. Gray

Hamamelis virginiana L. var. virginiana

Heuchera parviflora Bartl.

Hypericum gentianoides (L.)Britton, Sterns, &Poggenb.

Hypericum stragulum W.P .Adams & N. Robson

Hypnum imponens Hedw

Ilex opaca Aiton var. opaca

Itea virginica L.

Kalmia latifolia L.

Lygodium palmatum

Magnolia fraseri

Magnolia macrophylla

Maianthemum racemosum (L.) Links sp. racemosum

Medeola virginiana L.

Mitchella repens L.

Muscadinia rotundifolia (Michx.) Small var. rotundifolia

Nyssa sylvatica Marshall

Oxydendrum arboreum (L.) DC.

Panicum sp

Parthenocissus quinquefolia (L.) Planch.

Pinus strobus L.

Pinus virginiana Mill.

Platanus occidentalis

Podopyllum peltatum

Polypodium appalachianum Haufler & Windham

Polystichum acrostichoides (Michx.) Schott

Quercus alba L.

Rhododendron maximum L.

Robinia pseudoacacia L.

Rubus pensilvanicus Poir.

Sassafras albidum (Nutt.) Nees

Schizachyrium scoparium (Michx.) Nash var. scoparium

Securigera varia (L.) Lassen

Silene rotundifolia Nutt.

Smilax glauca Walter.

Smilax rotundifolia L.

Solidago erecta Pursh.

Thalictrum clavatum DC.

Thelypteris noveboracensis (L.) Nieuwl.

Vittaria appalachiana Farrar & Mickel, Amer.

The author on a rock outcrop above a *Rhododendron maximum* bush in bloom. *R. maximum* was the most abundant vascular species on sampled BISO cliffs. Photo: Mike Madritch.

APPENDIX 5. BRYOPHYTE SPECIES LIST

Andreaea rothii Web. & Mohr
Atrichum angustatum (Brid.) Bruch & Schimp. in B.S.G.
Atrichum cylindricum (Willd. in Web.) G.L. Sm.
Atrichum oerstedianum (C. Müll.) Mitt.
Bazzania denudatum (Torr.) Trev.
Bazzania trilobata (L.) S. Gray
Brotherella recurvans (Michx.) Fleisch.
Calypogeia fissa (L.) Raddi
Calypogeia sullivantii Aust.
Campylopus pilifer Brid.
Campylopus tallulenis Sull. & Lesq.
Cephaloziella cf. *massalongi* (Spruce) K. Müll.
Cephaloziella sp.
Ceratodon purpureus (Hedw.) Brid.
Cynodontium schisti (Web. & Mohr) Lindb.
cf. Dicranella sp.
cf. Hypnum sp.
cf. Jungermannia lanceolata L. emend. Schrad.
cf. Odontoschisma denudataum (Nees) Dum.
Conocephalum conicum (L.) Underw.
Dicranella heteromalla (Hedw.) Schimp.
Dicranodontium denudatum (Brid.) Britt. in Williams
Dicranum cf. scoparium Hedw.
Dicranum montanum Hedw.
Dicranum scoparium Hedw.
Diplophyllum apiculatum (Evans) Steph.
Diplophyllum cf. apiculatum (Evans) Steph.

Diplophyllum sp.

Frullania asagrayana Mont.

Grimmia laevigata (Brid.) Brid.

Harpanthus scutatus (Web. & Mohr.) Spruce

Hypnum imponens Hedw.

Hypnum pallescens (Hedw.) P. Beauv.

Kurzia sylvatica (Evans) Grolle

Leucobryum albidum (Brid. ex P. Beauv.) Lindb.

Leucobryum glaucum (Hedw.) Ångstr. in Fries

Leucobryum sp.

Leucolejeunea conchifolia (Evans) Evans

Mnium hornum Hedw.

Odontoschisma cf. *denudatum* (Nees) Dum.

Pellia sp.

Platygyrium repens (Brid.) Schimp. in B.S.G.

Pohlia sp.

Polytrichum commune Hedw.

Polytrichum juniperinum Hedw.

Polytrichum ohioense Ren. & Card.

Pseudotaxiphyllum elegans (Brid.) Iwats.

Pylaisiadelpha tenuirostris (Bruch & Schimp. ex Sull.) Buck

Racomitrium heterostichum (Hedw.) Brid.

Rhabdoweisia crispata (With.) Lindb.

Rhizomnium punctatum (Hedw.) T. Kop.

Riccardia cf. *multifida* (L.) S. Gray

Scapania nemorea (L.) Grolle

Schistidium apocarpum (Hedw.) Bruch & Schimp. in B.S.G.

Solenostoma cf. *gracillimum* (Sm.) Schust.

Solenostoma cf. *pumilum* (With.) K. Müll.

Solenostoma cf. *pyriforme* Steph.

Solenostoma gracillimum (Sm.) Schust.

Sphagnum compactum DC. in Lam. & DC.

Syrrhopodon texanus Sull.

Taxiphyllum cf. *deplanatum* (Bruch & Schimp. ex Sull.) Fleisch.

Tetraphis cf. *pellucida* Hedw.

Tetraphis pellucida Hedw.

Thuidium delicatulum (Hedw.) Schimp. in B.S.G.

APPENDIX 6. LICHEN SPECIES LIST

Lichens collected were identified to species when possible and genus with morphotype descriptors when resources did not allow for identification to species.

Arthonia green
Aspicilia bright green
Aspicilia green
Aspicilia white
Buellia
Buellia black
Buellia bright green
Buellia green
Buellia grey
Buellia light green
Buellia spuria
Buellia stigmacea
Buellia white
Buellia yellow
Caloplaca bright green
Caloplaca brown
Caloplaca orange
Caloplaca yellow
Chrysothrix yellow
Cladonia
Cladonia (cladina)
Cladonia apodocarpa
Cladonia bacillaris
Cladonia black
Cladonia bright green
Cladonia brown
Cladonia cenotea
Cladonia colorful
Cladonia dark grey
Cladonia green
Cladonia grey
Cladonia grey w/cups
Cladonia leafy
Cladonia light green
Cladonia mint
Cladonia rangiferina
Cladonia rough
Cladonia subtenuis
Cladonia tubes
Cladonia verticillata
Cladonia white
Cladonia pocillum
Cystocoleus green
Dimelaena
Dimelaena black
Dimelaena green
Dirinia black
Dirinia white
Flavoparmelia
Fuscidea recensa
green dot crustose
green foliose
grey cauliflower
grey/green crustose
Lasallia papulosa
Lecanora brown
Lecanora cenisia
Lecanora green
Lecanora grey
Lecanora light green
Lecanora white
Lecidella grey
Lecidella orange
Leprarai mint
Dirinia black
Dirinia white
Flavoparmelia
Fuscidea recensa

green dot crustose
green foliose
grey cauliflower
grey/green crustose
Lasallia papulosa
Lecanora brown
Leprarai white
Lepraria
Lepraria black
Lepraria blue
Lepraria blue/green
Lepraria blue/white
Lepraria bright green
Lepraria bright yellow
Lepraria dark green
Lepraria green
Lepraria grey
Lepraria grey/white
Lepraria incana
Lepraria light green
Lepraria light grey
Lepraria lobificans
Lepraria mint
Lepraria mustard
Lepraria white
Lepraria white and black
Lepraria white w/dots
Lepraria yellow
Lobaria green

Paraparmelia alabamensis
Parmelia
Parmelia black
Parmelia dark green
Parmelia green
Parmelia grey
Parmelia mint
Parmelia small
Parmelia squarrosa
Parmelia white
Parmeliaisidia green
Parmotrema green
Pertusaria
Pertusaria brown
Pertusaria green
Pertusaria grey
Pertusaria white
Pertusaria yellow
Phaeophyscia turquoise
Physciella grey
Physcia green
Physcia grey
Physcia light green
Physcia white
Physciella green
Physciella grey
Physciella squarrosa
Physciella white
Physconia grey
Pleopsidium flavum

VITA

Laura Boggess is a biologist, adventurer and climber, born and raised on a family farm in Western North Carolina. Her greatest passion is exploring the wild, wherever it may be found, and then working to understand and conserve it. Laura was a Peace Corps Volunteer in rural Guatemala, where she helped small communities preserve their forests through ecotourism initiatives. Prior to that she studied biology and environmental science as a Morehead-Cain scholar at the University of North Carolina at Chapel Hill. While at Carolina, she traveled to Asia, South America, Eastern Europe and the South Pacific to work in conservation and outreach. She spent her time in graduate school at Appalachian State University, exploring cliff ecosystems all over the southeast with Gary Walker and Mike Madritch and enjoying the fantastic rock-climbing in Boone. In September 2013 she began working at the Blue Ridge Conservancy, putting her passion for conservation to work in the mountains she loves.